Assessing Future Flood Risks: A GIS Simulation of Brooklyn's September 2023 Event with LiDAR Data

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Abstract

Brooklyn, one of the five boroughs of New York City, is situated only 67 meters above sea level, with small, yet noticeable elevation changes throughout it. This uneven surface, coupled with its low elevation and proximity to the water, makes Brooklyn very susceptible to flooding, as was the case on September 29th, 2023. With 2023 being the hottest year in recorded history and the trend of global warming having no end in sight, extreme weather events, including major, flood-producing rain storms like the one seen in September will become commonplace. Brooklyn will likely experience another flooding event in the foreseeable future. By reconstructing and simulating this flood using GIS programs such as GlobalMapper and Google Earth, and combining it with the use of the high-resolution LiDAR elevation data to map out which areas are most vulnerable- with special attention given to emergency services- Brooklyn residents and community leaders alike will be better prepared for future floods. Using the information collected, along with proposed alleviation measures like sewage cleanup and emergency services, can remain active and efficient during major future flooding events.

Introduction

In the last 250 years, carbon emissions from human activities have increased the concentration of CO_2 in the atmosphere by 50%, ushering in an era of rapid global warming, the likes of which have never been seen before in the entire geological history of the planet (EPA, 2022). This rapid warming is fraught with dangerous consequences- including sea ice loss, rising sea level, more frequent and intense heat waves and wildfires, and a sharp increase in major storms. Only in the last five decades have we begun to attempt to curb this activity, but it is the opinion of most experts that it is too little, too late- with the most optimistic predictions showing a minimum 1.5°C (2.7°F) increase in global temperature by 2050 (NOAA, 2001). The increase in major storms due to climate change means an uptick in urban flooding events, the damage of which is difficult to overstate. Floods from excessive rainfall in urban settings cause structural and property damage, electrical outages, road closures, and the suspension of public transportation. In extreme cases, flooding can overwhelm city sewage systems, causing contamination in the water supply. Cleanup efforts and emergency relief funds can reach hundreds of millions of dollars, and there is even the possibility of loss of life. One such case of urban flooding occurred in September 2023, when torrential rain caused flooding in major metropolitan areas of New York, New Jersey, and Connecticut, with the New York City borough. Brooklyn was hit particularly hard.

Photos of the event show mass confusion and panic as entire streets became inaccessible. It took a full day for the water to subside after the rain ended, and damages totaled at $100 million (Camacho-Suarez, 2023). This event is likely indicative of a trend. Global warming will increase both the frequency and severity of flooding, and based on the aftermath of a flood with a mean depth of only 4 inches (though in some areas this number was up to nearly 10 inches) (Lauren, 2023). Based on climate change models, future flooding is inevitable, so while it is likely impossible to prevent it, mitigating the impact that those floods have on Brooklyn may be possible. Our goals are to help prepare Brooklyn residents for future flooding events by predicting what areas will be most affected by reconstructing the flood in a GIS program so that community leaders can prioritize sewage cleanup and map out what emergency response services will be affected.

Methodology

We first collected a series of images of the event compiled in an article from the weather channel and determined the geographic location of 9 images (Bonaccorso, 2023). By marking these points on Google Earth, we could then download them as .kmz files and upload them to GlobalMapper (version 24.1), the main GIS software we used for the data. The points we collected came from a 24-square-kilometer area in northern Brooklyn where the flooding was especially significant, so this roughly triangular-shaped polygon (Fig. 1) served as our "study area". We downloaded LiDAR elevation data from the FTP's (File Transport Protocol) NYC 2021 database (ftp://ftp.gis.ny.gov/elevation/LIDAR/), totaling 83 LAS files and approximately 66.4 million points of data to construct a high-resolution Bare-Earth Digital Elevation Model (DEM). A Bare Earth model renders only the "last of many" points and includes no vegetation or structures, which were both subtracted to avoid artifacts (structures rendered on a GIS that do not exist, ie. a tree that is rendered as a building). The DEM gave us an understanding of how and where the water would accumulate. We color-coded the study area so that areas of low elevation were green and areas of high elevation were red (Fig. 2). We followed a previously discussed methodology of flood simulation and reconstruction of damaged areas (Mead, et. al, 2023; Tabarus, et. al, 2020; Mahoney, et. al, 2018). The flooding tool in GlobalMapper allowed us to simulate water flow in our study area to measure the impact of major rainfall events without needing one to actually occur. We determined which areas would flood first and what emergency services would be affected. All distance and elevation were measured in metric units.

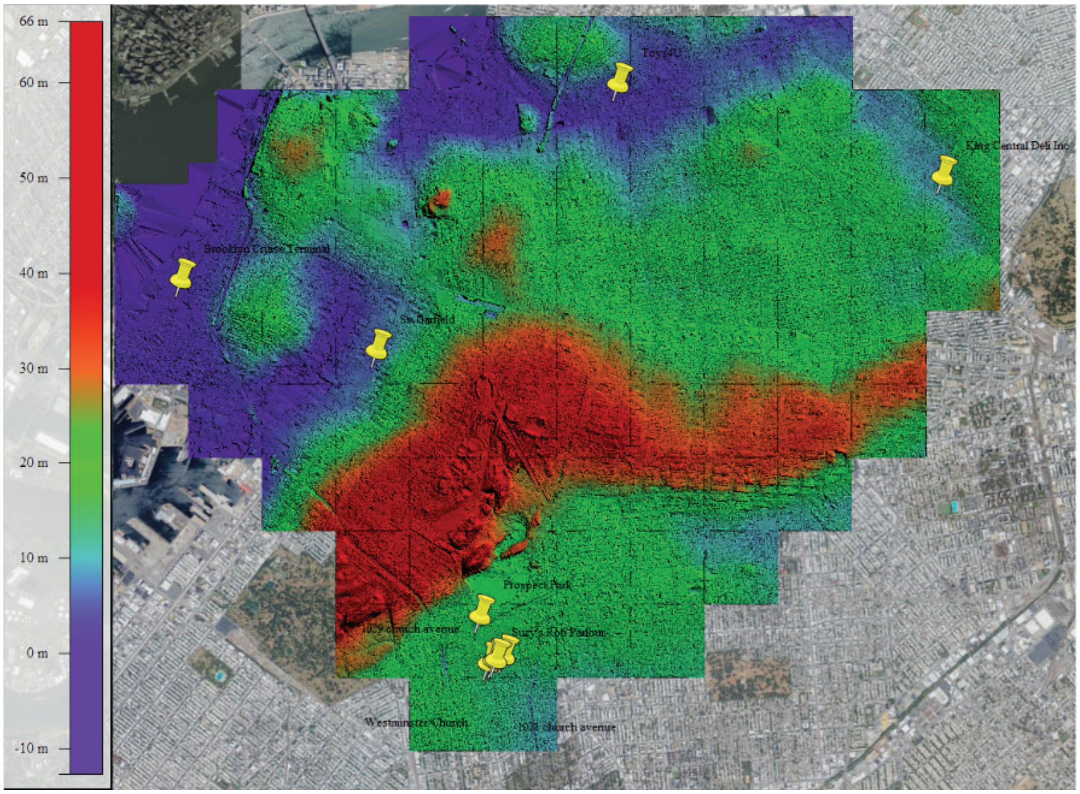

Figure 1: A Global Mapper elevation grid of our study area with 9 labeled points (yellow pins) where floods were reported and LiDAR data displayed. The elevation ranges from 0 meters (blue) to 66 meters (red).

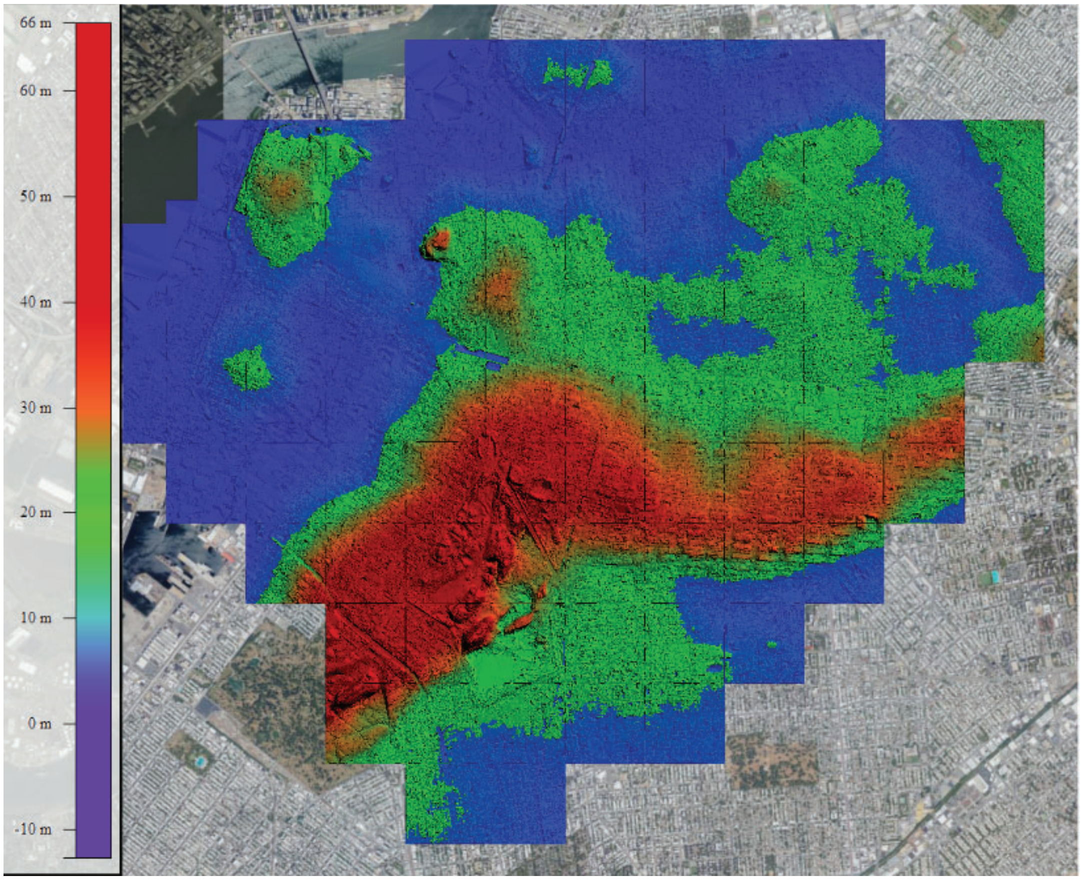

Figure 2: A Global Mapper elevation grid of our study area flood simulated (blue region) with LiDAR data displayed. The elevation ranges from 0 meters (blue) to 66 meters (red).

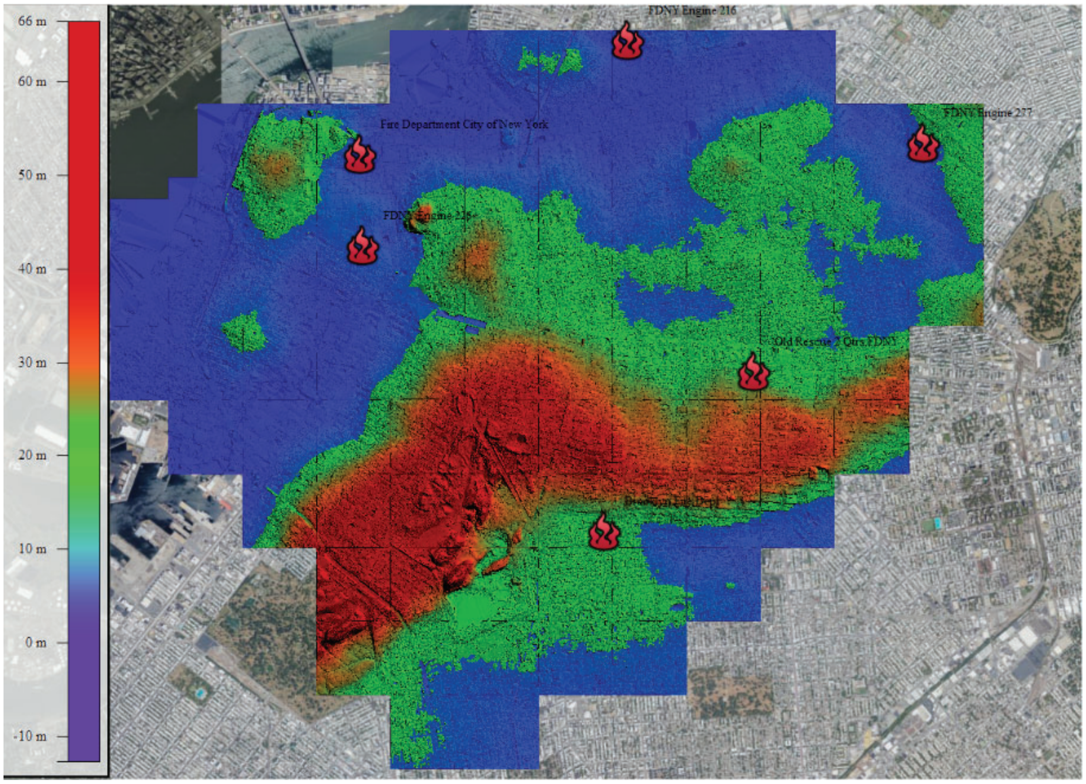

Figure 3: A Global Mapper elevation grid of our study area with flood simulation (blue region), 6 fire stations labeled (red fire pins), and LiDAR data displayed. The elevation ranges from 0 meters (blue) to 66 meters (red). Yellow pins show the reported floods by the media.

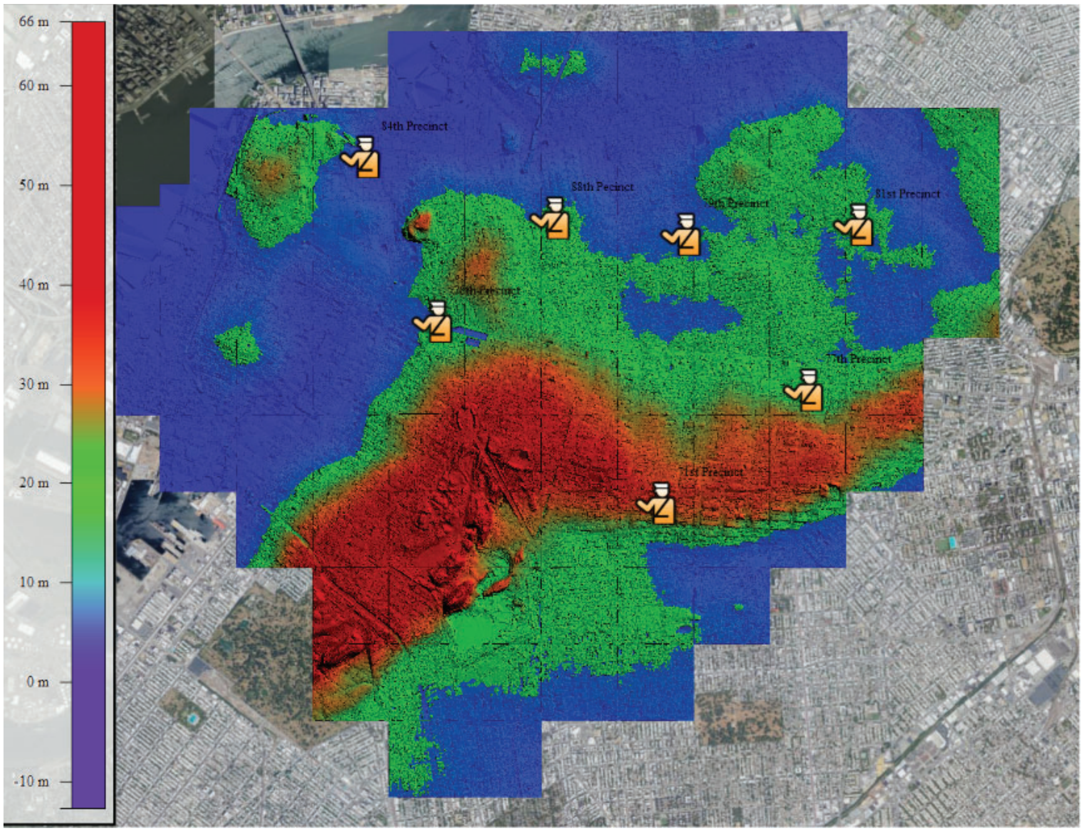

Figure 4: A Global Mapper elevation grid of our study area with flood simulation (blue region), 7 police precincts labeled (orange police officer pins), and LiDAR data displayed. The elevation ranges from 0 meters (blue) to 66 meters (red). Yellow pins show the reported floods by the media.

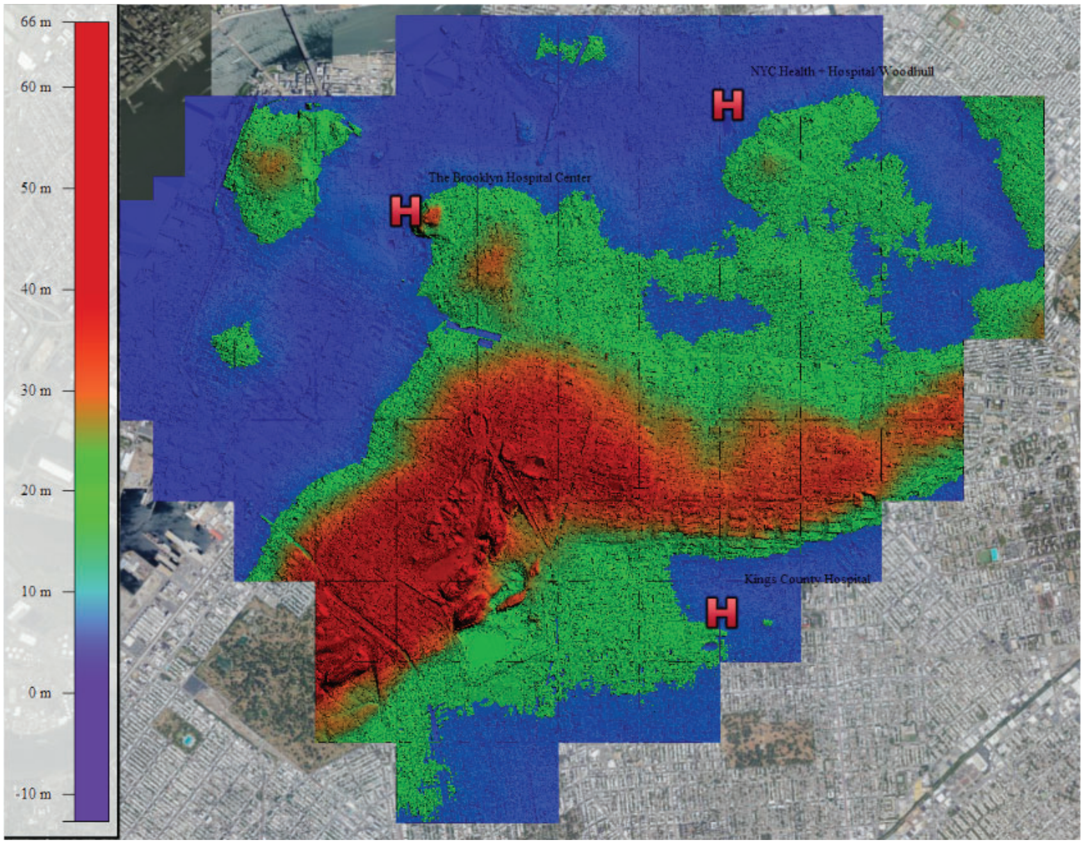

Figure 5: A Global Mapper elevation grid of our study area with flood simulation (blue region), 3 hospitals labeled (red H pins), and LiDAR data displayed. The elevation ranges from 0 meters (blue) to 66 meters (red). Yellow pins show the reported floods by the media.

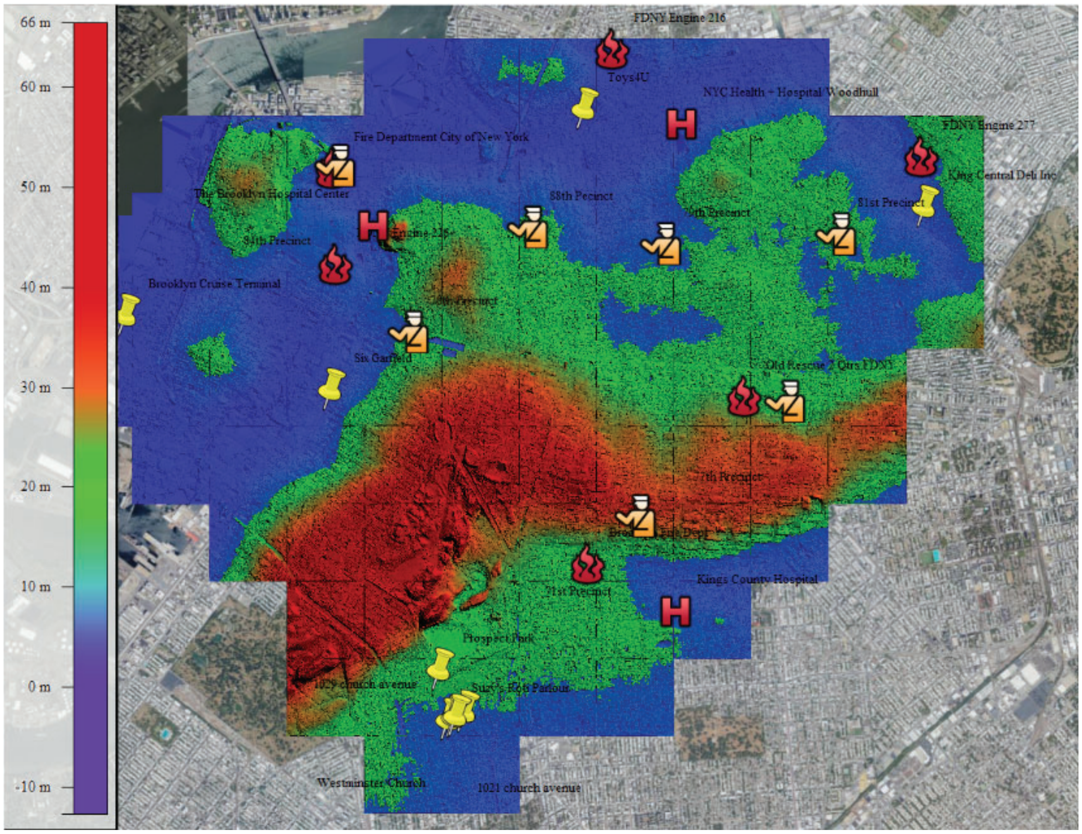

Figure 6: A Global Mapper elevation grid of our study area with flood simulation (blue region), all major rapid response authorities labeled and their vicinity to most affected places, and LiDAR data displayed. The affected roads are also contained within the defined area. The elevation ranges from 0 meters (blue) to 66 meters (red).

Results

The results of simulating the flood in our study area showed us that many of Brooklyn's emergency services, along with many of the borough's roads, will be affected by future flooding. Seven of the thirteen emergency services including FDNY 226, Fire Department City of New York, FDNY 216, FDNY 277 (Fig. 3), and the 71st, 77th, 78th, 79th, 81st, 84th, and 88th Police Precincts (Fig. 4), and all three of the hospitals (Fig. 5) located inside our study area experienced simulated flooding. A major highway, the Brooklyn-Queens Expressway I-278, became completely inoperable. Every road in our study area west of 5th Avenue was flooded (Fig. 6). The highest elevation point is the center of our study area, which encompasses Prospect Park. The flooding formed a circle around the park. In the areas south and west of Prospect Park, intersections experienced more flooding due to slight dips in elevation. Based on the elevation data we gathered in our project, The flooding would accumulate first in the western part of our study area, followed by the northern and southern sections.

Discussion

Climate change and global warming will increase the frequency and severity of extreme weather events that cause flooding, meaning that areas like Brooklyn that are prone to flooding will experience infrastructural and property damage with socio-economic impact in the coming decades. To alleviate some issues, places with lower elevations should be prioritized for sewage cleaning to prevent water contamination (Fig. 1), and Emergency services should be prepared for increased requests for assistance. Communities nearby the flooded area should also prepare to divert some of their emergency services to the affected area. Our data definitively shows that large portions of our study area are prone to flooding from excess rainfall, so it is reasonable to extrapolate the data and assume that Brooklyn and the nearby metropolitan areas of New York, New Jersey, and Connecticut could easily experience extreme weather as well, especially when taking into account the flooding of September 29th, 2023 that affected all of the aforementioned areas. There are also thousands of coastal settlements on Earth with varying levels of preparedness, so this issue is not isolated to the Northeastern United States. In addition, with frequent flooding, insurance costs in these areas may drastically increase, raising living costs for residents who may already be struggling. Our methodology can be applied by the authorities to prepare the regions so that when flooding does occur, the risks of damage to property, infrastructure, and water supplies could be substantially reduced.

Conclusion

As climate change and its accompanying extreme weather events become more widespread, residents in urban areas like Brooklyn must be prepared for recurrent floods. Our study highlights the need for preventative actions to mitigate the impacts these floods have on communities. While our simulation alone cannot resolve the climate crisis, it offers a tool for preparedness and response efforts. The potential damage done to emergency services and critical infrastructure revealed by our GIS simulation demonstrates Brooklyn's vulnerability to future flooding events. By identifying low-elevation areas that are at a high risk of flooding and outlining the potential impact on vital services- namely infrastructure damage, property damage, and water contamination- our study provides the information necessary for community leaders to allocate resources and funds in such a way that the damage is alleviated. Prioritizing sewage cleanup in vulnerable zones and readying emergency response teams are imperative steps towards resilience against flooding. Our findings apply to cities beyond New York: coastal cities and settlements face the same risk of flooding as Brooklyn, so while this specific study and related methodology only applies to the defined area of Brooklyn, preemptive measures guided by GIS mapping and LiDAR data can empower other communities to navigate and adapt to the changing world and respond to climate-induced flooding.

Credit Authorship Contribution Statement

Lawlor, J.: GIS processing, editing, writing - Abstract, Introduction, Methodology, Discussion, Conclusion, References; Jones, W.: Figures, GIS Processing, editing, writing - Abstract, Introduction, Methodology, Results, References; Tecusan, K.: GIS processing, writing - References; Marsellos, A.E.: Supervision, GIS processing, guidance, editing

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