A GIS-BASED MULTI-CRITERIA EVALUATION OF DISASTER VULNERABILITY IN AN URBAN SPACE

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A Capstone project presented in partial fulfillment
of the requirements for the degree of:

Master of Arts in Policy Studies

University of Washington Bothell
School of Interdisciplinary Arts and Sciences

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1. Introduction

1.1 Background

The notions of resilience and vulnerability are rapidly gaining ground in the urban sustainability and planning literature. The series of recent natural disasters around the world such as earthquakes, tsunami, and hurricanes, highlights the need for planning around natural hazard prevention and mitigation in human settlements. Historically, efforts have concentrated on recovery efforts, but rather than public engagement with emergency planning. Traditionally, most policy regarding disaster puts emphasis on the impact of natural phenomena. This notion has led to the dominance of technical interventions concentrating on prediction of hazards or modifying their impact. Catastrophic natural disasters such as Hurricane Katrina in 2005 taught us a hard lesson that traditional methods of communicating emergency information often fall short from the goal of reaching everyone in a community (Bates and Swan 2010). Accordingly, the incorporation of the notions of vulnerability and resilience in city's emergency preparedness and disaster management has become a new frontier. In this study, I employed a multi-criteria evaluation (MCE) method within a geographic information system (GIS) framework to evaluate the vulnerability at of the City of Bothell to natural disasters at the census block level.

1.2. Natural Hazards, Urban Space, and Planning

Natural hazards such as earthquakes, landslides, volcanic activities, and flooding are geophysical events that threaten lives, property, and other assets of human settlements (FEMA). After decades of migration from rural to urban space, nearly half of humanity lives in cities. It is predicted that this figure will skyrocket to 75 percent by 2050 (Patrick 2012). Unprecedented urbanization is creating new economic opportunities, but it is also placing extraordinary strains

on national and municipal authorities that struggle to provide the marginalized inhabitants of these chaotic agglomerations with basic security, sustainable livelihoods, and modern infrastructure (Patrick 2012). When it comes to natural disasters, today's burgeoning urban centers will increasingly be on the front lines. Vulnerability and exposure to natural hazards is increasing as more people move into urbanized areas. Since 1970, the world's population has grown by 87 per cent. During the same time, the proportion of people living in flood-prone river basins increased by 114 per cent and on cyclone-exposed coastlines by 192 per cent. More than half of the world's large cities, with populations ranging from 2 to 15 million, are located in areas of high earthquake risk. In addition to disaster vulnerability, the main drivers of risk are poorly planned and managed urbanization, environmental degradation, poverty and weak governance (Szlafsztein and Sterr 2007; Levy 2015). Disaster vulnerability is reduced as a direct product of sound development (United Nation International Strategy for Disaster Reduction 2015). Poorly planned and managed urbanizations by local authorities, which increasingly occurs in peripheral zones of marginal habitation, leaves hundreds of millions of people at the risk of natural disasters (Sanderson, Kayden, and Leis 2016). It is important to realize the importance and crucial role of disaster management, resilience and knowing the risks and vulnerabilities in order to bring down the impact of natural hazards in this rapidly changing urban environment (Sanderson, Kayden, and Leis 2016). It can not only prevent the loss of lives, but also the huge economic loss which is a result of breakdown of the finest infrastructure (housing, roadways, physical and social infrastructure etc.), which took many years to be built. The relationship between disasters and development is indeed very intense. While there is universal acceptance that disasters can damage, erode and destroy development gains, there is a very limited

recognition of the role that different approaches to development play in creating or increasing vulnerability.

The level and quality of development and planning to a large extent, determines the way in which hazards impact people, structures, and economies (Sanderson, Kayden, and Leis 2016). There is growing evidence of the intensity and frequency of hazard related extreme events on cities. It is therefore critical that disasters should be seen through the lens of risk reduction and resilience construction during the planning process of a city, rather than just as a response to a one-off disaster event. In today's world of rapidly changing environment, increasing urbanization, and vulnerability, it is very crucial to embed the concept of resilience into the development planning of our cities in order to have a sustainable development. Disaster resilience is thus a desired attribute that cities should possess throughout their planning and management processes. Systems that increase and incorporate resilience, enable cities to withstand shocks from man-made and natural disasters. It is very crucial to incorporate resilience in planning and development of city's infrastructure as disasters usually occur very abruptly giving no time to react or to take immediate mitigation actions. Therefore, resilience should be mainstreamed at the very early stages of development to make the final product strong, robust, and flexible to withstand shocks and stresses. Resilient cities are able to cope with disaster situations as they are robust and prepared for any such situation beforehand only (Hayashi, Suzuki, Sato, and Tsukahara 2016). Disaster mitigation plans that incorporate the resilience concept help cities quickly bounce back to normal functioning once a disaster passes away. Before planning to establish a resilient city framework, we must understand the basic variety of disasters such as earthquakes, floods, volcanic eruptions, avalanches, landslides etc. We face such disasters caused by natural hazards because we are setting cities dangerously close to

natural hazards due to rapid urbanization, and we cannot handle their impact with available resources and the way they are intentionally allocated across the city while ignoring geographic and societal aspects of the city. A focus on disaster resilience in the process of urban planning forms a basic backbone structure for a resilient and safe city.

Urban planning allows towns, cities and settlements to be analyzed and planned as a system comprised of various sectors and institutions (Levy 2015). This is crucial in coping with interdependencies among failures in lifeline infrastructure in disaster situations. Urban planning with integrated disaster resilience also contributes to preventing secondary disasters and delays in the rehabilitation and recovery process. While a primary disaster is the initial or triggering event, a secondary disaster is a consequence of the original occurrence (FEMA; H.O.P.E 2010). The planning practice can reinforce stakeholder relationships and integration at different levels and institutional frameworks and partnerships; it also helps address risk reduction and resilience in a holistic manner across public and private actors such as particularly planners, architects, engineers, disaster and risk reduction management specialists, and communities. It is important to strengthen the legal planning frameworks of risks in master plans and land use codes in urban areas to support resilience. Cities, towns, and settlements are expanding, and village settlements are becoming towns and cities. A legal framework within development plans can guide future planning and integration of disaster risk reduction (UNISDR, 2012). Unless cities and its citizens have a clear understanding of the risks they face, planning for meaningful disaster risk reduction may be ineffective and worthless. Risk analysis and assessments are also essential prerequisites for informed decision-making, prioritizing projects, planning for risk reduction measures, and identifying high, medium or low-risk areas, according to their vulnerability and the cost effectiveness of potential interventions (Hayashi, Suzuki, Sato, and Tsukahara 2016). A well-

maintained database of disaster losses and a comprehensive GIS to map hazards, vulnerabilities, the exposure of people and assets and capacities will provide the foundation for the assessment of risk and vulnerability (Szlafsztein and Sterr 2007; Bartholomew 2006). Planning helps to include risk and vulnerability mapping in land use suitability in order to plan for a resilient future development. This inclusion not only inculcates awareness about the disaster, but also makes the communities aware of the existing ways to minimize the impact of disasters. It enhances their knowledge about safe zones, mitigation measures, resilient building material to be used, and other useful knowledge. Within this context, strong disaster resilience is a product of the integration of communities' needs and emergency preparedness with emphasis on the complex relationship between human activities and hazardous physical events. This integration is possible throughout the urban planning process. This study focuses on the development of an assessable spatially explicit model to prioritize disaster mitigation criteria by investigating the multiple factors that contribute to deterioration of the resilience of a city.

1.3 Vulnerability, Resilience, and Adaptation

In this study, I define vulnerability as the inability to deal with the resulting hazardous event, and some risk combined with the level of social and economic liability (Birkmann 2006; Corbin 2015; Zahran, Brody, Peacock, Vedlitz, and Grover 2008). Vulnerability is a characteristic of individuals or groups of people that inhabit a given geographic, social, and economic space. Individuals or groups of people are differentiated according to their varying position in society into more or less vulnerable population (Birkmann 2006; VCOSS 2014). For example, people and groups that are socioeconomically disadvantaged, such as, poor and immigrants, are frequently consigned to more vulnerable locations. The vulnerability and resilience concepts are a measure of translating known everyday-process of the political and

economic separation of people into a more specific identification of those who may be at risk in hazardous environments (Cannon 1994). It is not that the victims of disasters were vulnerable to that hazard, as is demonstrated by them being its victim; there are particular characteristics of different groups of people, meaning some people avoid disaster and others do not because of the impact of a particular type of hazard of a given intensity.

Within the disaster risk community, resilience is defined as the ability of individuals, communities, organizations, and states to adopt to and recover from hazards, shocks, or stresses without compromising long-term prospects form development (GSDRC 2014). More specifically, scholars found consensus on two important points of resilience: first is that resilience is better conceptualized as an ability or process than as an outcome; Second, resilience is better conceptualized as adaptability than as stability (Brown and Kulig 1996/97; Pfefferbaum et al. 2005; Handmer and Dovers 1996; Waller 2001). For example, the resilience of system in general depends on one component or part of the system being able to change or adopt in response to the changes happened in other components. Therefore, the system would fail to function if that component remined stable (Adger 2001). Figure 1 visualizes stress resistance and resilience over time. Resilience occurs when resources are sufficient, robust, or rapid to counteract the effects of the stressor. While resistance is the ideal outcome, the process that produces adapted outcomes is resilience. Faster the return to pre-disaster functioning, the greater the resilience. George Bonanno (2004) characterized recovery as involving a period of dysfunction lasting several months or more followed by a gradual return to pre-disaster functioning. On the other hand, he defined resilience trajectories as something that involve transient perturbations lasting as long as several weeks involving a stable trajectory of healthy functioning.

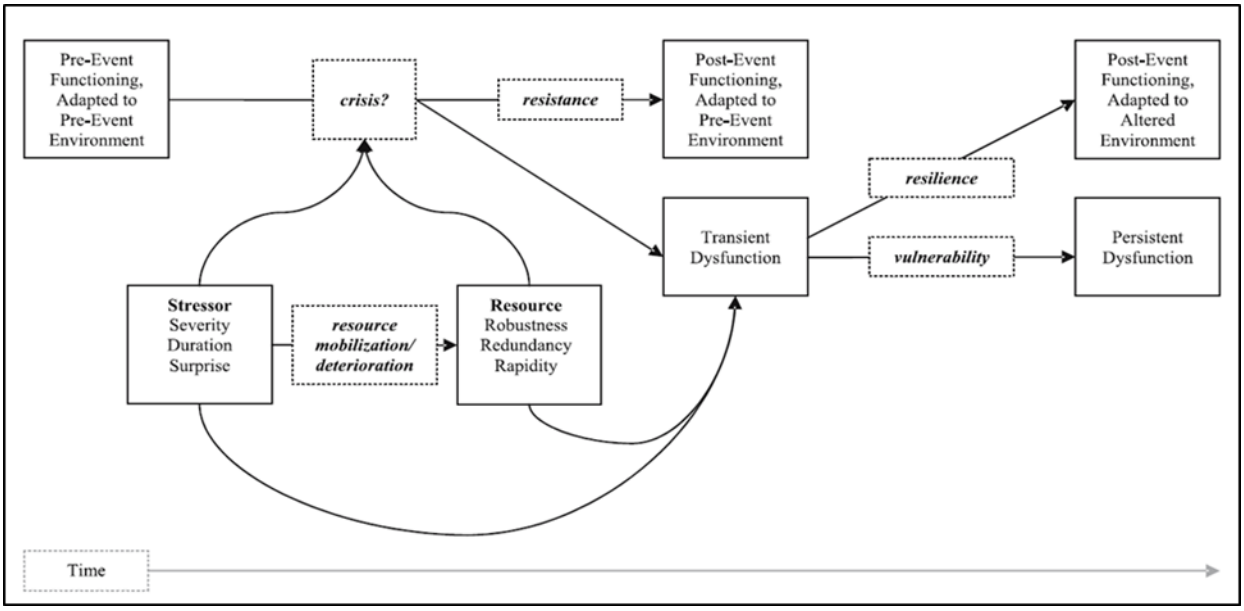

Figure 1: Stress resistance and resilience over time

Adaptation is generally perceived to include adjustments in social and ecological systems in response to actual or expected environmental changes and their impacts. Adaptation includes both moderation of harm and exploitation of beneficial opportunities, which consists of both minimizing the adverse effect of the event and maximizing its potential opportunities in response to the disturbance (Lei, Wang, Yue, Zhou, and Yin 2014). Some researchers such as Folke (2006) and Berkes (2007) tied the concept of vulnerability and resilience with adaptation and discuss the relationship among them, while some only talk of the relationship between vulnerability and resilience. The relationships among vulnerability, resilience, and adaptation can be categorized into three types of modalities: vulnerability preference, resilience preference, and overlapped relationships (Lei et al 2014). Current diversified understandings on their relationships indicate that any single concept of vulnerability, resilience, and adaptation should not be over emphasized separately from the others, but need to be understood based on an integral consideration of the three elements. Therefore, it is important to understand how each modality responds to and cope with impact of the hazard. Taking disaster risk management as an

example, comprehensive understandings on the internal relationships among vulnerability, resilience, and adaptation, and their linkage with disaster risk are critical base of scientific risk analysis and robust strategies (Nelson 2011, Lei et al 2014).

Vulnerability preference traditionally holds a standpoint that vulnerability is its most basic and inclusive attribute of a socio-ecological system (SES) met by an external stress or hazard. It integrates resilience and adaptation into response capacity under a vulnerability framework (Gallopin 2006). In this viewpoint, it suggests that reducing vulnerability to hazards is the fundamental approach to disaster risk mitigation (O'Brien et al 2004). Resilience preference views resilience as the key factor to mitigating the risk of a SES that was confronted with outside forces (external stresses) or natural hazard (Lei et al 2014). It considers resilience as a response capacity to external shocks or changes, including both in short-term coping capacity and long-term adaptive capacity (Lei et al 2014). Finally, overlapped relationship framework uses vulnerability focusing on the pre-disaster situation of a system and resilience as process focusing on the during- and after-disaster situation of a system. In this framework, adaptive capacity depends on scale and place that differs from location to location, among different social groups and individuals over time. Note that in this study, vulnerability emphasizes the situation of a system and social demographic attributes before a disaster while resilience refers to a process, mainly focused on the stages of during and post-disaster, which helps to enhance the abilities of the system to resist and recover from hazards. Although vulnerability and resilience defined in this study constitute different but overlapping characteristics, and the vulnerability and resilience concepts are individually linked through adaptability, this study aims to achieve identification of disaster vulnerable areas and how reducing vulnerability to natural hazards

contributes to consolidation of resilience towards hazardous events. Therefore, this study adopts vulnerability preference framework.

1.4 Evaluating Vulnerability

Despite the fact that the international community does not establish guidelines on how to create indicators or system to assess vulnerability and resilience, in the past decade, substantial attention has been given to the development of tools to measure the vulnerability, resilience communities to disasters. In order to quantify these concepts, particular attention has been given to the composite indices, mirroring their deployment in other fields such as sustainable development (Beccari 2017). This indicates that evaluating degree of a community's vulnerability and resilience to natural hazards requires a clear understanding and definition of it, as well as an assessable framework that allows us to evaluate the strength of emergency preparedness of a city with regard to natural hazards. Beccari (2017) analyzed 106 composite indicator methodologies to understand the range and depth of practice. The result of his research identified five key approaches with the use of hierarchical or deductive indices being the most common (Beccari 2017). The 106 methodologies used total 2298 unique variables, more specifically, approximately two thirds of the methodologies used less than 40 variables (a minimum of 2 variables and a maximum of 235 variables). Classification of variables used in each methodology is as follows: 34% related to the social environment, 25% to the disaster environment, 20% to the economic environment, 13% to the build environment, 6% to the natural environment, and 3% to other indices; However, variables specifically measuring mitigation effort or preparedness for disasters only comprised 12% (Beccari 2017). A key obstacle in creating composite indicators is the availability of quantitative data related to the conceptualization of vulnerability and resilience with respect to natural hazards. Thus, measuring

resilience and vulnerability in a truly quantitative way still appear to be very challenging (Beccari 2017).

The vulnerability perspective first assumes that a disaster occurs when it strikes an underprivileged population. Noy and Yonson (2018) argue that there is a new paradigm of discourse on disaster that disasters triggered by natural hazards have been perceived as unnatural occurrences brought about by a confluence of societal factors. This indicates that different populations encounter different levels of risk and vulnerability, and the sources of vulnerability is diverse such as population distribution and social diversity. King (2014), in a research by Victorian Council of Social Services (VCOSS), similarly argues that populations facing one or more disadvantages are at greater risk of becoming socially more vulnerable in an emergency. However, it is important to note that not everyone who faces individual disadvantages are socially vulnerable in emergency situations caused by a hazard; even disadvantaged communities can be resilient and hold unique skills, knowledge and resources they can utilize in the time of a disaster. Therefore, identification of social causes linked directly with disaster risk would help identify those vulnerable (at-risk) populations specifically when hazards occur. Several literatures on social vulnerability and disaster risk management suggest that the following types of social vulnerability must be considered: poverty, refugee and migrant populations, people with a disability, young people and children, women, housing quality, people with lack of education (King 2014; Nivaran 2016; PRB 2011). In addition to social vulnerability, economic vulnerability and built environment interrelating with the hazard itself and the exposure of populations and economic systems are also considered critical factors to determine the resulting disaster impacts (Noy and Yonson 2018). For example, economic vulnerability and economic resilience are shaped by the degree and quality of development governance and features of

development such as rapid urbanization and inequality. Built environment and existing conditions such as geography and geology of study area are also critical vulnerability indicators as conditions like eligibility for federal grants and building age directly impact the planning of mitigation efforts. In applying a GIS-based MCE model, determining the weights for this study that are applied to each evaluation factor relied on the subjective opinions of the Emergency Preparedness Coordinator from the City of Bothell.

1.5 Paradigm Shift in Building Resilience

Cannon (1994) argues that conventional analysis of disaster considers a direction of causality that proceeds from hazards through spatial variability to the impact on society. Explanation of disaster causality is only possible by understanding the ways in which social systems themselves generate unequal exposure to risk by making some group of people more prone to hazards than others. To comprehend the relationship between humans and nature, it is more important to distinguish how human system themselves accommodate people in relation to each other and to the environment than to interpreting natural systems. Following Cannon's argument, Birkmann (2006) stresses that the current trend in promotion of disaster-resilient societies is a paradigm shift from quantification prediction, analysis, and modification of the hazard itself to the identification, assessment, and ranking of vulnerabilities. Since the 1980s, the dominance of hazard-oriented prediction strategies based on technical interventions has faced challenges by the alternative approach of using vulnerability as the essential for risk reduction. The growing awareness that modified social systems and structures could cause a disaster out of a situation where otherwise may not have been a disaster, was the catalyst of today's understanding that human activity itself has established the conditions for natural hazards to transform into disastrous events had become a common understanding. This approach combines

the susceptibility of people and community exposed with their social, economic, and cultural abilities to cope with the damage that could occur (Hilhorst and Bankoff, 2004). This study looks to reinforcing the current conditions in Bothell surrounding four critical dimensions of a consistent system of resilience indicators – vulnerable populations, critical and environmental infrastructure, social factors, built infrastructure – identified by National Research Council (NRC 2012). Although measuring resilience remains a challenge in many cases, making adjustments that directly influence the way these four resilience dimensions are exposed to natural hazards benefits critically for communities to clarify and formalize what the concept of resilience means and looks like during an emergency for them.

1.6 Recovery vs. Mitigation

Jason Barnosky (2015) points out that unfortunately the United States' disaster policies are not well suited for problems caused by natural hazards such as extreme weather events with links to climate change. The United States disaster policy focuses its resources largely on responding and recovering from natural disasters after hazards occurred (Barnosky 2015). Policy analysts from Department of Homeland Security generally talk about five mission areas: prevention, protection, mitigation, response, and recovery (Brookings 20015). Given appropriation based on the possible threads and hazards people face, public officials squeeze resources (people and funding) between these five areas. When public officials deal with terrorism, prevention part is their main focus. However, prevention is not a primary option in cases of natural hazards. Instead, focuses are put on the other four areas (Brookings 2015). In attempt to build stronger resilience to natural hazards, which requires much attention to mitigation efforts prior to hazardous events than post-event recovery and rescue efforts, this study seeks resolutions that contributes to safer community that takes people out of harm's way

and prevents stressors from the natural hazard from reaching to vulnerable populations/areas. Thus, distinguishing the features and outcomes of recovery-focus and mitigation-focus solutions becomes important. Federal Emergency Management Agency (FEMA) spends much of its time assisting states and communities after they have been struck by hazardous events. For instance, FEMA obligated more than 3.2 billion for Hazard Mitigation Grant Program (HMGP). In the wake of a major event, emergency manager, firefighters, and law enforcement conduct search and rescue efforts, then if the damage is serious enough, in addition to FEMA's individual assistance through its public assistance program, other agencies such as the Department of Housing and Urban Development (HUD), the Small Business Administration, and the Department of Transportation provide with recovery assistance (Barnosky 2015). While federal and state-wide policies tend to focus on recovery efforts, it's well established that there are a number of actions local communities can take to reduce the impact of natural hazards. For example, well-designed building codes can ensure that structures can withstand the damage of earthquakes or floods; residential and community safe rooms can shield people from wind and debris; and homes can be elevated to reduce flood damage. These steps build resiliency against disasters. This means that there's less to repair and rebuild— and less need for costly response and recovery efforts.

The review of literature reveals the importance of integrating the concept of vulnerability and resilience in emergency preparedness and disaster risk management. It also points at the complex relationship between human activities and hazardous physical events and exposes the weaknesses of the existing risk management practices that emphasize on technical interventions and recovery-focused policies. It also revealed how social vulnerability is often exacerbated by the lack of access to resources after a disaster. Within this context, this study addresses the

following general research question: how can the City of Bothell measure its disaster vulnerability and implement or prioritize it in their disaster mitigation planning? I hypothesize that cities can prioritize disaster mitigation by identifying vulnerable areas to natural hazards and evaluating the degree of their vulnerability in comparison with other areas of the city.

2. Study Area

2.1. Socio-economics and demographics

This study focuses on the City of Bothell (Figure 2). Bothell is a city in Washington State, along the Cascadia subduction zone, which is an area highly susceptible to various types of natural hazards. The City of Bothell is located across two counties: the north-central region of King County and the south-central region of Snohomish County. The city has evolved from a logging town to an agricultural community to a bedroom suburb to a balanced city with residential areas and business centers (The City of Bothell 2010). The Emergency Preparedness department assists the city departments in the development and implementation of the hazard mitigation plan. Bothell has a population of 43,153 people with a median age of 37.5 and median household income of $86,167. Between 2015 and 2016 the population of Bothell grew at 4.72 % increase and its median household income grew at 5.12 % increase. The population of Bothell consists of 69.4 % White, 13.4 % Asian, 8.57 % Hispanic, and 0.23 % of the people in Bothell speak a non-English language. 12 % of overall population are 65 years old or older while 22.7 % are younger than 18 years old. Males in Bothell have an average income that is 1.37 times higher than the average income of female residents, which is $52,973. 6.69 % of the population in Bothell live below the poverty line, a number that is lower than the national average of 14 %. The largest living in poverty is female 18-24, followed by female 25-34, and then female 35-44.

In 2016, 66.6 % of the housing units in Bothell were occupied by their owner, which is higher than the national rate (63.6 %) and the state rate (62.4 %) (Data USA 2016).

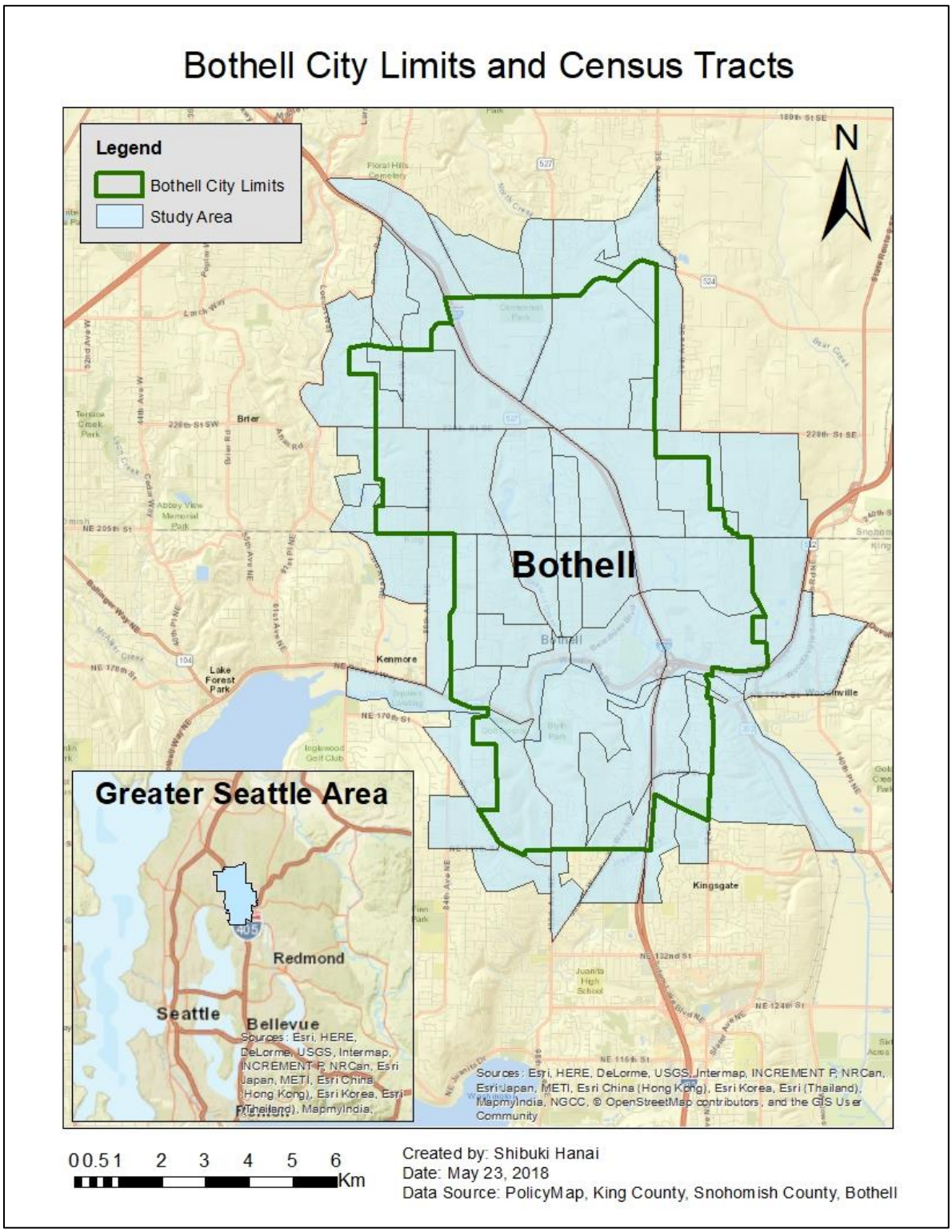

Figure 2: Bothell City Limits & Census Tracks

2.2. Natural disasters and policy

As disaster preparedness has become a popular topic among local and state-wide media and residents, it is critical to conduct comprehensive analysis of what we need to prepare for and how to do so more effectively in case of a natural disaster. Relevant literatures revealed that the probability of large scale natural hazard occurrence, especially destructive quakes and associated tsunami damages, still remains relatively higher in offshore of Washington and northern Oregon than farther south along the subduction zone although many efforts to mitigate the disaster risk. The City of Bothell is not an exception among other cities in the greater-Seattle area. In 2014, Rep. Suzan DelBene who represents Bothell as well as Kenmore in Congress, sent a letter to the House Appropriations Committee addressing the need for additional funding in the effort to mitigate landslide risks. Both King and Snohomish counties where Bothell is located acknowledge that they are exposed to various natural and unnatural hazards that potentially lead to disaster and social disfunction (King and Snohomish County 2018). In 2016, Snohomish County released a statement to reflect on National Preparedness Month in September "… an important step Snohomish County residents can take to prepare for emergencies is to understand potential hazards where they live, work, and play… It also offers guidance about how to reduce the effects of natural disasters such as floods, earthquakes, or volcanic eruptions" (Snohomish County 2016). Following the statement, Jason Biermann, Director of Snohomish County's Department of Emergency Management, (2016) said "I encourage everyone to prepare their families and homes for natural disasters, since even minimum preparation can have maximum benefit". Although the numbers of reports indicate that it is a matter of time until a catastrophic natural hazard hits the Pacific Northwest region, there is no holistic review of current emergency

preparedness at local municipal level in the Puget Sound region, including Seattle and its neighboring cities.

On May 1, 2015, the U.S. Department of homeland Security's Federal Emergency Management Agency (FEMA) approved the King County Regional Hazard Mitigation Plan (KCRHMP) as a multi-jurisdictional local plan including the City of Bothell (Bothell Disaster Mitigation Plan 2010). Meanwhile, the City of Bothell had developed its own hazard mitigation plan as an Annex to the KCRHMP, which was last updated in June 2010. To meet the FEMA's requirements for local mitigation plan, the City of Bothell sorted the Hazard Mitigation Plan into five categories: *Planning Process*, *Planning Area*, *Risk Assessment*, *Mitigation Strategy*, and *Plan Mitigation Process and Adoption*. In the mitigation plan, the City of Bothell conducted identification and analysis of the hazards that would affect Bothell, as well as the city's vulnerability to future events. It concludes that Bothell experiences the same types of natural and unnatural hazards as much of King County and considers the followings as hazards that could potentially impact the City of Bothell: severe weather, flooding, landslides, earthquakes, civil disorder, terrorism, fire hazards, hazardous materials, transportation, cyber-terrorism (Bothell Disaster Mitigation Plan 2010). Bothell has used an adjective description[1] (high, moderate, low) to indicate its vulnerability to the potential impact of hazards. It is determined by the ratio of population, property, commerce, infrastructure and service at risk, relative to entire city while lacking some significant indices such as economic and social aspects of the city. In this context, this study aims to compliment the Bothell Disaster Mitigation Plan by adding new dimensions to fulfill the inadequacy in its vulnerability evaluation process. Although there are multiple resources available to residents such as King County Hazard Mitigation Plan website that offers

[1] "A High rating would indicate a significant impact throughout the entire City, a Moderate rating would indicate an isolated significant impact or a moderate impact throughout the entire City, and a Low rating would indicate an isolated moderate impact in a selected area or a limited impact throughout the City" (Bothell 2010)

executive summary of the plan and frequently asked questions by its residents as well as hazard maps, they do not address local community level emergency preparedness with a detailed disaster mitigation plan that directly contributes to strengthening risk and disaster mitigation. Therefore, the city government of Bothell must develop capacity to assess its ability to withstand natural hazard and how to improve resilience to natural hazards.

3. Methods and Data

3.1 Multi-Criteria Evaluation

The use of multi-criteria decision analysis allowed researchers to conduct proper analysis of risks, an examination of where previous effort had been applied, and a focus on large gaps in the industry's risk assessment. Multi-Criteria Evaluation (MCE) is useful to suitability problem such as identifying best location or most likely location of phenomenon, using multiple layers of information. Typically, decision making on alternatives for risk reduction planning starts with an intelligence phase for recognition of the decision problems and identifying the objectives (Eastman 1999). Development of the alternatives and assigning the variable by decision makers to each alternative are employed to the design phase. The final phase evaluates the optimal choice by comparing the alternative, defining indicators, assigning a weight to each and tanking them. According to Hester and Velasquez (2013), the newest trend with respect to MCE method is to combine two or more methods to make up for shortcomings in any single particular method. MCE allows researcher to analyze a series of variables with ways to rank them from the most preferable to the least preferable. The main challenge of MCE application in general is to determine criteria weights. Different researchers are likely to give different weight on a criterion, making criteria determination could be time consuming and costly. A traditional weights approach is allowing decision maker to give his/her preferences with respect to the evaluation

criteria incorporated into the decision model. Another way of assigning weights is direct estimation of their relative importance. The outcome of MCE is frequently a set of weights linked to the variables used indicating the preference of objectives relative to each other (Musungu, Motala, and Smit 2012).

The integration of GIS into multicriteria decision analysis has gained significant interest over the last couple decades. GIS-based MCE has been vital in advancing GIScience in two major fields: spatial decision support and participatory GIS. Application of GIS to MCE has frequently been used in producing new information by spatial analysis of existing data and combination of multiple data sources. Spatial modelling using GIS has been applied when finding for areas suitable for a specific land use, identifying populations that fall into specific conditions, or for natural resources and/or species of interest. The outcome of GIS-based MCE is generally a map depicting locations fulfilling all the conditions set with threshold values. In GIS, there are typically two ways to approach MCE. First, all criteria are converted to Boolean statements of suitability to make decisions under consideration. This approach is very common with vector software system but is also widely used with raster systems. Second, quantitative criteria are evaluated as fully continuous variables rather than collapsing them to Boolean constrains. Such criteria are usually called factor and varying degrees of suitability for the decision under consideration. Thus, for instance, proximity to roads would be treated not as an all-or-none buffer zone of suitable locations, but rather, as a continuous expression of suitability based on a special numeric scale (e.g. 0–1, 0–100, etc.) (Eastman 1999). The process of converting data to such numeric scales is most commonly called classification (Voogd 1983).

3.2 Model Implementation

Based on the review of literature, the selection of social, economic, and environmental variables that correspond to the broader range of definitions of vulnerability becomes important. More specifically, factors that lower one's social status by preventing access to social system – such as, gender, ethnicity, age, disability, and level of educational attainment – are commonly examined to evaluate social aspects of disaster vulnerability. While there are hundreds of considerable economic factors that influences disaster vulnerability, several frequently-examined factors includes household income, status of employment, and mobility. Built environment and existing conditions such as geography and geology of study area are also critical vulnerability indicators as conditions like eligibility for federal grants and building ages directly impact the planning and mitigation effort.

All the data used for this research were gathered from PolicyMap (PolicyMap[2] 2018) at the census block level (N= 49). PolicyMap offers ready-to-use online mapping with data on demographics, real estate, health, jobs and more in communities across the United States. It is an online platform that enables government, commercial, non-profit and academic institutions to access data about communities and markets across the US. It is a common destination for researchers to find the right data for their research, market studies, business planning, site selection, grant applications and impact analysis. PolicyMap relies on more than hundreds of data sources to collect its data including U.S. Census, Administrative Office of the U.S. Courts, FEMA, HUD, IRS, etc. A few limitations in collecting data included maintaining consistency of pre-defined location at census block level. This narrowed the range of available data sets and public records. A strategy of building resilience involves more than changes to physical infrastructure. Increasingly, governments and planners are recognizing the importance of social infrastructure such as demographic of residents themselves, conditions they live in, institutions

[2] https://washington-policymap-com.offcampus.lib.washington.edu/maps

that foster cohesion and support (Klinenberg 2013). I also relied on Beccari's (2017) classification scheme for variables in composite indicator methodologies (Table 1) to identify evaluation factors. According to the limitations and these information I categorized all the evaluation factors and dimensions table below (Table 2):

Table 1: Beccari's classification scheme for variables in composite indicator methodologies

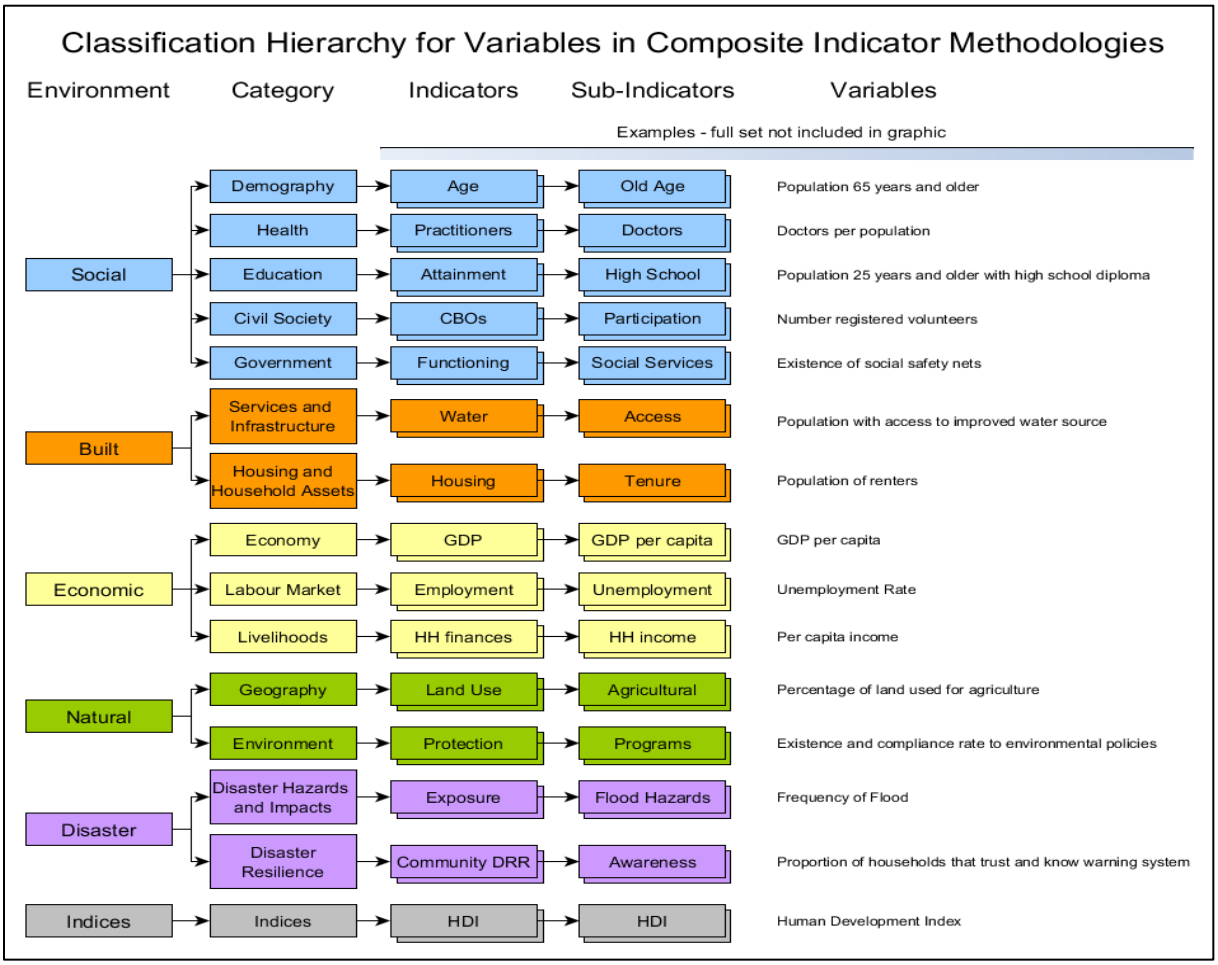

Table 2: Factors used for the evaluation of vulnerability and resilience at the census block level

Dimension	Category	Evaluation Factor	County	Pre-Defined Location
Social Map	Sex	Female	King County	Census Tract Level
			Snohomish County	Census Tract Level
	Ethnicity	Black	King County	Census Tract Level
			Snohomish County	Census Tract Level
		Asian	King County	Census Tract Level
			Snohomish County	Census Tract Level
		Non-White	King County	Census Tract Level
			Snohomish County	Census Tract Level
		American Indians and Alaskan Natives	King County	Census Tract Level
			Snohomish County	Census Tract Level
	Age	Population 65 and older	King County	Census Tract Level
			Snohomish County	Census Tract Level
		Population under 18 years old	King County	Census Tract Level
			Snohomish County	Census Tract Level
	Education Attainment	Less than 9th grade	King County	Census Tract Level
			Snohomish County	Census Tract Level
		Some high school	King County	Census Tract Level
			Snohomish County	Census Tract Level
		High school	King County	Census Tract Level
			Snohomish County	Census Tract Level
Economic Map	Unemployment	Unemployed people (16yrs-older)	King County	Census Tract Level
			Snohomish County	Census Tract Level
	Household Income	Median income of a household	King County	Census Tract Level
			Snohomish County	Census Tract Level
	Vehicles per Household	Average number of vehicles per household	King County	Census Tract Level
			Snohomish County	Census Tract Level
Built Environment Map	Building Age	Median building age	King County	Census Tract Level
			Snohomish County	Census Tract Level
	Rental Occupancy Rate	Rental Occupancy Rate	King County	Census Tract Level
			Snohomish County	Census Tract Level
	CDBG Eligibility	Community Development Block Grant Eligibility	King County	Census Tract Level
			Snohomish County	Census Tract Level
Natural Hazard Map	Hazard History	N/A	Bothell	City Level
Zoning Map	Zoning	N/A	Bothell	City Level

I implemented the MCE models using a raster GIS framework and map algebra. The weights were discussed with the Emergency Preparedness Coordinator of the City of Bothell who is considered an 'expert' in the field. The weights total must not exceed 1, which represents 100% (e.g. 0.25 = 25%, 0.0833 = 8.33%). As indicated by the expert, the highest weight of 25 % was assigned to "population who are 65 years old and older" for the social dimension map; the highest weight of 40 % was assigned to "average number of vehicle per household" for economic dimension map; and the highest weight of 40 % was assigned to "rental occupancy rate" and "building age". I used the following model specifications:

Social Dimension (MCE 1):

- F*0.0833 + 65yrs*0.25 + 18yrs*0.0833 + Black*0.0833 + Asian*0.0833 + AIAN*0.0833 + Non-White*0.0833 + HS*0.0833 + SomeHS*0.0833 + 9th*0.0833

Where:

F Female Population (%)

65yrs	Residents who are 65 years old and older (%)
18yrs	Residents who are 18 years old and younger (%)
Black	Black Population (%)
Asian	Asian Population (%)
AIAN	American Indians and Alaskan Natives Population (%)
Non-White	Non-White (Hispanic) Population (%)
HS	Residents whose highest education attainment is high school diploma (%)
Some HS	Residents whose highest education attainment is some high school (%)
9th	Residents whose highest education attainment is less than 9th grade (%)

Economic Dimension (MCE 2):

- Vehicle*0.4 + HHI*0.3 + Unemployment*0.3

Where:

Vehicle	Average number of vehicle per household
HH Income	Household income ($)
Unemployment	Unemployment Rate (%)

Built Environment (MCE 3):

- Rental Occupancy Rate*0.4 + Average Building Age*0.4 + CDBG Eligibility*0.2

Where:

ROR	Rental Occupancy Rate (%)
Building	Average Building Age (year)
CDBG	Community Development Block Grants Eligibility (eligible/not eligible)

In addition to descriptive models depicting disaster vulnerability of Bothell created the city's social, economic, and built environment characteristics at the census block level, I mapped the natural hazards in Bothell (Figure 3) from 2003 to 2017 and the city's zoning map (Figure 4) in order to provide more holistic disaster mitigation plan. Multiple existing conditions including the city's zoning, floodway, floodplain, known landslides from the past, and landslide-prone deposits were visualized using ArcGIS v. 10. 5 (ESRI 2018). Data were downloaded from the city of Bothell website. Zoning units were categorized into twelve groups based on their zoning description (e.g. multiple residential areas were all grouped together regardless of their size). The environmental conditions are taken into account when analyzing the level of disaster vulnerability in comparison with other maps.

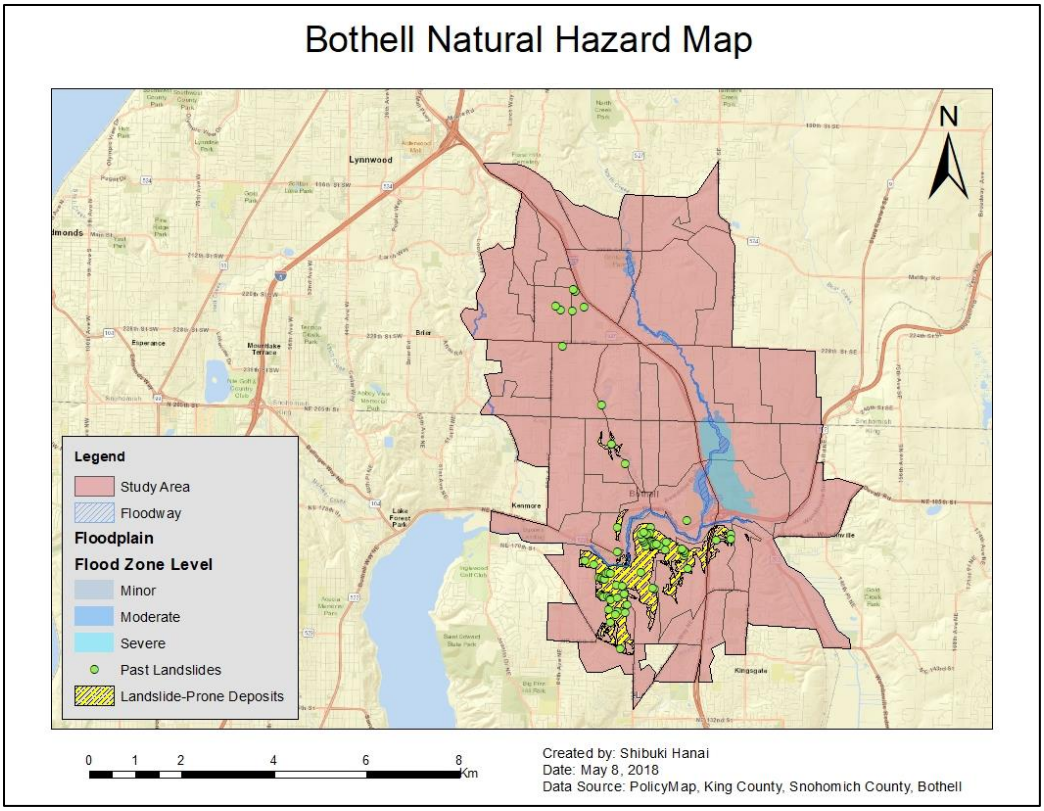

Figure 3: Natural Hazard Map of Bothell showing the past landslides and floods

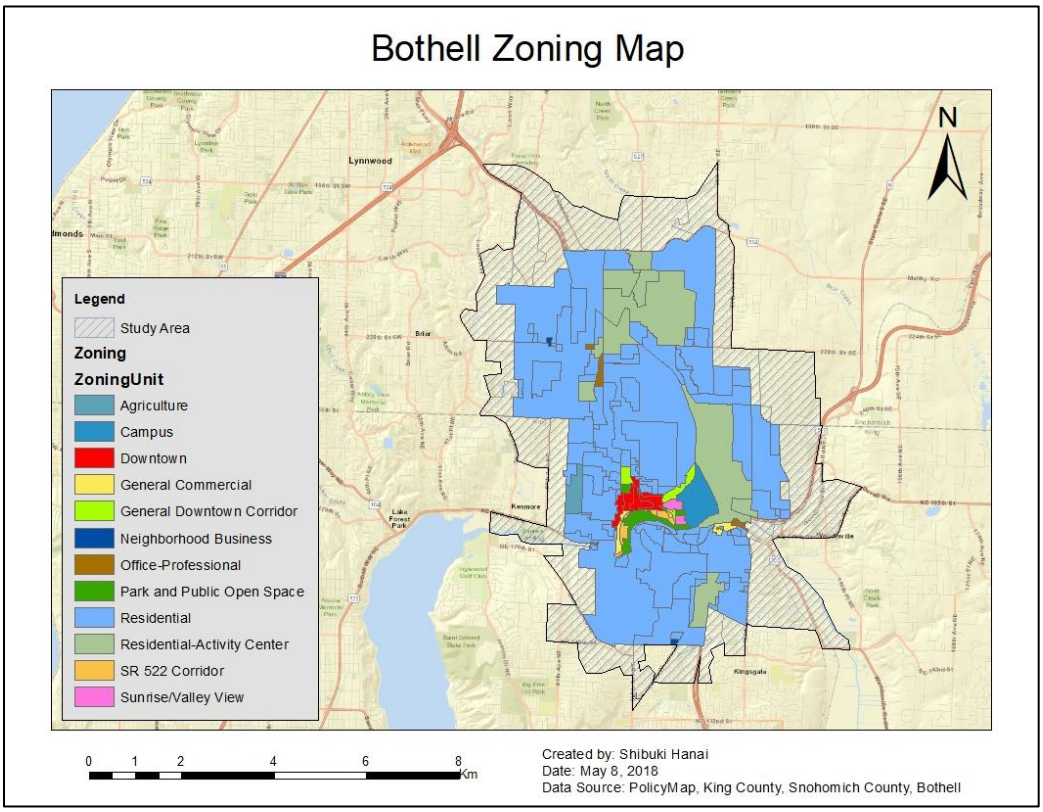

Figure 4: Bothell's zoning in 2018 (eliminate Zoning Unit label from the legend)

3.3 Data Processing

Since the city of Bothell is located within King and Snohomish counties, I prepared two data sets that contain the same variables for each section of the city within the corresponding county. Then, I have combined the data sets into one covering the entire city of Bothell. Finally, all the data were imported into ArcGIS and joined with the shapefile that captures all the blocks within Bothell. Due to some census blacks along the city border that share its territory with other cities, all the blocks that share its territory with Bothell and whose borderline touches Bothell's city limits were included in this study. However, analysis of results focuses on phenomenon within the Bothell's city border (see Figure 2). Next, as the variables do not share a common measuring unit, their values for each dimension must be standardized. Therefore, before conducting the geovisualization process, Z-scores[3][4] of the variables were calculated using the equation below:

$$\text{Z-score} = (X - \mu) / \sigma$$

Where X is the evaluation factor being calculated; μ stands for the mean of the evaluation factor; and σ is the standard deviation for the evaluation factor being calculated, which was calculated by ArcGIS (Table 3). For CDBG, eligible is 10, partially eligible is 5, and not eligible received a score of 1. Z score of Building Age, Rental Occupancy Rate, Household Income, and CDBG Eligibility were multiplied by -1 to reverse the score as higher scorers for these evaluation factors mean less vulnerable, and lower scores indicate more vulnerability. Z-scores were used to standardize measurement units. Once all the variables have a standard unit that can be compared, raster maps were created based on the Z-scores to depict each evaluation factor

[3] Z-score is the number of standard deviations from the mean a data point is.
[4] Z-score = (X - μ) / σ

spatially. Values of all the raster maps were reclassified into 10 levels using an equal interval classification scheme. Each map shows the highest and lowest Z-score values that measure how many standard deviations below or above the population mean a raw score is (Figure 5, 6, and 7 as examples).

Table 3: Z-Scores and summary statistics

Factor	Mean	Standard Deviation
Female	50.9228	3.54633
> = 65 years old	11.6904	7.558699
<= 18 years old	22.9186	4.658966
Education attainment: less than 9^{th} grade	2.2588	3.157124
Education attainment: Some HS	3.232	2.369392
Education attainment: HS	15.1976	5.771322
% of black residents	2.1894	2.818718
% of Asian residents	14.6148	10.03254
% of AIAN residents	0.7282	1.17713
% of Non-White residents	26.3372	11.347292
Median building age	1986.7	9.459915
Rental occupancy rate	26.615	20.492759
Median household income	93164.88	22390.52353
Average # of vehicle/household	1.72	0.693974
Unemployment rate	4.8982	2.99115

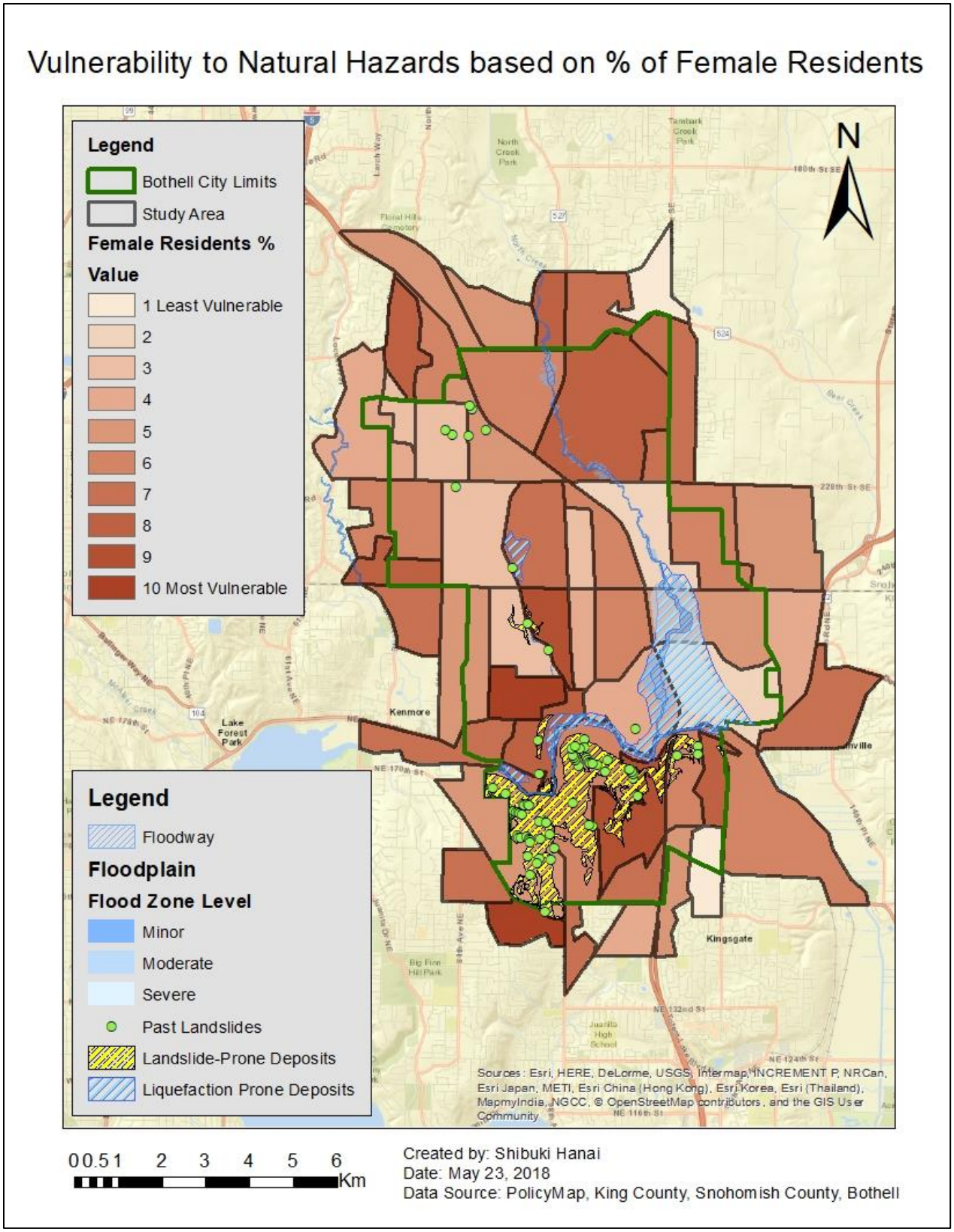

Figure 5: Z-Score of female ratio at the census block level and natural hazards in the City of Bothell

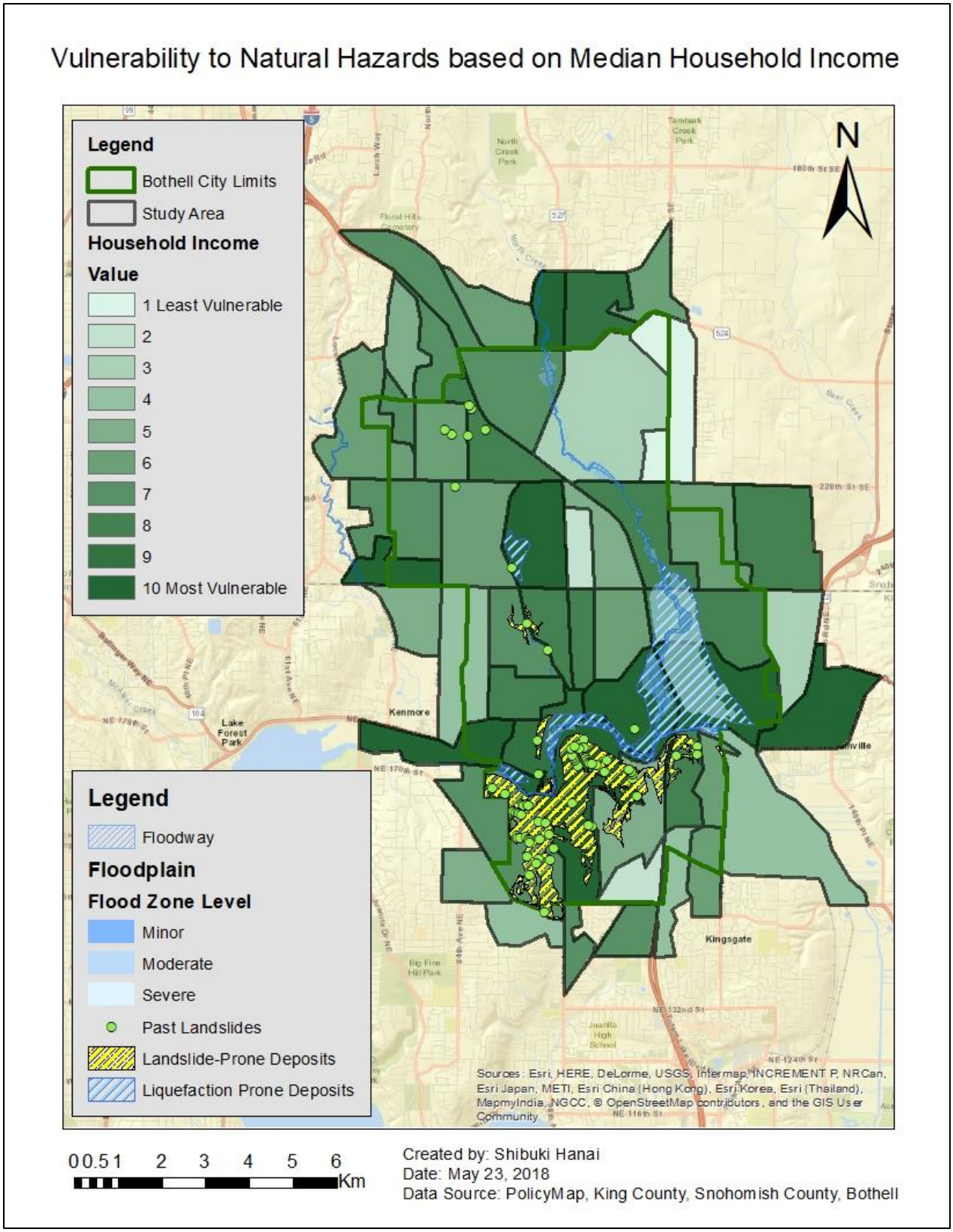

Figure 6: Z-Score of median household income at the census block level and natural hazards in the City of Bothell

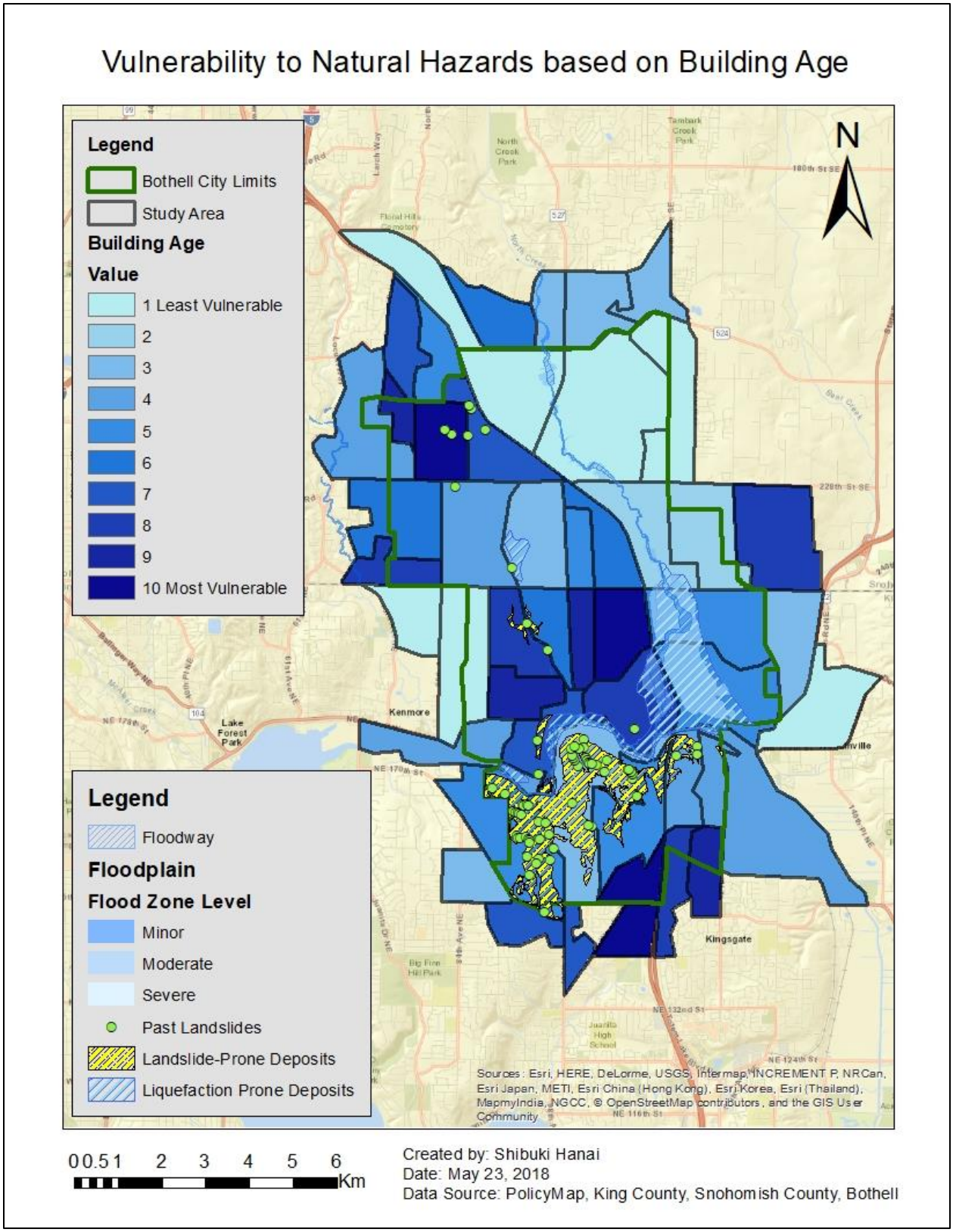

Figure 7: Z-Score of median building age at the census block level and natural hazards in the City of Bothell

3.4 Scenario Planning

Along with MCE, a scenario planning approach was also applied to uncover information about the city's future conditions to help communities and local government officials make decisions. Scenario planning methodology offers analytics to estimate how well existing or potential plans and strategies will function in meeting important local and regional needs given different assumptions about the future. In this step, I examined several "what if…" situations by modifying the original values and weights of each variable to see how changes to each evaluation factor affect the outcome. All the variables weighed by a new set of adjusted weights with a 10% change adjustment from the original weights[5]. 10 % weight adjustment was selected as anything below 10 % change of the original values did not show significant changes in scenario maps. For the same purpose, a new set of hypothetical values are assigned to all the variables. Value changes were determined in consideration of realistic standpoint reflecting the actual growth rate from the past year (for some data were not available) and value changes that make at least a noticeable change in the final outcome. All maps with the new sets of weights and values were compared with the status quo disaster vulnerability map to test the sensitivity of the model and detect if there are any patterns that indicate changes of vulnerability level.

[5] While one variable's weight increases, the weights of the other variables decrease as an overall weight cannot exceed higher than 100%.

Table 4: Hypothetical conditions and value adjustment of each evaluation factor

Evaluation Factors	Hypothetical Conditions	Value Change
Female (%)	Female population increased 2.5% at each block	2.5% Increase
Black (%)	Black population increased 3% at each block	3% Increase
Asian (%)	Asian population increased 3% at each block	3% Increase
Non-White (%)	Black population increased 2.5% at each block	3% Increase
AIAN (%)	Black population increased 2.5% at each block	3% Increase
Population 65 and older (%)	More elderly people move in to Bothell	5% Increase
Population under 18 years old (%)	Increase in young population under 18	5% Increase
Less than 9th grade (%)	Highest educational attainment increase	5% Decrease
Some high school (%)	Highest educational attainment increase	5% Decrease
High school (%)	Highest educational attainment increase	5% Decrease
Unemployed people (16yrs-older) (%)	Unemployment rate declines	3% Decline
Median income of a household ($)	Median household income increase by 5%	5% Increase
Average # of vehicles/household	1 additional vehicles per household	1 Increase
Median building age (year)	Average building age declines	5 Year Decrease
Rental Occupancy Rate (%)	Number of home owners increase by 5%	5% Decrease
CDBG Eligibility (Y/N/Partial)	All blocks are not eligible	All 0

Table 5: Weight changes to social dimension maps

Weight Adjustment with 10% Increase											
Impact Category	Original %	Female	Black	Asian	Non-White	AIAN	65/older	18/younger	9th Grade	Some HS	HS
Female	10%	11.08	9.88	9.88	9.88	9.88	9.88	9.88	9.88	9.88	9.88
Black	10%	9.88	11.08	9.88	9.88	9.88	9.88	9.88	9.88	9.88	9.88
Asian	10%	9.88	9.88	11.08	9.88	9.88	9.88	9.88	9.88	9.88	9.88
Non-White	10%	9.88	9.88	9.88	11.08	9.88	9.88	9.88	9.88	9.88	9.88
AINA	10%	9.88	9.88	9.88	9.88	11.08	9.88	9.88	9.88	9.88	9.88
Population 65 and older	10%	9.88	9.88	9.88	9.88	9.88	11.08	9.88	9.88	9.88	9.88
Population under 18 years old	10%	9.88	9.88	9.88	9.88	9.88	9.88	11.08	9.88	9.88	9.88
Less than 9th grade	10%	9.88	9.88	9.88	9.88	9.88	9.88	9.88	11.08	9.88	9.88
Some high school	10%	9.88	9.88	9.88	9.88	9.88	9.88	9.88	9.88	11.08	9.88
High school	10%	9.88	9.88	9.88	9.88	9.88	9.88	9.88	9.88	9.88	11.08
Total	100%	100	100	100	100	100	100	100	100	100	100

Table 6: Weight changes to economic dimension maps

Weight Adjustment with 10% Increase				
Impact Category	Original %	Unemployed people (16yrs-older)	Median income of a household	Average number of vehicles per household
Unemployed people (16yrs-older)	33%	36.3	31.85	31.85
Median income of a household	34%	31.85	36.3	31.85
Average number of vehicles per household	33%	31.85	31.85	36.3
Total	100%	100	100	100

Table 7: Weight changes to build environment maps

Weight Adjustment with 10% Increase				
Impact Category	Original %	Median building age	Rental Occupancy Rate	Community Development Block Grant Eligibility
Median building age	33%	36.3	31.85	31.85
Rental Occupancy Rate	34%	31.85	36.3	31.85
Community Development Block Grant Eligibility	33%	31.85	31.85	36.3
Total	100%	100	100	100

4. Results and discussion

4.1 Disaster Vulnerability in Bothell

From the Status Quo Disaster Vulnerability Map of Bothell (Figure 8), vulnerable areas seem to concentrate on the West half of the city, as well as the central areas of the city where King and Snohomish county meet together. In addition to the area near the county borderline, there are highly vulnerable blocks located around Bothell-Everett Highway extending along the highway from South to North. Although the assessment of degree of vulnerability based on the evaluation factors does not indicate most of the East half of the city as vulnerable area, overlaid floodways and flood plains are observed alongside North Creek River, the East side of the Freeway I-405, and Sammamish River. Most of the landslide-prone deposits and past landslides are heavily concentrated in the Southern region. By overlaying the zoning map (see Figure 4), the majority of vulnerable areas are dedicated to residential and commercial development including the downtown area. Overall, vulnerable areas are spread all over the City of Bothell; more specifically, vulnerable areas congregate in the Western and Southern half of the city to the central region of the city along with the county borderlines and the major highways/freeways. Furthermore, areas near the county and city borderlines are moderately to highly vulnerable spaces. Given the history of natural hazard and historical records, evaluation of the current disaster vulnerability of the city concludes that although the degree of vulnerability depends on each census block, the residents and businesses of Bothell are always at risk of facing natural disaster.

By breaking down the city as a whole into three dimensions, this study identified that depending on which lens is used in the analysis of disaster vulnerability, the city can focus on one or a few areas to put more emphasis over others in prioritizing mitigation. For example, in

the overall “Status Quo” map (Figure 8), areas around Bothell-Everett Highway are marked as either vulnerable or somewhat vulnerable, while three dimensional maps (Figure 9, 10, and 11) show totally different patterns; Social dimension map shows the West side of the highway as highly vulnerable; Economic dimension map shows the same area as less vulnerable; and Built environment map shows the same area as vulnerable to highly vulnerable. Other than these differences, in social dimension map, the Northern part of the city is less vulnerable than other two dimensions while some areas near the central region of the city are also less vulnerable than other two maps. The economic dimension map, overall, shows least vulnerable areas throughout the map marking the downtown area less vulnerable than the other dimensional maps and the Status Quo map. Finally, in the built environment map, vulnerable areas are heavily concentrated in the central to Southern region, and the majority of the rest of the city is highlighted as vulnerable or highly vulnerable (except a few blocks).

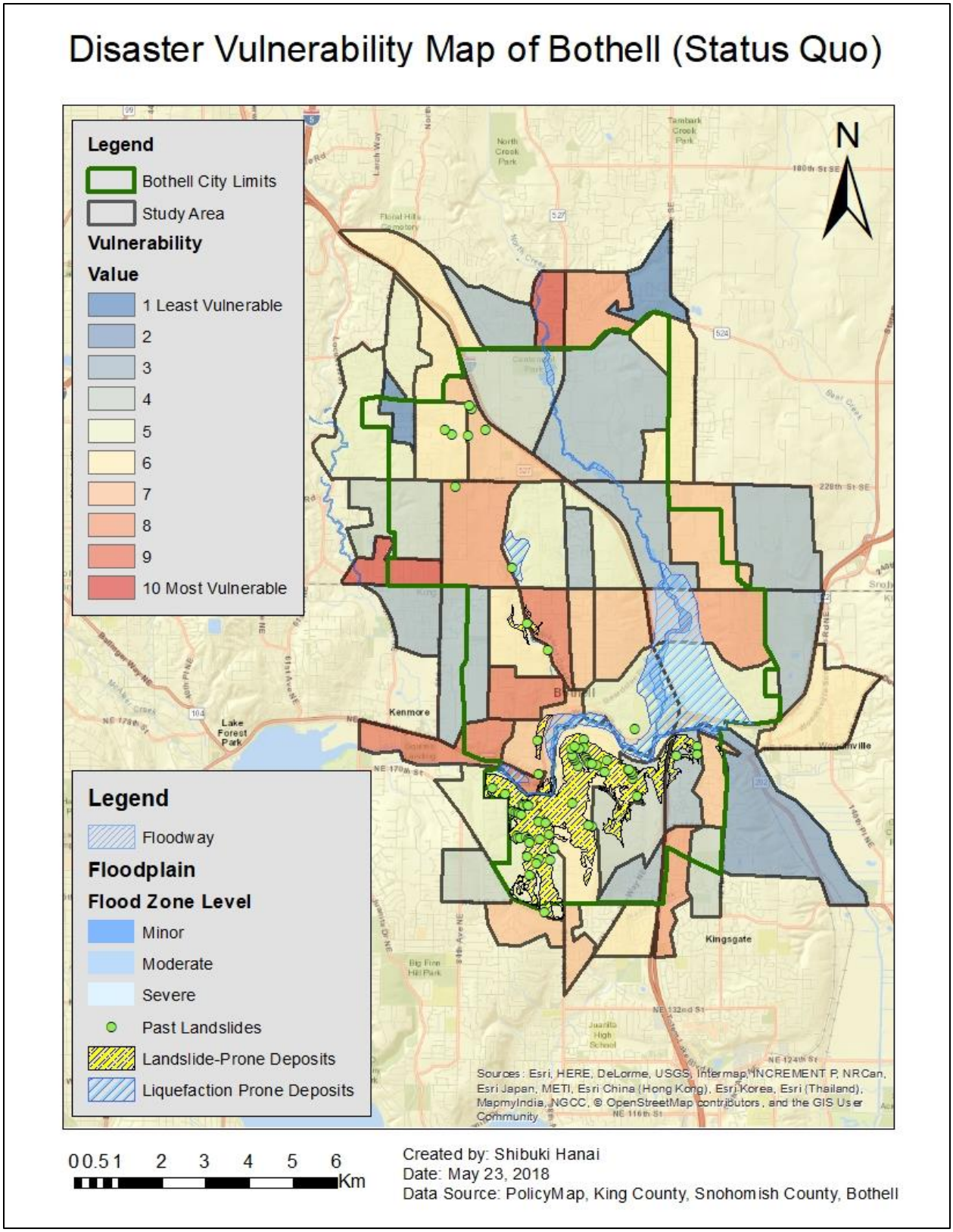

Figure 8: Current disaster vulnerability level of Bothell at census block level

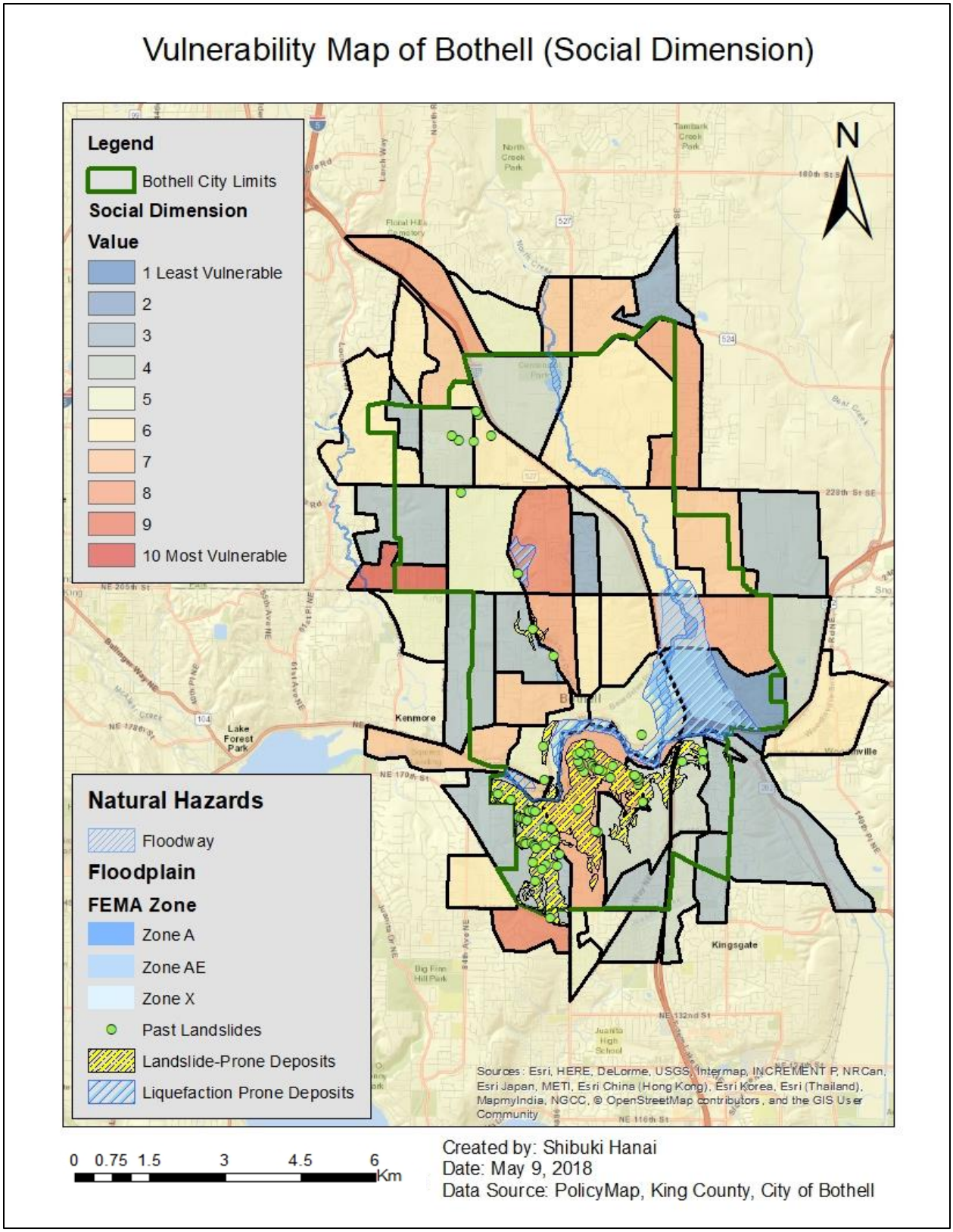

Figure 9: Disaster vulnerability based on the social characteristics of the City of Bothell at census block level

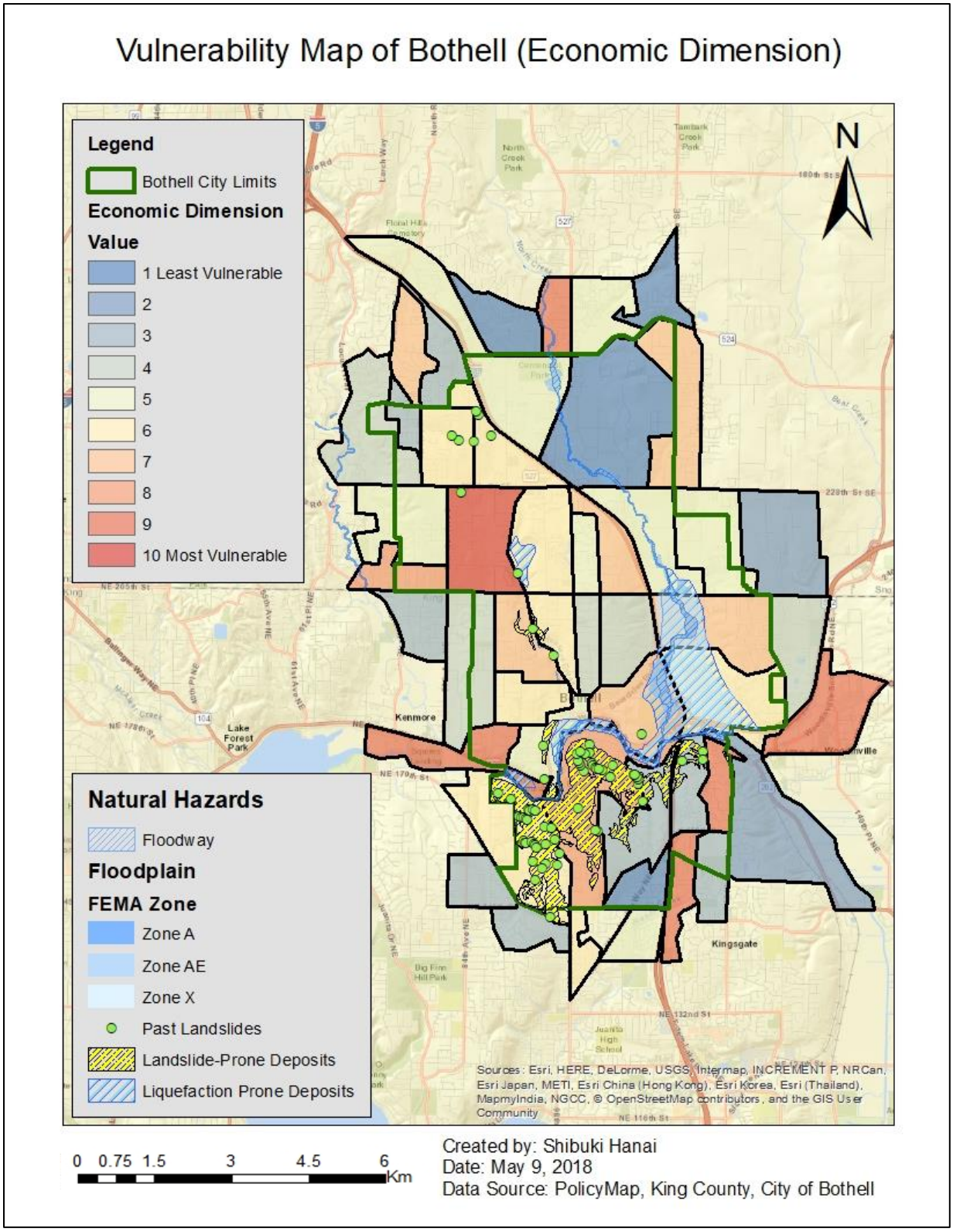

Figure 10: Disaster vulnerability based on the economic characteristics of the City of Bothell at the census block level

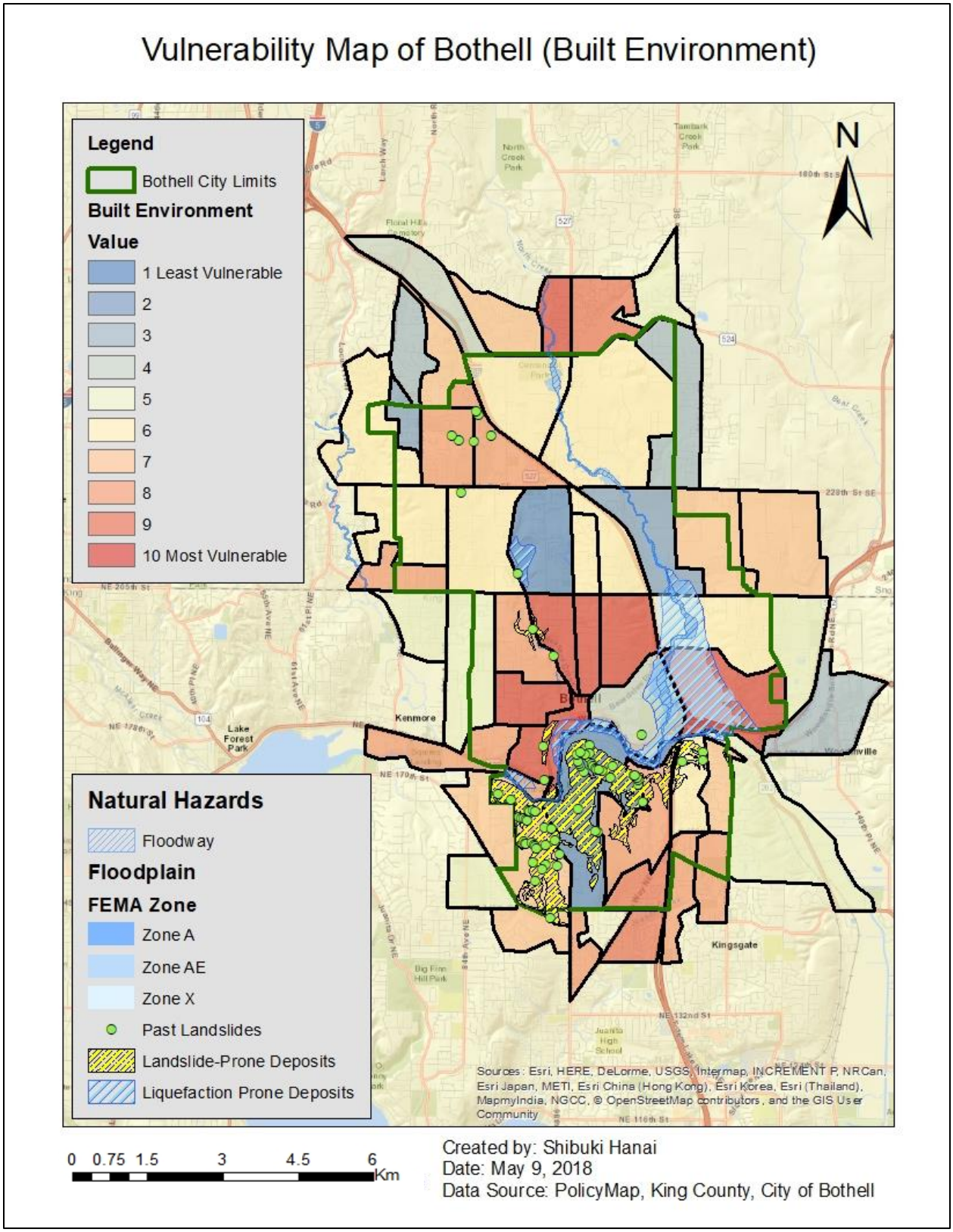

Figure 11: Disaster vulnerability based on the built-environment characteristics of the City of Bothell at census block level

4.2 Interpreting the Sensitivity of the Model

To test the sensitivity of the evaluation model, I modified factors and weights of the MCE models. Some changes made noticeable differences on the map in comparison to the Status Quo map while many changes did not drastically affect the outcome with very slight changes on the map. Overall, four noteworthy changes were observed:

1. Increasing educational attainment, blocks on Snohomish County side of the county borderline became less vulnerable. Blocks on the left side of I-405 also became much less vulnerable (Figure 12, 13, and 14);
2. Increasing elderly young population including families with children made some areas near the city limits more vulnerable – especially Northeast border of the city. However, the changes made the West side of I-405 less vulnerable (Figure 15 and 16);
3. Decreasing unemployment rate made the Northern half of the city (Snohomish County side) much less vulnerable; especially alongside I-405 and Bothell-Everett Highway (Figure 17);
4. Taking away Blocks Community Development Block Grants (CDBG) Eligibility made areas near county borderline and central to Southern region much more vulnerable (Figure 18).

Scenario planning revealed several important implications of the model and certain spatial patterns; whatever the evaluation factor being modified, county borderline and the city's periphery areas near the city boundary are always at high risk that resulting natural hazard events easily transform into disaster except small portion of the Northeastern region of the city; despite the changes to evaluation factors, areas around I-405 and Bothell-Everett Highway are always at risk, and they can potentially act as obstacle for many residents during the evacuation phase of a

hazardous event. Seemingly less vulnerable areas such as Northeast end of the city only become exacerbated; if there were changes, the majority occurred in the Snohomish County side of the city – especially changes to educational attainment and unemployment rate.

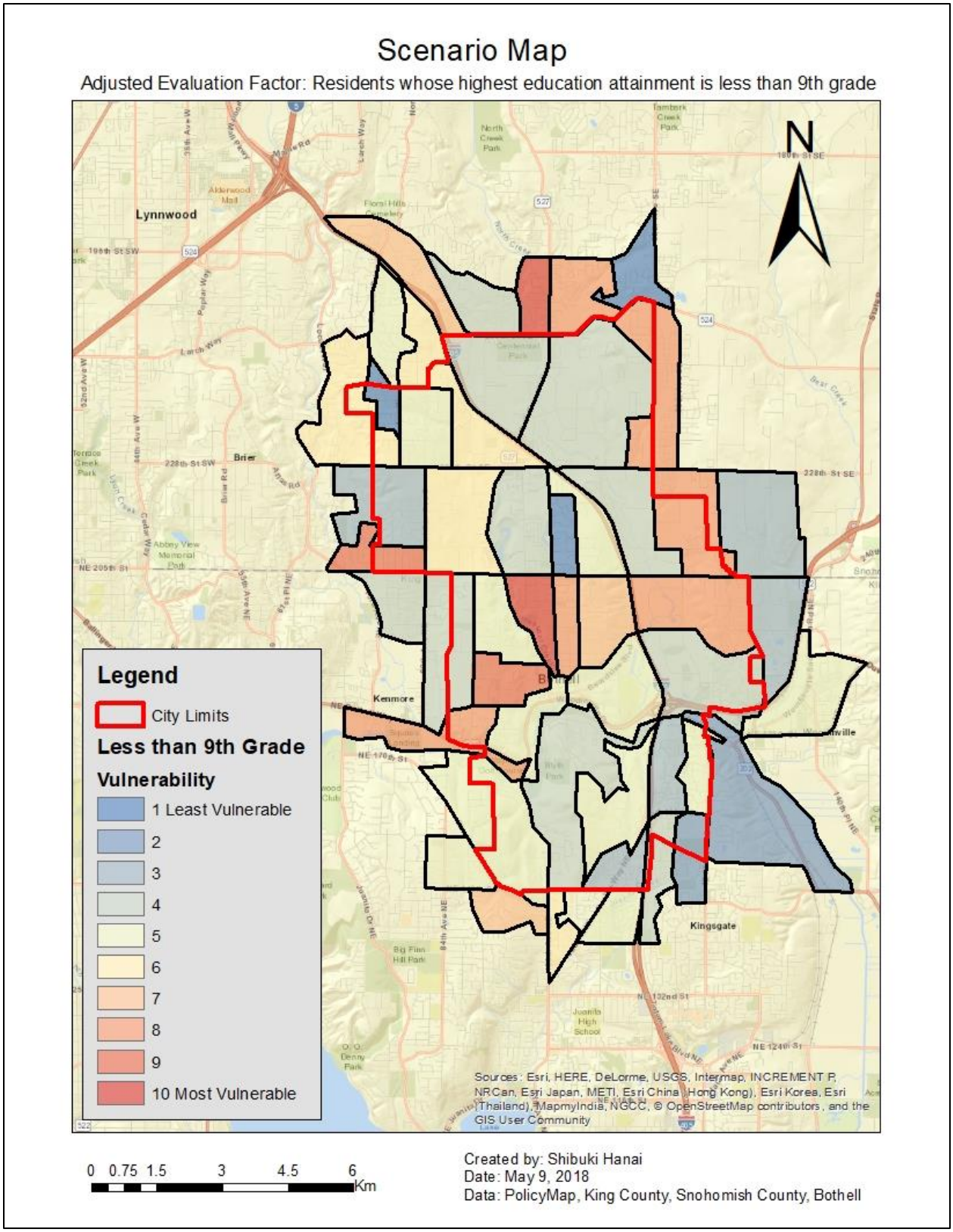

Figure 12: Scenario map showing how changes to evaluation factor "less than 9th grade" affect the outcome

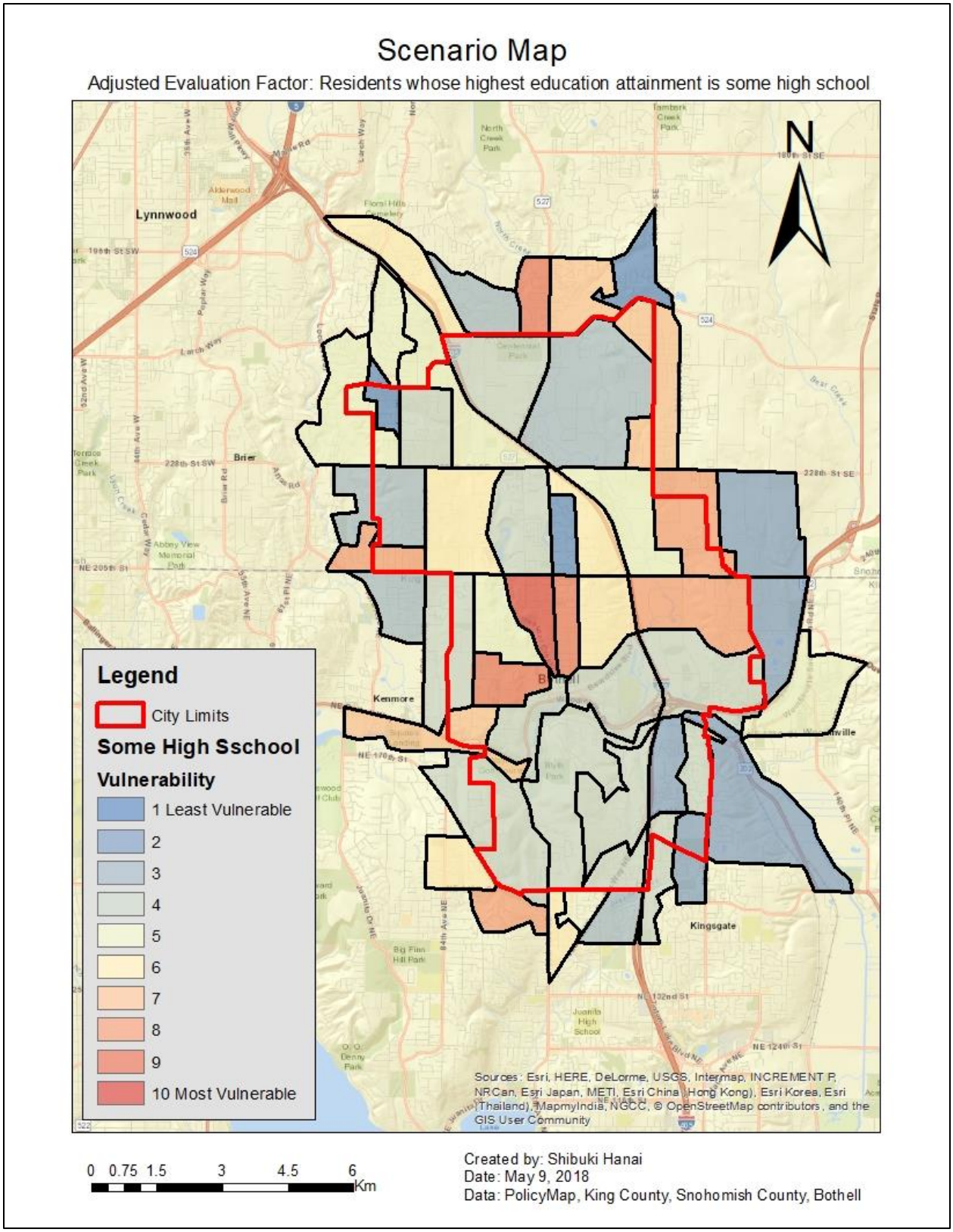

Figure 13: Scenario map showing how changes to evaluation factor "Some HS" affect the outcome

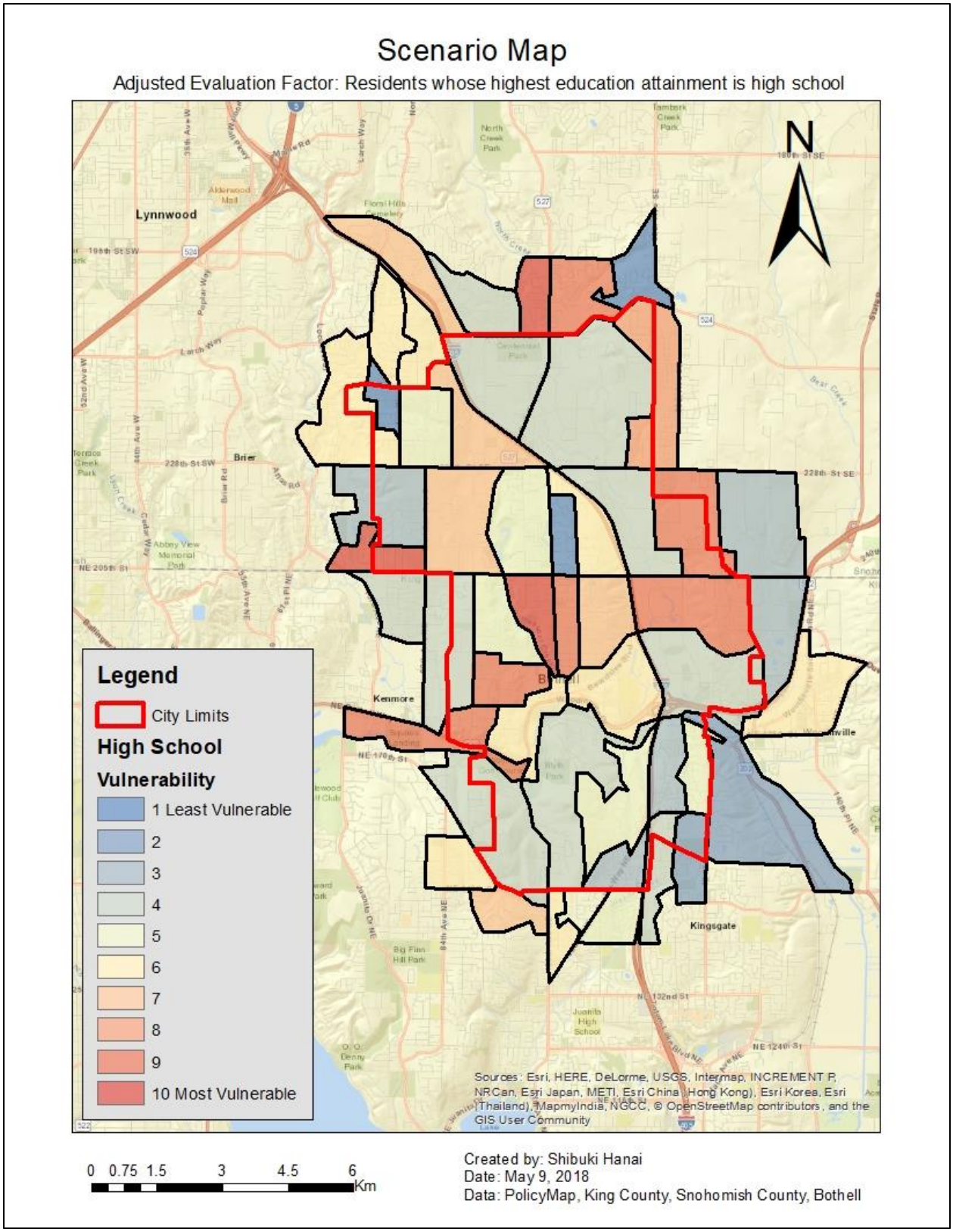

Figure 14: Scenario map showing how changes to evaluation factor "High School" affect the outcome

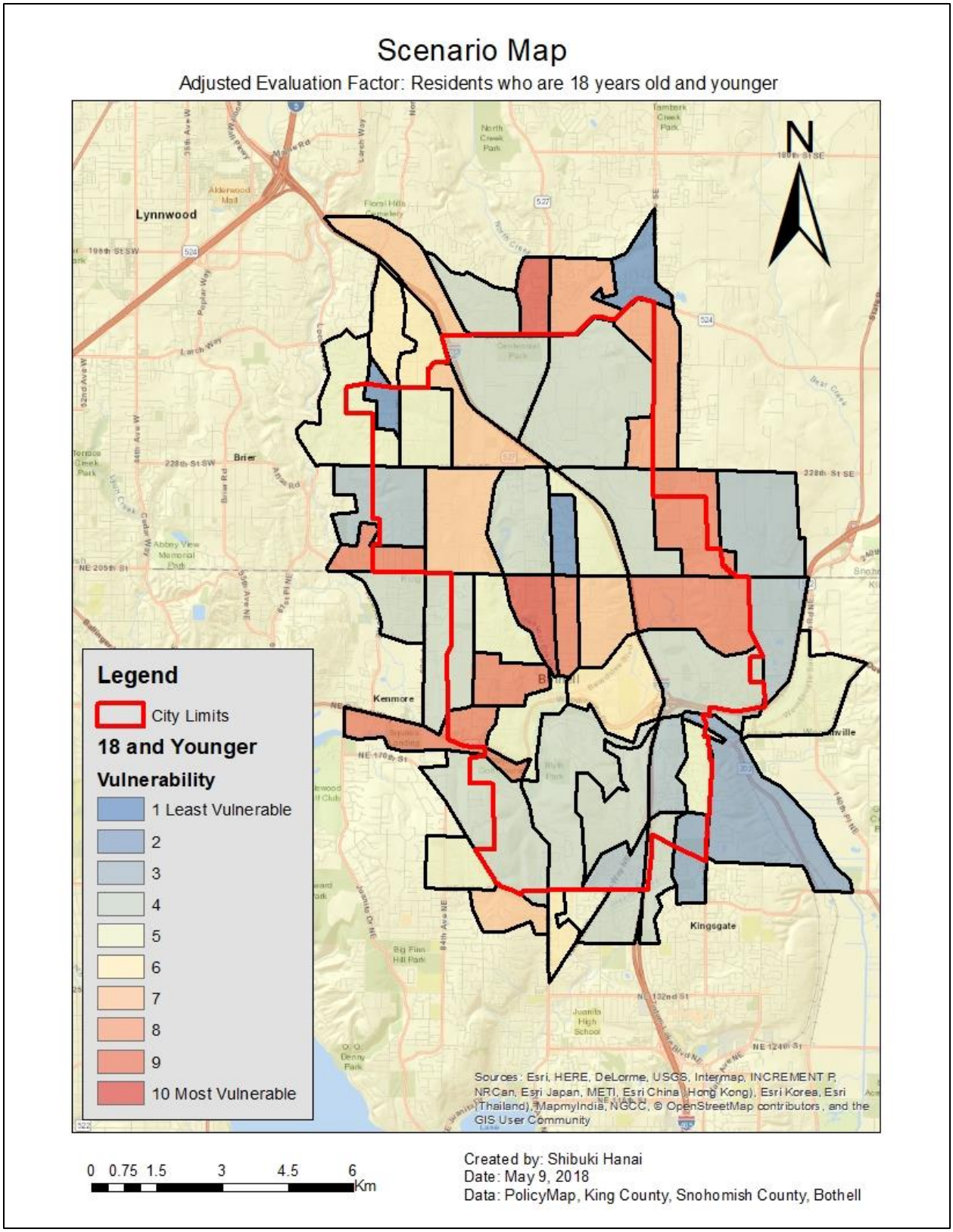

Figure 15: Scenario map showing how changes to evaluation factor "18 and younger" affect the outcome

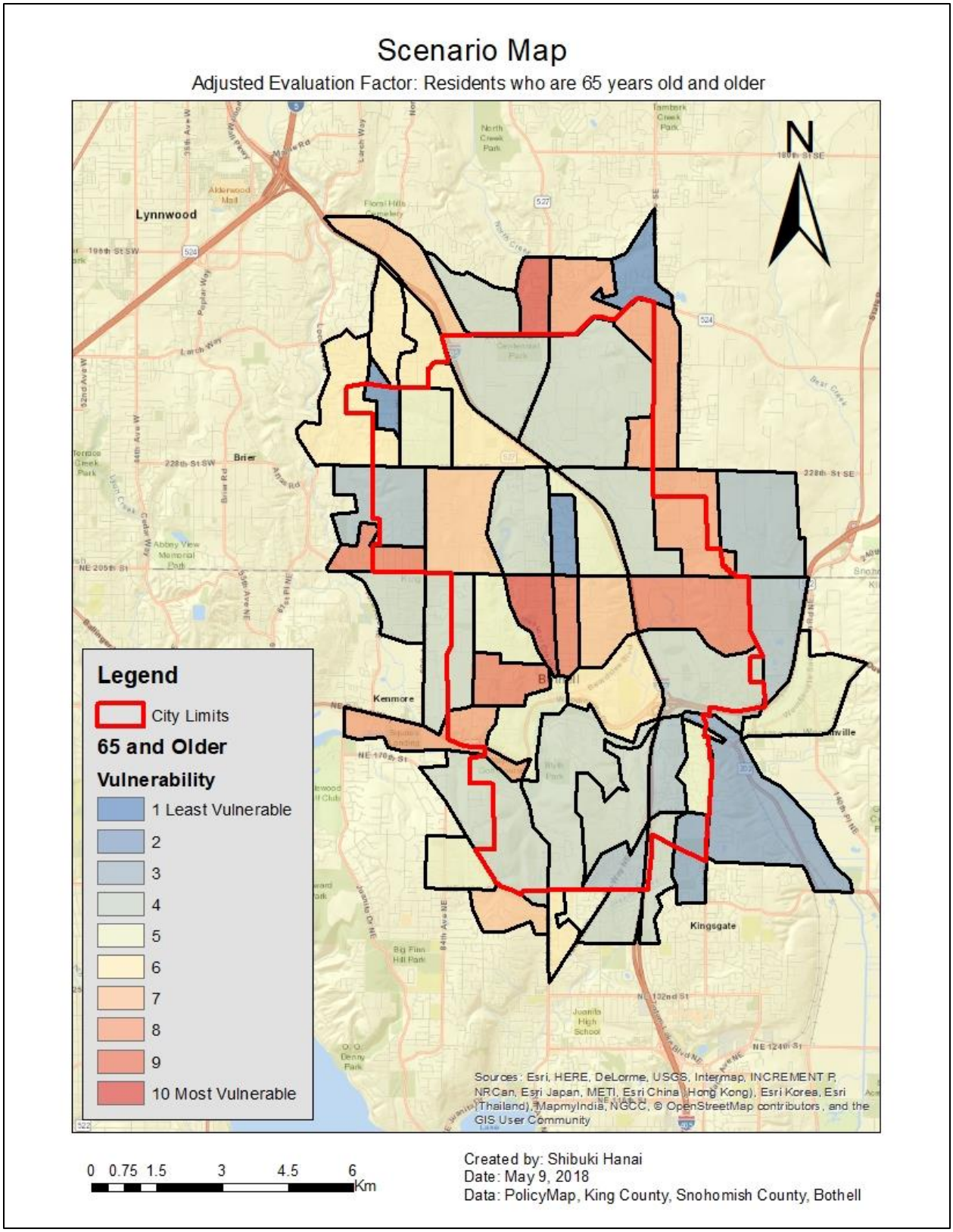

Figure 16: Scenario map showing how changes to evaluation factor "65 and older" affect the outcome

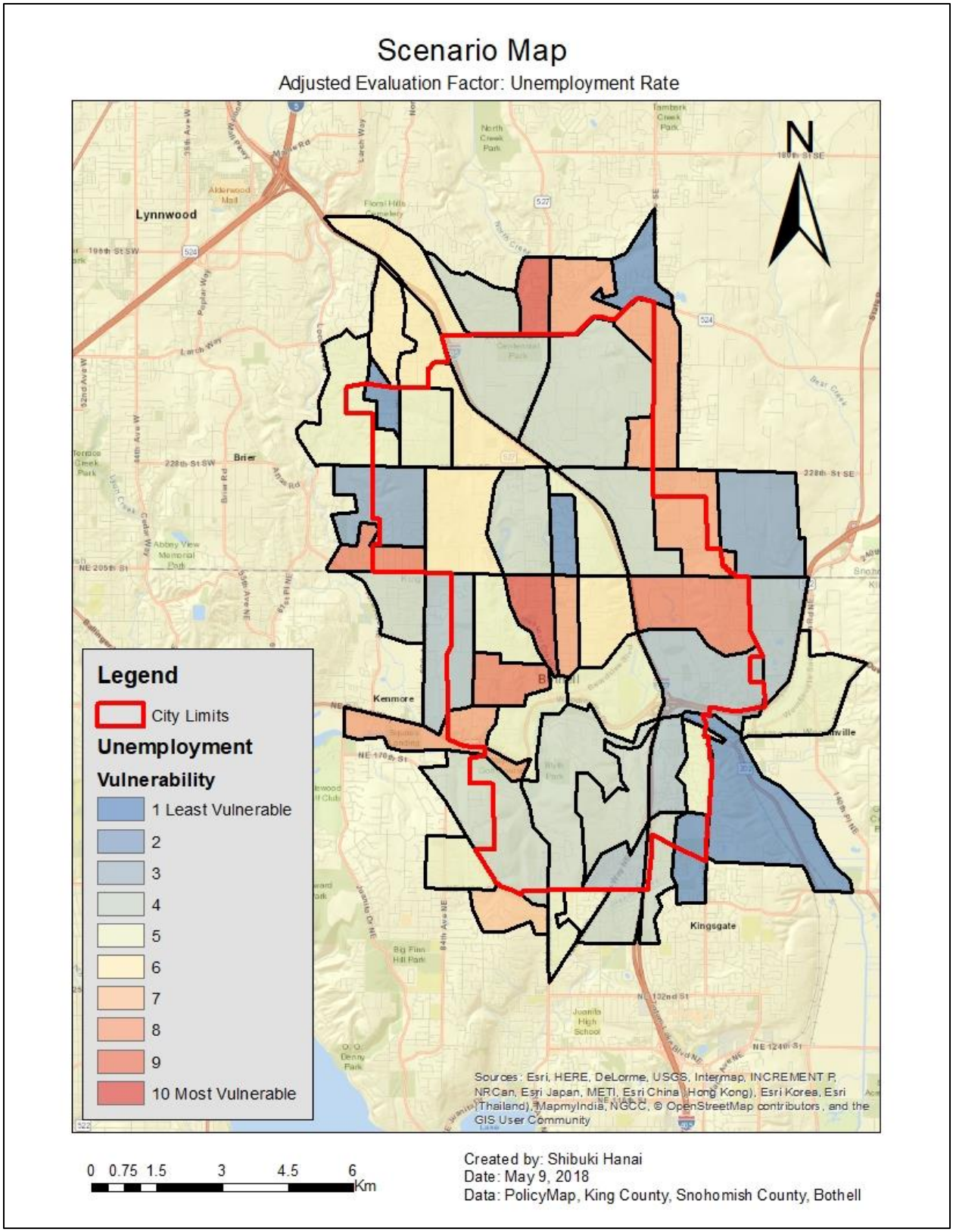

Figure 17: Scenario map showing how changes to evaluation factor "Unemployment" affect the outcome

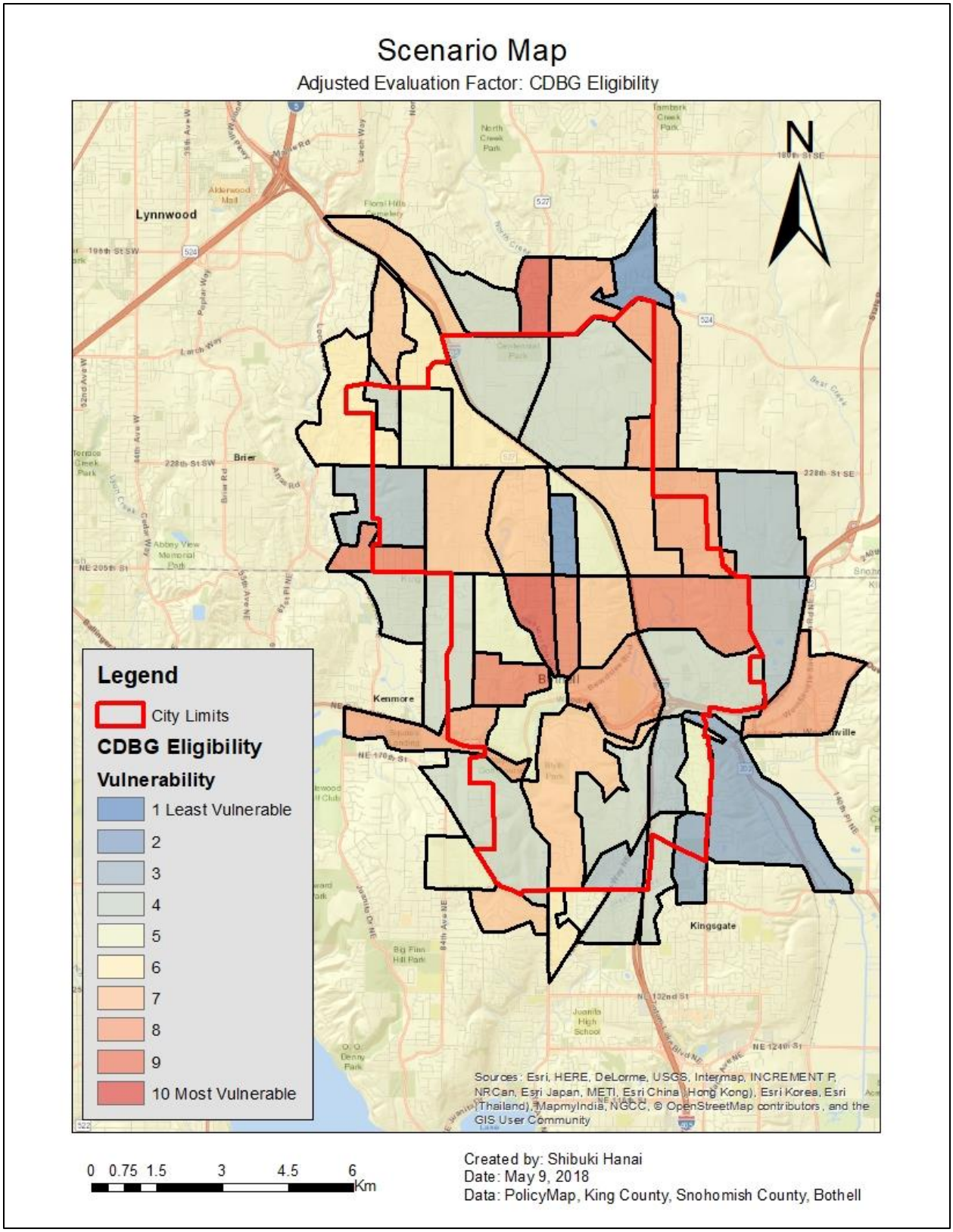

Figure 18: Scenario map showing how changes to evaluation factor "CDBG Eligibility" affect the outcome

4.3 Recommendations

There are clear steps that local governments can take to mitigate the impact of natural hazards and to increase resilience in their aftermath. Two important steps are building local capacity to anticipate risk levels of each community and establishing platforms through which to request resources from national, state, or provincial governments. As a city that expands into two counties, developing communication mechanisms and networks that facilitate information sharing and updating is critical to increase the accuracy of risk assessment. Particular attention should be placed on locations on the periphery of the city and counties. Local government must be able to provide residents with appropriate resources to support preparedness efforts before hazards and with access to resource during and after a natural hazard event. Another priority is a recalibration or reallocation of resources towards emergency preparedness in consideration of the city's population demographic and distribution. Incorporating population growth and distribution patterns and trends into a mitigation activity is an essential part of planning. For instance, Bothell's poverty rate is 6.69%; the top three largest groups living in poverty are female 18-24, followed by female 25-34, and then female 35-44; senior residents (12%) and children (22.7 %) who are more exposed to risk in general); there is a significant pay gap between female and male residents (male residents receive 1.37 times higher on average) although Bothell's income inequality index is lower than the national average. This study highlighted that these population-specific adversities that exist in every corner of the city can be organized into location-specific conditions. This process allows planners to more holistically assess communities' needs and determine primary targets for mitigation efforts with the help of spatial information. In order to achieve effective emergency preparedness, Bothell must work with multiple stakeholders

throughout the planning process to identify known risks, needs, and potential solutions, realizing the potential of community to contribute to risk reduction.

Recommendation 1:

Development of Administrative Structure for Cross-County Information Sharing

Developing cross-sectoral areas around the city limits and the county borderline for information sharing and collaborative discussion in building policy networks are crucial steps toward stronger resilience. In collaboration with King and Snohomish Counties, as well as with neighboring cities such as Kenmore and Woodinville, Bothell should invest in easily accessible channels of information and awareness systems about risk. This will provide an opportunity to build capacity and move away from a resilience of "those-who-we-know" to having actual shared resources to which all residents have access to. The primary objective here is to leverage services and stakeholders to support risk reduction and emergency response activities by delivering the right information to the right people at the right time. For complex emergencies caused by a natural hazard, governments rely on their own standard operating procedures and national-level mechanisms in which a specific organization leads emergency response coordination (such as FEMA or HUD). There are also regional-level mechanisms for sharing information for emergency response. Both national and regional mechanisms are expected to integrate seamlessly and complement one another. However, at county and municipal level in Washington state, there is no consolidated procedures in process for making the best use of the available resources and no comprehensive guidelines listing the options that are accessible and applicable to difference scenarios. There will be multitude of actors, interactions, and procedures needed to develop a structure for efficient sharing of space-based information during an emergency. Thus, there is a need for a decision-making framework for evaluating initial needs

around county borderline and city limits based on disaster scenarios and for the development of a mechanism to determined roles, values, and limitations of each county/city. Although information sharing is critical to recovery and search efforts, the structure of information sharing needs to put emphasis on mitigation activities and on reaching more vulnerable areas to mitigate the anticipated hazardous event. Given these criteria, new structures of sharing information and creating a collaborative network must include stakeholder analysis, each stakeholder's areas of responsibilities, and the identification of communication platforms.

Recommendation 2:

Incentives for People Living in the South Region to Move to Safer Areas

Bothell needs to create incentives for senior residents and families with children to reside in less vulnerable areas (e.g. building senior housings in the Northeastern region of the city while currently many senior housings are concentrated in the Southern region). This is not only a problem of developing incentives for those at vulnerable areas, but also providing safe spaces for urban development, avoiding construction in disaster prone areas, and providing recreational areas with reduced risk. Older adults and children tend to be less mobile and requires longer time to travel from point A to point B. Therefore, securing evaluation routes and establishing designated evaluation sites for those vulnerable populations is important. The results of this research indicate that the entire South region is not appropriate for residential or commercial activities and building new housing units in this area of the city should be banned as it is very prone to landslides and floods. Thus, moving those populations to different parts of the city would make more sense than creating evaluation sites there for two reasons: 1) as shown in the Status Quo Disaster Vulnerability Map, construction of a designated evaluation site in the Southern region where many elderly population reside and landslide-prone deposit lays, is not

realistic; 2) the Southern region of the city is physically and socially isolated from the rest of the city by being close to the city limits and Sammamish River running from East to West side. Also, moving forward, the future development of zoning should incorporate disaster vulnerability of neighborhoods within the city.

Another approach is to create incentives for developers and regulate their construction details based on number of units only available to specific populations. In the Northeast region of the city, creating inclusionary zoning area should be a mandatory requirement or a voluntary goal to reserve a specific percentage of housing units for family with children and/or elderly. Aging in Place report by AARP (2015) found that an inclusionary zoning creates communities with a richer mix of housing sizes and prices (AAPR 2015). Most communities offer significant incentives to developers in order to offset the cost of development such as providing affordable housing. Kinds of incentives include parking waiver, zoning variances, tax abatements, fee waivers, and expedited permitting. These incentives generally come at a real cost to the public sector (Calavita and Mallach 2009). Incentives such as tax abatements and fee waivers reduce revenues available to jurisdictions just as cash subsidies to development projects would. Even planning incentives such as density bonuses, which appear free, result in increased infrastructure and other public costs (Calavita and Mallach 2009). However, the goal of an inclusionary requirement here is not to enable developers to earn profits while capturing some share of "excess profits" for public benefit. Thus, any incentive the City of Bothell can offer to make development more profitable should also enable the imposition of a higher inclusionary requirement to attract vulnerable populations. However, communities have to carefully weigh the costs and benefits of each incentive and evaluate them relative to the cost of meeting criteria to build stronger resilience to natural hazards.

Recommendation 3:

Support and Protection for Small Businesses

There is a need to provide a program to support local-based small businesses. It is important to keep in mind that most of the small businesses are concentrated in the King County side of the city, and that reducing unemployment rate lessened the degree of vulnerability in downtown. FEMA's research shows 40% of small business never reopen after a disaster due to loss of employee, client, vendor information, environment changes, and loss of administrative records (FEMA). Creating a program to assist small businesses to establish emergency policies for employees, customers, and vendors would mitigate aftermath of natural hazard small businesses experience and secure the city's economic resources. The U.S. Small Business Administration (SBA) offers small businesses a set of general preparedness information including templates and guidelines on how to identify critical business functions and how to create an emergency communication plan. While SBA is an easily accessible resources to all small businesses, development and implementation of new emergency policy or management plan would require further work. Identifying critical business function during emergency would involve collaborative works in conjunction with the city's risk assessment analysis of potential natural hazards (SBA). Thus, the city should work closely with Greater Bothell Chamber of Commerce (GBCC) to develop resources that help small business owners independently initiate development of emergency management plan with input from the city.

This study showcased that decreasing unemployment rates can contribute to reducing vulnerability of the Northern half of the city, however, keep in mind that on average females in Bothell between 18 years old and 44 years old economically suffer the most during and after a disaster as they are the top living group in poverty. Increasing opportunities for females to on

more stable employment opportunities and supporting them to progress in their career would also make sense from the perspective of disaster mitigation as it rises the overall mobility of residents and financial capability. Advocacy for female residents is interconnected with a robust mitigation plan; developing resources to narrow the gap underserved females and less vulnerable populations with attention to spatial information – whether increasing access to education, career opportunities, or essential life supplies – would lead to stronger resilience to natural hazards. With this in mind, the areas of improvement include assistance for child care and better education system, more specifically among women with children. Along with the issue of improving the current education system, it is critical to provide parents with enough resources in order for them to focus on their education and work. Therefore, I would suggest a policy that support women pursuing education. I also recommend for the government to develop a program geared towards career strategies, professionalization, and tools that women between the ages of 18 and 44 may use to move up within their career or negotiate a higher salary. This way, the women feel more empowered and in control of higher positions within their career field, and it leads to better job retention rate, therefore broadening the support for women taking care of the country. Successful integration of increasing economic capability of female residents and development of a safeguard for small business can contribute to increased resiliency while lessening the vulnerability of the Northern half of the city.

Recommendation 4:

Create an Evacuation Model Specific to Neighborhood

One of the recurring image of natural disasters like flood by a hurricane are pictures of miles of bumper-to-bumper traffic along major freeways leading out of the affected area. Huston, Texas, for example, residents of Huston rushed into road when Hurricane Rita made its way

toward Huston just a few weeks after Katrina devastated New Orleans, which became one of the largest evacuations in the U.S. history (PBS). The direct death toll from the storm itself was fewer than 10, however, dozens of people died on the road in a bus fire, traffic accidents, or heat stroke. For this reason, when Hurricane Harvey struck the city in 2017, Huston Mayor Sylvester Turner told people to stay at home and not to evacuate, adding "If you think the situation right now is bad, you give an order to evacuate, you are creating a nightmare" (Turner 2017). It seems that fundamental understanding of risk management is that not encountering or getting away from a hazard is the best way to protect oneself. However, historical examples proved unplanned evacuation would potentially do more harm than protection. Given the situation in Bothell where all the major freeway/highway intersecting the city are near the areas vulnerable to natural hazards, a traffic congestion is expected during a mass-evacuation prompted by the order from state or local government. Or if even worse, the freeway/highway may not be functional at a pathway to safer land, trapping residents in the vulnerable area. Thus, ensuring that public space for evacuation site, reliable infrastructure, and parks are identified and protected at the planning phase is critical to prevent potential injury and death from the secondary impact of a hazard.

With these concerns in mind, upgrading vulnerable settlements alongside freeways/highways with attention to access roads, flood-risk, infrastructure, and other safety measures, can reduce the potential to penetrate into a vulnerable area during an emergency. Evacuation planning should involve determining how many cars and people are trying to leave a location and go to another location, and to figure out how they are going to get there (FEMA year?). An evacuation model for the city should be location specific, reflecting the population demographic of the neighborhood and physical attributes that may become an obstacle during evacuation. The city should also invest in an alternative way of utilizing I-405 and Bothell-

Everett Highway during an evacuation. Among the states that are subject to hurricane and flood threads, one of the evacuation toolbox's major features is some form of contraflow (also known as lane reversal) (Ballard and Borchardt 2006). Most of these plans call for operating the four-lane divided controlled-access highway traffic in all four lanes is traveling away from the coast toward inland destinations where the dangers posed by the approaching natural hazard (typically hurricane) are significantly reduced (Ballard and Borchardt 2006). Development and implementation of contraflow is time consuming and requires multiple stakeholders to participate at the planning stage, however, it can most effectively mobilize the vulnerable population near the freeway/highway. A big concern here in WA is earth quakes. How does preparedness around earth quakes fit within your recommendations? It doesn't have to be a long discussion, but something related specifically to earthquakes is missing.

5. Conclusion

This research examined disaster vulnerability of the City of Bothell by measuring social, economic, and built environment factors with supplemental information of natural hazard history in Bothell. This study demonstrated that a tool to measure vulnerability can help communities assess their priorities, goals, and needs, and help establish baselines for the future mitigation. Baselines are needed to better assess progress and to set goals to allocate resources. The model used in this study and scenario planning revealed that one factor being evaluated can have a different outcome on different part of the study area, depending on the conditions of the other factors in the location being examined. For example, residents' age is one indicator to assess the degree of vulnerability, but overall vulnerability of the area being studied depends on its spatial characteristics and other existing conditions, such as average household income and building age. Within the cohesive relationship between human activity and natural environment, actions for

the sake of vulnerability reduction, resilience building, and adaptability improvement can all contribute to natural hazard and risk mitigation. Thus, a sustainable mitigation strategy to the inevitable hazards or changes to society should not only seek to decrease vulnerability of social systems and marginalized populations, but also to foster their resilience and adaptive capacity to future uncertainties and potential risk. This study also reaffirmed the idea that either a communication mechanism or planning framework around emergency response, is needed to understand investments that were made to improve resilience, especially because such investments can be of considerable size for many communities (Cutter 2012). Therefore, at the planning level, local governments must consider that developing new capability against natural hazards in a community requires thorough research of risk and impacts, and close consultation with local experts and communities.

This study also highlighted the lack of resilience to disaster in Bothell and identified significant challenges and potential limitations to adaptation that the city may face. There are areas where the lack of resilience was more palpable than others, including the inability to reach vulnerable populations, immobility of vulnerable people, protection for the city's economic resources, and availability and access to safe public spaces. Understanding these adversities provides opportunities for better decision making with mitigation implications. While vulnerability exists almost at every corner of Bothell, it is important to take a look at the result of vulnerability from a three-dimensional perspective. In ranking of vulnerability this study used ten social, three economic, and three built-environmental evaluation factors. Addressing the problems infesting in the existing structures and potential disaster risks should be done at a dimensional level in addition to the city as a whole. It is helpful to take a closer look at each evaluation dimension individually to more specifically address underlying chronic conditions

rooted in the community as a result of how the social systems and the city itself are structured to provide services unevenly. After a strike of natural hazard, even when communities seem to be doing well, segments in society that used to be secure before the hazard have to deal with more risk and volatility than in the past. (Bates and Swan 2015).

I acknowledge that some indicators for each vulnerability dimension used by other researchers are not included in my model. This is mainly due to the data availability at census block level. To ensure the consistency and accuracy of the analysis and visualization result, data whose pre-defined location level is not census block level are not applied to this study. Thus, I suggest complementing the model used this study to advance its reliability by adding missing components. Although an expert's input was taken into consideration when calculating disaster vulnerability levels, there is a need for incorporating hazard-specific geological data to prioritize areas of attention based on the type of natural hazard. In this study, I focused on policy recommendations to foster the needs of vulnerable populations during emergency. This research illustrated that the determinants of disaster vulnerability overlap with of socioeconomically marginalized populations, which draws a connection between hazard mitigation planning and social justice endeavors. This finding reinforces the notion that location contributes to determining degree of relative advantage or disadvantage. Thus, seeing disaster mitigation planning as a social justice effort, the investigation of how fair and equitable distribution of space is, would be a step toward more successful disaster mitigation planning. Finally, although this study did not analyze the existing policies and disaster programs in depth, further research is encouraged to investigate the effectiveness and efficiency of existing preparedness programs and resources in an attempt to integrate federal, state, and local mitigation efforts seamlessly.

Although measuring resilience is a challenge in many cases, this study suggests that mapping vulnerability of a city and identifying where vulnerable populations reside is one of critical indicators for assessing and mapping resilience. Analyses of societies particularly focusing on natural disaster and human activities tend to focus on vulnerabilities. While a researcher focuses on the vulnerabilities, Nelson (2011) warns that we often overlook the fact that the larger system (which structures many of the observed vulnerabilities in smaller scales) may be quite resilient. This underscores the importance of ultimate changes rather than proximate causes of changes. In addition, even recognizing potential threshold changes, those at the top level of an organization or political structure are likely to respond to risk in a manner that does not threaten the existing organizational structure (Handmer and Dovers 2013). Thus, developing sources of resilience and adaptive capacities may require challenging the status quo. This study witnessed that solving some conditions in Bothell that contribute to reducing vulnerability requires fundamental change that may disrupt the larger systems that seem to be functional in non-emergency situations. Thus, failure to address the city's basic development challenges will result in increasingly large losses of life, damage to property, and loss of economic assets.

Lack of situational awareness of the existing system may prevent operators or government officials from reconfiguring the system either before or after the hazardous event. Being able to measure level of vulnerability also means being able to anticipate who is likely to get most damage. This is noteworthy as it gives more control to the operators by breaking the larger system into smaller clusters to prevent cascading failures during emergency. Accordingly, in building resiliency, it is important to have strong social networks and connections among communities to reduce the amount of uncertainties during emergency. This indicates that

inclusion of community members is necessary at the very beginning of planning. Efforts to develop communication networks should create horizontal relationships, not the hierarchical institutions, in order to provide communities with more autonomy and capabilities in situations where the social systems they normally rely on are not functional. Therefore, in essence, being able to identify vulnerable population and distinguish the difference level of vulnerability spatially at community level is crucial to prioritize strategies to improve resilience to natural disasters.

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