INFORMAL SETTLEMENTS AND THE GEOGRAPHY OF VULNERABILITY – A SPATIAL CASE STUDY OF HIDALGO COUNTY, TEXAS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Urban and Regional Planning – Master in Urban and Regional Planning

2019

ABSTRACT

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More than 2,000 colonias and more than 800 model subdivisions have been developed in unincorporated areas across the state of Texas. Since the 1980s, a substantial body of research has documented the poor housing conditions and inadequate infrastructure in these informal settlements in the United States. However, very little research has focused on the geographic vulnerability, such as exposure to environmental risks and the lack of access to amenities. This study adopts two Geographic Information System (GIS) methods (overlay analysis and proximity analysis) to investigate the vulnerability of informal settlements in Hidalgo County, Texas. This research finds that informal settlements experience more spatial vulnerability than formal neighborhoods as they are further away from the urban center, the job center, and other critical amenities. However, the prevalence of property crime in informal settlements is significantly lower. Within the informal settlements, colonias are still in need of basic infrastructures. Besides, this study finds that state-designated colonias are less vulnerable than newer model subdivisions that have developed largely without acknowledgment by the state.

These findings suggest the need for state and local governments 1) to make more targeted investments to provide water and wastewater service; 2) to develop public transportation system; 3) to reduce vulnerability by expanding access to amenities or services and 4) to partner with private entities and communities themselves to address the needs in informal settlements.

To my wife Fenfang
and my children Isabella, Lucas and Jacob
for their unlimited love

AKNOWLEDGEMENTS

I would like to express the deepest appreciation to my committee chair, Professor Noah Durst, who has an enormous passion for research with critical and creative thinking. His dedication to science and the teaching are truly impressive. He is kind and generous, entitling me the maximum financial and schedule freedom to participate in his projects. What I learned in those projects will provide me with lifelong benefits. He is a mentor and a wonderful friend. Without his guidance and constant help, this thesis would not be possible.

I would like to thank Professor Tongbin Qu and Professor Suk-Kyung Kim for their great help and support as members of my committee. I feel so relaxed every time after talking to Professor Qu. Whenever I feel down, she always inspires me with her great understanding of love, life, and the future. Although there are more than 10,000 miles between me and Professor Kim most of the time, she impressed me with her rigor and knowledge.

I sincerely thank Dr. Yue Cui, Wayne Beyea, Mary Beth Graebert for their generosity to fund my study; Dr. Mark Wyckoff, Dr. Mark Wilson, Dr. Trish Machemer for their great help during my time in the program; and my friends, Dr. Shengpan Lin, Wei Li, Weijing Wang, and Elena Cangelosi for their company and support. I am grateful to all other SPDC faculty and staff.

I am indebted to my beloved wife, Fenfang Ye, and three lovely children (Isabella Huang, Lucas Huang and Jacob Y. Huang) for their unlimited love. I am truly lucky to have a home to rest and to have them share my success and frustration. Without you all, I would not be able to make this success.

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KEY TO ABBREVIATIONS

ACS American Community Survey

BFE Base Flood Elevation

CCD Census County Division

CCN Certificate of Convenience and Necessity

CDP Census Designated Place

EDAP Economically Depressed Areas Program

ESRI the Environmental Systems Research Institute

FDAFI Federal Disaster Assistance and Flood Insurance

FEMA Federal Emergency Management Agency

FIRM Flood Insurance Rate Map

FOSS Free and Open Source Software

GIS Geographic Information System

ISD Intermediate School District

JSON JavaScript Object Notation

LEHD Longitudinal Employer-Household Dynamics

LODES LEHD Origin-Destination Employment Statistics

LRA Low Risk Area

LRGV Lower Rio Grande Valley

MCD Minor Civil Division

MRA Moderate Risk Area

MSA Metropolitan Statistical Area

MSRs Model Subdivision Rules

NAFTA North American Free Trade Agreement

NFIP National Flood Insurance Program

NGO Non-Governmental Organization

OAG Texas Office of the Attorney General

OD Origin - Destination

OSM OpenStreetMap

OSSF On-Site Sewage Facility

PSEO Post-Secondary Employment Outcomes

PUCT Public Utility Commission of Texas

QGIS Quantum GIS

QoL Quality of Life

SFHA Special Flood Hazard Area

TX the State of Texas

UN the United Nations

U.S. United States of America

VGI Volunteered Geographic Information

WHO World Health Organization

CHAPTER 1. INTRODUCTION

With rapid urbanization and globalization, more and more cities have been expanding dramatically, both in terms of their population size and the jurisdiction geography. According to a UN report, over 8 billion people will live on earth by 2030, an increase of 60% since 1990 (United Nations Department of Economic and Social Affairs, 2016). Sixty percent of the population in the world will live in cities by 2030, including 706 cities with more than 1 million residents and 43 "mega-cities" with more than 10 million residents. The growth of global population and high degree of urbanization have triggered conflict between housing demand and government's ability to accommodate it. When the regular housing market is not able to meet the needs, an alternative of housing emerges. In developing countries, more than half of the urban population finds housing in informal markets, also known as informal settlements or slums (UN-Habitat, 2004).

Although a number of studies (Lim, 1987; Shatkin, 2004; UN-Habitat, 2004) assert that informal settlements are a phenomenon more commonly witnessed in developing countries, a growing body of evidence has documented widespread patterns of informal settlements in developed nations (Iveson, Lyons, Clark, & Weir, 2019; Mendez & Quastel, 2015; Ward, 1999), including the United States (U.S.) (Durst and Wegmann, 2017). Such informal settlements are primarily concentrated along the border between U.S. and Mexico but are not limited to these regions. Ward and Peters (2007) have concluded that the informal settlements are also observed in so-called "gateway" cities, for example, the city of Charlotte in North Carolina. The phenomenon of informal settlements has attracted more and more attention from academia, governmental agencies and the public.

Over 400,000 people are estimated to live in 1,600 or more so-called colonias in Texas while about 162,000 people live in 77 colonia-like informal settlements in Arizona by the late

1990s (Ward, 1999). Colonia is a Spanish word meaning neighborhood or community. In the US context, colonias are defined by federal law (42 U.S. Code § 1479) as an identifiable community 1) within 150 miles of the US-Mexico border in the State of Arizona, California, New Mexico or Texas (excluding any standard metropolitan statistical area with more than 1 million population); 2) without basic services and infrastructures (such as the lack of potable water, lack of the adequate sewage systems and lack of decent, safe, and sanitary housing); and 3) in existence prior to November 28, 1990 (42 U.S. C., 2013). Colonias are often formed in peri-urban areas where the land price is low and the regulations are loose, driven by the demand for affordable housing from increases in the number of low-income households (Durst, 2016). The government's reluctance to provide affordable housing and the various land use regulations as well as an informal titling mechanism (known as contact for deed) also contributed to the emergence of colonias (Durst, 2016; Ward & Peters, 2007). The colonias are well-known for deteriorated living conditions without basic infrastructure, such as clean water, wastewater, and electricity. Despite the challenges that colonias face, they are one of the few means by which low-income workers can enter the housing market and become possible homeowners (Olmedo & Ward, 2016; Ward & Peters, 2007).

In order to stop the further spread of no-infrastructure colonias and to meet the federal funding requirement, the State of Texas (TX) passed the Model Subdivision Rules (MSRs) in 1989 (Olmedo & Ward, 2016). MSRs prohibit any residential development of "lots of five acres or less or without adequate water and sewer services, prohibit more than one single-family, detached dwelling to be located on each subdivision lot, and establish minimum setbacks to ensure proper operation of water supply and sewer services and to reduce the risk of fire hazards" (State of Texas, 1989).

Existing informal settlements' studies in the US are heavily focused on the emergence and the nature of the phenomenon (Durst & Wegmann, 2017; Sullivan & Olmedo, 2015; Ward & Koerner, 2005), the spatial and temporal patterns of informal settlements (Durst & Ward, 2014; Ward, 1982; Ward & Peters, 2007), the physical housing conditions (Olmstead, 2004; Rapier, 2009; Wekesa, Steyn, & Otieno, 2011), the land tenure and rental submarkets (Durst, 2014b, 2014a; Way, 2009), and the impact of legislation and policy (Durst & Wegmann, 2017). Hundreds of "model subdivisions" were developed after the passage of MSRs, and recent research suggests that model subdivisions and largely resemble colonias, except for the fact that they have water and wastewater (septic or sewer) services at the outset (Durst, 2016; Durst & Ward, 2016; Olmedo & Ward, 2016). Olmedo & Ward (2016) conclude that residents' life in model subdivisions are, in fact, worse than those in colonias, because the newer model subdivisions are located further from cities with relatively higher living cost and high dependence of automobile as well as the lack of financing resources and employment opportunities.

This study chooses Hidalgo County in the state of Texas as the research area to investigate the informal settlements' characteristics. Hidalgo County is located in the southern tip of Texas, bordering with Mexico. Since the early 1900s, local Latinos and Mexican migrants have settled in the county and worked in the agricultural sector on the fertile Rio Grande River Delta, which makes the region famous for its produce (Gass, 2018). Those settlements often sit in flood-prone unincorporated areas without water and electricity, which is still an unresolved problem a century later. Hidalgo County has the largest number (over 1,500) of informal settlements in Texas with at least 150,235 residents in 2010, which is nearly 20% of the county's total population and over 38% of the existing communities (Koordinates Limited, 2019; Texas Office Of The Secretary Of State, 2014; United States Census Bureau, 2010).

A review of the existing academic literature highlights three important gaps. First, current research often ignores or does not pay enough attention to the spatial component of informal settlements in Texas. The data used are often obtained from surveys, which leads to a limited understanding of spatial patterns of vulnerability. Second, there are no attempts to systematically compare colonias, model subdivisions and formal neighborhoods within a spatial context. Third, other than the flooding risk and the availability of infrastructure (Durst & Ward, 2014; Olmedo & Ward, 2016), namely the clean water, wastewater and electricity, there are limited studies that have evaluated the vulnerability of these informal settlements with regard to employment opportunities, access to education and health services and other amenities, and exposure to crime.

This study aims to investigate the spatial distribution of informal settlements (including colonias and model subdivisions) and to evaluate the geographic vulnerability regarding access to infrastructure, environmental risk, access to employment opportunities and amenities, and exposure to crime. The study adopts the Geographic Information System (GIS) framework to collect and analyze multi-source spatial data to differentiate between colonias, model subdivisions and formal neighborhoods. This study makes two contributions to the literature by 1) integrating the spatial component into the informal settlement study and 2) systematically examining the differences between colonias, model subdivisions and formal neighborhoods.

This thesis includes five chapters. Chapter 1 shows the background of the research, the current research gaps and the purpose and significance of this study. The following chapter reviews the current literature about informal settlements, including the definition of informality, the cycle of land tenure, types of informal settlements and the legislative efforts to address the spread of colonias. Chapter 3 introduces the area of study, the various data sources used, and the methodology used to conduct analyses for this study. The overlay analysis and proximity analysis

are adopted to examine the relationship between neighborhoods (both informal and formal) and the other GIS layers. Chapter 4 presents the results of the analysis one by one. Colonias and model subdivisions are further away from the city and more prone to flooding. They are also less accessible to the job market and other amenities. Then, the results are summarized, discussed and concluded in Chapter 5. Colonias and model subdivisions are more vulnerable than formal neighborhoods from every perspective, except neighborhood safety. In this chapter, this study also makes three suggestions for policymakers, including the continuing investment to improve housing conditions in informal settlements, the development of public transportation systems, a more comprehensive approach to planning for informal settlements' development and the advocation for a partnership of the government, private entities, and the communities themselves.

CHAPTER 2. LITERATURE REVIEW

2.1. The Definition of Informality

Informal housing typically refers to two critical criteria: the legal status of the ownership of the land and the legality of the property's physical characteristics (AlSayyad, 1993; Fekade, 2000; Lim, 1987). Payne (1988) has defined informal housing as "spontaneous, unplanned or unregulated sub-markets" with various forms, including self-help housing, slums and squatters. The existence of informal housing is depicted as an unacknowledged and illegal but tolerated and practically significant sector to accommodate the majority of low-income residents in urban areas (Fekade, 2000).

Lim (1987) proposes a classification system to identify various housing sub-markets from the legality standpoint. Aside from the regular or formal housing market, there are slum housing markets, invasion housing markets, and squatter housing markets. If considering the status of tenure, the aforementioned four sub-markets can be further divided tenure (owner or renter) into eight sub-markets (Lim, 1987). The slum housing market is composed of housing units with legal occupancy of the land but illegal (or non-compliant) construction. Invasions on not-owned land or residing in illegal subdivisions occur commonly in invasion housing markets, even though the units conform to the requirement for physical characteristics. The most vulnerable example of the informal housing market is the squatter settlement, which does not have legal occupancy nor the minimum physical standards.

Given the context of being a post-industrialized immigrant country, the formal housing market in the U.S. is distinct. For example, Durst and Wegmann (2017) define the informality in USA as "non-compliant, non-enforced, or deregulated economic activities" that may arise by circumventing property rights law, property transfer law, land use and zoning ordinances,

subdivision regulations and building codes. Colonias, in most cases, fall in the slum or squatter housing markets as they do not meet the standard building codes and were developed without basic water and wastewater infrastructure. Residents often purchase the land from developers who divide the lot into pieces (Gass, 2018), but often do so through highly informal contracts for deed. Model subdivisions, on the other hand, meet the minimum residential requirements with a legal title, which makes it very close to a formal housing market. However, the lack of financing and widespread patterns of self-building of the home all highlight the informal nature of the settlements (Olmedo & Ward, 2016).

Table 1 Categorization of Housing Market

		Occupancy of the Land			
		Legal		**Illegal**	
The Legality of Physical Characteristics	**Legal**	Formal Housing Market		Invasion Housing Market	
		Owners	Renters	Owners	Renters
	Illegal	Slum Housing Market		Squatter Housing Market	
		Owners	Renters	Owners	Renters

Source (Lim, 1987, p. 178)

2.2.The Cycle of Land Tenure

Land tenure is of great significance due to its interwoven relationship with property rights, which can directly affect the individual's wealth accumulation (Payne, 2001). The United Nations (1973) lists the five most common land tenure types in southern countries, namely customary tenure, private tenure, public tenure, religious tenure and informal tenure. Table 2 has listed the characteristics of each land tenure category.

Table 2 The Common Land Tenure Types and Characteristics

Tenure Type	Highlights	Monetary Element	Limitation
Customary tenure	• Lands are communal owned but individual use-right as needed • View land as sacred for agricultural cultivation but virtually no economic value • Low degree of usage, low efficiency	• The leaders manage the allocation use and transfer of lands • No Monetary Payment but A form of token if agree	• Facing more commercial pressures • Only benefit for the members of the community
Private tenure	• Private ownership and extensive individual right (unrestricted use) • View land as high economic value • Widely adopted in developed countries while imported by developing countries • High degree of usage, high efficiency	• Monetary payment is often involved with a legal process of title transfer	• Very difficult for low income group to enter
Public tenure	• The government or the collective group reserves the rights to own, allocate, use, develop and transfer the land (widely acknowledged) • High degree of usage, low efficiency	• Often involve monetary payment but the title transfer process can be difficult	• High land management cost • Inflexibility to be developed
Religious land tenure	• Closely related to certain religion • Detailed categorization of lands by various roles defined by the religion • Medium degree of usage and efficiency	• Certain category of lands, i.e., “mulk” in Islam, is more active than other categories	• Long-term threat for growing city • Most are managed poorly
Informal tenure	• Without planning, services and organizational assistance • Often do not meet the minimum construction standards • High degree of usage, medium efficiency	• Often involve monetary element • Multi-generation effort	• Lack of the land security Poor quality of life

Source: (Payne, 1988, 1996, 2001; United Nations, 1973)

From a long-term perspective, the land tenure of informal housing always presents a multistep or incremental transition as the residents' financial capability improves (Durst & Ward, 2014; Lim, 1987; Ward, 1982b; Ward & Peters, 2007). As the purchase of the land can only be cash payments or seller-financed via contracts for deed, the title of the land is typically not secured until the payments are completed. However, in the interim period, many residents make improvements to the home via self-help or DIY (Do-It-Yourself) methods (Ward, 1982b). Lim (1987) elucidates a diagram of multistep transition in a housing market (Figure 1). The dashed line is added to indicate the small possibility of transition from squatter market to regular housing market, which is not explicitly presented in the paper. Coccato (1996) has echoed with the same transition model in his dissertation on the alternative housing ownership.

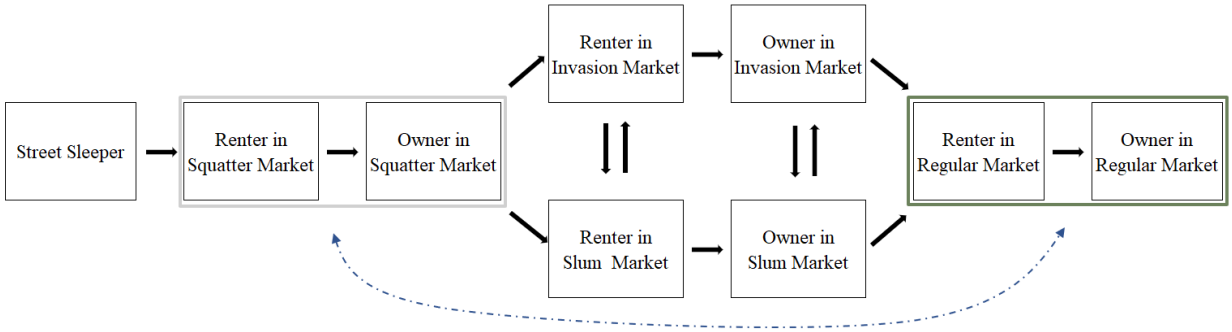

Figure 1 Multistep Transition Model of Land Tenure

Like others in the developing world, the informal settlement in the US often follows same pattern of development from squatting to full ownership. In the US, the formal housing market is highly planned. The development process begins with 1) platting (mapping) the development and 2) installing infrastructures, then 3) building the home and followed by 4) the sale of the property (Durst, 2016). However, in colonias, the order of development is typically reversed. Residents first purchased the lot and began constructing their homes; only years later was infrastructure installed (Ward, 1999) and lots were formally mapped. The whole process in colonias could take up years or decades to fully legalize the title and complete the construction of the home. The development

process in model subdivision largely resembles that of colonias, with the exception that infrastructure is installed at the outset – a requirement of the Model Subdivision Rules (Durst, 2016).

Self-built and self-managed housing solutions are often widely used in colonias. Prefabricated homes, such as modular homes and manufactured homes, are also observed (Ward & Peters, 2007). Self-help homeowners make many incremental improvements to their homes over time (Durst & Ward, 2014; Ward, 1982a). Durst and Ward (2014b) show that more than 70% of the informal housing units have completed at least one major improvement from 2001 to 2010. The benefits gained through the improvement are multifaceted. Most importantly, the self-help improvements lead to better housing conditions. They also, however, contribute to increases in property values, and thus to greater wealth accumulation for the household (Durst & Ward, 2014).

2.3.Typology of Informal Housing

Informal housing in the U.S. exists in a variety of forms. A series of studies by Peter Ward and colleagues (Ward & Koerner, 2005; Ward & Peters, 2007) has identified various types of informal settlements and some formal subdivisions. As Ward and colleagues argue, these neighborhoods differ regarding their locations, their residents, the land tenure, and the physical structure (morphology). Table 3 shows the details of five out seven different subdivisions based on Ward and Koerner (2005) and Ward and Peters (2007). One additional type of community not included in Ward's typology – model subdivisions – is elaborated in the following section.

Table 3 Typology of Informal Housing Markets

Name	Location	Resident	Settlement /Dwelling Characteristics	Service / Policy
Classic border colonias	Along the border line Most beyond the city limits Sited in the rural hinterland	Very low-income Mexican Mexican-Origins	A few lots on a single street Cul-de-sac Large settlements (> 300 lots) A trailer unit with /without A self-help extension False Roof	Extensive Policy Attention
Non-border peri-urban informal settlements	Be readily observed from the air, Several miles into the rural hinterland from major cities	Mixed ethnicity and races Whites could be the majority	"lozenge" shape Trailer home roof Less well-recognized Low density Larger individual lots Idiosyncratic dwelling arrangements and placement on lots Unpaved streets	Certain degree of service
Semi-urban or rural housing subdivisions		Elderly With extended households "truncated" (widowed/widower) household structures Less likely to be Hispanic	Very extensive low-density Uniform physical structures Often very old (built before 1950s)	Serious insufficient
Mobile Home Communities	Low-cost peripheral locations of cities	The moderately poor homeowners than those in trailer parks	Modular home New trailer home Larger lots than for trailer parks	Full Service Ineligible for conventional mortgage finance or state insured housing
Trailer parks	Within the city Extraterritorial jurisdiction	Low-income households	Very high densities, small sites Standard "lozenge" shape trailers arrayed in a regular layout, with a vehicle "pad" at the front of the lot	Low-cost rental for the site and services.

Source: Ward & Koerner, 2005; Ward & Peters, 2007

Two types of informal settlements, colonias and model subdivisions are highlighted in the literature. Colonias are defined by federal law to characterize those peri-urban neighborhoods along the US-Mexico border which are usually self-built and do not follow any zoning, subdivision regulations and building codes (Durst, 2016). Model subdivisions are informal settlements developed after 1990 with basic infrastructures, in which the self-help is also the norm (Olmedo & Ward, 2016). The MSRs have ensured some important dimensions of livable housing, such as requiring the development of water and wastewater infrastructure, limiting the number of dwelling units on one lot, and prohibiting development on flood plains. However, model subdivisions still are not subject to zoning ordinances and building codes, leading to haphazard and poor-quality dwelling construction (Durst, 2016). Of equal importance, model subdivisions are pushed out further from the urban area as the land cost is low. Figure 2 shows examples of colonias, model subdivision and formal neighborhood from Google Satellite Images. It is very clear that formal neighborhoods (bottom row) are more regular with paved roads and similar buildings, which are not observed in colonias (top row) or model subdivisions (middle row).

2.4.The Existing Legislative Efforts – The Model Subdivision Rules

Since the early 1990s, Texas has undertaken a number of policy initiatives to address the spread of colonias. The Administrative Code of SB2 (also known as the Model Subdivision Rules), passed in 1990, is the first policy effort by the State of Texas with the objective to stop the spread of colonias. The MSRs required that all new residential neighborhoods be developed with basic infrastructural services (water and wastewater) prior to the sale of land (Durst, 2016). The MSRs also made specific requirements for the adoption of On-Site Sewage Facilities (OSSFs), the implementation of setbacks from roads and multiple occupancy on single lot. While these rules prevented the spread of colonias with poor-quality or non-existent water and wastewater services,

they did not prevent the spread of low-income neighborhoods with poor-quality, self-built housing. Indeed, as Durst (2016) illustrates, since 1990 nearly 800 model subdivisions with poor-quality housing have been developed in the Texas border region. The vast majority of model subdivisions are located in rural parts of Hidalgo County. Little to no research has examined the implications of the continued proliferation of these informal settlements and its implication for issues of spatial vulnerability.

Figure 2 Examples of Colonias, Model Subdivisions and Formal Neighborhoods

2.5. Vulnerability and in Informal Settlements

Vulnerability in colonias and other informal settlements can take on a variety of forms. The most severe forms of spatial vulnerability – the lack of access to basic water and wastewater infrastructure – has been relatively widely studied (Durst, 2016; Durst & Ward, 2014; Olmedo & Ward, 2016; Ward & Peters, 2007). Other forms of spatial vulnerability – such as exposure to flooding risks and the lack of access to employment opportunities and amenities have largely been overlooked in the literature (Ward & Peters, 2007).

2.5.1. Water and Wastewater Collection

The lack of electrical, water and sewer service in colonias has been widely studied. Historically, many residents in colonias lacked clean water and wastewater infrastructure (Durst, 2016; Lemos, Austin, Merideth, & Varady, 2002). After the adoption of the Model Subdivision Rules in the 1990s, new subdivisions were mandated to include water and wastewater (septic or sewerage) infrastructure (Texas Water Development Board, 2014). Residents in older colonias often rely on private wells, which might be inadequate or maybe become contaminated or undrinkable. The use of hauled water in dwellings also indicates the low security of water consumption in the colonias' daily life. A survey conducted by Texas A&M University in June 2000 revealed less than 50% of colonias in six border counties (including Hidalgo County) had drinkable tap water in the house; and the rest relied on bottled water and water from machine dispensers (Cisneros, 2001).

2.5.2. Flooding Vulnerability

Hidalgo County, where this study focuses, has experienced frequent flooding in recent years (Texas Water Development Board, 2014). In June 2018, Hidalgo County experienced a severe flooding, known as "Great June Flood of 2018," with rainfall ranging from 5.6 in to 18.3

inches (US Department of Commerce, 2018). The flooding revisited the region in June 2019 with enormous damages to properties and roads (US Department of Commerce, 2019). Figure 3 is a screenshot of drone-taken video in 2018 flooding (RAMÍREZ, 2018).

Figure 3 Flooding in Indian Hills Colonia, Hidalgo County, TX from Texas Housers on Vimeo

2.5.3. Access to Employment Opportunities

Although prior research has illustrated that many residents in informal settlements have very low incomes (Durst and Ward, 2016), few studies have systematically examined spatial vulnerability in regard to access to employment opportunities for residents. For example, recent research documents the development of informal settlements such as colonias and model subdivisions in rural areas on the outskirts of cities (Durst, 2014b; Ward, 1999; Ward & Koerner, 2005), but no research to date has examined the geographic burden experienced by residents in informal settlements due the increasing distance between these neighborhoods and places of employment.

2.5.4. Quality of Life

The World Health Organization (WHO) at United Nations (UN) has heavily emphasized the importance of the life quality (The WHOQOL Group, 1998). The WHOQOL 100 (1998) defined the Quality of Life (QoL) as an overall well-being of individual's life status, including the dimensions of the physical health, psychological health, social relationships, independence, social relationships, environment and spirituality. Above-mentioned water and wastewater, flooding risk and the vulnerability of employment are representative of environment and social relationships dimensions. Richards et al.(2007) have found social relationships and personal health, besides the material living standards, are two other most important components factors in improving QoL in informal settlements of South Africa. In the context of the study, the QoL for residents in model subdivisions and colonias are examined from the prevalence of crime, the accessibility to obtain health services, the police and fire department services, and other life convenience services (such as grocery store).

CHAPTER 3. STUDY AREA AND METHODOLOGY

This study examines patterns of geographic vulnerability between formal and informal neighborhoods in Hidalgo County, Texas. Vulnerability is examined spatially in regard to environmental and social risk as a result of flooding, accessibility to employment opportunities, accessibility to amenities and crime. In this chapter, a detailed introduction is presented about the study area, the data sources, the analytical methods and the software used. Hidalgo County, with the most concentration of informal settlements in border states (Durst, 2016), is chosen as the study area.

3.1. Study Area

The Lower Rio Grande Valley (LRGV), often referred to as the Valley, sit in the southernmost tip of Texas along the US - Mexico border. It includes Cameron, Hidalgo, and Willacy Counties. Under the North American Free Trade Agreement (NAFTA), the Valley, with a total area of 9,216 km^2 (3600 mi^2), has emerged as a warehouse and transportation center between Central America and the U.S. (TSHA, 2003). The Office of Management and Budget ranks Metropolitan Statistical Areas (MSA) according to their population and economic growth. Hidalgo County, the largest of the three Valley counties, covers the western half of the region with an area of 3963 km^2 (1548 mi^2) and includes 8 Census County Divisions (CCDs), which are the statistical entities defined by the Census Bureau and other authorities since Minor Civil Divisions (MCDs) do not exist in Texas (US Census Bureau, 2018). This county is mostly urbanized, containing the McAllen–Edinburg–Mission MSA, the 5th fastest growing area in Texas (Sharf, 2018). However, Hidalgo is also known by its informal housing market which has been growing rapidly. The county has the largest number of colonias and model subdivisions in Texas (Durst, 2016). This fact makes

Hidalgo County an ideal area for research on spatial vulnerability and the informal housing market (Figure 4).

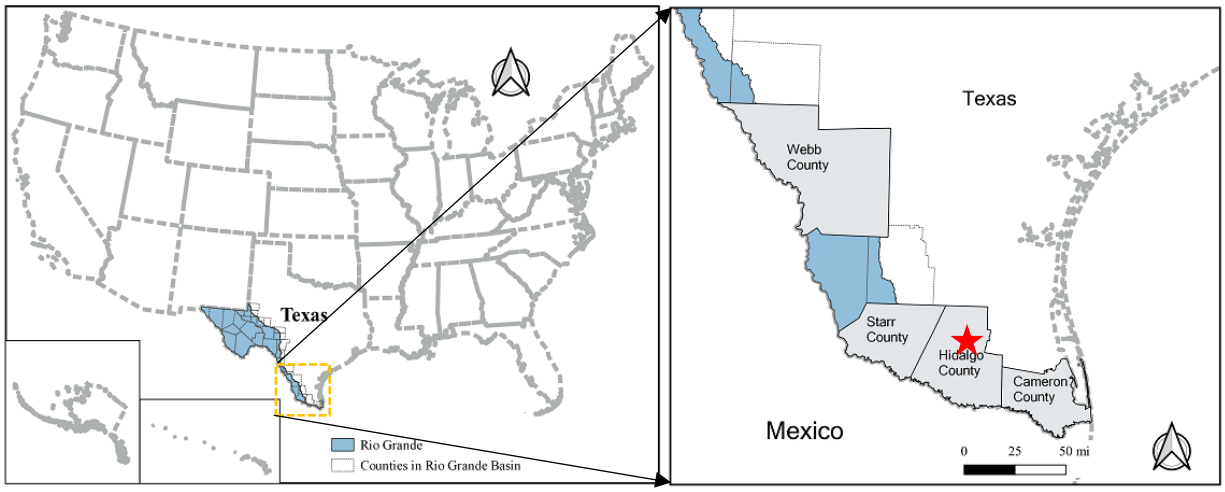

Figure 4 Research Area for Vulnerability Study

3.2. Data Source

3.2.1 Subdivision Datasets

In this study, both informal and formal subdivision data are used to demonstrate the differences between different types of neighborhoods. The informal subdivision data include two data sets. The first data set is the official colonias dataset, as maintained by and obtained from the Texas Office of the Attorney General (Texas OAG, 2019). There are 2,085 state-designated colonias in the dataset. The majority of colonias are located in border counties, including Hidalgo County. The dataset includes important variables about the characteristics of the neighborhoods, such as the total number of residents, the availability of water, ways to process wastewater, etc. Only the portion of colonias in Hidalgo County is analyzed in this study. The second dataset is the model subdivision data, provided by Durst's study (2016). An integrated method of using satellite imagery and census data was used to collect the model subdivisions data within six counties (Durst & Ward, 2016; Ward & Peters, 2007). Nearly 800 (796) model subdivisions were identified, out of which 72.3% are in Hidalgo County.

The distribution of informal settlements is uneven spatially among CCDs (Figure 5). In the north part of the county, namely Puerto Rico-San Manuel CCD, there is only one Colonia community within the jurisdiction and another two along the borders from Hargill and Edinburg. In contrast, a large number of informal settlements are located in the southern CCDs, such as Mission and Edinburg. Model subdivisions are observed more often in the peri-urban area on the east side of Edinburg, the northern area of Mission, and northeast of Southeast Hidalgo CCD. The land far from the city is considered cheaper for developers and more affordable for low-income buyers (Durst, 2016). Colonias, though developed in remote locations decades ago, have since been integrated into areas over time as cities have expanded their jurisdictional boundaries over time.

The formal neighborhood data was collected in the summer of 2019 by Durst's research team. The data set was built on the parcel data and the satellite image with a consistent method as Durst (2016). The identified neighborhoods were randomly sampled from census block groups across Hidalgo County, and thus, unlike colonias and model subdivision data sets, do not cover the whole county. Rather than providing comprehensive depiction of the characteristics of formal neighborhoods, the data enables the potential examination and the differentiation between informal and formal neighborhoods in Hidalgo County.

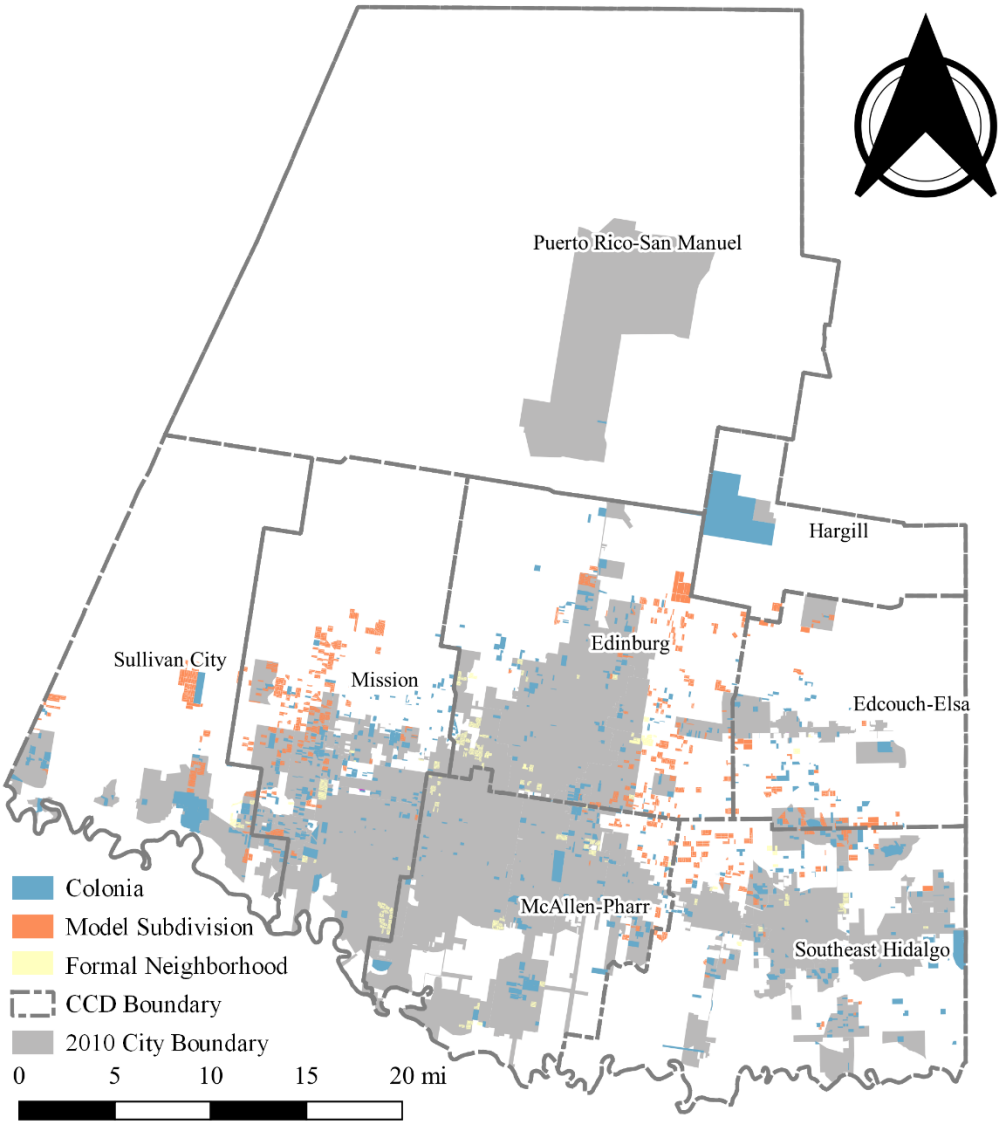

Figure 5 The Spatial Distribution of Informal and Formal Settlements in Hidalgo, TX

3.2.2 FEMA Flooding Map

The Federal Emergency Management Agency (FEMA) provides a flooding map service to facilitate the National Flood Insurance Program (NFIP) which was established in 1968. In order to assess the risk of flooding for insured properties, FEMA has mapped Special Flood Hazard Areas (SFHAs), base flood elevation levels (BFEs) and floodways, termed as Flood Insurance Rate Map (FIRM) or more commonly flooding map (Pralle, 2019). In recent decades, the flooding map has played an important role to inform and prepare homeowners and communities against the hazards

and save properties and lives. For local planning authorities, the flooding map is guidance to plan, develop and mitigate adaptively to the flooding risk. Communities will enter NFIP if they acknowledge the map and are qualified for Federal Disaster Assistance and Flood Insurance (FDAFI) (Pralle, 2019). Although some studies have questioned the accuracy and correctness of flooding maps as well as the comprehensiveness of their geographical coverage (Kailath, 2016; Pralle, 2019), the FEMA flooding map is still the only publicly accessible source to obtain the flooding risk information.

The flood map used in this study is obtained from ESRI ArcGIS Online Gallery and then re-projected to the needed projection (EPSG: 6579). The types of flooding areas and the distribution within Hidalgo County is shown in Table 4. Accepted widely, 100-year floodplain is viewed as flood-prone areas often while 500-year floodplain has relative small possibility to be flooded. The majority (62.3%) of the county is located in Moderate Risk Areas (MRAs) while 22.9% are in Low Risk Areas (LRAs). As for Special Flood Hazard Areas (SFHAs), the percentage is relatively low (nearly 15%). However, as Wright (2018) warned, flooding can occur anywhere even you are not living by a waterbody. Nationwide, about 20% of NFIP claims and 1/3 of FDAFI claims are from MRAs and LRAs (Wright, 2018). From historical observations, Hidalgo County is a flood-prone place.

Table 4 FEMA Flood Zones and Explanations

Risk Level	Zone	Explanation	Percentage	Impact
Special Flood Hazard Areas (SFHAs)	A	100-year floodplain, mapped by approximate methods; no BFEs determined. Mandatory to buy flood insurance from federally regulated or insured lenders for all home and business owners with mortgages	11.65%	
	A23	100-year floodplain, mapped by detailed methods; with BFEs determined and zones subdivided according to Flood Hazard Factor	0.81%	
	AE	100-year floodplain, with BFEs determined.	1.13%	
	AH	100-year floodplain, with ponding, with BFEs determined.	1.34%	
Moderate Risk Areas (MRAs)	B	The risk of flooding is moderate, but not completely removed	5.67%	20% NFIP 1/3 FDAFI
	C		56.50%	
Low Risk Areas (LRAs)	X	Outside flood zone The risk of flooding is low, but not completely removed.	22.91%	

Table 5 PUCT CCN Delineation Criteria in Texas

Methods	Description
Bounded Service Areas	Identifiable physical and cultural features such as roads, rivers, streams and political boundaries.
Facilities +200 Feet	Linear certificated service areas can have a specific buffer area (usually 200 feet)
Facilities Only	Linear certificated service areas are granted for a "point of use" that covers only the customer connections at the time the CCN is granted

3.2.3 Water and Sewer Service Area

More than half (62.8%) of colonias have inadequate wastewater disposal systems. According to the OAG colonias database, 595 out of 850 colonias have the public distribution of water while 583 colonias have potable water on the lots (see Table 6). However, 2,285 residents in colonias still lack accessibility to water, completely or partially. The cost of building wastewater infrastructure is high. Cameron County officials would need $3.3 million to connect the water and sewer networks and additional $26 million to dispose wastewater properly in 99 colonias (Cisneros, 2001). The inability of governmental investment has left about 40% of colonias residents in Hidalgo County depending on functional septic tanks, and other complimentary solutions, such as cesspool and pit privies to process the wastewater (Texas Office Of The Secretary Of State, 2014). Undoubtedly, the efficiency and performance of the on-site wastewater system are below the standards. Public Utility Commission of Texas (PUCT) is a governmental agency who regulates the rates and services of electricity, telecommunication and utility (Water and sewer). PUCT defines the Certificate of Convenience and Necessity (CCN) and grants the retail public utility the exclusive right to provide retail water and sewer utility service. The Texas Water Code (chapter 13) (Public Utility Commission Of Texas & OF TEXAS, 2017) mandates the CCN holders to serve the families and business within certificated service areas adequately and continuously. PUCT has adopted three different criteria to delineate the CCN service area, as shown in Table 5. This study uses the subset of statewide CCN service areas to overlay with Hidalgo County's subdivision datasets. The overlay result provides a clear picture of the coverage of CCN service among different types of neighborhoods (Shown in Table 6). Most of data-available *colonias* have adequate water and trash collection service but the wastewater disposal service. Nearly 90% of

colinas (with data) need certain type of wastewater service and the affected population is over 90,000.

Table 6 Water and Waste Condition in Colonias (N: 850)

Survey Question	Count of Colonias with Water and Waste Issue(s)				Demographic Summary of Colonias with Water and Waste Issue(s)			
	Yes	No	Partial	NA	Yes	No	Partial	NA
Public Distribution of Water?	595	2	5	248	99,449	95	671	38,243
Do All Lots Have Potable Water?	583	12	-	255	98,017	1,519	-	38,922
Private Wells?	1	255	1	593	18	37,620	-	100,820
Is Water Hauled In?	1	254	-	595	90	37,237	-	101,131
Is Wastewater Collection Available?	601	1	-	248	100,215	-	-	38,243
Inadequate Wastewater Disposal on Some Lots?	**62**	**534**	**4**	**250**	**9,252**	**90,579**	**261**	**38,366**
Is Trash Collection Available?	513	24	51	262	88,782	2,295	6,745	40,636
Wastewater community service? (Yes: Existing Treatment Facility, No: New Treatment Facility, Partial: On-site)	330	254	160	106	36,400	72,832	12,007	17,219

Source: OAG Colonias Database, 2019

3.2.4 OpenStreetMap Data

Originated in United Kingdom, OpenStreetMap (OSM) has been successfully running globally since 2004. OSM project is a collaborative and publicly accessible project aiming to create and provide free geographic data (Girres & Touya, 2010). The data can be used and shared freely under "Creative Commons Attribution-ShareAlike 2.0 license." By the nature, OSM project is a Volunteer Geographic Information (VGI) project (OpenStreetMap Wiki, 2018). Girres and Touya (2010) found the accuracy and the completeness of OSM data vary and are highly dependent on

the amount of individual contributions. A study in Wuhan, China, has illustrated that the OSM road network for the city has a high position accuracy and completeness (Wang, Li, Hu, & Zhou, 2013). By examining the data availability for Hidalgo County and the completeness of OSM data, this study has selected OSM data as the source of amenities.

Although OSM provides a programmatic accessing point for data users, the author used the interface of the website (http://overpass-turbo.eu) to extract needed data in this study. Figure 6 shows the example of using the website to filter out all the amenities within the interested region (the highlighted rectangular). The "Export" function allows the user to download the selected data and save it in various format (GeoJSON in this study). A total of 11 amenities were collected from the OSM database, shown as follows. The amenities cover four major categories, education (school, library), health (hospital, clinic and pharmacy), the law enforcement (fire station and police station) and the life convenience (bus stop, restaurant, supermarket, and bank facility)

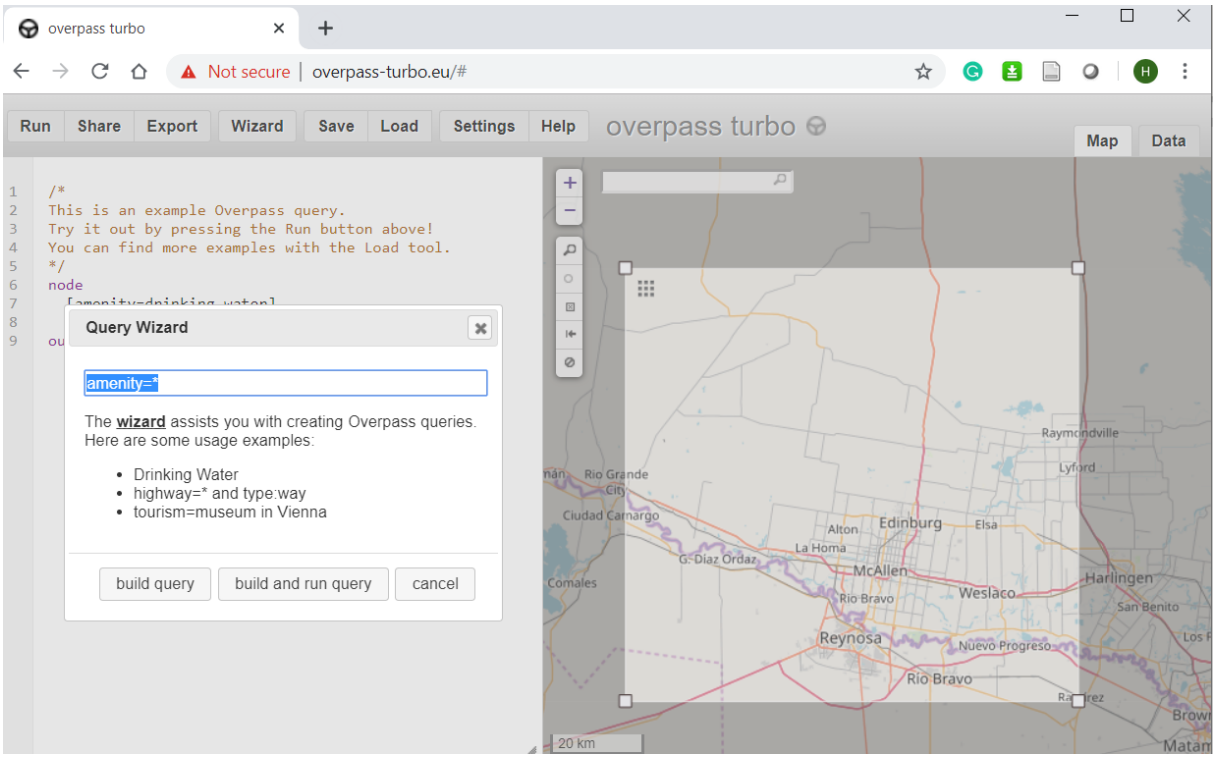

Figure 6 OSM Data Acquisition Demonstration

3.2.5 Longitudinal Employer-Household Dynamics (LEHD) Data

LEHD provides several data products that may be used to research and characterize workforce dynamics for specific groups. These data products include online applications, public-use data, and restricted-use microdata. The Quarterly Workforce Indicators, LEHD Origin-Destination Employment Statistics (LODES), Job-to-Job Flows, and Post-Secondary Employment Outcomes are some examples. The LODES database describes the employment patterns, namely by Origin-Destination (OD), the Residential Area Characteristics and the Workplace Area Characteristics. LODES 2010 data set is used in this study for Hidalgo County to be consistent with the informal subdivision's data (i.e., there were no new informal housing data after 2010, as documented by Durst, 2016). Currently, the LODES data has 3 versions, namely version 5, version 6 and version 7. This study will use the OD data to identify the job market and the commute time of workers.

3.2.6 ESRI Census Data and Crime Index

The demographic data in the neighborhoods, such as the educational attainment, is obtained from ESRI Business Analyst Online. Using the neighborhoods' centroids as the sites and 1 mile as the buffer distance, the needed variables are summarized for each neighborhood. Then the data is downloaded and joined with other spatial data for analysis.

ESRI's Crime Indexes data is also collected from ESRI Business Analyst Online, which contains relative measurement about major categories of personal and property crimes (Applied Geographic Solutions, 2019). The crime indexes are calculated based on governmental crime reports. An index value of 100 represents the national level of occurrence of certain type crime. Over 100 means more prevalence of the crime than the national average while less than 100 means less occurrence than the national average.

3.3. Methodology

In this study, all the data gathering, processing, analyzing and visualization will be accomplished within a Geographic Information System (GIS) framework. The GIS framework allows people to see, analyze, and understand spatial patterns and relationships more easily (Figure 7). Previous studies about self-help housing in colonias and model subdivisions (Durst & Ward, 2014, 2016; Ward & Peters, 2007) have also adopted the framework as one method. All the results obtained from the spatial analyses are compared among three different neighborhood types: colonias, model subdivisions and formal neighborhoods. The analytical process in this study is elaborated as follows.

3.3.1 Overlay Analysis

Overlay analysis is a basic but unique method in GIS to examine the suitability of a site or region, given multiple factors (ESRI, 2019b). The analysis can be performed using either vector data or raster data. However, the projection system of all layers should be identical to yield accurate results. Since the overlay analysis will merge multiple layers' information into one (typically the most important one), it will help answer questions about the relationships among data sets. This specific study uses overlay analysis to examine patterns of spatial vulnerability; for example, to identify how many neighborhoods are located in floodplains and how many are covered by CCN water and sewer networks.

3.3.2 Proximity Analysis

Proximity analysis is another GIS method used in the study to analyze what are near the neighborhoods in question. Similar to an overlay analysis, it can be applied to both vector and raster data. The proximity analysis contains many contents, such as finding the nearest neighbor (or facility), finding features within a buffer distance and calculating the distance between two

features of interest (ESRI, 2019a). Different tools might require different inputs as well as yield different outputs.

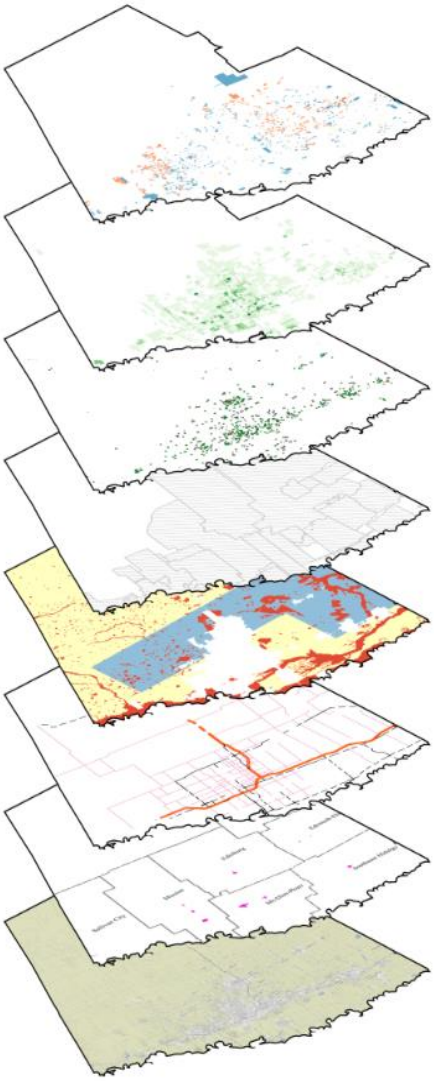

Figure 7 Demo of GIS Database

There are three different models of distance calculation, namely Euclidean Distance, Path Distance and Geodetic Distance, which apply to specific scenarios. Euclidean distance is suitable for cases when the network cost is not considered between two features, which differs from path distance. Geodetic distance is more often used in global studies or phenomena, such as airplane flight paths. In this study, Euclidean distances are used primarily because of the computational

cost of the alternative, path distance. Hence, when examining the proximity between a neighborhood and other feature in this study, the distance refers to as-the-crow-flies, Euclidean distance. A buffer distance of 1 mile around the neighborhood centroid is adopted to overlay with the crime and other data from ESRI Business Analyst database.

3.4.Software and Programming Language

The study will utilize a Free and Open Source Software (FOSS) named "Quantum GIS" (QGIS) to visualize and analyze the spatial patterns. QGIS is a powerful tool to accomplish many tasks, ranging from making a simple map to advanced ecological simulation. Almost all the functions in ESRI ArcGIS Series have corresponding versions in QGIS. This feature has been very attractive to budget-limited users. Like OSM project, QGIS is a volunteer driven project too. Since the initial release in 2002, QGIS has been used in geography, landscape, ecology, natural resource management, migration studies and many more subjects (QGIS Project, 2019).

The major part of the study, including the spatial processing and statistics, will be conducted by a script language named "Python." Python was invented by Dutch computer scientist, Guido van Rossum, in the late 1980s. Python has been gaining popularity in academic and commercial arena, especially in the machine learning field.

CHAPTER 4. THE GEOGRAPHY OF VULNERABILITY

Colonias are widely known as facing severe vulnerability, including, flooding, unsafe building materials, the lack of clean water, unsanitary sewage processing, and others (Lim, 1987; Coccato, 1996; Shatkin, 2004; Durst, 2016). Except the required water and sewage infrastructures, model subdivisions have not much improvements in terms of living conditions. A number of studies (Durst, 2016; Olmedo & Ward, 2016) have illustrated that model subdivisions are equally, if not more, vulnerable. In this study, vulnerability is examined in a spatial context by comparing the risk of flooding and exposure to crime, proximity to the central business district and major job centers, and proximity to amenities. This chapter presents the results of overlay analyses and proximity analyses.

4.1. Water and Wastewater

The overlay analysis of neighborhood data and the CCN water and sewer data reveals the coverage of CCN service network, which could be an indicator of the accessibility to clean water and sewage systems. Table 7 shows that CCN water and sewer service areas have covered most of colonias (98.5% and 97.1%) and model subdivisions (98.1% and 91.7%), after decades' effort from state and federal governments (Durst, 2016). As model subdivisions are required to have water and sewer services, the remaining 1.9% and 8.3% most likely have utilized approved non-CCN resources, such as private wells to obtain clean water and OSSFs to process the wastewater (State of Texas, 1989). For comparison, however, 100% of formal neighborhoods are covered by the CCN service network. This illustrates that the vast majority of colonias and model subdivisions are close enough to be serviced by water and sewer infrastructure; whether or not these communities actually have such services is a different question. However, as illustrated in Table

7, state data on colonias suggests that the vast majority now have access to water and wastewater infrastructure.

One pleasing fact is that the government has realized the issue and has made efforts to solve it. From 2010 to 2014, 20,135 more residents in 31 colonias have gained access to potable water, paved roads and operational wastewater disposal systems statewide (TOSOS,2014). If it is true that some neighborhoods are covered in the CCN areas but are not actually connected to the network, the government and the private entity could improve the water related problems with significantly lower costs. This would undoubtedly increase the livability of these informal settlements.

Table 7 Current CCN Water and Sewer Service Area

Neighborhood Type	Total Count	CCN Water Coverage		CCN Sewer Coverage	
		Count	Percentage	Count	Percentage
Colonia	850	825	98.47%	837	97.06%
Model Subdivision	567	520	98.06%	556	91.71%
Formal	230	230	100.00%	230	100.00%

Source: Calculated by the Author, 2019

4.2. Flooding Risk

Table 8 presents the spatial overlay of informal settlements with the FEMA flood zone data, comparing to the samples of formal neighborhoods. Colonias are much more likely to fall within the special flood hazard areas than are model subdivisions (4.0 mi^2 vs. 1.29 mi^2). In contrast to 1.3% of formal neighborhoods, 6.6% of model subdivisions and 13.1% of colonias fall in the special flood hazard areas. The majority of colonias (56.7%) is located in moderate risk areas, unlike most of model subdivisions and formal neighborhoods, which sit in low-risk areas. Colonias, undoubtedly, are the most vulnerable to flooding. According to historical flooding records, 95% of colonias are frequently flooded (Texas Water Development Board, 2014). The flooding,

accompanied with heavy rains, also leads to the deterioration of water quality in colonias that rely on septic tanks, cesspools and pit privies (Texas Office Of The Secretary Of State, 2014).

Table 8 FEMA Flood Zones of Informal and Formal Neighborhoods

		Special Flood Hazard Areas				**Moderate Risk Areas**		**Low Risk Areas**
	Neighborhood Type	A	A23	AE	AH	B	C	X
Area (mi^2)	Model subdivisions	0.29	0	0.49	0.51	1.7	5.6	11.3
	Colonias	2.63	0.28	0.58	0.51	4.88	12.44	9.24
	Formal	0	0	0	0.02	0.45	0.4	1.05
Percentage	Model subdivisions	1.5	0	2.5	2.6	8.6	28.1	56.8
	Colonias	8.6	0.9	1.9	1.7	16	40.7	30.2
	Formal	0.2	0	0	1.1	23.2	21	54.4

Source: Calculated by the Author, 2019

4.3. Proximity Analysis to Downtowns

In this study, the proximity analysis method is used to calculate various distances from neighborhoods and amenities. The results suggest that all the informal settlements are developed within a radius of 25 miles from the McAllen city center. Many of the informal settlements in the county are located at the range from 8 to 15 miles from the city of McAllen (Figure 8). When measured relative to the nearest downtown (i.e., including the downtowns of other nearby cities), informal settlements are still relatively far (typically more than 3 but less than 8 miles) from potential places of employment (Figure 9). As illustrated in Figure 10, model subdivisions are at even greater distance than colonias, given that they developed later and further from cities.

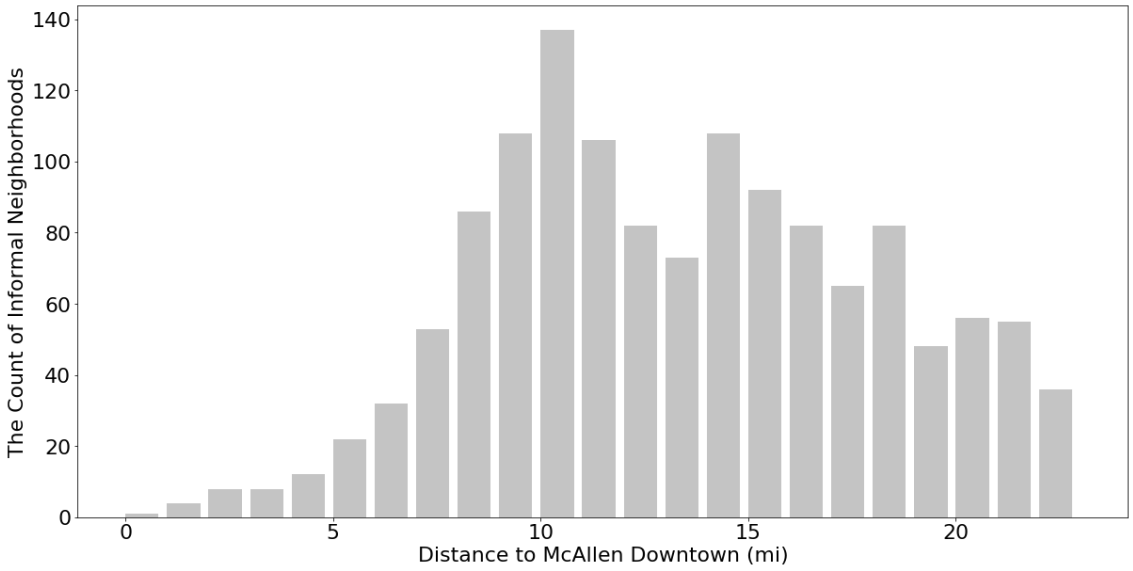

Figure 8 Histogram of Distances to McAllen Downtown from Informal Settlements

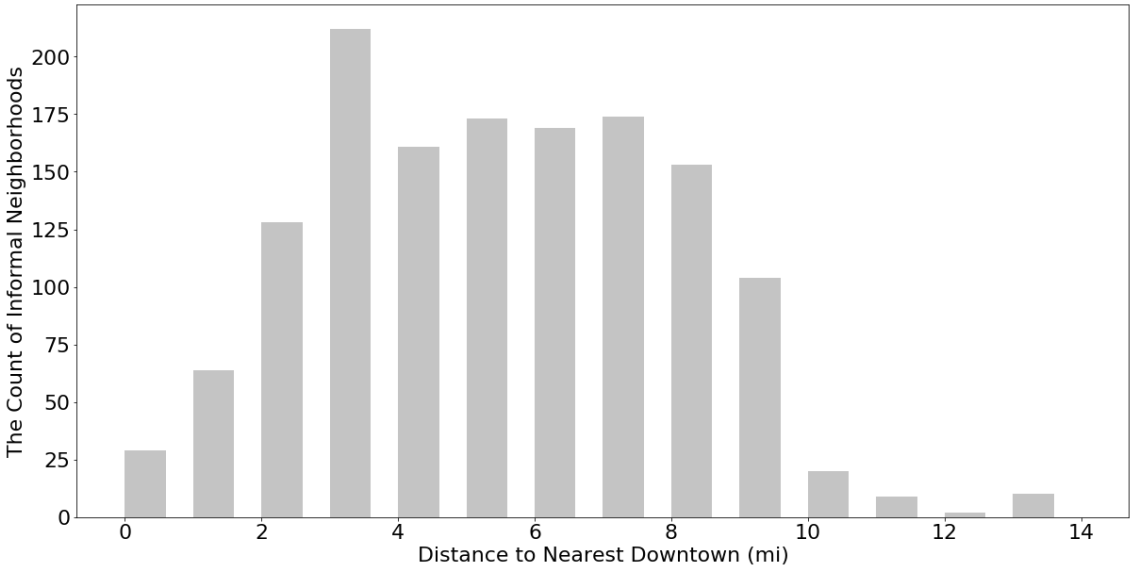

Figure 9 Histogram of Distances to Nearest Downtown from Informal Settlements

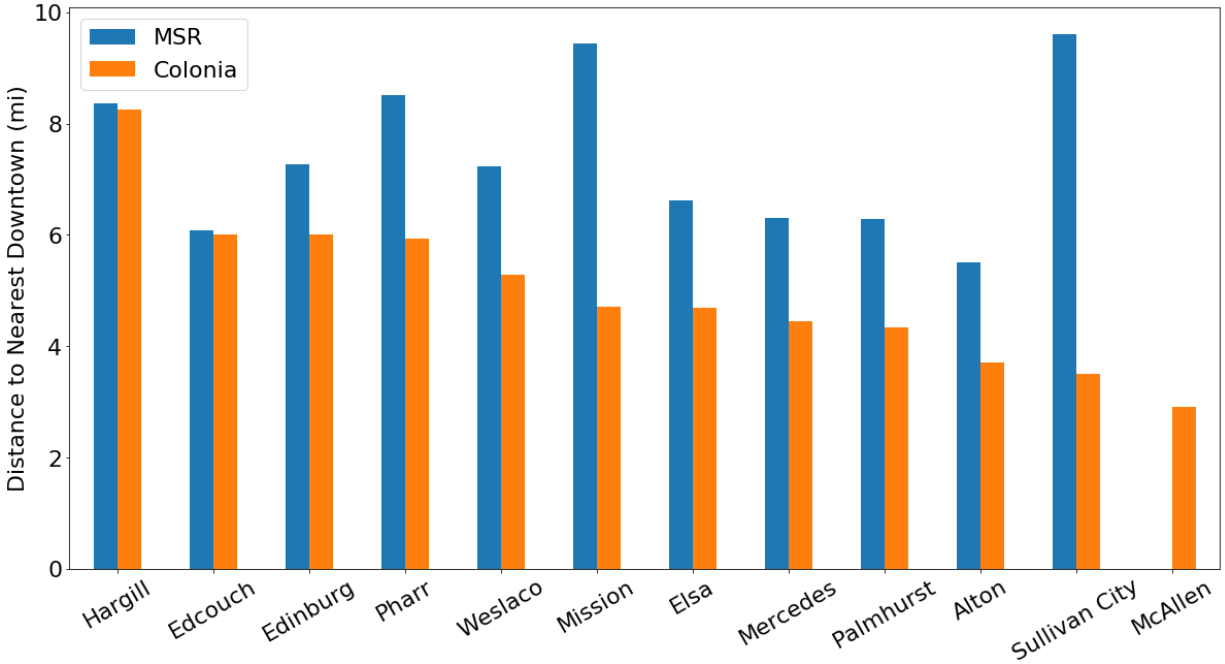

Figure 10 Distance Comparison to Nearest Downtown from Informal Settlements

4.4. Employment Vulnerability

Similar to informal settlements in Latin American cities, colonias and model subdivisions in Hidalgo County are home to extremely low-income populations (Dagodag, 1967; Durst, 2016; Ward & Peters, 2007). This section investigates the job market around the formal and informal settlements in order to examine difference in employment accessibility for formal and informal settlements. The LODES OD dataset and ESRI Business Analyst data are used here.

4.4.1 Job Accessibility

The spatial heterogeneity of job opportunities is presented in Figure 11 based on the LODES OD data. Figure 11 shows employment opportunities in Hidalgo County are extremely clustered in the urban center, around the downtowns of Edinburg, McAllen, Pharr and Mission. Some blocks have more than 500 job positions while many blocks do have any employment opportunities at all. In the southeastern part of the county, Weslaco is another cluster of available jobs. However, except the urban core, the jobs in the peri-urban and rural areas are insufficient. Especially in the north and the west of the county, there are almost no employment opportunities at all. Given that informal settlements are mostly distributed in the periphery, this spatial imbalance might lead to a lack of access to employment opportunities.

After identifying those census blocks with higher than average jobs and overlaying the informal settlements spatial data, the pattern is evident that colonias are located much more centrally and in closer proximity to employment opportunities than are model subdivisions (Figure 12). The model subdivisions are scattered much further around those job centers than colonias are. Most sampled formal neighborhoods are very close to the job centers. The differences of proximity to job centers will affect dramatically the way workers travel and the time they need to spend on commuting.

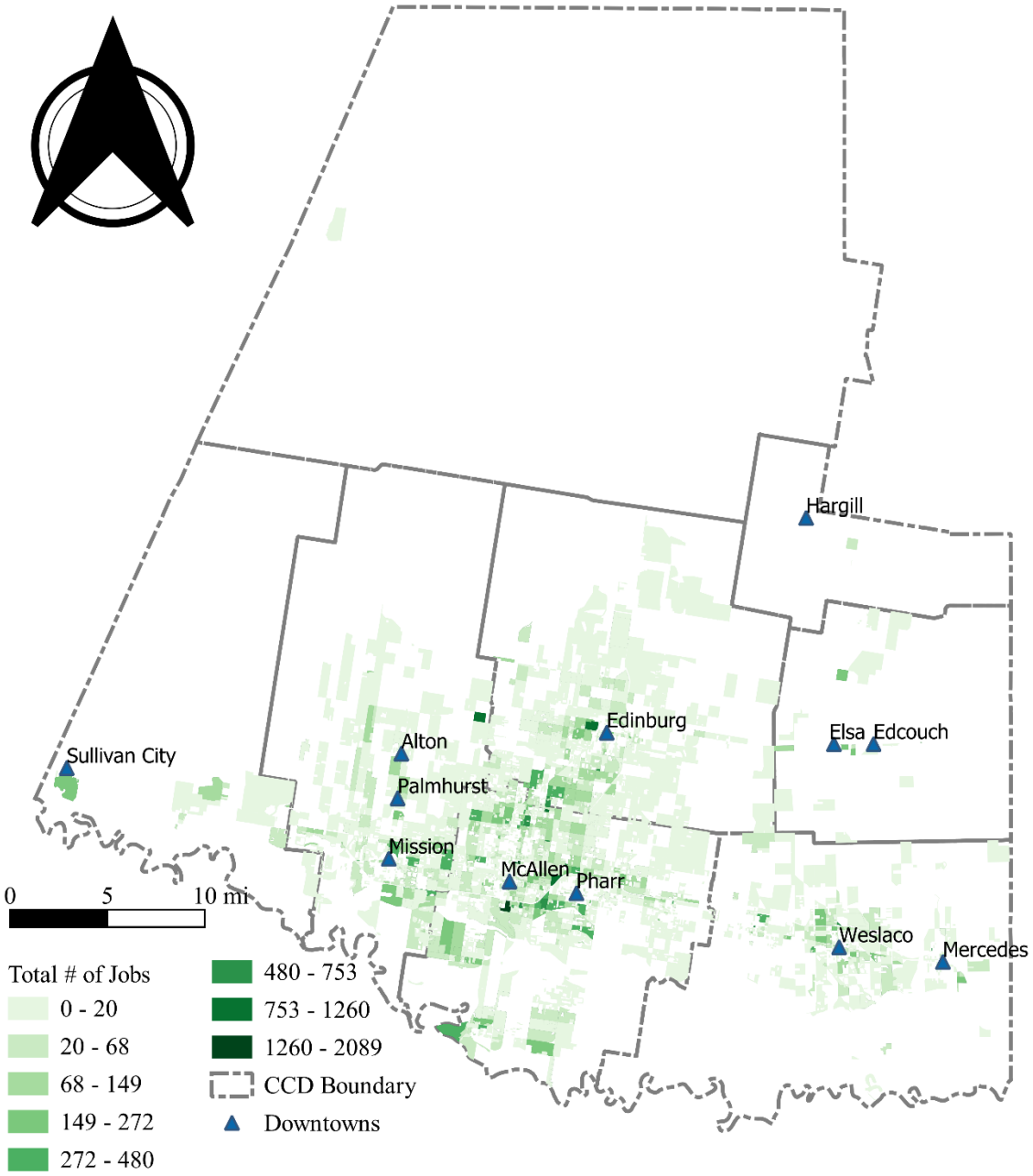

Figure 11 Total Number of Jobs in Hidalgo County

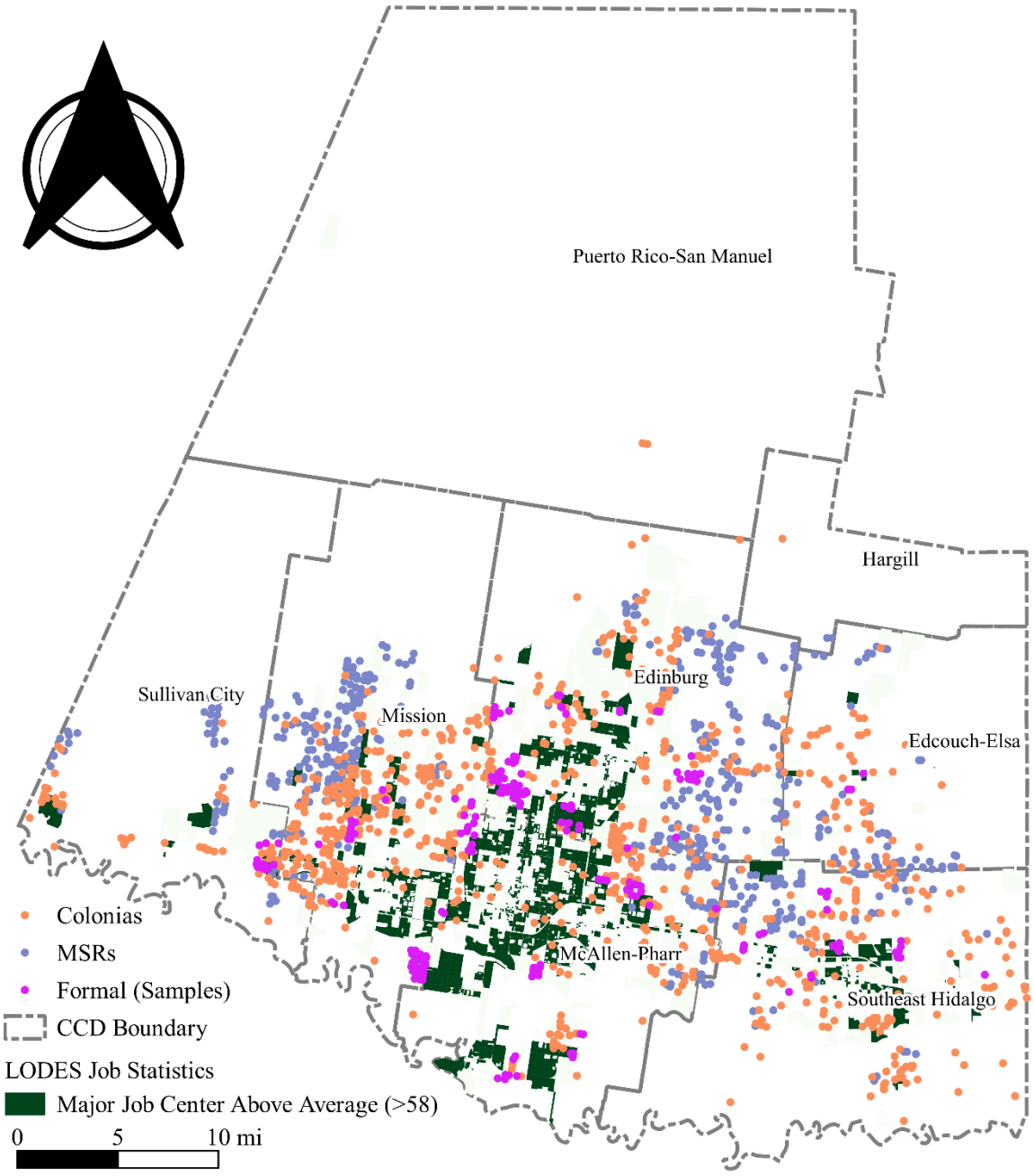

Figure 12 Informal settlements and Major Employment Centers in Hidalgo County

Undoubtedly, the formal neighborhoods are the closest ones to the main job centers (0.25 mile), which is about a half-mile closer than colonias and more than 1 mile closer than model subdivisions (Table 9). It is noticeable that the distances from model subdivisions to major job centers have the largest standard deviation, indicating the model subdivisions have the greatest spatial unevenness.

Table 9 Distances from Neighborhoods to Major Job Centers

Neighborhood Type	Mean	Maximum	Minimum	Standard Deviation
Model subdivisions	1.49	4.72	0	1.12
Colonias	0.73	8.4	0	0.89
Formal	0.25	2.38	0	0.35

Source: Calculated by the Author based on LODES Data Set

4.4.2 Commute to Work

In regard to the commute to work, formal and informal settlements depend heavily on the automobile (Table 10). More than 80% of workers drive to the workplace alone. There are only slightly less workers driving in informal settlements (80% versus 82%). Besides the difference in driving, the share within the 1-mile buffer of model subdivisions and colonias who carpool is about 1.5% less than that of the formal neighborhoods. No evidence shows the public transportation system, the biking and the walking have played important roles in workers' daily life. The sole dependence on the automobile for workers in both formal and informal settlements might indicate a need for diverse transit options for both formal and informal settlements in the county.

Table 10 Transportation Modes Utilization (%) with 1-Mile Buffered Areas of Neighborhoods

Buffer Distance	Transportation Means	Model subdivisions	Colonias	Formal
1 Mile	Bicycle	0.08	0.10	0.09
1 Mile	Carpooled	8.07	8.46	9.42
1 Mile	Drove Alone	80.44	80.64	82.23
1 Mile	Public Transportation	0.14	0.18	0.18
1 Mile	Walked	0.80	1.05	0.77

Source: ESRI Business Analyst Online Database

Table 11 Travel Time Compositions (%) with 1-Mile Buffered Areas of Neighborhoods

Buffer Distance	Travel Time (minutes)	Model subdivisions	Colonias	Formal
1 Mile	< 5	2.31	2.49	2.93
1 Mile	5 - 15	18.44	24.29	26.75
1 Mile	15 - 30	50.06	47.33	47.35
1 Mile	30 - 60	23.76	20.81	19.06
1 Mile	>= 60	5.43	5.09	3.92

Source: ESRI Business Analyst Online Database

The analyses of travel time within a one-mile buffer (Table 11) also clearly show how much more time the residents from informal settlements have spent on commuting. A time cost of 15 to 30 minutes is the most common (around 50%) in Hidalgo County's work trips. Within 1-mile buffer, the formal neighborhoods have significantly more jobs within 5- and 15-minutes commuting time (2.93% and 26.75%, respectively). In contrast, 50% and nearly 24% of model subdivisions workers have to spend 15 to 60 minutes when commuting to work; this is approximately 3% higher than colonias ' workers do (47% and nearly 21%). Moreover, more than 5% of trips from model subdivisions and colonias are longer than 60 minutes.

4.5. Accessibility to Amenities

Beside the employment-related vulnerability, this study also examines accessibility to amenities, including educational, financial, health, public and other services.

4.5.1 Education

There are 16 Intermediate School Districts (ISD) within the county of Hidalgo. The majority of model subdivisions are under La Joya ISD (32.76%), Edinburg ISD (26.69%) and Donna ISD (20.28%). Colonias, besides La Joya ISD (23.61%) and Edinburg ISD (19.49%), have 10.58% falling in Weslaco ISD. A total of 619 schools, from the kindergarten to the college, has been collected from OSM maps. Table 12 shows the composition of different types of schools in Hidalgo County. About 41% of the schools are kindergarten or elementary schools while nearly 12% are middle schools. There are 80 high schools within the county, accounting for 13% of the total schools. About 2% (14) are colleges or universities. Speaking of the educational resources, the children from model subdivisions and colonias travel considerably further, regarding the types of schools (Table 13). If there is no school bus available, those trips would be even further. Only about 5% of elementary and middle school students would choose walking or biking when the

distance to school is larger than 1 mile, which is about 5% less than in high school (McDonald, Brown, Marchetti, & Pedroso, 2011). Only student from K1 to K5 are able to walk to school in colonias and formal neighborhoods. The rest all need to depend on either the school bus or personal vehicle.

Table 12 Schools in Hidalgo County, TX

School Type	Total Count	Percentage (%)
Kindergarten /Elementary School	255	41.2
Middle School	73	11.79
High School	80	12.92
College/University	14	2.26
Other School	197	31.83
Total	619	100

Source: ESRI Business Analyst Online Database

Table 13 Distance to School for Neighborhood

Neighborhood Type	Model subdivisions	Colonias	Formal
Elementary School	1.74	0.90	0.47
Middle School	2.77	1.90	1.22
High School	2.70	1.81	1.51
College/University	6.64	5.00	3.20

Source: Calculated by the Author based on OSM Data

4.5.2 Accessibility to other Amenities

The degree of convenience in accessing amenities, such as a doctor's office, bank, bus stops, or a grocery store, will significantly affect the QoL. Residents could benefit from good accessibility to amenities physically as well as financially. The closer you live from the fire station, the more chance your property and your life would be rescued if a fire happens near you. By the same token, you would save time and money if there are public bus stops near your residency. With the amenity layer extracted from OSM data, the Euclidean distances from neighborhoods to various amenities (including the fire station, the police station, the library, the bus stop, the

restaurant, the bank facility, the supermarket, the clinic, and the pharmacy) are calculated and plotted. Table 14 shows the results of the average distance calculated for three different neighborhoods to various amenities. Randomly sampled formal neighborhoods have the best accessibility in terms of 10 different amenities while the model subdivisions are located the furthest from amenities.

The distances to the police station, the fire station, the pharmacy and the restaurant from formal neighborhoods are 1.83, 1.91, 2.15 and 2.37 miles, respectively. The same measurements for colonias are 2.19, 2.30, 2.97 and 3.85 miles while for model subdivisions they are 3.53, 4.03, 4.48 and 5.35 miles, respectively. The accessibility to amenities has dramatically decreased for model subdivisions since the developers are seeking cheap lands in more rural areas (Durst, 2016). Colonias have a higher degree of integration with the urbanization process, the infrastructure construction and thereafter the more accessible amenities than model subdivisions do. For amenities, including the library, the hospital and the bank facility, both model subdivisions and colonias have significantly longer distances, indicating additional spatial vulnerability for residents in these informal settlements.

According to the results from proximity analysis, the accessibility conditions for formal neighborhoods are quite spatially stationary (most less than 4 miles), compared to model subdivisions and colonias (Table 14). The formal neighborhood, no matter to which amenity, is always closer on average than informal settlements are. Model subdivisions are on the other end of the spectrum, with the furthest distance to each type of amenities, which indicates the low accessibility for the communities and high time and distance cost when travel is necessary. The distances to the supermarket, the bus stop, and the clinic are remarkably high. Since the clinic and supermarket are not as often scattered around the city to provide maximum coverage, it is

reasonable to have more than 10-mile travel distance. The bus stop is the other one out of three furthest amenities, which is intriguing at the beginning to understand. After searching in literature and the local bus operator's sites, except the metro bus running in McAllen city proper, the county is extremely in need of the public transportation system (Moore, 2015; Sharkey, Horel, Wendel, & Zhu, 2005).

Table 14 Comparison of Accessibility to Amenities for Model Subdivisions, Colonias and Sampled Formal Neighborhoods

Amenity	Model Subdivisions	Colonias	Formal
Hospital	7.34	5.25	3.3
Clinic	17.25	14.65	11.56
Pharmacy	4.48	2.97	2.15
Fire Station	4.03	2.3	1.91
Police Station	3.53	2.19	1.83
Bus Stop	17.39	14.53	11.64
Restaurant	5.35	3.85	2.37
Supermarket	21.37	18.86	15.68
Bank Facility	7.84	6.17	3.74
Library	5.8	3.93	3.34

Source: Calculated by the Author based on OSM Data

4.1. Crime and Safety

Overall, the crime levels around the informal and selected formal neighborhoods are lower than national levels. Surprisingly, the informal settlements in Hidalgo County are quite safe in terms of the crime occurrences. In 1-Mile buffer zone, the propensity for a crime in model subdivisions is more than 40 percent below the national average, which is also 32 percent and 35 percent less than those in colonias and formal neighborhoods. The property crime index is the highest in formal neighborhoods while the personal crime index is the lowest there. According to Gass (2018), informal settlements are much tighter than people typically think. The residents in the settlements are quite familiar with each other due to the kinship or other connections, which

may reduce some patterns of crime. Moreover, residents in informal settlements are often low-income, and the poverty in model subdivisions and colonias may discourage property crimes by increasing the risks and diminishing the returns to crime. On the other hand, poverty may lead to more personal conflicts related to the necessities (such as food, money and housing), and thus higher personal crimes.

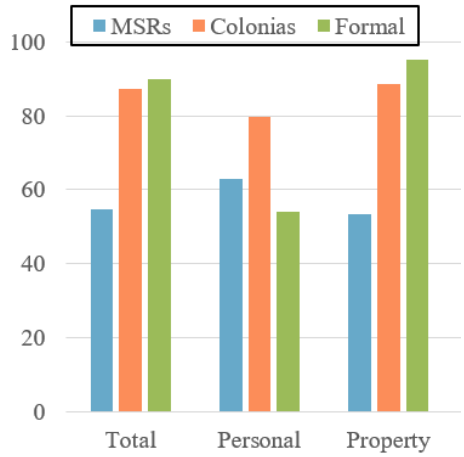

Figure 13 Comparison of Crime Index for 1-Mile Buffer Distance

CHAPTER 5. Discussion and Conclusion

Informal housing in Hidalgo County provides one of the only housing options for low- and very low-income residents (Durst, 2018; Durst & Wegmann, 2017; Lim, 1987; Ward, 1999). The informal housing market is more affordable because it circumvents more cumbersome planning and construction procedures in the formal housing market (Durst & Ward, 2016; Durst & Wegmann, 2017; Olmedo & Ward, 2016; Ward, 1982b; Williams, 2006). This comes with a number of important types of social, economic, and environmental vulnerabilities.

Paradoxically, however, this study finds that informal settlements, especially newer model subdivisions, have lower levels of crime than anticipated. Many studies have demonstrated the life in informal settlements is much optimistic than people often think (Gass, 2018; Olmedo & Ward, 2016; Ward & Peters, 2007). The residents in a neighborhood are very familiar with each other due to kinship ties (Gass, 2018). This, in turn, may reduce some patterns of crime. This reduced crime rate points to one of the potential benefits of living in informal settlements, in addition to low cost of housing and access to homeownership opportunities. In other words, families face a series of tradeoffs when making decisions about where to live.

However, in all the other perspectives of spatial vulnerability studied here, informal settlements experience a distinct disadvantage. For example, model subdivisions and colonias are more vulnerable to flooding since they often sit in the floodplain with limited or no drainage systems and have poor accessibility to reach needed resources. More than 58 percent of colonias are located in moderate or special hazards flood areas. How to alleviate the flooding is a pressing problem for local governments and the neighborhoods, especially informal ones (Texas Water Development Board, 2014). The lack of funding for studying issues of flooding, the geographically

large affected areas in Hidalgo County, and the lack of planning professionals to design and implement proposals are three potentially important barriers.

The continuing investment in infrastructure from the government (Durst, 2016) appears to have expanded the coverage of CCN water and sewer network for colonias, which could facilitate solving the water issues. Although the clean water and the wastewater are not problems for model subdivisions, they are facing similar (sometimes even worse) challenges as Colonia do, such as the lack of jobs, the inconvenience of access to amenities, and limited educational resources. Compared to formal neighborhoods, model subdivisions and colonias are further away from the major job centers and the workers have to spend significantly more time on commuting. Over 80 percent of workers from informal settlements drive to work while less than 1% take the public transport.

Other services are also lacking in informal settlements. Hidalgo County has established new subdivision rules in 2018 with a heavy focus on infrastructures. The new rules require the installation of fire hydrants within 600 feet of the subdivision entrance, where bus stops should also be built (Brownsville Herald, 2018). All intersections, at cul-de-sacs and at every 250 feet along the length of all internal streets in new subdivisions should have streetlighting integrated, according to the new rules. Those changes in legislations indicate that the government has realized the severity and the urgency of existing problems related to infrastructure and safety in model subdivisions and colonias.

Nearly all colonias (more than 97%) are covered by CCN water and sewer service areas while model subdivisions are surprisingly less covered by the network. Other legal water and sewer resources might play roles in those CCN uncovered areas. However, based on OAG's collected data, 89% of colonias have reported that wastewater is inadequate on some lots. The discrepancy

between the CCN coverage and the actual severity indicates that more assistance or investment should be provided by the government to expand access to water infrastructure for selected household. The well-built CCN network could make those assistances more feasible by lowering the cost of providing these services to colonias within the CCN service area.

It is unsurprising that colonias are facing more potential flooding risks, as 13% and 56% of the settlements are situated in SFHAs and MRAs, respectively. Most model subdivisions are in the LRAs, just like the formal neighborhoods; which is a direct result of the successful MSRs, which in Hidalgo County now prevent development in floodplains. However, the flooding in 2018 and 2019 have shown the flooding is a universal issue for LRGV, including the informal settlements.

The distance from informal settlements to McAllen concentrates in the range from 8 to 15 miles while the distance to nearest downtowns is significantly shorter (a range from 3 to 8 miles). It has been verified in this study that model subdivisions are developed much farther away from the city than colonias are. As a result, fewer jobs are available around model subdivisions than the formal neighborhoods and colonias, which is consistent with previous study asserting that the residents are experiencing the lack of employment opportunities in model subdivisions (Olmedo & Ward, 2016). However, the distance to major job center from colonias can be extremely far (8.4 miles). The high dependency on automobiles is also a possible cause for the low accessibility of informal settlements as the residents are low-income. Nearly 6% fewer jobs in model subdivision with a travel time from 5 to 15 minutes than in colonias. It costs more for them both in time and in money to work away from the settlements.

Informal settlements also experience greater vulnerability in regard to access to amenities. The average distance to college/university from a model subdivision is more than double that of

formal neighborhoods, which possibly explains the remarkable lower proportion of population with bachelor or higher degrees in model subdivision (only 9.1%, comparing to 14.2% in colonias and 26.4% in formal neighborhoods). Model subdivisions and colonias both have less accessibility to hospitals, the police station and other 9 amenities than formal neighborhoods. Due to the fact that colonias were developed decades ago and the cities are expanding considerably, colonias' accessibility to various amenities is greater than model subdivisions but less than formal neighborhoods.

To sum up, the main findings of this study include: 1) colonias need more assistance in improving water and wastewater processing, and are confronting more flooding risks than model subdivisions, as the MSRs have forbidden residential development in ecologically vulnerable regions; 2) the informal settlements suffer from longer distances to downtowns, low accessibility to employment centers, and low accessibility to amenities; 3) informal settlements are safer than formal neighborhoods, in terms of the prevalence of property and personal crimes; and 4) the overall geographic vulnerability is relatively severe in Hidalgo County's informal housing market, especially for model subdivisions.

5.1 Implications

This study investigates the characteristics of fragmented informal housing markets. The conclusions should be useful for both planners and policymakers. Monitoring the development of new and existing subdivisions is necessary. The GIS techniques used here provide great insight into the potential needs of residents in informal settlements in Hidalgo County. These findings could be used to identify unresolved problems in colonias and model subdivisions and to identify priorities for future planning or policymaking.

First, it is great that the government has committed to the improvement of conditions in colonias, as illustrated by the passage of the Model Subdivision Rules in 1989. As illustrated in this study, nearly all of the informal settlements are within the CCN water and sewer service area but still 62.8% of them do not have clean water and 40% have to depend on OSFFs. The government should consider the feasibility of providing basic services and the significance of the improvement; and then make a list of prioritized improvement content. The problems in informal housing would be solved one by one and in a logical manner.

Second, Hidalgo County should develop its public transportation system. There are extremely insufficient public transportation services in the region, except the McAllen Metro Bus system. More than 80% of residents in informal settlements and formal ones depend on the automobile to commute. The Rio Grande Valley Metropolitan Planning Organization has proposed 2015 - 2040 Metropolitan Transportation Plan but public transportation in the semi-rural and rural area is still the missing component (Moore, 2015). The public transportation network should resolve accessibility related vulnerability significantly.

Third, while building up the public transportation system, it is important to understand that amenities are critical for a neighborhood's QoL. There are no new colonias emerging. Models subdivisions, however, continue to spread at a rapid pace (Durst, 2016). When new model subdivision re proposed, the authority should consider planning the necessary amenities as well, perhaps by allocating land for parks, commercial property, or needed services.

Last but not least, the partnership between the community, private entity and the government should be advocated in informal settlements (even in formal ones). The model ensures the effective communication among parties, the adaptiveness of proposal and the maximum implementation power. Many non-governmental organizations (NGOs) are actively helping the

poor to build affordable house by themselves in colonias. Since 1974, the Community Development Corporation of Brownsville (CDCB) has been building clean, safe, and affordable housing for the low-income people in Brownsville, Texas (Community Development Corporation of Brownsville, 2019). Some urgent issues of the community, family issues, personal credit problem, and many other trivia will be solved at micro-scale.

5.2 Limitations

This study is an explorative effort to understand differences in vulnerability as a result of exposure to risks and access to amenities among various types of neighborhoods. It adopts a GIS framework to evaluate the informal sector in Hidalgo County, Texas. There are few limitations for this particular project. First, the study area is limited to only one county. Although informal housing is very concentrated within the county, there are certainly other characteristics in other counties or other states that are worthy of study. To obtain a comprehensive understanding about the pattern of the informal sector in border states, it is necessary to expand the study area. The result would be more useful to make national or regional policies. However, given the intensive nature of data collection used in this study, a broader scale of analysis such as this was beyond scope of this study.

Second, the study has used the Euclidean distance as an equivalent measurement of accessibility between neighborhoods and selected amenities, which might not accurately measure connectivity in real road network. The cost distance (travel time) will be more ideal. Due to the limited time and computational capacity, this project was not able to incorporate this.

The third limitation is related to the data. The amenity data obtained from OSM is not 100 percent accurate due to the nature of data. There are inconsistencies of spatial resolutions of multi-source data too. For example, the boundaries of neighborhoods and the census blocks do not

always align. Using the centroid to summarize demographic data is acceptable but not the best practice.

5.3 Conclusion

As discussed in the limitation section, some limitations can be addressed in future research. An interesting topic will be investigating the geographic vulnerability of informal housing across the border states. More detailed data about the informal settlements, such as the income, occupation, age cohort, could also be collected to better depict the vulnerability, with consideration of the surrounding amenity and infrastructures.

It is very important to monitor the development of informal neighborhood as the process will reveal the mechanism why people would like to live or leave here as well as the effectiveness of existing policies and programs. Given the incremental development pattern, the temporal perspective of land use/land cover change in informal housing could make the identification of underlying driving factors possible. The understanding about the residents and the neighborhood will provide the helpful local knowledge for planners.

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