Creating a Model to Optimize and Evaluate the Heat-Reducing Capacity of Green Infrastructure

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Contents

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1 Introduction

1.1 The Worsening Problem of Rising City Temperatures

Global warming is bringing an increase in the number of warmer than average days and extreme heat events (NWF, 2017). This is especially problematic in cities, where urban heat island impacts are adding additional stress to cities and energy grids, threatening energy demands, and increasing the risk of power outages and the incidence of heat-related illnesses (Cook-Anderson, 2006; EPA, 2015). The problem of rising temperatures in cities is worsening as urban sprawl continues to replace vegetation in response to the influx of population in urban areas (O'Hare et al., 2005). As cities continue to rapidly expand, local governments tend to focus on building gray infrastructure, which encompasses most traditional construction materials, such as concrete, brick, and asphalt, generally because they are inexpensive and easy to acquire. However, gray infrastructure traps large amounts of heat during the day and retains it during the cooler nights, contributing to the urban heat island effect, when an urban area is significantly warmer than its surrounding rural areas (Zeman, 2012). This only adds to the pre-existing urban issues, including high intensity of built structures, making urban populations more vulnerable to heat waves and thus at greater risk of heat-related illnesses. Because of this, it is evident that there is an increasing need to respond to climate change, particularly in highly urban areas.

1.2 Green Infrastructure - The Alternative to Gray Infrastructure with Many Side Benefits

The alternative to gray infrastructure is green infrastructure (GI). Although its definition is evolving, GI includes newly-developed green systems (vegetated areas that store stormwater) being installed on a large scale, such as bioswales (vegetated trenches along the side of roads) and stormwater greenstreets (planted areas typically constructed in the roadway). GI provides many benefits to cities, from improving water and air quality and preventing combined sewer overflow, to beautifying city streets. Perhaps most importantly, GI has the ability to reduce temperature (Foster et al., 2011), which is the focus of this study. Lack of green space has been associated with an increase in heat stress and heat-related deaths (Bradford et al., 2015). This may be because more urban areas tend to have lower levels of vegetation and more impervious surfaces, which directly relates to the urban heat island effect. Thus, GI is a logical and favorable solution to rising city temperatures.

GI can help reduce urban temperatures in three main ways: shading building surfaces, deflecting solar radiation, and releasing moisture into the atmosphere (City of New York, 2016). Trees are the most obvious example of green infrastructure's shading ability as their branches and leaves block the sun. GI deflects solar rays due to its lighter green color relative to the darker gray and black of gray infrastructure. Finally, GI releases moisture into the atmosphere due to a process called evapotranspiration, the combination of evaporation and plant transpiration, by which water moves within a plant and and a plant loses water as a vapor through stomata in its leaves. This process cools both the plant and its surroundings, making it one of the strongest cooling factors of GI.

Cities are now beginning to adapt to changing climates through GI initiatives (Adams, 2015). In the United States, the most prominent examples are in New York City, NY; Philadelphia, PA; Washington, DC; Kansas City, MO; Montgomery County, MD; Portland, OR; and Seattle, WA (Freehan, 2013). The best example of GI being used to reduce high heat vulnerability is in New York City (Rosenzweig et al., 2006; Ito et al., 2015; Kinney et al., 2014).

1.3 New York City - A Strong Empirical Example for the Study of GI and Heat Reduction

New York City is a prime example of the need to protect cities from rising temperatures. It has a high heat vulnerability due to its high built intensity and large population. In addition to its large inhabitant population, it has a large tourist population that peaks in the summer (NYCEDC, 2017), adding an influx of 60.5 million people to the 8.5 million inhabitants (NYC & Company, 2017). Because of this, policymakers in New York City have taken initiative to reduce the danger of heat.

In September 2010, the New York City Department of Environmental Protection (DEP) began to address New York City's heat vulnerability by creating the DEP Green Infrastructure Program, one of the largest GI programs in the country. The DEP agreed to invest $2.4 billion over the subsequent 18 years starting in March 2013 (Economides, 2014). The program is an effort to construct a variety of sustainable GI practices, such as rain gardens, stormwater greenstreets, and bioswales, on city-owned property, including streets, sidewalks, and public housing, throughout the City (City of New York, 2016). The program is currently building GI in compliance with the New York State Department of Environmental Conservation (DEC) requirements to reduce combined sewer overflow discharges into New York City's waterbodies (City of New York, 2016). In 2015, in OneNYC, the New York City Mayor's Office's plan for a sustainable New York, the City announced a plan to expand the GI program to mitigate heat vulnerability (OneNYC, 2015).

The NYC GI program is especially important since it must protect one of the world's largest cities, which also has a large vulnerable population. Because of this, the DEP has made its GI program one of the largest in the country and incorporated local firms and contractors into its plan. 59% of all stormwater management firms are located in New York State, 86% of which see their firm's share of revenue from GI projects increasing over the next five years (McEwen et al., 2013). In fact, the NYC GI program is so extensive that the only comparable plan in scope is Philadelphia's Long Term Control Plan Update (McEwen et al., 2013). However, since Philadelphia is one-third the size of New York City and overall less vulnerable to heat, its GI program is smaller in scale.

1.4 Heat Vulnerability Index

A heat vulnerability index (HVI) is a measure of vulnerability to heat-related illness during an extreme heat event. By identifying higher risk neighborhoods, the City can better direct resources to these communities, including focusing GI programs to these areas. Vulnerability is driven by risk factors, exposure, and sensible populations. This study focuses on risk factors and sensible populations, although exposure is briefly discussed.

Within New York City there are differences in urban form and demographics that lead to some geographies presenting as more vulnerable to heat stress than others. Poverty and age are the two clearest indicators of heat vulnerability. Greater poverty prevents people from adapting to rising temperatures, as it makes them unable to buy a new air conditioning unit or pay for the elevated electricity bills that result from increased usage of cooling units. Age is a risk factor at both ends of the spectrum as both young and elderly populations have weakened bodies that prevent them from effectively regulating internal body temperature. These risk factors were demonstrated in the 2003 European heat wave and the 1995 Chicago heat wave. Analysis of mortality data in France indicated that deaths during the 2003 heat wave were disproportionately concentrated in poorer neighborhoods (ORS, 2003) and analysis of mortality data in Chicago indicated that the poor, elderly, and infant had elevated risks of mortality during the 1995 heat wave (Klinenberg, 2002). Race and gender are often considered influences of heat-related mortality, but evidence is inconsistent, so these factors were not considered in this study (Basu and Samet, 2002).

1.5 Problem Statement, Objective, and Hypothesis

Initiatives similar to New York City's can help build adaptive capacity through reducing climate-related vulnerabilities, but the uncertainty involved in calculating their economic and social costs and benefits inhibits local governments from taking action (Foster et al., 2011). This project aims to solve this policy gap by evaluating the DEP GI Program in terms of its effectiveness in mitigating increased heat in New York City through looking at how it addresses several biophysical and social risk factors. Social risk factors are especially important as the least is currently known about the social aspects of vulnerability (Cutter et al., 2003). This project also proposes an ideal distribution of GI sites throughout New York City so that new sites can be built efficiently according to heat vulnerability patterns to prevent thousands of heat-related deaths in a relatively inexpensive and noninvasive manner (Irfan, 2016). It was hypothesized that New York City's GI program was not functioning at optimal efficiency in terms of reducing heat vulnerability due to a group of few neighborhoods containing the vast majority of GI sites, rather than a more even distribution throughout the City.

1.6 Impact

This research has the ability to affect the four billion people living in cities, a number that will only rise in the future as population increases and people continue to urbanize. It could be applied both to improve the heat-reducing capacity of current GI programs, such as the ones in Los Angeles, Houston, and Washington, D.C., or to ensure that new GI programs run at maximal heat-reducing capacity from inception. This will ensure that the greatest number of people can benefit from GI and will be protected from the world's dangerously-rising temperatures.

2 Methods

2.1 Creating the Heat Vulnerability Index (HVI)

This project focused on developing a heat vulnerability index (HVI) for New York City neighborhoods in order to determine their need for GI. This HVI was applied to create an ideal distribution of GI sites in New York City to evaluate New York City's current GI program, as well as to propose improvements to it.

To create the index, several factors were considered, each accounting for different percentages of the index values depending on their importance. These factors were the percentage of each of the 188 Census neighborhood's population below 5 years old, the percentage of the neighborhood's population 65 years old and older, and the percentage of the neighborhood's population with an income of less than $25,000. Factors from Census neighborhoods are much more accurate than those of the existing case studies using United Hospital Fund (UHF) neighborhoods as there are only 42 UHF neighborhoods while there are 188 Census neighborhoods, so Census neighborhoods function at a more local scale (NYC DOHMH, 2013).

The percentages of a neighborhood's population below the age of 5 (PCTKIDS), above the age of 65 (PCTOLD), and with an income below $25,000 (PCTPOV) were retrieved from the 2009-2013 American Community Survey (ACS) Profile via the NYC Census FactFinder (NYC DCP, 2016).

Using the ACS Profile allowed for more recent data and easier access than using the 2010 Census. PCTKIDS and PCTOLD were important because they represent the ages most vulnerable to heat waves. PCTPOV represents the percentage of people in poverty because it is harder for them to adapt to temperature increases. The income brackets below $25,000 were chosen since the ACS Profile only reports incomes in intervals, such as $15,000 to $24,999, and it best approximated the poverty line as the average New York City household size is 2.61 (IndexMundi, 2014) and the federal poverty line for a household size of 3 is $20,160 (Families USA, 2017).

Since each of the three demographic factors affected the neighborhoods' vulnerability differently, bivariate analyses were performed between each of these factors and the 2013 rate of heat stress emergency department visits. The rate of heat stress emergency department visits is one of the heat stress morbidity indicators and is tracked as the number of emergency department visits due to heat stress. It was chosen as the heat stress morbidity indicator over the number of heat-related deaths because heat-related deaths is too small a dataset to be an accurate indicator at the extremely local level of this study. Rather than using the 188 Census neighborhoods for the bivariate analyses, the 42 United Healthcare Fund (UHF) neighborhoods had to be used because the rate of heat stress emergency department visits could only be accessed for the UHF neighborhoods. This data was acquired from the New York State Statewide Planning and Research Cooperative System (SPARCS) Deidentified Hospital Discharge Data via the NYC Health Environment and Health Data Portal (SPARCS, 2017). After the relationships between the demographic factors and heat stress morbidity were established using the UHF neighborhoods, the trend was extrapolated for the Census neighborhoods to create their weighted HVI values.

The total weighted value of the factors related to heat-related illness, established by Myagmartseren et al., 2017, was calculated from

$$Value_{weighted} = \sum_{i=1}^{n} w_i x_i \tag{1}$$

where $Value_{weighted}$ is the total weighted value, n is the number of values, w_i is the relative weight of factor i, and x_i is the criteria score of factor i. Through this weighted linear combination of factors, all weights can be directly associated with their corresponding percentage of importance.

The different weighted percentage values for each factor were incorporated into the weighted average value for each neighborhood by replacing w_i with the slopes of the factors' associated graphs, replacing n with the number of factors, 3, and then adding these together. This weighted value was then divided by 3 to create a simple mean average value.

$$Value_{avg} = \frac{0.3605(PCTOLD) + 0.6326(PCTKIDS) + 0.0363(PCTPOV)}{3} \tag{2}$$

These weighted average values were normalized by subtracting each value from the lowest value and dividing this difference by the difference of the highest and lowest value.

$$Value_{normal} = \frac{Value_{avg} - min}{max - min} \tag{3}$$

Additionally, values for each neighborhood were added to create a total value. Each of the values were divided from the total value and multiplied by the total number of DEP GI sites, 3847, to create an ideal number of GI sites in each neighborhood.

$$GI_{ideal-neighborhood} = 3847(\frac{Value}{\sum_{n=1}^{188} Value_n}) \tag{4}$$

2.2 Creating the control

There was no heat vulnerability index (HVI) for the control distribution, so a scale had to be extrapolated from the actual number of GI sites currently in each neighborhood. The map of all DEP GI sites was available at ArcGIS Online, so the Shapefile of the 2010 Census neighborhood borders, which was accessed using the Neighborhood Tabulation Areas from NYC OpenData by the NYC Department of City Planning (NYC DCP, 2017), was overlaid onto this map. The GI sites in each neighborhood were counted using the Summarize Within function in ArcGIS Online.

Figure 1: 2010 New York City Census neighborhood borders overlaid over map of DEP GI sites.

Working backwards from Equation 4, the actual number of sites in each neighborhood (GI_{actual}) was divided by the total number of sites, 3847, and then multiplied by the total value determined by the ideal distribution using Equation 4, 2474.41, to find the control HVI value ($Value_{normal}$) for each neighborhood.

$$Value_{control} = \frac{2474.41 GI_{actual}}{3847} \tag{5}$$

2.3 Mapping the HVI

The number of GI sites for both the control and ideal distributions were displayed on maps where dark red indicated many sites and light pink indicated few. The ideal map was made in Tableau Public 10.2.1 utilizing OpenStreetMap, and the control map was made in ArcGIS Online.

2.4 Proposing future green infrastructure site locations

With each neighborhood assigned a control and ideal number of GI sites, it was possible to compare the two to determine which neighborhoods were in the greatest need for new GI sites. Based on this, a spatial multicriteria decision analysis was used to propose the optimal locations for new sites within each neighborhood. Different factors were evaluated to determine if a location was suitable for ground-level GI. A boolean process was created such that if a factor for a possible site location indicated suitability, it was assigned a 1, and if it indicated unsuitability, it was assigned a 0. The factor values were then multiplied together, and the sites with remaining values of 1 were considered suitable sites. The first set of factors was the set of 21 planimetric factors from the NYC Planimetric Database (NYC DoITT, 2017). The dataset used was the 2016 Planimetric Delivery, the most recent dataset. Each factor was added as a vector layer in QGIS 2.18.0 Las Palmas to form a composite map. For ground-level GI, the four planimetric factor layers tested for suitability were PAVEMENT_EDGE, MEDIAN, OPEN_SPACE_NO_PARK, ROADBED, and PLAZA.

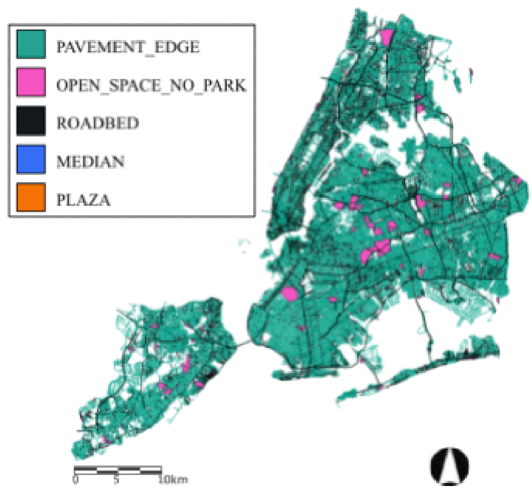

Figure 2: Map of suitable layers for ground-level GI.

PAVEMENT_EDGE represents anything between pavement and other surfaces or features, such as curbs, sidewalks, or grass. Each segment was captured as a continuous feature across a blockface (typically from one intersection to the next along that side of the road). PAVEMENT_EDGE features are continuous across driveways, alleys, or access to parking. On highways, PAVEMENT_EDGE corresponds to ROADBED and does not include the shoulder.

MEDIAN represents anything that physically divides a roadbed. This includes medians, traffic islands, "Jersey Barriers", and painted areas that are used to separate traffic flow. Medians are sometimes paved, are normally elevated (have a curb), or have dirt or grass. Medians can have sidewalks crossing them. In those cases, the outline of the largest area was incorporated into a single median feature.

OPEN_SPACE_NO_PARK includes any open space that is not a park (softscape recreational areas and greenstreets), such as cemeteries, hardscape recreational areas, and vacant areas.

ROADBED represents the interior polygon of PAVEMENT_EDGE. The edges of these features are coincident with the linear feature class PAVEMENT_EDGE. Converging roadbeds were not split when crossing one another at different elevations (such as on ramps that cross each other). Roadbed was usually cut by Median features (such as curbs and grass) with the exception of painted, barrier, and fence medians. Special care was applied to ensure that highway shoulders were not confused as sidewalk features.

PLAZA represents public space plazas, hard surfaced "parks" adjacent to sidewalks or pavement edges. Where a plaza is connected to a sidewalk by steps, the steps were considered to be part of the plaza polygon. Planters at the edge of plazas were included as part of the plaza boundary. Plazas cannot overlap medians or sidewalks. Walkways within the plaza were captured as part of the overall plaza polygon and were not considered a separate polygon (NYC DoITT, 2017).

The difference between the control and ideal number of GI sites (d_GI_Sites) was found for each neighborhood, such that neighborhoods in need of more sites had negative d_GI_Sites values and neighborhoods with excess sites had positive values. Using Microsoft Excel, the d_GI_Sites values were assigned to each neighborhood to create a CSV file. This file was converted to an ESRI Shapefile using FME Workbench to properly work with it as a vector in QGIS. Once uploaded to QGIS as a vector layer, the data points were filtered and separated into two different layers based on their d_GI_Sites values. If a point's d_GI_Sites value was greater than or equal to zero, it represented a boundary to a neighborhood that was considered a "no build zone" for GI. If a point's d_GI_Sites value was less than zero, it represented a boundary to a neighborhood that was considered a "build zone" for GI.

Figure 3: Evaluation of d_GI_Sites values. Neighborhoods included within green points indicate d_GI_Sites<0, while neighborhoods included within red points indicate d_GI_Sites≥0.

In order to compare d_GI_Sites to the planimetric factors, the neighborhoods included within the green points ("build zones") had to be converted to polygons. To do this, a convex hull was taken with the "build zone" Shapefile as the input layer and the neighborhood name (ntaname) as the field so that separate polygons would be drawn for each neighborhood. Each of the four planimetric layers was then clipped with the convex hull to properly analyze the remaining four factors. OPEN_SPACE_NO_PARK did not overlap with the "build zone" at all, so it was not considered for future GI site construction. One layer was created of all the clipped planimetric factors using the union algorithm.

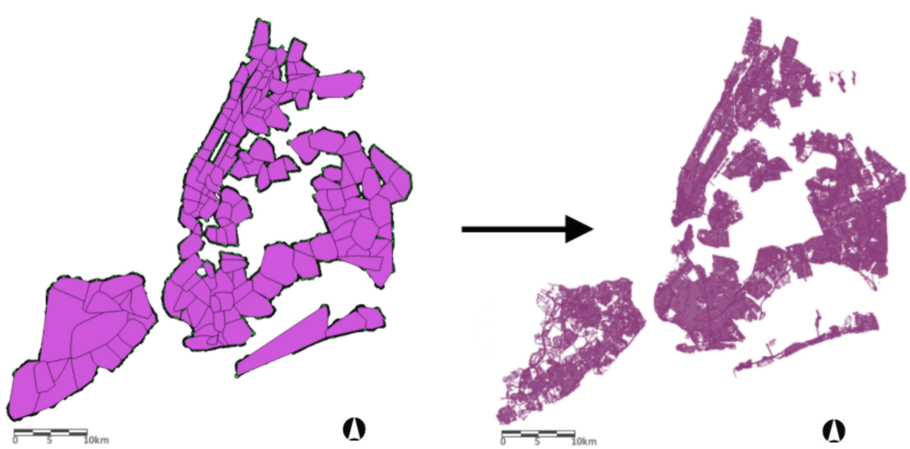

Figure 4: Union of clipped planimetric layers overlaid over convex hull of "build zone" layer.

According to the DEP GI standards, ground-level GI must have dimensions of 20'x5', 15'x5', 10'x5', 20'x3'-6", 15'x3'-6", or 10'x3'-6" (DEP, 2017). Locations that were too small to accommodate these dimensions were considered unsuitable for GI sites. Since width was not a feature of the planimetric layers, it was calculated by dividing SHAPE_Area by SHAPE_Leng. All features were long enough, but many were too narrow. The planimetric layers were then refiltered based on the type of GI that could be built there. For MEDIAN and PLAZA, features with widths of less than 5' were removed as only rain gardens and bioswales, which have widths of 5', can be on traffic islands and sidewalks. For ROADBED and PAVEMENT_EDGE, features with widths of less than 15.5' were removed because stormwater greenstreets, which have widths of 3.5', are built from sidewalks onto streets, and an additional 12' must remain on the streets for cars to pass (DEP, 2017). This removed much of ROADBED and PAVEMENT_EDGE.

Polygons were then made summarizing the actual GI sites using the Freehand Editing plugin. The actual GI site locations were removed from the possible locations of future GI sites by subtracting this polygon layer from the union of clipped planimetric layers.

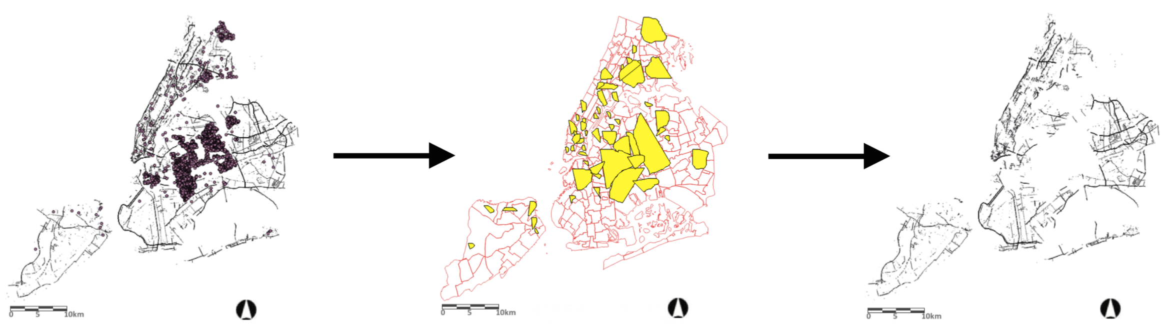

Figure 5: Removal of actual GI site locations from consideration for future GI construction.

3 Results

All three risk factors, neighborhood population 65 and older, neighborhood population below the age of 5, and neighborhood population with an income of less than \$25,000, were significant as they had p-values of less than 0.10 when correlated with the rate of heat stress emergency department visits. The most strongly correlated factor was senior population ($r = 0.292$). The Pearson product-moment correlation coefficients of all the demographic factors ranged from 0.258 to 0.292, indicating small association with the rate of heat stress emergency department visits. After conducting a three-way ANOVA, the three-way interaction between the demographic factors was found to be significant (p= 0.004). Despite the low R^2 values for each of the factors, residual analyses for each of the factors showed that a linear model was appropriate due to the random distribution of the points in the residual plots around the horizontal axis. Overall, the statistical analyses showed that although the demographic data was noisy with high variability, it had a significant trend when correlated with the rate of heat stress emergency department visits.

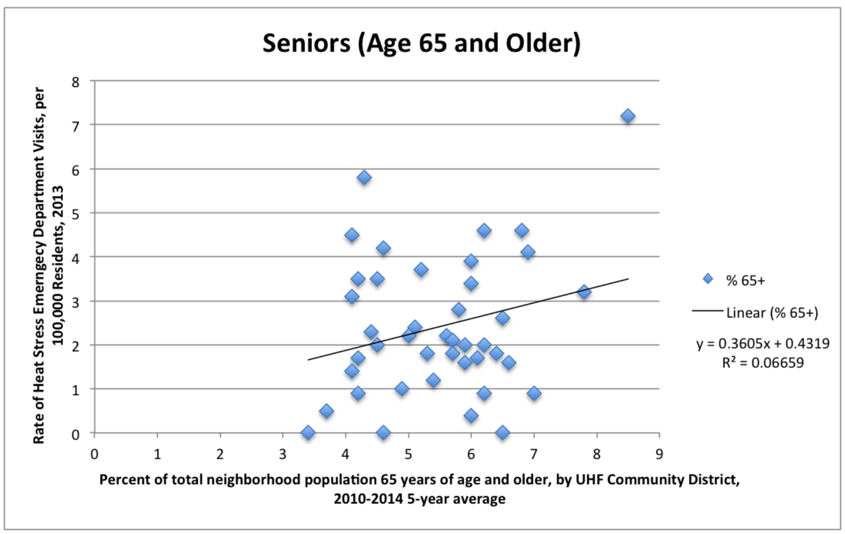

Figure 6: Relationship between UHF neighborhood senior population and rate of heat stress emergency department visits (r = 0.292, p = 0.060).

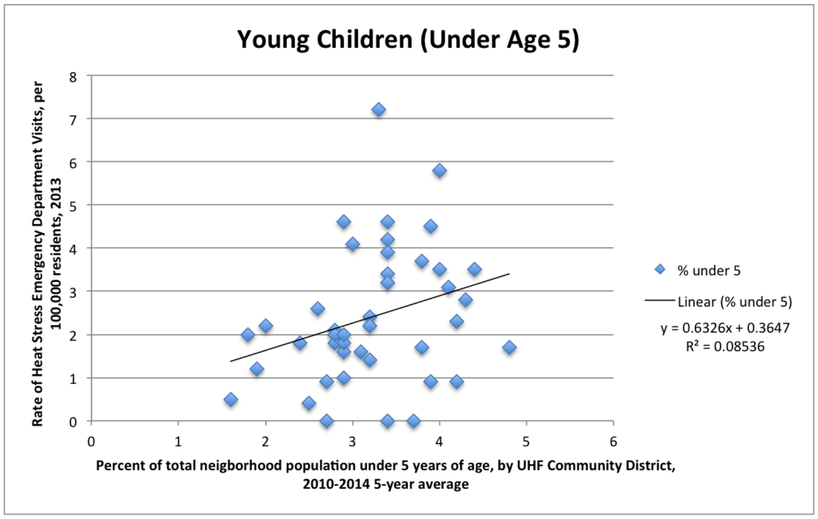

Figure 7: Relationship between UHF neighborhood young-child population and rate of heat stress emergency department visits ($r = 0.258$, $p = 0.099$).

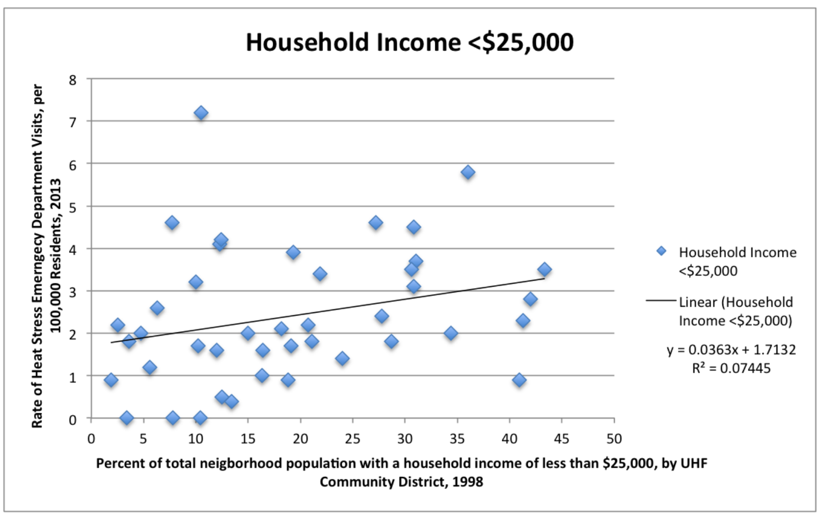

Figure 8: Relationship between UHF neighborhood percentage of households living below poverty line and rate of heat stress emergency department visits ($r = 0.273$, $p = 0.080$).

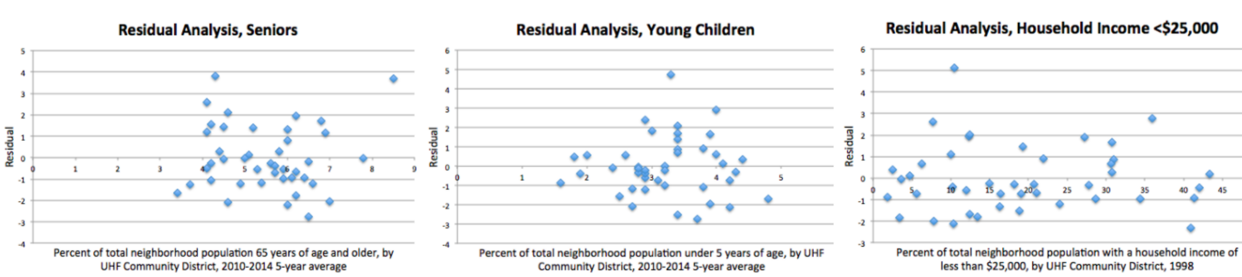

Figure 9: Residual analyses of demographic factors. Random distribution of points in all residual plots around horizontal axis showed that linear model was appropriate.

The ideal GI sites were more evenly distributed than the actual sites, with an average value of 13.16 and standard deviation of 2.40, but there were several outliers. The most significant was Crotona Park East in the Bronx with an ideal value of 26.51, followed by Williamsburg (22.64), West Brighton (21.59), Starrett City (19.48), Seagate-Coney Island (18.37), and Brighton Beach (17.76) in Brooklyn, and Far Rockaway-Bayswater (17.59) in Queens.

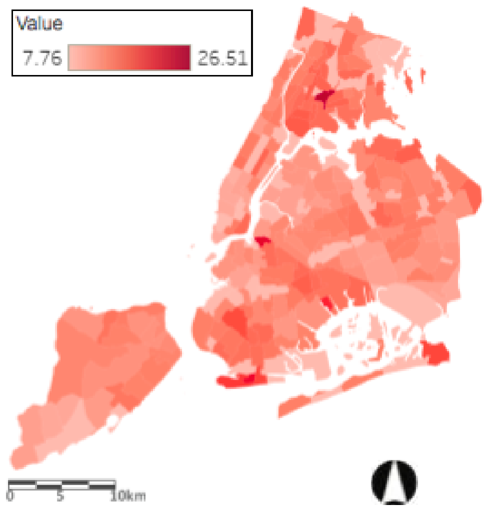

Figure 10: Map with ideal HVI values. Light pink denotes low heat vulnerability and dark red denotes high vulnerability.

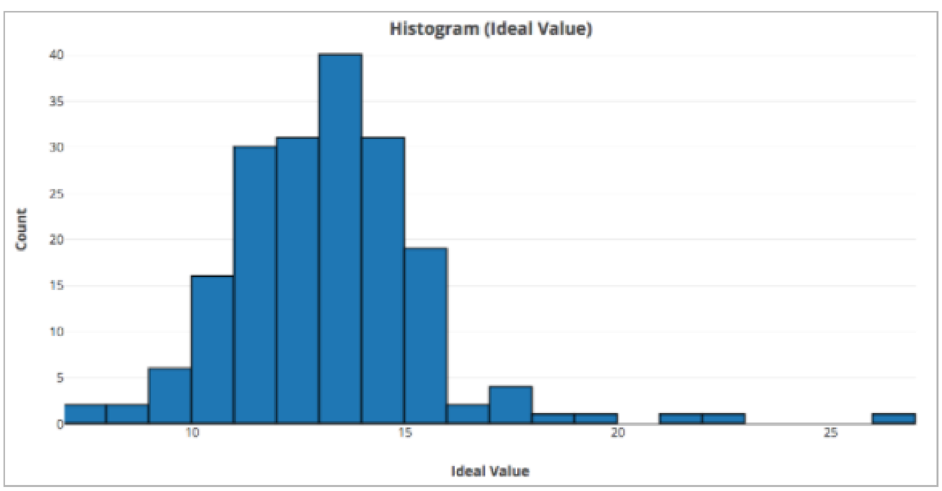

Figure 11: Histogram of ideal HVI values. Peak represents ideal HVI values of 10 to 15. Near-normal distribution indicates that a more even distribution of GI sites is best.

The actual locations of GI sites were found to be almost entirely concentrated to Northern Brooklyn and Southern Queens, with an average of 13.16 and a standard deviation of 35.46.

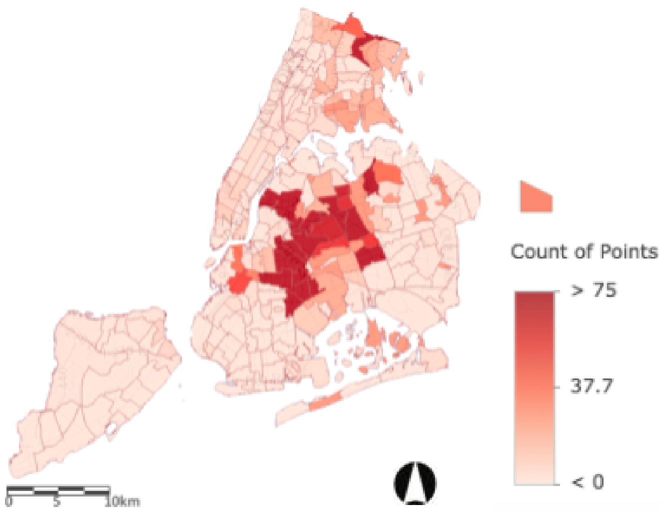

Figure 12: Map with control HVI values. The red area in Central Queens indicates that most GI sites are concentrated there.

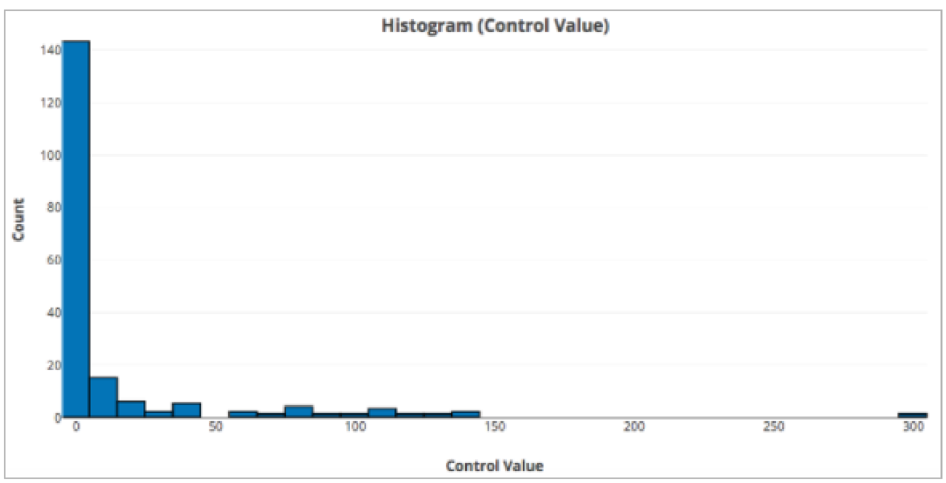

Figure 13: Histogram of control HVI values. Peak at values of 0 to 10 indicates that most neighborhoods currently have few GI sites and few neighborhoods contain vast majority of sites.

This uneven distribution of sites was further confirmed by a histogram of d_GI_Sites. 63% of all sites were between -23 and -12 and 75% were between -45 and -12. This demonstrates that most neighborhoods were in need of GI sites. 9% of neighborhoods had d_GI_Sites values between 65 and 219, meaning that they had far too many GI sites. Only 11% of neighborhoods had d_GI_Sites values between -12 and 10, the most ideal range.

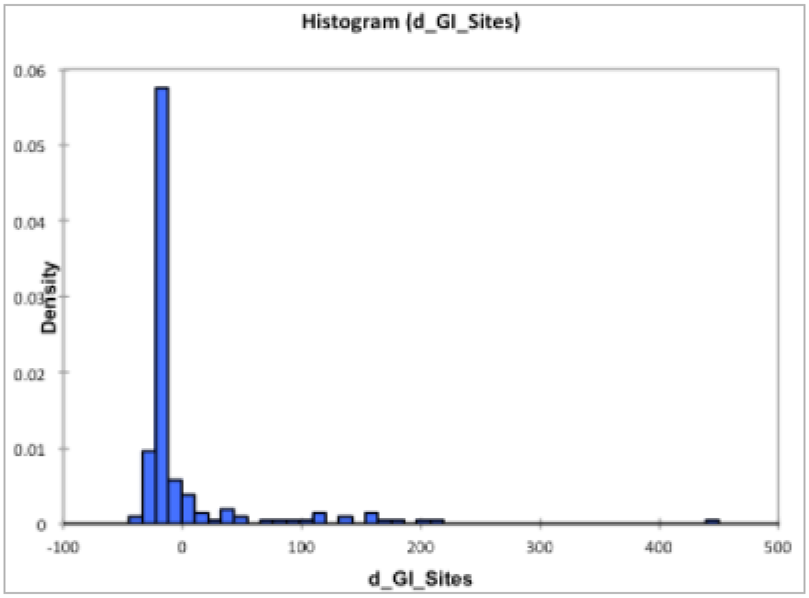

Figure 14: Histogram of d_GI_Sites densities. Peak represents range -23 to -12, which had a frequency of 119 (63% of sites), indicating most neighborhoods were in need of GI.

GI was shown to be needed most in the Eastern Bronx and Southern Brooklyn, while it was shown to be needed least in Central Queens and Lower Manhattan.

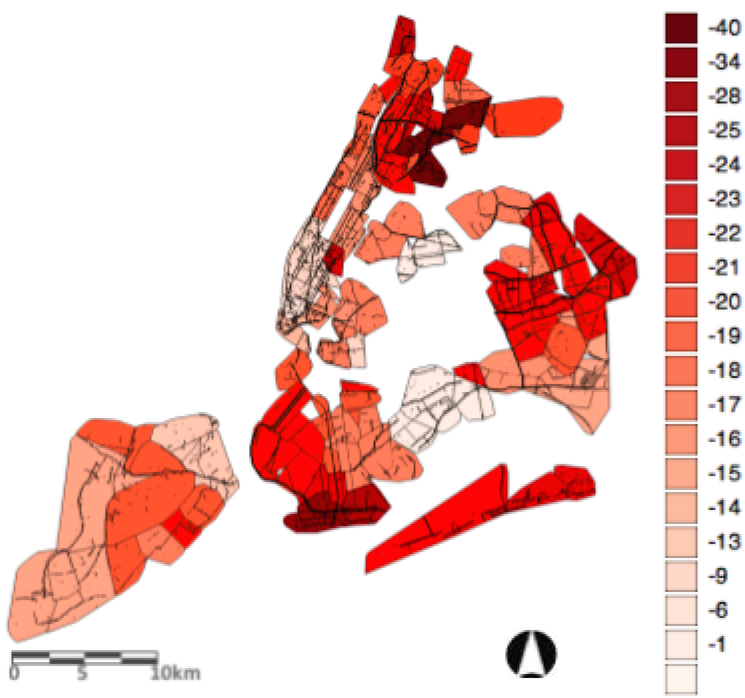

Figure 15: Proposed locations for GI sites (black lines) categorically formatted by d_GI_Sites values. Darker red indicates greater need for GI and white indicates no need.

4 Discussion

4.1 Comparison to Mayor's Office Plan

The most important goal of this research was to improve New York City's plans for future GI development. Because of this, the HVI developed in this study was compared to the heat vulnerability map published by the City in One New York (OneNYC), a plan put forth in 2015 by the Mayor of New York that explains the City's goals and priorities for improving the City, including GI (OneNYC, 2015). There were several flaws with this map, the most prominent of which was the vague designation of vulnerable neighborhoods. The City was divided into large portions unrepresentative of demographics. A graduated color scale with only 5 levels was used, without any numbers or methodology. This made it difficult for the City to take efficient action.

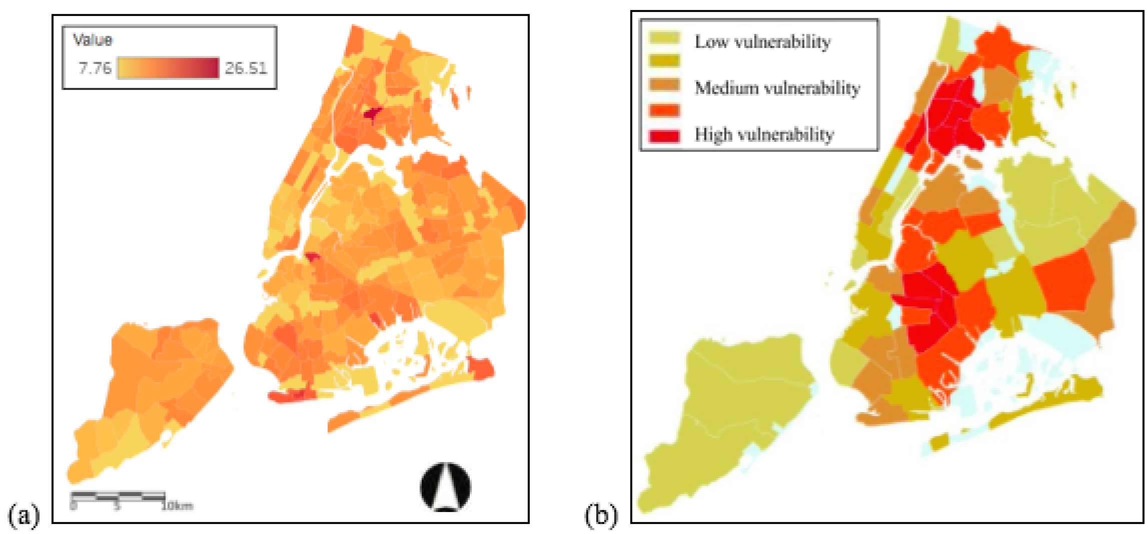

Figure 16: Map with (a) ideal and (b) OneNYC HVI values (OneNYC, 2015). Light blue denotes no data.

In comparing the OneNYC map with the ideal HVI map, there were several similarities and some key differences. This study showed Staten Island as a whole and Southern Brooklyn as more vulnerable than predicted by the City. Both saw the Bronx and Northern Brooklyn as areas of high vulnerability. However, what distinguished this study was the use of much smaller neighborhoods than the City, providing a better understanding of demographic shifts.

4.2 Comparison to Rosenthal et al., 2014 HVI

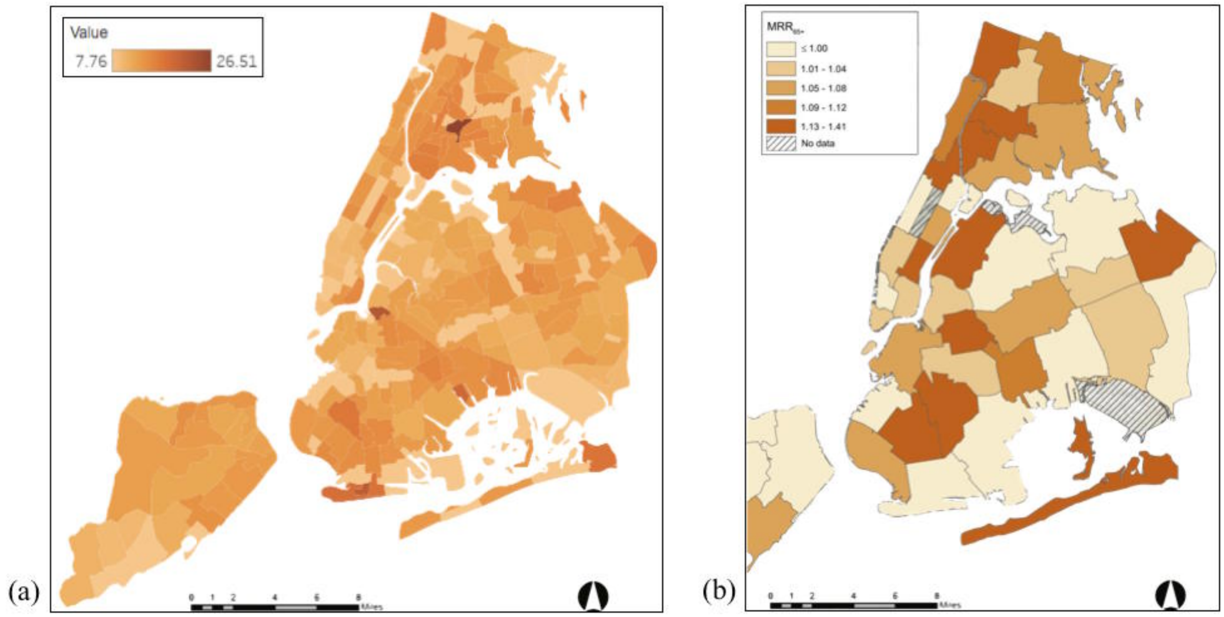

Figure 17: Map with (a) ideal and (b) Rosenthal et al., 2014 HVI values (Rosenthal et al., 2014).

Rosenthal et al., 2014 was the first study analyzing heat-related mortality risk at the intra-urban level, rather than the municipal or regional scale (Rosenthal et al., 2014). The major limitation in the Rosenthal et al. study was the analysis of mortality rates of only people above the age of 65. Because of this, it neglected the heat vulnerability of young children, who are also at a higher risk for heat-related illness, as well as the impacts of poverty and location on non-seniors' heat vulnerability. This study solved for this limitation by correlating the relationship of age and poverty and heat vulnerability independent from each other and by examining ages other than above 65. Another limitation in the Rosenthal et al. study was the designation of HVI values by UHF neighborhood. By using the 188 Census neighborhoods rather than the 42 UHF neighborhoods, this study created a much more accurate HVI that can determine the heat vulnerability between city blocks rather than miles. This increased accuracy is important because it highlights more, smaller-level shifts in vulnerability risks and advises policymakers to build GI in more specific locations, thus targeting more people in greater need of GI. Both this study and the Rosenthal et al. study showed that the Bronx and Southern Brooklyn had high vulnerability, but because the Rosenthal et al. study did not analyze most of Staten Island, it found Staten Island to be less vulnerable than this study did.

4.3 Further study

Further study would allow similar strategies to be utilized for GI programs in other cities, even before they have begun. By indicating where people are most vulnerable to heat and where they need GI the most, other cities would be able to better protect their inhabitants from rising temperatures. Further research is also required to improve this model by incorporating more factors, such as access to air conditioning and highest degree of education. It also must be kept up to date with future GI construction in New York City.

5 Conclusions

This study successfully created a new accurate HVI for New York City based by Census neighborhood. Based on the three socioeconomic factors evaluated, a neighborhood's senior population size was the strongest indicator of its heat vulnerability, but both of the other factors, the young child population and poverty index, were still significant factors and linearly correlated with the rate of heat-stress hospitalizations. When applying this new HVI to GI planning, only 11% of neighborhoods had an acceptable amount of GI sites and 75% of neighborhoods were significantly in need of GI, thus supporting the hypothesis that the City's current GI plan was not functioning at optimal efficiency. After evaluating relative heat vulnerability and current levels of GI in each Census neighborhood, GI was found to be need most in the Eastern Bronx and Southern Brooklyn and least in Central Queens and Lower Manhattan. By integrating planimetric factors and current locations of GI into the model, new locations for GI were proposed throughout the City and ranked based on the neighborhood's need. The simple map created in this study will allow policymakers to plan GI in the future to better protect cities from deadly rising temperatures and heat waves.

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