New York City Housing Authority Public Housing Residents' Disproportionate Vulnerability to Storm Surge Flooding: A Mixed-Method Approach

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Abstract

This thesis seeks to contextualize the inequitable neighborhood conditions of New York City Housing Authority (NYCHA) public housing residents that are largely shaped by the presence of a complex urban social-ecological-technological system and have often influenced resident vulnerability and resilience to worsening environmental hazards. This thesis uses a mixed-method approach to examine NYCHA public housing residents' disproportionate and compounding vulnerability to storm surge flooding. A case study of Hurricane Sandy is used to provide specific context of localized neighborhood conditions of NYCHA public housing residents before and after an environmental hazard. Additionally, using ArcGIS, a social vulnerability index for all five counties of New York City (NYC) is combined with the locations of NYCHA public housing developments and modeled storm surges. This analysis is used to examine the spatial and temporal distribution of environmental hazard vulnerability throughout NYC. The results show that neighborhoods such as East Rockaway Beach, Coney Island, South Bronx, and Lower East Side have high values of social vulnerability where higher concentrations of NYCHA public housing developments are located within the various modeled extents of storm surges. The findings of this thesis were used to propose future policy and planning recommendations that can be implemented to reduce the vulnerability and strengthen the resilience of public housing residents to future environmental hazards to mitigate future calamitous disaster outcomes.

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Chapter 1: Introduction

On October 29, 2012, Hurricane Sandy struck New York City (NYC), home to the largest public housing authority in North America since 1935 (New York City Housing Authority, 2023). Impacts from record-high storm surges damaged 402 New York City Housing Authority (NYCHA) owned buildings consisting of over 35,000 housing units, which provides housing for over 80,000 NYCHA residents (Furman Center, 2013; McArdle, 2013). This equates to about 20% of all NYCHA buildings that were impacted by storm surges, leaving behind an estimated $3 billion in damages (NYCHA, 2023). To this day, Hurricane Sandy has been deemed the most costly and destructive disaster to impact NYCHA public housing (NYCHA, 2023). However, Hurricane Sandy exacerbated preexisting dilapidated housing conditions. Largely due to decades of disinvestment conjointly with damage produced by environmental hazards, today NYCHA is reporting an estimate of over $40 billion worth of needed repairs. (Leeds, 2023; Cohen & Liboiron, 2014; Hernández et al., 2018).

The scope of disaster planning research in its entirety is vast, but the presence of climate change and environmental hazards has given researchers the ability to have a more circumscribed view of disaster planning. The environment dictates the disaster planning approach, as certain hazards require specific resources to be effectively prepared (Miller et al., 2006). The same should go for a community, as every community requires specific resources to be effectively prepared for a hazard (Hernández et al., 2018). Some people are more vulnerable to environmental hazards than others, such as public housing residents, as compounding stressors such as low-income and where you live within a city influences someone's risk and resilience to the shock of an impending disaster (Flanagan et al., 2018; Thomas et al., 2019). The impact of

Hurricane Sandy on NYCHA's public housing residents presents an example of how chronic daily stressors were compounded by the effects of Hurricane Sandy, consequently leading to baneful disaster outcomes (Hernández et al., 2018).

The fulfillment of needed resources in all stages of disaster plans prepares people for uncertainty, making them less vulnerable and more resilient to potential environmental hazards (Gil-Rivas & Kilmer, 2016; Thomas et al., 2019). Vulnerability is often defined by researchers as the predisposed susceptibility of an individual, system, or community to an environmental hazard and is commonly viewed as a function of exposure, sensitivity, and adaptive capacity (Cumberbatch et al., 2020; Thomas et al., 2019). Exposure within the context of vulnerability is described as the extent to which a system is subjected to an environmental hazard (Thomas et al., 2019). The exposure of a system is often expressed through a model such as future sea level rise scenarios or inundation zones (Bathi & Das, 2016; Rygel et al., 2006). Sensitivity is often defined as the extent to which a system is susceptible to harm because of stressors stemming from an environmental hazard (Thomas et al., 2019). The sensitivity of a system is often contingent on social and economic factors (Thomas et al., 2019). Adaptive capacity is described as an individual's ability to adapt to the changing environment around them. Adaptive capacity is defined by four factors: resource access; governance; culture; and knowledge (Thomas et al., 2019). The strength of a community's adaptive capacity often dictates how resilient a community can be when faced with an environmental hazard (Gallopin, 2006; Parsons et al., 2016). Resilience is often defined as an individual, community, or system's ability to prepare, recover, and adapt in the event of an environmental hazard (Links, 2017). Planners and other practitioners can plan for such future disasters to mitigate vulnerability and strengthen a community's

resilience and adaptive capacity. This can be done by addressing the unique social attributes that cause inequitable levels of vulnerability, resilience, and adaptive capacity for an entire city (Graham et al., 2016). Social vulnerability recognizes the diverse social attributes of public housing residents that would lead them to be more vulnerable to an environmental hazard compared to others in the city (Hamideh & Rongerude, 2018; Hernández et al., 2018).

The urbanization of land has created unique systems that encompass the inextricable interactions between a changing climate and social inequities of public housing residents (Cutter et al., 2003; Frank et al., 2017; Hernández et al., 2018; Herreros-Cantis et al., 2020; McPhearson et al., 2022). The concept of social-ecological-technological systems involve social and natural processes and highlights the relationship between people and the environment (Frank et al., 2017; Herreros-Cantis et al., 2020; McPhearson et al., 2020). Humans' exploitation of earth's natural resources has sped up the process of global warming, something that naturally occurs, but not to the degree seen due to the presence of anthropogenic activities such as industrialization (Raj & Singh, 2012). Global warming continues to exacerbate environmental hazards, as we are seeing higher inundation zones, and more damage inflicted upon communities than previous hurricanes (Knowlton & Rotkin-Ellman, 2014). Consequently, public housing residents living in NYCHA developments located on coastal land are subjected to a heightened risk of environmental injustices. Implementing adequate risk reduction strategies can help reduce vulnerability and strengthen the resilience of public housing residents to an environmental hazard (Naheed, 2021).

Population and infrastructure density are two characteristics that contribute to the spatial makeup of a city. The NYC Department of Planning projected a 3.2% increase in the population of NYC residents, from 8,550,971 in 2020 to 8,821,027 by the year 2030 (New York City Department of City Planning, 2013). This presents new challenges for city planners and practitioners, as they must take climate uncertainty into account when making future planning and policy decisions for a growing city (Finucane et al., 2023; Hawley, 1972; Wamsler et al., 2013). If the uncertainties of the climate are not considered, residents of NYC will be left in a further vulnerable position when in the presence of an environmental hazard. For example, storm surges have caught NYC off guard, causing mass flooding, and avoidable costly damage to its infrastructure, such as housing (McArdle, 2014; McPhearson et al., 2020). Integrating climate resiliency strategies into city policy and planning is one step practitioners can take to protect the physical and social integrity of cities. However, in practice, prioritizing the climate resilience of a city has various outcomes depending on whose interests align with the selected adaptation and mitigation strategies. Public housing residents are often left out of the discussion regarding what needs must be met before experiencing the next environmental hazard (Graham, 2016). Community-based resiliency strategies evoke community engagement and contribution to integrate local knowledge into future climate resilience interventions (Graham et al., 2016).

This thesis will highlight the inequitable neighborhood conditions of public housing residents that have historically been neglected when making disaster plans in anticipation of urban storm surge flooding. A mixed-method approach will add both a qualitative and quantitative view on the subject as a case study and ArcGIS will be used. More specifically, this

thesis analyzes resident vulnerability based upon demographic characteristics, specifically within the geographic context of NYC, while using Hurricane Sandy as a case study.

This study proposes the following central research question and sub-research questions:

1. What is the nexus between neighborhood social vulnerability, New York City Housing Authority public housing development locations, and storm surge flooding in New York City?
    a. How is neighborhood social vulnerability, storm surge risk, and NYCHA public housing developments spatially and temporally distributed within the five counties of New York City?
    b. What factors enable and constrain NYCHA public housing pre-disaster resilience and post-disaster adaptation?

Chapter 2: Literature Review

Examining New York City Housing Authority Public Housing Residents Position within an Urban Social-Ecological-Technological System

The urbanization of coastal land has not only influenced the physical alteration of the environment but has also created a unique system where various networks work concurrently within a city (Chang et al., 2021; Frank et al., 2017). The result of the interaction between systems is contingent on not only spatial and temporal attributes, but also social, ecological, and technological attributes as well. An urban social-ecological-technological systems perspective can be used to describe the implications of NYCHA public housing residents' position within

such a system and how such implications influence residents' vulnerability, risk, and resilience to environmental hazards. This process has been referred to as contextualizing vulnerability and resilience and is implemented to describe the intrinsic ways in which social, ecological, and technological variability influence outcomes of vulnerability and resilience within the context of risk to environmental hazards (Mngumi, 2021; Sanne et al., 2021).

Social attributes such as income, race, gender, and age influence the surroundings of an individual (Adger et al., 2018; Thomas et al., 2019). For example, those with low and middle incomes are more restricted in their choice of where to live within NYC compared to high-income residents (Adger et al., 2018). NYCHA provides many low (51-80% of AMI) and moderate-income (81-120 % of AMI) residents with public housing where the rent is based on typically no more than 30% of a household's anticipated gross income (U.S. Department of Housing and Urban Development, 2011). Those selected to live in NYCHA public housing stock are often subjected to live in developments in areas prone to coastal flooding (McArdle, 2014; Zimmerman et al., 2019). Rapid urbanization has subsequently been shown to speed up environmental degradation, consequently jeopardizing the integrity of a city's infrastructure, whether social, ecological, economic, or technological (Frank et al., 2017; Wakefield, 2022). Environmental degradation exacerbated by anthropogenetic climate change has been shown to strengthen the severity and frequency of climate events experienced by coastal cities such as sea level rise and storm surge flooding (McPhearson, 2020; McPhearson et al., 2022). This in turn has detrimental impacts on the technological systems of a community. Technology is increasingly intertwined in the fabric of our society and the ecosystem, influencing unnatural outcomes such as a disaster. Whether technology is used to maintain electrical, satellite, or

internet systems, not everyone has equal access to them (Chang et al., 2021). For example, those with a generator will not experience power outages the same way as someone who does not have access to a generator (Meng & Mozumder, 2021).

Figure 1

Social-Ecological-Technological Systems Framework

Note: Reprinted from "Interdependent Infrastructure as Linked Social, Ecological, and Technological Systems (SETSs) to Address Lock-in and Enhance Resilience," by Markolf, S. A., Chester, M. V., Eisenberg, D. A., Iwaniec, D. M., Davidson, C. I., Zimmerman, R., & Chang, H. (2018), Earth's Future, 6(12), 1638-1659.

Social-ecological-technological systems are multi-scale and dynamic (Frank et al., 2017). Whether it is on a local level or city-wide, cities provide a unique environment to observe the dynamics of social-ecological-technological systems. The density and diversity of people and infrastructure of urban communities influence the ways in which people and the environment interact (Wamsler et al., 2013). Responses to climate change are politicized and research

frameworks such as political ecology and spatial politics elucidate how environmental hazards impact New Yorkers differently depending on where they live and their personal socio-economic attributes (Faber, 2015; Goh, 2021). Both frameworks of political ecology and spatial politics can also be used to explain the ways in which power dynamics dictate public housing residents' resilience and vulnerability within a social- ecological- technological system (Goh, 2021; Quandt, 2016). Power asymmetries experienced by public housing residents can spatially marginalize and sustain disproportionate vulnerabilities to a rise in sea level and storm surge flooding (Grow et al., 2022). For example, those with more political power are less likely to be continuously exposed to environmental hazards. Political ecology describes the influence of political power on what ecological decisions are made and who makes them (Goh, 2021). *Spatial Politics of Urban Resilience and Climate Justice* (2021) by Kian Goh explains that social, ecological, and technological systems are manipulated by those who hold political and decision-making power (Goh, 2021; Faber, 2018). Therefore, an individual's resilience and vulnerability to environmental hazards is not universal and instead is often contingent on the political power one possesses that strengthens a person's influence over the implementation of climate justice policies that address disparate outcomes to climate events (Faber, 2018). Residents with limited political power have a more challenging time recovering from a disaster due to a lack of autonomy and political leverage (Faber, 2018). While residents with greater political power have more direct involvement and influence on recovery decisions due to their social status and place of residence (Goh, 2021; Faber, 2018). Goh brings up the question, "How are contesting visions of the future brought to fruition and how is the power needed to complete such a vision obtained? (Goh, 2021, p.161)". Climate change has increased the need for decisions to be made

in preparation for the changing environment. One must question who is involved in the decision-making process and what goals are being prioritized throughout urban environmental decision-making (Miller, 2016).

Social Vulnerability of New York City Housing Authority Public Housing Residents

Social vulnerability describes the degree of susceptibility of urban social- ecological-technological systems to adverse environmental hazards (Jozaei et al., 2022; Lee, 2014; Shockley, 2023). The spatial and temporal dynamics of social vulnerability are multiscalar (Cutter & Finch, 2008; Drakes & Tate, 2022; Murphy et al., 2015). It can be defined in terms of the social characteristics of a person or community that affect their capacity to anticipate, confront, repair, and recover from the effects of a disaster (Hendricks et al., 2018). Social vulnerability begins to explain the disparate outcomes public housing residents often experience compared to other NYC residents experiencing the same environmental hazard (Flanagan et al., 2018). Using social vulnerability as a tool to approach disaster planning and policy for public housing steps away from the historical focus on physical infrastructure (Lee, 2014). Integrating a social vulnerability framework when measuring public housing disaster resilience can help explain the compounding social disparities of NYCHA public housing residents that other New Yorkers do not have when confronted with an environmental hazard, such as being heavily dependent on the government for resources (Hernández et al., 2018).

Social vulnerability can be measured and spatially analyzed to identify geographic areas that are most vulnerable to environmental hazards. The selection of indicators to conceptualize and quantify social vulnerability often reflects the population it is being used to describe, such as socioeconomic status, homeownership, disability status, vehicle ownership, and an individual's

relative location to a flood plain. The research question presented dictates the approach of measurement as it provides guidelines to develop an appropriate procedure of measurement. The approach of measurement is also contingent on the research and data available for use (Nguyen et al., 2017).

Spatial Politics and Marginalization of New York City Housing Authority Public Housing Residents

NYC has a long history of adopting discriminatory policies and laws that resulted in intentional de jure and de facto residential segregation, most notably in the housing market (Trachtenberg, 2022). Systematic racism prevailed, causing NYCHA developments to remain racially segregated until the 1950s; however, socioeconomic segregation continued (Leeds, 2023; New York City Department of Housing Preservation and Development, 2020). NYCHA intentionally created isolated and concentrated areas of low-income and non-white residents that are still present today (Leeds, 2023). In *The Color of Law* (Rothstein, 2017), Rothstein describes the suppressive and racist history of America and its influence on the development of our environment. Specifically, the use of redlining and exclusionary zoning practices in NYC caused coastal land to be cheaper, leading to the placement and development of public housing developments within coastal zones of NYC (Graham et al., 2016; Herreros-Cantis et al., 2020; Rothstein, 2017). The low prices of coastal land also led to the development of coastal industries that contaminated the environment along the coast (Herreros-Cantis et al., 2020). This, in turn, caused many public housing residents to be disproportionally exposed to environmental degradation and industrial pollution (Herreros-Cantis et al., 2020; Anguelovski et al., 2018). NYC districts such as Rockaway, East Harlem, and the Lower East Side are two flood-prone

areas where NYCHA housing consisting of low- and middle-income residents have been heavily concentrated. The intentional concentration of public housing developments within flood-prone coastal areas of the city has created disproportional environmental hazard experiences between neighborhoods (Graham, 2020).

Leigh Graham (2020) reminds us that stakeholders must consider what Graham describes as a "differentiated state", a theory based on empirical evidence collected in Rockaways, Queens. This theory describes the recovery experience of public housing residents after Hurricane Sandy and the influence of being in a "differentiated state" during post disaster recovery efforts. A "differentiated state" is described to be a conglomeration of four sociopolitical features: 1) the stigmatization of public housing residents, 2) expectations to abide U.S. Department of Housing and Urban Development regulations, 3) the "para-governmental" status of NYCHA and their role as both a landlord and property manager, and 4) the spatial concentration of public housing developments (Graham, 2020). Public housing residents have unique attributes that non-public housing residents do not obtain, causing them to be put in a position of a differentiated state compared to the rest of the city during the recovery period a disaster. For example, having a lack of autonomy and heavily relying on a government entity for essential services or being unable to fulfill basic federal government disaster recommendations puts public housing residents in a differentiated state when recovering from a disaster.

Studies have shown that tenant governance of public housing residents is minimal compared to homeowners or market-rate renters due to the weak social and civic infrastructure that is often present in public housing developments, and the minimal resident autonomy

(Graham, 2020; McDougall, 2012). Social and civic infrastructure influence a community's capacity to organize in efforts to improve their resilience to a disaster (Graham et al., 2016). A lack of social and civic infrastructure reduces the amount of potential social capital available to public housing residents as there is a lack of spaces where social capital can be adequately supported and sustained (McDougall, 2012; Graham et al., 2016; Greenspan & Mason, 2017; McDougall, 2012; MacGillivray, 2018; National Academies of Sciences, Engineering, and Medicine, 2023). Social capital is often described as the presence of social networks that connect individuals and communities together, such as local community-based organizations (Aldrich & Meyer, 2015; MacGillivray, 2018; Williamson et al., 2012). Social capital provides social support in several forms, such as financial or informational, and strengthens civic action (Aldrich & Meyer, 2015; Links, 2017; Schoch-Spana, 2019). In a disaster, social capital can influence the adaptive capacity of a community and in turn the resilience of communities. Individuals and communities with a lack of social capital do not have access to the same resources and networks that address risk and vulnerabilities (Aldrich & Meyer, 2015; Graham et al., 2016; Parsons et al., 2016). Often public housing residents are unprepared for a disaster and must turn to local community-based organizations for assistance with resources, information, and advocacy (Aldrich & Meyer, 2015; Graham et al., 2016).

There are often obstacles for public housing residents to overcome to gain access to important conversations to be considered a legitimate stakeholder in the matter. A weak social and civic infrastructure makes it difficult for individuals to organize themselves and collectively have the power to implement certain outcomes (Graham et al., 2016). For example, renters do not have access to the same decision-making power as homeowners in areas such as government

buy-out programs for land in flood-prone areas (Aldrich, 2021; Dundon & Camp, 2021; Koslov et al., 2021). Uneven distribution of power has the potential to spatially marginalize residents and disproportionally influence their exposure, risk, and vulnerability to sea level rise and storm surge flooding (Lindersson et al., 2023; Graham, 2016; Graham et al., 2016). Planning and policy makers can strengthen tenant governance of public housing residents by intentionally dismantling the barriers that are preventing residents from having direct involvement in the decision-making process (Camponeschi, 2021). One way to strengthen tenant governance is by integrating local knowledge of NYCHA public housing residents into disaster plans to evoke more equitable outcomes (Goh, 2021). There are several methods for integrating local knowledge disaster planning process. One way is through spatial visualization and analysis. Local knowledge is fundamentally spatial, and the use of GIS mapping can integrate community knowledge of the social and physical environment to reflect a community's unique vulnerability to storm surges (Tran et al., 2009). Another way to integrate local knowledge is by supporting place-based participatory disaster planning practices (Meyer et al., 2018). A place-based participatory planning model provides residents with opportunities to participate in the decision-making process while prioritizing locational variability and knowledge in the process (Leichenko & Silva, 2014; Cutter et al., 2008). Not every neighborhood is physically or socially homologous, so its unique attributes should be considered and planned for accordingly (Cutter et al., 2008). This is a risk reduction strategy often used by practitioners to direct the right resources to their most appropriate locations (Chakraborty et al., 2020). Inviting public housing residents to participate in the development of NYCHA disaster plans and policy can be a proactive and collaborative process that creates and supports outcomes that are more applicable to NYCHA

residents. For example, disaster plans that determine evacuation procedures should not rely on residents having access to a vehicle in the event of an evacuation when realistically vehicle access and ownership are limited for public housing residents compared to other NYC households (Pratt Center for Community Development, 2009). Creating disaster plans and policies that are applicable to NYCHA public housing residents can strengthen the understanding and confidence of residents for future environmental hazards (Sandifer & Walker, 2018).

Pre-Disaster Resilience and Post-Disaster Adaptation for New York City Housing Authority Public Housing Residents

Ideally, municipalities want to have a proactive and systematic response to an environmental hazard as opposed to a reactive and ad hoc response (Cutter, 2018). There are planning and policy measures that can be implemented either before or after a disaster to help address the vulnerabilities of NYCHA public housing residents that have the potential to influence the trajectory of community disaster response and recovery outcomes (Graham, 2020; Hernández et al., 2018; Lazrus et al., 2020). Pre-disaster resilience and post-disaster adaptation work in tandem to protect residents against determinants of health and safety while working to ensure a smooth recovery process in the event of an environmental hazard. Resilience policies and planning work to ensure resources are available for public housing communities to have the capacity to respond to an environmental hazard in an effort to mitigate a disaster (Meerow et al., 2019). Adaptive policies and planning work to address the changes that need to be made to reduce resident vulnerability and mitigate residents' future risk of environmental hazards (Keim, 2008; Pelham et al., 2011). Research has shown a relationship between resilience and adaptation, as strong resilience sets residents up for robust adaptation measures, and vice versa (Gallopin,

2006; Gil-Rivas & Kilmer, 2016; Keim, 2008; Parsons et al., 2016; Zhang et al., 2021). Resilience and adaptation have the potential to reduce vulnerability and influence the capacity of a system to come back from an environmental shock (Gallopin, 2006; Gil-Rivas & Kilmer, 2016; Keim, 2008; Parsons et al., 2016; Zhang et al., 2021). Adaptive policies and planning work together to reduce vulnerability and mitigate the future risk of environmental hazards (Keim, 2008).

Pre-disaster resilience measures can be implemented to identify vulnerabilities within a community and help prepare NYCHA public housing residents and their communities before the next hurricane strikes (Hernández et al., 2018). The scale at which the interaction of environmental hazards in cities is viewed presents various levels of resilience- a personal level and a community level (Maxwell, 2018). On a personal level of resilience, we are primarily concerned with an individual's physical, emotional, and psychological ability to recover after a disaster. However, on a community level, there is a conglomeration of entities within a system of order that must be maintained for a community to be resilient and restore itself back to a fully functioning community. For example, the disruption of essential services that help society function such a public transportation, is most likely to disrupt an individual's ability to work, disrupting one's income leaving them less resilient to the next hurricane (Links, 2017; Sandifer & Walker, 2018; Schmeltz et al., 2013;). When the government on all levels (local, state, and federal) fail to adequately provide the necessary post-disaster recovery resources necessary to recover, local community-based organizations step in to provide public housing residents with aid (Anguelovski et al., 2018; Goh, 2021; Graham et al., 2016). Whether it is application assistance, fuel assistance, groceries, childcare or job training, local community-based

organizations play a critical role and are out in the community already doing the work when crisis strikes (Aldrich, 2021; Gil-Rivas & Kilmer, 2016; Goh, 2021).

Many public housing residents rely on government social safety nets, such as Social Security benefits, to help supplement the gap between what residents have and need (Hernández et al., 2018). Public housing residents are less likely to have a financial safety net to pay for the number of resources needed to adequately protect themselves from a disaster (Vale et al., 2014). Preemptively strengthening social and financial safety nets during the pre-disaster resilience period has been shown to help residents manage the impacts of environmental hazards (Pelham, 2011). However, during a disaster, residents must not rely solely on a safety net for all their needs as this has been shown to negatively influence the resilience of public housing residents to environmental hazards (Zhou et al., 2016). Safety nets must work in conjunction with other policies and plans to be effective for disaster prevention (Pelham et al., 2011). Pre-disaster resilience planning and policy making can take the time to address the relationships between resident social capital and social vulnerability. There is little consensus on the ways in which social capital and social vulnerability impact the resilience of public housing residents, but it begins to explain how strong social networks reduce vulnerability (Adrich & Meyer, 2015; Rowan & Kwiatkowski, 2020). Strengthening community-level networks and resources, such as economic development and social capital promotes stability and can help strengthen the resiliency and reduce the vulnerability of public housing residents (Aldrich & Meyer, 2015). Economic development addresses a community's ability to overcome economic disruptions and fund necessary resilience and adaptation measures (Adger, 2003). Social capital enhances social cohesion and collective efficacy during times of uncertainty that environmental hazards often

evoke (Sandifer & Walker, 2018). Vale et.al (2014) provides guidance for maximizing public housing's ability to create and sustain a resilient city in the event of a hazard. First, there is a distinction made between resilient housing and housing for resilient cities. Resilient housing focuses on a dwelling unit's physical integrity, while housing for resilient cities also considers social factors such as social relationships and local community economic development (Vale et.al, 2014). It has been found that safe, sustainable, and affordable housing is linked to having a healthier and longer life (Wahowiak, 2016). However, access to affordable housing alone does not address the inequities communities experience when impacted by an environmental hazard. Before Hurricane Sandy, NYCHA's housing stock was already dilapidated and in desperate need of physical maintenance. Hurricane Sandy exacerbated preexisting damage, making public housing developments further inhabitable for NYCHA residents (Gates et al., 2018). Even though Hurricane Sandy made landfall over 10 years ago, today, NYCHA has an estimated $40 billion in unmet maintenance needs because of decades of disinvestment (Leeds, 2023). Employees of NYCHA claim that a lack of adequate funding is deemed a reason for the backlog in maintenance requests (Hernández et al., 2018; Krakoff, 2019). NYCHA's inability to secure adequate funding for infrastructure updates will cause further issues regarding inequitable vulnerability as climate change increases the likeliness of an environmental hazard to occur (Krakoff, 2019; McArdle, 2013). Mold and physical damage, known to be physical determinants of health, are commonly seen in city-owned public housing developments (Jessel et al., 2019). Providing vulnerable populations with social, economic, and political support helps to further address the underlying social factors that influence coastal community's ability to anticipate respond, resist, and recover from disasters (Van Zandt et al., 2012; Vale et al., 2014). Focusing on

the physical integrity of a city's infrastructure is no longer a viable option if practitioners and planners want to protect the health, safety, and welfare of residents. Planners must focus on the connection between public health and safety and the infrastructure that supports—or detracts—from the same (Hernández et al., 2018; Schmeltz et al., 2013).

Post-disaster adaptation initiatives can work to implement equitable changes to physical and social infrastructure to not only reflect the vulnerabilities of public housing residents but to be more conducive to climate change's influence on urban environmental hazards (Adger et al., 2018; Jozaei et al., 2022). Adaptation measures to urban climate change are intrinsically social and spatial meaning that they encompass the needs and values of diverse communities while simultaneously integrating the diversity of geographical spaces (Goh, 2021). Determining which pre-disaster adaptation measures are selected to implement is often a top-down process and is contingent on who holds the power to make such decisions. Public housing residents are often not given an opportunity for direct involvement in the decision-making process due to political and social reasons. Local community-based organizations play a key role in advocating for adaptation policies and plans that integrate direct input from public housing residents (Hernández et al., 2018).

Post-disaster adaptation efforts for NYCHA public housing developments can be both short and long-term. The short-term post-disaster adaptation period is a time when policies and plans are quickly adjusted to reflect the changing climate and the inequities public housing residents experience daily (Kim & Lim, 2016). For example, changes in building codes and zoning ordinances can help reduce the construction of new NYCHA public housing

developments in storm surge prone areas of the city (Graham et al., 2016; UNFCCC Authors, 2019). Keeping current building codes and zoning ordinances the same have been shown to not be conducive or sustainable to projected future flood risk in NYC due to climate change (Graham et al., 2016). The long-term adaptation period is a time when larger projects are undertaken such as adapting infrastructure to a changing climate or fulfilling NYCHA's maintenance backlog. Post-disaster adaptation in all forms is contingent on the adaptive capacity of a community and influences a community's ability to cope and adjust to a climate disaster (Murphy et al., 2015). Again, adaptive capacity is a conglomeration of social capital, economic development, community competence, information, and communication. Urban planners and practitioners can strengthen the adaptive capacity of public housing residents during the pre-disaster resilience stage to catalyze the presence of equitable and adequate adaptation measures during the post-disaster adaptation period (Kim & Lim, 2016).

Chapter 3: Data and Methodology

Case Study

A case study approach is used to assess an event within a specified context (Crowe et al., 2011). In this case, Hurricane Sandy's impact on NYC provides an excellent case study for analyzing whether NYCHA public housing developments (located in a unique social-ecological-technical system), are disproportionately vulnerable to storm surge flooding (Graham et al., 2016; Graham, 2020; Maantay, 2002). The social vulnerability of residents was quantified and compared to the spatial distribution of NYCHA developments within Hurricane Sandy's

inundation zone by applying publicly accessible data that was collected before and after the Hurricane. The practices, policies, procedures, and residents of NYCHA before and after Hurricane Sandy were studied by reviewing published interviews with NYCHA residents as well as laws, policies, plans, procedures, and practices in place before and after the occurrence of Hurricane Sandy.

Data Collection

Table 1

List of GIS Data to be Analyzed

Description of Data	Source of Data	Year	Spatial Projection
Sandy Inundation Zone (SHAPEFILE)	City of New York,NYC Open Data	2015	WGS 1984 Web Mercator (auxiliary sphere)
NYCHA Resident Data Book Summary Variables: Total Number of Families, Total Male, Total Female, Average Family Size, Average Age, Total Families on Welfare	City of New York, NYC Open Data	2022	WGS 1984 Web Mercator (auxiliary sphere)
NYCHA Residential Addresses Variables: Building Number, Street, Zip code	City of New York, NYC Open Data	2021	WGS 1984 Web Mercator (auxiliary sphere)
Projected Sea Level Rise (SHAPEFILE)	City of New York, NYC Open Data	2021	WGS 1984 Web Mercator (auxiliary sphere)
American Community Survey 5-Year	United States Census Bureau	2017-2021	WGS 1984 Web Mercator (auxiliary sphere)

Data Preparation

Census Data

I used the American Community Survey (U.S Census Bureau, 2022) 5-year estimates at the county level from 2017 to 2021 to extrapolate census tract data for my areas of interest: Staten Island; New York City; Bronx; Queens; and Kings. The 5-year estimates represent a 5-year period where data is being continuously collected and is known to increase the reliability of data as more individuals are represented over the 5-year period. I matched data for the entire state and then focused on the 5 counties of NYC. Data is being used from different time periods due to its availability.

Public Housing Developments

Data describing current locations of the public housing developments of the NYCHA as of June 2022 was extracted from NYC Open Data as a Shapefile.

Sea Level Rise

Shapefiles consisting of Sea Level Rise Maps (2020s 100-year Floodplain) and Sea Level Rise Maps (2050s 100-year Floodplain) were downloaded from NYC Open Data. The term "100-year flood" means that for every year there is a 1% chance that a flood will happen in that area. The maps assume and show a chance of 11 inches of sea-level rise by 2020 and 31 inches of sea level rise by 2050 (Rosenzweig & Solecki, 2013).

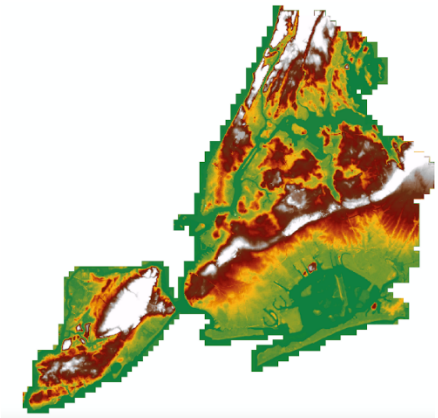
Inundation Zone

Inundation Zone table FID (FeatureID) attributes were geo-processed and joined with the

NYCHA FID attribute. Inundation zones model the spatial extend of land where flooding may occur. Often referred to as a Digital Elevation Model (DEM), software is used to calculate the difference between the water surface and the ground to calculate estimated flood depth grids using local elevation data (Figure 2). Flood depth grids can be visually mapped to support researchers locate areas that would be impacted by a hypothetical flood (Office of Technology and Innovation, 2022).

Figure 2

Digital Elevation Model (DEM) of New York City



Note. The values of the cell represent the elevation of the ground relative to sea level (Office of Technology and Innovation, 2022)

Storm Surge

ArcGIS allows users to calculate a storm surge for a specific area with user specified parameters by using local elevation data. Adding a terrain raster layer allows for elevation of each pixel to be accurately displayed for the area of interest (ESRI, 2023). The data of the terrain raster layer is exported and clipped to display the current display extent. The size of each cell is set to X (10) and Y (10), signifying that each pixel represents 100 square meters on earth (ESRI,

2023). I then used the Remap tool to apply elevation data for NYC. I then created two new layers visualizing NYC storm surges totaling 3-meters (9.8 feet) and 9-meters (29.40 feet). Mapping potential storm surges can help planners and policy makers visualize and predict the potential impact future storm surges may have on NYCHA public housing developments (Shepard et al., 2012).

Table 2

Methods for Visualizing the Spatial Distribution of Social Vulnerability and Storm Surge Flooding

Method	Social Vulnerability Index	A spatial autocorrelation	Clusters and Outliers (Anselin Local Moran's I)	Hot Spot Analysis	Search by Attribute	Storm Surge
Description	Various social indices can be ranked amongst each other and compiled to create an index.	Preemptively measures whether the analysis's features have a pattern expressed as clustered, dispersed, or random.	Identifies areas of concentrated high or low data values, as well as outliers.	A technique used to identify clusters of similar data within a given spatial context. This approach requires the presence of clustering within the data.	Specific features can be spatially searched for within the context of a data set.	Elevation data for a specific location can be used to calculate storm surge maps. Future storm surge levels can be modeled by changing the parameters to predict changing flood levels.

Geospatial Analysis of Sea Level Rise and Storm Surge Risk Models in Conjunction with Locations of New York City Housing Authority Public Housing Developments

Conducting a spatial analysis of NYCHA public housing developments within future modeled delineations of NYC sea level rise and storm surge predictions is used to conceptualize the future risk of residents living within an area predicted to flood in the future (Herreros-Cantis et al., 2020). ArcGIS's Select by Location search tool can be used to select a feature based on the feature's location relative to another feature on a different layer (ArcGIS Pro, n.d.). I applied the

Select by Location tool to identify the location of NYCHA public housing developments within the resulting models of future sea level rise and storm surge risk.

Social Vulnerability Index

Table 3

Social Vulnerability Index Indices

	Indicator Theme	Indicator
Social Vulnerability	Socioeconomic	% of Population Unemployed
		% of Population with Less than a High School Degree
		% of Population Living in Poverty
		% of Population with No Health Insurance
		% of Population Living in a Household Receiving Supplemental Social Security
		% of Population with Single Parent Household
	Transportation	% of Population with No Vehicle
	Minority Status	% of Non-White Population

A social vulnerability index is a single metric that describes several variables of social vulnerability (Table 3). Research often calculates estimates of social vulnerability in the present by using recent data, while comparing historical data. Temporal changes in social vulnerability can be recorded and further analyzed (Nguyen et al., 2017). Even though no social vulnerability index has been definitively validated, they are still commonly used by researchers to conceptualize the complexity of social vulnerability (Spielman et al., 2020). One common approach to constructing a social vulnerability index is by creating a composite indicator consisting of a conglomeration of preselected individual indicators and their z-scores (Burton et

al., 2018; Chang et al., 2015). For this thesis, an index was created by calculating z-scores for each characteristic selected to represent social vulnerability. These z-scores were summed (characteristics that enhanced vulnerability were added) and a composite index value was assigned to each census tract. I created a composite index consisting of z-scores of the following variables: (+) proportion of population unemployed, (+) population with less than a high school degree, (+) proportion of population living in poverty, (+) proportion of population with no health insurance, (+) promotion of population with single parent household, (+) proportion of population with no vehicle, and (+) proportion of non-white population.

Social Vulnerability Index was created using the U.S. Census Bureau's "American Community Survey" data (5-years) for all five counties of NYC on a census track scale. The data necessary to create a social vulnerability index regarding only NYCHA residents is unavailable to the public as it has not been collected by the City of New York, or other researchers on the same scale as the Census. To show how NYCHA residents are disproportionately vulnerable to storm surge flooding compared to other NYC residents, locations of NYCHA developments are overlayed onto a mapped social vulnerability index of the city. This presents a way to conceptualize the unique compounding vulnerabilities many NYCHA residents have from living in areas more susceptible to storm surge flooding. No weights have been allocated to any vulnerability indicator as each indicator is of equal importance when calculating my index. The use of an equal-weighting scheme poses questions since not all vulnerability indicators are necessarily equal and equal weights are unlikely to reflect reality (Nguyen et al., 2017). However, due to the poorly understood nature of social vulnerability and the indices used to describe social vulnerability, there is a lack of validity when it comes to allocating arbitrary

weights towards certain indicators. The index value was rescaled to a 0 to 1 interval. A condensed scale of three intervals was used to differentiate areas of Low, Medium, and High values of social vulnerability (Cumberbatch et al., 2020).

Spatial Analysis of Social Vulnerability Index

There are many ways in which a social vulnerability index can be spatially analyzed. For this thesis, I utilized several ArcGIS spatial analysis tools within a series of succinct steps to calculate and analyze spatial autocorrelation, cluster and outliers and hotspots within the data.

- **Spatial Autocorrelation Analysis**

First, a spatial autocorrelation test using ArcGIS was conducted after the construction of the composite social vulnerability index to indicate whether clustering and statistically significant patterns are present within the input data. A z-score and p-value is calculated based on the input data and interpreted in relation to a 95% confidence level. When interpretating the results, a very high or very low z-score with a small p-value reflects that the spatial pattern is unlikely to reflect a random pattern (ArcGIS Pro, n.d.). The spatial autocorrelation test also computes a Global Moran's I summary consisting of a calculated Global Moran's I statistic that combines attribute similarity and locational similarity that is standardized by the variance (Getis, 2010).

- **Cluster and Outlier Analysis (Anselin Local Moran's I)**

I utilized a cluster and outlier analysis (Anselin Local Moran's I) to analyze the spatial patterns of social vulnerability and highlight the presence or absence of statistically significant clusters of high and low outliers within the data set (ArcGIS Pro, n.d.).

- **Hot Spot Analysis**

The use of hot spot analysis will test for randomness and identify clusters of similar high and low value densities within the data input for a given area of interest (ArcGIS Pro, n.d.).

Chapter 4: Findings and Analysis

Case Study: New York City Housing Authority and Hurricane Sandy

My mixed method approach to explore the central research question and sub-research questions of this thesis focused on a case study of Hurricane Sandy's impact on NYHCA public housing residents and the ways in which NYCHA public residents' individual and community social and spatial attributes shape disaster outcomes. The presence of dilapidated, ill-funded NYCHA developments located in worsening storm surge areas of the City compromises the vulnerability and resilience of public housing residents and in turn, presents a potential for calamitous outcomes in the event of an environmental hazard. Hurricane Sandy exposed the consequences of a lack of preemptive planning for the presence of NYCHA residents' inequitable vulnerability and resilience to environmental hazards (Hernández et al., 2018; Jessel et al., 2019). Critical systems such as electricity, running water, and elevator service were interrupted for NYCHA residents before, during, and after Hurricane Sandy, causing many residents to be

trapped in high-rise buildings and unable to fulfill their basic needs such as charging their cell phones or have working heat for weeks (Hernández et al., 2018; McArdle, 2014; Zimmerman et al., 2019). By looking at various publications released after Hurricane Sandy, we can see a trend of a lack of preemptive reduction to public housing residents' vulnerability to storm surges (Hernández et al., 2018; Stringer & Landa, 2015). We can also see a lack of measures preemptively taken to strengthen the resilience, adaptive capacity and social capital of public housing residents while simultaneously reducing their social vulnerability (Hernández et al., 2018; Stringer & Landa, 2015; Schmeltz et al., 2013).

The Housing Authority's disaster plans were inadequate to anticipate or respond to Hurricane Sandy. Resident testimony highlights resident experiences before Hurricane Sandy and throughout the recovery process (Alliance for A Just Rebuilding, 2014; Graham, 2020; Hernández et al., 2018). NYCHA evacuated public housing buildings in Zone A and turned off elevator service shortly before Hurricane Sandy made landfall in NYC (Hernández et al., 2018; McArdle, 2014). During Hurricane Sandy, evacuating public housing developments was found to be a disorganized process where many ad hoc decisions were made due to a lack of preparedness made by NYCHA (Graham, 2020). There is little published about NYCHA resident disaster preparedness, but in several interviews conducted by researchers, public housing residents expressed a lack of preparation made by NYCHA for the impact of Hurricane Sandy (Alliance for a Just Rebuilding, 2014; Graham, 2016; Hernández et al., 2018). In a study by the Alliance for a Just Rebuilding (2014), 28% of the 597 NYCHA residents interviewed were unaware of evacuation information regarding the storm. Information is distributed in several ways, such as flyers or by word of mouth (Dowty Beech & Wallace, 2019; Lazrus et al., 2020; Schmeltz et al.,

2013). Further research conducted by Hernández et al. (2018) investigated the reasons why residents decided to shelter in place instead of evacuating by conducting a total of eight focus group sessions with 74 residents from various NYCHA developments. Hernández et al. (2018) conclude that there was a mix of personal and external factors, such as a lapse in communication from NYCHA, residents' consideration of evacuation shelters to be unsafe and unsuitable, underestimation for the strength of the storm, fear of property theft, and distrust in authorities. Lazrus et al. (2020) had similar findings but noted that residents in private housing had a different evacuation experience with greater access to hurricane-related information and transportation. NYCHA residents noted a lack of information regarding where NYCHA appointed evacuation buses were transporting residents which in turn deterred NYCHA residents from evacuating their homes (Lazrus et al., 2020).

Under the New York City Charter, the New York City Comptroller must audit every City agency at least once every four years to examine its performance and efficiency (New York City Comptroller, 2024). In 2015, three years after Hurricane Sandy, the City of New York Office of the Comptroller Audits and Special Reports published the Audit Report on the New York City Housing Authority's Emergency Preparedness (Stringer & Landa, 2015). The audit found that NYCHA's inability to adequately prepare for emergencies has influenced the agencies' inability to recover from an emergency, such as a hurricane. The audit describes NYCHA's emergency procedures as vague and fails to clearly define roles and responsibilities for staff to follow. NYCHA's usage of staff in an emergency is undocumented and property managers failed to maintain the required information on staff in efforts to maintain essential services to residents in the event of an emergency (Stringer & Landa, 2015). The audit report also found that NYCHA

did not maintain accurate records of disabled tenants within NYCHA's data system and property managers were left with incomplete information on tenants with disabilities (Stringer & Landa, 2015). The findings of the audit report conflict with the contents of NYCHA's Emergency Procedures Manual that states that managers must first identify residents with physical disabilities so that they may be appropriately assisted during an emergency (Stringer & Landa, 2015). Local media sources such as Able, a local newspaper created by the disabled, for the disabled, provides a platform for residents and local organizations to share their experiences related to Hurricane Sandy (Early, 2012). Able published in their December 2012 issue that the Center for Independence of the Disabled, NYC (CIDNY) reported on a lack of preparation NYCHA had done in anticipation of Hurricane Sandy. Disabled residents of NYCHA found themselves without their necessary medication or assistive devices when evacuated from their place of residence in anticipation of the storm. CIDNY also expresses its belief that NYCHA does not have an adequate central tracking system for residents. Other disabled New Yorkers living in both public and market-rate housing had similar experiences, catalyzing the Brooklyn Center for Independence of the Disabled to sue the city of New York (Brooklyn Center for Independence of the Disabled v. Bloomberg, 2013).

NYC experienced extreme flooding from the storm, impacting about 45% of NYCHA-owned developments (Graham, 2016). Storm surge flooding created corrosive damage to boilers and generators, as well as the interior and exterior infrastructure of public housing developments. Some residents were stranded in their apartment buildings without food, water, heating, or electricity for lengths greater than a few days (Zimmerman et al., 2019). Damp conditions from flooding are a breeding ground for microbial pollution, such as mold, creating public health

hazards (Heseltine & Rosen, 2009; Rosen et al., 2015). Many NYCHA public housing developments experienced mold because of damp living conditions from insufficient remediation and clean up (Bondesson, 2022). However, NYCHA owned and operated developments did not receive the proper removal remediation for mold, and instead often experienced the widespread practice of simply painting over it, exacerbating chronic health issues like asthma (Bielory & Spatola, 2013; Kim et al., 2016). A spike of respiratory illnesses post Hurricane Sandy was referred to as "Sandy Cough" (Bielory & Spatola, 2013; Kim et al., 2016). Marlene Gardenhire, a resident of NYCHA's Alfred. E. Smith Houses for over 31 years returned to her apartment after evacuating, only to find it flooded and filled with mold. After moving back into the mold ridden apartment, Marlene's five-year-old child was hospitalized with pneumonia. The pneumonia was said to be due to her apartment's condition due to the flooding, according to the doctors. The Urban Justice Center helped Marlene file a lawsuit for her and her son to be relocated to another apartment with more suitable living conditions (Alliance for A Just Rebuilding, 2014).

Hurricane Sandy overwhelmed NYCHA and residents often found government-led recovery efforts to be disorganized and did not fully address the needs of public housing residents (Alliance for a Just Rebuilding, 2014; Hernández et al., 2018; McArdle, 2014). Local community-based organizations filled the gaps left behind by government-led recovery efforts by providing residents with the services and resources they need to thrive as individuals. When residents need services and resources that they are unable to obtain through the NYCHA or other government agencies, they often turn to local non-profits and community action agencies to receive what they are in search of (Graham et al., 2016). Practitioners and government officials should recognize how organizations are deeply interwoven throughout the community, as they

have historically neglected to help strengthen community-social relationships (Goh, 2021). Unlike government officials who often have little direct involvement with the community, local community-based organizations have already created and maintained relationships and trust with community members (Goh, 2021). Community-based organizations are almost always the first to distribute post-disaster relief as opposed to state or federal aid that requires longer wait times (Camponeschi, 2022; Goh, 2021). For example, local nonprofit Red Hook Initiatives (RHI) provides New Yorkers with support and resources needed to begin to dismantle systematic inequities (Red Hook Initiative, 2013). Immediately after Hurricane Sandy, RHI became an essential hurricane relief hub where residents could go to receive supplies, healthcare, and social services. In the post-disaster phase, RHI advocated for community driven solutions regarding long-term repairs to NYCHA developments.

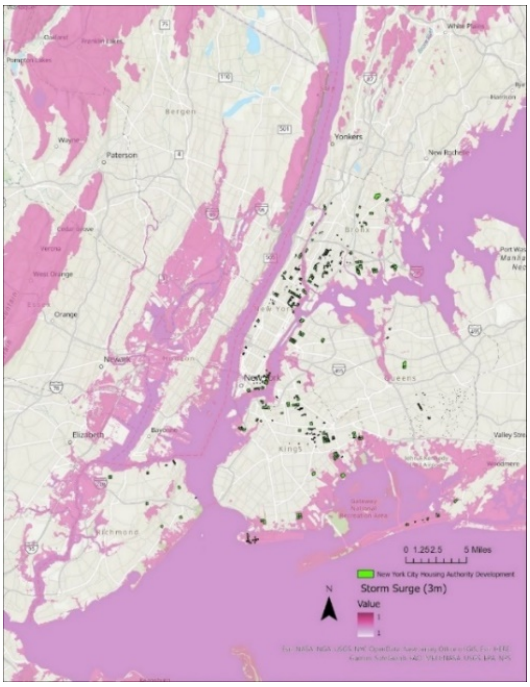
Planners and policy makers can work directly with local community-based organizations to strengthen their capacity to fulfill the level of assistance they provide public housing residents before and after a hurricane (Gil-Rivas & Kilmer, 2016). The participation of public housing residents in post-disaster efforts was minimal post-Hurricane Sandy as public housing resident involvement is strained by the differentiated state (Graham, 2016; McArdle, 2021). Many NYCHA public housing developments lack social and civic infrastructure and are not conducive to uplifting the collective voices and actions of residents (Graham, 2016; McPhearson et al., 2022). Post-disaster adaptation measures throughout NYCHA developments presents a great window of opportunity to allocate direct participation in the decision-making process to public housing residents (McArdle, 2021).

Modeling Future Storm Surge and Sea Level Rise in Relation to the Locations of NYCHA Public Housing Developments

Modeling storm surges and sea level rise can help planners and policy makers conceptualize the future flood risk of NYCHA public housing developments (Bathi & Das, 2016). Today, the percentage of census tract with NYCHA developments is 305/2325 census tracts or about 13%, and the percentage of census tracts citywide that were inundated by Hurricane Sandy shows 588/2325 census tracts are in Hurricane Sandy inundation zone, or about 25% (City of New York, 2021; City of New York, 2015; U.S. Census Bureau, 2022). The amount of NYCHA public housing residents located in Hurricane Sandy inundation zone is 55/277 developments or about 20% (City of New York, 2021; City of New York, 2015). A spatial analysis of NYCHA public housing developments within the modeled 3m storm surge identified 64/277 public housing developments or about 23% of the total amount of public housing developments (Figure 3) (Airbus et al., 2023; New York City Housing Authority, 2021). When the storm surge extent is increased to 9m, 167/277 public housing developments or about 60% of public housing developments are located within the modeled 9m storm surge area (Figure 4) (Airbus et al., 2023; New York City Housing Authority, 2021).

Figure 3

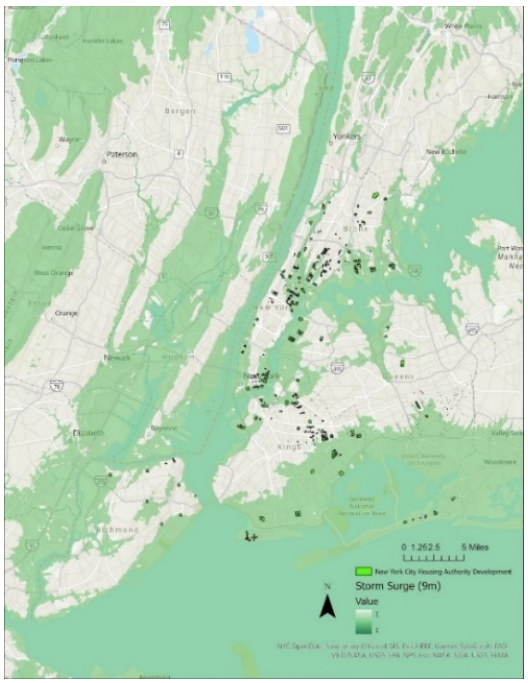
Storm Surge (3m)



Note: (Airbus, USGS, NGA, NASA, CGIAR, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community, 2023; New York City Housing Authority, 2021)

Figure 4

Storm Surge (9m)



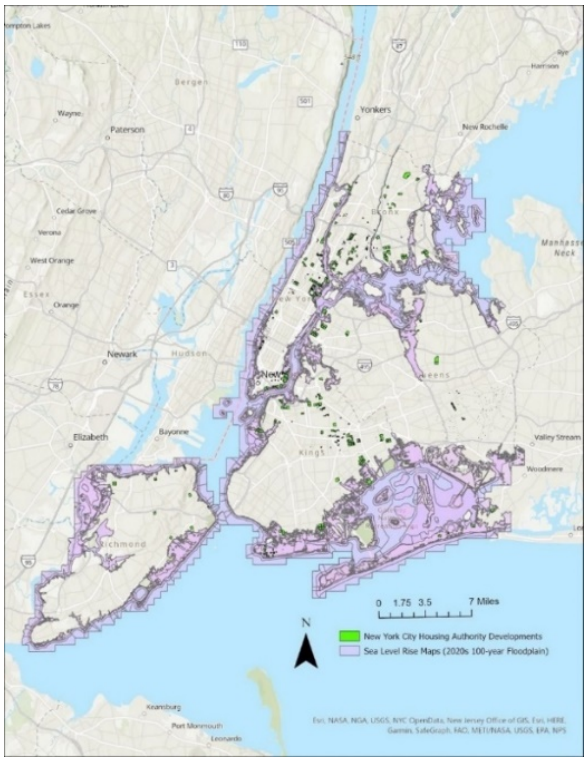
Note: (Airbus, USGS, NGA, NASA, CGIAR, NLS, OS, NMA, Geodatastyrelsen, GSA, GSI and the GIS User Community, 2023; New York City Housing Authority, 2021)

There is a 37% increase in the amount of public housing developments located within the modeled storm surge area when the extent of the storm surge is extended from 3m to 9m. When calculating the amount of NYCHA public housing developments in the flood plain polygon overlay, there are 84/277, or about 30% of public housing developments located within the projected Sea Level Rise 2020s 100-year flood plain (Figure 5) (City of New York, 2023; New York City Housing Authority, 2021). Climate change projections are shown to increase the extent to which a storm surge will encroach on land. My results show that 103/277 public housing developments, or about 37% of public housing developments are located within the projected

Sea Level Rise 2050s 100-year flood plain (Figure 6) (City of New York, 2023; New York City Housing Authority, 2021). Compared to the Sea Level Rise 2020's 100-year flood plain, that is a predicted 7% increase in developments within a 30-year period. Figure 5 highlights the 100-Year Floodplain for the 2050s based on FEMA's Preliminary Work Map data and the New York Panel on Climate Change's 90th Percentile Projections for Sea-Level Rise (31 inches). Data is provided by the Mayor's Office of Long-Term Planning and Sustainability (OLTPS) on behalf of CUNY Institute for Sustainable Cities (CISC) and the New York Panel on Climate Change (NPCC).

Figure 5

Sea Level Rise 2020s (100 Year Flood)



Note: (City of New York, 2023; New York City Housing Authority, 2021)

Figure 6

Sea Level Rise 2050s (100 Year Flood)

Note: (City of New York, 2023; New York City Housing Authority, 2021)

Social Vulnerability Index

The results of the social vulnerability index I constructed contain a range of values with 0 being the lowest and 2.35 being the highest (Figure 7). The values of social vulnerability were rescaled to reflect areas of low, medium, and high values. The index illustrates high values in areas of the City including the Bronx, Harlem, the Lower East Side, East Rockaway Beach, North Queens, and Central Brooklyn. Specifically, Census Tract 245, New York County, NY in Washington Heights, has a social vulnerability index value of 2.35, ranking first out of 2325 census tracts. There are higher concentrations of NYCHA developments located in areas where social vulnerability values are high than there are in areas with low values of social vulnerability.

Figure 7

Social Vulnerability Index Results

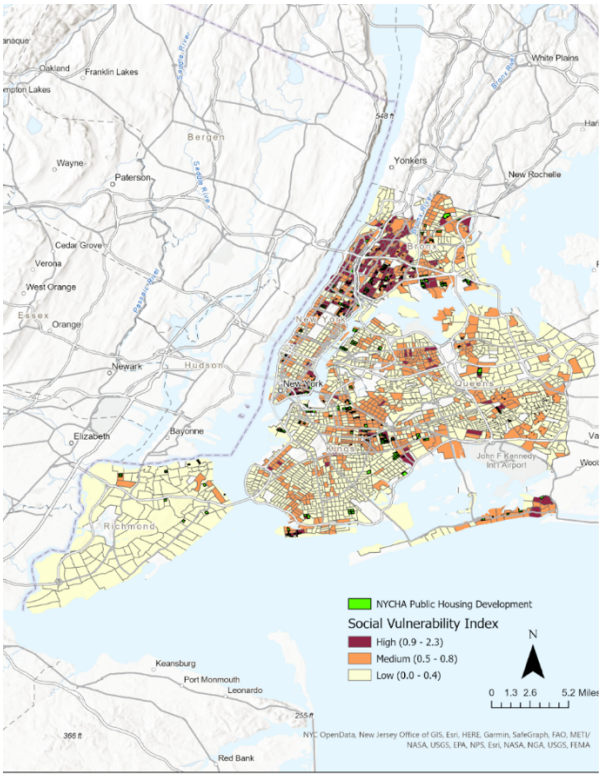
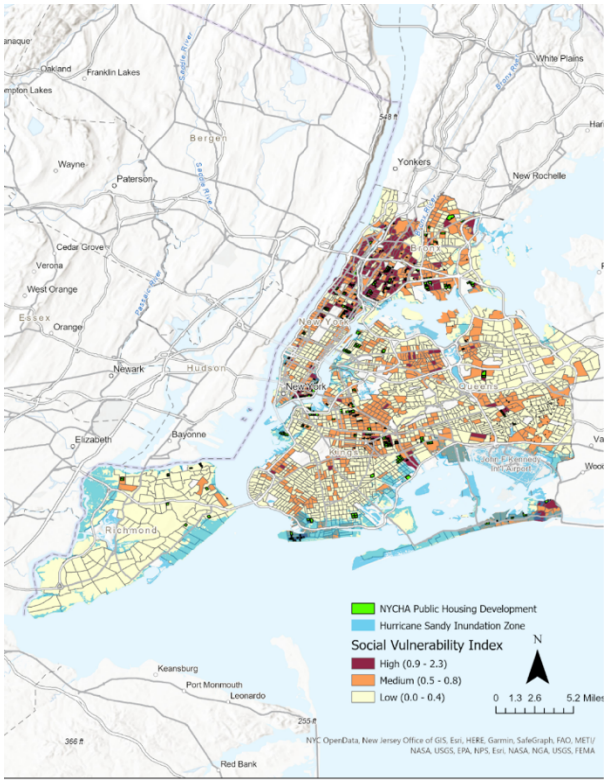


Figure 8

Social Vulnerability Index Results with Hurricane Sandy Inundation Zone Overlay



The spatial distribution of vulnerability can be analyzed within the context of Hurricane Sandy Inundation Zone and locations of NYCHA developments to provide a visual aid for the ways in which social-ecological-technical systems manifest themselves in a city. The inundation zone can act as a compounding factor between vulnerability and spatial location within Hurricane Sandy inundation zone. The results show significant clusters of high SVI composite scores within areas where NYCHA developments are present such as East Rockaway Beach, Coney Island, South Bronx, and Lower East Side (Figure 8).

Figure 9

Clusters and Outliers Analysis (Anselin Local Moran's I)

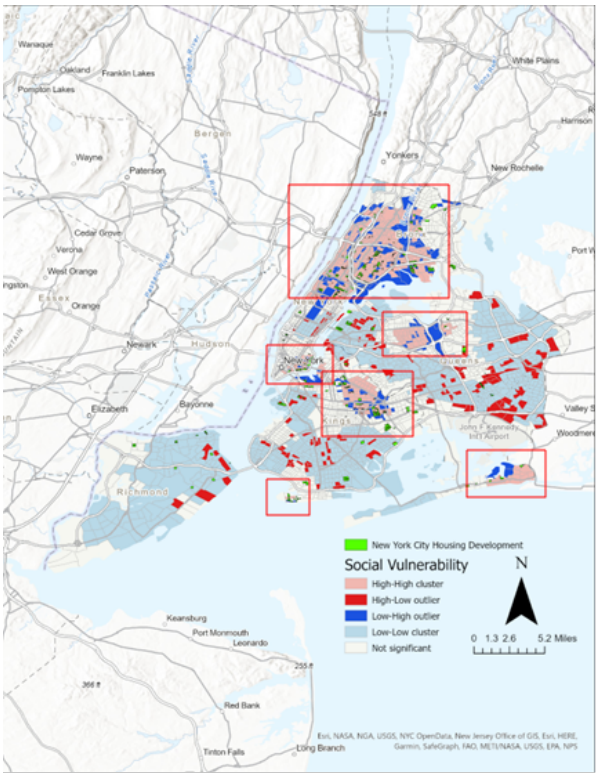
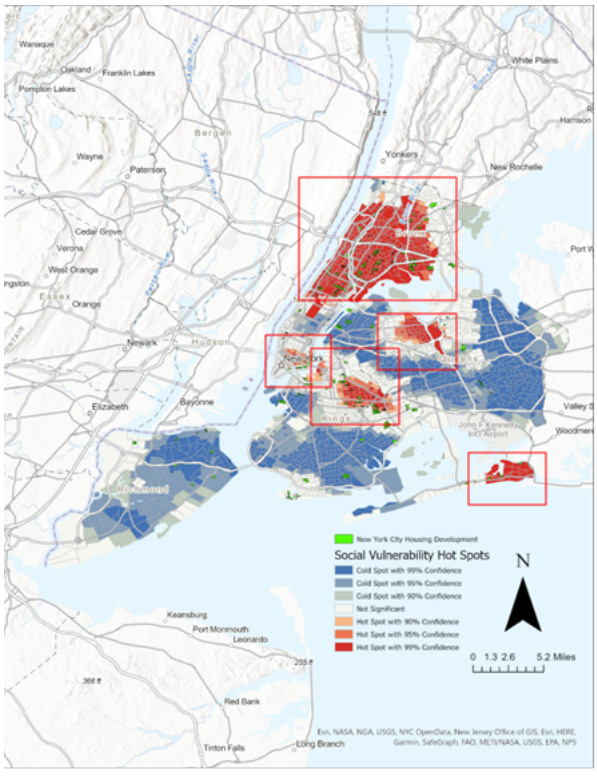


Figure 10

Social Vulnerability Hot Spot Analysis



A spatial autocorrelation was first conducted and concluded that clustering was present within the social vulnerability index dataset and further analysis can be conducted. A full report

is located in the appendix. A cluster and outlier analysis (Anselin Local Moran's I) was then conducted to determine whether there were clusters present within a data set. A full report is in the appendix. The clusters and outliers' analysis results (Figure 9) show statistically significant high-high values of social vulnerability in areas such as East Rockaway Beach, Harlem, the Bronx, Central Brooklyn, Lower East Side, and North Queens. After filtering out the high-high data, 423/ 2325 census tracts are selected. After filtering out the low-low valued data, 872/2325 census tracts are selected. Both findings demonstrate the spatial distribution of high and low clustering patterns of social vulnerability throughout NYC.

Mapping hot spots of a certain feature allows researchers to visualize clustering within a dataset. The Hot Spot Analysis tool in ArcGIS calculates the Getis-Ord Gi statistic for a selected feature in a data set, and clusters data values based on high and low values (Songchitruksa & Zeng, 2010). Despite using data that encompasses NYC residents at the census tract level, using locations of NYCHA developments helps to provide a spatial context of where NYCHA residents live within social vulnerability hot spots. Similar areas to the cluster and outlier analysis are highlighted by a hot spot analysis (Figure 10). Statistically significant areas of high-valued clusters of social vulnerability values are in the Bronx, Harlem, East Rockaway Beach, North Queens, Central Brooklyn, and Lower East Side. These are all areas commonly referred to in research as having high social vulnerability values in the event of an environmental hazard (Graham et al., 2016; Greenberg, 2014).

Likely Errors in Data or Spatial Analysis

Census tract data was used to analyze NYCHA residents' vulnerability to storm surge flooding. The scale to which social vulnerability is being assessed impacts what the research outcome will encompass. Census block data does not accurately encompass the entirety of the block group it is describing (Blackwood & Cutter, 2023; Flanagan et al., 2011; Schmidtlein et al., 2008; Sonik & Herrera, 2022). This is due to several reasons. One reason Census block data is noisier data, meaning that there is additional meaningless information (US Census Bureau, 2021). Another reason is due to its smaller sample size compared to census tract data which has been shown to reduce the margin of error within the sample (Spielman & Folch, 2015).

Chapter 5: Discussion

Uneven Distribution of Vulnerability to Storm Surge Flooding

The frequency and severity of environmental hazards continue to increase due to climate change, making them very volatile and unpredictable (Jessel et al., 2019). Climate unpredictability can be remedied with clear objectives and procedures to be adhered to when warranted (Kim and Lim, 2016). The spatial accuracy of data allows for more accurate flood assessments and disaster plans. By using flood assessments paired with a social vulnerability index when making disaster plans, practitioners and planners will have a more holistic view of how neighborhoods are impacted differently based on their position within an urban social-ecological-technical system (Chang et al., 2021; Frank et al., 2017; McArdle, 2013). Analyzing predicted future NYC sea level rise maps jointly with locations of NYCHA public housing

developments and the social vulnerability of NYC neighborhoods can help conceptualize the disproportionate vulnerability NYCHA public housing residents have to urban storm surge flooding. The use of future storm surge prediction modeling to demonstrate NYCHA public housing residents' vulnerability can aid planners and policymakers with a tool to conceptualize the presence of compounding vulnerabilities. My findings show a predicted 7% increase in the amount of NYCHA public housing developments located in areas of the city that are at risk of storm surges within the next 30 years. These findings suggest a need for a shift in current practices regarding preparing NYCHA residents for anthropogenic climate change and the strengthening of storm surge flooding that is predicted to occur. The use of participatory disaster planning increases the integration of community voices and allows residents to have direct involvement in the planning and implementation process (Hidayat & Rasadi, 2020; Nkombi & Wentink, 2022). This approach to planning for a disaster allows for resident-specific needs and local knowledge as a community to be integrated into urban resiliency policy and planning efforts, in turn reduces their vulnerability to future environmental hazards (Graham et al., 2016; Hidayat & Rasadi, 2020; Nkombi & Wentink, 2022; Tran et al., 2008). This approach, however, does not address the perpetuating use of discriminatory zoning ordinances and redlining practices that have spatially concentrated NYCHA public housing developments in flood prone areas of the city (Graham et al., 2016; Hernández et al., 2018; Herreros-Cantis et al., 2020; Rothstein, 2017). For example, areas such as the Lower East Side and East Rockaway have a higher concentration of NYCHA public housing developments located along the coastline where levels of social vulnerability are high (Herreros-Cantis et al., 2020). The ways in which NYCHA have been historically located in flood- exposed areas has created environmental justice communities

where residents are disproportionately impacted by an environmental hazard based on social attributes such as race and poverty (Anguelovski et al., 2018; Foster, 2017; Ottinger, 2017). There is a need for the implementation of policy and planning measures to address the coupling of past practices of discriminatory zoning that continues to sustain vulnerability and jeopardizes the resilience of residents living in flood-prone coastal areas of NYC.

Sustaining Climate Resilient Public Housing

Hurricane Sandy presented NYCHA and its residents with a substantial amount of damage that negatively disrupted residents' access to essential services such as electricity, heating, transportation, and elevator service, which in turn made it more difficult for residents to fulfill responsibilities such as going to work or doctors' appointments (Zimmerman et al., 2019). The sudden disruption of normalcy for NYCHA showed to heavily impact public housing residents, especially those with disabilities who were often left immobile for weeks (Brooklyn Center for Independence of the Disabled v. Bloomberg, 2013). It is inevitable that NYCHA and its public housing residents will experience a hurricane again one day and preemptive actions can be taken to mitigate the impacts that resulted previously from Hurricane Sandy while simultaneously strengthening the resiliency of residents (Schmeltz et al., 2013). Strengthening social capital and adaptive capacity can begin to address NYCHA public housing residents' disproportionate resilience and social vulnerability that influences their ability to adapt, prepare, anticipate, and recover from an environmental hazard (Schmeltz et al., 2013). My findings show that depleted adaptive capacity can negatively influence the resilience and social vulnerability of public housing residents in the event of a hurricane. To help public housing residents achieve

resilience in the event of an environmental hazard, NYCHA must be given consistent and adequate funding to supplement local capacity building (Hernández et al., 2018; Cutter, 2016; Leeds, 2023). NYCHA receives funding from a range of federal, city and other sources but has been continuously operating on a budget deficit largely attributed to a shifting political climate and a series of budget cuts made by federal and state funders (Giller, 2020). The Department of Housing and Urban Development (HUD) is a large contributor of funding to NYCHA, but subsidies available to NYCHA have been jeopardized by federal cuts to HUD's budget (Giller, 2020). Regarding physical infrastructure, NYCHA has historically not been given sufficient funding to fulfill a long backlog of maintenance requests and resolve operating gaps, causing residents to live with a persistent presence of mold and dilapidated infrastructure that is not conducive to climate change resiliency (Bach & Waters, 2014; McArdle, 2014). The presence of dilapidated public housing has been shown to negatively influence the resiliency of residents in the event of a hurricane as they are preemptively exposed to environmental hazards (Hamideh et al., 2021; Hernández et al., 2018). Developing infrastructure that is adaptable to a changing climate is shown to strengthen resiliency to future environmental hazards. However, the gentrification of neighborhoods is a rightful concern for NYCHA residents when discussing the implementation of climate-resilient infrastructure and disaster mitigation measures in public housing developments. The implementation of urban resilience often disregards the concerns of marginalized groups and fails to consider how they may be impacted throughout the implementation process (Shamsuddin, 2020). Implementing equitable environmental hazard mitigation measures such as a place-based participatory approach to the development of future disaster planning and policy can begin to address neighborhood gentrification (Leichenko &

Silva, 2014; Cutter et al., 2008). Resilience to future environmental hazards is heavily contingent on resident's political power and often, public housing residents have little political power with little to no involvement in the creation of disaster mitigation plans and policy (Graham, 2016). The concepts of political ecology and spatial politics encompass NYCHA public housing residents' predisposition to the adverse effects of a changing climate within such a system (Goh, 2021). Political ecology and spatial politics begin to explain the political, economic, and social factors associated with making environmental decisions (Goh, 2021). NYCHA residents experience limited political participation in decision making that allows for their vision of a physical space to prevail over contested visions of the same space (Graham, 2016). The use of place-based participatory approach begins to minimize the barriers of entry to the decision-making process and directly integrates the voices and needs of NYCHA residents into future disaster mitigation efforts and land use decisions.

Prepare Community Based Organizations for Future Environmental Hazards

Local community-based organizations (CBOs) play a crucial role both before and after the occurrence of an environmental hazard by creating, and sustaining social and civic infrastructure that allows social networks to provide public housing residents with resources such as fresh food, clean water, warm clothing, and poverty reduction (Storr et al., 2017). The case study of Hurricane Sandy's impact on NYCHA public housing residents demonstrated the importance of local community-based organizations both before and after a disaster. During the post-disaster recovery period, CBOs such as the Red Hook Initiative (RHI) advocated for the interests of public housing residents in how funding should be spent. Strengthening the capacity

of CBOs likewise strengthens the social and political capital of public housing residents and, in turn, reduces social vulnerability and strengthens resident resiliency to future environmental hazards (McArdle, 2014). Studies have concluded that strengthening the capacity of community-based organizations can also help fill the gaps of government-led disaster recovery efforts (Carrasco et al., 2023; Graham et al., 2016; Stajura et al., 2012). Most government organizations do not work as intimately in communities as community-based organizations and CBOs often provide some form of disaster relief before government organizations (Graham et al., 2016; Storr et al., 2017). Policymakers and practitioners can better equip local CBOs who have already established community relationships and trust with more funding and political power in decision making (Graham et al., 2016; Kapucu et al., 2011). Strengthening the capacity of those who are already doing the work is one way to effectively reach the necessary residents who are often neglected to have their vulnerabilities to environmental hazards addressed.

Chapter 6: Conclusion and Policy Recommendations

Conclusion

The goal of this thesis was to implement a mixed-method approach to explore and convey the complex nexus between NYC residents' social vulnerability at the census tract level, NYCHA public housing building locations, and various extents of storm surge flooding in NYC. Hurricane Sandy serves as a suitable case study to examine how locations of NYC with high values of social vulnerability, NYCHA public housing developments, and storm surge flooding coalesce to influence disproportionate disaster outcomes. In Chapter 2, a social-ecological-

technological systems framework was implemented to characterize and analyze NYCHA public housing residents' social vulnerability, resilience, and adaptive capacity to urban flooding brought on by Hurricane Sandy. Within such a system, many NYCHA public housing residents are subjected to precarious dilapidated infrastructure that has not been sufficiently retrofitted to withstand a predicted future of worsening environmental hazards. This in turn has influenced disproportionate disaster outcomes to the same environmental hazard throughout NYC.

The findings of this thesis support the claim that NYCHA public housing residents experienced disproportionate disaster outcomes to the same environmental hazard that was Hurricane Sandy. This was largely due to preemptive spatial and social marginalization of NYCHA public housing residents with a lack of disaster resilience, insufficient adaptive capacity, and high values of social vulnerability. The NYCHA disaster plans in place at the time of Hurricane Sandy were shown to lack adequate consideration for public housing residents' uneven resilience, social vulnerability, and adaptive capacity disparities compared to other New Yorkers. The absence of accurate government-led preemptive disaster planning was largely remediated by local community-based organizations (CBOs) such as the Red Hook Initiative (Goh, 2021). However, local CBOs were overwhelmed and did not have the capacity to sufficiently fulfill assistance requested by public housing residents during the post-disaster period. Local CBOs also played a role in advocating for the needs and preferences of public housing residents who as renters possess limited political power compared to homeowners.

The findings of future storm surge and sea level rise models in relation to the location of NYCHA public housing developments show a continual increase in the number of developments at risk of flooding. A predicted change in storm surge extent from 3m to 9m yields a 37%

increase in the amount of NYHCA public housing developments impacted by storm surge flooding. Furthermore, when comparing modeled Sea Level Rise 2020s 100-year floodplain predictions to modeled Sea Level Rise 2050s 100-year floodplain predictions, there is a predicted 7% increase in the amount of impacted NYCHA public housing developments within the 30-year period. These findings warrant planners and policymakers to consider the location of current and future NYCHA public housing developments within predicted storm surge areas to mitigate the risk of disaster outcomes experienced as a result of Hurricane Sandy.

The results of the social vulnerability index utilized in this thesis yielded results that support the findings of previous studies that have identified areas of NYC such as East Rockaway Beach, Harlem, the Bronx, Central Brooklyn, the Lower East Side, and North Queens to contain higher levels of social vulnerability. The disproportionate social vulnerability is heavily influenced by the presence of long-term compounding inequities experienced by public housing residents in NYC. When spatially analyzing the social vulnerability index concurrently with the location of Hurricane Sandy inundation zone and the location of NYCHA public housing developments, the results show areas such as East Rockaway Beach, Coney Island, South Bronx, and Lower East Side to have high values of social vulnerability where higher concentrations of NYCHA public housing developments are located within the modeled Hurricane Sandy Inundation zone. These results show areas of concern that should be prioritized when discussing future disaster plans for NYCHA public housing developments. Failure to prioritize such areas has the potential to lead to the recurrence of injustices experienced by NYCHA public housing residents because of Hurricane Sandy.

Policy and Practice Recommendations:

1. **Integrate an urban social-ecological-technological systems framework within future NYCHA public housing disaster plans.**

    a. Policymakers and planners should understand the interconnected nature of an urban social-ecological-technological system to accurately conceptualize the dynamics of public housing residents experiencing the effects of anthropogenic climate change within NYC. In NYC, considering the social attributes of neighborhoods in conjunction with the effects of climate change and physical infrastructure of NYCHA public housing developments begins to encompass the preexisting spatial inequities that have the potential to worsen because of a changing social-ecological-technological system. The use of a social-ecological-technological systems framework also begins to depict NYCHA public housing residents insufficient political and decision-making power that has increased their exposure, their sensitivity, and reduced their adaptive capacity to impending environmental hazards. The presence of power asymmetries has spatially and socially marginalized NYCHA public housing residents and in turn has created disproportionate vulnerabilities to sea level rise and storm surges. For example, social vulnerability and spatial marginalization of NYCHA public housing residents stem from a long history of discriminatory practices and systematic inequities that have been perpetuated by government-led decisions. Using discriminatory practices such as redlining and exclusionary zoning have located NYCHA public housing developments in coastal areas due to the lower cost of land. Inexpensive coastal land also led to coastal industries that worsened

industrial pollution and environmental degradation. NYCHA public housing residents' disproportionate exposure to environmental burdens that stem from industrial pollution and environmental degradation is systematic. NYCHA public housing residents' position within NYC's social-ecological-technological system that is interconnected with political, economic, and environmental components of a city has negatively influenced their political power over climate justice policies, causing a lack of direct involvement in the creation of pre-disaster resilience and post-disaster adaptation decisions. The lack of direct involvement of public housing residents hinders the integration of local knowledge and needs within disaster plans, influencing a constant depletion of resilience with limited capacity to handle and adapt to unprecedented shocks and stressors to the social-ecological technological system. This in turn perpetuated the continuation of inequitable pre-disaster preparedness and post-disaster outcomes that are misaligned with the needs of public housing residents, such as the omission of adequately addressing the maintenance backlog of NYCHA developments (Stringer& Landa, 2015). NYCHA can integrate a social-ecological-technological systems framework into future disaster plans to accurately depict the unique parameters and needs of public housing residents.

2. **Adopt a place-based participatory planning model to allow public housing residents direct involvement in the decision-making process.**
    a. A place-based participatory planning model prioritizes locational variability and local knowledge by ensuring public housing residents have direct involvement in

the creation of disaster policies and plans that align with the needs and goals of residents. This approach to planning emphasizes the unique attributes of public housing residents that are often left out of disaster plans and in turn, influence the implementation of policies and plans that do not apply to public housing residents. It's been theorized that NYCHA public housing residents are living within a "differentiated state" that negatively influences post-disaster recovery efforts. Being renters, along with the common stigmatization of NYCHA public housing residents, often results in limited political power and persuasion over policies and plans compared to real property owners. A place-based participatory planning model begins to address the limits of tenants and actively integrates their needs and preferences into policy and plans. The implementation of a place-based participatory planning model has been shown to help mitigate the occurrence of gentrified outcomes that have the potential to displace residents out of their own neighborhoods because of the implementation of resilience and adaptation measures.

3. **Implement a social vulnerability index that is constructed based on unique attributes of NYCHA public housing residents and identifies areas with disproportionally higher values of social vulnerability.**
    a. The construction of a social vulnerability index using applicable indices that influence disaster risk pragmatically conceptualized how the social vulnerabilities of NYC residents differ spatially and temporally. This thesis integrates an indicator used to quantify the amount of NYC residents who receive supplemental

social security income as it characterizes the spatial prevalence of restricted incomes within NYC. Analyzing the spatial distribution of social vulnerability throughout the five counties of NYC shows disproportionally higher values of statically significant clustering in neighborhoods located in the Bronx, Harlem, the Lower East Side, East Rockaway Beach, North Queens, and Central Brooklyn. This information can be used to inform future disaster planning and policy as certain neighborhoods require a greater allocation of resources than others to reduce risk and increase resilience. NYC residents experienced Hurricane Sandy differently depending on their spatial and social attributes. The case study of Hurricane Sandy demonstrates the relationship between high values of social vulnerability and close spatial proximity of NYCHA public housing developments within storm surge zones in conjunction with insufficient preparation and response to Hurricane Sandy.

4. **Consider the future of sea level rise and storm surge risk within future NYCHA public housing disaster plans.**
    a. The outcomes of the spatial analysis of future storm surge and sea level rise models yield a predicted 7% increase in the amount of NYCHA public housing developments impacted by impending sea level rise within the years 2020 to 2050. Failure to plan for an imminent sea level rise in the future can put more NYCHA public housing residents at risk, jeopardizing their health, safety, and welfare. Many NYCHA public housing developments are spatially marginalized and unevenly exposed to flood risk. Implementing a long-term outlook on

adaptation efforts can improve NYCHA public housing infrastructure that is sustainable to future environmental hazards projected to be exacerbated by climate change.

5. **Allocate more funding to local community-based organizations who already play a vital role in pre-disaster resilience and post-disaster adaptation.**
    a. It is arguably unreasonable to expect NYCHA public housing residents to independently prepare for the influx of resources needed to adequality support disaster preparedness, response, and recovery, as many public housing residents frequently rely on external assistance for social and financial matters. Local community-based organizations often fill the resource gap that limited government assistance leaves for public housing residents. Hurricane Sandy demonstrates the importance of local community-based organizations and their role of creating and sustaining robust social and civic infrastructure, as well as enhancing social networks and social capital. The findings of this thesis indicate that compared to other NYC residents, there was insufficient consideration and accommodation for NYCHA public housing residents' disproportionate and compounding vulnerabilities to an impending increase in storm surge levels within the NYCHA disaster plans that were in place during Hurricane Sandy (Schmeltz et al., 2013). As a result, NYCHA and other government agencies were overwhelmed by Hurricane Sandy, causing the occurrence of ad hoc response efforts that jeopardized the well-being of NYCHA residents (Graham, 2016). For example, NYCHA public housing residents with disabilities were inadequately

accounted for by NYCHA during the evacuation period, leaving many disabled residents stranded in their apartments with an insufficient supply of resources. Neglecting to accurately account for at-risk, vulnerable public housing residents such as those with disabilities is not conducive to achieving a goal of strengthening and sustaining community level public housing disaster resilience in the age of anthropogenic climate change (McArdle, 2014).When revising disaster plans for future hurricanes, NYCHA has a window of opportunity to meaningfully collaborate with local community-based organizations who have already established trustful relationships with public housing residents and play a vital role in pre-disaster resilience and post-disaster adaptation.

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Appendix

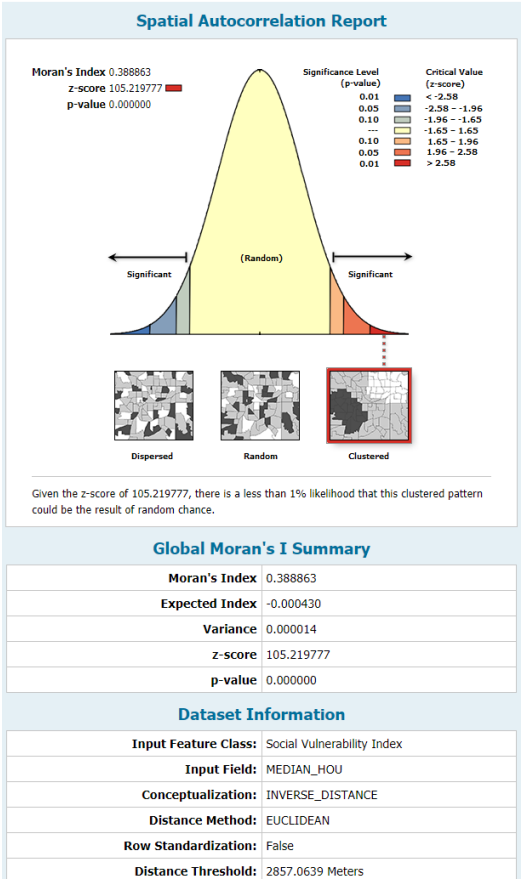
Appendix 1

Glossary

Term	Definition
Vulnerability	An entity's susceptibility to a negative impact like a natural hazard. Often seen as a function of exposure, sensitivity, and adaptive capacity.
Resilience	An entity's ability to prevent damage and can recover in the event of an environmental hazard
Adaptive Capacity	The extent as to how much an entity can adjust to a changing climate
Risk	A function of hazard, exposure, and vulnerability.
Disaster Planning	Viewed as four phases: Mitigation, Preparedness, Response , and Recovery

Appendix 2

Spatial Autocorrelation Report of Social Vulnerability



Spatial Autocorrelation Report

Moran's Index 0.388863
z-score 105.219777
p-value 0.000000

Significance Level (p-value)	Critical Value (z-score)
0.01	< -2.58
0.05	-2.58 - -1.96
0.10	-1.96 - -1.65
---	-1.65 - 1.65
0.10	1.65 - 1.96
0.05	1.96 - 2.58
0.01	> 2.58

Given the z-score of 105.219777, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Global Moran's I Summary

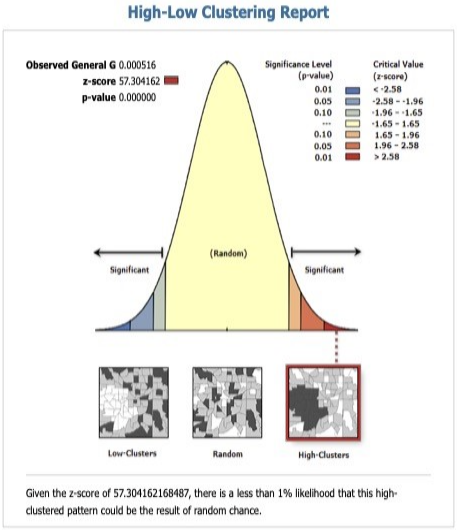
Moran's Index	0.388863
Expected Index	-0.000430
Variance	0.000014
z-score	105.219777
p-value	0.000000

Dataset Information

Input Feature Class:	Social Vulnerability Index
Input Field:	MEDIAN_HOU
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	2857.0639 Meters

Appendix 3

High-Low Clustering Report of Social Vulnerability



High-Low Clustering Report

Observed General G 0.000516
z-score 57.304162
p-value 0.000000

Significance Level (p-value)	Critical Value (z-score)
0.01	< -2.58
0.05	-2.58 - -1.96
0.10	-1.96 - -1.65
---	-1.65 - 1.65
0.10	1.65 - 1.96
0.05	1.96 - 2.58
0.01	> 2.58

Given the z-score of 57.304162168487, there is a less than 1% likelihood that this high-clustered pattern could be the result of random chance.

General G Summary

Observed General G	0.000516
Expected General G	0.000430
Variance	0.000000
z-score	57.304162
p-value	0.000000

Dataset Information

Input Feature Class:	Social Vulnerability Index
Input Field:	F8
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN