ASSESSING FUTURE FLOOD RISKS IN ROCKAWAY, NY: A GEOMORPHOLOGICAL ANALYSIS USING GIS AND LiDAR TECHNIQUES

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Abstract

As a result of climate change, there has been a gradual increase in the rate and severity of coastal flooding due to rising sea levels. Long Island is particularly vulnerable to high rates of flooding due to its topography. Located in the New York City borough of Queens, Rockaway is approximately 1.5 meters above sea level. Bounded by Jamaica Bay to the north and the Atlantic Ocean to the South, Rockaway is extremely at risk of flooding due to changing sea levels combined with its flat topography and low elevation. To demonstrate the high rates of flooding, Geographical Information Systems (GIS) methods used in a previous study were applied to simulate and assess future rates of flooding in Rockaway. Using GIS software Global Mapper, and Light Detection and Ranging (LiDAR) data we constructed a high-resolution digital elevation model (DEM) that excluded trees, buildings, and any other surface objects. Completion of the bare-earth model allowed us to perform flood simulations and demonstrate a greater understanding of the flood risks associated with different geomorphological regions of Long Island and associated flood rates, specifically those of Rockaway. Based on our simulations we can see that most of Rockaway has a very low elevation especially in the southwestern parts of the island and that those areas should be a first priority for first responders due to the high flooding risk of these areas, while areas in the middle of Rockaway should be addressed afterwards because the risk of flooding is much lower. The data collected using the programs and techniques within this study can be used in many different regions of the world that might be affected by rising sea levels or areas that are more prone to flooding. This will help prepare first responders and provide them with a map of areas that are most at risk.

Introduction

The purpose of this study is to provide crucial information and data that can be used to help first responders know when and where to act first to protect areas impacted by flooding and/or sea level rise, in this case that area is Rockaway, New York. With this information first responders will know which areas of Rockaway to prioritize rather than relying on which area they get a call from first. Knowing in advance the relative time of a region being flooded is a key information for risk management and decision making. After Hurricane Sandy hit the Atlantic coast in 2012, more than 1,000 homes were destroyed on the Rockaway Peninsula due to the

10-foot storm surge flooding the area. Ten years later, New York State has spent $11 billion to repair the damages caused by the storm and some areas still haven't completely recovered. Since Hurricane Sandy, market rate values have increased 44% for the 100-year floodplain to over $174 billion (Lander et al. 2022). Flood rate data is critical as climate change persists and storms similar to Sandy are becoming more frequent with even greater strength. Knowing which areas are most vulnerable due to topography and geomorphology is crucial in aiding first responders in limiting damages. Rockaway is very susceptible to flooding due to sea level rise or major storms due to its low-topography and location. The data gathered from Rockaway is just one example of how this technology can benefit an area vulnerable to flooding and sea level rise.

By 2100, global sea level is projected to increase by 0.5 to 1 meter (Horton et al. 2014). Since the end of the last deglaciation, sea level has continued to fluctuate due to the earth's delayed viscoelastic response to the redistribution of mass on its surface (Peltier et al. 1999). Global average sea level has risen about 8 to 9 inches since the 1880s. The rising sea levels are connected to the melting of glaciers and ice sheets as well as the thermal expansion of the ocean as the water warms (Tay et al. 2022). Another small contributor to sea level rise is the decline in the amount of water on land largely due to groundwater pumping (Tay et al. 2022). With an elevation of approximately 1.5 meters above sea level, the popular summer destination Rockaway, New York is extremely vulnerable to this rapid increase.

Following a previous methodology, a high-resolution Light Detection and Ranging (LiDAR) Digital Elevation Model (DEM) was constructed to predict the flooding of Rockaway, New York (Weinstein and Marsellos, 2018). Our study was carried out through Global Mapper in order to determine which areas of Rockaway are critically endangered from sea level rise and flooding. With a length of 11 miles and a width of 0.75 miles, Rockaway is home to approximately 125,000 people as of 2020. The Rockaway Peninsula frequently floods due to saltwater coming up from sewers and rain that will not drain through sewers blocked by high sea levels (Orton et al. 2019). Waterfront Alliance estimated that 61% of Rockaway residents have a one-in two chance of a major flood in their home by 2060. While more money and attention is being put into the Atlantic Ocean side due to the rebuilding of recreational facilities, the bayside is more vulnerable to flooding due to its lower topography. The New York State Department of Environmental Conservation found (Schiffman et al. 2022) that Jamaica Bay was losing about 50 acres of wetlands per year due to erosion. In 2020, NOAA classified 15 of the 62 high-tide events that impacted Jamaica Bay as minor floods. However, if there had been no historical changes to the bay's landscape, only two of these minor flooding events would have occurred and only one would have occurred without sea-level rise (Pareja‑Roman et al. 2023).

Methods

In order to create the bare earth digital elevation model of Rockaway, Google Earth was used to create a shapefile of Rockaway cut out along the coastline to acquire the required LiDAR data (Fig. 1). LiDAR were retrieved by the New York state government website which was then processed in Global Mapper (version 23.1) utilizing the LiDAR module. The study area of Rockaway ignoring the surrounding bay and ocean was re-constructed in a digital elevation model of 32 bit resolution with LiDAR data.

Figure 1: A high resolution image of the study area (Rockaway, NY). The image was taken from the most recent updated version of Google Earth Pro.

A bare earth model was then created in Global Mapper by isolating ground return LiDAR points. A grid was applied to this area with cells of 500 m by 500 m. Simulations of the flooding were then created within each cell on the grid in order to get an idea of how flooding will affect areas at different elevations as well as to identify high risk areas. The bare earth model gives a sense of how the flooding impacts the area without the interference of small-scale structures such as buildings, roads, trees and other surface objects. The tree structures especially provide strong artifacts on flood simulations because the digital elevation models should see tree-stems of a few feet diameter as small footprint on a flood. Unfortunately the large canopy of a tree is considered by the above-the-ground LiDAR returned points as a large-structure, and a forest would be seen as a collection of giant structures that could potentially block or redirect the flow of water in a flood simulation. Also, giant structures wrongly fill up the simulated volume between the minimum and maximum elevation of DEM.

The values of simulated elevation on a flat polygon (simulated flood) ranged from -8 to 10 meters in order to include possible ground areas with elevation less than the mean sea level. Data in the simulation was taken every 0.1 meter to maintain an appropriate resolution of flood rate without overloading the CPUs of the workstation. The first derivative of the simulation data was taken to observe the slope of the volumetric-fill and that of the area-fill at a given elevation. The lowest and highest flood rate cell per volume and area was then graphed (Fig. 4 and 5). The lowest and highest cells data was then standardized and compared (Fig. 6). ArcMap Pro was then used to create and layout classification maps for the volumetric and area flood rates. The maps were sorted into four different risk levels; low, moderate, high, and very high. These levels were color coded in order to see the contrast easily (Fig. 2 and 3).

Results

The classification maps were sorted into four different risk levels; low, moderate, high, and very high (Fig. 2 and 3). The volumetric map shows a majority of high risk areas in the southwestern side of the island while the central and eastern parts are mainly a low to moderate risk (Fig. 2). The classification map for the area doesn't show as great of contrast as a majority of regions show a high risk of flooding (Fig. 3). The lowest and highest flood rate cell per volume and area was then graphed with the slopes being 18007.58 m^3, 164026.3 m^3, 0.0059m^2, and 0.0205m^2 per 0.1m change in elevation respectively. (Fig. 4 and 5). The lowest and highest cells data was then standardized and the flood rate window is much smaller in the high risk areas compared to the low risk which have a bigger window (Fig. 6).

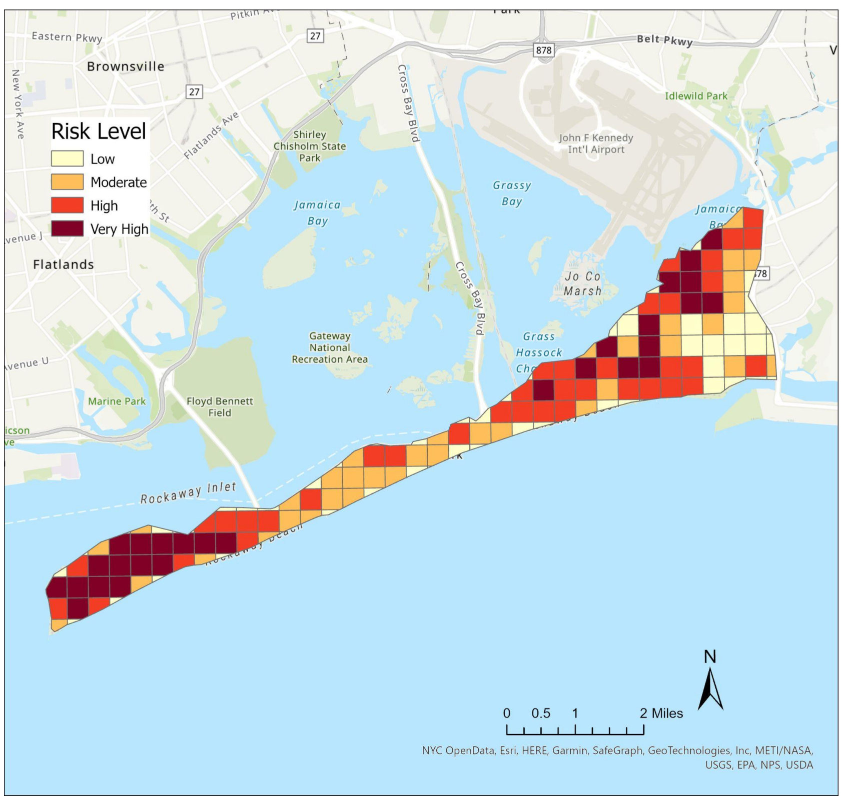

Figure 2: A classification GIS map that displays the risk level per cell of the grid based on volumetric flood rate. The risk levels were categorized into 4 levels ranging from low (yellow color) to very high (dark red color).

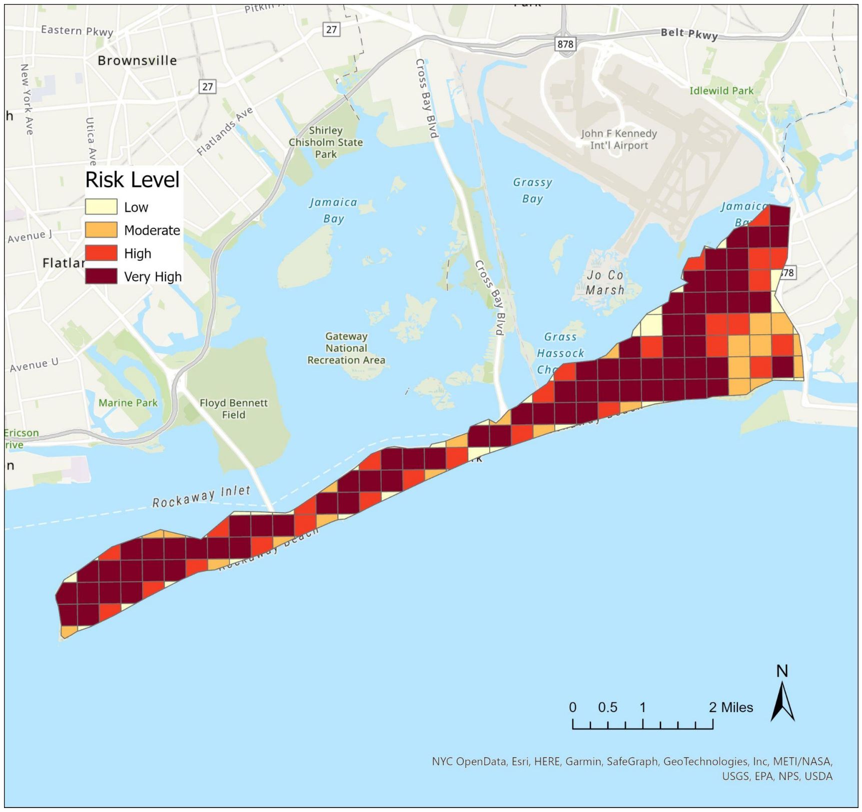

Figure 3: A classification GIS map that displays the risk level per cell of the grid based on flood rate per area. The risk levels were categorized into 4 levels ranging from low (yellow color) to very high (dark red color).

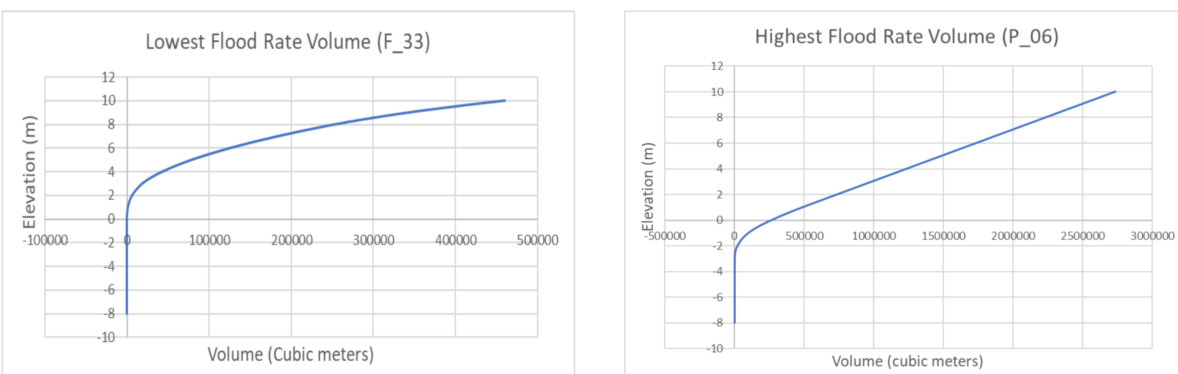

Figure 4: The lowest flood rate volume was found in cell F_33 with a slope of 18007.58m^3 per 0.1m change in elevation (left). The highest flood rate volume was found in cell P_06 with a slope of 164026.3m^3 per 0.1m change in elevation (right).

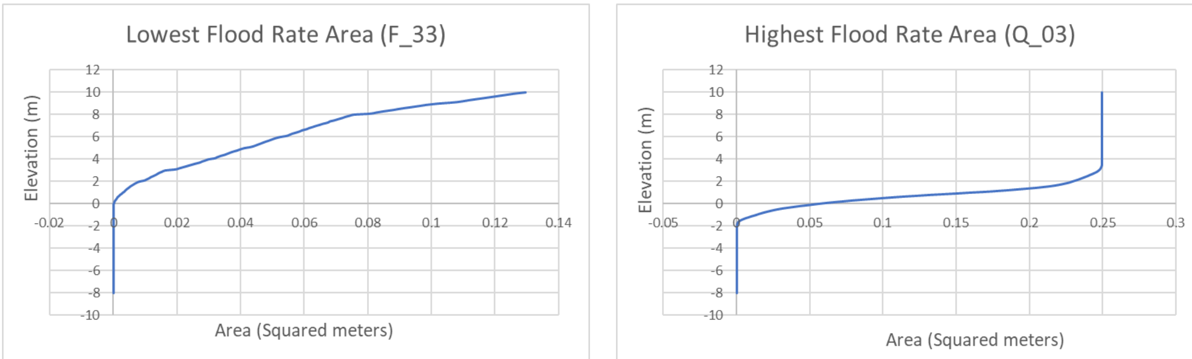

Figure 5: The lowest flood rate area was found in cell F_33with a slope of 0.0059m^2 per 0.1m in elevation change (left). The highest flood rate area was found in cell Q_03 with a slope of 0.0205m^2 per 0.1m in elevation change (right).

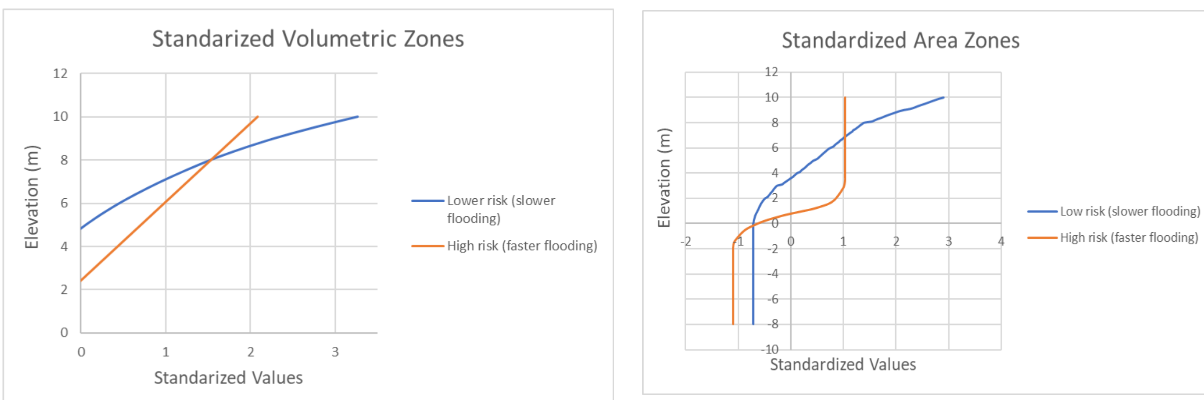

Figure 6: Standardized values of the lowest and highest flood rate volumetric cells (left). Standardized values of the lowest and highest cells of flood rate by area (right).

Discussion

As we know, the amount of flooding and sea level rise is projected to increase greatly over the next few decades which puts areas like Rockaway on high alert. Rockaway is densely populated as it is located in the New York City borough of Queens which makes natural disasters such as floods and hurricanes that much more devastating. Based on the maps that have been created, it is evident that volume provides a more contrasting guide of which areas should have first priority of decision making upon crisis rather than the map of the flood rate per area (Fig. 3). This is due to the higher level of contrast shown in the volumetric flood rate map (Fig. 2). Using the volumetric flood rate map as a guide, first responders can see how the areas with the greatest risk are located in southwest Rockaway as well as certain areas in the northeast of Rockaway as indicated by the dark red colored cells of the grid. The central part of Rockaway as well as parts of the southeast should be addressed after the aforementioned areas, as they have a lower risk of flooding which is indicated by the yellow and orange cells of the grid.

Rockaway, like most other barrier islands, has very low topographic relief. This puts many of its regions at risk of flooding. But, there is a slight difference in the topography which allows some areas to have a smaller risk due to higher topographic relief in that area. A high-topographic relief area implies that there are sporadic places at a higher ground with a lower-risk. It should also be noted that not all of the cells in the grid were of equal size which is why when calculating and comparing flood rates (slope of the graph), cells that are not full size (500 m x 500 m) have been excluded as they would skew the flood rates due to the small variance in elevation. When excluding the smaller incomplete cells, the lowest flood rate by volume was found in cell F_33 with a rate (slope) of 18007.58 m^3 per 0.1 m change in elevation (Fig. 4 left). The highest flood rate volume was found in cell P_06 with a slope of 164026.3 m^3 per 0.1 m change in elevation (Fig. 4 right). The data from these cells was then standardized and the flood rate window for each cell can be easily seen and helps to explain why areas are at high risk and others are not. The graph in Figure 6 shows that the cell with the highest flood rate volume has a much steeper slope (flood rate) and higher-risk than that of lowest flood rate volume. Due to the low variance of elevation as flat areas show, a much smaller amount of water is required for those high-flood rate areas to become flooded. Its slope will rise very rapidly compared to low-flood rate areas which have a higher elevation and require larger amounts of water before flooding will begin so its slope is much more gradual (Fig. 6 left). This higher flood rate shows that flooding will occur much faster with the same amount of water than it would for another area at a higher elevation to be flooded.

Data similar to the flood rate by volume is found when the flood rate by area is measured. When excluding incomplete cells that do not maintain the full 500 m x 500 m cell size, the lowest flood rate by area was found in cell F_33 with a slope of 0.0059 m^2 per 0.1 m in elevation change (Fig. 5 left). The highest flood rate area was found in cell Q_03 with a slope of 0.0205 m^2 per 0.1 m in elevation change (Fig. 5 right). Once standardized, the data showed a very similar flood rate window (that is the slope with values ranging between values that flooded area or volume is not constant along with elevation changes) to that of the volumetric data. The cell with the highest flood rate by area also had the smaller flood rate window. This means that this area will become flooded in a very short amount of time (Fig. 6 right). Between just zero and two meters of elevation the entire area within this cell will be completely flooded which is why tails can be seen on this graph. The tail on the right of the graph represents a constant standardized value which shows that there is no longer any land left to flood as the water has already reached the highest elevation for that area. The tail at the left side of the graph also has a constant standardized value that represents the area that is below sea level (Fig 6 right). Ideally the “tails” of the elevation vs area or volume graphs would be removed to improve accuracy as the flood window is the section between the tails without a constant value. The cell with the lower flood rate shows that more water is needed to completely flood this area since it has a much higher elevation. This is due to topographic relief differences in these areas. An area with a low topographic relief will flood more quickly causing a higher flood rate which can be seen in cells P_06 and Q_03 (Fig. 4 and 5 right). A high topographic relief area is flooded at a much slower rate due to higher elevations. The change in gradient allows for the lower elevations to be flooded first but it takes longer for the water to build up and flood the higher elevations causing a lower flood rate which can be seen in cell F_33 (Fig. 4 and 5 left). The cells with higher flood rates are considered a high risk because these areas will be flooded in a shorter period of time and with a smaller amount of water than the areas that have a lower flood rate.

Since Rockaway is a barrier island that is relatively flat with a low elevation, it is extremely sensitive to environmental disasters and sea level rise so it may seem difficult to know where to act first. The maps and graphs that have been created prior to a crisis provide a clear visual of which areas of Rockaway should be a first priority. This methodology can be applied to virtually any area with sufficient LiDAR data and more contrasting rates may be seen due to greater topographic relief areas compared to Rockaway. This data and methodology will provide first responders with useful information on flood risk assessment of a given area.

Conclusion

Home to one of the most densely populated coastal areas in the world, New York is extremely vulnerable to rising sea levels and floods. To understand which areas are more at risk, a geomorphological analysis using a bare Earth LiDAR model was developed to simulate flooding and to determine where the major risk areas are on Rockaway Peninsula. As to be expected, the majority of the cells closest to the shoreline and western most part of the island are estimated to encounter the most severe flooding, and as you move further inland there is a lower risk of flooding.

The crucial information found in this study can help aid first responders and authorities for future devastating floods. This study shows that first responders shouldn't necessarily respond to the first call, instead they may prioritize when available resources do not exceed the number of emergency requests, and they need to go to the high risk areas in dark red (western part of the island) where it floods more quickly, and then respond to the lower risk areas in yellow and orange (center of the island) where it takes longer to flood. By having this knowledge beforehand of what cells have a higher risk and should be responded to first, emergency responders can enhance efficient decision making and diminish potential injuries and loss of life that otherwise may have occurred.

Credit Authorship Contribution Statement

Mead, N.: Figures, tables, GIS processing, ArcMap processing, data analysis in excel, writing - Results, Discussion, Conclusion; Bourgeois, J.: editing, GIS processing, writing - Abstract, Introduction, Methods, Discussion; Pelletier, A.: references, literature, ArcMap processing, editing, writing - Introduction; Badger, T.: editing, literature; Marsellos, A.E.: supervision, GIS processing, data analysis in excel, guidance, editing.

Acknowledgements

We would like to thank Dr. Antonios E. Marsellos and the Geology, Environment and Sustainability department at Hofstra University for providing us with the necessary tools to conduct this research.

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