Flood Risk Assessment for the Vulnerable Populations and Infrastructure: Village Creek, Birmingham, Alabama

by

Mohammad Khalid Hossain

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Approved by

Philip Chaney, Chair, Associate Professor of Geosciences
Chandana Mitra, Assistant Professor of Geosciences
Ashraf Uddin, Professor of Geosciences

Abstract

Urban flooding is a prominent natural hazard in Village Creek that is associated with the large expanse of impervious surfaces in the area, which enhance storm runoff and overwhelm the drainage capacity of the storm sewer system. While some areas possess physical characteristics that make them more vulnerable to urban flooding, others possess socio-economic characteristics that make them more vulnerable to the impacts of flooding. This study assessed flood risk in Village Creek by evaluating both physical and social vulnerability factors. Flood zone and demographic data for this project were obtained from the Federal Emergency Management Agency (FEMA) and the Census Bureau. The FEMA flood zone maps were used to identify the location and the total area likely to be inundated during floods, and the infrastructure and roads likely to be affected. The Census data were used to identify the total population within the flood hazard zones, and a social vulnerability index was developed to identify the more vulnerable populations within the hazard zones. The findings of the study will contribute to hazards management efforts to reduce vulnerability in the city, which will enhance Village Creek's resilience to flood hazards in the future.

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Chapter 1

Introduction

Floods are a major concern in the U.S. and around the world due to the extreme amount of deaths, damages, and other related social and economic impacts. In the United States, almost 90 percent of all declared disasters include a flooding component (Opdyke 2004). According to the United States Geological Survey (USGS), the U.S. faces $6 billion in property damage and 140 deaths on average annually because of the national floods (USGS 2006). The five main causes of flood damages are debris impact, hydrodynamic forces, soaking, hydrostatic forces, contaminants and sediment (FEMA 2010). Historically, people wanted to live in near the water bodies as the early settlement of the United States people who lives in near the water bodies have the better access to transportation, water supply, and water power (FEMA 2010). As they have developed their communities near the water bodies that are flood prone, these populations experienced the most flood damages. In the United States, floodplains contain approximately 10 million households and $800 to $900 billion in property subject to flood risk (FEMA 2010). Flood-related property losses have also risen to $6 billion a year, from approximately $3.3 billion in the mid-1980s (Frangos 2003).

The costliest river-related flood in U.S history occurred in the Upper Mississippi River Basin in 1993. That event caused 47 deaths and $20 billion in property damage (USGS 2004). Flood disasters are responsible for the most deaths and property damage. According to EM-DAT (2016) global database, China faced the worst flood in 1931 and 1959 regarding most deaths that caused 3.7 million and 2 million deaths respectively. Regarding property damages, Thailand and China faced the worst flood in 2011 and 1988 respectively, and the estimated property damage for Thailand was $40 million, and for China, it was $30 million (EM-DAT 2016). In the U.S. history of the flood from 1900 to 2016, this event caused 2945 deaths and $63.7 billion in property damage (EM-DAT 2016).

Since the property damages are concerned due to flood, federal programs like National Flood Insurance Program was established to reduce the floodplain development (FEMA 2010). Federal Emergency Management Agency (FEMA) identifies flood hazard areas within a community and publishes a Flood Hazard Boundary Map (FHBM) that shows approximate hazard areas. This delineation helps to initiate implementation of the National Flood Insurance Program (NFIP) in that particular area. The National Flood Insurance Program (NFIP) is a part of the Federal Emergency Management Agency (FEMA). It was designed as a partnership between the federal government and local communities. Local government set a minimum floodplain management policies for homeowners and businesses to purchase flood insurance. Policies may include, for example, that new buildings be elevated or otherwise protected from flood damage. Once a community joins the NFIP, anyone can purchase the insurance though the coverage is limited.

According to FEMA (2010), approximately 20,000 communities participate in the National Flood Insurance Program (NFIP). FEMA divides the participating communities into varying flood-risk zones to set premiums. Premiums are established for each zone nationwide (GAO 2008). The flood insurance rate varies by flood zones and characteristics of the property. The properties that were placed before the community was mapped called pre- Flood Insurance Rate Maps (FIRM) properties. These properties receive subsidized rates to encourage community to join the flood insurance program. The NFIP also not penalize the homeowners who had built their homes in the floodplain without knowing the risk. Contrarily, they would face high rates and a decline in property values (Pasterick 1998).

People who are living in flood hazard areas lack interest in purchasing hazard insurance through the NFIP provides the flood insurance to communities (FEMA 2010). Even, they rarely take voluntary loss prevention measure to protect their property, and by this way, they are making them more vulnerable. Lack of accurate knowledge about risk, budget constraints and myopia are the reason they do not purchase insurance (Michel-Kerjan 2010). However, elevating the house is the best reduction measure against flood which can be a significant cost for properties that are already built and would pay back only over a long period (Michel-Kerjan and Kousky 2010).

Alabama is vulnerable to flood hazards due to the high density of population and development. The major flood hazard areas in Birmingham are Fivemile Creek, Village Creek, Valley Creek, Shades Creek, and their tributaries (Department of Planning, Engineering and Permits Planning Division 2003). Particularly, along with the Village Creek, the area is subject to flash flooding associated with severe thunderstorms. In 1996, the flood occurred in Village Creek resulted in Federal disaster declaration (FEMA 2000). After that, the City of Birmingham received two FEMA-HMGP grants. The funds were used to acquire 250 properties approximately in Ensley neighborhood in Village Creek (FEMA 2000). This study proposes to conduct a flood risk assessment for Village Creek, Birmingham, Alabama which has a history of flood disasters. The study will follow the tradition of applied geography research by conducting a flood risk assessment that will contribute to flooding disaster management policy and strategy formulation. Applied geography research is of particular importance because it helps solve problems and the results are used to inform decision and policy makers (Torrier and Michael 2003).

Research Questions

The following questions will be addressed in this study:

1. What is the history of flood activity in the area of Village Creek, Birmingham, AL?
2. What would be the most likely and the worst-case scenario regarding flood frequency in Village Creek, Birmingham, AL?
3. Where are the socially vulnerable populations located in Village Creek, Birmingham, AL?
4. Where are the vulnerable buildings and infrastructure in Village Creek, Birmingham, AL?

Thesis Outline

This research is fragmented into six chapters. Chapter one discusses some introductory statement like the history of the flood in the United States, National Flood Insurance Program and the floods in the Village Creek. Chapter two deals with relevant literature review. It examines some models related to flood hazard and also reviews the factors social vulnerability. Chapter three describes and provides the detail information about the study area. This section will provide some insights why this study area was chosen. Chapter four discussed the methods that were used for the historical flood assessment, social and physical vulnerability assessment. The methods used in this section can also be used for future flood risk assessment. Chapter five presents the results from historical flood assessment, social and physical vulnerability assessment. The historical flood assessment will provide the past activity of flood in the Village Creek. The social vulnerability assessment assesses the factors related to social vulnerability and produces the vulnerability maps that shows the location of socially vulnerable populations. The physical vulnerability assessment provides the maps that show the vulnerable buildings and infrastructure within the flood hazard area. Chapter seven summarizes the results and answer the research questions.

Chapter 2

Literature Review

Flood Hazard

A hazard is a threat, not the actual event. According to Alexander (2000), “a hazard is an extreme geophysical event that is capable of causing disaster.” The community has the impact of hazard that is influenced by the level of risk. The risk is defined as the "likelihood that a particular hazard will cause adverse effects within a community, an organization, or some subset of the population" (Ferrier 2008). Risk expresses the likelihood that harm from a potential hazard will be realised and considering the likely severity of harm. The calculation of risk assessment involves the magnitude of possible consequences, and the likelihood of these consequences to occur (Paul 2011).

Risk = Likelihood of Hazard Occurrence x Consequence

In the above equation, likelihood is the probability of occurrence of an impact that affects the environment; and the consequence is the Environmental impact if an event occurs.

The term "100-year floodplain" is the common way to delineate the threat of flood. This term represents the area that has a 1% annual chance of flooding. The Federal Emergency Management Agency (FEMA) estimates that nearly 150,000 square miles of the United States that are over 4% of the total area are within the 100-year floodplain (FEMA 1983).

Hazard Vulnerability Models

The purpose of this section is to provide information about the different models of hazard vulnerability. This section aims to explain the models related to hazard vulnerability, primarily focusing on how these models work in hazard research. It begins with the elements of flood vulnerability analysis and concludes with the protective action decision model.

Elements of Flood Vulnerability Analysis

Messner and Meyer (2005) used three indicators to analyze the flood vulnerability (Figure 2.1):

1. Element-at-risk Indicators
2. Exposure Indicators
3. Susceptibility Indicators

In any flood vulnerability analysis, it is important to find out the group of elements that are at risk of being harmed during the flood events. Element-at-risk indicators help to specify these groups like the amount of social, economic or ecological units which are at risk of being affected concerning all kinds of hazards in a given area (Messner and Meyer 2005).

There are two categories of exposure indicators; the first one is the type of exposure and the second one is flood characteristics (Figure 2.1). The first category of indicators supplies the information about the return periods of different types of floods in the floodplain area, the location of the various elements at risk, their proximity to the river, their elevation, and their closeness to inundation areas. The second category indicators give the general flood characteristics such as duration, velocity, sedimentation load and inundation depth (Messner and Meyer 2005).

Susceptibility indicators that measure the sensitively of an element at risk behave when it is confronted with hazard. According to Messner and Meyer (2005), susceptibility indicators affected the social, economic and ecological systems or to individual units (Figure 2.1). Susceptibility measures the absolute or relative impacts of the flood on individual elements regarding the social and economic systems.

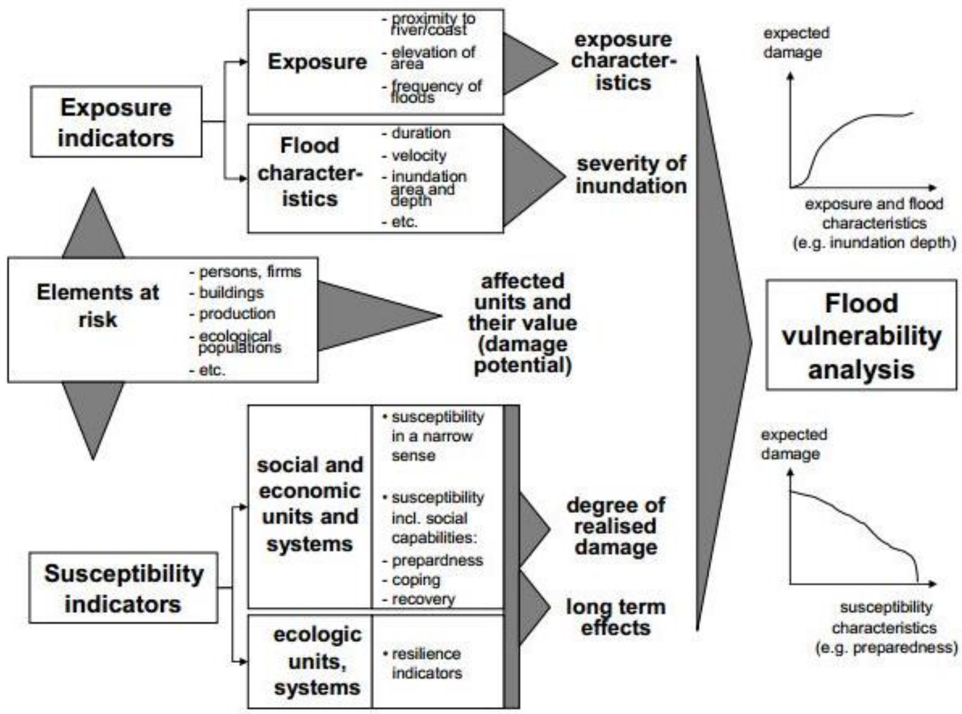

Figure 2.1. Indicators to be used in flood vulnerability analysis (Messner and Meyer 2005)

Hazards-of-Place Model of Vulnerability

Hazards-of-place model of vulnerability was first introduced by Cutter (1996). In this model, risk interacts with mitigation that leads to hazard potential (Figure 2.2). The hazard potential is either enhanced or moderated by geographic context and the social fabric of the place. The social fabric includes community experiences and perception of hazard. The social and biophysical vulnerabilities interact to produce overall place vulnerability.

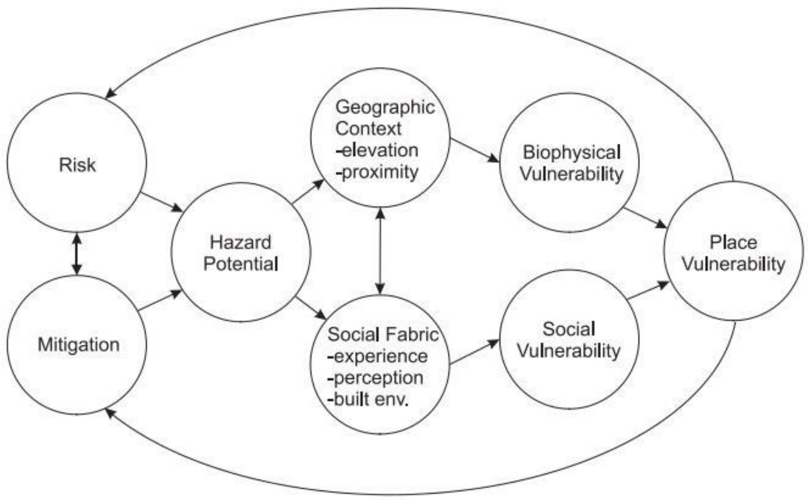

Figure 2.2. Hazards of Place Model (Cutter 1996)

Disaster Resilience of Place (DROP) Model

Cutter et al. (2008), propose the disaster resilience of place model as a new conceptualization of natural disaster resilience. There is a relationship between vulnerability and resilience, and this model is designed to present that relationship. Cutter et al. (2008), made some critical assumption in the conceptualization of the Disaster Resilience of Place (DROP) model (Figure 2.3). The first assumption is, this model will address natural hazards specifically, but it could be used to assess other rapid onset events such as technological hazards, or slow onset natural hazards like drought. The second assumption is, the DROP focuses on resilience at the community level. The final assumption is, the main focus of this model is on the social resilience of places. However, they also acknowledged that other forms of resilience exist in social process and cannot be separated. That is why the DROP will present resilience as both an inherent or antecedent condition and a process.

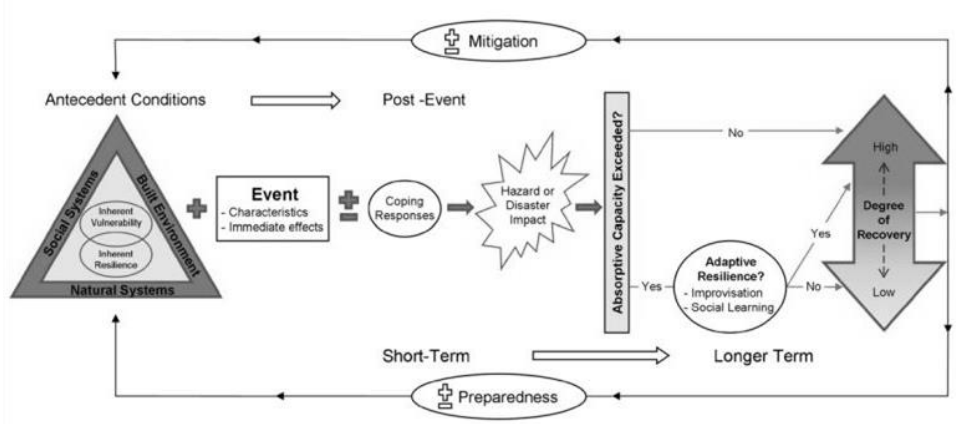

Figure 2.3. Disaster Resilience of Place (DROP) Model (Cutter et al. 2008)

Protective Action Decision Model

Lindell and Perry (2012) describe the process of the protective action decision model (Figure 2.4). It begins with environmental cues, social cues, and warnings. Social cues arise from observations of others' behavior whereas environmental cues are sights, smells, or sounds that signal the onset of a threat. Warnings are messages that transmitted through the channel to a receiver, and it depends on receivers' characteristics include their physical, psychomotor, and cognitive abilities as well as their economic and social resources.

The pre-decision process produces a core perception of the environmental threat, alternative protective actions, and relevant stakeholders that have been initiated by environmental cues, social cues, and socially transmitted warnings. These perceptions create the basis for protective action decision making, and the outcome of this process are combined with situational facilitators and situational impediments to behavioral response. The behavioral response can be categorized by information search, protective response or emotion focused coping. There is also a feedback loop that observed the additional environmental and social cues.

According to Lindell and Perry (2012), the stages in the Protective Action Decision Model (PADM) characterize the way people “typically” make decisions about adopting actions to protect against environmental hazards (Figure 2.4). These stages are sequential, and a few people follow every step in the model in the exact sequence.

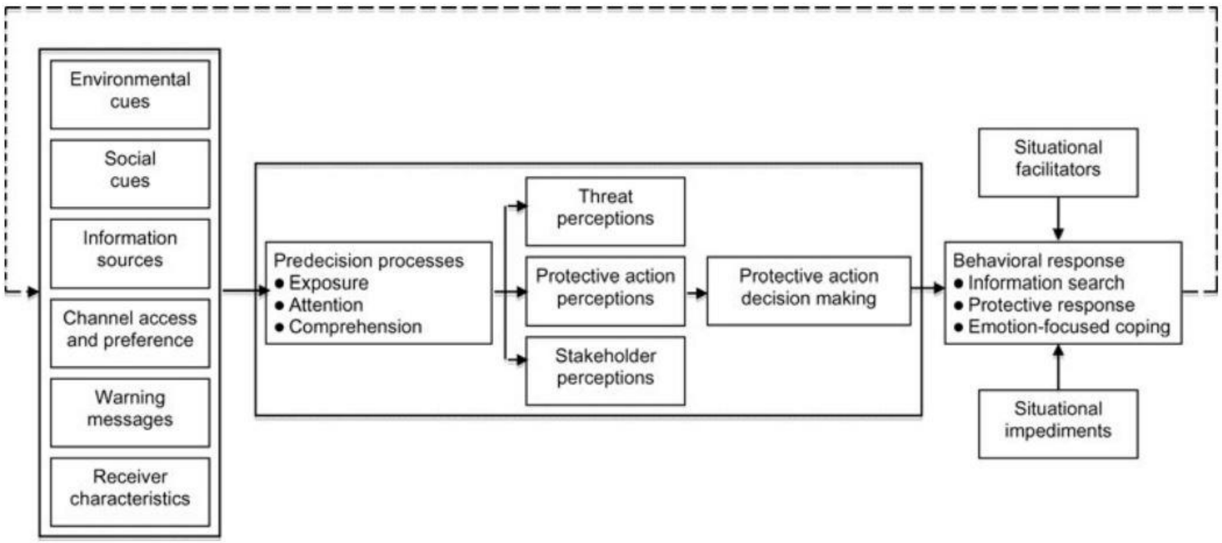

Figure 2.4. Protective Action Decision Model (Lindell and Perry 2012)

Lindell and Perry (2012) conducted research on citizen’s perceptions of flood hazard adjustment in Netherlands. In the research, they apply the Protective Action Decision Model to explain flood preparedness intentions in the Netherlands. They conducted a survey of 1,115 people and found that hazard-related attributes were positively correlated, but failed to show that resource-related attributes were negatively correlated with preparedness intentions. In the research, among the demographic characteristics, they found that only female was consistently correlated with higher risk perception and the hazard-related attributes.

In the research, Lindell and Perry (2012) developed a research model that shows the application of PADM to flood hazard adjustment (Figure 2.5). This model predicts the people’s intentions to adopt flood hazard adjustments that are determined by their perceived risk and the perceived importance of the hazard- and resource-related attributes. A series of hypotheses has been implied by this model.

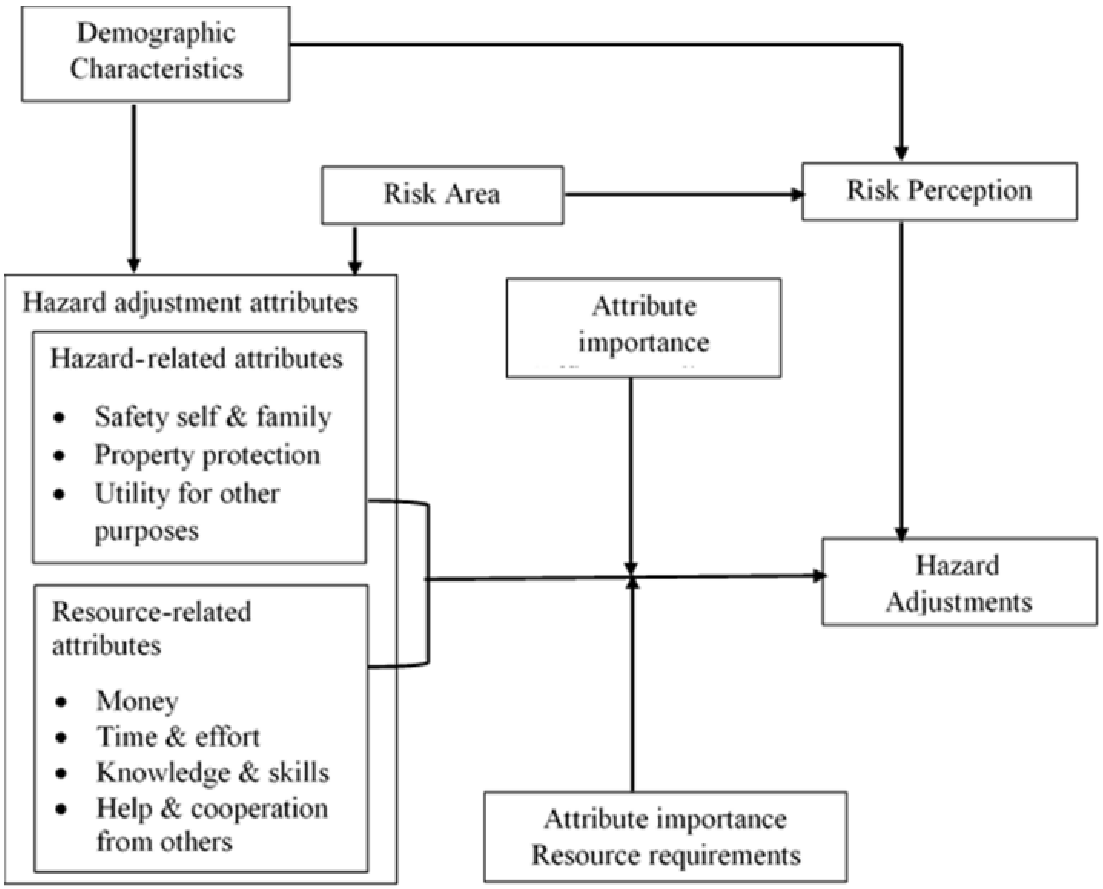

Figure 2.5. Application of PADM in flood hazard adjustment (Lindell and Perry 2012)

Social Vulnerability

Social vulnerability focuses on the social and economic forces that shape disasters outcomes (Zahran et al. 2008). People are considered socially vulnerable because of access to resources and political power. Social vulnerability is defined by the possession of social attributes that increase susceptibility to disasters (Blaikie et al. 1994). Below are the fundamental causes of social vulnerability (Blaike et al. 1994 and Mileti 1999):

- Lack of access to resources, information, and knowledge.

- Limited access to political power and representation.
- Certain beliefs and customs.
- Weak buildings or weak individuals.

Factors Influencing Social Vulnerability

Several factors influence social vulnerability such as age, gender, lack of access to resources, type and density of infrastructure, limited access to political power and representation, social networking and connections, and weak and physically limited individuals (Blaikie et al. 1994; Cutter, 2001; Tierney et al. 2001). For this research, the following factors influence the level of social vulnerability.

Age

Some research argues that children are the most vulnerable part of the population, but according to Walker et al. (2012), they can serve as resilience drivers by creating community networks through their schooling. In the recovery process, they can also provide assistance to the households (Kuhlicke et al. 2011). Elderly people are also considered as a most vulnerable group, but young and middle-aged people can also be vulnerable because of their risk-taking behavior (Doocy et al. 2013). However, elderly people increase the burden of care and lack of resilience due to their mobility constraints (O'Brien and Mileti 1992; Hewitt 1997; Cutter et al. 2000; Ngo 2001). They recover more slowly and suffer health related problem in the post-disaster period (Morrow and Phillips 1999). Older people also tend to be troubled by the prospect of leaving their homes and living in group quarters (Gladwin and Peacock 1997).

Gender

Gender affects vulnerability (Enarson and Morrow 1997), and this is linked to flood vulnerability because of the unequal family care responsibilities between men and women (Vu and Vanlandingham 2012). During the flood events, women can be more vulnerable than men due to sector-specific employment, lower wages, and family care responsibilities (Fothergill 1996; Peacock et al. 1997, 2000; Cutter 1996; Hewitt 1997). Their responsibilities also restrict them to the very young and the very old, both of whom require help and supervision during the disaster (Fothergill 1998). Women are especially divorced mothers, and never-married mothers are more likely to live in poverty and more vulnerable than men (Bianchi and Spain 1996). In the recovery period, women can have more difficult time than men (Blaikie et al. 1994; Enarson and Morrow 1998). Nevertheless, women have more knowledge of risk and social relations that lead them to more coping capacities (Steinfuhrer and Kuhlicke 2007).

Race and Ethnicity

Race and Ethnicity are also important factors in social vulnerability. They contribute to social vulnerability through the lack of access to resources, cultural differences, and the social, economic, and political marginalization (Cutter et al. 2003). It is also noticeable that the African-American female-headed households are more vulnerable than any other. These factors are mostly correlated with Hispanics and Native Americans (Cutter et al. 2003) and impose language and cultural barriers that affect the access to post-disaster funding and residential locations in high hazard areas (Bolin 1993; Peacock et al. 1997, 2000; Bolin and Stanford 1998; Pulido 2000;). In the United States, racial minorities are more vulnerable because they are likely to be poor (Bianchi and Spain 1996). Especially, the minorities are immigrants from non-Englishspeaking countries; language difficulties can greatly increase vulnerability to a disaster (Gladwin and Peacock 1997) and recovery (Yelvington 1997).

Education

Risk perception, skills, and knowledge can be directly and promote access to information and resources, improve health, and reduce poverty can be indirectly influenced by education (Muttarak and Lutz 2014). Educated persons might be more capable of responding and acting during the disaster events because of their problem-solving skills (Moll 1994; Ishikawa and Ryan 2002; Schnell-Anzola et al. 2005). Education can also improve the socio-economic status of individuals by increasing the earnings (Psacharopoulos 1994; Psacharopoulos and Patrinos 2002). This high income allows them to have disaster insurance and live in low-risk areas (Muttarak and Lutz 2014). Moreover, highly educated individuals have better communication linkages and access to useful information (Cotton and Gupta 2004). However, lack of education or lower level of education can increase the level of vulnerability because it constrains the ability to understand warning information and access to recovery information (Heinz Center for Science, Economics, and the Environment 2000 and Cutter et. al. 2003). In the case study of households in Brazil and El Salvador reports that residents who live in high-risk areas have a lower level of education than the residents live in low-risk areas (Wamsler et al. 2012).

Housing

The quality and the nature of housing stock, nature of ownership, and the location is an important factor of vulnerability. The combination of these factors can produce social vulnerability (Cutter et. al. 2003). Renters are considered as vulnerable as they depend on their landlords. During the hazardous events, landlords are responsible for the repairs or rebuilding the house that left the tenant homeless during the post-disaster periods (Morrow 1999). Though the renters are associated with lower economic loss (Adeola 2009) but the displacement and job loss are higher among them (Elliott and Pais 2006). Compared to renters, homeowners are more aware of the flood risks (Kuhlicke et. al. 2011), and they take prompt action to reduce damage (Parker et. al. 2009). Damage of residential property also considered as the loss of housing. Especially mobile homes are easily destroyed and less resilient to hazards due to their weak infrastructure (Bolin and Stanford 1991; Heinz Center for Science, Economics, and the Environment 2000; Cutter et al. 2000). The people who have the lack of access to transportation also considered as vulnerable because it caused the failure of evacuation plans (Elliott and Pais 2006).

Chapter 3

Study Area

The city of Birmingham is the most populous city in the State of Alabama (Figure 3.1). The city has a total area of 151.9 square miles with the total land area of 149.9 square miles and the water area of 2 square miles. According to the 2010 U.S. Census, the city's population was 212, 237. The estimated 2014 population of the city is 318,718 (US Census 2014).

Village Creek that is located within the city of Birmingham, Alabama is selected as the study area for this research. Village Creek is a populated place and water body in the city of Birmingham that runs 44 miles through the Jefferson County and city of Birmingham. The total area of the Village Creek is 45.97 square miles. According to the 2010 U.S. Census, the area's population was 41,242.

Geographically, the city of Birmingham located in a valley on the western slopes of the Appalachian Mountains. In Birmingham, there are entire eight watersheds, and they are Village Creek, Shades Creek, Black Warrior River, Valley Creek, Turkey Creek, Five Mile Creek, Cahaba River, and Little Cahaba River (Figure 3.2). Among these watersheds, Village Creek accounts for approximate 53 percent of Birmingham's Special Flood Hazard Area (Federal Emergency Management Agency 2000). The direction of the flow of Village Creek is southwest (Figure 3.2), and it flows through the city for 12 miles that drain an area of approximately 40 square miles. The slope of Village Creek moderately steep and the velocities of flood ranges

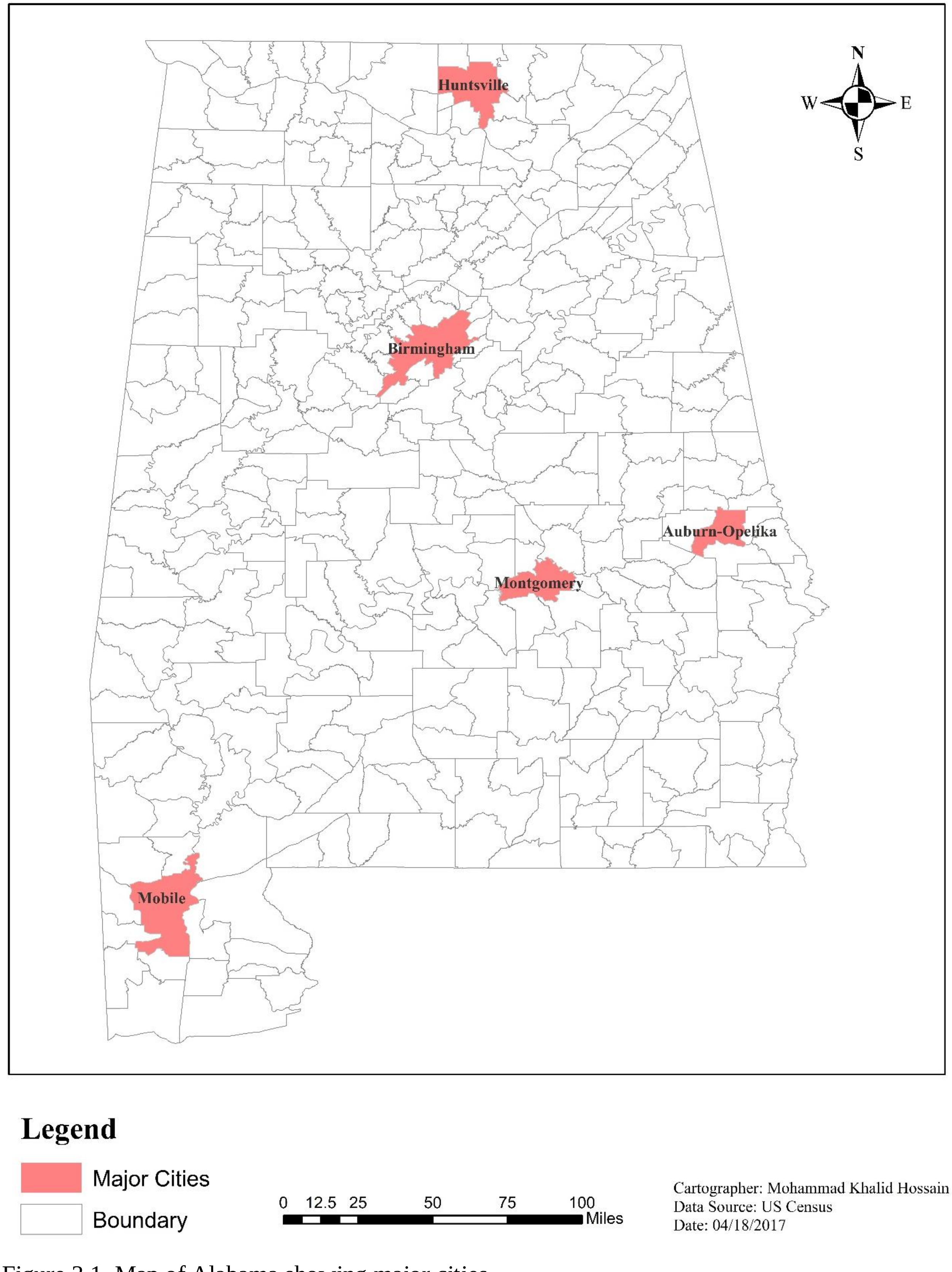

Figure 3.1. Map of Alabama showing major cities

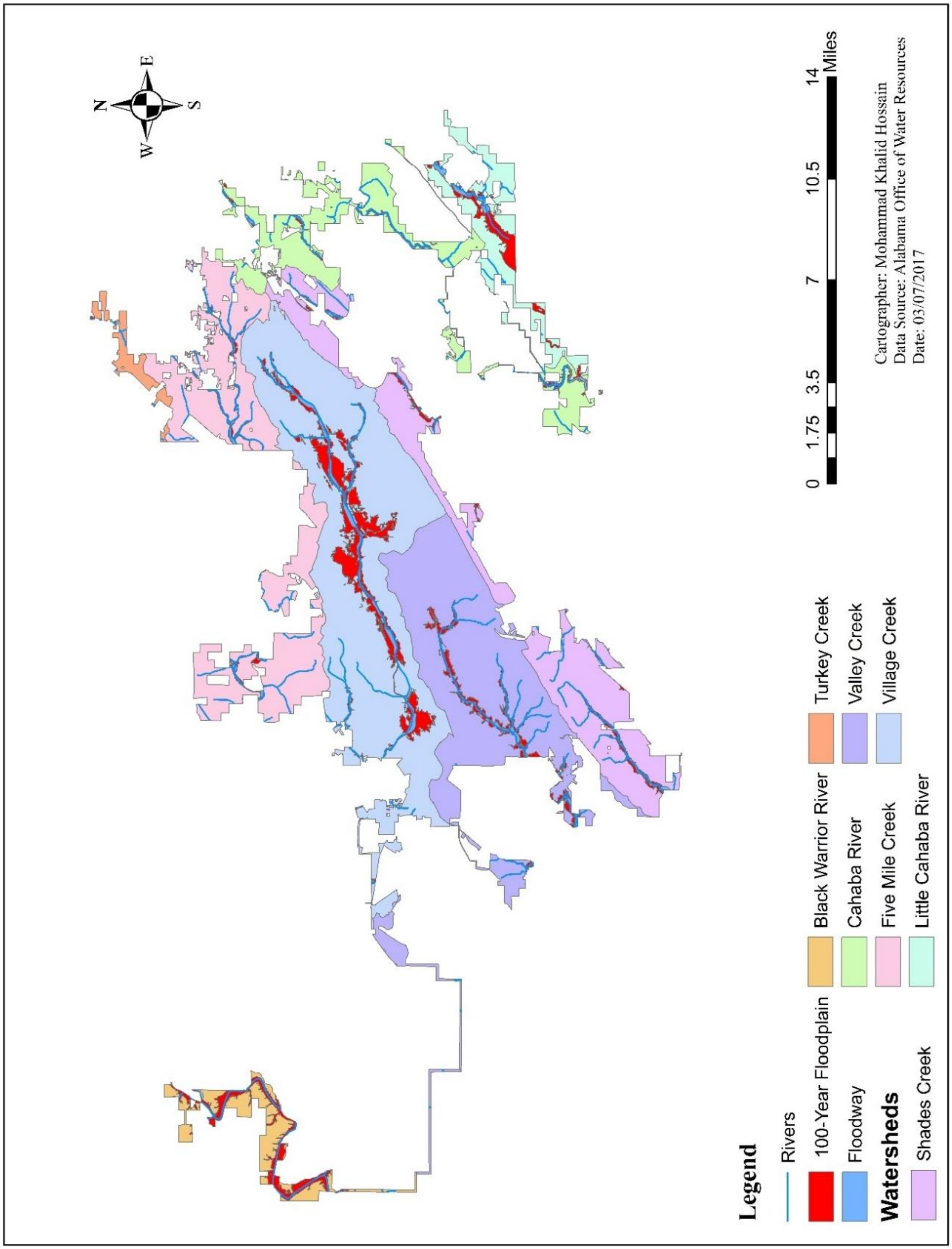

Figure 3.2. Major watersheds and floodplain map of Birmingham, AL

from 3 to 9 feet per second. The usual duration of the flood is less than 10 hours, and flood reaches the maximum stage in two to four hours after an intense rainfall (Federal Emergency Management Agency 2000). However, the flood can rise at a rate of three feet per hour in some areas of Village Creek.

The flood activity is common in the Village Creek and for this reason this area has been selected as a study area. Historically, thousands of homes in Village Creek have been inundated by repetitive flooding, and still many neighborhoods are within the floodway and floodplain of the Village Creek. In the year from 1995 to 2015, Village Creek has flooded these neighborhoods fourteen times (Table 3.1). The floods occurred in October 1995, January 1996, March 1996, January 1998, June 1999, March 2000, April 2001, July 2002, September 2002, and May 2003 caused over $15 million in damages to public and privately-owned properties (Department of Planning, Engineering and Permits Planning Division 2003). The Congress passed Water Resources Development Acts in 1986 and 1990 that authorized $29.6 million for non -structural flood control projects in the flood hazard area of Village Creek. The City of Birmingham contributed $7.4 million additional funds to purchase 642 properties in the flood plain (Federal Emergency Management Agency 2000).

Birmingham has a humid subtropical climate and characterized by abundant rainfall. The fall and spring months frequently bring severe thunderstorms, especially November and early December considered as severe weather season. The precipitation is well-distributed throughout the year in Birmingham (Table 3.2).

Table 3.1. Flood damages for Village Creek in Birmingham, AL. 1995-2015. Source: City of Birmingham, Department of Planning, Engineering, and Permits

Date	**Damage ($)**	**Damages**
10/3/95	$571,000	200 Homes, 25 businesses, 100 families
1/26/96	$39,000	97 Homes
3/6/96	$65,000	111 Homes, 9 businesses
3/18/96	$38,000	65 Homes, 10 Businesses
1/8/98	$67,000	208 Homes
6/14/99	$250,000	100+ Homes
3/10/00	N/A	50+ Homes
7/12/02	N/A	25+ Properties
9/22/02	N/A	50+ Properties
5/07/03	$1,000,000	1000+ Properties
2/5/04	$75,000	123 Structures
9/15/04	$1,500,000	400+ Properties
4/6-7/15	$100,000	100+ Properties

Table 3.2. Climate Data of Birmingham, Alabama. 1981-2010. Source: National Oceanic and Atmospheric Administration.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average precipitation inches	4.84	4.53	5.23	4.38	4.99	4.38	4.80	3.93	3.90	3.44	4.85	4.45
Average precipitation days	10.5	10.0	10.2	9.1	10.2	11.0	11.7	9.6	7.4	7.6	9.1	10.4

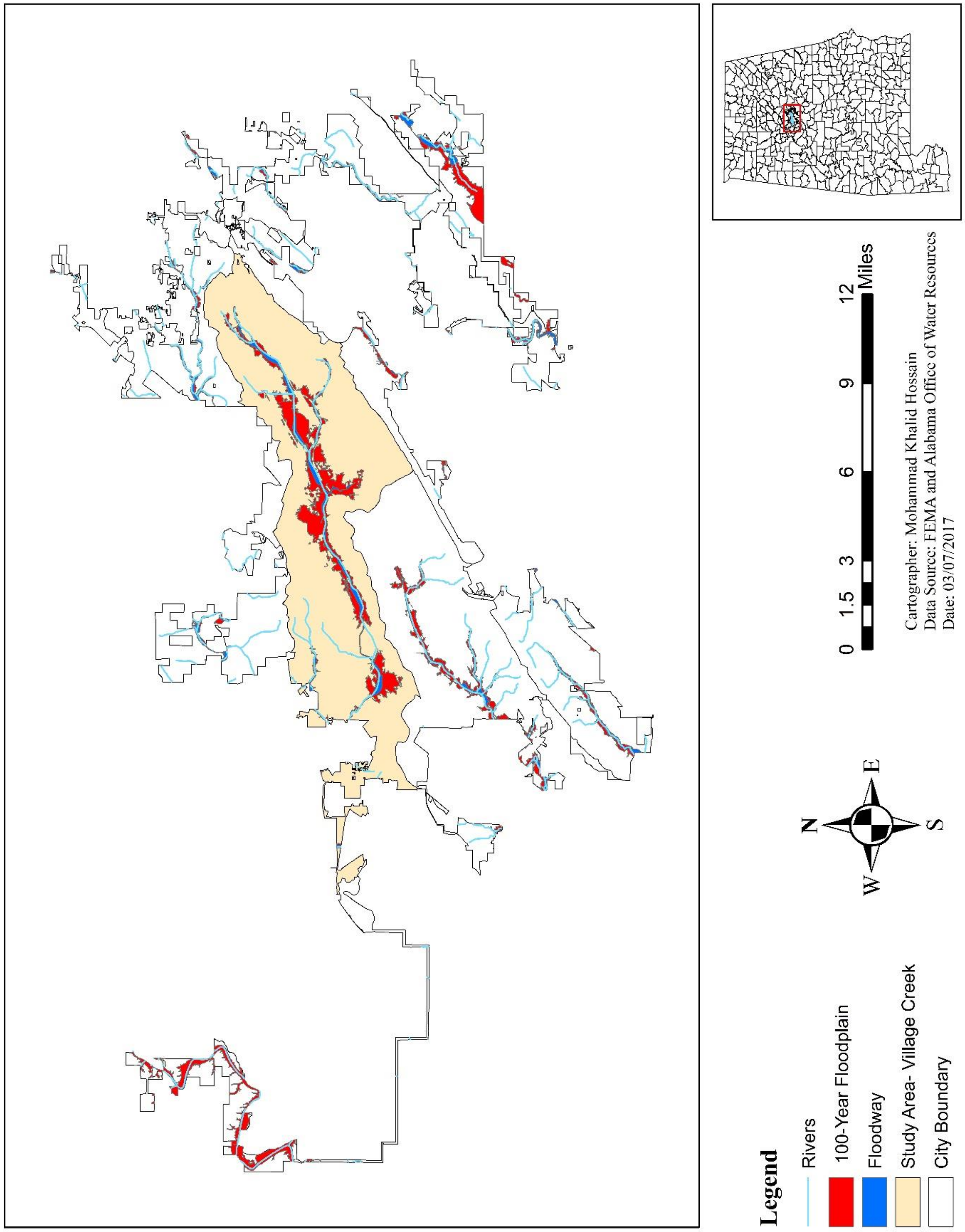

Figure 3.3. Village Creek, Birmingham, AL, Study Area

Chapter 4

Methods

This research followed the hazards of place model of vulnerability introduced by Cutter (1996). Three outcome indicators were used to assess the flood risk in Village Creek. Firstly, the biophysical vulnerability that was assessed by calculating flood frequency and delineating the flood hazard zones. Secondly, the social vulnerability that was measured by developing the social vulnerability index using the sociodemographic factors. Thirdly, the place of vulnerability that is the interchange of biophysical and social vulnerability. Though the place vulnerability consists of biophysical and social factors, is also compounded by population's reliance on infrastructures (Cutter et al. 2000) and the vulnerable infrastructure has been identified by doing the physical vulnerability assessment. The place of vulnerability has a feedback loop to the initial risk and mitigation inputs; this will allow the enhancement and reduction of both risk and mitigation would lead to decreased or increased vulnerability.

The methods for this study included 3 major phases of analysis: 1) historical flood assessment, 2) social vulnerability assessment, 3) physical vulnerability assessment. The results of each phase were combined to produce overall social and physical vulnerability maps.

Historical Flood Assessment

The 100-year floodplain data has been collected from the Federal Management Agency's website. In the Flood Insurance Rate Map (FIRM), Flood hazard areas identified as the Special Flood Hazard Area (SFHA). The area that are subject to one percent annual chance of flooding is called Special Flood Hazard Area. The one percent annual chance flood (100-year flood), also known as the base flood. The area of Special Flood Hazard includes Zones A, AE, AH, AO, AR, A99, V, and VE. The base flood elevation is considered as the water-surface elevation of the one percent annual chance flood. The moderate flood hazard areas are the area that is between 0.2 percent annual chance of flood (500-year flood) and the limits of the base flood. These moderate flood hazard areas considered as Zone B and Zone X. Some areas are outside of the Special Flood Hazard Area considered as minimal of flood hazard. These areas labeled as Zone C and have the elevation higher than the 0.2 percent annual chance of flood. Below table shows the description of each zone:

Table 4.1. Description of Flood Hazard Zones. Source: Alabama Office of Water Resources, 2015.

Flood Hazard Zones	**Description**
Zone A	No base flood elevations determined.
Zone AE	Base flood elevations determined.
Zone AH	Flood depths of 1 to 3 feet (usually areas of ponding); base flood of elevations determined.
Zone AO	Flood depths of 1 to 3 feet (usually sheet flow on slipping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
Zone AR	Special Flood Hazard Area formerly protected from the one percent annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the one percent annual chance or greater flood.
Zone A99	Area to be protected from one percent annual chance flood by a Federal flood protection system under construction; no base flood elevations determined.
Zone VE	Coastal flood zone with velocity hazard; base flood elevations determined.
Zone X	Areas of 0.2 percent annual chance of flood.
Zone C	Areas determined to be outside 500-year floodplain determined to be outside the one percent and 0.2 percent annual chance floodplains.

A historical flood assessment was done using the data from 1995 to 2015 obtained from the United States Geological Survey (USGS) and Planning, Urban Design and Watershed Management Division of City of Birmingham. The data regarding the gage height was collected from the USGS 02458300 gauging station on Village Creek (Figure 4.1) that refers the elevation of the water surface. Gage height for each flood events was shown and displayed on Table 4.1. The mean gage height for the specific day (Appendix 1.2) also collected from the USGS website and displayed on Table 4.2.

Table 4.2. Streamflow and gage height for each flood event at Village Creek gage station, 1995-2015. Source: USGS

Date	**Streamflow (CFS)**	**Gage height (Feet)**	**Mean gage height on that day (Feet)**
10/03/95	1680	N/A	N/A
01/26/96	1790	4.26	0.81
03/06/96	1160	4.24	0.98
03/18/96	154	1.09	0.6
01/08/98	149	1.41	0.43
06/14/99	235	1.34	0.54
03/10/00	960	3.14	0.93
07/12/02	658	2.56	0.52
09/22/02	941	3.56	0.57
05/07/03	1960	5.32	0.64
02/05/04	50	0.47	0.66
09/15/04	26	0.43	0.32
04/06/15	56	0.6	0.69
04/07/15	42	0.49	0.84

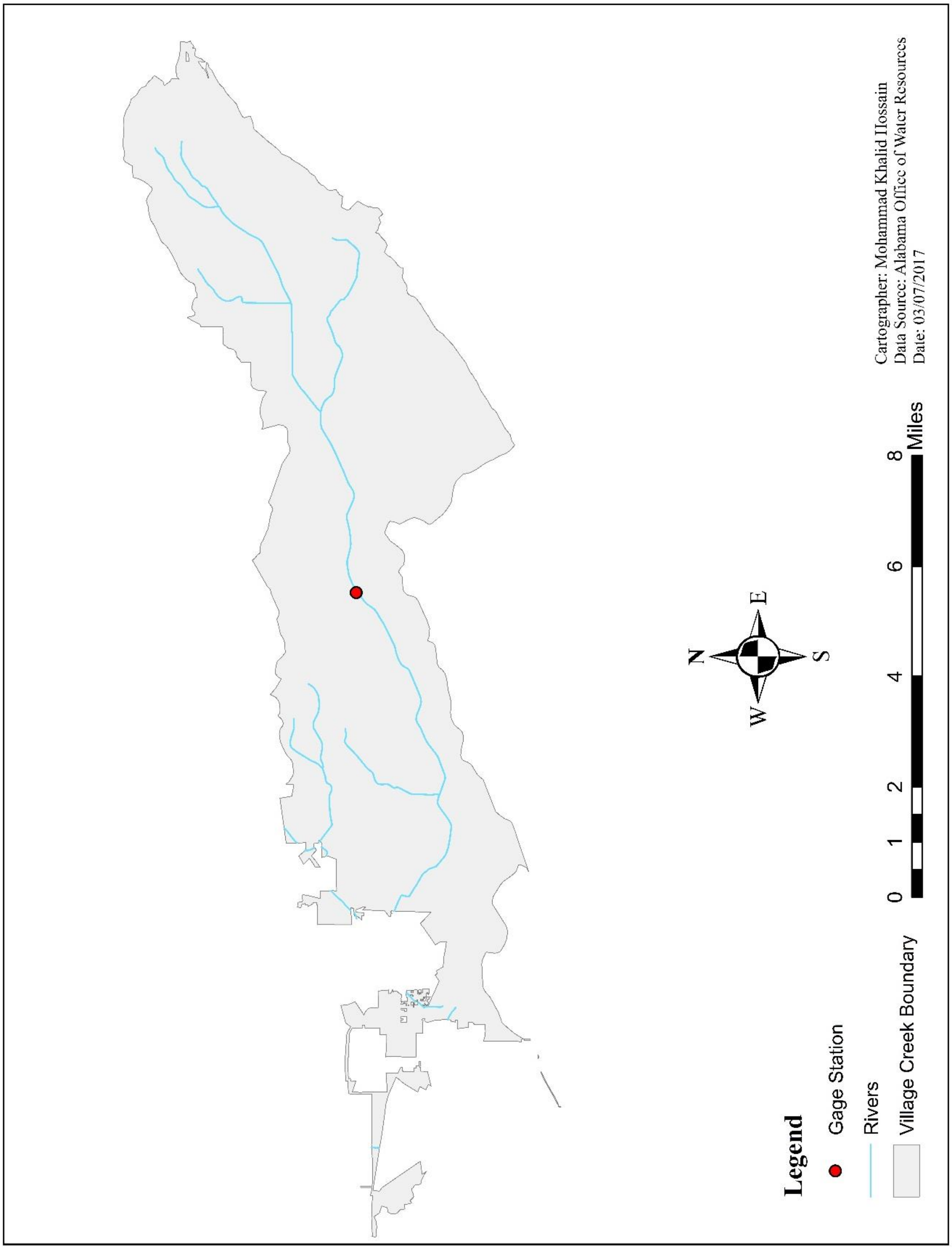

Figure 4.1. Location of 02458300 Village Creek gage station

As the part of historical flood assessment, flood frequency analysis was performed that can be used to predict design floods. There are many techniques that can be used to analyze the flood frequency. In this research, the Log-Pearson Type III Distribution was used for flood frequency analysis as it is recommended by the U.S. Water Advisory Committee on Water Data (1982).

The Log-Pearson Type III distribution is a statistical technique for fitting frequency distribution data to predict the design flood. This is the standard technique that used by Federal Agencies in the United States. The general equation of the Log-Pearson Type III distribution is:

$$\log x = \overline{\log x} + K\sigma_{\mathrm{bgx}}$$

Where,

x= Flood discharge value of some specified probability.

$\overline{\log x}$ = Average of the *log x* discharge values.

K= Frequency factor.

σ= Standard deviation of the *log x* values.

The skewness coefficient is the function of frequency factor K. The frequency factor table (Haan, 1977, Table 7.7; Appendix 1.1) was used to find out the return period. The flood magnitudes for the various return periods were found by solving the general equation. The mean, variance and standard deviation of the data were calculated using the formulas below:

Mean= $\overline{\log x} = \frac{\sum \log x_i}{n}$

Variance= $\frac{\sum_i^n (\log Q - avg(\log Q))\text{^}2}{n-1}$

Standard Deviation= $\sigma \log Q = \sqrt{variance}$

After calculation all these, the skewness of coefficient C_S was calculated by using the following formula:

$$C_s = \frac{n \sum(\log x - \overline{\log x})^3}{(n-1)(n-2)(\sigma_{bgx})^3}$$

Where,

n= Number of entries.

x= Flood of some specified probability.

σ_{bgx} = Standard deviation.

A generalized estimate of the coefficient of skewness, C_w need to be calculated for the instantaneous peak flow data based on the following equation:

$C_w = WC_s + (1-W)\ C_m$

Where,

W= Weighting factor.

$C_{s=}$ Coefficient of Skewness.

C_m= Regional skewness.

The weighing factor W and Variation of the station skew $V(C_s)$ was calculated by using the following equations:

$$W = \frac{V(C_m)}{V(C_s) + V(C_m)}$$

$$V(C_s) = 10^{A - B\log_{10}(\frac{n}{10})}$$

Where,

A = -0.33 + 0.08 | C_s| if | C_s | ≤ 0.90 or

A = -0.52 + 0.30 | C_s | if | C_s | > 0.90,

B = 0.94 - 0.26 | C_s | if | C_s | ≤ 1.50 or

B = 0.55 if | C_s | > 1.50

Based on the available historical record, the Log-Pearson Type III distribution will help to determine the likely values of discharges at various recurrence intervals. This technique is also helpful when designing structures to protect against the largest expected event. However, by using this technique, the discharge values of flood water can be estimated for the 2, 5, 10, 25, 50, 100, and 200 recurrence intervals. The Microsoft Excel was used to calculate the flood frequency. The annual frequency and return period data can be were used to help estimate what is most likely to occur during a flood event (most probable case scenario) and what might be the most severe outcome (worst case scenario).

Social Vulnerability Assessment

The social vulnerability assessment highlighted the areas where the high concentration of vulnerable populations is located within the area of Village Creek. For assessing the social vulnerability, census block data from the 2010 decennial census has been collected from the United States Census Bureau website. The hierarchical modeling approach (Figure 4.2) was followed in this research to construct the social vulnerability index. In the model, the social vulnerability indicators separated into groups that share the same dimension. These individual indicators were divided into sub-indices, and the sub-indices were, in turn, aggregated to construct the final composite model. This hierarchical approach is useful to analyze and map each subcomponent separately.

The first sub-component was the population that consists of demographic attributes (Table 4.3). The communities with the higher percentage of very young and elderly populations, percentage of female populations, percentage of African-American populations and percentage of Hispanic populations are likely to possess a higher level of social vulnerability. These factors were included in the sub-component of the population. The second sub-component was education that consists of a percent of the population not enrolled in school and studied below 12th grade. The housing sub-component was the third component that includes percent of housing units that are mobile home, percent of housing units that have no vehicle available, and renters.

Table 4.3. Variable selection for social vulnerability index

Indicator Description	**Category**
Percent of the population under 5 years and over 65 years of age	Population
Percent of the population that is female	Population
Percent of the population that is Hispanic	Population
Percent of the population that is African-American	Population
Percent of population not enrolled in school	Education
Percent of population studied below 12^{th} grade	Education
Percent of housing units that are mobile home	Housing
Percent of housing units that have no vehicles available	Housing
Renters	Housing

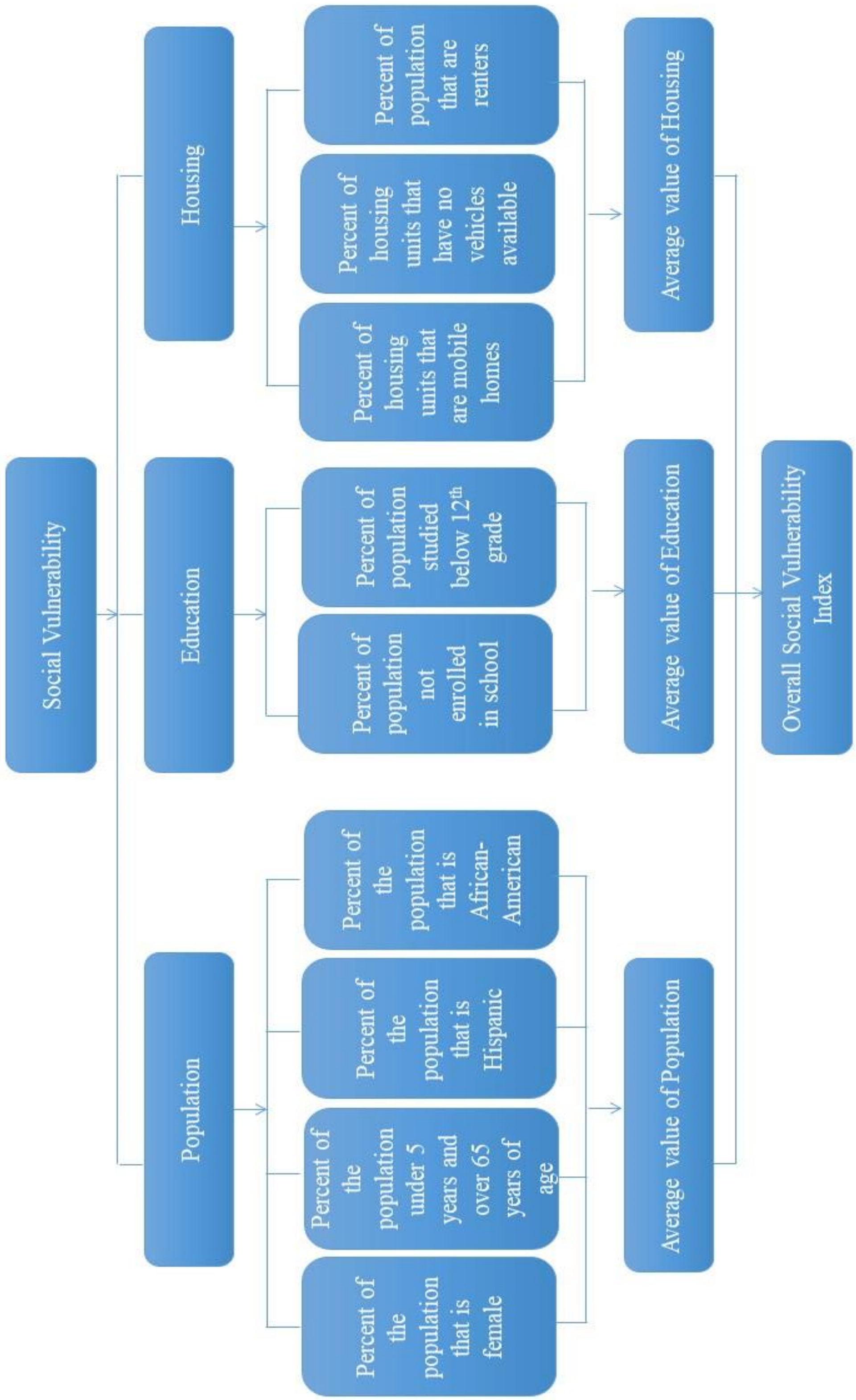

Figure 4.2. Hierarchical model structure

Before constructing the social vulnerability index, Census Block data were normalized using the Min-Max rescaling function outlined below. In this method, lowest values received the score zero being areas of low vulnerability, and highest values received the score one being areas of high vulnerability. In Table 4.4, for example, the number of children and elderly population and female population in each census block was tabulated (column 2 and 5). The percentage of children and the elderly and female population was computed (column 3 and 6). Then the value of these two sub-indices of population sub-component was normalized through min-max equation (column 4 and 7). The normalized value was summed (column 8) and rescaled by using the min-max equation to get the social vulnerability index ranges from 0 to 1. Higher index value indicates higher social vulnerability, and in this example, block B had the highest value and considered as most vulnerable (Table 4.4).

After normalizing the data, the variables score in sub-index (e.g. population, education, and housing) were averaged to reduce the influence of the varying number of variables in each sub-index. Each sub-component was summed to derive a final composite score, and in this case, the composite indicator was ranged between zero and three (zero being the least vulnerable and three being the most vulnerable) as there are three sub-components. After that, the composite social vulnerability scores were rescaled using the Min-Max function to produce the final composite score ranges between zero and one (zero being the least vulnerable and one being the most vulnerable).

$$z_i = \frac{x_i - x_{min}}{x_{max} - x_{min}}$$

Here, z_i is the normalized indicator.

Table 4.3. Example of social vulnerability index calculation-population

Census Block	**Number of Children and Elderly Population**	**Percentage of Children and Elderly Population** P= (Children and Elderly population at each block *100)/Total Population in the Village Creek	**Normalization of Children and Elderly Population** Q= (P-Pmin)/(Pmax-Pmin)	**Number of Female Population**	**Percentage of Female Population** R= (Female population at each block *100)/Total Population in the Village Creek	**Normalization of Female Population** $S = (R - R_{min})/(R_{max} - R_{min})$	**Sum** X= Q+S	**Vulnerability Index for Population** $Z = (X - X_{min})/(X_{max} - X_{min})$
A	302	0.73	0.58	503	1.22	0.61	0.61	0.59
B	439	1.06	1	763	1.85	1	1	1
C	112	0.27	0	103	0.25	0	0	0
D	274	0.66	0.49	746	1.81	0.98	0.98	0.73

The GIS techniques were used to combine each sub-component layers that produced an overall social vulnerability map. This map showed the areas of highest overall vulnerability as well as areas of lowest overall vulnerability. In GIS, the index values were classified into five classes and ordered in ascending order. There is no defined rule to determine low, moderate, and high vulnerability from the classified values and for this research the first class was considered as low, second and third classes as moderate, and fourth and fifth classes as high vulnerable. Below the Table 4.5 shows the example of this:

Table 4.5. Determination of low, moderate, and high vulnerable

Number of Classes	**Index Values**	**Label**
1	0.00-0.13	Low
2	0.14-0.26	Moderate
3	0.27-0.42	Moderate
4	0.43-0.61	High
5	0.62-1.00	High

Physical Vulnerability Assessment

The physical vulnerability highlighted the areas where the most vulnerable infrastructure is concentrated throughout the area of Village Creek. The data for this assessment were collected from the Alabma Office of Water Resources (OWR), City of Birmingham, Alabama, and the US Census Bureau website. The roads and building types that includes residential and commercial used as a parameter for the physical vulnerability assessment.

Like the social vulnerability assessment, GIS techniques were also used here to assess the physical vulnerability and to produce the physical vulnerability maps. Any building located within the flood hazard zones were consider as vulnerable, but for this research, only the residential and commercial buildings were highlighted as a vulnerable infrastructure. Once the vulnerable buildings types were selected, vulnerability maps were produced to show the physical vulnerability.

The roads data that was one of the parameters to analyze physical vulnerability were collected from the US Census Bureau website as a shape file format. In GIS, the layer of flood hazard zones was displayed over the roads layer. Then the tools in Geoprocessing were used to identify the vulnerable roads within the flood hazard zones and was displayed on maps. The total mileage of roads impacted by flood hazard was calculated and displayed on a table.

Chapter 5

Results

Historical Flood Assessment

The historical floods data from 1995 to 2015 were used for this assessment. Between 1995 to 2015 there were 14 flood events occurred within the Village Creek (Table 3.1). During these flood events, the maximum amount of damages were recorded as $1,500,000, and the minimum amount of damages were $38,000. From this historical data, it can be said that the average amount of damages for each flood event is $370,500. The City of Birmingham office only maintains the flood data that is related to Village Creek, and it was not possible to collect the data (related to damages) block-wise at the city level. Thus, the result of this damage assessment has limitations, and it shows only the overall damages at each flood event that applied for the Village Creek area.

The data collected for the historical flood assessment was also used to find out the peak month of flood activity within the Village Creek. The rains have produced the major floods in Village Creek and usually between November and April it produces steady rainfall over the large areas (U.S. Geological Survey Water-Supply Paper 2375, 1989). From 1995 to 2015 Village Creek experienced the peak flood activity between January to April (Table 5.1). The total number of flood events occurred during this time is eight which means 57 percent of all flood events took place between the month of January and April. The findings also suggest that the month of March has the most flood activity.

Table 5.1. Flood events by month

Month	Number of Flood Events
January	2
February	1
March	3
April	2
May	1
June	1
July	1
September	2
October	1

From the daily maximum instantaneous flow data (cubic feet per second) covering 20 water years of record for USGS 02458300 gauging station on Village Creek (Table 4.1) it can be determined that the maximum instantaneous flow of 1,960 cubic feet per second was recorded in 2003 while the lowest streamflow of 26 cubic feet per second was recorded in 2004. The mean streamflow is 704.36 cubic feet per second.

The highest gage height of 5.32 feet was recorded in 2003, and the lowest gage height of 0.43 feet was recorded in 2004 (Table 4.1). The average gage height for each flood event is 2.23 feet. The line graph was created to show the comparison between the gage height of flood events and the mean gage height on that day (Figure 5.1).

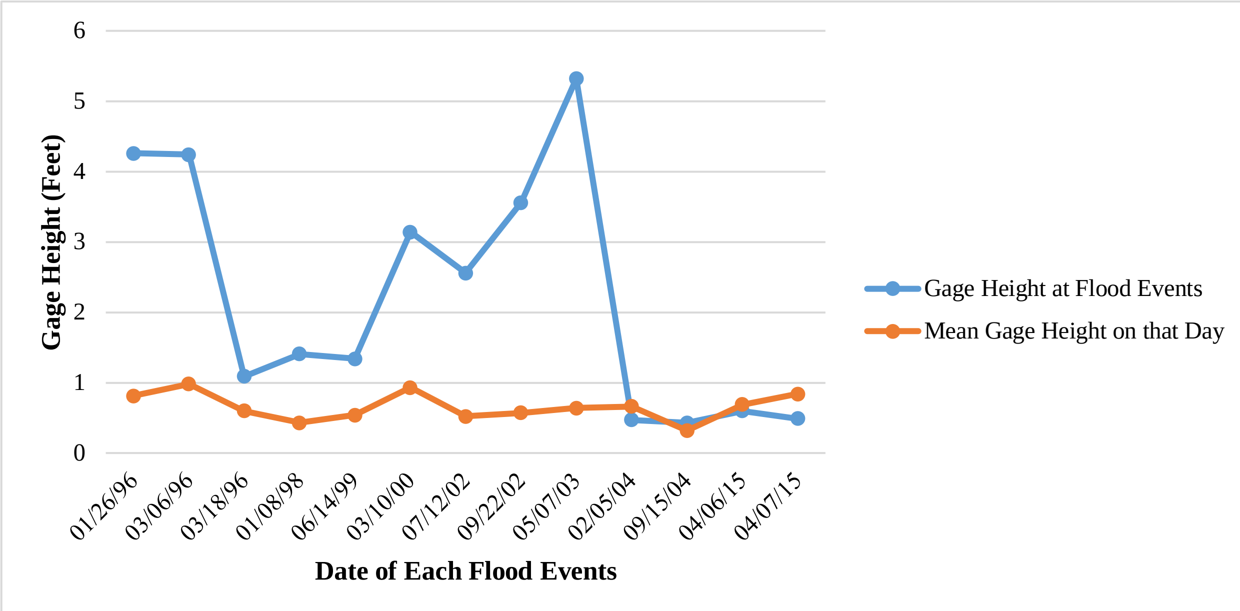

Figure 5.1. Comparison between the gage height of flood events and mean gage height

The rating curve was created for the USGS 02458300 gauging station at Village Creek to show the relationship between the gage height and discharge (Figure 5.2). The data for this gage station were collected from the USGS website over the 20 year periods (1995-2015) and presented in a table (Appendix 1.3). It is important to keep rating curve up to date for the gage station because it helps to provide the forecasts as accurate as possible.

The flood frequency analysis was also conducted based on this historical streamflow data. The Log-Pearson Type III distribution technique was used to estimate the probability of the occurrence of a given precipitation event. The return periods, also known as recurrence interval was calculated to estimate the likelihood of an event such as flood to occur.

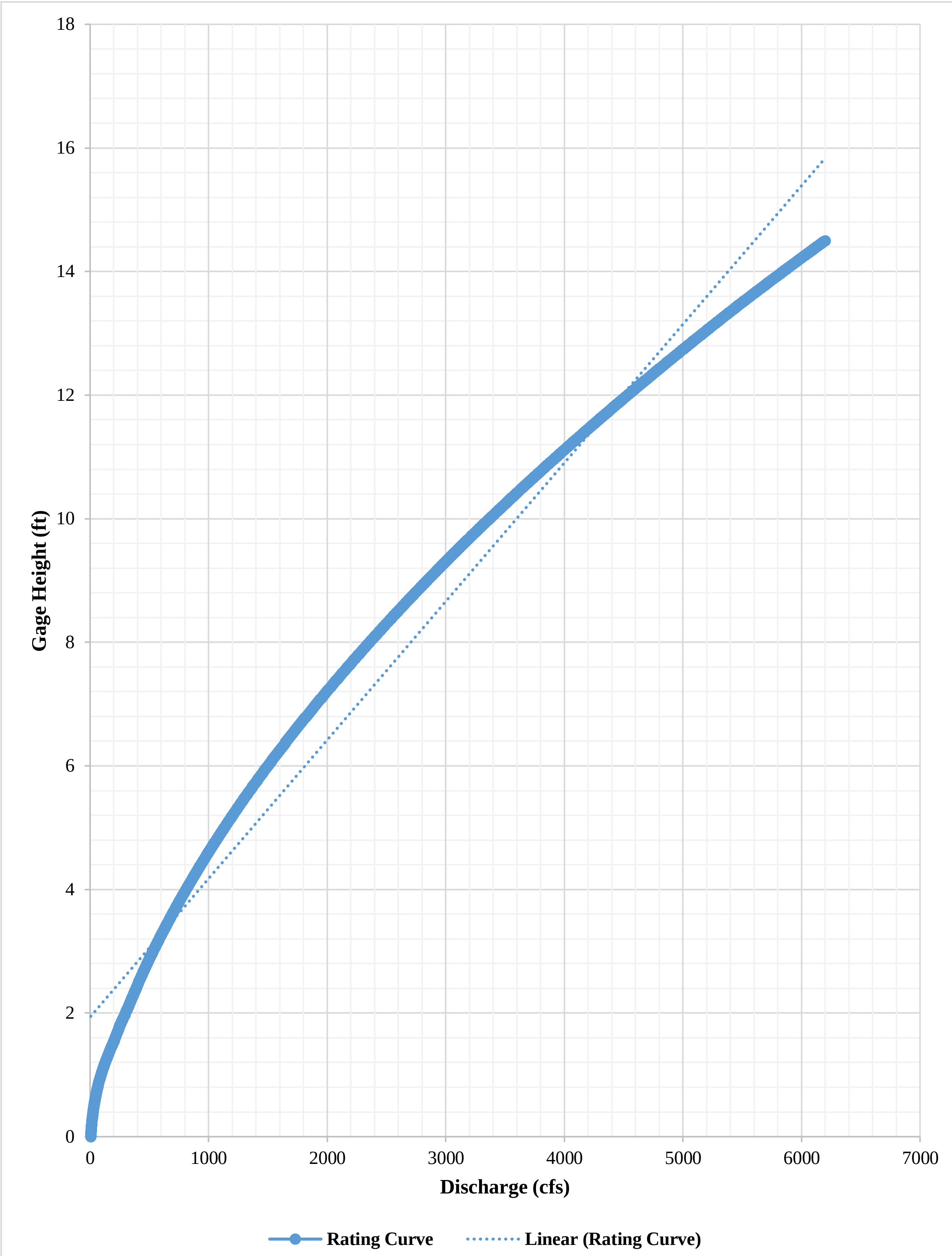

Figure 5.2. Rating curve for 02458300 Village Creek gage station

Table 5.2. Return period and discharge value of flood water

Return Period (Years)	**Discharge (cfs)**	**Percent of Chance of Occurrence in any Given Year (%)**
2	318	50
5	1,153	20
10	2,217	10
25	4,396	4
50	6,787	2
100	9,968	1
200	14,139	0.5

From the above table, it can be said that there is a 1 in 100 chance that a streamflow of 9,968 cubic feet per second (ft^3/s) will occur during any year at a Village Creek gauge station. Thus, a peak flow of 9,968 ft^3/s at the site is said to have 100-year return periods. The term "100-year flood" here used to simplify the definition of a flood that statistically has a 1-percent chance of occurring in any given year. Similarly, the peak flow of 318 ft^3/s, 1,153 ft^3/s, 2,217 ft^3/s, 4,396 ft^3/s, 6,787 ft^3/s, and 14, 149 ft^3/s at the Village Creek gauge station have 2, 5, 10, 25, 50, and 200 years respectively. The flood frequency curve also created to display the possible values of discharges to expect in the river at various return periods (Figure 5.3). Below is the chart that shows the flood frequency curve:

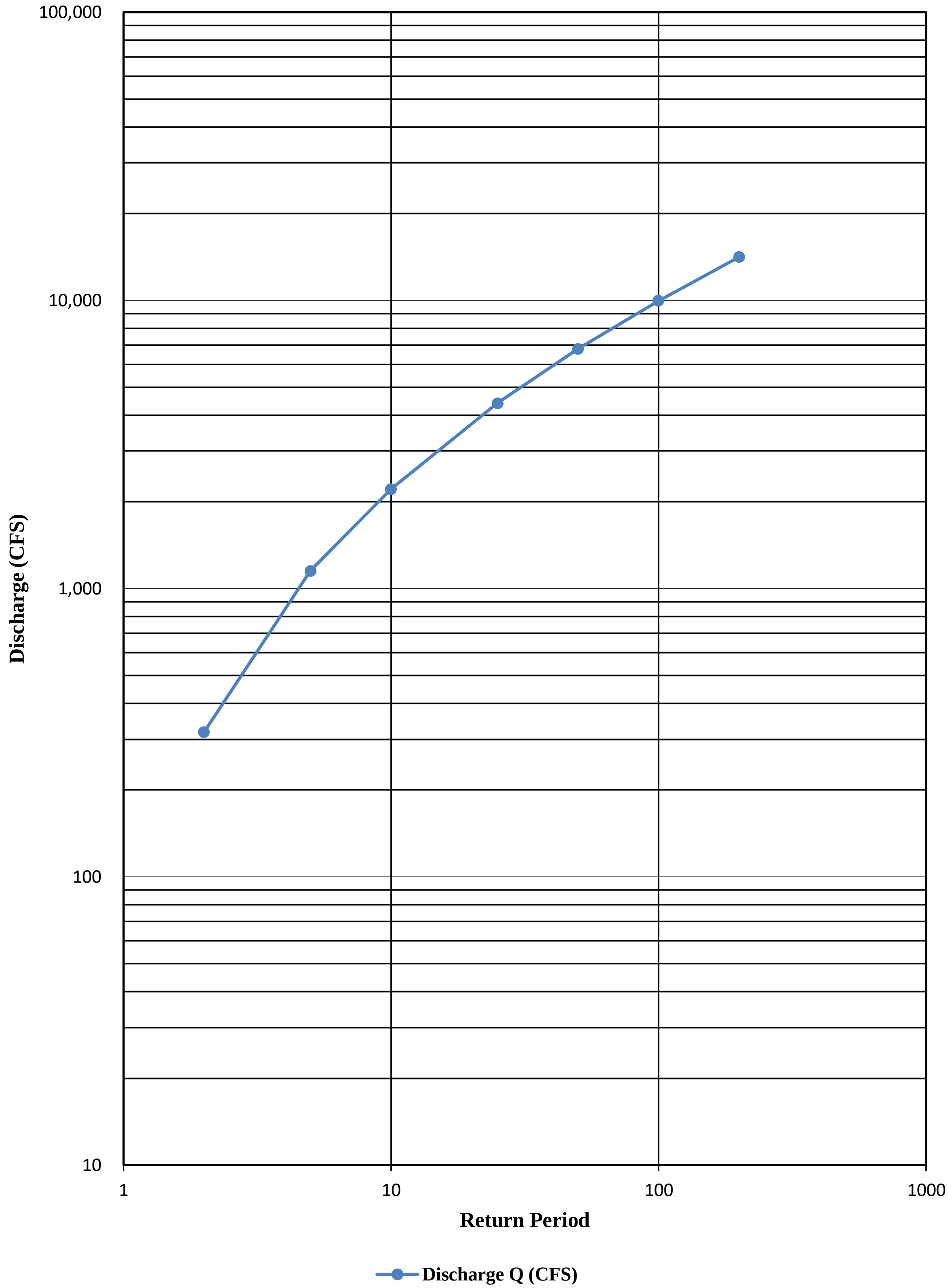

Figure 5.3. Flood frequency curve

Social Vulnerability Assessment

The three sub-components of social vulnerability were used for this study: population, education, and housing (Table 5.3). Each sub-component has several sub-indices, and these sub-indices were normalized to create a social vulnerability map for each sub-component. These separate maps for each sub-component help to analyze each sub-component separately. After analyzing each sub-component separately, these were combined to produce overall social vulnerability map. The GIS techniques were used to show the location and distribution of socially vulnerable populations at Village Creek.

Table 5.3. Total number of each assessed variable for Village Creek 2010

Sub-component of Social Vulnerability	**Variables**	**Total Number of People in Village Creek**	**Total Number of People in Birmingham**
Population	Population under 5 years and over 65 years of age	8,664	62,440
	Population that is Female	21,251	169,573
	Population that is Hispanic	1,570	12,922
	Population that is African-American	34,467	188,602
Education	Population not enrolled in school	28,252	148,570
	Population studied below 12th grade	4,473	23,112
Housing	Housing units that are mobile home	177	3,353
	Housing units that have no vehicles available	2,306	14,286
	Renters	7,173	58,392

Population

Children and elderly people are more vulnerable because of their dependence upon someone else (Morrow 1999). There is a total of 8,664 populations who are under 5 years and over 65 years of age at Village Creek (Table 5.3). These populations make up only 21 percent of the Village Creek's total population. Among the total of 8,664 populations, there is a total number of high, moderate, and low vulnerable population is 2927, 4510, and 1227 respectively that approximates the 33.8 percent, 52.1 percent, and 14.1 percent of the area's total children and elderly population respectively (Table 5.4).

Table 5.4. Level of social vulnerability of children and elderly people

Level of social vulnerability	**Number of population (under 5 years and over 65 years of age)**	**Percentage of Village Creek's total children and elderly population (%)**	**Percentage of Birmingham's total population (%)**
Low	1,227	14.1	0.58
Moderate	4,510	52.1	2.12
High	2,927	33.8	1.38
Total	**8,664**	**100**	**4.08**

Women are more vulnerable because of their family care responsibilities (Cutter 1996) and risk taking behavior (Doocy et. al. 2013). The female population in the Village Creek was 21,251 (Table 5.3). The female population makes up approximately 51.5 percent of area's total population. The number of socially high, moderate, and low vulnerable female population is

7030, 11343, and 2878 respectively that approximates 13.5 percent, 53.4 percent, and 33.1 percent respectively of area's total female population (Table 5.5).

Table 5.5. Level of social vulnerability of female population

Level of social vulnerability	**Number of female population**	**Percentage of Village Creek's total female population (%)**	**Percentage of Birmingham's total population (%)**
Low	2,878	13.5	1.36
Moderate	11,343	53.4	5.34
High	7,030	33.1	3.31
Total	**21,251**	**100**	**10.01**

The Hispanic populations are more vulnerable due to their language and cultural barriers that affect their access to post-disaster funding and residential locations in high hazard areas (Bolin 1993; Peacock et al. 1997, 2000; Bolin and Stanford 1998; Pulido 2000). The total number of Hispanic population in Village Creek is 1,570 that makes up only 3.8 percent of total population (Table 5.3). Among these Hispanic populations, a total number of socially high, moderate, and low vulnerable population is 1012, 463, and 95 that approximates 64.5 percent, 29.4 percent, and 6.1 percent of area's total Hispanic population (Table 5.6).

Table 5.6. Level of social vulnerability of Hispanic population

Level of social vulnerability	**Number of Hispanic population**	**Percentage of Village Creek's total Hispanic population (%)**	**Percentage of Birmingham's total population (%)**
Low	95	6.1	0.04
Moderate	463	29.4	0.22
High	1,012	64.5	0.48
Total	**1,570**	**100**	**0.74**

The African-American people are vulnerable because they are racial minorities in the United States and minorities are likely to be poor (Bianchi and Spain 1996). The number of African-American people in Village Creek is 34,467 that makes up 83.6 percent of area's total population (Table 5.3). The total number of socially high, moderate, and low vulnerable African-American population is 10234, 18896, and 5337 respectively that approximates 29.7 percent, 54.8 percent, and 15.5 percent of area's total African-American population (Table 5.7).

Table 5.7. Level of social vulnerability of African-American population

Level of social vulnerability	**Number of African-American population**	**Percentage of Village Creek's total African-American Population (%)**	**Percentage of Birmingham's total population (%)**
Low	5,337	15.5	2.51
Moderate	18,896	54.8	8.90
High	10,234	29.7	4.82
Total	**34,467**	**100**	**16.23**

After normalizing and analyzing the data of the sub-indices of the population, the social vulnerability map was created to show the spatial distribution of social vulnerability of Village Creek (Figure 5.4). The social vulnerability scores for each block provide a comparative assessment and the blocks mapped in the darker shades of red shows higher level of social vulnerability. There was a total of 9 highly vulnerable blocks for the population sub-components of social vulnerability in Village Creek (Table 5.8). Among the 9 blocks, the people live in the southwest part of the Village Creek are more vulnerable. The people in the northeast part clustered from moderate-to-low vulnerability (Figure 5.4).

Table 5.8. Number of vulnerable blocks for population sub-component

Level of social vulnerability	**Number of Blocks**
Low	13
Moderate	26
High	9
Total	**48**

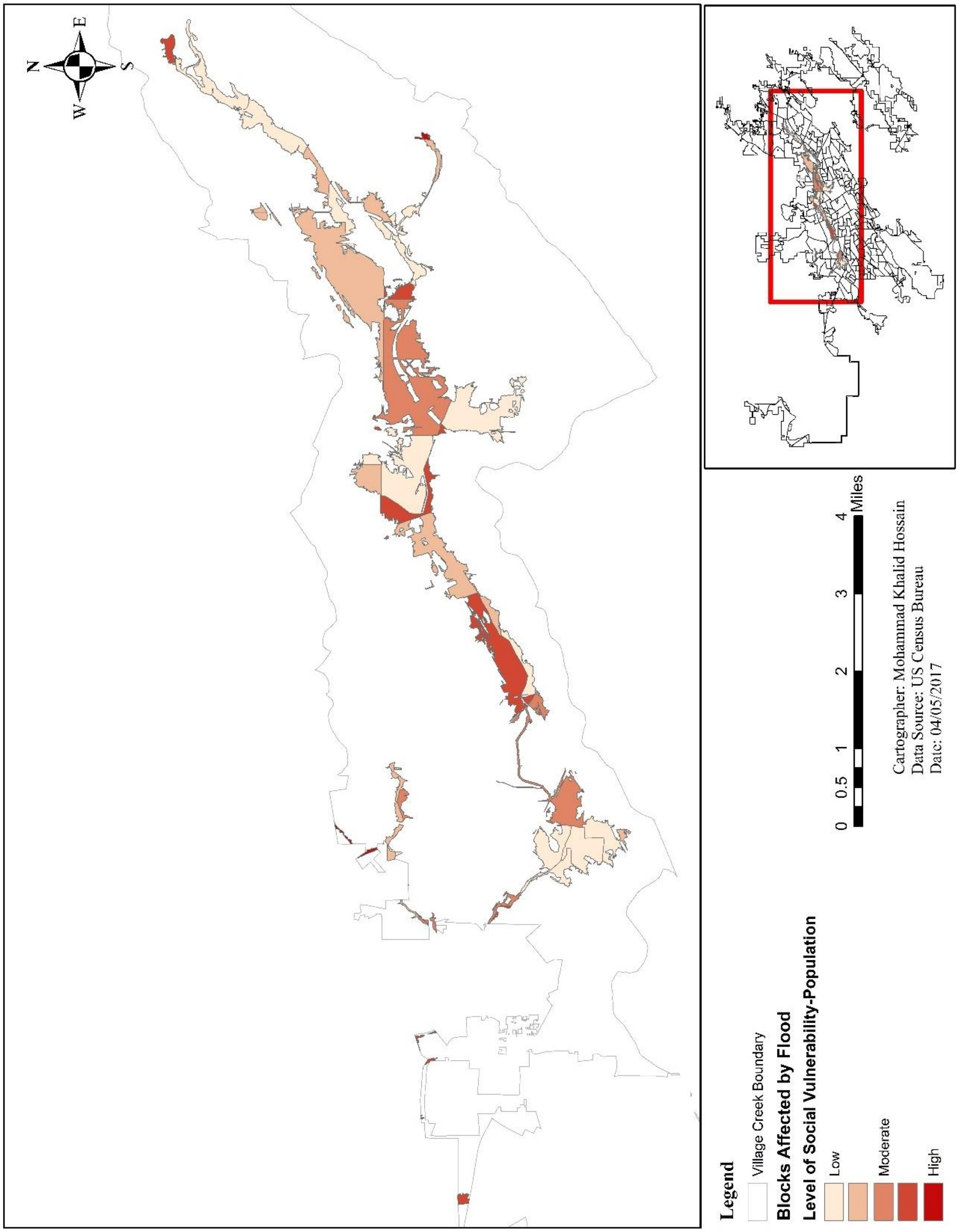

Figure 5.4. Social vulnerability index for population sub-component

Education

Education is the second sub-component of social vulnerability, and under education, there are two sub-indices: population not enrolled in school, and population studied below 12th grade. Lack of education reduces the chances to have better communication linkages and access to useful information that makes them more vulnerable. The people who have a lack of education or low level of education usually do the low-income job, and they cannot afford the disaster risk insurance; thus, they live in high-risk areas (Wamsler et al. 2012).

In the Village Creek, the number of the population who did not enroll in school was 28,252 that makes up 68.5 percent of area's total population (Table 5.3). Among these populations, the total number of socially high, moderate, and low vulnerable population is 12732, 10186, and 5334 respectively that approximates 45.1 percent, 36.1 percent, and 18.8 percent of area's total population who are not enrolled in school (Table 5.9).

Table 5.9. Level of social vulnerability of the population not enrolled in school

Level of social vulnerability	**Number of population not enrolled in school**	**Percentage of Village Creek's total population who are not enrolled in school (%)**	**Percentage of Birmingham's total population (%)**
Low	5334	18.8	2.51
Moderate	10,186	36.1	4.80
High	12,732	45.1	6.00
Total	**28,252**	**100**	**13.31**

There is a total number of 4,473 population who studied below 12th grade in Village Creek, and this makes up only 10.8 percent of area's total population (Table 5.3). The level of social vulnerability was assessed for these populations, and there is a total number of 2234, 1734, and 505 socially high, moderate, and low vulnerable population lives within the Village Creek (Table 5.10). The percentage of the socially high, moderate, and low vulnerable population who studied below 12th grade is 49.9, 38.8, and 11.3 respectively (Table 5.10).

Table 5.10. Level of social vulnerability of the population studied below 12^{th} grade

Level of social vulnerability	**Number of population studied below 12^{th} grade**	**Percentage of Village Creek's total population who studied below 12^{th} grade (%)**	**Percentage of Birmingham's total population (%)**
Low	505	11.3	0.24
Moderate	1,734	38.8	0.82
High	2,234	49.9	1.05
Total	**4,473**	**100**	**2.11**

The spatial distribution of the socially vulnerable population of education sub-component was examined by creating the social vulnerability index map (Figure 5.4). In the map, the darker red color shows the location of highly vulnerable population and light red color indicates the lower vulnerability. There were total 14 highly vulnerable blocks in Village Creek (Table 5.11). The areas of highest vulnerability located southwest part of the Village Creek (Figure 5.5).

Table 5.11. Number vulnerable blocks for education sub-component

Level of social vulnerability	**Number of Blocks**
Low	14
Moderate	20
High	14
Total	**48**

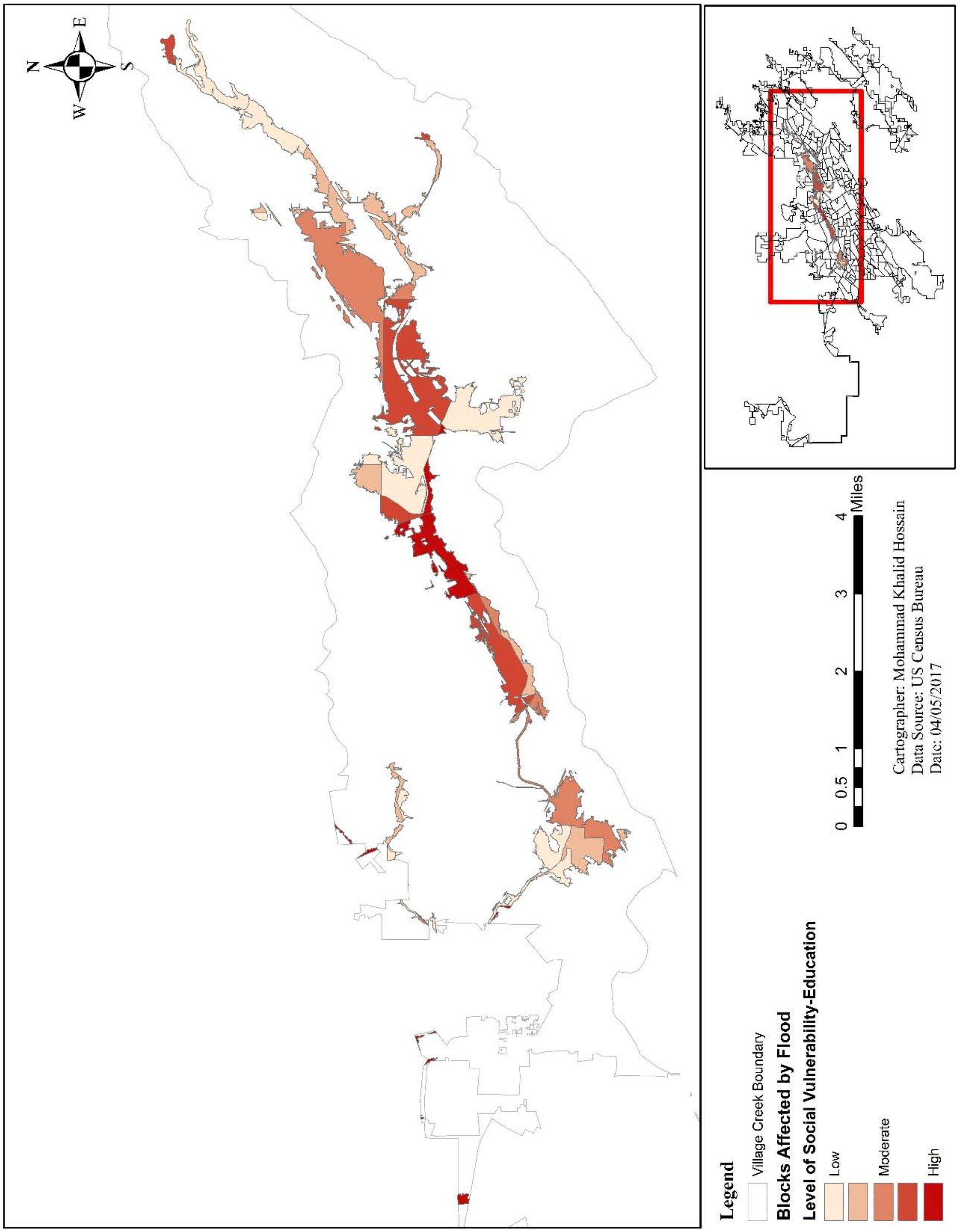

Figure 5.5. Social vulnerability index for education sub-component

Housing

In this research, housing considered as the third sub-component of social vulnerability. There are three sub-indices under housing sub-component: housing units that are mobile homes, housing units that have no vehicle available, and renters.

People who live in mobile homes are more vulnerable because mobile homes are easily destroyed and less resilient to hazards due to their weak infrastructure (Bolin and Stanford 1991; Heinz Center for Science, Economics, and the Environment 2000; Cutter et al. 2000). There was a total of 177 mobile homes in Village Creek (Table 5.3). Among these mobile homes, 121 mobile homes are highly vulnerable that approximates 68.4 percent of area's total mobile homes (Table 5.12).

Table 5.12. Level of social vulnerability of mobile homes

Level of social vulnerability	**Number of mobile homes**	**Percentage of Village Creek's total mobile homes (%)**	**Percentage of Birmingham's total mobile homes (%)**
Low	6	3.4	0.18
Moderate	50	28.2	1.49
High	121	68.4	3.61
Total	**177**	**100**	**5.28**

People who do not have vehicles available in their housing units are considered as vulnerable because the lack of access to transportation caused the failure of evacuation plans (Elliott and Pais 2006) and, they will be not able to return their home in the post-disaster period. In Village Creek, there was a total of 2,306 housing units that do not have any vehicle available

(Table 5.3). The total number of high, moderate, and low vulnerable housing units that do not have vehicles available were 809, 1305, and 192 respectively (Table 5.13).

Table 5.13. Level of social vulnerability of housing units that do not have vehicle available

Level of social vulnerability	Number of housing units that do not have vehicles available	Percentage of Village Creek's total population who do not have access to vehicle (%)	Percentage of Birmingham's total population (%)
Low	192	8.3	0.09
Moderate	1,305	56.6	0.61
High	809	35.1	0.38
Total	**2,306**	**100**	**1.08**

Renters are also considered as vulnerable because of their dependence on landlords who are responsible for repairing or rebuilding the houses after the disaster that left the renters homeless (Morrow 1999). In Village Creek, 7,173 people rent a house that accounts approximately 17.4 percent of area's total population (Table 5.3). Among the renters, there was a total of 2,176 people who are highly vulnerable that approximates 30.3 percent of area's total renters' population (Table 5.14).

Table 5.14. Level of social vulnerability of renters

Level of social vulnerability	Number of population who rent the house	Percentage of Village Creek's renters' population (%)	Percentage of Birmingham's total population (%)
Low	801	11.2	0.38
Moderate	4,196	58.5	1.98
High	2,176	30.3	1.03
Total	**7,173**	**100**	**3.37**

The social vulnerability map was created for the housing sub-component to show the spatial distribution of vulnerable population throughout the flood affected area of Village Creek (Figure 5.6). The dark red color shows the high vulnerability, and the light red color shows the low vulnerability. There was a total of 8 blocks that are highly vulnerable due to housing sub-component (Table 5.15). The people live in the southwest and northeast part of the Village Creek clustered from moderate-to-low vulnerability (Figure 5.6).

Table 5.15. Number of vulnerable blocks for housing sub-component

Level of social vulnerability	**Number of Blocks**
Low	15
Moderate	25
High	8
Total	**48**

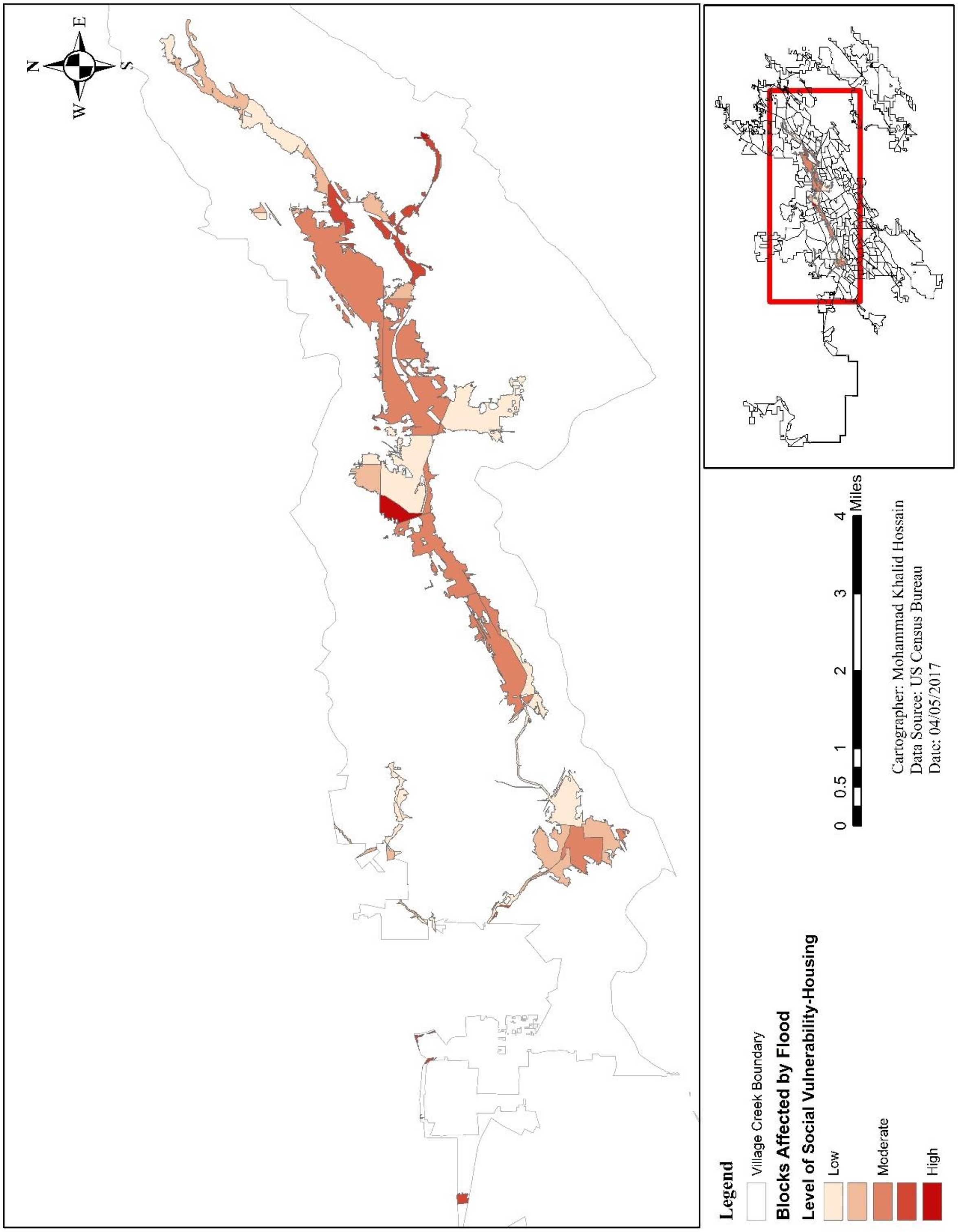

Figure 5.6. Social vulnerability index of housing sub-component

Overall Social Vulnerability Index

Understanding the distribution of social vulnerability within Village Creek is an integral part of planning, and mitigating against the area's flood risk. In this study, three sub-components of social vulnerability were assessed: population, education, and housing. Theses three-subcomponents were normalized and displayed using GIS to show the spatial variation of the overall social vulnerability of Village Creek (Figure 5.6). The social vulnerability scores for each block provide a comparative assessment and the blocks mapped in the darker shades of red shows higher level of social vulnerability. The total number of highly vulnerable blocks were 9 (Table 5.16). There was total of 31 blocks out of 48 blocks that are moderate to high vulnerable, and this indicates that the vulnerable populations are well distributed throughout the area. The southwest and northeast part of the Village Creek is clustering from high-to-moderate levels of social vulnerability (Figure 5.7).

Table 5.16. Number of vulnerable blocks for overall social vulnerability

Level of social vulnerability	**Number of Blocks**
Low	8
Moderate	31
High	9
Total	**48**

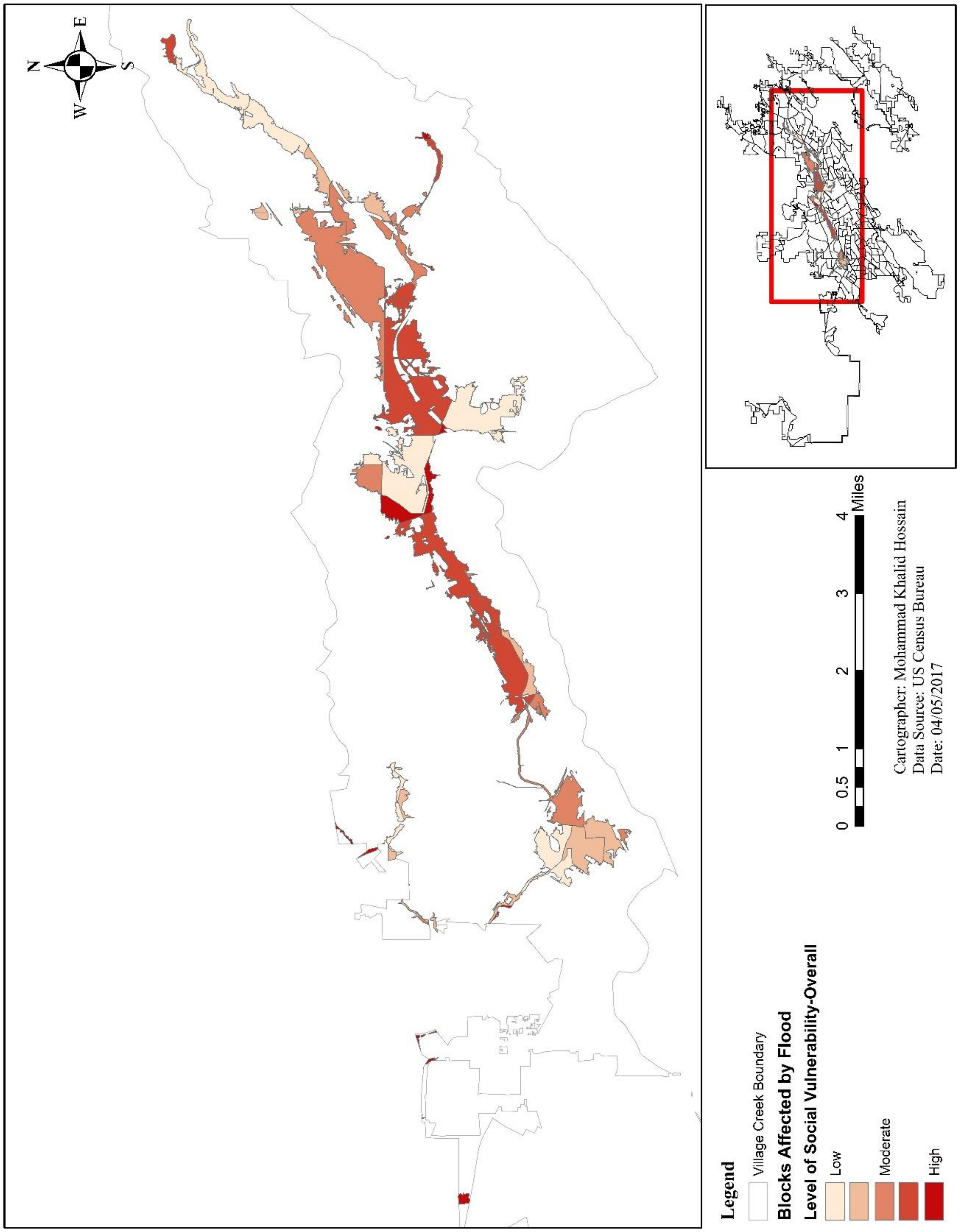

Figure 5.7. Overall social vulnerability index

Physical Vulnerability Assessment

The roads and buildings were considered as a factor of physical vulnerability in this research. The impact of flooding on buildings and roads can be extensive. People left trapped in homes when the road covered by flood waters that delayed the recovery process. Flooding also caused the physical damage to buildings and buildings can be damaged due to slow rising flood waters. Thus, many people who live in urban areas left homeless and stuck for days due to flooding. It also takes time for the community to recover if a large number of buildings and roads impacted by the flood.

Among the buildings, only residential and commercial buildings were used to assess the physical vulnerability of Village Creek. The buildings data were collected from the City of Birmingham office, and according to the data, there was a total of 46,683 residential buildings and 2,785 commercial buildings in Village Creek (Table 5.17). In GIS, the layer of residential and commercial buildings was displayed over the layer of flood hazard area. Then the intersect tool in geoprocessing was used to identify the vulnerable buildings (commercial and residential) within the flood hazard area. The total number of residential and commercial buildings that will be impacted by the flood is 3,229 and 459 respectively (Table 5.17). The total number of residential and commercial buildings in Birmingham was 119,531 and 5,882 respectively. During the flood event 2.7 percent of residential buildings and 0.38 percent of commercial buildings of Birmingham will be affected (Table 5.17). The physical vulnerability maps for the residential and commercial buildings were created to show the location of these vulnerable buildings in Village Creek (Figure 5.8 and 5.9).

Table 5.17. Number of vulnerable buildings

Buildings type	Total number of buildings in Village Creek	Total number of Buildings in Birmingham	Number of buildings within 100-year floodplain in Village Creek	Percentage of Birmingham's total buildings (%)
Residential	46,683	119,531	3,229	2.70
Commercial	2,785	5,882	459	0.38

Roads are another factor that considered to assess the physical vulnerability due to flood hazards. The roads data were collected from the U.S. Census Bureau website, and according to the data of 2010, there was a total of 2317.70 miles and 981.6 miles of roads in Birmingham and Village Creek respectively (Table 5.18). In GIS, the layer of the road was displayed over the layer of flood hazard area. Then the intersect tool in geoprocessing was used to identify the vulnerable roads within the flood hazard area. The flood hazard impact on the road was moderate with 91 miles of roads within the flood hazard area (Table 5.18). That means, during the flood, approximately 9.3 percent of the Village Creek's total roads and 3.92 percent of Birmingham's total roads will be damaged. These damaged roads were shown in red colors in the map of physical vulnerability (Figure 5.10).

Table 5.18. Total miles and percentage of damaged roads

Total mile(s) of roads in Birmingham	Total mile(s) of Roads in Village Creek	Total mile(s) of damaged roads	Percentage (%) of damaged roads	Percentage of Birmingham's total roads (%)
2317.70	981.6	91	9.3	3.92

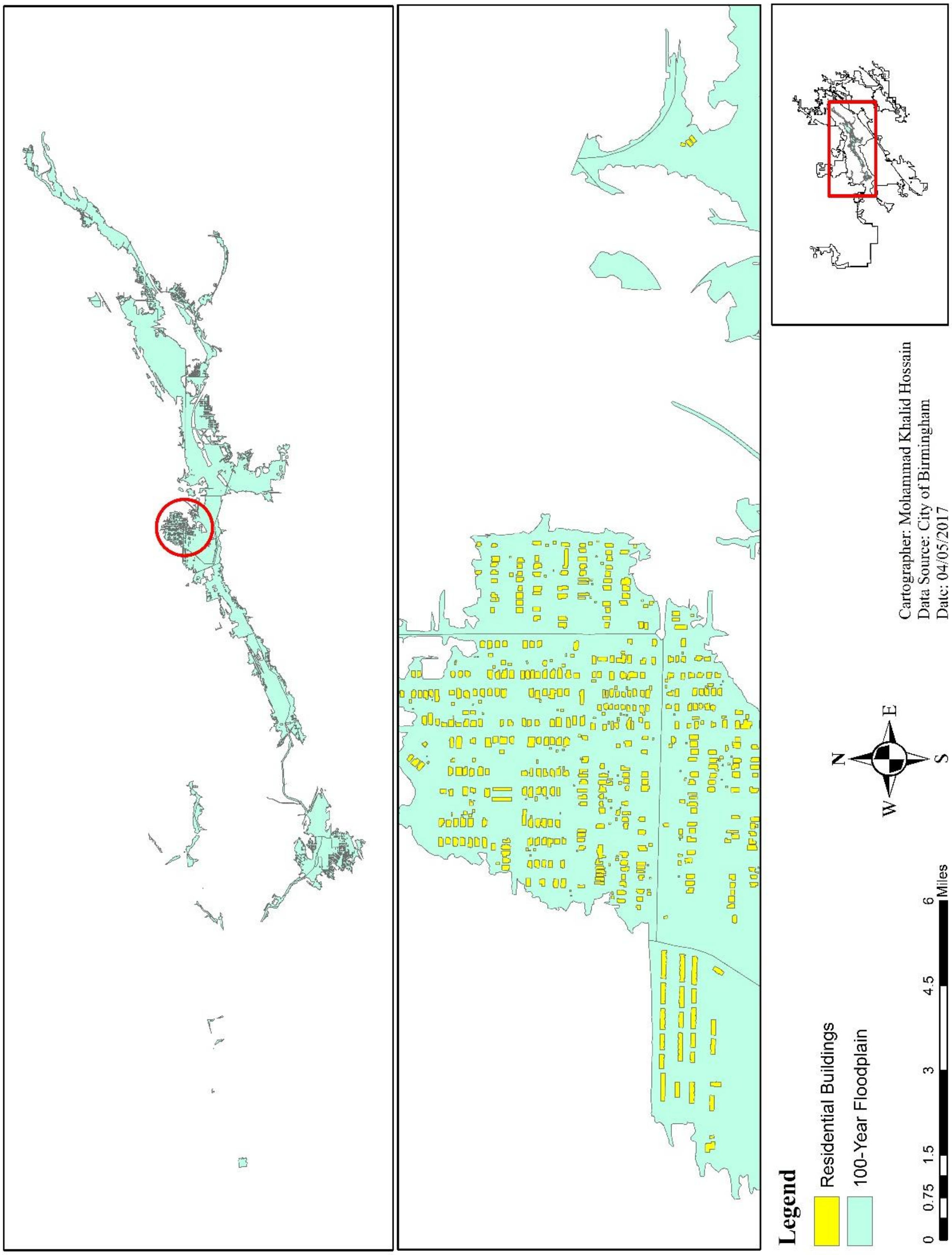

Figure 5.8. Residential buildings that are within 100-year floodplain

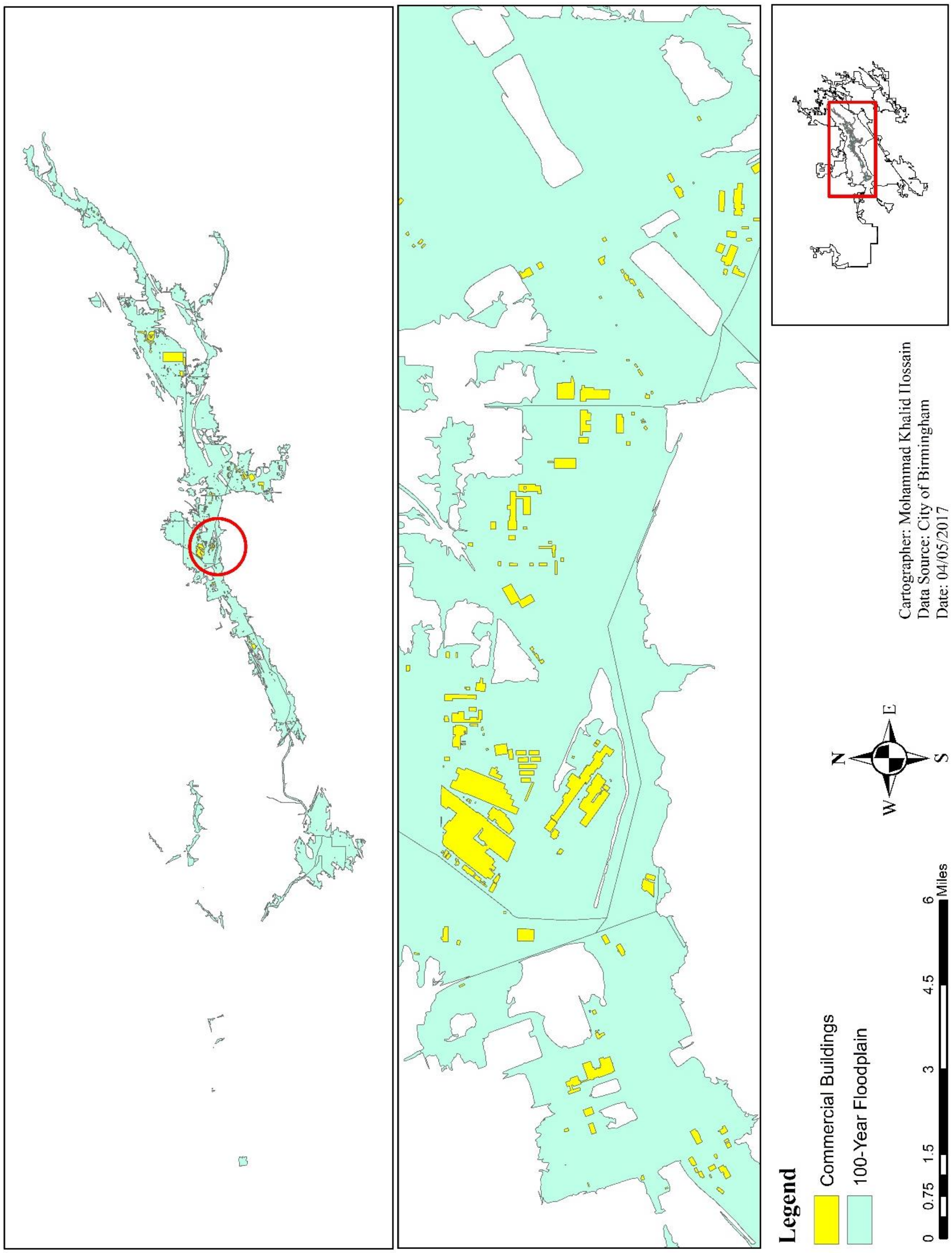

Figure 5.9. Commercial buildings that are within 100-year floodplain

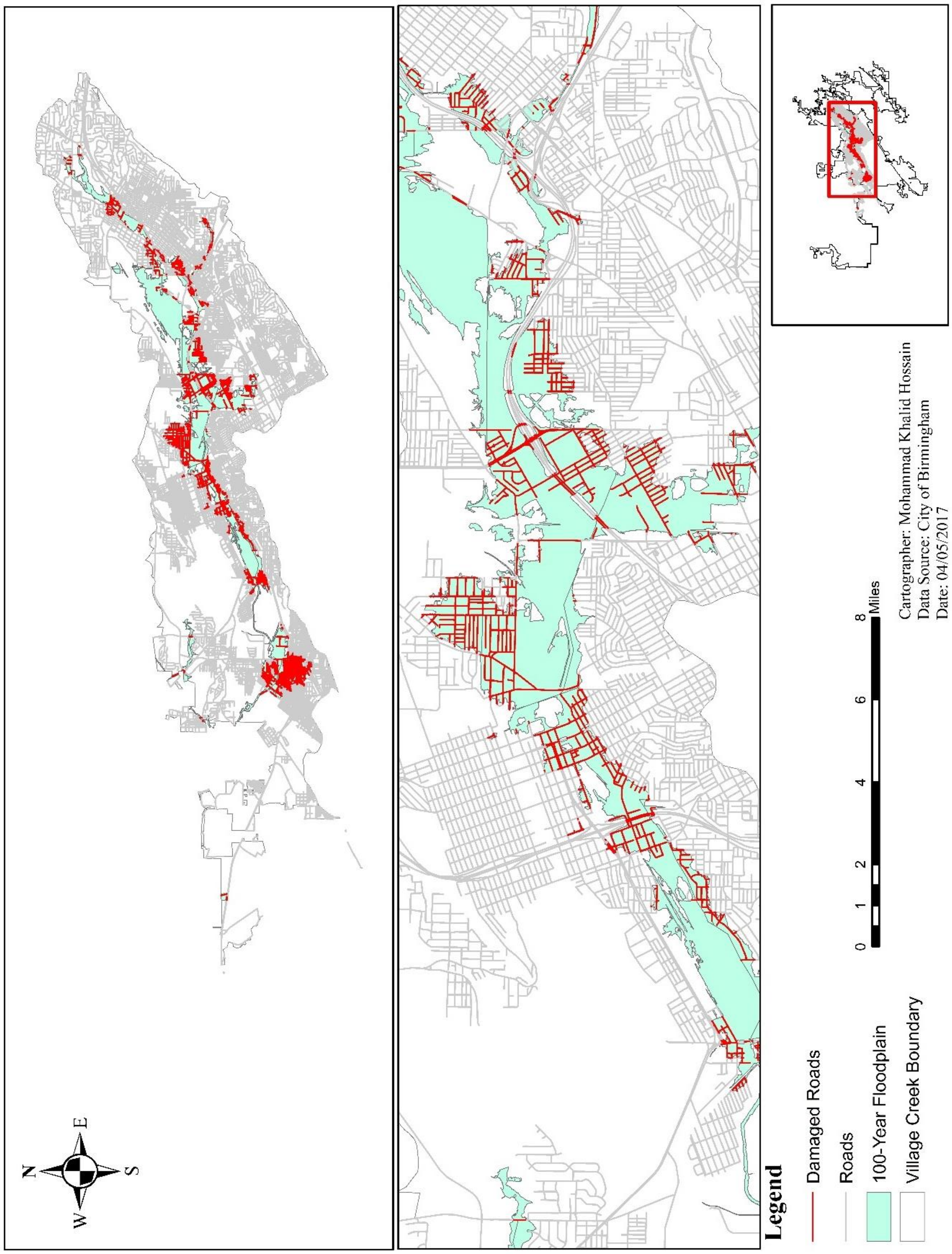

Figure 5.10. Vulnerable roads

Chapter 6

Summary and Conclusions

Research Question Conclusions

1. **What is the history of flood activity in Village Creek, Birmingham, AL?**

From 1995 to 2015, there was a total of 14 flood events occurred in Village Creek. Among these floods, the maximum amount of damages was recorded in 2014. Village Creek has the peak activity of floods between the months of January to April. The highest gage height of 5.32 feet was recorded in 2003, and the lowest gage height of 0.43 feet was recorded in 2004. Based on the history of flood activity in Village Creek, it can be determined that the average gage height of each flood event would be 2.23 feet. The flood frequency analysis also has been conducted by using the 20 years' historical flood data. The return periods were also calculated to estimate the likelihood of flood to occur in 1.43 years.

2. **What would be the most likely and the worst-case scenario regarding flood frequency in Village Creek, Birmingham, AL?**

To predict the most likely and worst-case scenario a substantially longer record than the 20 years of data presently available is required. Plus, the stream gage data needs to be analysed with sophisticated flood inundation modeling software to simulate how urban development (houses, roads, etc.) would influence flood depths. In this case for the Village Creek, it was not possible to determine what would be the most likely and worst-case scenario regarding the flood frequency in Village Creek, Birmingham, Alabama.

3. **Where are the socially vulnerable populations located in Village Creek, Birmingham, AL?**

In this research, three sub-components of social vulnerability were used to assess the social vulnerability of populations. The social vulnerability index was created for each sub-component and mapped separately. For the population sub-component, the number of highest vulnerable female population, children and elderly, Hispanic, and African-American population was 7030, 2927, 1012, and 10234 respectively. Most of them are in the southwest part of the Village Creek. In total, under the population sub-component of social vulnerability, there are 21,203 highly vulnerable people in Birmingham that is approximately 10 percent of Birmingham's total population.

The populations under the education sub-component are more vulnerable around the southwest and east part of the Village Creek. The total number of the socially high vulnerable population who are not enrolled in school and have studied below 12th grade is 12,732 and 2,234 respectively. For the entire Birmingham, the total number of socially high vulnerable people under the education sub-component is 14,966 that is approximately 7.05 percent of city's total population.

The total number of the vulnerable population also calculated for the housing sub-component of social vulnerability. There are 2,176 people who rent the houses, 809 people who do not have access to the vehicle, and 121 mobile homes are socially highly vulnerable. Most of these vulnerable population located in the southwest and northeast part of the Village Creek. For the Birmingham, the total number of socially high vulnerable people that are under housing sub-component is 3,106 that is approximately 1.46 percent of city's total population.

The overall social vulnerability index map was created by combining these three sub-components that show the location of the vulnerable population. Overall the most vulnerable populations are located in the southwest and northeast part of the Village Creek.

4. **Where are the vulnerable buildings and infrastructure in Village Creek, Birmingham, AL?**

Roads and buildings were assessed as the factor of physical vulnerability. In this research, only residential and commercial buildings were considered for the physical vulnerability assessment and the physical vulnerability maps were created to show the location of these vulnerable buildings. The number of vulnerable residential and commercial buildings were 3,229 and 459 respectively that is approximately 2.70 percent of city's total residential buildings and 0.38 percent of city's total commercial buildings. There are total 981.6 miles of roads in Village Creek and if the flood occurs then the 91 miles of road will be damaged that is approximately 3.92 percent of Birmingham's total roads.

Summary

The Village Creek in Birmingham is the most flood prone area and risk assessment should be conducted for this area in every couple of years as the demographic data changes every year. This assessment highlighted the areas of vulnerability to flood hazard and will help the local government and Emergency Management Agency (EMA) officials to take actions against any future flood hazards event. In community planning, this type of natural hazard risk assessment is also essential. Risk assessment not only help to reduce the risk but also help to build the resilience (Cutter et al. 2008). Therefore, this flood risk assessment will help the community of Village Creek to prepare better in future.

The limitations of this study are the availability of data. The data was available only for the 20 years and available only for the Village Creek area. The 20 years of data were not sufficient to predict the most likely and worst-case scenario regarding the flood frequency.

This study analyzed the historical flood activity and showed the report of flood frequency in Village Creek. It included the peak month of flood activity as well as gage height of each flood events. The social vulnerability maps were also produced to show the location of the highest and lowest vulnerable populations for each sub-component separately. These maps will help the Emergency Management Agency to find out the socially vulnerable populations according to social vulnerability factors. By combining all social vulnerability factors, an overall social vulnerability map was created to show the areas of highest vulnerability in the event of a flood. Finally, the physical vulnerability maps were produced to show the vulnerable infrastructure and damaged roads of Village Creek during the flood events.

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Appendix 1

Appendix 1.1. Frequency Factors K for Gamma and log-Pearson Type III Distributions

Frequency Factors K for Gamma and log-Pearson Type III Distributions
(Haan, 1977, Table 7.7)

	Recurrence Interval In Years							
	1.0101	**2**	**5**	**10**	**25**	**50**	**100**	**200**
SKEW COEFFICIENT	**Percent Chance (>=) = 1-F**							
Cs	**99**	**50**	**20**	**10**	**4**	**2**	**1**	**0.5**
3	-0.667	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	-0.690	-0.390	0.440	1.195	2.277	3.134	4.013	4.904
2.8	-0.714	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	-0.740	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	-0.867	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	-0.946	-0.319	0.592	1.294	2.230	2.942	3.656	4.372
2	-0.990	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.140	-0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	-1.256	-0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	-1.518	-0.180	0.745	1.341	2.066	2.585	3.087	3.575
1	-1.588	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.9	-1.660	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.7	-1.806	-0.116	0.790	1.333	1.967	2.407	2.824	3.223
0.6	-1.880	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-0.083	0.808	1.323	1.910	2.311	2.686	3.041
0.4	-2.029	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.3	-2.104	-0.050	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.400	2.67
0	-2.326	0.000	0.842	1.282	1.751	2.054	2.326	2.576

	Recurrence Interval In Years							
	1.0101	**2**	**5**	**10**	**25**	**50**	**100**	**200**
SKEW COEFFICIENT	**Percent Chance (>=) = 1-F**							
Cs	**99**	**50**	**20**	**10**	**4**	**2**	**1**	**0.5**
0	-2.326	0.000	0.842	1.282	1.751	2.054	2.326	2.576
-0.1	-2.4	0.017	0.846	1.27	1.716	2.000	2.252	2.482
-0.2	-2.472	0.033	0.850	1.258	1.680	1.945	2.178	2.388
-0.3	-2.544	0.050	0.853	1.245	1.643	1.890	2.104	2.294
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	-2.755	0.099	0.857	1.200	1.528	1.720	1.880	2.016
-0.7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	-2.957	0.148	0.854	1.147	1.407	1.549	1.660	1.749
-1	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.180	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.210	0.838	1.064	1.240	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.270	1.318	1.351
-1.5	-3.33	0.240	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.880	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.970	1.075	1.116	1.140	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.920	0.996	1.023	1.037	1.044
-2	-3.605	0.307	0.777	0.895	0.959	0.980	0.990	0.995
-2.1	-3.656	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	0.330	0.752	0.844	0.888	0.900	0.905	0.907
-2.3	-3.753	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	-3.800	0.351	0.725	0.795	0.823	0.830	0.832	0.833
-2.5	-3.845	0.360	0.711	0.711	0.793	0.798	0.799	0.800
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	0.376	0.681	0.724	0.738	0.740	0.740	0.741
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	0.390	0.651	0.681	0.683	0.689	0.690	0.690
-3	-4.051	0.396	0.636	0.660	0.666	0.666	0.667	0.667

Appendix 1.2. Mean values of gage height for each day. Source: USGS

00065, Gage height, feet,												
Day of month	Mean of daily mean values for each day for 22 - 28 years of record in, ft (Calculation Period 1987-10-01 -> 2016-09-30) Calculation period restricted by USGS staff due to special conditions at/near site											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.62	0.63	0.69	0.67	0.47	0.52	0.54	0.43	0.34	0.41	0.48	0.43
2	0.61	0.68	0.76	0.66	0.49	0.46	0.51	0.40	0.42	0.34	0.41	0.46
3	0.55	0.73	0.81	0.96	0.72	0.47	0.40	0.41	0.65	0.36	0.36	0.45
4	0.60	0.67	0.66	0.81	0.70	0.50	0.54	0.40	0.55	0.41	0.49	0.61
5	0.73	0.66	0.91	0.67	0.60	0.53	0.48	0.40	0.65	0.32	0.44	0.49
6	0.72	0.93	0.98	0.69	0.55	0.50	0.48	0.50	0.42	0.36	0.45	0.54
7	0.90	0.63	0.85	0.84	0.64	0.50	0.42	0.40	0.35	0.39	0.50	0.49
8	0.67	0.58	0.74	0.73	0.60	0.51	0.49	0.46	0.34	0.32	0.40	0.55
9	0.61	0.58	0.91	0.58	0.57	0.47	0.46	0.38	0.35	0.35	0.52	0.58
10	0.60	0.73	0.93	0.57	0.58	0.48	0.54	0.40	0.32	0.40	0.58	0.82
11	0.81	0.67	0.80	0.62	0.49	0.52	0.53	0.43	0.35	0.30	0.56	0.59
12	0.70	0.63	0.75	0.59	0.47	0.49	0.52	0.52	0.41	0.41	0.46	0.50
13	0.69	0.66	0.68	0.59	0.58	0.54	0.65	0.42	0.35	0.34	0.38	0.61
14	0.64	0.58	0.66	0.61	0.54	0.54	0.49	0.44	0.37	0.42	0.41	0.61
15	0.63	0.72	0.79	0.67	0.50	0.52	0.49	0.36	0.32	0.39	0.51	0.49
16	0.54	0.79	0.85	0.59	0.49	0.52	0.47	0.34	0.64	0.32	0.51	0.62
17	0.68	0.71	0.65	0.54	0.52	0.47	0.38	0.37	0.48	0.39	0.37	0.52
18	0.65	0.62	0.60	0.53	0.61	0.49	0.36	0.40	0.43	0.35	0.39	0.56
19	0.69	0.69	0.70	0.63	0.44	0.47	0.38	0.35	0.43	0.33	0.36	0.49
20	0.61	0.62	0.76	0.67	0.51	0.42	0.43	0.38	0.42	0.31	0.48	0.52
21	0.73	0.77	0.67	0.63	0.57	0.49	0.51	0.47	0.56	0.33	0.51	0.47
22	0.65	0.82	0.65	0.52	0.43	0.54	0.58	0.39	0.57	0.42	0.63	0.62
23	0.83	0.73	0.73	0.48	0.38	0.47	0.52	0.33	0.47	0.31	0.49	0.74
24	0.88	0.55	0.63	0.56	0.42	0.51	0.44	0.42	0.42	0.32	0.62	0.85
25	0.71	0.78	0.62	0.55	0.42	0.46	0.38	0.40	0.48	0.34	0.42	0.63
26	0.81	0.72	0.63	0.56	0.40	0.48	0.51	0.42	0.45	0.41	0.51	0.50
27	0.62	0.80	0.74	0.59	0.43	0.50	0.52	0.41	0.39	0.37	0.60	0.58
28	0.62	0.87	0.76	0.55	0.61	0.58	0.47	0.34	0.36	0.37	0.61	0.74
29	0.71	0.47	0.68	0.54	0.56	0.52	0.51	0.36	0.40	0.33	0.50	2.17
30	0.81		0.75	0.60	0.47	0.45	0.45	0.39	0.34	0.31	0.50	0.51
31	0.62		0.77		0.52		0.56	0.46		0.34		0.61

Appendix 1.3. Discharge and gage height data of 02458300 Village Creek gage station, 1995-2015

Discharge (cfs)	Gage Height (feet)
5.2	0.02
5.48	0.01
5.77	0
6.06	0.01
6.37	0.02
6.69	0.03
7.02	0.04
7.35	0.05
7.7	0.06
8.04	0.07
8.39	0.08
8.74	0.09
9.11	0.1
9.48	0.11
9.87	0.12
10.26	0.13
10.66	0.14
11.08	0.15
11.5	0.16
11.93	0.17
12.36	0.18
12.81	0.19
13.26	0.2
13.73	0.21
14.2	0.22
14.69	0.23
15.18	0.24
15.69	0.25
16.2	0.26
16.77	0.27
17.34	0.28
17.93	0.29
18.54	0.3
19.15	0.31
19.78	0.32
20.42	0.33

21.08	0.34
21.75	0.35
22.43	0.36
23.12	0.37
23.83	0.38
24.55	0.39
25.29	0.4
26.04	0.41
26.8	0.42
27.58	0.43
28.37	0.44
29.18	0.45
30	0.46
30.78	0.47
31.57	0.48
32.38	0.49
33.19	0.5
34.02	0.51
34.86	0.52
35.72	0.53
36.58	0.54
37.46	0.55
38.36	0.56
39.26	0.57
40.18	0.58
41.11	0.59
42.05	0.6
43.01	0.61
43.98	0.62
44.97	0.63
45.96	0.64
46.98	0.65
48	0.66
49.04	0.67
50.09	0.68
51.15	0.69
52.23	0.7
53.33	0.71
54.43	0.72
55.55	0.73
56.69	0.74

57.84	0.75
59	0.76
60.2	0.77
61.42	0.78
62.65	0.79
63.9	0.8
65.16	0.81
66.44	0.82
67.74	0.83
69.05	0.84
70.37	0.85
71.71	0.86
73.07	0.87
74.44	0.88
75.83	0.89
77.24	0.9
78.66	0.91
80.09	0.92
81.54	0.93
83.01	0.94
84.5	0.95
86	0.96
87.53	0.97
89.09	0.98
90.65	0.99
92.24	1
93.84	1.01
95.46	1.02
97.1	1.03
98.76	1.04
100.43	1.05
102.12	1.06
103.83	1.07
105.55	1.08
107.29	1.09
109.05	1.1
110.83	1.11
112.63	1.12
114.45	1.13
116.28	1.14
118.13	1.15

120	1.16
121.83	1.17
123.69	1.18
125.55	1.19
127.44	1.2
129.34	1.21
131.26	1.22
133.2	1.23
135.16	1.24
137.13	1.25
139.12	1.26
141.13	1.27
143.15	1.28
145.2	1.29
147.26	1.3
149.34	1.31
151.43	1.32
153.55	1.33
155.68	1.34
157.83	1.35
160	1.36
162.09	1.37
164.2	1.38
166.33	1.39
168.47	1.4
170.63	1.41
172.8	1.42
175	1.43
177.2	1.44
179.43	1.45
181.67	1.46
183.93	1.47
186.2	1.48
188.49	1.49
190.8	1.5
193.12	1.51
195.47	1.52
197.82	1.53
200.2	1.54
202.59	1.55
205	1.57

207	1.58
209.02	1.59
211.04	1.6
213.08	1.61
215.12	1.62
217.18	1.63
219.24	1.64
221.32	1.65
223.4	1.66
225.5	1.67
227.6	1.68
229.72	1.69
231.84	1.7
233.98	1.71
236.12	1.72
238.28	1.73
240.44	1.74
242.62	1.75
244.8	1.76
247	1.78
249.34	1.79
251.69	1.8
254.05	1.81
256.42	1.82
258.8	1.83
261.2	1.84
263.61	1.85
266.03	1.86
268.46	1.87
270.9	1.88
273.36	1.89
275.83	1.9
278.31	1.91
280.8	1.92
283.3	1.93
285.82	1.94
288.34	1.95
290.88	1.96
293.44	1.97
296	1.98
298.36	2

300.73	2.01
303.1	2.02
305.49	2.03
307.88	2.04
310.29	2.05
312.7	2.06
315.13	2.07
317.56	2.08
320	2.09
322.28	2.1
324.57	2.11
326.86	2.12
329.16	2.13
331.47	2.14
333.79	2.15
336.11	2.16
338.45	2.17
340.78	2.18
343.13	2.2
345.48	2.21
347.85	2.22
350.21	2.23
352.59	2.24
354.97	2.25
357.36	2.26
359.76	2.27
362.17	2.28
364.58	2.29
367	2.3
369.11	2.31
371.22	2.32
373.34	2.33
375.46	2.34
377.58	2.35
379.71	2.36
381.85	2.37
383.98	2.38
386.13	2.39
388.28	2.4
390.43	2.41
392.58	2.42

394.75	2.43
396.91	2.44
399.08	2.45
401.26	2.46
403.44	2.47
405.62	2.48
407.81	2.49
410	2.5
412.3	2.51
414.61	2.52
416.92	2.53
419.23	2.54
421.55	2.55
423.88	2.56
426.21	2.57
428.55	2.58
430.89	2.59
433.24	2.6
435.59	2.61
437.94	2.62
440.31	2.63
442.67	2.64
445.05	2.65
447.42	2.66
449.81	2.67
452.2	2.68
454.59	2.69
456.99	2.7
459.39	2.71
461.8	2.72
464.21	2.73
466.63	2.74
469.05	2.75
471.48	2.76
473.92	2.77
476.36	2.78
478.8	2.79
481.25	2.8
483.7	2.81
486.16	2.82
488.63	2.83

491.1	2.84
493.57	2.85
496.05	2.86
498.53	2.87
501.02	2.88
503.52	2.89
506.02	2.9
508.52	2.91
511.03	2.92
513.55	2.93
516.07	2.94
518.59	2.95
521.12	2.96
523.65	2.97
526.19	2.98
528.74	2.99
531.29	3
533.84	3.01
536.4	3.02
538.97	3.03
541.54	3.04
544.11	3.05
546.69	3.06
549.27	3.07
551.86	3.08
554.46	3.09
557.05	3.1
559.66	3.11
562.27	3.12
564.88	3.13
567.5	3.14
570.12	3.15
572.75	3.16
575.38	3.17
578.02	3.18
580.67	3.19
583.31	3.2
585.97	3.21
588.62	3.22
591.29	3.23
593.95	3.24

596.63	3.25
599.3	3.26
601.98	3.27
604.67	3.28
607.36	3.29
610.06	3.3
612.76	3.31
615.47	3.32
618.18	3.33
620.89	3.34
623.61	3.35
626.34	3.36
629.07	3.37
631.81	3.38
634.55	3.39
637.29	3.4
640.04	3.41
642.79	3.42
645.55	3.43
648.32	3.44
651.09	3.45
653.86	3.46
656.64	3.47
659.42	3.48
662.21	3.49
665	3.5
667.78	3.51
670.57	3.52
673.36	3.53
676.16	3.54
678.96	3.55
681.76	3.56
684.57	3.57
687.39	3.58
690.21	3.59
693.03	3.6
695.86	3.61
698.69	3.62
701.53	3.63
704.38	3.64
707.22	3.65

710.07	3.66
712.93	3.67
715.79	3.68
718.66	3.69
721.53	3.7
724.4	3.71
727.28	3.72
730.17	3.73
733.06	3.74
735.95	3.75
738.85	3.76
741.75	3.77
744.66	3.78
747.57	3.79
750.48	3.8
753.4	3.81
756.33	3.82
759.26	3.83
762.19	3.84
765.13	3.85
768.08	3.86
771.02	3.87
773.98	3.88
776.93	3.89
779.89	3.9
782.86	3.91
785.83	3.92
788.81	3.93
791.79	3.94
794.77	3.95
797.76	3.96
800.75	3.97
803.75	3.98
806.75	3.99
809.76	4
812.77	4.01
815.79	4.02
818.81	4.03
821.83	4.04
824.86	4.05
827.89	4.06

830.93	4.07
833.97	4.08
837.02	4.09
840.07	4.1
843.13	4.11
846.19	4.12
849.25	4.13
852.32	4.14
855.4	4.15
858.48	4.16
861.56	4.17
864.65	4.18
867.74	4.19
870.83	4.2
873.93	4.21
877.04	4.22
880.15	4.23
883.26	4.24
886.38	4.25
889.5	4.26
892.63	4.27
895.76	4.28
898.9	4.29
902.04	4.3
905.18	4.31
908.33	4.32
911.48	4.33
914.64	4.34
917.8	4.35
920.97	4.36
924.14	4.37
927.32	4.38
930.5	4.39
933.68	4.4
936.87	4.41
940.06	4.42
943.26	4.43
946.46	4.44
949.66	4.45
952.88	4.46
956.09	4.47

959.31	4.48
962.53	4.49
965.76	4.5
968.99	4.51
972.23	4.52
975.47	4.53
978.71	4.54
981.96	4.55
985.22	4.56
988.47	4.57
991.74	4.58
995	4.59
998.27	4.6
1001.55	4.61
1004.83	4.62
1008.11	4.63
1011.4	4.64
1014.69	4.65
1017.99	4.66
1021.29	4.67
1024.6	4.68
1027.91	4.69
1031.22	4.7
1034.54	4.71
1037.86	4.72
1041.19	4.73
1044.52	4.74
1047.85	4.75
1051.19	4.76
1054.54	4.77
1057.88	4.78
1061.24	4.79
1064.59	4.8
1067.95	4.81
1071.32	4.82
1074.69	4.83
1078.06	4.84
1081.44	4.85
1084.82	4.86
1088.21	4.87
1091.6	4.88

1095	4.89
1098.39	4.9
1101.8	4.91
1105.21	4.92
1108.62	4.93
1112.03	4.94
1115.45	4.95
1118.88	4.96
1122.31	4.97
1125.74	4.98
1129.18	4.99
1132.62	5
1136.06	5.01
1139.51	5.02
1142.97	5.03
1146.43	5.04
1149.89	5.05
1153.35	5.06
1156.83	5.07
1160.3	5.08
1163.78	5.09
1167.26	5.1
1170.75	5.11
1174.24	5.12
1177.74	5.13
1181.24	5.14
1184.74	5.15
1188.25	5.16
1191.76	5.17
1195.28	5.18
1198.8	5.19
1202.33	5.2
1205.85	5.21
1209.39	5.22
1212.93	5.23
1216.47	5.24
1220.01	5.25
1223.56	5.26
1227.12	5.27
1230.68	5.28
1234.24	5.29

1237.8	5.3
1241.37	5.31
1244.95	5.32
1248.53	5.33
1252.11	5.34
1255.7	5.35
1259.29	5.36
1262.89	5.37
1266.48	5.38
1270.09	5.39
1273.7	5.4
1277.31	5.41
1280.92	5.42
1284.54	5.43
1288.17	5.44
1291.8	5.45
1295.43	5.46
1299.07	5.47
1302.71	5.48
1306.35	5.49
1310	5.5
1313.68	5.51
1317.37	5.52
1321.06	5.53
1324.76	5.54
1328.46	5.55
1332.17	5.56
1335.87	5.57
1339.59	5.58
1343.3	5.59
1347.03	5.6
1350.75	5.61
1354.48	5.62
1358.22	5.63
1361.95	5.64
1365.7	5.65
1369.44	5.66
1373.19	5.67
1376.95	5.68
1380.71	5.69
1384.47	5.7

1388.24	5.71
1392.01	5.72
1395.79	5.73
1399.57	5.74
1403.35	5.75
1407.14	5.76
1410.93	5.77
1414.73	5.78
1418.53	5.79
1422.33	5.8
1426.14	5.81
1429.96	5.82
1433.77	5.83
1437.59	5.84
1441.42	5.85
1445.25	5.86
1449.08	5.87
1452.92	5.88
1456.76	5.89
1460.61	5.9
1464.46	5.91
1468.32	5.92
1472.17	5.93
1476.04	5.94
1479.9	5.95
1483.77	5.96
1487.65	5.97
1491.53	5.98
1495.41	5.99
1499.3	6
1503.19	6.01
1507.09	6.02
1510.99	6.03
1514.89	6.04
1518.8	6.05
1522.71	6.06
1526.63	6.07
1530.55	6.08
1534.47	6.09
1538.4	6.1
1542.33	6.11

1546.27	6.12
1550.21	6.13
1554.15	6.14
1558.1	6.15
1562.06	6.16
1566.01	6.17
1569.97	6.18
1573.94	6.19
1577.91	6.2
1581.88	6.21
1585.86	6.22
1589.84	6.23
1593.83	6.24
1597.82	6.25
1601.81	6.26
1605.81	6.27
1609.81	6.28
1613.81	6.29
1617.82	6.3
1621.84	6.31
1625.86	6.32
1629.88	6.33
1633.9	6.34
1637.93	6.35
1641.97	6.36
1646.01	6.37
1650.05	6.38
1654.09	6.39
1658.14	6.4
1662.2	6.41
1666.26	6.42
1670.32	6.43
1674.39	6.44
1678.46	6.45
1682.53	6.46
1686.61	6.47
1690.69	6.48
1694.78	6.49
1698.87	6.5
1702.96	6.51
1707.06	6.52

1711.16	6.53
1715.27	6.54
1719.38	6.55
1723.49	6.56
1727.61	6.57
1731.74	6.58
1735.86	6.59
1739.99	6.6
1744.13	6.61
1748.27	6.62
1752.41	6.63
1756.55	6.64
1760.71	6.65
1764.86	6.66
1769.02	6.67
1773.18	6.68
1777.35	6.69
1781.52	6.7
1785.69	6.71
1789.87	6.72
1794.05	6.73
1798.24	6.74
1802.43	6.75
1806.62	6.76
1810.82	6.77
1815.02	6.78
1819.23	6.79
1823.44	6.8
1827.65	6.81
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1836.09	6.83
1840.32	6.84
1844.55	6.85
1848.78	6.86
1853.02	6.87
1857.26	6.88
1861.51	6.89
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1874.27	6.92
1878.53	6.93

1882.79	6.94
1887.06	6.95
1891.34	6.96
1895.61	6.97
1899.89	6.98
1904.18	6.99
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1921.36	7.03
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1929.97	7.05
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1938.6	7.07
1942.92	7.08
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