Vulnerability Assessment Using Time Series Mapping: A Case Study of Typhoon Haiyan in Tacloban City, Philippines

Time-Series Vulnerability Assessment to Typhoons in Tacloban City, Philippines

Ana Sofia Gonzalez Rojas

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Abstract

This study assessed the changes of vulnerability to typhoons in Tacloban City, Philippines, by mapping and comparing vulnerability dynamics before and after the Typhoon Haiyan. Coastal communities in the Philippines are disproportionally affected by the impacts of typhoons due to their vulnerable housing, lack of access to information, and low capacities to cope and recover from natural hazards. Understanding the vulnerability dynamics over time can help to reduce the risk of deaths and other losses by aiding the targeted implementation of disaster risk reduction strategies.

My main research questions were: Which barangays in Tacloban City were the most vulnerable in both years? How have vulnerability scores changed from 2010 to 2015 after the Typhoon Haiyan? What effect did resilience strategies implemented by the government have on vulnerability levels? My hypothesis was that vulnerability decreased from 2010 to 2015 due to the resilience strategies implemented to reduce disaster risk. In order to test this hypothesis, I used census data (2010 and 2015) from Tacloban City to assess the 138 barangays (neighborhoods).

I created an index that evaluated the three components of vulnerability: exposure, sensitivity and adaptive capacities, using the four-step approach methodology (Krishnamurthy, Lewis, & Choularton, 2014). To visualize the spatial dynamics of vulnerability, the scores resulting from the index were mapped and compared. I concluded that results support that vulnerability was reduced to attain a low vulnerability level. The barangays with higher vulnerability (Barangay 88, 89 and 90) showed a

reduction of almost 45%. This reduction can be explained by the efforts and resilience strategies and recovery programs implemented after Typhoon Haiyan. I discussed the further questions and analysis that needs to be done on site with more qualitative data from interviews and focus groups in order to understand the changes in adaptive capacities.

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Definition of Terms

Adaptive Capacity: the ability of people, organizations, and systems, using available skills and resources, to manage adverse conditions, risk or disasters.

Barangay: in the Philippines: a village, suburb, or other demarcated neighborhood; a small territorial and administrative district forming the most local level of government.

Disaster: a serious disruption of the functioning of a community or society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope with using its own resources.

Disaster Risk Reduction: the practice of reducing disaster risks through systematic efforts to analyze and reduce the causal factors of disasters.

Exposure: The people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

GIS: Geographical Information Systems

Resilience: The capacity to recover quickly from disasters.

SoVI: Social Vulnerability Index

Typhoon: Regional name used for "tropical cyclone" in the North Pacific basin.

Storm surge: A rising of the sea as a result of atmospheric pressure changes and wind associated with a storm.

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

Chapter I

Introduction

Tropical cyclones (known as typhoons in the southeast Asia region) pose an increasing natural disaster risk for coastal communities. In coastal cities, typhoons expose human life, and the associated assets and livelihoods, to disproportionate impacts from this disaster hazard (Baas, 2006). Strong winds, heavy rains, and storm surge can damage homes and buildings, health, and income sources (Gaillard, 2015). The Republic of the Philippines (Philippines), an archipelagic nation in Southeast Asia, experiences 20 typhoons per year (ADCR, 2017). Communities have been forced to adapt to and cope with the associated disturbances from these natural disasters (Walch, 2018), but when these storms are intense, as in the case of Haiyan Typhoon in 2013, the severe effect on coastal communities can signal a national disaster (Toda, 2015).

Typhoons have always been present in Southeast Asia; however, climate change, demographic changes, and other socioeconomic trends have led to more hazardous impacts over the last decade (EMDAT, 2019). Experts claim that climate change can exacerbate the intensity of typhoons, which increases the probability of disasters when they hit a vulnerable area (Yusuf & Francisco, 2009). Rapid urbanization and inadequate city infrastructure have led to the proliferation of slums and informal settlements (Ballesteros, 2010). Some fisher people communities build and reside in stilt houses over the sea for easy access increasing settlements in coastal zones (Toda, 2015).

In Philippine coastal communities, fishing and farming are subsistence economic activities (FAO, 2014). Reports indicate that 45 % of sampled communities reported farming as their primary source of income, which causes livelihoods to be more fragile to natural hazards (MIRA, 2013). Socioeconomic trends like poverty and lack of access to resources negatively affect the capacity of citizens to adequately cope with natural disasters (Wisner, Blaike, Cannon, & Davis, 2003). Therefore, it is necessary for the government and policy makers to focus resources and attention in building resilient communities in order to reduce disaster vulnerability in developing countries like the Philippines.

When a natural hazard, such as a typhoon, hits an area susceptible to storm impacts, a higher level of vulnerability leads to an increase in the disaster risk (UNDP, 2018). It is impossible for humans to control the frequency and intensity of natural hazards; however, it is possible to increase resiliency and build strong communities that are better prepared for future disasters by reducing local vulnerability (Gaillard, 2015). In other words, in order to reduce the risk of disaster, the aim must be to: reduce vulnerability by identifying areas that are exposed to hazards, focus resources and public programs to these areas within the city, and empower the most vulnerable groups identified (Toda, 2015).

Vulnerability assessments are a critical tool to identify at-risk areas and to prioritize appropriate interventions for the areas under study (Fekete, 2012). Even though vulnerability to typhoons is primarily driven by geographical characteristics such as elevation and distance from a water body, socioeconomic and household-level indicators can help identify social vulnerability in at-risk areas (Cutter, Boruff, & Lynn Shirley, 2003). Understanding vulnerability components and dynamics can help predict the spatial distribution of vulnerability to identify at-risk neighborhoods within cities (Zandt et al., 2012).

Due to a limited amount of resources and time, it is important that governments prioritize areas with higher risks in order to attend to the most vulnerable (Tuhkanen et al., 2018). Significant efficiency could be gained if local governments and disaster managers were able to visualize which barangays (neighborhoods in the Philippines) are at a higher risk of suffering the consequences of typhoons by producing vulnerability maps of the city that include the social characteristics of the inhabitants. Socioeconomic indicators can be extracted from national census databases which provide spatial data of the indicators. This allows experts to create vulnerability maps based on the combination of geographic and socioeconomic factors (Cutter & Finch, 2008).

Vulnerability mapping approaches are adequate for long-term planning (Edwards, Gustafsson, & Naslund-Landenmark, 2007). The method is capable of integrating typhoon risk areas using a GIS-based model to provide a rational and non-biased approach for making decisions in typhoon disaster (Shiva Prasad Sharma, Roy, & Chakravarthi, 2018). However, the main limitation of vulnerability assessments is that they don’t evaluate vulnerability over time. They are typically done once, reflecting a snapshot in time, ignoring the dynamic nature of vulnerability.

Vulnerability changes over time due to local dynamics and public initiatives, therefore a dynamic analysis that assesses more than one year, helps to understand its changes and drivers (Cutter & Finch, 2008). By using a method that extracts indicator values from census databases that are updated every determined period of time, it is possible to analyze a time series to evaluate spatial vulnerability through time. This approach allows a low-cost assessment from satellite geographical data and census databases.

Tacloban City, a coastal city in the Philippines, was hit by Typhoon Haiyan in 2013, which caused a major disaster with more than 6000 deaths (Ching, Reyes, Sucaldito, & Tayag, 2015). After the typhoon, the government developed a plan to increase resilience in vulnerable barangays (neighborhoods) in the city. In order to support local initiatives that build social resilience against typhoon risk, it is necessary to clearly delineate the most vulnerable areas (Zandt et al., 2012). The ability to compare and analyze vulnerability dynamics and indicators before and after a major national disaster can illustrate the evolution of vulnerable communities after a typhoon. Additionally, such analysis can provide a clear picture of the areas in the city that are still vulnerable, which can lead nations to be better prepared for future hazards.

Previous methods to assess vulnerability in the Philippines used census data, and are based on the adoption of census variables to create a Social Vulnerability Index (SoVI), which helped to identify differences in vulnerability levels between different neighborhoods in Tacloban City (Cutter et al., 2003; Luigi Toda, 2015). However, creating a multitemporal vulnerability assessment using the same indicators from a variety of years is useful to compare spatial vulnerability dynamics over time (Monterroso-Rivas et al., 2018). In the case of Tacloban City, the Philippines Statistical Institute performed a census in 2010, three years before Haiyan Typhoon, and in 2015, two years after Haiyan Typhoon. The availability of frequent census data allows for a comparison of vulnerability indicators before and after a major natural disaster, providing an increased understanding of the dynamics of vulnerability and the effects of the interventions after Typhoon on longer temporal and spatial scales. Additionally, it helps to evaluate and monitor disaster relief programs and resilience strategies.

Research Significance and Objectives

This thesis presents an insightful method for analyzing vulnerability over time at a low-cost using census data and satellite geographic data. The creation of comparative vulnerability maps of Tacloban City in 2010 and 2015 using census information from each neighborhood of the city helped to visualize the way in which social vulnerability has evolved over these five years and to better predict which barangay should be prioritized due to its vulnerability risk level.

This study aimed to provide an analysis of the spatial distribution of vulnerability of 138 barangays in Tacloban City to the typhoon impact. It explored two large datasets: 1) socioeconomic indicators that indicate an increased vulnerability sourced from census 2010 (before Haiyan Typhoon), and 2) the socioeconomic indicators sourced from census 2015 (after Haiyan Typhoon). Both datasets are compared using an adapted SoVI methodology to determine the level of vulnerability for each of the 138 barangays of Tacloban City in Eastern Leyte, Philippines. The overarching goal of this research was to compare vulnerability of the city over spatial and temporal dynamics using Tacloban City census data from 2010 and 2015 in order to identify systematic vulnerabilities that still need to be addressed in some areas of the city to increase resiliency in the face of natural disasters.

Background

The world is experiencing a new era of natural disasters. One of the critical effects of climate change is changing weather conditions, and growing incidents of heavy precipitation that can lead to hazards and impacts (Franta, Roa-Quiaoit, Lo, & Narisma, 2016). Disasters are increasing in frequency and severity in relation to their magnitude and length of exposure (Franta et al., 2016). These trends are being experienced globally as a result of rising atmospheric temperatures which contributes to the unpredictable intensity of rainfall patterns. Over the past decade, more than 1.5 billion people have been affected by disasters that have cost at least $1.3 trillion (NDRRMC, 2017). Climate change, weak governance, and an increasing concentration of people and assets in areas exposed to natural hazards are elevating disaster risk, especially in areas where communities experience high social vulnerability (UNDP, 2018).

According to the Intergovernmental Panel on Climate Change (2012), over the next 50 years, shifts in precipitation patterns will cause stronger and more frequent natural hazards like floods. Rapid urban growth is a crucial factor of disaster exposure due to overpopulation and unauthorized settlement in areas of high risk of natural hazards (Balaban, 2016). Moreover, poverty and social inequity are the main factors that increase vulnerabilities to hazards and reduce the capacities to cope and recover from the hazardous event (Denton, 2002). Therefore, policymakers at all levels of government should be aware of the vulnerabilities and integrate a disaster risk reduction agenda in their development plans in order to reduce overall vulnerability and strengthen the capacities of vulnerable groups (Zandt et al., 2012).

International policy, as well as community-level actions, can reduce vulnerabilities of specific groups that are most susceptible to disaster impacts (Blaikie, Wisner, Cannon, & Davis, 2003). In order to reduce vulnerabilities, the international community recently came together to ensure that Disaster Risk Reduction (DRR) is a priority in development (UNISDR, 2016). DRR is a systematic approach to assess and reduce the risk of disasters. In 2005, the UN International Strategy for DRR adopted The Hyogo Framework for Action (2005-2015), which commits the international community to consider resilience to disasters a priority in development plans. However, the strategy for DRR is not always easy to implement, as one of the most common challenges of disaster risk management is the lack of information and assessments at the local level (UNISDR, 2014).

One of the priorities of the Hyogo Framework is to use informed risk assessments in order to reduce disaster risk. It is important that risk assessments consider the two main factors that determine the severity of disasters: hazard and vulnerability (Figure 1). The degree to which populations and communities are vulnerable to natural disasters is determined not only by a population's proximity to the hazard but also by its social vulnerability status (Yoon, 2012). Risk assessment is a methodology to determine the level of risk through the analysis of hazards and evaluation of existing vulnerability conditions that, combined, could potentially harm exposed people, and the assets and livelihoods on which they depend (Turkana Wescoord, n.d.). Risk assessments are important to effectively plan and implement adaptation strategies to reduce the risk of exposed populations and vulnerable communities. For instance, if nothing can be done to avoid exposure or reduce the impact of the natural hazard, then efforts should be focused on reducing vulnerability to floods in populated areas.

Hazard	:	potential threat to humans and their welfare
+		
Vulnerability	:	exposure and susceptibility to losses
=		
Risk	:	probability of hazard occurrence
Disaster	:	realization of a risk

Figure 1. Risk disaster equation (UNFCCC, 2012).

Impacts of Typhoons in the Philippines

The Philippines ranks third in disaster-proneness among nations globally due to its geographic location, which leaves it vulnerable to natural disasters (World Risk Report, 2018). The country is at risk from different types of natural hazards such as earthquakes, droughts, landslides, and heavy rains (Acosta et al., 2016). The east coast of the country is exposed to high-intensity typhoons as well as tsunami and storm surge risk (Figure 2).

Typhoons are extreme weather phenomena that can cause strong winds, heavy rainfall, and storm surges, which can lead to an extreme loss of life and widespread damage to property (Acosta et al., 2016). The US National Hurricane Center noted that since 1970, the Philippines has been "hit by more tropical cyclones than any country on earth except for China" (Doyle, 2013). The country is in the northwest Pacific, the most active in tropical cyclone formation (Landsea, 2006). Because of their annual recurrence

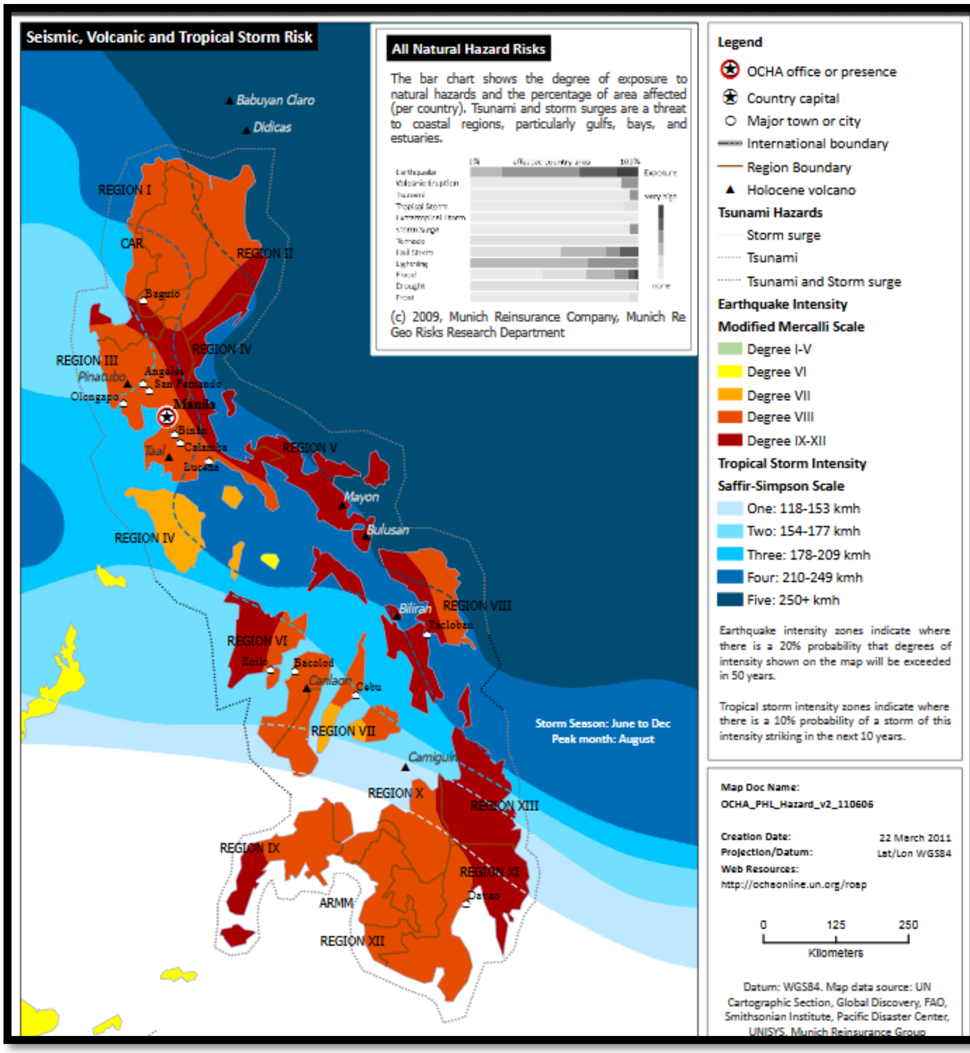

Figure 2. Risk map of the Philippines: seismic, volcanic and typhoons (Acosta et al., 2016).

patterns, typhoons are a fact of life in the Philippines; therefore, reducing the impacts on the population becomes a high priority in the public agenda for coastal cities.

As the primary natural disaster impacting the Philippines, typhoons cost the nation more than $100 million per year (NDRRMC, 2018). Apart from the devastating loss of life and property, communities impacted by typhoons are negatively affected in the medium- and long-term too (Figure 3). Typhoons can destroy infrastructure in the impacted cities, which causes sewage contamination of clean water in flooded areas, resulting in serious sanitation problems that can cause severe bacterial infections (Cheng & Wang, 2004) Livelihoods, especially in rural areas, are also affected by typhoons. Studies on the aftermath of Haiyan Typhoon show that 77% of farmers and 74% of fishermen lost their primary source of income (Acosta et al., 2016).

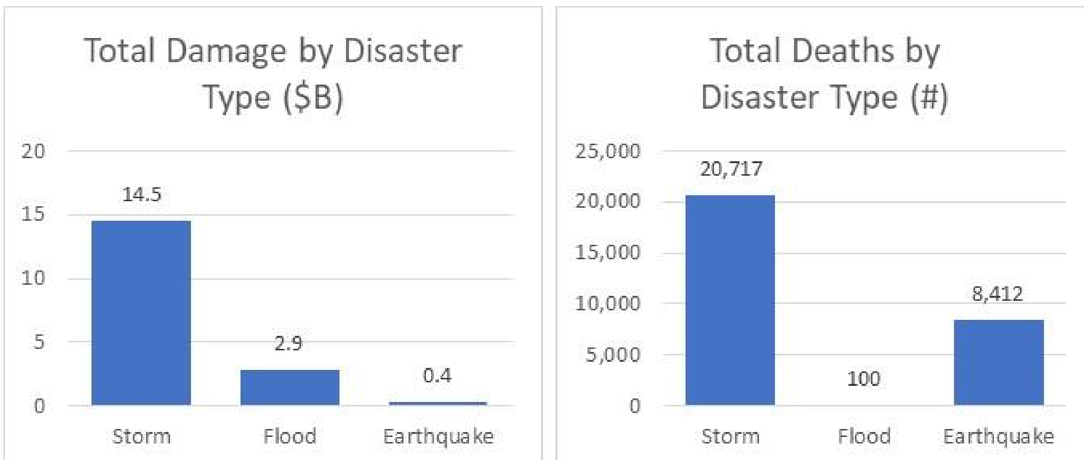

Figure 3. U.S. dollar loss (left) and total deaths (right) by disaster type from 1905 to 2019. (EMDAT, 2019).

Typhoons have more severe impacts on disadvantaged populations than wealthier victims (Blaikie et al., 2003). Wealthier populations have more means to avoid hazards and recover more quickly from the events that are disastrous to low-income households (Karim, 1995). Access to material, social, and political resources is essential to promote adaptation (Blaikie et al., 2003). The critical nature of these resources required for resiliency illuminates the need to pay particular attention to social conditions that may influence vulnerability.

Impacts of Social Conditions on Vulnerability

Vulnerability refers to the "characteristics and circumstances of a community, systems or assets that make it susceptible to the damaging effects of a hazard" (UNISDR, 2014, p. 25). This vulnerability definition considers the capacities to prepare for, respond to, and recover from the impact of hazards (Blaikie et al., 2003). As a result of biophysical and social factors, both people and places can be considered vulnerable to natural disasters. Social vulnerability focuses on the social attributes which could have a negative impact on the outcome of disasters or natural hazards (Lawal & Arokoyu, 2015). These are social characteristics of a place, such as inequality, poverty, and limited access to jobs, that can deprive communities of the ability to respond to, cope with, and adapt to the consequences of disasters (Zandt et al., 2012).

A particular social condition that increases people's vulnerability and exposure to harm is rapid and unplanned urbanization (Parker, Maynard, Garcia, & Yoseph-Paulus, 2017). In the Philippines, welfare inequality and disproportionate income distribution have created many landless and land-poor households who migrate and find housing space in hazardous locations (Ignacio, Cruz, Nardi, & Henry, 2016). New settlers build their homes on the islands' narrow coastal plains and lived off subsistence fishing and farming. Studies show that landless people and informal settlers can only engage in short-term land management and accommodation practices, which compromises their resilience in the longer term (Gaillard, 2015). As a result, migrants and illegal settlers are the most affected by typhoons in the Philippines and have recovered more slowly than people owning land (Walch, 2018).

Despite high economic growth in the Philippines in the last five years, poverty reduction has not been as encouraging (Daantos, Mateo, & Rosete, 2017). The economic growth rate in 2015 was 7.2%; however, the poverty rate remained 21.6%, only reduced by 1.2%, a minimal reduction (World Bank, 2018). People under poverty conditions are impacted by disasters more harshly and it takes longer for them to recover (Blaikie et al., 2003). For instance, the rise in prices of basic products creates a more severe and lasting negative impact on the welfare of populations under poverty levels than wealthier populations (Sakai, Estudillo, Fuwa, Higuchi, & Sawada, 2017). Assets and savings are critical for recovery from disaster, and when a household lacks savings, it is forced to get loans at higher interest rates, exacerbating the impacts of the disasters for several years (Hallegatte, Vogt-Schilb, Bangalore, & Rozenberg, 2016).

Another preexisting inequality which is likely to be magnified by climate disasters, is access to information (Fuchs & Thaler, 2018). In the case of Haiyan Typhoon, evacuation and early warnings were delivered; however, the victims were unfamiliar with the term "storm surge", which indicated the risk and impact of the typhoon (Bricker et al., 2014). Since the Philippines is a nation of regional languages, the government did not have local terms to describe the phenomenon to everyone (Morelia, 2018). "A weather bureau official says more could have been done in explaining to the public the magnitude and gravity of a storm surge"; therefore, after the experience with Haiyan, the government implemented programs that better provide information about risks of natural disasters and typhoons (Bernal, 2014).

Another important social condition that impacts vulnerability to typhoons is the dependency on the livelihood system (Krishnamurthy et al., 2014). In the province of

Leyte, coconut and *copra* production is an important source of economic activity with almost 80% of the population involved in the farming, production, distribution, and logistics of the crops (Baltazar, Sabyte, Lee, & Hilario, 2013). Haiyan Typhoon massively destroyed the coconut plantation, leaving many families that relied on this plantation for subsistence with no income (MIRA, 2013). Another important economic activity in Tacloban and many other municipalities is fishing and other marine livelihoods. Typhoons can damage and decimate the houses of these communities, as well as destroying the boats, docks, and infrastructure necessary to perform this economic activity (FAO, 2014). According to reports, after the Haiyan Typhoon, fish and produce trading was disrupted, affecting mainly poor fishermen and small traders (Baltazar et al., 2013). Rice and standing crops directly within the path of the hurricane were destroyed. Small agricultural communities suffered major losses from both crop losses and asset losses (MIRA, 2013).

Social vulnerability influences the level of risk from a natural disaster. Social attributes of a place, such as housing characteristics, and economic and demographic structure variables, influence how the community experiences a hazard, and its capacities to respond to, cope with, recover from and adapt to it (Cutter et al., 2003). Socioeconomic variables of the population are often used to measure the level of vulnerability of the community; these variables are explained in the next section.

Vulnerability and Components

In 2014 the United Nations Intergovernmental Panel on Climate Change (IPCC) published the fifth assessment report, summarizing the latest knowledge on climate change and stating that vulnerability as one of the main determinants of risk to climate events. The IPCC defines vulnerability as a result of the interaction of three broad components: exposure, sensitivity to hazard, and adaptive capacities (Sharma & Patwardhan, 2008).

Exposure to storm-induced floods is nearly inevitable because people tend to settle around water bodies and fertile flat land which are typically impacted by rainy seasons (Weis et al., 2016). There are certain physical and geological characteristics that increase the exposure to floods, like susceptibility, storm surge risk, and proximity to water bodies (Denton, 2002). Some approaches to quantify exposure are reflected in hazard maps developed by remote sensing data (Weis et al., 2016). In the case of flood hazard, elevation and distance from water bodies are variables that contribute to exposure to the flood hazard (Toda, 2015). Other physical characteristics include the type of housing, as there are some construction materials that are more vulnerable. For instance, the population living in houses with makeshift and tarpaulin roof materials are more likely to be affected by floods (Proverbs & Lamond, 2017).

Sensitivity to hazard is the degree to which a system, asset, or species may be affected, either adversely or beneficially, when exposed to climate variability or change or geophysical hazards (World Bank, 2014). Previous studies have measured sensitivity as the amount of population at risk, identifying the sensitive population to include children, elders, and disabled persons (Toda, 2015). Other assessments include sensible infrastructure as hospitals, bridges, schools, to measure the sensitivity (Weis et al., 2016).

Adaptive capacity can be defined as "the combination of strengths, attributes, and resources available within a community or system that can be used to achieve agreed goals" (UNDP, 2014, p. 12). Adaptive capacities are the resources and skills of a community that can be useful to resist and recover from the impact of a disaster (Paton & McClure, 2013). An important disaster management strategy is based upon a capacity development process that systematically stimulates and develops the capacities of a community to prepare for, respond to, and recover from disasters quickly and effectively (Zandt et al., 2012). Adaptive capacities can be measured by assessing socioeconomic variables like poverty levels, education, type of livelihoods, and assets and debts (Fuchs & Thaler, 2018). Interviews, forums, and surveys are ways in which these types of variables can be measured. Additionally, census surveys can be helpful to identify adaptive capacities in a community (King & Macgregor, 2000).

Reducing Social Vulnerabilities

Studies have shown that the most effective way to reduce vulnerabilities is increasing adaptive capacities to the hazard; thus, identifying the adaptive capacities lacking in a community is the first step to reduce the impacts of typhoons in vulnerable communities (Ubac, 2016). A call for urgent assistance to enhance the resilience of vulnerable populations is growing (Walch, 2018). High population density in cities has led to a steep rise in the number of informal settlements that cannot withstand natural hazards (Mones, 2018). Research shows that focusing on specific vulnerable groups and implementing grassroots initiatives through a community-based approach has positive outcomes for disaster risk management (Blaikie et al., 2003).

Experts argue that early warning systems are key for saving lives in disaster-prone areas (Zschau & Küppers, 2013). Educating communities about disaster risks, terms, and concepts could increase population awareness and promote the evacuation in vulnerable areas when early warnings are delivered (Ahmed, Kodijat, Luneta, & Krishnamurthy, 2015). Nature-based solutions, such as coastal rehabilitation, can provide protection from storm surges and the impacts of typhoons (Ubac, 2016).

A common approach for reducing climate-related risks is capacity-building, which often consists of meetings and workshops for decision-makers, community members, and experts to raise awareness of risk, find local solutions that may be present, which include those derived from local knowledge, funds, or other resources, and to disseminate technical information and mobilize participants to carry out actions expected to reduce risk (Paton & McClure, 2013). One of the most important community-based adaptation strategies is to incorporate poor and socially-vulnerable groups into decision making (Renaud, Sudmeier-Rieux, Estrella, & Nehren, 2016). Equitable participation by vulnerable communities and specific groups, like women, helps minimize vulnerability and build resilience (Paton & McClure, 2013). Community engagement identifies specific needs and vulnerabilities in order to prioritize adaptive capacities based on local knowledge. For an emerging economy like the Philippines, the country can mitigate natural disasters and experience faster recovery from their impacts by focusing on vulnerability and the poor (Rockefeller Foundation, 2014). The challenge remains that national and local governments need tools and capacity to translate them into actions at the city level.

After Haiyan Typhoon had a devastating impact in Tacloban City, preparedness and resilience efforts were implemented (Palagi & Javernick-Will, 2018). Many of these efforts were organized by international aid organizations, civil society organizations, academic institutions, and government agencies (NDRRMC, 2017). However, it is still hard to evaluate the outcome of resilience projects and the impact they had on decreasing vulnerability. Methods to measure vulnerability are often focused on spatial vulnerability in a specific moment, which disregards the dynamic nature of vulnerability and its components (Monterroso-Rivas et al., 2018). The approach for assessing vulnerability over time could be a useful tool to evaluate the effectiveness of resilience strategies.

Spatial Vulnerability

To efficiently direct resources for increasing resilience at the city level, the most vulnerable areas must be identified and prioritized (Cutter & Finch, 2008). Assessing the spatial aspect of vulnerability can provide information to target typhoons risks by disaster management aid, policy advisors and professionals to develop disaster preparedness at a local scale and increase community and organizational resilience.

There is a clear diversity of geographic conditions that contribute to increased exposure to natural disasters (Fekete, 2012). Vulnerability varies spatially because natural environments, social structure, and housing differ spatially (Uitto, 1998). For instance, populations situated near the cost and other major bodies of water are particularly at high risk to floods and storm surge impacts (Lapidez et al., 2015). Vulnerability unequally distributes disaster impacts on populations and across geography areas due to factors apart from forces of nature like social systems and socioeconomic conditions(Cutter & Finch, 2008). It is common to find clusters of the population with similar socioeconomic condition living together. In urban areas, irregular settlements that develop housing areas with makeshift materials heighten their disaster risk areas and expose their lives and assets to the strong winds and floods(Hilvano, Nelson, & Coladilla, 2014).

In the Philippines, impacts from disasters like typhoons are felt most severely in areas with the most vulnerable populations, rampant poverty, and least political influence (Yoon, 2012). In the Philippines, most areas of the country are vulnerable to typhoons in varying degrees (Figure 4).

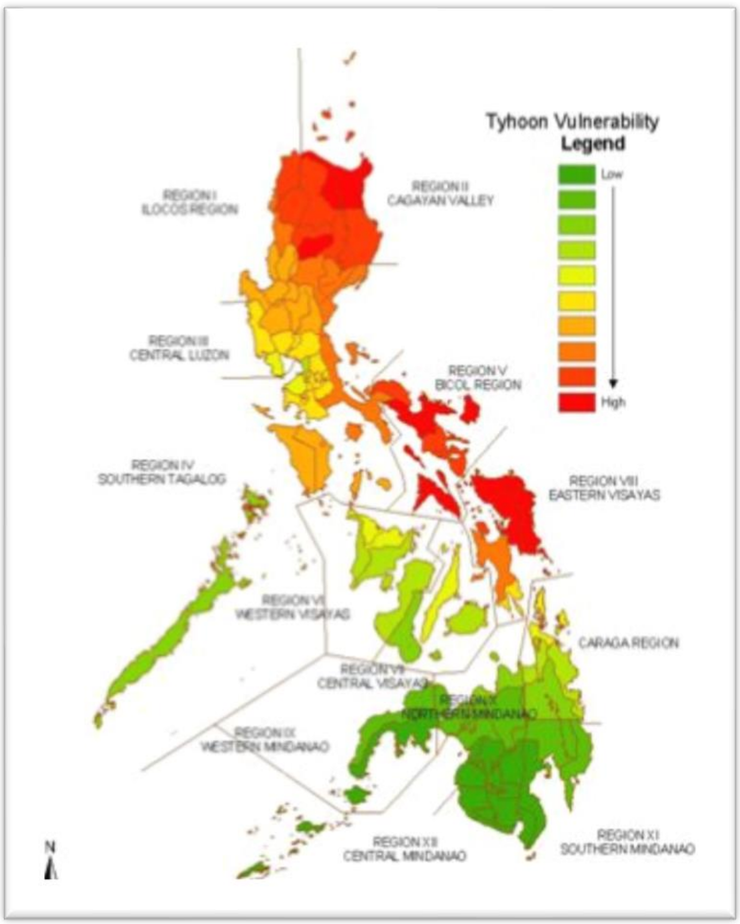

Figure 4. Map of typhoon vulnerabilities in the Philippines (NDRRMC, 2017).

Vulnerability over Time

Vulnerability changes over time due to the social dynamics and characteristics that naturally fluctuate in a community (Alam, 2015). However, it is hard to assess the changes in vulnerability because usually these analyses only evaluate indicators at a determined time. Using databases from national censuses allows replicating the analysis using similar indicators over time in order to visualize the decrease or increase of vulnerability in each spatial unit. This method is valuable to the scholarship of vulnerability studies and could aid to evaluate resilience strategies outcomes.

It is crucial to identify the most vulnerable areas at a local level within the different barangays in Tacloban City but it is even more important to visualize vulnerability dynamics over time and assess the effects of resilience strategies implemented since Haiyan Typhoon in order to monitor and evaluate the resilience strategies, as well as to understand the effect that these had in the vulnerability changes from 2010 to 2015. Demographic and socioeconomic variables can be collected from the Philippine Statistics Authority (PSA) census databases which provide information on the barangay level.

Measuring Vulnerability

To measure vulnerability levels, different types of vulnerability indices have been proposed that include the variables and factors that increase social vulnerability to floods. The Social Vulnerability Index (SoVI) developed by Cutter et al. (2003) is one of the methods that quantifies vulnerability. The SoVI measures the social vulnerability of a place based on socioeconomic variables. This index was developed using data in the public domain, such as socioeconomic indicators extracted from census variables (Cutter et al., 2003).

The Social Vulnerability Index (SoVI) was developed at the county level for the entire United States using census data (Cutter et al., 2003). They initially collected data on 250 variables; however, these were reduced to only 11 independent factors after checking for their collinearity and necessary computation of data. Similarly, for the flood plain vulnerability assessment in Italy, the authors reduced the number of variables to three per component (Roder, Sofia, Wu, & Tarolli, 2017). Additionally, a social vulnerability assessment in southwestern Nigeria adapted the sociodemographic information retrieved from national and international sources to incorporate into the SoVI (Lawal & Arokoyu, 2015). In most of these studies, the predominantly applied variables were demographic (elderly, children, gender), disability, literacy, socioeconomic (income, employment, poverty, etc.), ethnicity, housing (type, ownership, etc.), and access to basic services. Cutter et al. (2003) have compiled a detailed list of variables that are frequently found in the literature influencing social vulnerability (King & Macgregor, 2000).

Census data have been often used by experts in vulnerability assessment related to natural hazards (Cutter et al., 2003). Census data are the main source of demographic and socioeconomic data in any country. However, the type, scope, and level of detail may vary from country to country. Census data are usually collected at the household level and for confidentiality, is usually aggregated to a higher level. Additionally, census data are collected routinely, which reduces the cost of additional surveys when assessing vulnerability over time. For instance, in the Philippines, census data are aggregated to barangays before being shared with other government organizations.

Census data surveys are performed in most countries by national authorities on a routine basis (every five years) and most databases are open to public use. The routine work of recollecting the census information by the government every certain period of time allows similar socioeconomic variables of the population to be compared year to year. And of course the cost of the vulnerability assessment is reduced significantly when using open public data like census databases. Moreover, most recent census information is aggregated in a geographic unit, which is necessary to map spatial vulnerability.

Mapping Vulnerability

Several studies have shown that Geographical Information Systems (GIS) tools are very useful to analyze and visualize the combination of hazard exposure with vulnerabilities. GIS tools generate maps that illustrate the areas at risk and identify the degree of community vulnerability (Hagenlocher & Castro, 2015; Krishnamurthy et al., 2014; Ouma, Tateishi, Ouma, & Tateishi, 2014; Weis et al., 2016). Mapping vulnerability can improve communication about risks and threats. The visual presentation of a map helps to understand the risks and vulnerabilities spatially. Policy and decisionmakers can visualize where resources must be directed for resilience and preparedness to disasters (Edwards et al., 2007). Vulnerability maps allow them to decide on mitigating measures to prevent or reduce losses and impacts before a disaster occurs.

Typhoon Haiyan's Impact on Tacloban, Philippines

Located in Southeast Asia, the Philippine archipelago has a population of 92 million when the last census was taken in 2010 by the Philippine Statistics Authority (PSA). The Philippines is a densely populated country and its urban areas can be divided into numerous barangays (138). The urgency to make vulnerable neighborhoods more resilient was being addressed by local governments in the Philippines since before Haiyan Typhoon, as evidenced by the Climate Change Act in 2009 and the Disaster Risk Reduction and Management Act of the Philippines in 2010.

In November 2013, Tacloban City (Figure 5) was hit by Typhoon Haiyan, the deadliest typhoon ever to hit the Philippines in recent history, which killed more than

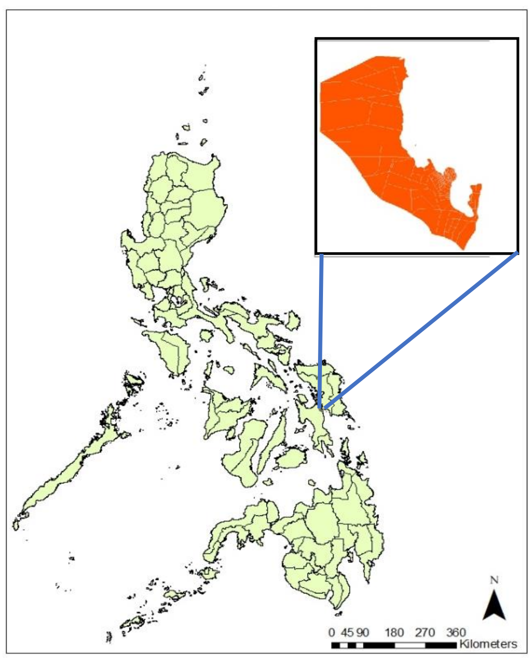

Figure 5. Tacloban City, Philippines.

6,000 people and sustained damages totaling $1.3 billion (NDRRMC REPORT, 2018). An estimated 16.1 million people were affected in the country (CARE Philippines, 2015). It's impact brought to the surface the underlying vulnerability of Tacloban City, particularly those inhabitants that live in proximity of natural hazards and those who endure a deeply entrenched poor socioeconomic condition (Toda, 2015).

Typhoon Haiyan's very high wind speed caused massive destruction of homes, flooding in low areas, landslides, and storm surges. According to the annual report of the Philippine Department of Social Welfare and Development, by the end of 2014 the extended cash for work assistance to a total of 247,659 typhoon Haiyan-affected individuals was worth 584,687 million Philippine pesos (approx. $13 billion US dollars) (NDRRMC, 2017).

The storm surges were devastating for Tacloban City, with extensive coastline experiencing 3-4 m and higher (Figure 6). According to the provincial government of Leyte, the storm surge was estimated to reach three building stories. Studies reveal storm surges to have inundated an estimated 98 km^2 in Leyte, Philippines (Figure 2). Others estimated the waves that flattened Tacloban City were six meters high and powerful enough to destroy most of the houses, overturn vehicles, and take thousands of lives (Lagmay et al., 2015). Storm surges were mainly responsible for the 6,300 dead, 1,061 missing and 28,689 injured in Haiyan's aftermath (Lagmay et al., 2015).

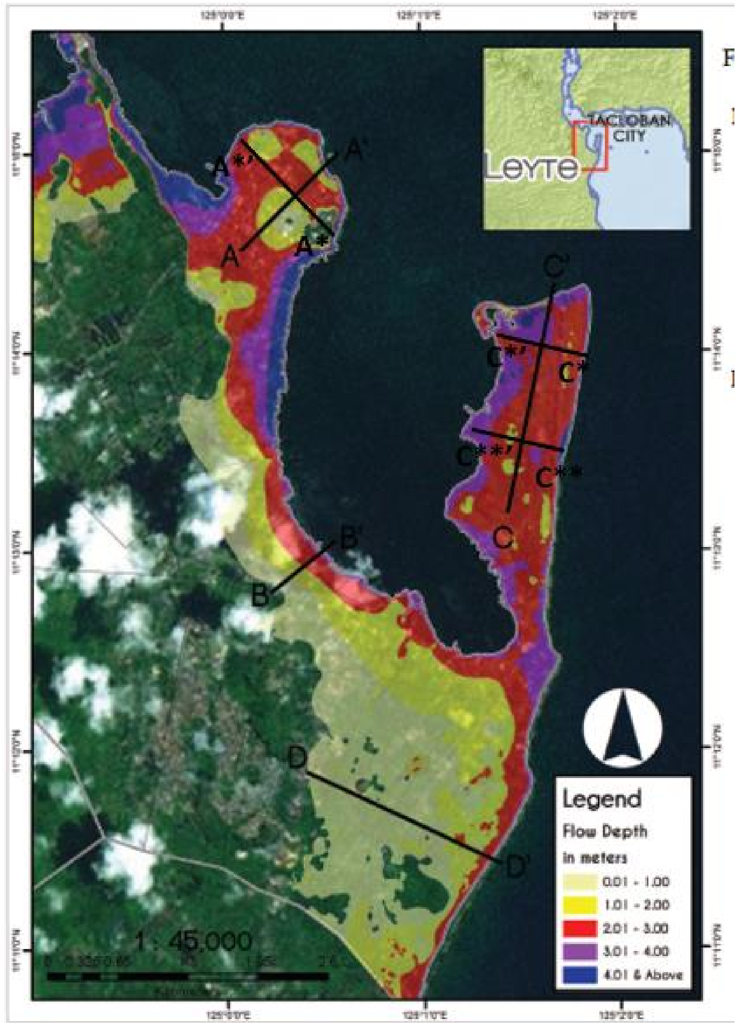

Figure 6. Haiyan storm surge modeling of Tacloban City (Lapidez et al., 2015).

A study published about the aftermath mortality of Typhoon Haiyan in Tacloban indicated the main factors associated with death: over 55 years of age, living within 50 meters of the ocean, and risk-taking behaviors. All victims died inside or near their houses with drowning as the documented cause of death (Ching et al., 2015). Tacloban City was seriously affected by Typhoon Haiyan with 2,321 deaths; the highest mortality was found in barangays San Jose Beach, San Jose Balanak, Diit and Rawis Anibong (Figure 7).

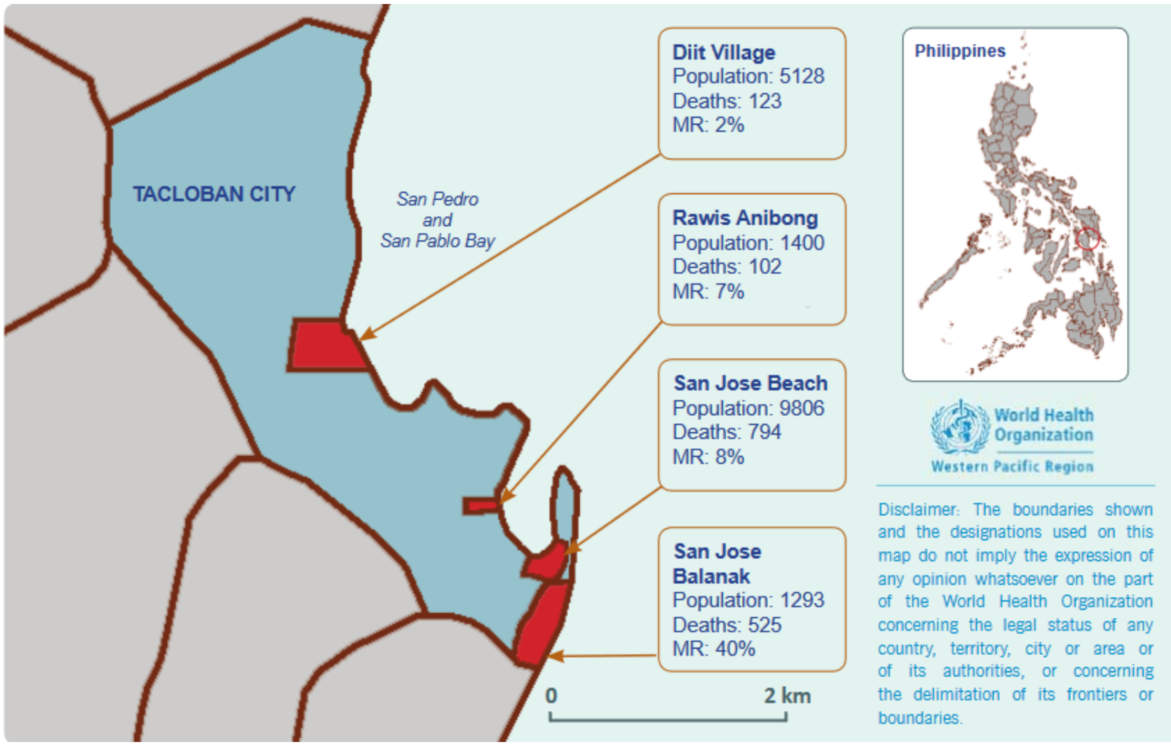

Figure 7. Tacloban Mortality (Ching et al., 2015)

After Haiyan Typhoon, Tacloban City approved the City Disaster Risk Reduction Management Program (CDRRMP) in 2016, which extends through 2022. Risk, hazard, and vulnerability assessments for Tacloban were intended to be included in risk reduction activities to inform the "no-build zone" in downtown coastal areas where informal settlers lived prior to Haiyan. Additionally, risk assessments identified landslide, flooding, and liquefaction risks, which were minimized using hard infrastructure measures, and those areas were deemed safe to inhabit (Tuhkanen et al., 2018). State-led resilience policies focused on technical aspects of recovery rather than the root cause of vulnerabilities, explaining, to some extent, the high number of casualties in the wake of Typhoon Haiyan (Walch, 2018). In 2010, the Disaster Risk Reduction Management Act was signed by local authorities in the Philippines, which established the importance of social vulnerability to increase resilience, and stated explicitly:

> Among the priorities for resilience we have identified are ensuring adequate DRR finance and investment particularly for local levels of government, better use of risk transfer strategies such as insurance, harnessing of science, technology and innovation, and more resilient infrastructure and agriculture" (DRRMA, 2010).

After Haiyan Typhoon, the following recovery and disaster preparedness strategies were proposed and implemented. The Philippine government launched an $8.2 billion, four-year plan, Reconstruction Assistance on Yolanda, which focuses on rebuilding areas affected by the typhoon and developing resilience to natural disasters. The U.N. Humanitarian Country Team (HCT), in partnership with U.N. organizations and non-governmental and international organizations, designed a Strategic Response Plan (SRP) to support the Philippines government's activities in meeting immediate humanitarian needs and reconstruction goals (Lum & Margesson, 2014). The resilience strategies implemented were the following:

- Exposure: Resettlement projects were built in safer areas in the north of Tacloban City. Development policies were modified for reconstruction and new buildings regulating zoning classification to secure coastal buffer zones.
- Sensitivity: The Tacloban City Disaster Reduction Management Plan (TCDRRMP) was implemented locally for a better early warning system and evacuation strategies, improved contingency plans and emergency response procedures.
- Adaptive Capacities. Education on disaster risk and tropical storms were reinforced among local population in different barangays. Livelihoods programs

for affected populations as well as housing options to ensure the supply of adequate land were provided.

To evaluate vulnerability and explore how these resilience strategies affected the spatial vulnerability in Tacloban, census data can be used to create vulnerability maps of 2010 and 2015. These can provide policymakers with better spatial and temporal vulnerability analysis to reduce the risk of disasters like typhoons.

The local government of Tacloban City needs to identify the most vulnerable barangays in order to efficiently direct resources to prepare communities to cope with typhoons better and reduce disaster losses. It is critical to identify local areas in Tacloban City that are at elevated disaster exposure risk, as DRR theory recognizes this need and encourages risk assessments to be performed at the most local level possible.

Research Questions, Hypotheses and Specific Aims

This research brought together the two databases, census data 2010 and 2015, to address the following questions:

1. Which *barangays* in Tacloban City were the most vulnerable to typhoons?
2. How have vulnerability levels in each barangay changed from 2010 and 2015 after Typhoon Haiyan in 2013?
3. What effects did resilience strategies implemented by the government after Typhoon Haiyan have on the barangays' vulnerability?

My main hypotheses, with respect to these research questions, include the following:

1. Barangays with the highest mortality levels after the Haiyan Typhoon in 2013 (barangay 88, 89, 99, 109A, 87) had the highest vulnerability scores in 2010.
2. Vulnerability scores decreased significantly from 2010 to 2015. The largest changes were in the barangays most affected by the typhoon (San Jose Bay (88) and Diit (99)).
3. Policies and resilience strategies implemented after the Haiyan Typhoon reduced vulnerability levels in the barangays with the highest vulnerability scores from 2010 to 2015.

Specific Aims

To address these questions and hypotheses, I completed the following steps:

1. Constructed a vulnerability database of socioeconomic variables from census data from the years 2010 and 2015.
2. Developed a Social Vulnerability Index which I applied to each barangay in Tacloban City in order to identify and assess which barangays have the highest vulnerability levels.
3. Created Vulnerability Maps for 2010 and 2015 showing the difference in vulnerability levels between barangays.
4. Evaluated the practical implications of the preceding analysis for policies and resilience strategies.

Chapter II

Methods

The main objective of this research was to construct a Vulnerability Index to characterize the social vulnerability of local communities to typhoons, at the barangay level in Tacloban City, in order to spatially compare vulnerability dynamics before and after the Haiyan Typhoon in 2013. The vulnerability index was developed using the methodology of the four-step process of Krishnamurthy et al. (2014)) (Figure 8).

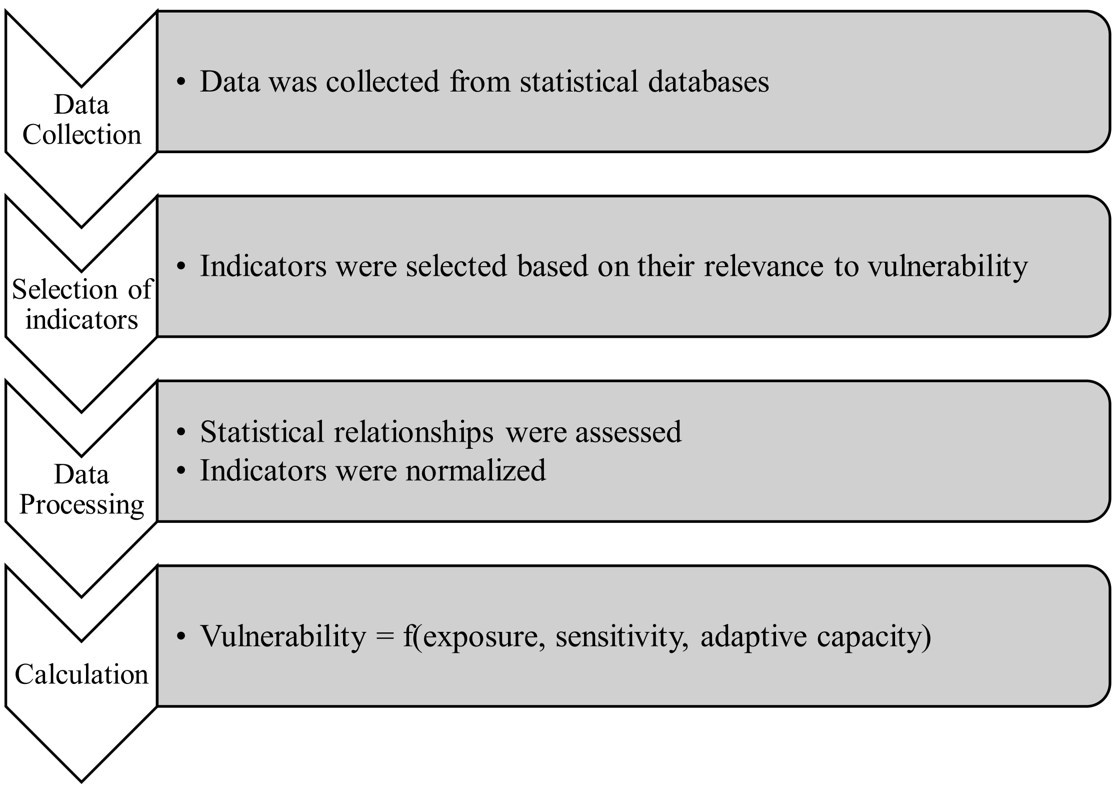

Figure 8. The four-step methodological process to develop the Vulnerability Index (Krishnamurthy et al., 2014).

This study developed a method to characterize the social vulnerability of local communities to climate-related hazards, particularly flood, storm surge, and typhoons, at the barangay-level in Tacloban City, Philippines, using census data from 2010 and 2015. The index was built on available and recent datasets from PSA. Exposure level, sensitivity, and adaptive capacity have been estimated by means of statistical and Geographical Information Systems (GIS) approaches.

Data Collection

A thorough literature review was completed to identify relevant variables and choose the indicator for each component under investigation. The variables were collected from the Philippines Statistical Authority (PSA) census datasets of 2010 and 2015 for each barangay. The PSA performs and publishes a detailed national census every five years which offers the possibility of updating the analysis periodically. An indicator is defined as a variable that quantifies and characterizes the level of vulnerability or resilience. Therefore, the index is a composite of indicators that summarizes the overall vulnerability to typhoons for each barangay (Table 1).

Data from exposure was collected from geographic imagery and elevation models extracted from the humanitarian exchange database (HDX) and census databases 2010 and 2015. The variables of low elevation and proximity to the coast were selected from the geographic models. To measure house exposure, roof construction material data was extracted from the PSA census databases 2010 and 2015. The final exposure indicators were: % vulnerable roof materials, coastal barangay (yes or no) and elevation.

Table 1. Summary of components and indicators used for the vulnerability index.

Component	Profile	Indicator	Data Source
Exposure	Typhoon Risk	Elevation	DEM – HDX
		Distance from coast	OCHA 2014
	Housing	Vulnerable roof (%)	PSA Census 2010 / 2015
Sensitivity	Population at risk	Population	PSA Census 2010 / 2015
	Sensitive population	Elder >60 (%)	PSA Census 2010 / 2015
		Kids <10 (%)	PSA Census 2010 / 2015
Adaptive Capacity	Education	College (%)	PSA Census 2010 / 2015
	Livelihood	Rural	PSA Census 2010 /2015

Data for sensitivity were also collected from the census databases 2010 and 2015 from the PSA. The variables extracted were: population, % children (age<10), % elder (age>60). These variables were used to measure the population at risk.

Finally, data for adaptive capacities extracted from census databases 2010 and 2015 used the variables of: percent of houses owned or rented by the owner, which worked as an inverse proxy for poverty; and percent of the population with higher education (college), an education indicator. In order to measure livelihoods vulnerability, the variable used was whether the barangay was urban or not.

Data Processing and Calculations

In order to integrate the indicators into the vulnerability index, they required standardization and normalization (Krishnamurthy et al., 2014), because each indicator was measured on a different scale and unit. In order to carry out the conversion, the values were indexed and represented as a percentage of the total population in each barangay. Once the variables were standardized, they were normalized and represented a percentage of the maximum indicator:

$$Indicator\ (standardized) = \frac{Indicator\ Value}{Indicator\ Maximum}$$

Next, the indicator values were summed to obtain the value of the component, where n is the number of indicators for a particular component:

$$Component\ value = \frac{(Indicator\ 1 + Indicator\ 2 + \cdots + Indicator\ n)}{n}$$

Indicator values were added using the balanced weighted approach. Since the information available did not suggest the weight of the variable was distributed differently, it was assumed that each component contributed equally to the index, regardless of the number of indicators under each component.

In order to compare the two databases (2010 and 2015), each component was normalized representing a percentage of the maximum indicator between the two databases. The resultant values of each component were multiplied to get the Vulnerability Score value for each of the barangay:

$$Vulnerability\ Score = Exposure \times Sensitivity \times Adaptive\ Capacity$$

The index score was also normalized with the maximum value between the two datasets. The resultant score of each barangay was entered into *ArcGIS* software in order to create a map that allows for visualization of the vulnerability of each barangay.

Mapping the Vulnerability Index

The results of the vulnerability index calculations, as well as its components, were mapped using the Geographic Information System (GIS) tools in ArcMap 10, to determine the geographical distribution of vulnerability. The same process was used for both 2010 and 2015 in order to visualize how the vulnerability score varied within a five-year span before and after the Haiyan Typhoon in 2013. The databases were joined to the georeferenced layer of the barangay administrative boundaries. Next, the values of the vulnerability score were divided into five categories using the quantile method, with each range cumulatively representing 20% of the maximum vulnerability (Table 2) (Krishnamurthy et al., 2014).

Table 2. Criteria for vulnerability to typhoons.

Vulnerability index	<0.2	0.2-0.4	0.4-0.6	0.6-0.8	>0.8
Severity of vulnerability	Very low	Low	Medium	High	Very high

A total of eight maps were created using the same quintile method in order to allow for comparisons between them (Table 3). Additionally, an extra map was created showing the most affected barangays by the Typhoon Haiyan in 2013 (Ching et al., 2015).

Limitations of the Research

The methodology used in this research is an approach to measure vulnerability with public census database. This approach is useful for a preliminary analysis of spatial vulnerability dynamics before performing an on-site assessment. However, certain limitations arise due to the author's inability to be on-the-ground, in-the-field in Tacloban City, and the lack of a direct source of qualitative information such as surveys or interviews.

Table 3. Description of vulnerability and component maps.

Map 1	Vulnerability Score 2010
Map 2	Exposure Score 2010
Map 3	Sensitivity Score 2010
Map 4	Adaptive Capacities 2010
Map 5	Vulnerability Score 2015
Map 6	Exposure 2015
Map 7	Sensitivity 2015
Map 8	Adaptive Capacities 2015
Map 9	Vulnerability Changes

Other limitations specific to the database include the inconsistency of the census questionnaires from 2010 to 2015. The most recent census questions of 2015 included a description of the occupation, which serves as an appropriate proxy for poverty; however, the previous census of 2010 did not include such a question. For these reasons, high land tenure and high education, present in both censuses, were used as proxies for poverty.

Chapter III

Results

Vulnerability scores and their components were processed and mapped in GIS to show the spatial dynamics of vulnerability. To analyze the changes of vulnerability over time, indicator databases from 2010 and 2015 were constructed. Finally, the results were mapped in order to allow the visualization. The map showed that vulnerability was reduced significantly to a Medium or Low-level score in most areas of Tacloban City.

The first research question, “Which barangays are the most vulnerable to typhoons?” was answered by the results of the Vulnerability Maps of 2010 and 2015, which shows that in 2010 the barangays with highest vulnerability scores were 88, 89 and 90 (Figure 9). The Vulnerability Index was validated since the barangays that reported the highest mortality and asset losses in the aftermath of Typhoon Haiyan in 2013 coincide with the barangays with the highest vulnerability scores in 2010 (Figure 9).

San Jose Bay (Barangay 88 and 89) was the most affected area by the typhoon with a 40% mortality rate. Other highly affected barangays included 99, 109A, 90 and 87 (Ching et al., 2015). Three out of the five barangays with the highest vulnerability score match the reported list (Table 4).

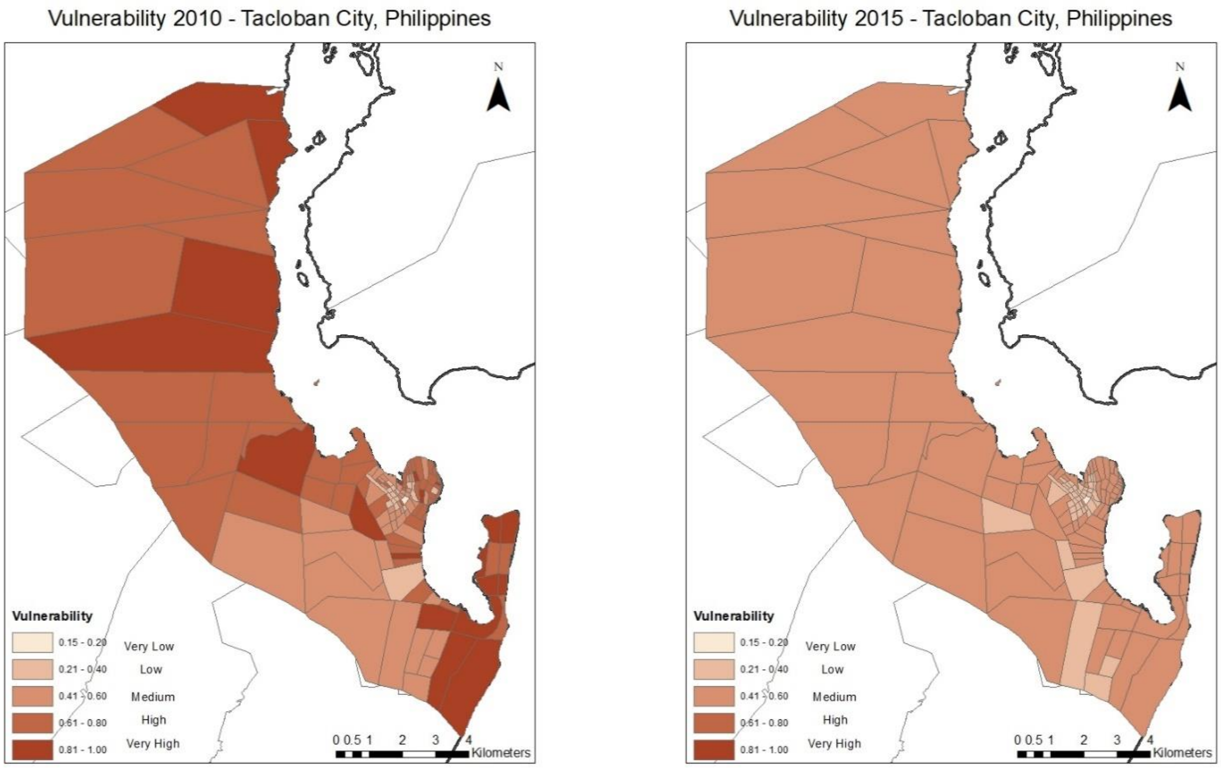

Figure 9. Comparison of overall vulnerability maps 2010 and 2015.

Table 4. Barangays with highest vulnerability scores in 2010 and 2015.

Highest Vulnerability 2010	**Score**	**Highest Vulnerability 2015**	**Scores**
Barangay 89 (San Jose Balanak)	0.99	Barangay 90	0.55
Barangay 90 (San Jose Bay)	0.98	Barangay 97	0.55
Barangay 97 (Cabalawan)	0.96	Barangay 89	0.54
Barangay 110 (Utap)	0.94	Barangay 110 (Utap)	0.54
Barangay 88 (San Jose Bay)	0.92	Barangay 88 (San Jose Bay)	.49

In order to answer the second research question "How have vulnerability levels in each barangay changed from 2010 and 2015 after Typhoon Haiyan in 2013?", barangay vulnerability variation between 2010 and 2015 was analyzed and mapped to show the difference in vulnerability in each barangay by subtracting vulnerability scores in 2010 from vulnerability scores in 2015. The barangays with highest decrease in vulnerability are shown in dark green and the lowest decrease were marked in red (Figure 10). The maps allows us to visualize that the most affected barangays by Typhoon Haiyan showed major decreases in vulnerability (Figure 10).

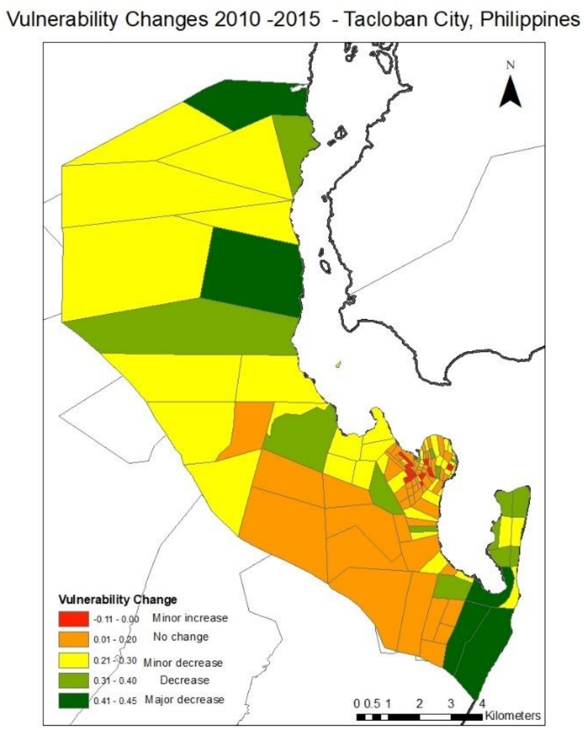

Figure 10. Map showing positive score change from 2010 to 2015

The San Jose area (barangay 88, 89, 90) showed the highest decrease of vulnerability after implementing resilience strategies after the typhoon (Table 5).

Table 5. Barangays with the highest decrease of vulnerability.

Highest decrease in vulnerability	**Score difference**	**Percentage**
Barangay 89 (San Jose Balanak)	0..45	45%
Barangay 88 (San Jose Bay)	0.43	47%
Barangay 90 (San Jose Bay)	0.43	43%
Barangay 97 (Cabalawan)	0.41	42%
Barangay 108	0.40	44%

Components of Vulnerability

In order to answer the third research question, "What effects did resilience strategies implemented by the government after Typhoon Haiyan had on the barangays' vulnerability?", the vulnerability components of exposure, sensitivity and adaptive capacities were scored and mapped independently. The results of years 2010 and 2015 were compared.

Exposure. Exposure maps show that there was a reduction in exposure to typhoons, mostly in coastal barangays (Figure 11). Most of the barangays ranked in 2010 as Very High were reduced to High. Even though physical variables such as distance to shoreline and elevation are impossible to change, the infrastructure and housing materials were changed in Tacloban, which contributed to a reduction of the Exposure component.

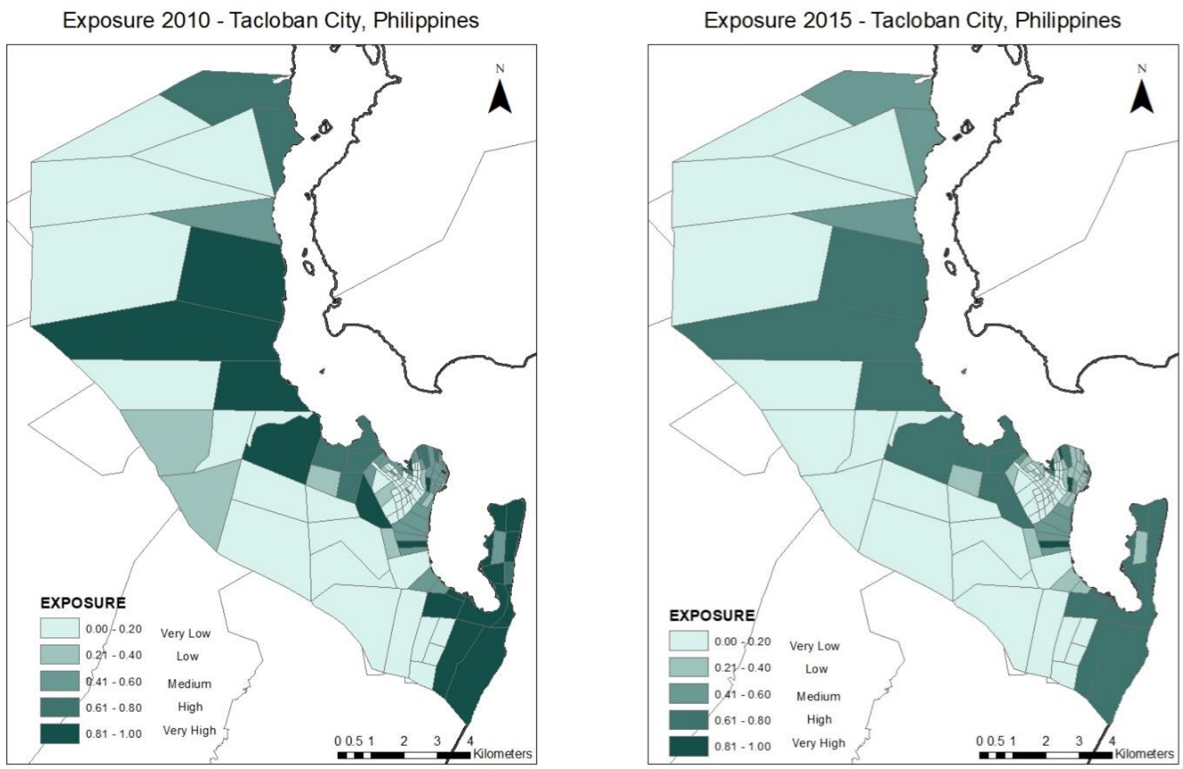

Figure 11. Exposure levels map comparison between 2010 and 2015.

Sensitivity. When analyzed separately the results show that sensitivity scores in most barangays were reduced from High to Medium sensitivity, which contributed significantly to reduce overall vulnerability. This can be attributed to the population variable which changed from 2010 and 2015 due to policy enforcement in irregular settlements.

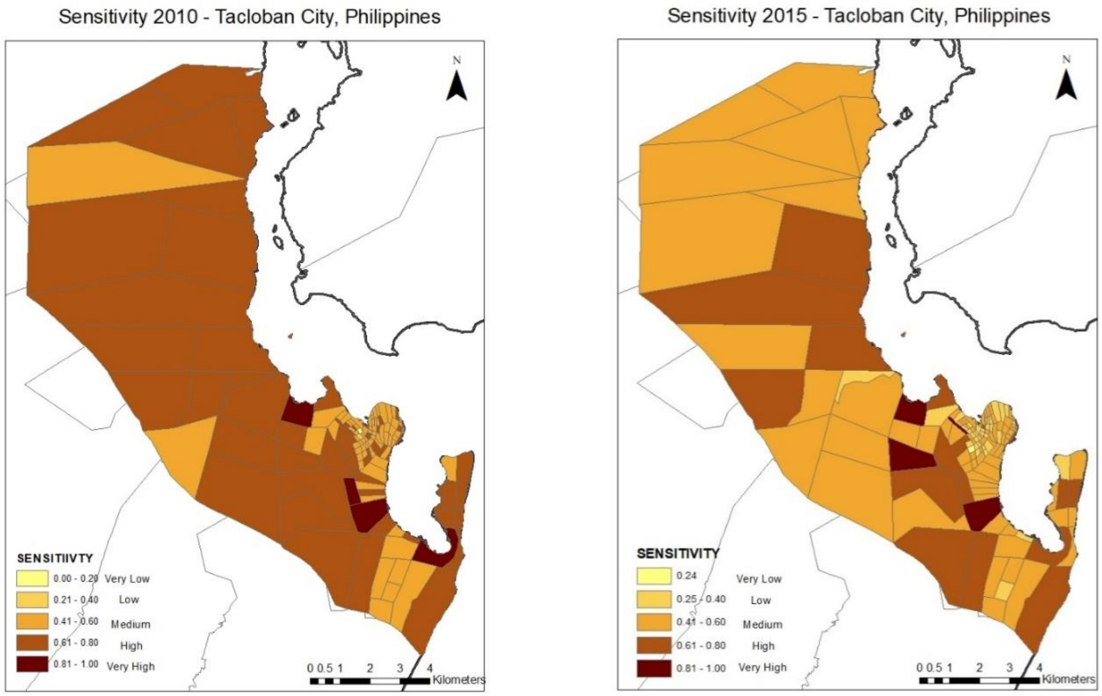

Figure 12. Sensitivity levels map comparison between 2010 and 2015

Adaptive capacities. Adaptive capacities are a positive component, therefore increasing adaptive capacities its desired in order to reduce vulnerability. The map shows that only a few barangays had a slight increase in adaptive capacities from 2010 to 2015. However, the limitations of this research didn’t allow me to measure adaptive capacities such as livelihoods and disaster risk training.

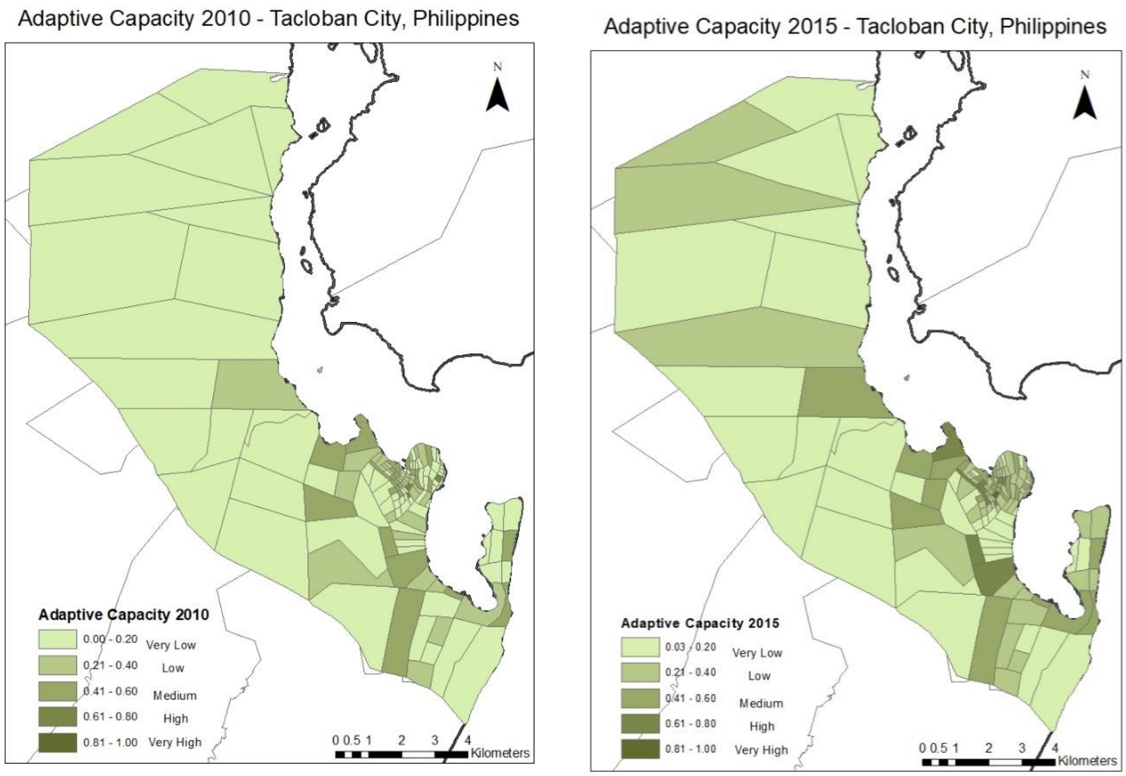

Figure 13. Adaptive Capacity maps comparison between 2010 and 2015.

Chapter IV

Discussion

By calculating and mapping overall vulnerability, a significative reduction in barangays classified as high risk was observed, resulting in every barangay ranking either medium, low or very low risk in 2015. The analysis showed that the barangays that had the major reduction in risk was barangays ranked as Very High Risk in 2010. Furthermore, barangays like San Jose Bay, which were most impacted by Haiyan Typhoon reduced its vulnerability score the most. The top five barangays showed a reduction of more than 40%, which was interpreted as a positive increase in resilience due to the strategies and projects implemented in Tacloban City after Haiyan Typhoon (Ching et al., 2015).

Barangays with high vulnerability scores (88, 89, 90) reduced the scores by 47%, 45%, and 43% respectively (Table 5). Barangay 97 (Cabalawan) also showed a high decrease of 42% in vulnerability. According to Haiyan Typhoon reports (UNDP, 2017), these barangays were some of those that showed highest mortality rates when Haiyan hit in 2013. Therefore, two of the research questions can be answered comparing vulnerability scores for both years. The second hypothesis, which suggested that the highest vulnerability ranked barangays are expected to present the most damage and mortality, was validated. Furthermore, the vulnerability reduction shown from 2010 and 2015 suggests a successful implementation of resilience strategies; however, the components need to be analyzed separately to understand which factors contributed most to this reduction. It is important to point out that additional research and information must be collected on site in Tacloban in order to understand the local dynamics that contribute to the vulnerability of the citizenry.

When exposure is analyzed separately, there was a clear reduction of exposure risk, particularly in coastal barangays where scores were reduced from Very High in 2010 to High in 2015 (Figure 11). It was expected that the exposure risk of barangays would not be reduced due to geographic nature. Barangays close to the coast and in low elevations present a much higher risk than other non-coastal barangays; however, an important non-geographical factor considered in exposure risk is infrastructure. In this case, roof materials was selected as the variable that can contribute to an increase or reduction in vulnerability. For instance, makeshift materials are more likely to be destroyed by a typhoon than galvanized or concrete roofs. After Typhoon Haiyan in 2013, vulnerable roofs changed drastically, which can be attributed to the "Build Back Better" United Nations Development Programme (UNDP) reconstruction program (UNDP Philippines, 2017). In order to analyze the influence of the change of roof material in affected barangays, the variable was analyzed and mapped individually (Figure 14).

According to Palagi and Javernick-Will (2018), while people living in coastal high-risk barangays were relocated to northern barangays (other places?) barangays in the northern areas of Tacloban were still close to the coast, and a typhoon with the same strength as Haiyan will pose a risk in these barangays, too. A lesson learned from Haiyan was the need to improve evacuation communications. In 2013 many people disregarded the early warnings due to lack of understanding of the risks of storm surge. The term “storm surge” was unfamiliar for many citizens, leading to an underestimation of the risks and resulted in high mortality (Ahmed et al., 2015). For this reason, early warnings and evacuation strategies are essential in the case of typhoon alert. Disaster education campaigns are critical for the population, which have been implemented in local government units (LGUs) in the Philippines since 2018 (Palagi & Javernick-Will, 2018).

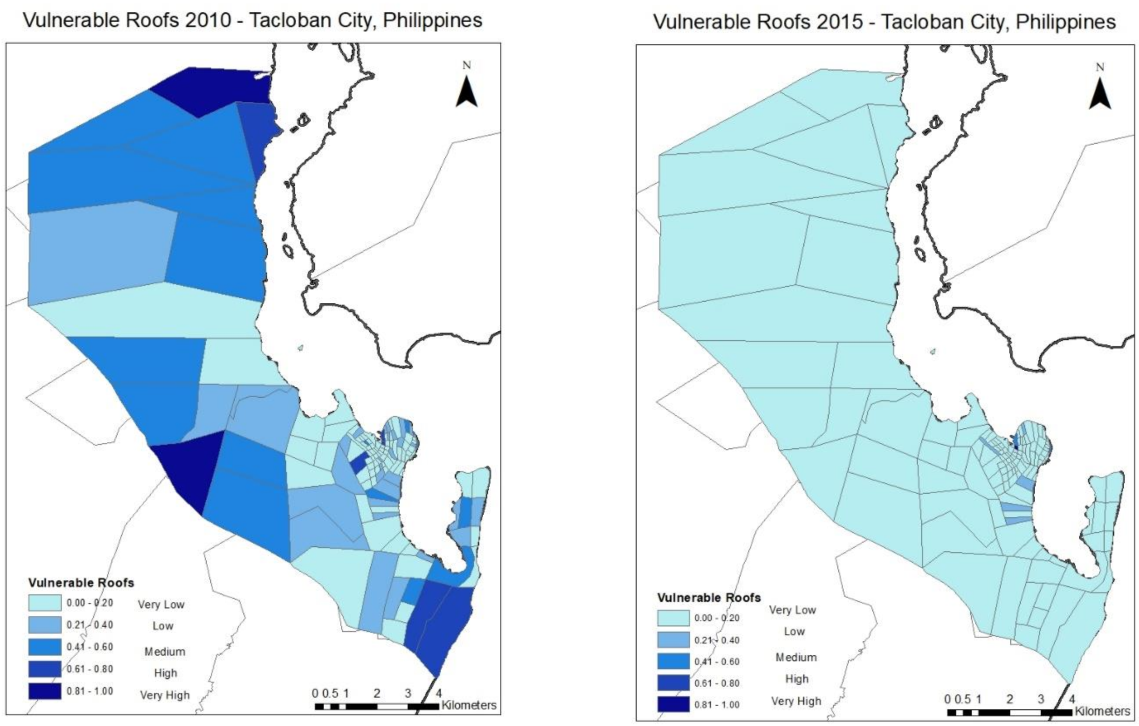

Figure 14. Vulnerable roofs per barangay comparison between 2010 and 2015

All LGUs were trained on disaster risk reduction, preparedness, and response and were also provided with basic communications, emergency response, rescue equipment, and training support on evacuation (UNDP Philippines, 2017). The local government led the construction of a community evacuation center (CEC) in barangay 97 (Cabalawan).

The CEC is located in a city resettlement site which includes disaster-resilient housing built by UNDP and EU for 55 families affected by Haiyan (UNDP Philippines, 2017).

Sensitivity was composed of three main indicators: population, the percentage of elders (age>60), and the percentage of children (age<10). When the sensitivity component was analyzed and mapped separately it resulted in a strange dynamic wherein most of the barangays in Tacloban presented the same amount of reduction from High risk to Medium risk when each indicator was evaluated separately (Figure 12). Meanwhile, the percentage of elders and children showed minor fluctuations within barangays, which could be explained by relocation efforts and normal population dynamics. The population indicator showed a clear increase of population to northern barangays (Figure 15). This could be a consequence of relocation efforts from most impacted barangays like San Jose Bay (Palagi & Javernick-Will, 2018).

The government implemented a Tacloban population redistribution plan in order to expand settlement in safer areas. Tacloban resettlement program consisted of building over 16,000 households designated for relocation (Palagi & Javernick-Will, 2018). Even though resettlement projects apparently had an important impact in reducing vulnerability, over 70% of households reported either minor or major construction defects such as roof leaks and lack of access to potable water and electricity, along with increased distance to the inhabitants' workplaces and schools (Bonifacio, 2015). Even though a portion of the population was relocated, it can be observed that people are still living in vulnerable areas; therefore, evacuation strategies are essential.

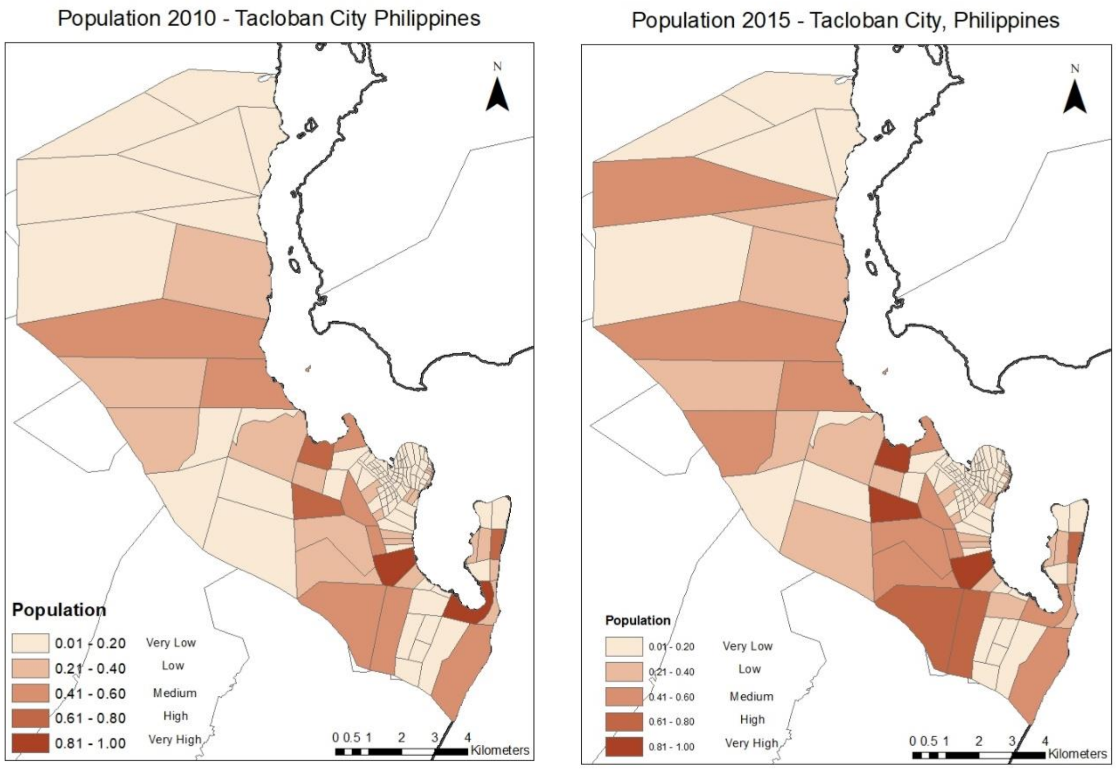

Figure 15. Population per barangay comparison between 2010 and 2015

Literature also suggests large migrations after the Haiyan Typhoon. Due to the extensive displacement after the typhoon, migration outflows occurred after the arrival of Haiyan IOM reports from the 14th of November 2013, people leaving Tacloban via Ormoc city on the island of Leyte accounted for 10,000 people per day on average. (IOM, 2015).

The Adaptive Capacities component is an indicator that measures how families cope with the disasters in the following years (Weis et al., 2016). Coping capacities to disasters are necessary to create a resilient community. Even if the risk of mortality and infrastructure is neutralized, the ability of families to recover as fast as possible from a disaster is key for sustainable development (Fuchs & Thaler, 2018). Poorer households also have fewer resources to manage disaster risk and withstand the impacts of frequent, repeated disasters. Therefore, increasing adaptive capacities is crucial to accelerate welfare recovery and increase community resilience.

This research used two indicators of the positive component of Adaptive Capacities: low poverty and high education. These indicators are important for adaptive capacities; however, livelihood of the population is crucial to measure in order to create a clear picture of the local adaptive capacities dynamics. The inability to measure livelihoods in this index is a major limitation that should be addressed in a further study where surveys can be implemented on site.

The census databases showed clear comparable data about education. However, the census lacked a clear poverty metric. In order to measure poverty a proxy component was used. Using the variable tenure status (own/rent), it was assumed that if a person owns or rent a house, he/she will have a better economic condition compared to those who rent free without owner's consent. The inconsistency of the components in the census database represented a limitation to compare both years with the same indicator.

Initially it was assumed that after resources and efforts were invested to increase resilience in Tacloban City, adaptive capacities would show a significant increase. However, only minor increases were identified which suggests that limited efforts to target adaptive capacities to disasters were implemented. Typhoon Haiyan destroyed farmer and fishermen livelihoods; however, the Philippines has developed one of the most advanced social protection (SP) systems in the East Asia Pacific region, designed to help poor households manage risk and shocks (Bowen, 2015). Along with resettlement and reconstruction projects, a livelihoods program, which consisted of money management, livelihood planning training, and cash to initiate a quick income-generating activity, was implemented after Haiyan to support most vulnerable families. This thesis lacked data to evaluate the livelihoods dynamics through time after implementing the post-Haiyan livelihoods program. I hypothesize that if information about livelihoods could be collected on site and included in the databases, then the adaptive capacities would show a higher increase between 2010 and 2015.

Limitations

The general limitation in this thesis research was the lack of information in the Philippines census data to measure social aspects such as informal settlements and occupation, which have a direct impact in overall barangay vulnerability.

The main limitation in measuring exposure risk was the lack of data about informal settlements, which indicates an increase in vulnerability due to weak materials and constructions in areas that are not permitted (Zandt et al., 2012). Reports say that informal fishing villages were wiped out after the Haiyan Typhoon (IOM, 2015). Therefore, not being able to measure it represents a clear limitation in this thesis's exposure results. Additionally, while the distance to water bodies, including rivers, is an important indicator to measure exposure to floods, in this study only the barangays proximity to the coast was considered.

The largest limitation to understand the changes in Adaptive Capacities was the lack of information to measure livelihoods. The Urban/Rural variable was used as a proxy for livelihoods, which didn't result in changes over time. Therefore, the variable wasn't useful in exploring the impacts of livelihoods programs implemented. The recovery project included a livelihood program which extends support to families and communities engaged in the farming and fishing industries, as well as those in off-farm economic activities (UNDP Philippines, 2017). In the case of the 2015 Census Population Housing Questionnaire 2015, the question "During the past 12 months, what was your usual activity/occupation?" was added, but unfortunately, it could not be compared with the 2010 data because there was no variable that could indicate more accurate livelihood information for that year.

In the case of sensitivity, lack of consistency between 2010 and 2015 data was the main limitation. For example, the questionnaire in 2010 had a question about disabilities which was erased in the 2015 census questionnaire. The index could have been improved if disabilities data were available and could be used as an indicator of vulnerability.

Even though the vulnerability index in this thesis presents some minor inconsistencies due to lack of information, the missing indicators were identified and with further information gathered onsite and comparable data, the analysis was able to show a clear projection in vulnerability.

Conclusions

The results of this approach show the dynamic nature of vulnerability over time. These results can help experts and decision makers to observe these dynamics to bring to light key information that can aid in measuring vulnerability and analyzing resilience strategies. As the population of developing countries grows and more natural disasters hit populated cities, it is important to have a tool that allows for visualization of social aspects of vulnerability to focus resources efficiently and evaluate the effects of resilient strategies.

This thesis presented an innovative method that has the potential to fill a key gap in the literature. The method can be replicated in any country that provides census data at a household level for a low cost. Census data is free and available and there are open source GIS and resources online that can be possible to replicate the analysis in other places. The indicators of the vulnerability index can be adapted to specific cities and applied to available information. The same methodology could be used to measure vulnerability for other natural hazards aside from typhoons by changing the indicators and data to meet research goals.

In the case of Tacloban City, I conclude that the policies and resilience strategies had a positive effect on the reduction of the vulnerability scores of barangays in Tacloban City but strategies such as resettlement of population are affected by behavioral characteristics of the population, therefore it needs to be monitored to measure it success in the following years.

The methodology is useful in order to determine and predict the areas that represent the highest vulnerabilities; however, in order to be able to prioritize vulnerable barangays and implement effective measures to increase resilience, it is fundamental to do on-site research and incorporate qualitative information obtained by interviews and forums to understand local dynamics of the particular site.

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