Comparing the Effects of Coastal Erosion on Unprotected vs. Protected Shorelines Using GIS and 2011/2014 LiDAR Data

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Abstract

Long Beach is a barrier island and one of the many protective barrier islands found in the southern area of Long Island, NY. Barrier islands are crucial to the safety of areas on the mainland as it serves as a shield against erosion for coastlines on multiple cities of Long Island such as Oceanside. Oceanside's shorelines are protected by Long Beach; for the beach often takes the brunt of any coastal erosion without any protection. In recent years, sea-level rise and storm surge have increased enough to make this barrier islands' job progressively harder. These ongoing threats have tested Long Beach's effectiveness as a barrier island and its resilience to erosion. This study employs geospatial analysis methods, specifically Global Mapper and LiDAR data, to compare the effects of coastal erosion on Long Beach (unprotected) and Oceanside (protected) and the conditions of protected shorelines versus unprotected shorelines. Our research shows there is damage to protective barrier islands such as Long Beach, as a result of climate change that was not seen in the protected areas of the island. We found that there was up to 3.1 meters (approximately 10 ft) of erosion in some areas and up to 3 meters (9 ft) of deposition in others. Using GIS to analyze coastal erosion will help to create response plans for the communities of Long Island to combat and adapt to the changes caused by coastal erosion. LiDAR data from USGS surveys for 2011 and 2014 were obtained for geospatial analysis and subtraction comparison. Our results depicted that the coastal changes and storm surges have led to significant erosion of at least 100% decrease in elevation on parts of the shoreline over the span of four years, and it is forecasted to erode even more.

Introduction

Long Island is surrounded by the Atlantic Ocean on all sides, in the southeast corner of New York. Its history extends back to the early years of the Appalachian Mountains and the Atlantic Coastal Plains from 90 million years ago. During this time, the Appalachian Mountains were heavily subjected to weathering and erosion, and its "gravel, sand, and mud flowed down their eastern slope creating a broad apron of deep soils and sediments called the Atlantic Coastal Plain" (Lynch, 2021). As time progressed from the Cretaceous to the Pleistocene periods, glaciers deposited sediments along the coasts of the northeast part of the US. For Long Island, it was during the Pleistocene ice ages when "glaciations scraped the ancient coastal plain sediments off the landscape, depositing much of the sediment as the great regional moraines that created the coastal surface geology of Long Island" (Lynch, 2021). The ice ages were a turning point for the creation of Long Island's mainland. The glacial activity created its foundation, and the sediments leftover from the episodes created the barrier islands examined in this study. Long Island and its surrounding features formed through erosion and deposition, which makes it just as vulnerable to evolve by the same methods.

The island is naturally known for its tourist attractions and rich biodiversity and is also at the center of wildlife attractions. With the Island witnessing significant tourism and climate change impacts slowly growing, the Island has become prone to floods and, most importantly, erosion. Erosion has been at the forefront of the negative side that Long Island has been facing for a long time. The island's coast is highly dynamic and constantly changing depending on various factors such as wind, ocean patterns, natural hazards, and anthropogenic activities. The presence of plant life on dunes on the south shore of Long Beach that have prevented erosion on Long Beach has also deteriorated in recent years. Long Island particularly faces erosion from the north and south sides as it is surrounded by the Atlantic Ocean on the south and the Reynolds Channel on the north. Beaches tend to get narrower during winter as it is a repetitive cycle in the coastal regions. However, in the case of Long Island, this pattern is different and needs to be followed accordingly (Tanski, 2012). Storm surges can have more impacts on the coastal beaches of Long Island and affect the shorelines in various ways. Depending on the level of the storm surge, it can rapidly erode the shorelines. The increased levels of storm surge are a byproduct of global warming, but sea level rise and ocean currents also play a massive role in the erosion seen on Long Island's coasts. Sea level along the U.S. coastline is projected to rise, on average, 10 - 12 inches, creating a profound shift in coastal flooding over the next 30 years (Sea Level Rise Technical Report, 2022).

Methodology

This study was conducted by using geospatial analysis consisting of ArcGIS and GlobalMapper software usages for the LiDAR data that were extracted from United States Geological Survey (USGS). We downloaded the surveys for the years 2011 and 2014 of LiDAR elevation data from the FTP's (File Transport Protocol) NYC 2021 database (ftp://ftp.gis.ny.gov/elevation/LIDAR/), totaling 22 LAS files and approximately 15.1 million points of data to construct a high-resolution Digital Elevation Model (DEM) (ftp://ftp.gis.ny.gov/elevation/LIDAR/) to make two digital elevation models (DEM-2011, DEM-2014) in particular a bare-earth model for each survey. We created a bare-earth model to avoid artifacts made by trees and other distractions. The differences in elevation shown on this created model for both years were subtracted to determine the magnitude of land change occurring on the coastlines of our two study areas on Long Beach and Oceanside (DEM-DIF). Google Earth Pro was also utilized to capture aerial photographs of the coastlines of our study areas for both 2011 and 2014, to facilitate the identification of changes at the coastline areas as they would appear in real time.

In order to calculate the percent change in elevation for the two years (2014 and 2011), the meters above sea level of the specific area was taken from the 2011 USGS NorthEast LiDAR map. Then, the change in elevation was taken from the digital elevation model that was created by subtracting the differences in elevation from both years. Using this information, the percent change in elevation was calculated by hand using the formula (elevation change from DEM-2011 x 100). For example, in Figure 5, the maximum elevation in the red areas in the channel was 1.5 meters in 2011. According to DEM-2014 it lost 3.1 meters of elevation, which means the percent elevation change was ((3.1/1.5) x 100) = 206.7%.

For Figure 2, the elevation in 2011, right before the dune vegetation, was 3 m, and according to the DEM-2014 it changed by -3m, which makes the percent change in elevation decrease 100%. For the area at the top of the dune with the vegetation, it was 4.3m in 2011 which increased from the previous 3 m, which makes the change in elevation ((3/4.3) x 100)) = 69.8 % increase. For Figure 3, the percent change in elevation for the red areas near the middle of the channel was 206.6% as it was 1.5 m and lost 3.1 meters in elevation. For Figure 4 the middle of the channel in red areas decreased by 91.2 % and in the yellow areas, it decreased by 100% from 2011. For Figure 5, the red area was on average -1.2m deep in DEM-2011 and changed by 2.8 m. That causes a 233.2% decrease in elevation.

Results

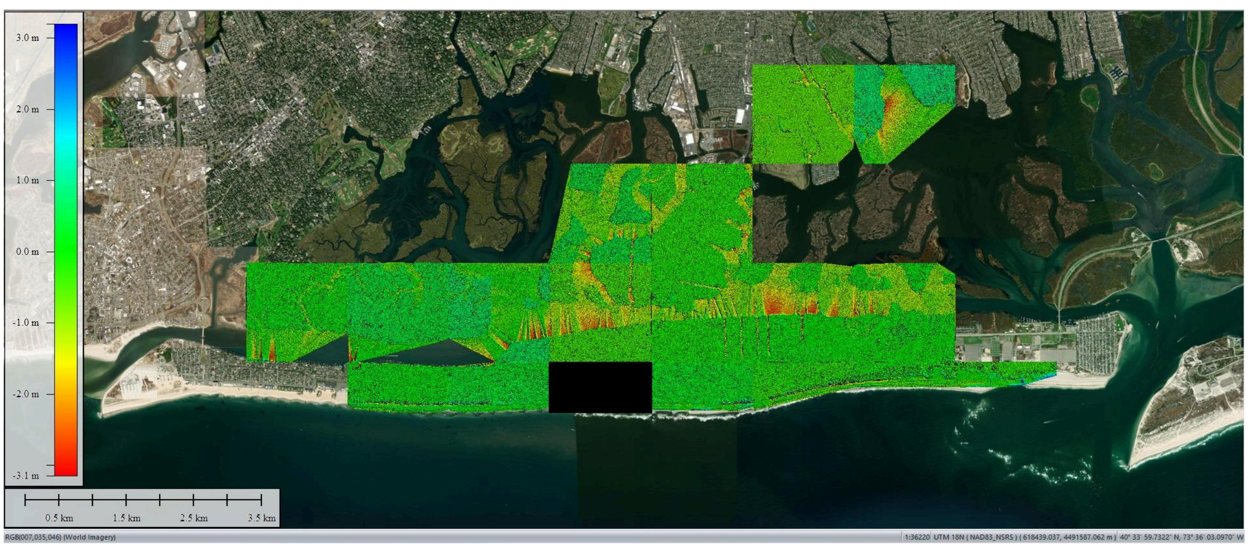

Figure 1: Digital Elevation Model (DEM-DIF) of the difference in meters above sea level in 2011 to 2014 using LiDAR of the study areas in the comparison. The locations are in Long Beach and in Oceanside. The black box is an area that was not used in the study because of missing data. The areas in red represent erosion with the maximum erosion being 3.1m loss of elevation in some areas. The blue represents deposition, which was noted to be up to 3 m in some areas.

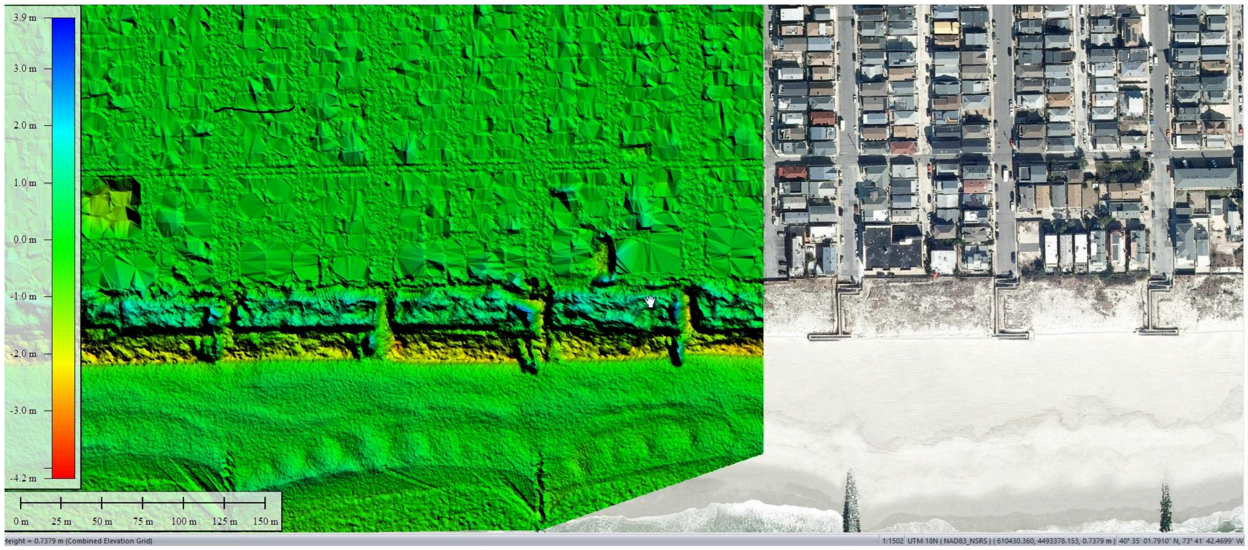

Figure 2: Digital Elevation Model (DEM-DIF) of the difference in meters above sea level in 2011 to 2014 using LiDAR data of a portion of Long Beach coast on the south side of the island. Half of the model was replaced with satellite imagery of the same area for better comparison. The areas in red represent significant land change caused by erosion; the loss in land was around 3.1 meters. The blue represents deposition and was up to 3 meters. The impact of dunes on coastal erosion can also be observed. The areas before the dunes have lost a little more than 2 meters worth of elevation, but the dunes gained 2-3 meters of height where the vegetation is.

Figure 3: Digital Elevation Model (DEM-DIF) of the difference in meters above sea level in 2011 to 2014 using LiDAR imagery of a portion of Long Beach coast on the north side of the island. Part of the DEM model was replaced with satellite imagery of the same area for better comparison. The areas in red represent erosion with the maximum erosion being 3.1 m loss of elevation in some areas. The blue represents deposition, which was noted to be up to 3 m in some areas.

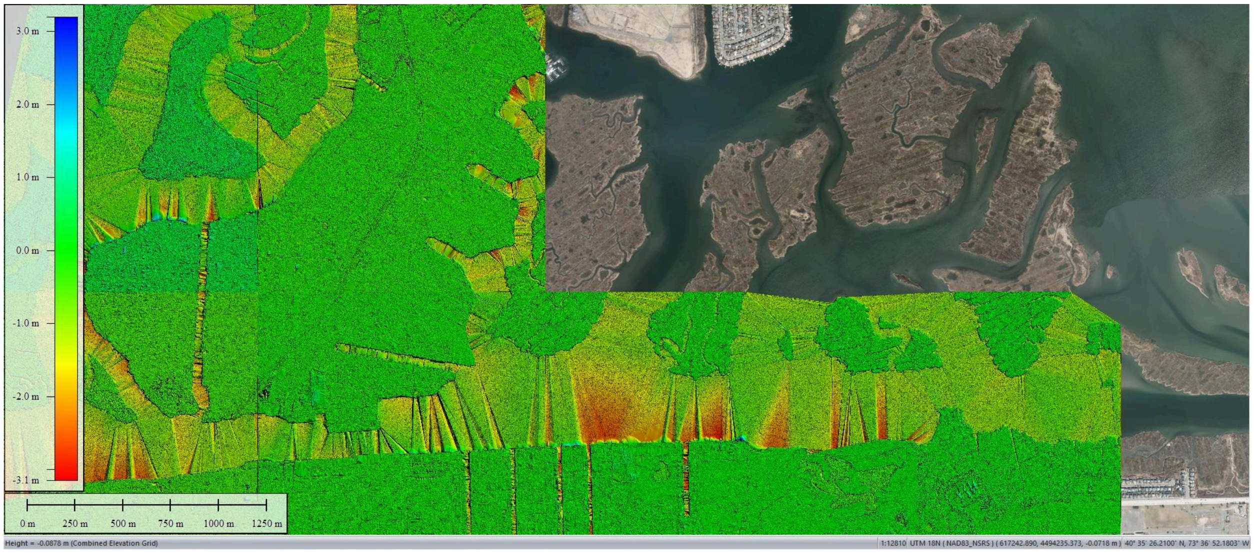

Figure 4: Digital Elevation Model (DEM-DIF) of the difference in meters above sea level from 2011 to 2014 using LiDAR imagery of a portion of Long Beach coast on the north side of the island at a different location from Figure 3. The areas in red represent erosion, with the maximum elevation loss being 3.1 m. The blue represents deposition, which was noted to be up to 3 m in some areas.

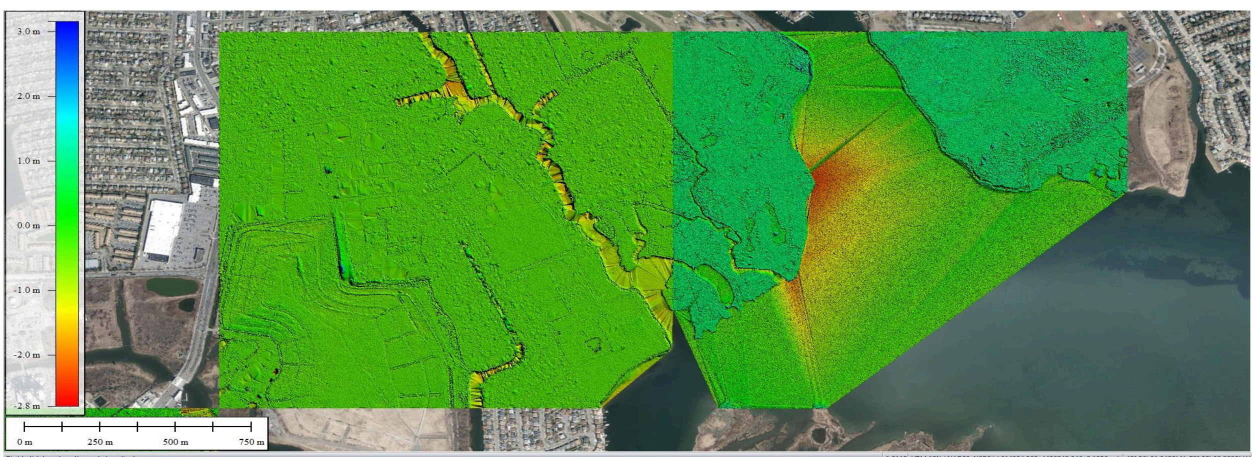

Figure 5: Digital Elevation Model (DEM-DIF) of the difference in meters above sea level from 2011 to 2014 using LiDAR data of Oceanside, NY; it is on the south shore of Long Island NY, with a satellite imagery map behind it to give context for its location. The areas in red represent erosion, with the maximum loss of elevation being 3.1m in some areas. The blue represents deposition, which was noted to be up to 3 m in some areas.

Figure 6: Satellite image of Long Beach taken at 4938ft, June 2010. The image, taken from Google Earth, marks previous vegetation and the jettie system present before significant erosion.

Figure 7: Satellite image of Long Beach taken at 4938ft, October 2014. Image taken from Google Earth, marks significant vegetation loss and jettie destruction as the beach recedes. The jetties eventually succumbed to the strengthened natural force of ocean currents, for they are no longer present on Long Beach in Fig. 7. Approximately half of the vegetation that was present on the beach in 2010 was gone in 2014.

Figure 8: Real-time satellite image of Oceanside Park taken at 4938ft, June 2010. Image taken from Google Earth, marks previous vegetation and marsh presence along the coast.

Figure 9: Real-time satellite image of Oceanside Park taken at 4938ft, October 2014. Image taken from Google Earth, marks vegetation and marsh presence after four years. Loss of vegetation cover can be witnessed on the left hand side of the figure, and along the coast of Oceanside Park. The beachline of the far right corner also witnessed a recession of the shoreline and small amount of erosion.

Discussion

Overall, the trends shown in Figure 1 show that the most erosion in Long Beach occurred on the north side and by the coast. The dunes, seen in more detail in Figure 2, likely protect the island from erosion and land loss, as most of the land loss and gain is seen on the south side of the island.

Figure 2 shows a close-up of the beaches on the south side of Long Beach. The impacts of the jetties can be seen in how the land is shaped near the water. Shifting dune height to rest where the vegetation is demonstrates the plant's ability to keep sand and soil trapped in its roots. This is important not only for preventing erosion, but also because the plants act as a buffer against storms and flooding. The land elevation behind the dunes has stayed relatively consistent; this is the same for the land on the north side of the island as well as at Oceanside.

The land cover on the north side of Long Beach is more consistent than the coasts of the south side. However, as seen in Fig. 3, the north side of Long Beach is the Reynolds Channel, and there is more elevation change in its waterways. Fig. 3 shows that there is a decrease in land elevation wherever there is water. With the larger rivers in the channel having a notable portion of the land in the channel, it has lost up to 3.2 meters of elevation. This pattern of more elevation loss in the land near the shore of the channel was expected as the channel has more moving water in a narrower space, which would cause more erosion. This pattern can be seen in Figure 4 as well.

The biggest difference between the northern and southern sides of Long Beach is that even though there is more erosion in the waters (because of the channel), the land is more consistent than the shoreline. The entire south shore of Long Beach shows the same pattern seen in Figures 1 and 2, which is that there is consistent erosion and elevation loss along the coast, but the coast is protected from further erosion by the dunes. On the north side of the island and in Oceanside, there are no signs of erosion along the coasts, only in bodies of water already there.

Like the northern coast of Long Beach, the southern coast has also displayed significant evidence of erosion. Comparisons of Fig. 6 and Fig. 7 show multiple indicators of this, such as the total degradation of the jetties put in place along the beach before 2010. Jetties are known as blocks put in place along a beach to protect it from water-related damage. They are typically made of wood, concrete, or stone, as in the case of Long Beach. Unfortunately, a major part of the erosion seen in Long Beach was caused by the jettie system put in place there. The intended purpose of the jetties was to protect the beach from coastal erosion, but it only brought more erosion to the beach through ocean currents and sand pileup.

In addition to the Jettie destruction, the large amounts of disappearing dune vegetation are quite noticeable. Native vegetation and its roots act as an anchor that keeps the land below it in place, making it difficult for weathering and erosion to displace it. When that vegetation is no longer present, the ground is weakened and more prone to be impacted and shifted by natural surface processes. For beaches, recession inland is one of the main consequences, and the sand-dominated parts of the beach spread further inland, eventually risking damage to nearby property that cannot move with the shore. This is the exact situation shown on the southern coast of Long Beach.

The evidence for coastal erosion is expected to become more prominent for Long Beach, an unprotected shoreline facing natural coastal erosion caused by sea level rise and storm surge, in addition to the failure of human innovation. These combined forces led to the receded beachline's visibility in the 2014 photos, and will most likely be seen clearer in more recent documentation.

The location of Oceanside has witnessed erosion over the years as well, but the rate of erosion is pretty low compared to Long Beach. Based on geographical location and patterns of wind, the erosion level can change. The north side of Long Beach has the most erosion closest to the shore for Figure 9, likely due to the movement of the water from the ocean currents. In Oceanside, this pattern is seen with the channel cutting through Oceanside Park, where erosion is likely from the movement of water, but in the delta, there is only one large area of erosion while the rest of the land mass seems stable. That one spot may be where currents converge, which could contribute to the large spot of land that eroded.

The reason why Oceanside displays fewer effects of erosion than Long Beach can be attributed to the location of the study area, which falls under the protection of Long Beach. Since Long Beach is the barrier island on the outskirts absorbing most of the impacts of erosion, areas such as Oceanside that fall behind it will experience less devastation. If Oceanside was an unprotected shoreline like Long Beach, the currents of the Atlantic ocean would exacerbate the existing erosion patterns of the bodies of water surrounding Oceanside.

Oceanside's existence as an area under protection by other land masses is the main reason barrier islands such as Long Beach are important. The relationship between Long Beach and Oceanside can be seen throughout Long Island with multiple other cities and beaches. This study is simply one case of the many that make up this corner of New York State.

More research is needed as the most recent LiDAR data we found was a decade old and missing part of the island. We were able to complete the analysis without the missing data, but the experiment bears repeating because the changing climate makes it important to monitor changes. The erosion and coastal changes we found spanned over the course of four years, and storm surges and damage have been getting worse since then. This presents the possibility that the erosion we found could have increased significantly since the creation of this study, which is another reason why it needs to be repeated after the collection of more recent data.

Conclusion

While more erosion was expected to be seen on the south shore, the fact that the erosion seen on the dunes of the north side of Long Beach and Oceanside showed no coastal elevation change, furthers the hypothesis that Long Beach is a barrier island that is a source of protection against land loss and erosion for Oceanside and many other areas on Long Island. In addition, dunes and other native vegetation are an important environmental defense as it protects against erosion and acts as a buffer to storm damage as well. This is increasingly important as the severity and frequency of storms and erosion have increased. The numbers and costs of disasters have been increasing for several decades as well due to increases in exposure (more people moving into harm's way and increases in the values of property and infrastructure at risk), vulnerability of people and infrastructure, and climate change.

Credit Authorship Contribution Statement

Abstract: Appel, C., Rahman, M. M., Boddu, D., Marsellos, A.E. (*Supervision*). *Introduction*: Rahman, M. M., Boddu, D. A.E. *Figures*: Appel, C., Boddu, D., *Methods*: Appel, C., Rahman, M. M., Boddu, A.E. *Results*: Appel C., Rahman, M. M., Boddu, D., *Discussion:* Appel, C., Rahman, M. M., Boddu, D., *Conclusion:* Appel, C., Rahman, M. M., Boddu, D.

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Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, (2022). *Global and Regional Sea Level Rise Scenarios for the United States.* National Oceanic and Atmospheric Administration. https://aambpublicoceanservice.blob.core.windows.net/oceanserviceprod/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf