Flood rate investigation as a response to climate change: an example on Coney Island, New York

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Abstract

With global temperatures increasing as human influence gradually accelerates an impending environmental calamity, the need for accurate and precise flood rate data is essential in creating a foundation for proper assessment by emergency responders. Coney Island is located in the southernmost part of Brooklyn in New York at a current elevation of 7 feet (2.1 meters) above sea level. Due to the area's low lying elevation, the study region is significantly more susceptible to sea-level changes and tidal floods. To determine the current flood rate, a Digital Terrain Model (DTM) using Light Detection and Ranging (LiDAR) was constructed for the study area in a Geographical Information System (GIS) software (Global Mapper), and divided into several cells. Each cell was utilized to implement flood simulations. Incremental sea level calculations were applied by digitally simulating a rising sea level with increments of 0.1 meters until we have reached the max elevation of Coney Island to be fully submerged. Data obtained and methodology described from this study can provide valuable information regarding coastal flooding around the globe as a result of climate change effects including but not limited to rising sea levels. This methodology can be applied to other regions in which emergency response is critical for efficient mitigation, decision making, and risk management.

Introduction

Global sea levels in the New York City area are projected to rise 17.5 to 25 cm by the 2050s, with an increase of almost 50 cm by the 2080s (Gornitz et al. 2006). This environmental issue is even more pressing given the multitude of neighborhoods, businesses, airports, and other important infrastructure located at an elevation less than 3 meters. The surge from a strong category two or three storm could easily surpass this height, before the consideration of additional factors which may contribute to the change in sea level such as the tidal forces. Therefore, the need to accurately identify flood rate will become increasingly crucial. The flood rate is the first derivative of the flooded area of land per incremental sea level rise. Our study follows a similar known procedure wherein a high-resolution digital elevation model a GIS application may determine the flood rate (Weinstein, Marsellos, 2018). Our study is accomplished by utilizing a simulated Digital Terrain Model (DTM) in Global Mapper in order to calculate the flood rate of various regions of Coney Island to determine which are in imminent danger due to sea-level rise or tidal flooding. This model provides insight to first responders to determine which locations must be prioritized and given immediate aid during a flood crisis.

Coastal areas have become increasingly susceptible to environmental stressors, such as storm surge, sea-level rise, and beach erosion. Global warming has a multitude of effects on low-lying areas, primarily due to worldwide ocean warming, the retreat of mountain glaciers, and the recent thinning of the Greenland and West Antarctic coastal ice sheets (Gornitz et al. 2006). This warming has caused the global sea level to rise approximately 1.7-1.8 mm/yr over the past fifty years, placing low-lying areas at immediate risk for flooding and storm surge. Strong storm tides are among the world's most costly and deadly environmental threats, bringing in floodwaters and waves capable of damaging and destroying homes and infrastructure, as well as threatening the livelihood of millions of residents (Orton et al. 2015).

The New York City metropolitan area is one of the most densely populated and culturally rich regions in the United States, with approximately 8.6 million residents as of 2016 (Hopper and Meixler, 2016). Coastal populations in the area have soared on average 17% since 1995, with some local communities experiencing a population increase over 100% (Gornitz et al. 2001). For instance, New York City coastal wetlands, which are valued at over \$5.1 million dollars per km^2, are considered among the most valuable wetlands in the nation due to the large population, dense infrastructure, and high property value (Hopper and Meixler, 2016). Given the massive amount of inhabitants, New York City is particularly vulnerable to catastrophic economic, structural, and geological damage, as well as injury and loss of life if a large storm or hurricane were to bring in an extensive storm surge.

While strong hurricanes seldom make landfall as far north as the New York City metropolitan area, their effects are considerably worse than storms of similar intensity that impact coastal states in the south. The northeastern United States has unique geographic, geologic, meteorologic, and oceanographic characteristics typically causing large storms to move at an accelerated rate with an enlarged wind field amplifying the overall destruction once landfall is made (Coch, 2015). Although nearly a hundred years have passed since the last major hurricane made landfall in the New York City area, the destruction caused by recent storms, such as Irene (2011) and Sandy (2012), serves as a reminder that catastrophic coastal damage is plausible regardless of storm intensity.

The purpose of this study is to provide critical data for first responders to utilize when considering which areas are most at risk from storm surges and imminent flooding on coastal regions. The specific area of study and our main focus for coastal flood investigation is Coney Island, a peninsula located in southern Brooklyn. The area has been especially ravaged by coastal flooding in the past twenty years. In 2011, Hurricane Irene made its final landfall as a category one storm precisely at the heart of Coney Island, eventually moving west north-westward. The following year, the area was flooded once again as Superstorm Sandy made landfall in Atlantic City, New Jersey as a category one extratropical cyclone. Storm surge in the area was the primary cause of destruction, as water heights reached 15-20 feet in some regions, leaving entire homes and businesses underwater for days and shattering storm surge records set by previous parameters (Coch, 2015). Warm ocean waters fuel strong hurricanes, and with the current increased rate of ocean warming, destructive storms that make their way as far north as Coney Island will only become a more frequent occurrence. Flood rate data will provide the necessary tools for officials to ascertain which areas at risk are of utmost importance in order to mitigate damage from future environmental disasters.

Methods

The study area was delineated by extracting the coastline. Low-lying areas, such as the surrounding beach and highways north of the peninsula, were excluded to avoid skewing the flood rates. Beach area was decisively cut off due to imminent flooding that would be evident when a storm surge occurs in the area.

The study area was then divided into several 300x300 meter cells. The cells were utilized to facilitate data processing as well as to act as comparable danger zones for first responders. The cells were cropped to our study area so the determined flood rates will not be affected by irrelevant information for this study.

On each cell, a surface area/volume simulation was applied. The flood simulation was implemented in a digital terrain model (DTM) which was created utilizing LiDAR ground points. DTM was converted to a GeoTiff with a 32bit floating elevation to assure precision over three decimal points.

Elevation values were then assigned to a virtual surface on each grid cell of the DTM model. Elevation was taken from an approximate range of -5 to 10 meters at intervals of 0.1 meters, resulting in over 150 elevation simulated surfaces per grid cell. The aforementioned procedure was repeated 98 times to generate the total of 14,700 simulated surfaces and related values for every grid cell applied to Coney Island DTM. Our method processed volumetric calculations using fill area and volume data to determine the rate at which the area at a particular grid cell will flood.

This information was then utilized to determine the first derivative, or slope, of the volumetric-fill and the slope of the area-fill with the change in elevation. Our model ran elevations ranging from -5 to 10 meters; however, the data below the lowest actual elevation of Coney Island ultimately resulted in zero and was disregarded in order to eliminate inaccuracy within the flood rate. In addition, the high end of the elevation range unveiled issues since the volumetric-fill will continue to increase even if the water level has already surpassed the highest point of Coney Island; therefore, we looked at when the area-fill remained stagnant and disregarded all elevations above the highest area for each cell. The lowest and highest elevations were omitted from both the area and the volumetric model in order to prevent skewing the flood rate.

Results

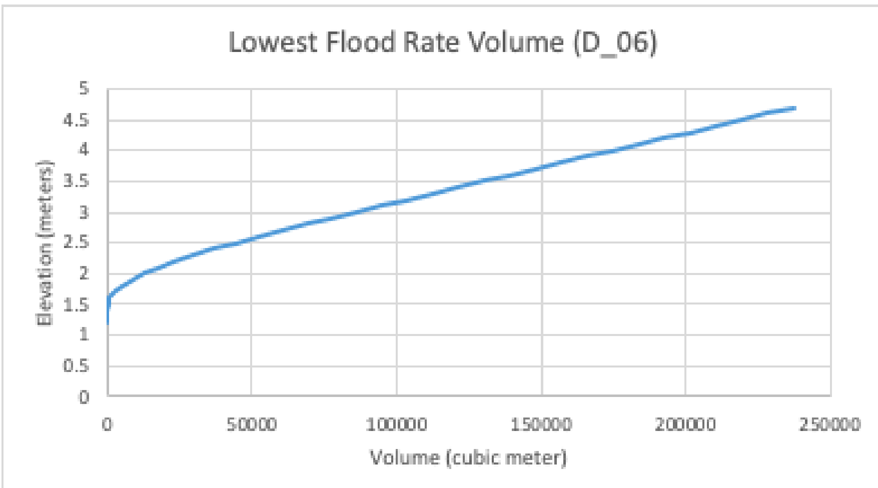

Figure 1: The lowest flood rate by volume is found in cell D_06 with a rate of 1.3 x 10^{-4} m^3 per 1 meter of vertical elevation change.

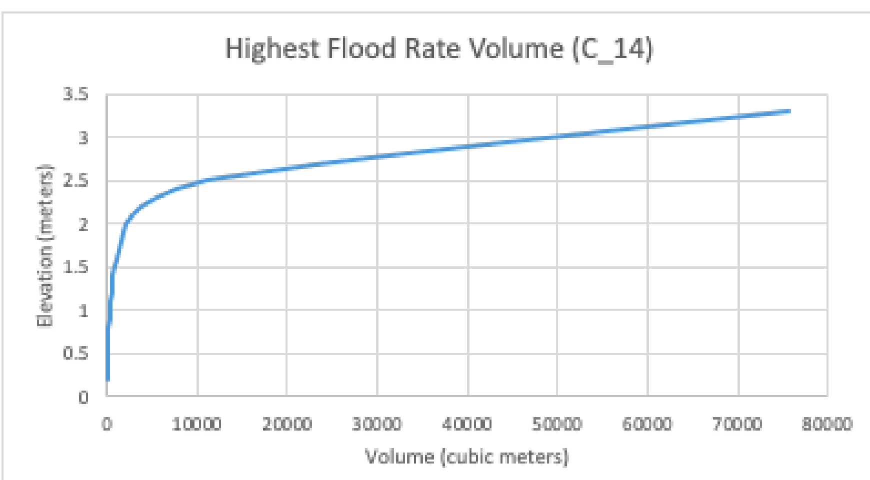

Figure 2: The highest flood rate by volume is found in cell C_14 with a rate of 3.4 x 10^{-4} m^3 per 1 meter of vertical elevation change.

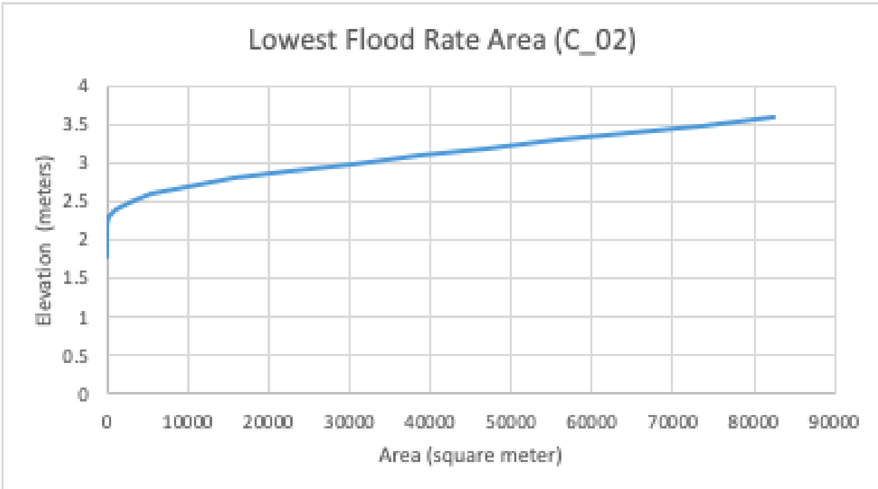

Figure 3: The lowest flood rate by area is found in cell C_02 with a rate of 139.8 m^2 of flooded area per 1 meter of vertical elevation difference.

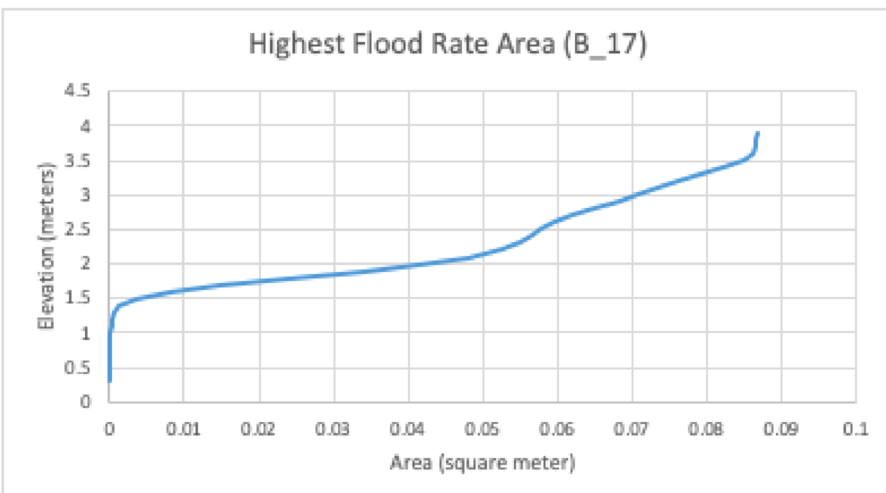

Figure 4: The highest flood rate by area is found in cell B_17 with a rate of 303.6 m^2 of flooded area per 1 meter of vertical elevation difference.

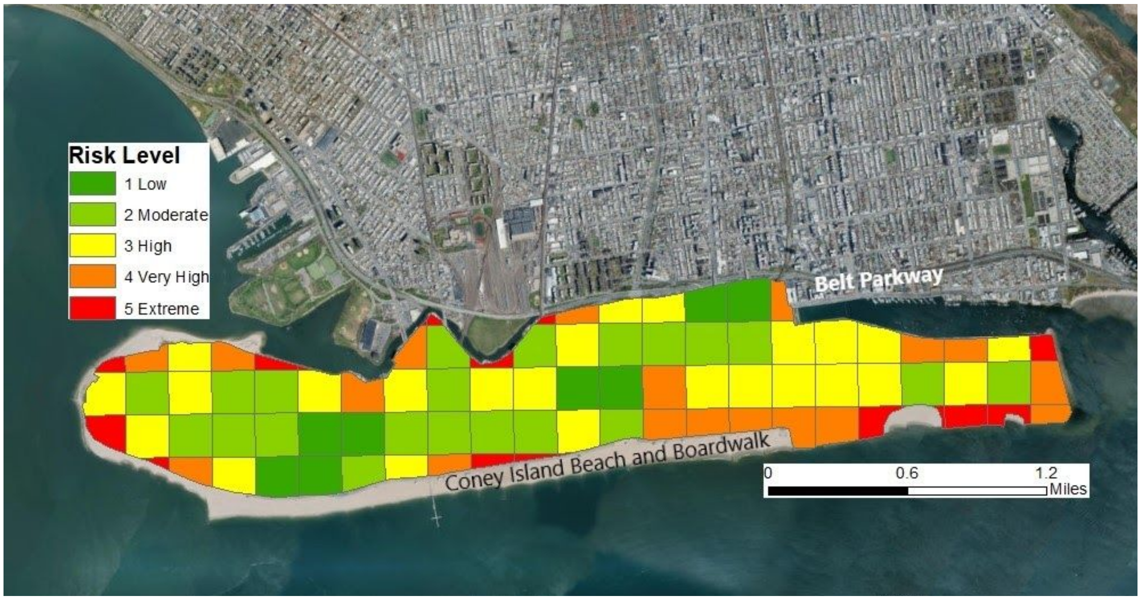

Figure 5: A GIS classification map that presents the volumetric flood rate in terms of the risk level. Risk level was described with five risk levels starting from low risk (level 1; green color) to high risk (level 5; red color).

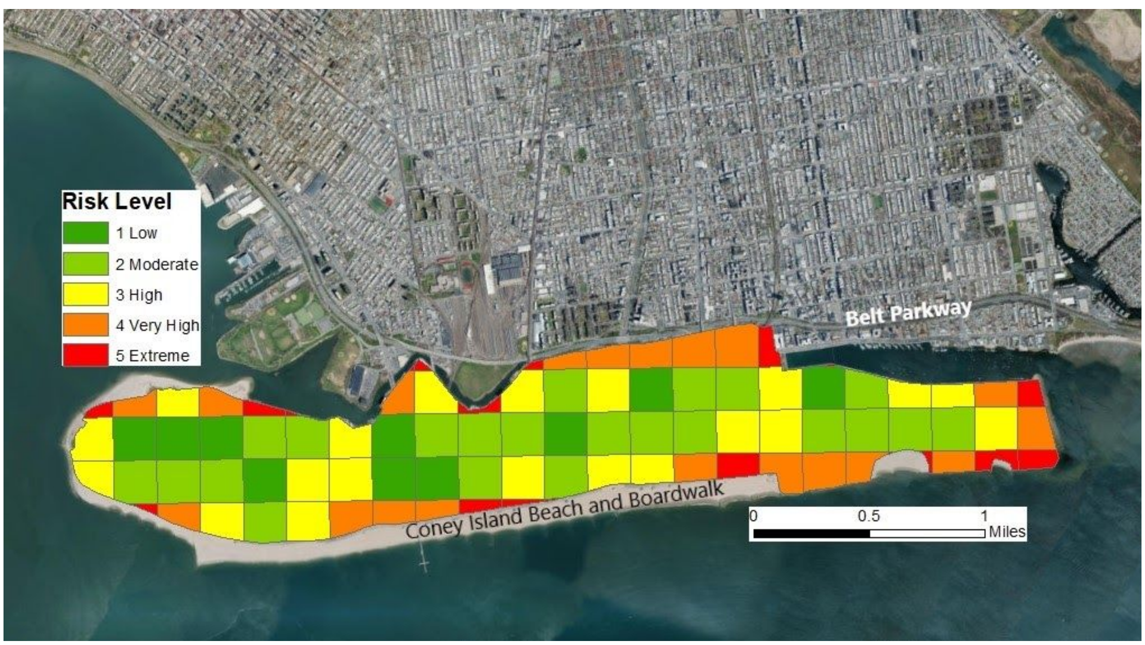

Figure 6: A GIS classification map that presents area flood rate in terms of the risk level. Risk level was described with five risk levels starting from low risk (level 1; green color) to high risk (level 5; red color).

Discussion

Coastal regions are extremely susceptible to destructive flooding and storm surge. Most large low-lying coastal cities, such as New York City, are incredibly densely populated, which exacerbates environmental disasters. With global warming accelerating the rate of sea-level rise and the melting of ice caps, coastal regions, such as Coney Island, are expected to be negatively impacted by flooding and strong storms. To further conceptualize the extent of this flood, envision that on average for each 0.1m of sea-level rise, the square area of two Macy's department store floors like those in New York City is flooded.
Both the volumetric and area flood rate depicts that the eastern side of Coney Island is more at risk than the western side. In the volumetric flood simulation model (Fig. 5), 10/19 cells on the western end are in extreme or very high risk of flooding, while on the eastern end only 7/19 cells are. In the area, flood simulation model (Fig. 6), 10/19 cells on the western end are in extreme or very high risk of flooding, while on the eastern end only 6/19 cells are. Specifically, the southeastern end of Coney Island is most at risk since every cell in this region is in very high or extreme danger in both the volumetric and area flood model.

The majority of extreme or very high-risk areas are located adjacent to the shoreline, as these grids contain the lowest elevation and closest proximity to the ocean, making said areas more susceptible to storm surge, tidal flooding, and erosion caused by strong waves before reaching the interior of the peninsula. Furthermore, the grid size utilized for each square cell in the study area has a length of 300 meters; however, the cell size is not always equal, especially closer to where the study area has been cropped, which is at the coastline. It is worthy to note that those smaller rectangular or triangle shaped cells may include smaller variations of elevations, thus higher rates of a flood. Therefore, the cells with the smaller incorporated land are biasedly simulated to flood quicker than a larger land area. When excluding the cells which incorporate small land areas, the lowest flood rate by volume is at a rate of 139.8 m^2 of flooded area per 1 meter of vertical elevation difference while the highest flood rate by volume is at a rate of 303.6 m^2 per 1 meter of sea-level rise. This is significant since the cell with the highest flood rate will flood nearly three times faster than the cell with the lowest rate. When excluding the cells which incorporate small land areas, the lowest flood rate by area is at a rate of 139.8 m^2 per 1 meter of sea-level rise, while the highest flood rate by area is at a rate of 303.6 m^2 per 1 meter of sea-level rise.

It is understandable that a relatively flat area such as Coney Island would flood quite rapidly. This study is just an example and can be applied to other areas with a more diverse morphology or to distinguish vulnerable areas in regions of similar morphology. Similar studies have analyzed flood rates via a calculated flood window using a LiDAR-DEM to simulate which areas will flood first (Weinstein & Marsellos, 2018). However, our study varies since it utilizes a DTM instead of DEM which eliminates buildings and foliage from the model. Coupling results from alike studies with the volumetric flood risk calculated in this study could provide essential information to first responders as very little research has been published regarding location-based flood risk assessment. Knowing which specific blocks would require immediate aid first in the event of a large flooding emergency can help ensure the safety of both those affected and emergency response teams.

Although the Coney Island peninsula is a rather small study area, the methodology of our research may be applied to other regions near bodies of water such as islands or coastal regions. Our study area was constrained into Coney Island for simplicity; however, the approach and information can be obtained by adjusting the grid size for a given location. For instance, organizations could calculate worldwide flood rates in a similar manner to obtain knowledge about which regions around the globe are currently projected to be at the highest risk for coastal flooding due to climatic sea level rise in the coming decades. Furthermore, insurance companies could utilize flood risk data to assess insurance rates for homes near areas prone to flooding. By quantifying the risk data and making it public, individuals looking to purchase a home near the coast could take advantage of this information to become aware of the possibility of their home flooding and the resulting insurance rates. In addition, this information allows architects to properly build or update houses in these regions in order to withstand the foreseeable damage caused by flooding.

Conclusions

With global temperature rise and increasing coastal flooding, the need for valuable flood rate information is becoming more necessary than ever before. By creating a DTM with publicly available resources such as LiDAR data of the area, it is possible to digitally simulate the rising sea level to determine which areas will specifically flood the quickest, as well as the worst. After our initial calculations, it's apparent that the eastern and southeastern shores of Coney Island are the most susceptible to rapid, intense flooding. As expected, most cells adjacent to the shoreline are projected to experience the worst coastal flooding, with more inland grid cells at a lower risk.

Data from this study provide indispensable information and a useful tool for future catastrophic disasters to first responders in the event of a major storm. Emergency personnel can often become overwhelmed during a major flooding event such as during Superstorm Sandy. Prior knowledge of specific locations with the highest risk allows Emergency Medical Technicians and public authorities to prioritize the most high-risk areas first in order to minimize injury and loss of life.

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