Effect of Local Context on Flood Vulnerability Identification

A comparison between New Orleans' flood vulnerability assessment tools and globally applicable vulnerability indices

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Abstract

Flood occurrences are on the rise all over the world and large numbers of people are constantly exposed to the risk associated with these disasters. Vulnerability assessment is integral to flood risk management. It helps identify areas with high flood risk and guides resilience policies. Vulnerability, being an intangible notion, is difficult to assess. Many municipalities resort to field survey and community outreach based assessment processes. These tools are sensitive to local context, but are time and resource intensive. Consequently, municipalities with limited resources, especially those in developing countries, cannot adopt this methodology. Moreover, these tools are susceptible to political biases and corruption. Another widely used assessment method is indicator-based, which involves developing Flood Vulnerability Indices (FVIs) by using available data to provide a logical image of a region's vulnerability to disaster. The quantitative nature of this tool makes it quicker, cost effective, and objective. But this attempt to measure a qualitative concept like vulnerability exposes these indices to statistical fallacies, leading to inadequate results. Moreover, these one-size-fits-all indices fail to acknowledge the distinct characteristics of a society.

This study aims to investigate the effectiveness of FVIs and find out whether their quantitative nature, that ignores the intangible local characteristics of society, compromises the credibility of outcomes derived. The purpose is to learn if these indices can provide adequate understanding of vulnerability in areas where governments either don't have the time and capital to invest in extensive field surveys, or are plagued by corruption. As a case study, this thesis examines the application of Bathi and Das' flood vulnerability index on New Orleans' socioeconomic and environmental data and compares the results to those attained via the assessment methods developed by the city of New Orleans. This would help understand how flood risk identification

through local tools differs from FVIs, and the extent to which this influences the flood mitigation and adaptation policies that are made. The research concludes with recommendations for statistically improving the FVIs and, when necessary, using a combination of local knowledge-based qualitative techniques and FVIs to get adequate results, in turn making better informed decisions when devising flood resilience policies.

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CHAPTER 1: INTRODUCTION

Natural disasters disrupt the normal activities of human society and natural habitats. Flooding is one of the most damaging forms of disaster. Over centuries, people have been settling in flood-prone areas due to their favorable geographic conditions that facilitate economic growth, such as accessibility (transportation) and food production (fertile land). Today, one-third of all annual natural disasters and economic losses and more than half of all disaster victims are flood related (Douben 2006). This forces societies all over the world to protect themselves against flooding. Due to the devastating nature of its interaction with the built fabric and its inhabitants, flooding is a topic of great concern for urban planners.

1.1 Flood and its impacts:

"Flood is a relatively high streamflow overtopping the natural or artificial banks in any reach of a stream" (USGS 2010). Impacts of flooding on people and communities are immense. Flooding can cause physical injury, illness, and loss of life. The risks increase if the floodwater is carrying debris or is contaminated by sewage or other pollutants (e.g. chemicals stored in garages or commercial properties). It is particularly dangerous as it is likely to cause illnesses, either because of direct contact with the polluted floodwater or indirectly as a result of sediments left behind (Dublin: Stationery Office 2009). The impact on people and communities because of the stress and trauma of being flooded, or even of being under the threat of flooding, can be immense. Long-term impacts can arise due to chronic illnesses and the stress associated with being flooded and the lengthy recovery processes (Dublin: Stationery Office 2009).

In terms of lives lost and property damaged, floods are just behind tornadoes as the top natural disaster. In the past 30 years approximately 2.8 billion people have been affected by floods worldwide, of which 4.5 million were left homeless, approximately 540,000 died, and 360,000 were severely injured (Doocy, Daniels, Murray & Kirsch 2013). In 2015 alone 152 floods were reported globally, causing 3,310 deaths and 27,504,263 people affected (UNISDR 2016). In the United States, the first six months of 2016 witnessed six flooding events, causing 60 fatalities and an estimated overall loss of $3,300 million (Catastrophes: U.S. 2016). According to the Climate Wire index, river flooding is expected to affect 54 million people worldwide in 2030 as more extreme rainfall and the rapid expansion of cities double exposure to inundation (Lehmann, E. 2015). Researchers estimate that climate change causes two-third of the increase in population exposed to the peril of flooding worldwide (Lehmann, E. 2015). Remaining one-third is triggered by socioeconomic vulnerability.

Devastation caused by flooding, both internationally and in the US, is widespread. Increasing environmental depletion is accelerating the occurrence of these events. Despite increased focus on flood mitigation and adaptation strategies and technological advancements, countries have been unable to pacify the damaging effects of flooding. This subject requires more research so that better procedures and policies can be devised to help minimize the adverse effects of flooding.

1.2 - Need for flood vulnerability assessment tools:

Flood mitigation policies globally attempt to empower societies to increase their resilience to flood hazards. Resilience is the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter how chronic the stresses and acute the shocks they experience (City of New Orleans, 2015). With increasing population and higher values of property and infrastructure, consequences of flooding have become less acceptable, making flood resilience a topic of great importance worldwide. Douben (2006) suggests that societal changes such as interference by developments, investments, and land-use changes are exacerbating vulnerability in flood-prone areas, which is in turn increasing the trends in flood frequencies and flooding damage.

Vulnerability is the condition of a community that increases its susceptibility to the impact of hazards. Risk, on the other hand, is generally defined as the product of the hazard probability and its consequences. Risk can be viewed as a function of the hazard event and the vulnerability of the elements exposed. (Birkmann, 2007). There is a global need to enhance our understanding of flood risk and vulnerability and to develop methodologies and tools to assess it. There are a variety of flood vulnerability assessment methods which differ in their theoretical framework, indicators used, and methodology. Some of these tools are devised by local municipalities, customized to match their specific needs, while others are developed by academics and international organizations to be used globally. Best practices include local, context specific assessment tools which involve conducting on-ground research, combined with participatory methods that take stakeholders' perception of vulnerability and risk into account (Moret, 2014).

But for selecting a suitable method, factors like time and resources available to undertake the study should be considered. These participatory practices take months, often years, to provide with conclusive results. Moreover, the effectiveness of these approaches is greatly dependent on availability of monetary resources and community's attitude towards the researcher (Moser). Another challenge is that the current socioeconomic settings and institutional and legislative context of many countries, especially in the developing world, may not allow stakeholders to participate in the decision-making process. People's participation is still quite low in current planning processes of countries like Bangladesh, Pakistan, and India (Gain et al., 2012). Developing local capacities to facilitate these methodologies in such contexts requires improved adaptive management techniques through better education - a process that may take years, if not decades. Other institutional challenges like lack of coordination among different agencies and sectors is also a significant reason for these tools to be unsuitable for poor municipalities and developing countries (Gain et al., 2012).

It is difficult to assess vulnerability in places like these. Such municipalities require a method that cannot get jeopardized by political biases and isn't as time and resource intensive. Quantitative tools tend to minimize these problems. One of the most commonly used quantitative assessment tools is the Flood Vulnerability Index (FVI). It presents flood vulnerability as a single number that is applicable for a range of different spatial scales (Balica et al., 2012). This technique is quantitative in nature and is usually generalized enough to be applicable in different parts of the world. Planners and policy makers can develop flood mitigation and adaptation plans based on risk identification maps which are a derivative of the findings of these FVIs. This study aims to explore the potential of such FVIs and the credibility of their outcomes.

1.3 - New Orleans, USA:

New Orleans is a major port and the largest city in the State of Louisiana, USA. As of 2010 US Census, the population of the city was 343,829 (U.S Census Bureau, 2012). New Orleans is situated between the Mississippi River to the south and Lake Pontchartrain to the north. It is one of the nation's poorest cities, with a poverty rate more than twice the national average (Center for Progressive Reform, 2005). The City of New Orleans was built on the lowest elevation in the state of Louisiana, and is one of the lowest points in the US (Leatherman and Burkett, 2002). The oldest parts of the city were built close to levees along the shores of the Mississippi. But as the city expanded, lower elevation neighborhoods were settled. Much of the city is located between 0.3 and 3 meters below sea level and is protected by a series of levees. Because much of New Orleans is located below sea level and lacks natural drainage, the city is geographically predisposed to severe flooding from the Mississippi River, coastal storms, and heavy precipitation (Carter, 2005).

In August 2005, New Orleans experienced severe flooding due to Hurricane Katrina which, despite having evacuated over 80 (Wolshon 2006) percent of the city before the hurricane made landfall, resulted in a death toll of 1,464 (Ezra 2006). In 2015, the city , along with Resilient NOLA (a project of The Rockefeller Foundation's 100 Resilient Cities), devised a strategic action plan to reduce the city's vulnerability to environmental and manmade disasters. The city's geographical location makes it prone to coastal flooding and an abundance of work is being done to address this problem. The city of New Orleans was selected as the case study for this research because it uses a participatory vulnerability assessment process to help devise its resilience policies. It also provides publicly accessible demographic and climatological data which can be plugged into a suitable FVI. This can provide comparable results to understand how and to what extent the two approaches differ in their outcomes.

1.4 – Research Question:

This thesis poses the following questions: Does local context matter in determining flood vulnerability? To what extent do locally produced flood vulnerability assessment tools differ from global flood vulnerability indices? And how does this difference affect the flood risk identification process and in turn the flood mitigation and adaptation policies devised?

To help answer this question, the current debate on the issues of flood vulnerability and resilience will be discussed in the following chapter.

CHAPTER 2: THE DEBATE ON VULNERABILITY AND ITS ASSESSMENT

The purpose of this chapter is to analyze any research done in the past or currently being conducted that may be relevant to this study; recognize the implications of these researches on defining the intent and scope of this project; and identify how this thesis can add to these theories or address any potential gaps found in the current planning procedures. This critical review will culminate into a set of guidelines that this thesis will follow to answer the research question posed.

2.1 - Flood Contingency Plans and Risk Assessment:

Godschalk (1999) explains that when natural hazard events take place in unpopulated areas, no disaster occurs; when they take place in a developed region, damaging life and property, they are called natural disasters. Hence, the magnitude of a disaster depends on the intensity of the natural hazard event, the number of people and structures exposed to it, and the effectiveness of pre-event mitigation actions in protecting people and property from hazard forces (Godschalk 1999). Though the occurrence of a flood event cannot be prevented, its impacts on people and property can be reduced if advanced action is taken to mitigate the risks and minimize vulnerability to flooding.

Following the disasters in early 1990s, the US Congress directed the Federal Emergency Management Agency to place its highest priority on hazard mitigation (Godschalk, 1999), shifting its emphasis from responding to, and recovering from, disasters once they have occurred to mitigating future hazard events. This marked a fundamental change in policy, moving from a reactive to a proactive national emergency management policy. “When you see the water rising, it’s too late to plan for a flood. To effectively manage the hazards associated with floods, it is imperative that you already have in place a thorough flood risk mitigation strategy that you can implement before, during and after the event" (Willis 2010). Pre-emergency flood risk mitigation and adaptation planning allows for the immediate implementation of policies and procedures that have been practiced and are understood by everyone onsite. Hence, flood resilience plans are critical for communities that are situated in flood prone areas to minimize affect.

The effectiveness of flood mitigation and adaptation plans depends greatly on flood risk identification (Malcolm & Parkin 1997). Government agencies all over the world focus on incorporating flood risk assessment into the process of laying down flood contingency plans, providing the national, regional and local authorities with guidelines to introduce comprehensive mechanisms for incorporating flood risk identification, assessment and management into the planning process (Dublin: Stationery Office 2009). These government authorities are expected to provide input into risk and vulnerability assessment, take action to reduce vulnerability of health and safety, property and businesses, and other aspects of residents' lives, and finally prepare for response to and recovery from these flooding events (Malcolm & Parkin 1997). Flood risk identification and vulnerability assessment are integral to the development of a flood mitigation and adaptation plan and the tools for carrying out these processes must be selected carefully.

2.2 - Understanding and Assessing Vulnerability:

The term vulnerability has already been used multiple times in this study. Its commonplace meaning is of being prone to or susceptible to damage or injury. Different scholars have had their own definitions of the term. Vulnerability may refer to the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (Blaikie 1994). Another well-known definition of vulnerability was formulated by the International Strategy for Disaster Reduction, which regards it as a set of conditions and processes resulting from physical, social, environmental and economic factors, which increase the susceptibility of a community to the impact of hazards (ISDR, 2004). Vulnerability is thus a combination of factors that determine the degree to which someone's life, livelihood, property and other assets are put at risk by an event in nature or society. Here the risk event is viewed primarily as external to the system, whereas the term vulnerability is an intrinsic characteristic of the system.

Vulnerability of a society is related both to the physical susceptibility of the exposed elements (physical vulnerability) and the socioeconomic frailties or lack of resilience of the flood-prone communities (socioeconomic vulnerability) (Cardona, 2003). For this thesis, the operational definition of vulnerability is the one that the United Nations/International Strategy for Disaster Reduction (UN/ISDR) has devised. It defines vulnerability as the "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of a community to the impact of hazards" (UN/ISDR, 2004).

There are a variety of vulnerability assessment methods that differ in their description, theoretical framework, variables and methodology. These tools may be qualitative, based on local knowledge collected by conducting public outreach events and community charrettes, or quantitative. There are four distinct types of quantitative tools: Indicator-based method, curve method, disaster loss data and models approach. The vulnerability indicator method, which uses quantitative data to provide an image of the area's vulnerability, is often preferred by policy makers (Nasiri, Yusof, & Ali 2016). A hazard vulnerability indicator can be defined as "an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of an element at risk to an impact of a hazardous event linked with a hazard of natural origin" (Nasiri, Yusof, & Ali 2016).

Flood vulnerability is a multidimensional and complex issue (Messner and Meyer 2006). There are various indices with multicriteria processes for assessing economic, social and ecological dimensions of flood vulnerability in an integrated fashion (Moel et al. 2009). King (2001) and Kaplan et al. (2009) developed integrated vulnerability indices for different kinds of natural hazards, with an emphasis on social vulnerability indicators. Geospatial Research, Analysis & Services Program of ATSDR (Agency of Toxic Substances and Disease Registry) has recently devised a social vulnerability index (SVI) that uses US census data to indicate the relative per-census-tract vulnerability of every part of the country. Kienberger (2009) used a quantitative and spatial multicriteria approach for an integrated assessment and mapping of susceptibility. But, multicriteria indices for an integrated assessment specifically for flood vulnerability are relatively rare.

The Natural Capital project devised a coastal vulnerability model (InVEST) in 2016 which differentiates areas with relatively high or low exposure to erosion and inundation during storms. This model, unlike the indices defined earlier, takes coastal flooding into account, but fails to recognize the area's socioeconomic potentials and limitations.

There has been research done on the topic though. Bathi & Das (2016) suggest that it is a common practice to measure vulnerability of communities to a flood hazard using either socioeconomic indicators or by calculating physical flood extent. However, their combined impact is often ignored. They devised an index that assesses vulnerability to coastal flooding by taking the region's economic, social and ecological dimensions into account. Bathi and Das's index builds upon the methodology developed by Chakraborty, Tobin, Montz (2005) to assess spatial variability in geophysical risk and social vulnerability of communities to natural hazards. Other similar attempts include Connor and Hiroki's (2005) vulnerability indicator and Villordon and

Gourbesville's (2014) social vulnerability index for urban flooding. This paper uses Bathi and Das' index due to three reasons. Firstly, it is a comprehensive index as it combines both socioeconomic and climatological data to calculate flood vulnerability. Secondly, this research was published in February 2016 and is the most recent amongst all the indices discussed above. Finally, this index builds upon variables that can be obtained from American Community Survey (ACS) data sets to assess socioeconomic vulnerability and Federal Emergency Management Authority's (FEMA) data to calculate climatological vulnerability. Both datasets are available to public.

2.3 – Understanding Bathi and Das' Vulnerability Index for Coastal Flooding

Jejal Reddy Bathi and Himangshu S. Das, in their paper Vulnerability of Coastal Communities from Storm Surge and Flood Disasters published in 2016, devised a quantitative index to identify critical populations vulnerable to coastal flooding. This index was designed to help planners and communities better understand how socioeconomic, geographical and climatological shortcomings of neighborhoods contribute toward their vulnerability to flooding. This can help planners and policy makers prioritize resources for the communities that need it most.

This index is built on the concept that not all people in a hazard-exposed area are equally affected. There are multiple characteristics of a neighborhood, like demographics, income, and education level, that play an important role in determining how its population will be influenced by the disaster. This index expresses the vulnerability of a community in three closely tied ways: (1) social vulnerability (race, ethnicity, etc.); (2) economic vulnerability (income level); and (3) the climatological vulnerability (flood exposure) (Bathi, & Das 2016). The index combines the first two as socioeconomic vulnerability and the third uses FEMA data to analyze flood extent. The assessment method involves using specific demographic indicators from ACS data to calculate average socioeconomic vulnerability. It uses data on 100-year flood areas to calculate a region's climatological vulnerability. The overall flood vulnerability, a combination of socioeconomic and climatological vulnerability, is calculated as an average of the two numbers. Results obtained are presented as thematic maps. The variables used and procedures involved in obtaining these results are explained as follows:

(i) *Socioeconomic Vulnerability Index:*

Socioeconomic or social vulnerability arises from the potential of a disaster to cause changes in people's daily routine and lifestyle based on their socioeconomic conditions (FEMA 2007). This index uses eleven variables from ACS data that represent the social and economic conditions of the population living in each census tract of the city.

Table 1: Variables used in Bathi and Das' FVI.

1	Total Population
2	Minority Populations
3	Number of Female Households
4	Population Under 18 Years
5	Population 65 Years and Older or Disabled
6	Households with No Vehicle
7	Housing Units in Mobile Homes
8	People in Group Quarters
9	People Below Poverty in Past 12 Months
10	Population 18 Years and Over with No Diploma
11	No One Age 14 and Over Speaks English Only or Speaks English "very well";

The larger the population of a census tract, the higher will be the expected number of people affected by disaster, thus requiring more robust preparation and rescue policies. The Belmont Report, produced in 1979 by a United States government commission, includes minority (non-white) populations among its list of vulnerable research participants (NCPHSBBR 1979). This index also acknowledges that these population groups are more susceptible to disasters like flooding. Women are expected to be more vulnerable to disasters. This is because they usually have low wages and due to the nature of their responsibilities as caregivers to children, and often elderly, it is harder for them to seek for assistance and safety (Cutter, Emrich, Webb & Morath 2009) (Tierney 2006). Due to their dependence on parents or guardians and limited capability to deal with physical and psychological stresses, children under 18 years of age are among the most vulnerable group of individuals during a disaster cycle (Morrow 2008). People who need physical assistance, especially those over the age of 65 or disabled, are most affected under such situations (Morrow 2008). Not having a personal vehicle or access to public transport impedes emergency evacuation process, thus increasing vulnerability (Bathi, & Das 2016). Since Mobile homes do not have a strong foundation, they are more likely to be affected by such severe weather (Donner 2007). People living in multiunit housing and high-rise apartments are more vulnerable due to their dense population limiting access and ability to evacuate (Bathi, & Das 2016). It is less likely for poor populations to have the resources to prepare for and recover from the effects of a flooding disaster (Cutter, Emrich, Webb & Morath 2009). Since there is a direct correlation between educational attainment and economic status, people with less education are expected to have lesser resources to minimize the effects of disaster (Bathi, & Das 2016). Most of the disaster information is communicated by the government in the country's official language (English in US). Therefore, lacking the ability to speak the language can exacerbate their vulnerability to the hazardous event (Flanagan, Gregory, Hallisey, Heitgerd & Lewis 2011).

The above variables are used to conduct disaggregated (census tract-level) spatial analyses to identify the demographic segments most likely to be vulnerable to disaster impacts. The methodology section provides an overview of the basic functions used to conduct this analysis.

(ii) *Climatological (Flood) Vulnerability Index:*

To compute climatological (flood) vulnerability, the index uses geospatial data reported in FEMA's National Flood Risk Report as input data for identifying flood hazard areas. Flood hazard areas are identified on the Flood Insurance Rate Map (FIRM) and Flood Hazard Boundary Map (FHBM) as Special Flood Hazard Areas (SFHAs). A Special Flood Hazard Area (SFHA), as defined by FEMA, is an area that is at a high risk of flood, mudflow or flood-related erosion hazards (FEMA Definitions, n.d.).

Since 1960s, the United States has used the '1-percent annual exceedance probability (AEP) flood' as the basis for its National Flood Insurance Program. SFHAs are the areas that will be inundated by a flood event having a 1-percent or one in hundred chance of being equaled or exceeded in any given year (USGS, n.d.). SFHAs are divided into multiple zones, each representing either high flood risk areas for 100-year flood; areas with temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam); dual flood zones that, because of flooding from water sources that the flood protection system does not contain, will continue to be subject to flooding even after the flood protection system is adequately restored; or areas along coasts subject to inundation by the one-percent-annual-chance flood event with additional hazards due to storm-induced velocity wave action (Bathi, & Das 2016).

This index calculates flood exposure area as the amount of land identified as SFHA by FEMA, or area within the 100-year flood zone, as a fraction of the total land area in each census tract.

(iii) *Interactive Vulnerability Mapping:*

Overall flood vulnerability index is computed by taking an average of the results (in ratios) for each of the aforementioned indices, that is socioeconomic and climatological. Finally, to visually identify areas of varying vulnerabilities, thematic maps of the calculated flood vulnerability scores are created. These risk maps can be used by planners and policy makers to understand, in a single glance, how the flood vulnerability of different census tracts in a region varies.

This thesis uses Bathi and Das' FVI to develop a flood risk map for New Orleans which will later be compared to the results of flood assessment tools used by the city of New Orleans and Resilient NOLA to develop the city's 2015 Resilience Plan. Following section analyzes the city's resilience plan and its assessment tools.

2.4 - Critique on the methodology of Bathi and Das' FVI:

The FVI, in an attempt to simplify a complex phenomenon like vulnerability, has left room for statistical fallacies. Following is a detailed account of a few statistical and logical fallacies that this index may be subject to. The findings section of this thesis uses New Orleans data to demonstrate how these problems affect the results of this index.

(i) *Modifiable Areal Unit Problem (MAUP):* The MAUP is "a problem arising from the imposition of artificial units of spatial reporting on continuous geographical phenomena resulting in the generation of artificial spatial patterns" (Heywood, 1988). The size and scale at which one analyzes information can produce different results. For example, flood vulnerability for New Orleans as a whole is different from what it is for a census tract in the city, which is again different from that of each household in that tract.

In case of this FVI, FEMA's NFHL shapefile for SFHA data provides information for the continuous geography of the area. But the ACS socioeconomic data comes in prepackaged sizes - census tract being the smallest scale available. Since finer-scale data can be aggregated relatively easily, this index aggregates the FEMA data to fit the census tract scale of the socioeconomic information, in order to perceive the collective impact of the two data sets. But aggregating FEMA data by census tract can increase the chances of distorting or exaggerating the actual data patterns. Next chapter demonstrates how this index is susceptible to misrepresentation of data due to the modifiable areal unit problem.

(ii) *Multicollinearity:* Multicollinearity is a statistical phenomenon in which two or more variables are highly correlated, meaning that one can be linearly predicted from the others with a substantial degree of accuracy. This FVI, in its selection of socioeconomic variables, does not indicate going through a multicollinearity test, which implies that there may be redundant variables in the index that may lead to skewness of results obtained. For example, there appears to be a rational relationship between variables 9 (Poverty level) and 10 (educational attainment). Low educational attainment might lead to lesser paying jobs, which may further lead to increased poverty. In this case, if one indicator explains a substantial amount of variance in the other indicator, the index will be subject to multicollinearity. This statistical fallacy can be minimized by running a multicollinearity test on the variables and getting rid of redundant variables, if any.

(iii) *Omitted Variable Bias:* The authors of the FVI have given a fair explanation of why these particular socioeconomic variables are being used, but the model may have left out one or more important variables. This statistical phenomenon is known as the omitted-variable bias (OVB), which is created when the model compensates for the missing factor by over- or underestimating the effect of one of the other factors. The model should also test for OVB. But unlike the multicollinearity test, this cannot be done through a straightforward statistical tool. The process requires a comprehensive understanding of the subject matter and local context to check if OVB exists and identify the variables that must be added to make the model more robust.

(iv) *Weighted arithmetic mean*: In the socioeconomic index, the authors have used ordinary arithmetic mean to aggregate the impact of 11 standardized variables, suggesting that all variables affect the tract's vulnerability equally. It is hard to justify how a white person with income below the poverty line, lacking resources to elevate his/her home above flood inundation level, is just as vulnerable as a rich non-white individual. The index fails to address the fact that different circumstances affect people's vulnerability to disaster differently. In such a case, use of weighted arithmetic mean (WAM) might make the index more robust. WAM is similar to an ordinary arithmetic mean, except that instead of each of the data points contributing equally to the final average, some data points contribute more than others. Of course, assigning weights to these variables is not as straightforward as it sounds, but if guided by literature and results of on-ground surveys, there is the possibility of developing a comprehensive weighting system.

(v) *Discrepancies in data:* Authors of the index wanted to include people living in multiunit housing and high-rise apartments to the vulnerability assessment process. For this reason, the index uses American Community Survey (ACS) data for 'people living in group quarters'. But US Census Bureau's definition of group quarters is different from that of authors. The bureau classifies all people not living in housing units (house, apartment, mobile home, rented rooms) as living in group quarters. There are two types of group quarters, institutional (correctional facilities, nursing homes or mental hospitals) and non-institutional (college dormitories, military barracks, group homes, missions or shelters) (US Census Bureau, 2016). The ACS sample includes both institutional and non-institutional quarters. Though most of the people living in these facilities usually have fewer resources to protect themselves from disasters like flooding, ACS variable used in the index is not a representative of the data that the authors intended to include.

These problems can substantially distort the results produced and limit the applicability of the index. But the good news is that they are manageable. If not completely corrected, their impact can be minimized by using correct statistical tools and planning expertise.

2.5 – City of New Orleans' Resilience Plan

A resilience strategy helps cities prepare for, adapt to, and quickly rebound from shocks and stresses. *Resilient New Orleans*, published by the city of New Orleans in 2015, is a strategic action plan that addresses the questions of equity, adaptability to natural environment, and prosperity for the current and future generations of NOLA. The plan builds upon assessments and studies done in the past decade (post-Katrina) to devise policies for a sustainable, resilient future. The plan was devised with the help of Resilient New Orleans, an initiative of 100 Resilient Cities, pioneered by The Rockefeller Foundation. Resilient NOLA combines local expertise with global best practices to plan for the most urgent threats faced by the city. This strategic action plan acknowledges that "Sea level rise and a projected increase in frequency and intensity of storm events are expected to accelerate coastal land loss, adding greater stresses to the NOLA's levee and flood protection system" (City of New Orleans, 2015), and recognizes the urgency to solve this problem.

The plan acknowledges that New Orleans carries a legacy of inequity and risk (City of New Orleans, 2015), suggesting that socioeconomic differences among population have been impeding the city's progress towards resilience.

> "Many New Orleanians suffer chronic social stresses of poverty, unemployment, and violence. Wide disparities exist in employment, wages, educational attainment and health conditions. These social stresses are correlated with greater vulnerability to shocks" (City of New Orleans, 2015).

These socioeconomic vulnerabilities exacerbate the risks of intermittent shocks and expose neighborhoods, that are already a victim of inequity, to flood hazard. The plan posits that NOLA requires flood mitigation strategies that prioritize racial equity to build a more resilient society. It is worth noticing that both the above mentioned FVI and NOLA's resilience plan acknowledge the unavoidable increase in occurrence of flooding events and the role played by socioeconomic disparities within communities in intensifying the risk. Let us now explore how, despite similar aims, their vulnerability assessment methods differ from one another.

2.6 - Understanding NOLA's Risk and Vulnerability Assessment Strategy:

In 2015 the Resilient NOLA team conducted the preliminary resilience assessment for New Orleans. This report represents a compilation and baseline evaluation of assets, shocks and stresses, stakeholder perceptions, current approaches, and emerging opportunities that inform the creation of focus areas, which were used as a guide for the city's strategy development process. These processes include broad and intensive outreach and engagement of residents, civic leaders, and experts across the city and beyond (City of New Orleans, 2015).

Resilient NOLA uses two critical tools to identify risk and vulnerability in the city: Shocks and Stresses Analysis and City Resilience Strategy's phase 1. These processes build upon researches carried out by different organizations during the past decade to assess the connections between city's challenges, identify critical areas of weakness, and develop actions that build upon its strengths. Following is a detailed analysis of these tools.

1. Shocks and Stresses Analysis:

   The Resilient NOLA team met with local leaders, experts and stakeholders to map the relationship between city's shocks, including natural hazards like hurricanes, and its stresses. This analysis was conducted based on the research and findings of leading global experts, especially ARUP's 'Perspectives on City Resilience' - a comprehensive analysis on New Orleans' shocks and stresses (100 Resilient Cities 2015). One of the integral parts of ARUP's research is the 'City Resilience Index'. This globally applicable index is a combination of qualitative and quantitative assessment methods that assesses four dimensions of a city's resilience. These include health and well-being, economy and society, infrastructure and environment, and leadership and strategy. These dimensions are further divided into 12 goals and the assessment of each goal is carried out using a set of indicators. The index uses a total of 52 indicators (ARUP 2015). Refer to appendix 1 for a graphic representation of the assessment framework and appendix 2 for a list of the 52 indicators and their relationship with each of the 12 goals. One of the main elements that differentiate this index from FVIs discussed in the previous section is its use of subjective data, collected through public outreach, in addition to quantitative one. The purpose of including qualitative data in this tool is to assess the adequacy of mechanisms and processes in place, to achieve the outcomes articulated by the indicators (ARUP 2015). It helps include public and professional perception of the programs in place, thus adding another layer to the quantitative metrics. A complete profile of the city's shocks and stresses, an accumulation of the city provided answers and quantitative data available or collected, is a score assigned to each of the 12 resilience goals. The results obtained were used by Resilient NOLA to devise resilience strategies for the city. While this index is quite comprehensive in its approach to assessing the overall level of preparedness of the city, its focus on environmental resilience, especially that against flooding, is limited.

1. City Resilience Strategy – Phase 1:

The second method used by Resilient NOLA team to assess the city's vulnerability situation was phase 1 of *City Resilience Strategy* - a customized roadmap for cities to plan for resilience, devised by 100 RC. The strategy development process involves two phases which build cross-sector and cross-discipline engagement and support, culminating in the public release of a resilience strategy. This strategy development process is 6-9 months long and is expected to help cities innovate and create new opportunities depending on their local context (City Resilience Assets & Risks Tool, n.d.). The first phase comprises of outreach and analysis activities during which the city, led by their City Resilience Officer (CRO), conducts a holistic review of the state of resilience and identifies priority areas for further exploration in Phase II.

During Phase I, the CRO's office is expected to actively engage and empower stakeholders, critical voices, and experts around resilience. While this phase contains a significant amount of work, it is expected to be limited to 2-3 months, as the insights collected are preliminary inputs to much deeper work. Following are the three essential assessment tools from phase 1 of the strategy that the city used:

Asset Scan and Risk Assessment Tool: Relying heavily on data from interviews with experts and the review of draft documents, this tool was used to identify key risks to critical city assets. It helped understand the complex relationship among assets and their exposure to shocks and stresses.

Resilience Perceptions Assessment: This tool was used to gather stakeholder perceptions about the city's resilience. The Resilient NOLA team consulted with key stakeholders in the public, private, and NGO sectors to gather their opinions and observations about resilience in New Orleans through questionnaires and interviews (100 RC 2015).

Resilience Actions Inventory: This tool documents and analyzes already in place plans, policies and projects in the city. This was done by using a combination of desktop research and surveys of key government and external stakeholders. A working list of resilience-building activities across government, private, and nonprofit sectors in New Orleans was then compiled to understand the city's level of preparedness (100 RC 2015).

This phase of *City Resilience Strategy*, like the *Shocks and Stresses Analysis*, relies heavily on qualitative research. Both the tools exhibit a robust methodology for analyzing the perception of NOLA's resilience in the eyes of experts, stakeholders, local leaders and residents. This methodology helps identify problems on ground but is highly subjective in nature. Unlike the FVIs, it does not benefit much from the climatological and socioeconomic data to develop a composite picture of the city's vulnerability situation.

2.7- A critique on NOLA's vulnerability assessment tools:

A detailed analysis of these tools revealed some limitations. The subjective nature of these processes exposes them to political and personal biases. It can take researchers months, or even years, to complete the assessment. The data is processed as separate sets of information and their combined effect is often ignored. Lastly, these tools are not adequate for conducting disaster-specific assessment. Following is a detailed account of these issues:

i) *Context responsive or biased?* NOLA's assessment tools rely heavily on qualitative variables, resulting in a more context responsive assessment tool. But, this element of subjectivity sometimes leaves room for biases, making it susceptible to producing unrealistic results. For example, one of the twelve goals of the shocks and stresses analysis index is 'reduced exposure and fragility' and the four indicators used to assess this are comprehensive hazard and exposure mapping; appropriate codes, standards and enforcement; effectively managed protective ecosystem; and robust protective infrastructure. There is no detailed description of what qualifies as comprehensive, appropriate, effective and robust. This flexibility of the index can be considered both a merit and a demerit, and requires great effort on the researcher's part to use the tool responsibly and manage potential biases.

ii) *Time and capital intensive process:* These processes, by considering community's perception of risk and providing on-ground insights that may have been misrepresented or unreported in state-wide or municipality wide databases, have the potential of providing more comprehensive outcomes. But, as Moser (2011) posits, the effectiveness of such an assessment approach is greatly dependent on availability of monetary resources and the community's attitude towards the researcher. Moreover, it may take months to come up with any conclusive results. As a result, for municipalities with limited time or monetary resources, or with residents having a hostile attitude towards government's representatives, a case commonly found in the developing countries, such an index may not be a suitable assessment tool.

iii) *Flood specific vulnerability:* These methods are quite comprehensive in their approach to assessing the city's overall assets. However, they do not evaluate how vulnerability scenario will change against different kinds of shocks and disasters. Thus, the results obtained do not highlight flood-specific vulnerabilities. Little focus on flood hazard during the assessment process is expected to limit the policy makers' knowledge about city's strengths and weaknesses in case of an extreme event, resulting in inadequate policies. This index alone may be inadequate to identify flood related vulnerabilities but is a great resource to build off from. This can be done by adding layers of relevant geographic and climatological data to analyze how the effectiveness of these assets changes during occurrence of a flood-specific disaster.

iv) *Fragmented Information:* The data, be it socioeconomic, climatological or regarding city's built fabric, is analyzed by planners and policy makers as individual/ fragmented sets of information. For example, maps included in these reports either depicted population density, ethnicity, median income and other demographic data or represented 100, 200 or 500-year flood zones. There were no maps found that aggregated this information to sketch a complete picture of the city's vulnerability. This leaves room for ignoring the combined impact of these multiple layers of information, resulting in under or over estimation of certain factors.

LCPRA (Louisiana Coastal Protection and Restoration Authority) has developed an interactive mapping website, called flood risk and resilience viewer, that provides information on how different parts of the state will be affected economically, socially and infrastructurally in case of flooding of varying intensity both before and after the addition of new levees and sea walls proposed in their coastal protection master plan. This web service does a fine job of collecting multitudes of datasets, from different government agencies, under one portal. It even takes the process a step further by developing a socioeconomic vulnerability index. But this index only takes six demographic variables into account i.e. income, density, educational attainment and percentage of rural, elderly and non-English-speaking populations, and thus it is not very comprehensive in its approach. Yet, this web service is a good starting point and can be improved by adding other relevant demographic variables to the socioeconomic index and combining it with layers of climatological, geographic and infrastructure and community facility related data. This can enable planners to perceive the combined effect of these data sets.

v) *Intuitive process*: Risk and vulnerability assessment processes in NOLA, as already discussed, rely heavily on observations made by planners during field surveys, through public and stakeholder outreach and by looking at demographic and flood data as separate sets of information. This means that the decision-making process is subject to planners' personal interpretation and understanding of risk and resilience. Such a subjective planning process leaves room for biases. These methods are unfit for municipalities where political aspirations over shadow planning practices. For example, in Pakistan, where corruption and clientelism dominate political behavior, the $468 million budget designated for reconstruction of houses, schools, hospitals and transportation infrastructure after the 2005 Kashmir earthquake was diverted by the government to developments in other parts of the country (Nelson, 2010). Such cases are commonplace in developing countries. In regions where government organizations are plagued by corruption, these techniques leave loopholes for bureaucrats to make policies that serve their personal interests instead of helping vulnerable communities.

Data cannot replace intuition, but there is need for unbiased representation of existing data, so that planners make better informed decisions. Indices that can provide planners with a more detailed insight on available information can help yield better outcomes.

2.8 – Quantitative vs. Qualitative Assessment tools:

The previous section has highlighted two distinct flood vulnerability assessment methods, one solely relying on quantitative data, while the other focusing heavily on qualitative techniques. This section looks at Moser's (2011) argument on vulnerability to climate change and natural disasters and effectiveness of techniques used to assess it. Moreover, it discusses Moser & Stein's (2011) point of view regarding the need for bottom-up initiatives, building on community participation, to assess risk.

Moser and Stein (2011) stress the importance of listening to local people's voices regarding incrementally worsening and often unrecorded effects of natural disasters. Each community differs from another based on its distinct characteristics. These characteristics can be both tangible and intangible. This means that in addition to the physical and demographic information of a community, which 'global' or as I would call them 'one-size-fits-all' FVIs usually build upon, the community's own understanding of its exposure, susceptibility and resilience to flooding is also highly important. Severity of disaster as perceived by the locals, native peoples' understanding of factors that make them susceptible to these events and the assets which they deem as most vulnerable, are also factors that need to be considered when measuring risk and vulnerability. Moreover, experiences and learnings of institutions like NGOs and grassroot organizations that support local process of adaptation to and recovery from catastrophic natural disasters also needs to be taken into consideration. This is the information that is not available on national databases such as the ones maintained by the Census Bureau or meteorological agencies. This is the data that can only be gathered if the researcher conducts on-ground qualitative research that invites the local community to participate in these assessment procedures. Thus, community participation is an important part of the vulnerability assessment methodology (Moser and Stein 2011).

A large proportion of those most at risk from the occurrence of natural disasters are urban area populations of low and middle-income countries (Moser 2011). Even within cities and towns almost all serious disaster related injuries and deaths occur among low-income groups. This explains that there is a direct relationship between vulnerability and lack of assets. The more assets people have, the less vulnerable they generally are; the greater the erosion of people's assets, the greater their insecurity. Let's first define the term asset. The Ford Foundation (2004) defines asset as a stock of financial, human, natural or social resources that can be acquired, developed, improved and transferred across generations. This means that these assets can be both tangible and intangible. Issues like gender, age, health and disability are also important factors as they affect people's ability to respond to the disaster. As climate change exacerbates the frequency and intensity of catastrophes like flooding, these assets are being increasingly threatened. Thus, to assess the vulnerability of a population, it is important to identify the variation in their capacity to cope and adapt to the disaster (Moser 2011). This makes identifying discrepancies in assets owned by people and neighborhoods a critical part of this process. Developing a database of such assets requires both quantitative techniques (since many of these details can often be found in data collected by census bureaus), and qualitative tools that ensure a more in-depth data collection process that is in tune with realities on ground.

CHAPTER 3: METHODOLOGY, FINDINGS & RECOMMENDATIONS

This chapter elaborates on the methodology adopted by the author to answer the above stated research questions, the significant findings of this study, and final recommendations made to improve vulnerability assessment tools.

3.1 – Research Methodology:

This thesis aims to test the following hypothesis: '*Results of globally applicable FVIs are significantly different from those of NOLA's local vulnerability assessment tools.*'

To test this hypothesis, American Community Survey (ACS) data and climatological data for the city of New Orleans was plugged into Bathi and Das' FVI to devise a quantitative flood vulnerability map that represents the vulnerability score for each census tract in NOLA. Since most assessment tools used by the city of New Orleans were qualitative, no comprehensive, per census tract, flood vulnerability map was developed by the city. To compare the results obtained using the FVI to those of the city, planners working or having worked in the past on developing NOLA's resilience plan, and academics with substantial knowledge on this topic were interviewed. The purpose of these interviews was to show them the flood vulnerability map devised using the FVI and ask how similar or different the situation was as per city's findings from the on-ground research conducted; and how incorporating FVIs in their methodology could affect flood resilience policies made. They were also asked to elaborate on any potential gaps they could identify in the FVI and how, in their professional opinion, these gaps could be addressed. The questionnaire for these semi-structured interviews is attached in the appendices section. This thesis thus adopts a methodology that is a combination of quantitative, spatial and qualitative research tools.

3.1.1 - Quantitative and Spatial Analysis:

This study used Bathi and Das' FVI to develop a flood vulnerability profile for all neighborhoods in New Orleans. As explained earlier, socioeconomic and climatological (flood exposure) indices were calculated separately and were later aggregated to develop a holistic picture of the city's vulnerability. Detailed findings of these tools are as follows:

(i) *Socioeconomic Vulnerability Index (SEVI)*:

The 2015 ACS data, obtained through US Census Bureau, was used to devise the per census tract socioeconomic vulnerability of New Orleans. 11 variables used in this process and the rationale behind their selection is explained in section 2.7.2. To compute the socioeconomic vulnerability (SEV) per census tract, first each indicator i was standardized by dividing the indicator value (Ni) for each tract by the maximum value (Nmax) of the indicator throughout New Orleans. The equation used is as follows:

$$\mathbf{SEV}i = \frac{\mathbf{N}i}{\mathbf{N}max}$$

The purpose of standardization was to create comparative proportions among all variables. Then, an aggregate value of socioeconomic vulnerability of each census tract was calculated as the arithmetic mean of all standardized variables for that tract. The equation used is as follows (where 'n' is the total number of variables):

$$\mathbf{SEV} = \frac{\sum \mathbf{SEV}i}{\mathbf{n}}$$

The per census tract socioeconomic vulnerability calculated through this process is a score normalized between zero and one. See Appendix 4 for a tabular representation of NOLA's per census tract socioeconomic vulnerability profile calculated through this methodology. ArcGIS was then used to develop a choropleth map of these scores, categorized by standard deviation.

(ii) *Climatological (Flood) Vulnerability Index:*

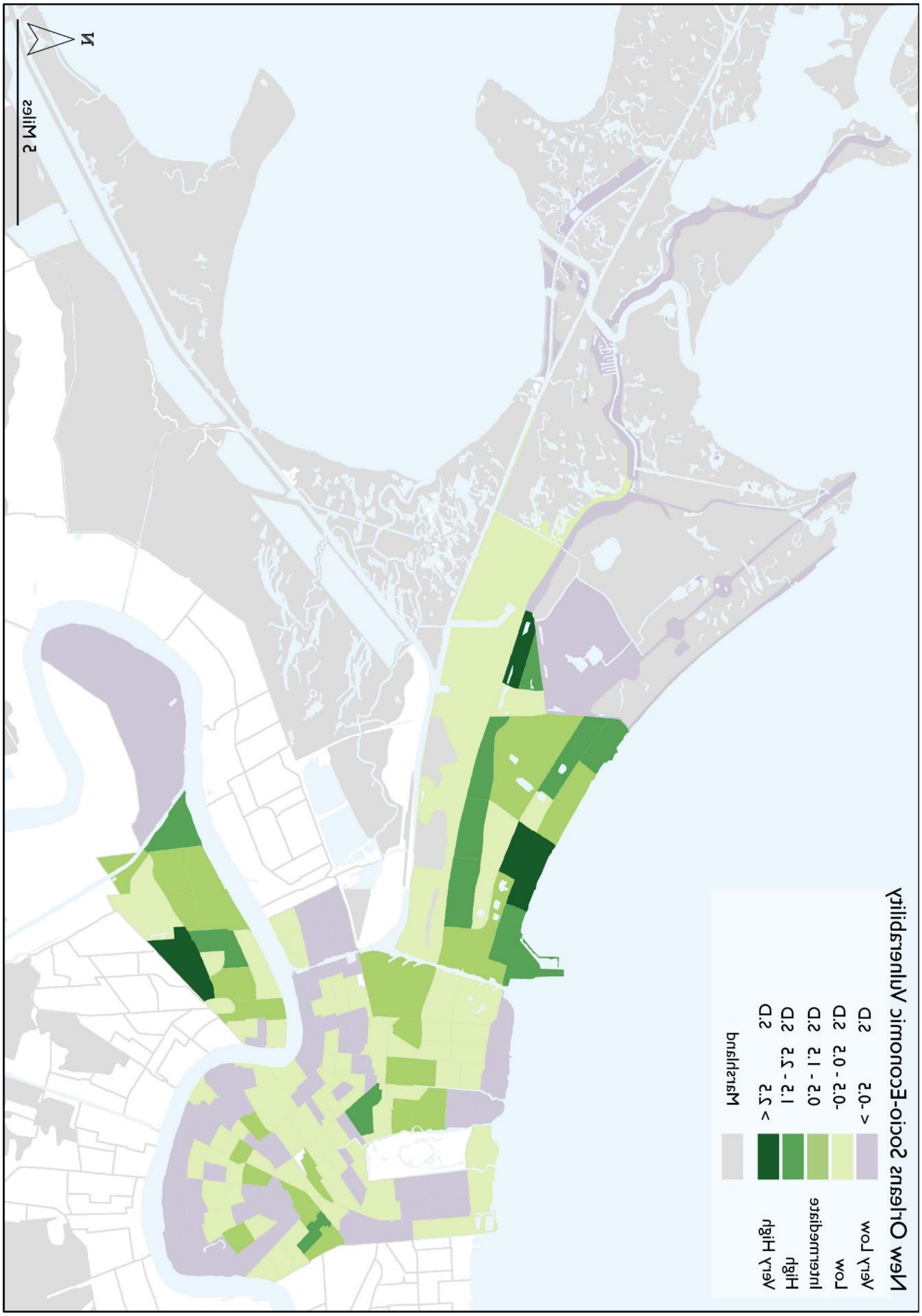
Climatological (flood) vulnerability index was developed using FEMA data on NFHL

(National Flood Hazard Layer), obtained from the US FEMA Flood Map Service Center. (updated through September 2016). This data, obtained as a shapefile, included the areal extent of SFHAs (Special Flood Hazard Areas) in the city of New Orleans. Percentage of SFHA within each census tract was calculated through a spatial intersect process conducted in GIS. This gave us the flood exposure area as the amount of land within the 100-year flood zone as a fraction of the total land area in each census tract. These fractional values of the census tracts were assigned to represent the flooding vulnerability of the tracts. A choropleth map representing the per-census-tract climatological (flood) vulnerability of New Orleans, categorized by standard deviation, was then developed (see map 2). To move forward with developing a holistic FVI for the city, this data was exported as a .csv file. (see appendix 4).

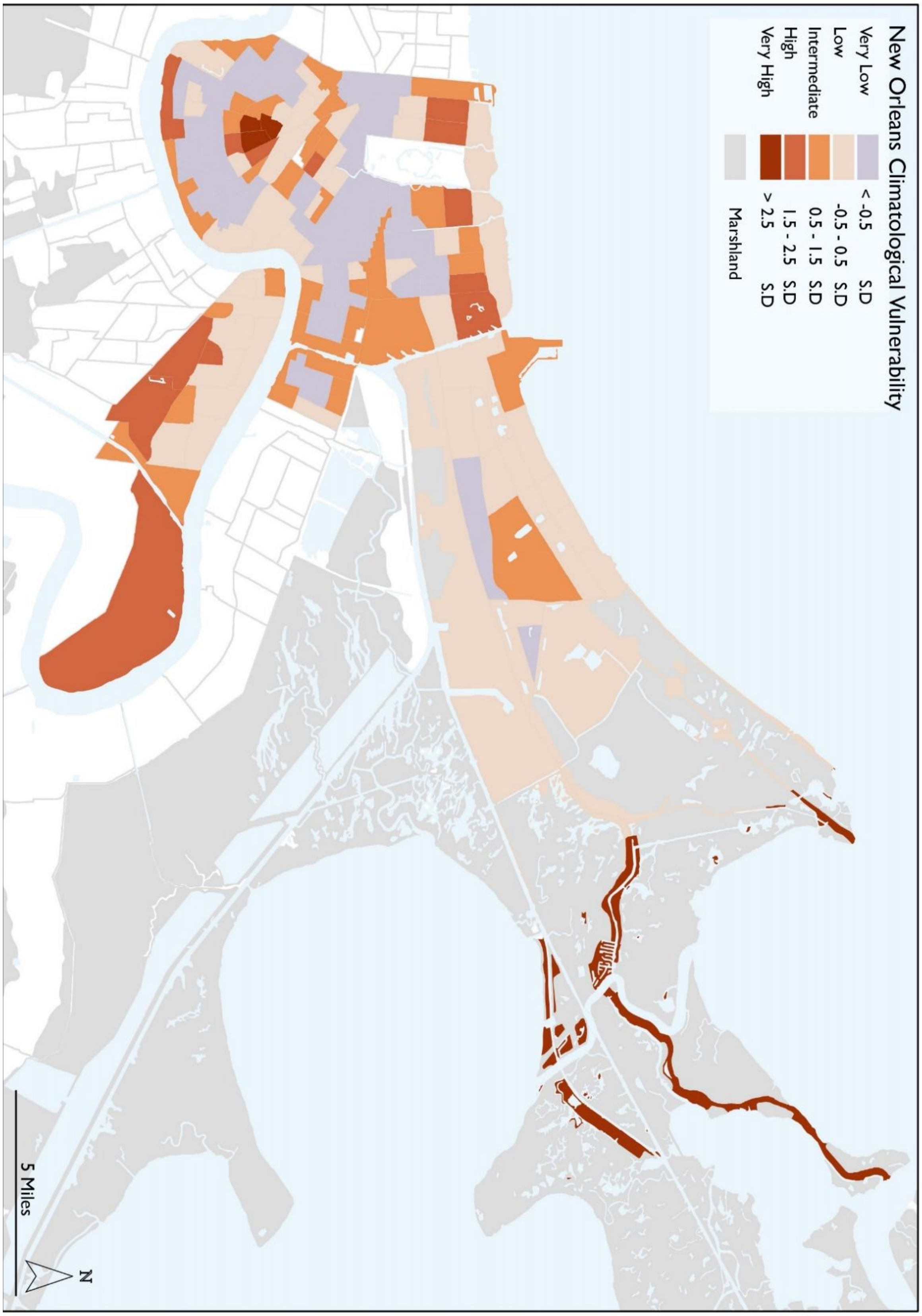
(iii) *Interactive Vulnerability Mapping:*

Finally, an arithmetic mean of the socioeconomic vulnerability score (normalized between zero and one) and the climatological vulnerability score (SFHA as a fraction of the total land in the tract) for each census tract in the city was calculated. The resultant value was the overall flood vulnerability score of each tract. See choropleth map 3 for visual depiction of the final flood vulnerability scores of New Orleans per census tract, categorized by standard deviation. Appendix 4 shows a tabular representation of the overall flood vulnerability profile of each census tract in New Orleans.

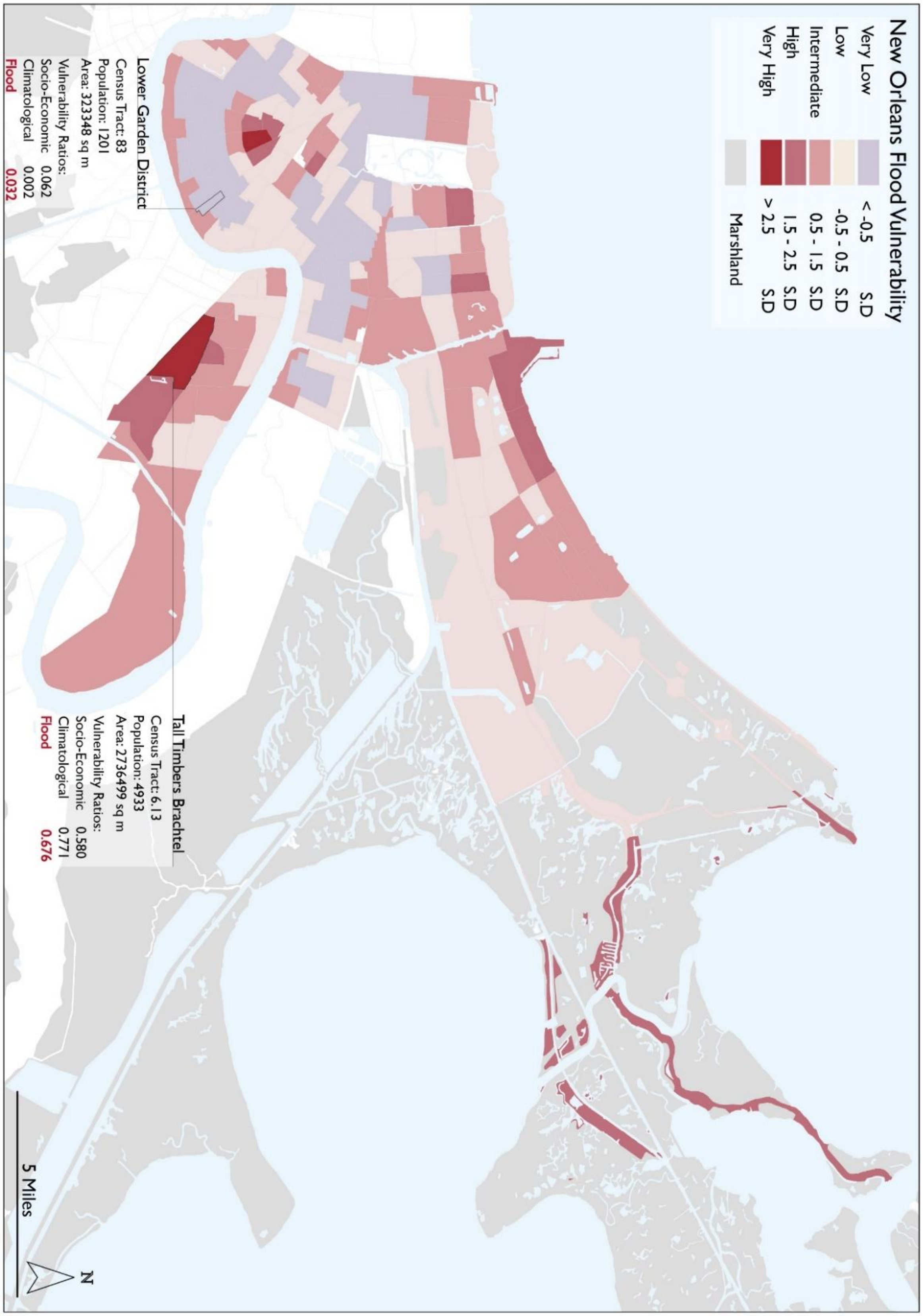
Map1: Depicting New Orleans' socioeconomic vulnerability, by census tract.



Map2: Depicting New Orleans' climatological (flood exposure) vulnerability, by census tract.



Map3: Depicting New Orleans' overall flood vulnerability, by census tract.



3.1.2 - Qualitative Analysis:

To compare the results obtained above with findings of NOLA's vulnerability assessment tools, relevant planners were interviewed. See appendix 3 for the questionnaire. Since anonymity must be maintained, names and positions of the interviewees cannot be declared. Four professionals were interviewed: one working for the city of New Orleans and greatly involved in the city's planning initiatives for flood resilience; two professionals working with Resilient NOLA, one involved in developing resilience policies and the other in developing vulnerability assessment processes; fourth interviewee is an academic whose research interests include post-Katrina resilience strategies. In a semi-structured interview setting, these professionals were asked to give insight on the FVI map and its process and to draw a comparison between its findings and those of assessment tools used in the city's flood resilience plan. They were also asked to comment on the policy implications of this flood risk map devised using Bathi and Das' FVI and to elaborate on how these may be different from or similar to the decisions made in Resilient New Orleans strategic plan.

3.2 – Findings:

This section critiques the results obtained from the FVI and analyzes how they differ from the findings of New Orleans' resilience team. It also discusses the gaps identified in these assessment tools. Interviews conducted, literature reviewed and researcher's personal observations guide the insights made in this section.

3.2.1: A comparison between the outcomes of the two vulnerability assessment methods:

Map 3 uses the FVI to provide an easy-to-read illustration of the city's flood vulnerability profile. The map highlights north of Tall Timbers Brachtel neighborhood as most vulnerable. It has a vulnerability score of 0.676, which is over 2.5 standard deviations (SD = 0.142) higher than the mean vulnerability score of the city, i.e. 0.229. On the other hand, map 2, which depicts the city's climatological vulnerability, signifies relatively lower vulnerability of this tract. It is the neighborhood's demographic profile (see map 1), illustrating their lack of resources to combat the effect of disaster, that is exacerbating its vulnerability to flooding.

What's worrisome here is that this climatological map (map 2) is the illustration of FEMA's flood exposure data and, as one interviewee explained, "is the most commonly referred to mapped representation of a city's flood risk". Socioeconomic information, though taken into consideration, is either gathered qualitatively through stakeholder interviews and public outreach or through analysis of various demographic indicators mapped as individual sets of information - a practice also observed in NOLA's vulnerability assessment method. This fragmentation of socioeconomic data can lead to underestimating the combined effect of these factors, which may result in misleading understanding of vulnerability.

The index marked west of Lower Garden District as least vulnerable. When the FVI map was presented to the interviewees, one of them explained it thus:

> "This neighborhood is situated on old high ground and suffered little from the extensive flooding of hurricane Katrina. Wind damage was the only notable effect of disaster here and the rate of return of residents after Katrina was almost 100 percent. Most of its residents are well off and it has very low minority (non-white) population."

Lake Terrace and Lake Shore, despite their proximity to lake Pontchartrain, were identified amongst the least vulnerable neighborhoods by the FVI. When asked, one interviewee clarified that,

> "Lake Terrace and Lake Shore, despite their proximity to the coast, experienced minimal damage during Katrina. While some homes and businesses were affected, most of them escaped the flood by virtue of the higher elevation of this man-made land. We weren't surprised because these are wealthy neighborhoods. After every flood disaster, the residents of this neighborhood come back to build stronger and higher than before."

One of the interviewed professionals stated:

> "It isn't surprising that the index identified north of Tall Timbers Brechtel, a low-income, African-American neighborhood, situated almost 6 feet below sea level, and south of Broadmoor, a neighborhood built on marshland, as areas of high vulnerability to flooding. This model identifies the obvious targets but seems to exaggerate or underestimate the flood effect in some situations".

For example, due to the robust levee system of Lake Shore and Lake Terrace neighborhoods, "Fillmore is perceived as an area of moderate and not high risk". Moreover, "It identifies Lower Ninth Ward as a region of low risk, even though it sits on substantially low-lying ground and was amongst the most devastated areas during Hurricane Katrina". In cases like these, the index, due to its lack of sensitivity to the complex structure of cities, leaves out certain areas while over estimates some others.

When inquired about the policy implications of these assessment tools, one interviewee explained, "identifying areas with higher sensitivity to disaster is among the most critical stages of resilience planning. In addition to understanding which areas are susceptible, it is also important to realize which factors contribute to worsening of the situation and how". Once the need to improve an area's resilience is realized, years of planning and large capital is invested in upgrading it. For example,

> “the government has recently invested $141 million in NOLA’s Gentilly Resilience District in an effort to reduce flood risk in the area, slow down land subsidence, and encourage neighborhood revitalization. For projects so time and capital exhaustive, it is crucial to make sure that resources are targeted towards alleviating the struggles of the most vulnerable.”

There are two important takeaways. Firstly, most interviewees acknowledged the importance of assessing flood vulnerability in decision making process. Secondly, Bathi and Das’ index was able to assess the vulnerability of some neighborhoods well. There were some cases where the index overestimated or underestimated the vulnerability profile of the tracts. Overall, the results of this index may not be in complete alignment with those of on-ground participatory assessment, but it does provide an approximate understanding of the city’s vulnerability to flooding. This index can provide researchers with a reasonable starting point for conducting more detailed analysis in selected areas.

3.2.2: Shortcomings of Bathi and Das’ Flood Vulnerability Index:

The results also demonstrated examples of many statistical limitations in the index. Some of these were introduced in the previous chapter. Appendix 6 shows a map of FEMA’s Special Flood Hazard Area data for New Orleans. This data set provides information on the region’s susceptibility to flooding by its natural, continuous geography, while the ACS data uses census tract as the areal unit. To combine the two data sets, FVI’s climatological map determines vulnerability as the percentage of area determined as an SFHA within each data set. This technique triggers the modifiable areal unit problem. Appendix 6 shows that within tract 33.02 in south Fillmore, tract 65 in west of mid-city, tract 6.11 i.e. neighborhood New Aurora, and many other tracts, certain areas are designated as flood hazard zones, while the rest of the census tract is in a safe zone. Map 2, on the other hand, gives the illusion that the entire census tract is equally likely to be flooded. One interviewee explained that in Fillmore, "the region east of St. Bernard Avenue is not designated as an SFHA because its land elevation is 2 to 4 feet higher than the rest of the tract. But the climatological map identifies the entire tract as intermediately vulnerable". This false perception of similar vulnerability throughout the tract can mislead planners when making policies.

Tracts 17.44 in Little Woods and 17.50 in Village de L'Est were identified as areas with very high socioeconomic vulnerability and have the same score i.e. 0.5. Following is a breakdown of their demographic profile:

Table 2: Demographic profile of Census tracts 17.44 and 17.55 in New Orleans (ACS 2015)

Census Tract	Total Population	All Non-White Population	Number of Female House-holds	Under 18 population	Over 65 & Disabled	No-Vehicle House-holds	Mobile Homes	Population In Group Quarters	People Below Poverty Line	People Without Diploma	No one Speaks English well
17.44	4955	4933	680	1923	553	320	0	2	2298	631	45
17.50	3553	3050	134	867	510	179	76	0	1098	938	1497

Tract 17.44 has higher poverty rate and higher number of non-white population, female households and under 18 population. On the other hand, tract 17.50 has large populations that live in mobile homes and cannot speak English and have lower educational attainment and automobile ownership. Despite having significantly different socioeconomic profiles, the two tracts have similar vulnerability scores. Such patterns were observed throughout the results of the FVI. This is because the index assumes that poverty is just as significant in determining vulnerability as living in a group quarter and automobile ownership is just as important as educational attainment of the population. According to one interviewee, "attributes like poverty and educational attainment have far reaching effects, as they determine individuals' overall capability to save themselves and later recover from a disaster. Whether the individual lives in a group quarter will

have relatively little effect on exacerbating vulnerability". The Index, by associating equal weight with each of the 11 variables, overlooks such realities. A system of weighted averages can help minimize this problem, but developing a system like this will have its own complexities.

Moreover, the socioeconomic index, in case of New Orleans, exhibits multicollinearity. A collinearity test of the ACS data set was conducted in STATA. It was observed that the variance in variable 9 (i.e. Poverty level of a census tract) is substantially explained by most of the other variables in the index. This means that poverty level is a redundant variable, excluding which might improve the results of the index.

A multivariate regression test was conducted, which regressed poverty (dependent variable) against all the other 10 variables in the index (independent variables) and the interactions between these independent variables. In the model output, slope coefficients for interactions and three of the independent variables i.e. total population, non-white people and non-English speaking population were not statistically significant. Hence these variables and interactions were excluded and the test was conducted again.

Image 1: STATA output of multivariate regression model, where independent variable = poverty

```
. regress Below_Poverty_Line Number_Of_Female_Households Under18_Pop Over65_Plus_Disabled No_Veh
> icle Mobile_Homes Group_Quarters Over18_Without_Diploma
```

Source	SS	df	MS			
				Number of obs	=	172
				F(7, 164)	=	196.55
Model	26612921.1	7	3801845.87	Prob > F	=	0.0000
Residual	3172253.6	164	19343.0098	R-squared	=	0.8935
				Adj R-squared	=	0.8889
Total	29785174.7	171	174182.308	Root MSE	=	139.08

Below_Poverty_Line	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Number_Of_Female_Households	1.272346	.1693072	7.52	0.000	.9380432	1.606649
Under18_Pop	.3914919	.0619715	6.32	0.000	.269127	.5138569
Over65_Plus_Disabled	-.3697426	.0704027	-5.25	0.000	-.5087551	-.2307302
No_Vehicle	1.072202	.1103729	9.71	0.000	.8542671	1.290137
Mobile_Homes	2.214194	.9998239	2.21	0.028	.2400069	4.188381
Group_Quarters	.120517	.0391528	3.08	0.002	.0432084	.1978255
Over18_Without_Diploma	.4719973	.1045127	4.52	0.000	.2656334	.6783612
_cons	25.05889	24.0847	1.04	0.300	-22.49718	72.61497

Here, the adjusted r2 = 0. 89 suggests that approximately 89% of the variation in a census tract's poverty is already being explained by the seven independent variables (number of female households, population under 18, population over 18 or disabled, households without vehicles, number of mobile homes, number of group quarters, and population without diploma). Since this value is greater than 0.8 and the slope coefficients of all the independent variables are statistically significant at alpha = 0.05, the regression model predicts the independent variable very well. In other words, we can be 95% certain that most of the variables that constitute the characteristics of poverty are already in the index. Therefore, removing poverty level as a separate variable can make the index more robust. This was just one example of multicollinearity. All other variables should also be tested to make the index better.

Unlike multicollinearity, there is no straightforward test to check for the omitted variable bias in a model. The process requires intuition to check if OVB exists and which variables must be added to make the model more robust. Two important layers of information that were deemed missing from the index by one of the interviewees are physical condition of the housing stock (elevation from sea level and year of construction etc.) and infrastructure and amenities provided. For example, the scenario sketched in section(ii) illustrates that factors like proximity to transit system, access to freeways and elevation of residential unit can play an important role in determining vulnerability. Adding these layers of information to the FVI can result in more comprehensive outcomes.

3.2.3: Shortcomings of NOLA's Vulnerability Assessment tools

Upon conducting the interviews, some weaknesses of the city's participatory methods were also highlighted. Phase one of the city resilience strategy, according to 100 Resilient Cities' team, is designed to deliver results for preliminary risk assessment within two to three months (City Resilience Assets & Risks Tool, n.d.). One of the interviewees explained that "the process is not this straight forward when implemented on-ground. It took the city much longer to accumulate this information and derive conclusive results". The strategy thus underestimates the effort and time that is truly involved in conducting such a participatory approach to risk and vulnerability assessment processes, as "it is susceptible to multiple externalities like political will and public support".

The city resilience strategy is a tool designed to help cities develop a plan of action within six to nine months. This plan should articulate the city's priorities for building resilience through specific initiatives that will trigger action, investment and support within city government and from outside groups (City Resilience Assets & Risks Tool, n.d.). Appendix 5 illustrates a step by step development of this strategy. Results of phase 1, that already took much longer than its stated development time, were published by Resilient NOLA team in the preliminary assessment report in June 2015. The stated methodology of this strategy requires two to seven months for phase 2 to provide with conclusive results. So far, twenty months down the road, results for this phase have not been published. It is worth mentioning here that one of the stages of this phase, called 'resilience diagnostics', requires the development of a comprehensive quantitative vulnerability index, devised to respond to NOLA's local context. Upon asking, one interviewee explained that their resilience team is working on the development of this vulnerability index. While the Resilient NOLA team is still working on devising an index that responds to its unique character, the 'Resilient New Orleans: a strategic action plan' was published by the city in 2015. What guided these policies, if not the City Resilient Strategy, is a question we don't have a definitive answer to.

This brings us to the realization that, considering the intricacies of its methodology, the timeline for this strategy is too idealistic. While elaborating on this matter, one interviewee explained that,

"it is unrealistic to imagine that a customized vulnerability assessment procedure like this, which is complicated, labor intensive, and requires public support, political will, professional expertise in multiple disciplines, and coordination between several city agencies to gather data, can take such minimal time to provide with robust results."

3.3 – Recommendations:

This section provides recommendations for analysts, researchers, and academics developing assessment tools, and for cities using them, to maximize their effectiveness. Quantitative indices take a bulk of information and try to make their analysis easily comprehensible in minimal time and with minimal resources. In doing so some of these indices, like Bathi and Das' FVI, tend to oversimplify the data and lead to inaccurate outcomes. Optimizing varying sets of data to quantitatively measure a subjective phenomenon like vulnerability is a pressing concern among statisticians. In case of this particular FVI, it is recommended to manage statistical limitations by accounting for the modifying areal unit problem (MAUP), running tests to minimize multicollinearity and the omitted variable bias (OVB) and using appropriate statistical tools where needed, like weighted arithmetic mean in socioeconomic vulnerability analysis. In addition to statistical experts, developing an index free from these biases will require a team of planning professionals, because deciding which variables to factor in while testing OVB and devising a strategy for assigning weights to demographic variables asks for deep insight and understanding of the subject.

Another recommendation is to expand the index's applicability by using variables that are available in other parts of the world as well. This adds two important challenges. The first is to devise factors that are relevant in a multitude of cultural, political and geographical contexts and the second involves making sure that the data for most, if not all variables, exists with municipalities around the globe. International organizations like the United Nations and World Bank hold extensive demographic data sets for countries around the world. This can be used as a good resource to begin with.

The index should also be modeled to integrate the city's built fabric. This includes infrastructure details like transit facilities, water management system, communication system and levee and flood walls etc., and building characteristics like land use, elevation from ground and construction year etc. Other factors like existence and efficiency of public outreach and flood awareness programs etc. can help get a better understanding of each community's preparedness for flood disasters. Moreover, adding flood scenarios (ranging from mild flooding to catastrophic disasters) can also illustrate which areas will be affected and how in flood occurrences of different intensities. In case of US, FEMA's data on 200-year and 500-year flood zones can be used to achieve this. In addition to intensity, developing vulnerability scenarios for various types of flooding (like coastal, flash or urban floods etc.) can also be a useful tool to visualize how an area's susceptibility to disaster changes with varying types of flood calamities. This information is usually easily accessible through the meteorological departments of most countries. These initiatives are expected to improve the overall performance of this FVI.

Bathi and Das' FVI, as discussed in the findings section, can help understand a city's approximate vulnerability profile. This FVI, after fixing the above-mentioned errors, and other statistically sound indices can be used by municipalities with limited resources and by those where planning agencies are overwhelmed by politics, bureaucracy, and corruption, to understand flood vulnerability. These indices can provide a starting point for conducting more detailed analysis in selected areas. Municipalities that do not have these concerns can make their assessment process more accurate by combining these indices with field surveys and participatory assessment processes.

Vulnerability is a complex phenomenon. A quantitative index can provide an estimated vulnerability profile of a city but data can not completely replace the genius of field-survey, public engagement, and intuition, and vice versa. These indices report and aggregate quantities but some qualitative characteristics, which can only be observed and felt, are left out. Intangible assets like the traditions, customs, legal system, local norms, obligation and social reciprocity within a community are an integral part of its vulnerability assessment process (Moser 2011). These observations are crucial because they influence a community's reaction to disaster. FVIs, due to their reliance on national and municipal level generic data often tend to neglect these important aspects. Moreover, in many countries, grassroot organizations like social movements and activist groups which are instrumental in flood management process, especially during the immediate response phase, are not registered as formal organizations in state's records. As a result, traditional FVIs do not account for these organizations in their vulnerability assessment process. Identification of such initiatives is necessary as their existence in a society can immensely reduce vulnerability (Moser & Stein 2011). It is probably the absence of these intangible aspects of society which caused some discrepancies between the results of FVIs and those of NOLA's methods. For municipalities with limited resources or high political obstacles, FVIs can ensure that a minimum level of understanding of flood vulnerability is achieved. The effectiveness of results is subject to how statistically and logically sound the index is. Cities are recommended to enhance their assessment methodology by combining it with participatory tools as per their financial and administrative capability. Thus, adopting a methodology which uses qualitative field research in addition to, as opposed to instead of, using flood vulnerability indices (unlike New Orleans). A methodology that optimizes both quantitative and qualitative tools effectively can develop comprehensive outcomes.

3.4 - Conclusions:

Considering the findings of this thesis, our hypothesis (i.e. results of globally applicable FVIs are significantly different from those of NOLA's local vulnerability assessment tools) can be both accepted and refuted at the same time. The index provides us with an approximate picture of the city's vulnerability profile. As one interviewee explained, "it certainly identifies the 'obvious' targets, but leaves out or exaggerates the conditions of some other tracts". Thus, this global FVI, though unable to produce accurate results, does a fair job combining multiple layers of information to sketch an estimate of a city's susceptibility to floods.

Although we did not deduce a definitive result for our hypothesis, we did construe enough to answer the research questions. Local context does matter in determining flood vulnerability. Some elements of the assessment process can be standardized in the form of FVIs. This can help underprivileged municipalities get a basic understanding of their vulnerability profile. But information provided in national databases cannot replace one's understanding of a community's intangible characteristics. Hence, where possible, cities are recommended to combine both qualitative and quantitative assessment techniques, so that indigenous characteristics of a community are also accounted for.

In the case of New Orleans, locally produced vulnerability assessment tools differ from the approach adopted by Bathi and Das' FVI significantly. Unlike the FVI's mathematical approach, the city uses a qualitative and intuitive assessment method to understand vulnerability. While the assessment methodology that it aspires to follow does acknowledge the importance of quantitative indices as well, one interviewee explained that their "resilience team has not yet come up with a customized index for the city". Developing a context specific quantitative index is very time consuming and considering the nature of problem we are dealing with, planners are often required to make decisions quickly. In such cases, instead of relying solely on qualitative research and analyzing fragmented data obtained from multiple government agencies, it is preferable to use a global FVI like Bathi and Das' index. We have already seen that the index's results are approximate, not incorrect. This index, after making necessary statistical and logical amendments as recommended in the previous section, can provide a reasonable overview of the combined effect of varying quantitative data sets. Gaps in its results can be filled by combining this analysis with field surveys, public meetings and interviewing stakeholders to get comprehensive outcomes. It is true that a customized index would be a better solution, but NOLA has already suffered from the perfection dilemma for almost a decade now. Its resilience policies had to be published before a customized index assessing vulnerability comprehensively was even devised. Planning is a practical profession, that deals with the management of a dynamic, constantly evolving urban machine. Planners can't afford waiting for the perfect methodology, because important decisions must be made in time. Practicality must outweigh perfection. In such a situation, it is better to rely on a relatively imperfect model, supplemented by professional experience and on-ground analysis, than wait indefinitely for a customized qualitative model or depend solely on intuition.

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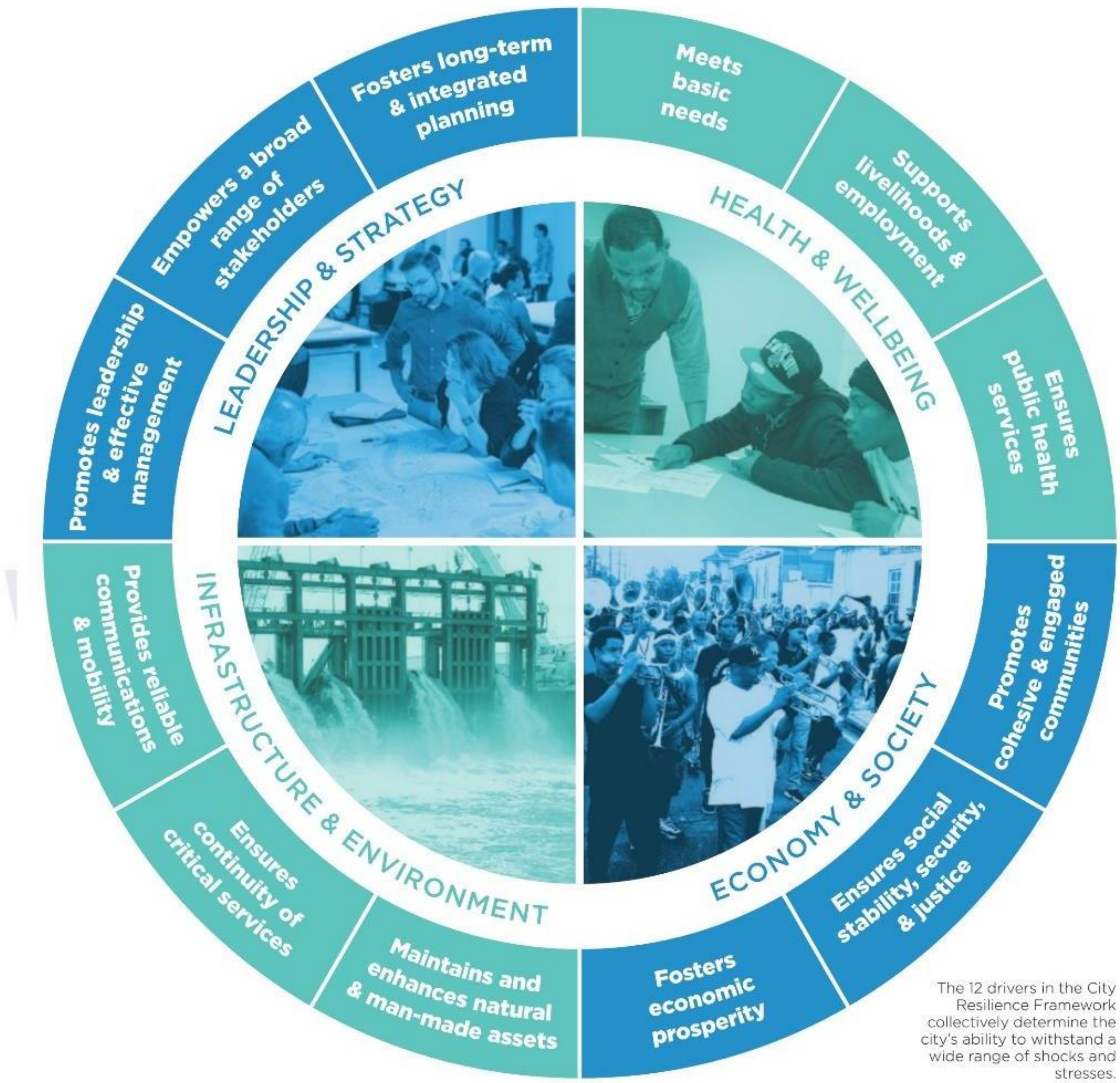
Appendix 1 – City Resilience Framework



Source: (100 RC, 2015).

Appendix 2 – 12 Goals and 52 Indicators for City Resilience Framework

Goals	Indicators
1 Minimal human vulnerability	1.1 Safe and affordable **housing**
	1.2 Adequate affordable **energy supply**
	1.3 Inclusive access to safe **drinking water**
	1.4 Effective **sanitation**
	1.5 Sufficient affordable **food supply**
2 Diverse livelihood and employment	2.1 Inclusive **labour policies**
	2.2 Relevant **skills and training**
	2.3 Dynamic local **business development and innovation**
	2.4 Supportive **financing mechanisms**
	2.5 Diverse **protection of livelihoods** following a shock
3 Effective safeguards to human health and life	3.1 Robust **public health systems**
	3.2 Adequate access to **quality healthcare**
	3.3 Emergency **medical care**
	3.4 Effective **emergency response services**
4 Collective identity & community support	4.1 Local **community support**
	4.2 Cohesive **communities**
	4.3 Strong **city-wide identity and culture**
	4.4 Actively **engaged citizens**
5 Comprehensive security and rule of law	5.1 Effective **systems to deter crime**
	5.2 Proactive **corruption prevention**
	5.3 Competent **policing**
	5.4 Accessible **criminal and civil justice**
6 Sustainable economy	6.1 Well-managed **public finances**
	6.2 Comprehensive **business continuity planning**
	6.3 Diverse **economic base**
	6.4 Attractive **business environment**
	6.5 Strong **integration with regional and global economies**
7 Reduced exposure & fragility	7.1 Comprehensive **hazard and exposure mapping**
	7.2 Appropriate **codes, standards and enforcement**
	7.3 Effectively managed **protective ecosystems**
	7.4 Robust **protective infrastructure**
8 Effective provision of critical services	8.1 Effective **stewardship of ecosystems**
	8.2 Flexible **infrastructure services**
	8.3. Retained **spare capacity**
	8.4 Diligent **maintenance and continuity**
	8.5 Adequate **continuity for critical assets and services**
9 Reliable mobility and communications	9.1 Diverse and affordable **transport networks**
	9.2 Effective **transport operation & maintenance**
	9.3 Reliable **communications technology**
	9.4 Secure **technology networks**
10 Effective leadership and management	10.1 Appropriate **government decision-making**
	10.2 Effective **co-ordination with other government bodies**
	10.3 Proactive **multi-stakeholder collaboration**
	10.4 Comprehensive **hazard monitoring and risk assessment**
	10.5 Comprehensive **government emergency management**
11 Empowered stakeholders	11.1 Adequate **education for all**
	11.2 Widespread **community awareness and preparedness**
	11.3 Effective **mechanisms for communities to engage with government**
12 Integrated development planning	12.1 Comprehensive **city monitoring and data management**
	12.2 Consultative **planning process**
	12.3 Appropriate **land use and zoning**
	12.4 Robust **planning approval process**

18 City Resilience Index - The Rockefeller Foundation | Arup

Source: (ARUP 2015)

Appendix 3 – Interview Questionnaire

COLUMBIA UNIVERSITY

Interview Questionnaire

Effect of Local Context on Flood Vulnerability Identification:

A comparison between New Orleans' flood vulnerability assessment tools and globally applicable FVIs

Investigator: Maira Khan
GSAPP, Columbia University
(732) 319 3006 – mk3816@columbia.edu

- Your current professional sector: public /private /not for profit
- Number of years working as a planner __________________________
- Do you know what a Flood Vulnerability Index (FVI) is? Y/N
- Have you ever worked with Flood Vulnerability Indices? Y/N
- Are you well informed about the New Orleans' flood mitigation and adaptation policies? Y/N
- Did you in any way contribute to the development of 'Resilient New Orleans: A strategic Action Plan, 2016'? If yes, in what capacity? Y/N

  ____

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1. Can you briefly define flood vulnerability? (Which factors, in your opinion, are most significant in increasing a community's vulnerability to floods?)

2. Do you have knowledge about the flood vulnerability assessment methods used by the city of New Orleans to devise its flood resilience policies? If yes, please explain.
   To what extent do you think these assessment tools influenced the decision-making process?

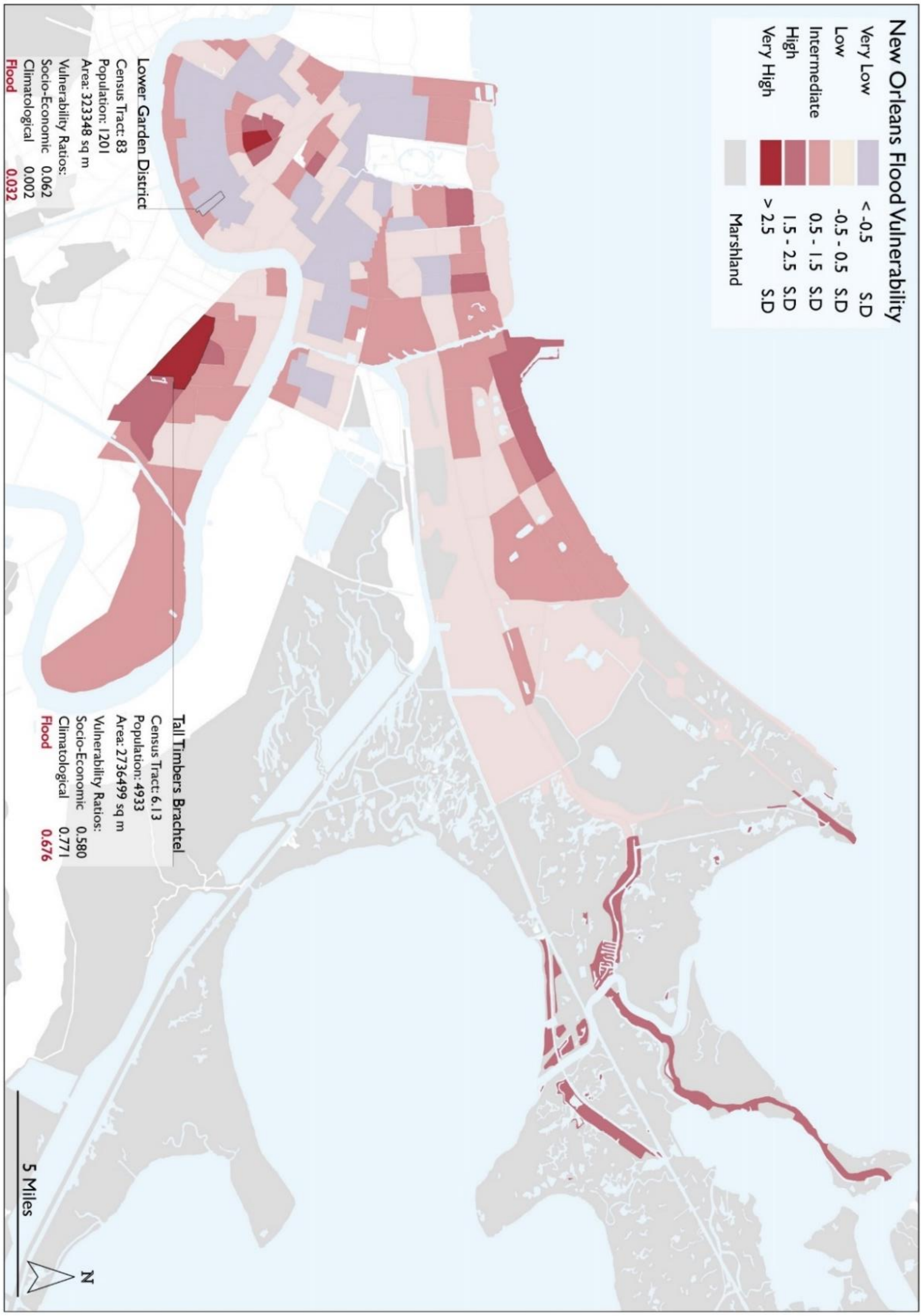
3. Do you think the city's current flood resilience policies cater for socioeconomically vulnerable communities? If yes, how?

4. In your opinion, what is the importance of quantitative FVIs in this process?

5. You are being presented with a flood vulnerability map for New Orleans, which I developed using Bathi and Das' vulnerability index for coastal flooding.
   - Do you think it is a fair representation of the city's flood vulnerability profile?
   - Had this index been used in addition to the current New Orleans vulnerability assessment tools, in your prof. experience, what impact would it have made on the flood resilience policies of the city?

   (Map is on the next page)

Map showing the per-census-tract flood vulnerability of New Orleans. This map was devised using the 2015 Anerican community Survey data and FEMA data for SFHA (Special Flood Hazard Areas) to account for both socio economic and climatological vulnerability of the area.



Appendix 4 – FVI Scores for NOLA's Socioeconomic, climatological and flood vulnerability

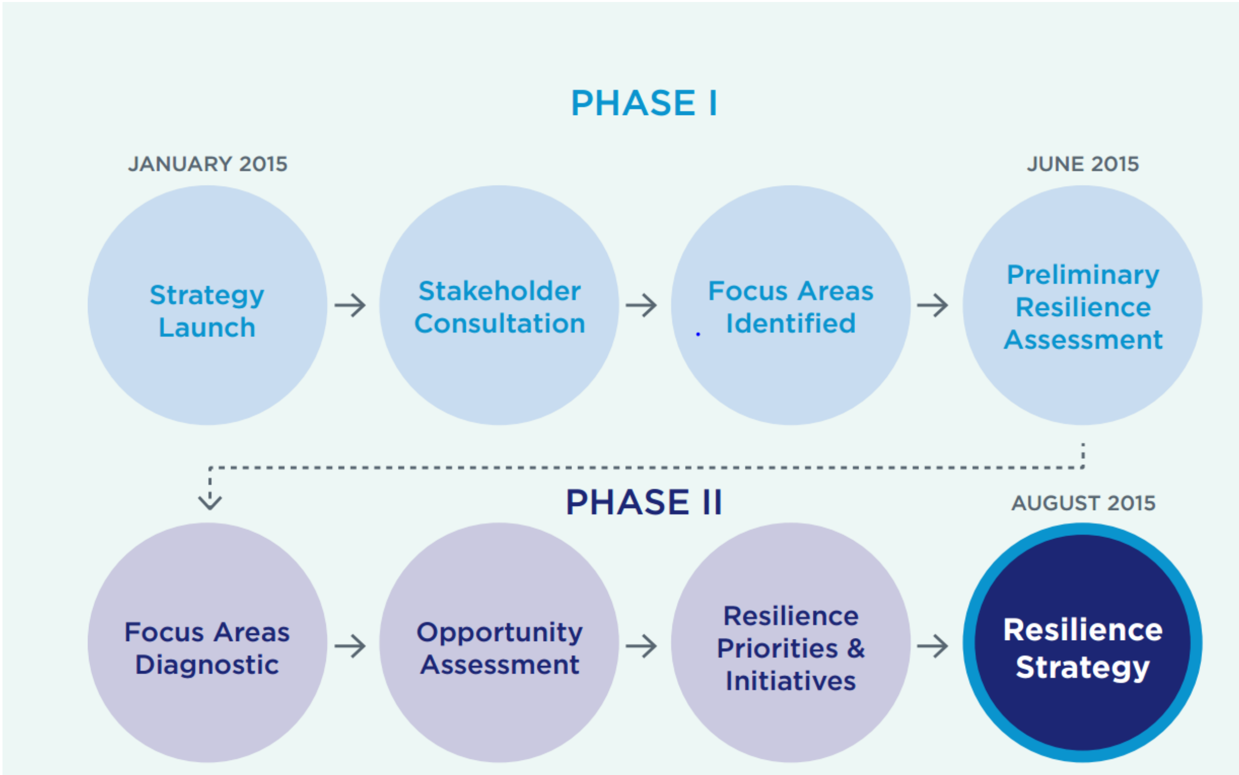
Tract #	Soceo-Economic Vul.	Climatological Vul.	Total Flood Vulnerability
Census Tract 1	0.1739	0.487	0.3305
Census Tract 2	0.1185	0.2649	0.1917
Census Tract 3	0.14	0.3811	0.2606
Census Tract 4	0.285	0.2351	0.26
Census Tract 6.01	0.141	0.4937	0.3174
Census Tract 6.02	0.2957	0.3639	0.3298
Census Tract 6.03	0.152	0.7633	0.4576
Census Tract 6.04	0.4641	0.2906	0.3773
Census Tract 6.05	0.1974	0.3814	0.2894
Census Tract 6.06	0.3133	0.3097	0.3115
Census Tract 6.07	0.2634	0.2765	0.27
Census Tract 6.11	0.4277	0.4061	0.4169
Census Tract 6.12	0.127	0.7022	0.4146
Census Tract 6.13	0.5803	0.7707	0.6755
Census Tract 6.15	0.314	0.495	0.4045
Census Tract 6.16	0.2627	0.24	0.2514
Census Tract 6.17	0.2569	0.4987	0.3778
Census Tract 6.18	0.2431	0.7028	0.473
Census Tract 7.01	0.0874	0.4393	0.2633
Census Tract 7.02	0.1799	0.4761	0.328
Census Tract 8	0.1509	0.0677	0.1093
Census Tract 9.01	0.1109	0.2274	0.1691
Census Tract 9.02	0.0432	0.4611	0.2521
Census Tract 9.03	0.048	0.0222	0.0351
Census Tract 9.04	0.1207	0.0404	0.0805
Census Tract 11	0.128	0.4312	0.2796
Census Tract 12	0.0872	0.4291	0.2582
Census Tract 13.01	0.1738	0.0066	0.0902
Census Tract 13.02	0.1403	0	0.0702
Census Tract 14.01	0.1439	0.5378	0.3409
Census Tract 14.02	0.2028	0.0002	0.1015
Census Tract 15	0.0988	0.1224	0.1106
Census Tract 17.01	0.1922	0.6463	0.4192
Census Tract 17.02	0.2388	0.181	0.2099
Census Tract 17.20	0.326	0.2862	0.3061
Census Tract 17.22	0.4106	0.2621	0.3363
Census Tract 17.23	0.4456	0.1255	0.2855
Census Tract 17.24	0.4555	0.6132	0.5343
Census Tract 17.25	0.7387	0.2711	0.5049
Census Tract 17.30	0.0957	0.3916	0.2436
Census Tract 17.34	0.075	0.9295	0.5022

Census Tract 17.35	0.2192	0.3155	0.2673
Census Tract 17.36	0.2166	0.2449	0.2307
Census Tract 17.37	0.2963	0.3156	0.3059
Census Tract 17.39	0.1502	0.2524	0.2013
Census Tract 17.40	0.3901	0.2665	0.3283
Census Tract 17.41	0.1896	0.262	0.2258
Census Tract 17.43	0.2488	0.3018	0.2753
Census Tract 17.44	0.5	0.1805	0.3402
Census Tract 17.45	0.3048	0.3089	0.3068
Census Tract 17.46	0.4565	0.2889	0.3727
Census Tract 17.47	0.2695	0.3976	0.3335
Census Tract 17.48	0.444	0.1156	0.2798
Census Tract 17.49	0.3616	0.14	0.2508
Census Tract 17.50	0.4894	0.1749	0.3321
Census Tract 17.51	0.1574	0.3849	0.2712
Census Tract 18	0.07	0.2257	0.1478
Census Tract 19	0.1777	0	0.0889
Census Tract 20	0.1311	0	0.0656
Census Tract 21	0.0998	0.2659	0.1828
Census Tract 22	0.0974	0.5821	0.3398
Census Tract 23	0.2189	0.4915	0.3552
Census Tract 24.01	0.1773	0.2681	0.2227
Census Tract 24.02	0.2801	0.083	0.1815
Census Tract 25.01	0.1775	0.6084	0.3929
Census Tract 25.02	0.2206	0.693	0.4568
Census Tract 25.03	0.1696	0.0016	0.0856
Census Tract 25.04	0.2115	0.0025	0.107
Census Tract 26	0.1064	0.0777	0.092
Census Tract 27	0.1598	0	0.0799
Census Tract 28	0.1957	0.0008	0.0982
Census Tract 29	0.1535	0	0.0768
Census Tract 30	0.1134	0.0591	0.0863
Census Tract 31	0.1043	0.0262	0.0653
Census Tract 33.01	0.1298	0.887	0.5084
Census Tract 33.02	0.2649	0.4928	0.3788
Census Tract 33.03	0.1926	0.6215	0.4071
Census Tract 33.04	0.212	0.2491	0.2305
Census Tract 33.07	0.1633	0.0615	0.1124
Census Tract 33.08	0.3487	0.0369	0.1928
Census Tract 34	0.1388	0	0.0694
Census Tract 35	0.1248	0	0.0624
Census Tract 36	0.163	0	0.0815
Census Tract 37.01	0.1573	0.1068	0.132
Census Tract 37.02	0.3791	0.0042	0.1916

Census Tract 38	0.0916	0.3426	0.2171
Census Tract 39	0.1278	0.0356	0.0817
Census Tract 40	0.1989	0.0137	0.1063
Census Tract 41	0.0804	0.056	0.0682
Census Tract 44.01	0.1371	0.4332	0.2852
Census Tract 44.02	0.0149	0.216	0.1155
Census Tract 45	0.1903	0.3171	0.2537
Census Tract 46	0.1377	0.0716	0.1046
Census Tract 48	0.1202	0	0.0601
Census Tract 49	0.1856	0.1292	0.1574
Census Tract 50	0.1526	0.2836	0.2181
Census Tract 54	0.1069	0.0339	0.0704
Census Tract 55	0.1516	0.033	0.0923
Census Tract 56.01	0.1057	0.6802	0.393
Census Tract 56.02	0.1186	0.6548	0.3867
Census Tract 56.03	0.0951	0.1983	0.1467
Census Tract 56.04	0.08	0.1783	0.1292
Census Tract 60	0.1927	0.4105	0.3016
Census Tract 63	0.2036	0.8158	0.5097
Census Tract 64	0.1938	0.5033	0.3486
Census Tract 65	0.2037	0.3164	0.2601
Census Tract 69	0.1079	0.2311	0.1695
Census Tract 70	0.1339	0.3712	0.2526
Census Tract 71.01	0.2921	0.4165	0.3543
Census Tract 72	0.2692	0.2053	0.2372
Census Tract 75.01	0.294	0.4303	0.3622
Census Tract 75.02	0.3612	0.2387	0.2999
Census Tract 76.04	0.0952	0.0638	0.0795
Census Tract 76.05	0.1881	0.4072	0.2977
Census Tract 76.06	0.2412	0.5138	0.3775
Census Tract 77	0.1072	0.2629	0.1851
Census Tract 78	0.0752	0.0045	0.0399
Census Tract 82	0.0886	0.0029	0.0457
Census Tract 83	0.0615	0.002	0.0318
Census Tract 84	0.101	0	0.0505
Census Tract 85	0.213	0	0.1065
Census Tract 86	0.1182	0.4813	0.2998
Census Tract 88	0.0938	0	0.0469
Census Tract 90	0.0843	0.0292	0.0567
Census Tract 91	0.1852	0.0013	0.0932
Census Tract 92	0.1795	0	0.0897
Census Tract 94	0.2005	0.8814	0.541
Census Tract 96	0.0904	0	0.0452
Census Tract 97	0.0987	0	0.0493

Census Tract 99	0.1755	0.036	0.1058
Census Tract 100	0.1752	0.0159	0.0955
Census Tract 101	0.1173	0.057	0.0871
Census Tract 102	0.1747	0.7032	0.4389
Census Tract 103	0.3425	0.9716	0.657
Census Tract 106	0.0812	0	0.0406
Census Tract 107	0.0869	0.0438	0.0653
Census Tract 108	0.0559	0.203	0.1294
Census Tract 109	0.2027	0.001	0.1019
Census Tract 111	0.1686	0.4355	0.302
Census Tract 112	0.1036	0.9476	0.5256
Census Tract 114	0.1032	0	0.0516
Census Tract 115	0.0685	0.0211	0.0448
Census Tract 116	0.0696	0.1903	0.13
Census Tract 117	0.1531	0.0562	0.1046
Census Tract 119	0.0838	0.563	0.3234
Census Tract 120	0.076	0.3178	0.1969
Census Tract 121.01	0.1805	0.0707	0.1256
Census Tract 121.02	0.2659	0.0053	0.1356
Census Tract 122	0.0959	0.4729	0.2844
Census Tract 123	0.1247	0.9595	0.5421
Census Tract 124	0.1214	0.217	0.1692
Census Tract 125	0.108	0.5494	0.3287
Census Tract 126	0.0983	0	0.0491
Census Tract 127	0.1262	0.0004	0.0633
Census Tract 128	0.1292	0.0402	0.0847
Census Tract 129	0.1348	0.4013	0.268
Census Tract 130	0.1476	0	0.0738
Census Tract 131	0.1819	0.0202	0.101
Census Tract 132	0.2172	0.1088	0.163
Census Tract 133.01	0.1685	0.3434	0.256
Census Tract 133.02	0.1317	0.3695	0.2506
Census Tract 134	0.206	0.1969	0.2015
Census Tract 135	0.147	0.3631	0.2551
Census Tract 136	0.071	0.0535	0.0622
Census Tract 137	0.3066	0.4254	0.366
Census Tract 138	0.261	0.1327	0.1969
Census Tract 139	0.1312	0.0157	0.0735
Census Tract 140	0.2817	0.1114	0.1965
Census Tract 141	0.2205	0.4171	0.3188
Census Tract 142	0.1327	0.5361	0.3344
Census Tract 143	0.2502	0.2513	0.2507
Census Tract 144	0.115	0.6818	0.3984

Appendix 5 – A step by step development of City Resilience Strategy



Source: (City Resilience Assets & Risks Tool, n.d.)

Appendix 6 – Map of FEMA's Special Flood Hazard Area data for New Orleans