2011-01-01

Application Of The Water Poverty Index In Border Colonias Of West Texas

Marcelo Korc
University of Texas at El Paso, mkorc@miners.utep.edu

APPLICATION OF THE WATER POVERTY INDEX IN BORDER

COLONIAS OF WEST TEXAS

MARCELO KORC

Department of Public Health Sciences

APPROVED:

María Duarte-Gardea, Ph.D., Chair

Oralia Loza, Ph.D.

Hector G. Balcazar, Ph.D.

Benjamin C. Flores, Ph.D.
Acting Dean of the Graduate School

Dedication

To my wife Rebecca and my children Yael, Noa, and Itai for their love and support.

APPLICATION OF THE WATER POVERTY INDEX IN BORDER *COLONIAS* OF WEST TEXAS

by

MARCELO KORC, Ph.D.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF PUBLIC HEALTH

Department of Public Health Sciences

THE UNIVERSITY OF TEXAS AT EL PASO

December 2011

Acknowledgements

This work would not have been possible without the constant interaction, guidance, and advice of my thesis advisor and committee chair, Dr. Paula B. Ford, and my other committee members, Dr. Oralia Loza and Dr. Hector G. Balcazar.

The study is part of an integrated health strategy for border *colonias* coordinated by Texas state agencies with support of the Pan-American Health Organization (PAHO/WHO). I am indebted to Kathryn Hairston of the Office of the Texas Secretary of State, Yuri Orozco and Adriana Corona of the Texas Department of State Health Services, Albert Alvidrez of the Texas Department of Housing and Community Affairs, Eugenia Posada and Jose Castro of the Texas Commission on Environmental Quality, Bea Martinez of the Texas Health and Human Services Commission, and Mark Pearson of the Texas Water Development Board for the numerous discussions during this research.

Abstract

This study applied the Water Poverty Index (WPI) in border *colonias* and other rural areas of west Texas. The *colonias* are mostly unincorporated communities located primarily in New Mexico and Texas along the border with Mexico and are characterized by high poverty rates and substandard living conditions. In Texas, access to drinking water and sanitation services has been identified as one of the most significant determinants of health in over 350 *colonias* with about 50 thousand residents.

The WPI is a multidimensional measure that links household welfare with water availability. WPI components were identified and prioritized by a wide range of state stakeholders. For this study, the index encompassed four key components: resources (the physical availability of surface- and groundwater), access (the ease of access to water for human use), capacity (the people's ability to purchase and manage water), and environment (the environmental impact of water management). The values of the WPI and its underlying components were calculated for *colonia* Revolución in El Paso County and three areas of Fort Hancock in Hudspeth County, Texas.

This study demonstrated that the WPI can be an effective tool in integrating physical, social, economical, and environmental information and for determining priorities associated with the water situation in *colonias*. It identified *colonia* Villa Alegre in Fort Hancock as the neediest community and showed water poverty differences between *colonias* with the same basic service infrastructure.

These results highlight the need to classify the water necessities of *colonias* using a comprehensive but simple assessment tool that integrates several factors and is not based solely on infrastructure. They provide information that can be used to advance more equitable and sustainable rural drinking water and sanitation policies and programs, and help reduce health disparities associated with water-borne diseases along the Texas border with Mexico.

Table of Contents

List of Tables

List of Figures

Chapter 1: Background and Significance

1.1 The U. S.-Mexico Border *Colonias*

The United States (U. S.) side of the border with Mexico is dotted with over two thousand rural subdivisions called *colonias*. The *colonias* are mostly unincorporated communities located primarily in New Mexico and Texas and are characterized by high poverty rates and substandard living conditions. Texas has the largest number of *colonias* and the largest *colonia* population. Figure 1.1 shows the location of *colonias* in Texas (The *Colonia* Initiatives Program of the Office of Texas Secretary of State, 2006). The Office of the Texas Secretary of State defines a *colonia* as a residential area along the Texas-Mexico border that may lack basic living necessities, such as drinking water and sanitation services, electricity, and paved roads. Other federal and state agencies may define a *colonia* differently due to funding requirements (Texas Secretary of State, n. d.). Although there are no specific census data for *colonias,* studies estimate that there are approximately 370,000 Texans living in about 1,800 *colonias* (The *Colonia* Initiatives Program of the Office of Texas Secretary of State, 2010).

1.1.1 History

The development of *colonias* can be traced to the rapid growth along the U. S.-Mexico border associated with the guest worker Bracero Program in the 1940s and the Border Industrialization Program initiated in 1965. At that time, there was a limited supply of adequate and affordable housing along the border coupled with an increased demand for such housing (Texas State Historical Association, 1999). Land developers divided agriculturally worthless land into small lots, installed limited infrastructure, and sold them to low-income individuals through a contract for deed (Federal Reserve of Dallas, 1995).

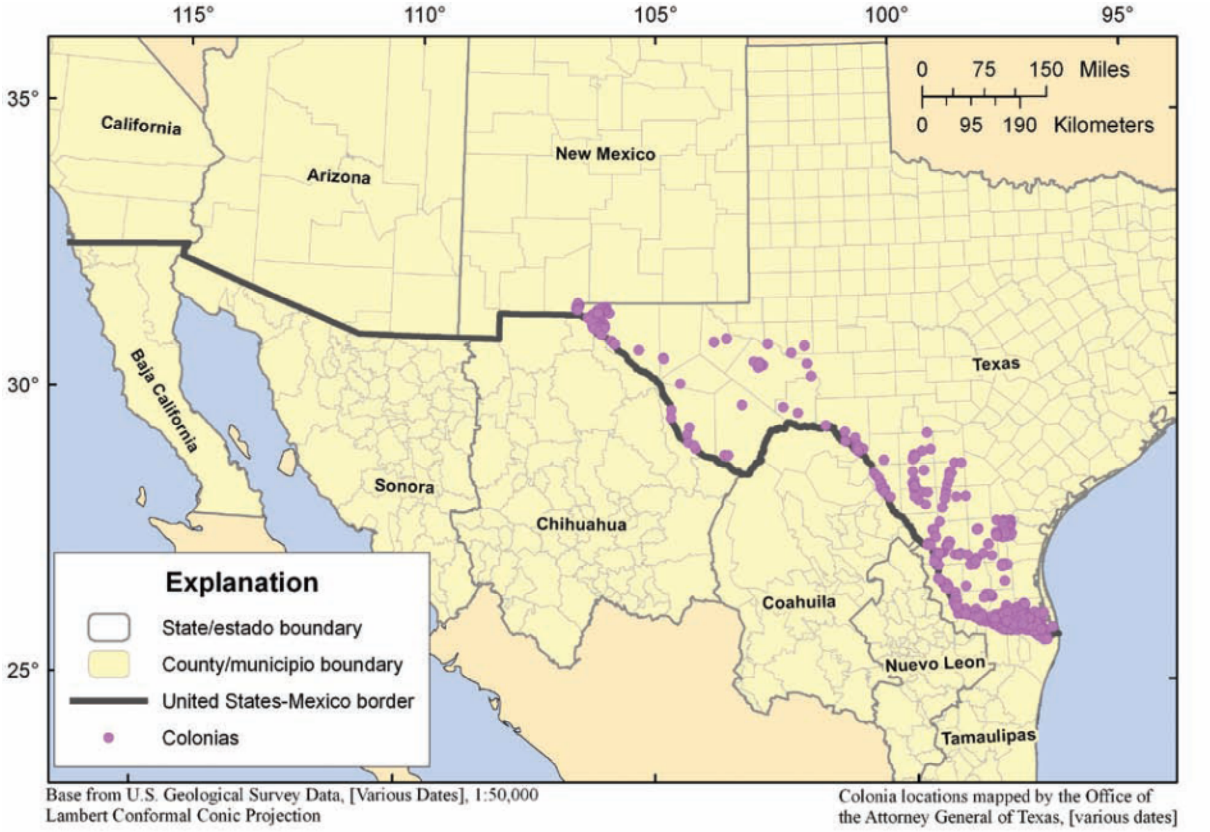


Figure 1.1: Location of *colonias* in Texas within 160 kilometers of the U. S.-Mexico border in 2003 according to the data of the *Colonia* Initiatives Program of the Office of Texas Secretary of State.

1.1.2 *Colonia* Demographics and Health

The *colonia* population is one of the most disadvantaged, hard-to-reach populations in the U. S. In general, *colonia* residents are of Mexican origin, have lived in the U. S. for an extended period of time, and travel often across the border. In addition, they speak primarily Spanish, have limited education, low income and high unemployment rates, and lack basic health care services (Ward, 1999; Parcher & Humberson, 2009). Table 1.1 compares demographic characteristics among the six Texas border counties with the highest *colonia* populations, the state of Texas, and the U. S. (U. S. Census Bureau, 2009).

Table 1.1: Demographic characteristics among the six Texas border counties with the highest *colonia* populations, the state of Texas and the U. S.

Demographic characteristic	Cameron County	El Paso County	Hidalgo County	Maverick County	Starr County	Webb County	Texas	U. S.
Average household size	3.27	3.06	3.35	3.76	4.04	3.67	2.81	2.60
Median age (years)	29.1	30.7	27.4	28.8	26.0	26.5	33.0	36.5
Hispanic or Latino (of any race)	86.0%	81.3%	89.4%	94.5%	98.6%	94.5%	35.9%	15.1%
Population 25 years and over high school graduate or higher	62.4%	69.8%	59.5%	53.7%	46.5%	61.7%	79.3%	84.6%
Speak a language other than English at home (population 5 years and over)	72.8%	74.9%	83.3%	93.3%	96.0%	92.1%	33.6%	19.6%
Per capita income (in 2009 inflation-adjusted dollars)	$13,474	$16,285	$13,130	$12,438	$9,717	$13,617	$24,318	$27,041
Individuals below poverty level	35.7%	26.6%	36.0%	30.2%	39.8%	29.9%	16.8%	13.5%

Several research studies have examined the leading causes of mortality and morbidity among Hispanics living along the Texas-Mexico border (United States-Mexico Border Health Commission [USMBHC], n. d.); however, little is known about the specific health status of border *colonia* residents. A few documented studies suggested potential health disparities between border *colonia* residents and other U. S. populations (Anders et al., 2008; Mier et al., 2008; Ramos, Baker Davis, He, May, & Ramos, 2008). For example, a cross-sectional study on health-related quality of life among *colonia* residents in Hidalgo County, Texas found that *colonia* residents were worse off in terms of physical health compared to the general U. S. population. Almost half of the study participants were identified as being obese or severely obese and almost 20 percent reported at least three co-existing chronic conditions. Poor education and long-term residency in *colonias* were associated with lower physical health (Anders et al., 2008).

Even less is known about actual physical environmental factors that may be associated with adverse health outcomes in border *colonias* of Texas. The bi-national U. S.-Mexico Environmental Program: Border 2012 (U. S. Environmental Protection Agency & Secretaría de Medio Ambiente y Recursos Naturales, 2008) and Healthy Border 2010 (USMBHC, n. d.) programs have identified access to drinking water and sanitation services as one of the most significant physical environmental determinants of health in rural areas along the U. S.-Mexico border. These programs have also highlighted a lack of information regarding the quality of these services in the most underserved areas of the region.

There has never been a universal drinking water service mandate in the U. S. In addition, anti-poverty programs have given little attention to water issues and water policies have given little attention to problems faced by the poor (Wescoat, Jr., Theobald, & Headington, 2008). Most federal agencies have not comprehensively assessed the needs in the region, lack coordinated policies and processes, and in several cases have not complied with statutory requirements and agency regulations. Recently, the U. S. General Accounting Office (2009) indicated that federal efforts to meet rural drinking water and sanitation services in the U. S.-Mexico border region have been ineffective.

1.1.3 Texas State Activities in *Colonias*

The unsanitary living conditions created by inadequate drinking water and sanitation services in *colonias* of Texas triggered the creation of a political movement in the late 1980s that lobbied the state legislature to support public funding for infrastructure improvement (Carter & Ortolano, 2004). As a result, in 1989, the Texas Legislature established the Economic Distressed Areas Program (EDAP) administered by the Texas Water Development Board (TWDB) to subsidize service providers constructing water and sewer systems in *colonias*. EDAP assistance

grants have been provided to communities with inadequate water and sewer systems located in counties with 25 percent unemployment and a per capita income 25 percent below the state average. During the late 1990s, the state legislature passed a series of bills to regulate the subdivision or development of land in certain economically distressed areas, including *colonias*. In 1999, the 76th Texas Legislature passed Senate Bill 1421 in an effort to manage *colonia* infrastructure priorities for water and wastewater services. As a result, the Office of Texas Secretary of State created positions for a Director of *Colonia* Initiatives Program and six ombudspersons to work in border counties with the highest *colonia* populations: Hidalgo, El Paso, Starr, Webb, Cameron, and Maverick counties. Recently, a seventh ombudsperson has been added to the Program to work in Corpus Christi. The ombudspersons have served as advocates among border *colonia* residents, federal and state agencies, local governments, and utility companies to ensure residents receive adequate services (Texas Secretary of State, n. d.).

In 2005, the 79th Texas Legislature passed Senate Bill 827 in an effort to further develop the *Colonia* Initiatives Program of the Office of Texas Secretary of State (2006). Senate Bill 827 created a *colonia* identification system based on an existing system developed by the TWDB. In addition, it classified *colonias* by the degree of health hazard posed based on their status of infrastructure (see Table 1.2). In 2007, the 80th Texas Legislature passed Senate Bill 99 to continue the work started under Senate Bill 827. Senate Bill 99, like Senate Bill 827, charged the Secretary of State with three tasks: 1) developing and maintaining a *colonia* identification system; 2) creating and maintaining a statewide system for classifying *colonias* with the highest public health risks; and 3) developing a report to the legislature on the progress of state funded infrastructure projects. The Senate Bill 99 report submitted in December, 2010 indicated that in the six Texas border counties with the highest *colonia* populations, there are 1,825 *colonias* with

about 369,000 residents. Of these, 891 *colonias* with a population of about 194,000 residents had complete piped drinking water and wastewater services and have been classified as “green”; 519 *colonias* with a population of about 126,000 residents had partial services and have been classified as “yellow”; and 353 *colonias* with about 45,000 residents still lack services and have been classified as “red.” Furthermore, for 62 *colonias* with a population of about 4,000 residents, it was not possible to obtain information on the status of services available (The *Colonia* Initiatives Program of the Office of Texas Secretary of State, 2010). Olmstead (2004) attributed this inadequate water service to high infrastructure cost, low utility revenue potential, strong influence of a current water service provider, and political factors. Moreover, in the absence of a universal drinking water service mandate, Olmstead suggested that a rate regulation may do more harm than good to *colonia* residents.

Table 1.2: Classification criteria for *colonias* according to the *Colonia* Initiatives Program of the Office of Texas Secretary of State.

Degree of health risk	Classification level	Criteria
High health risk	Red	Satisfies at least one of the following: 1. Either all of some lots have inadequate wastewater disposal (cesspools). 2. All lots do not have a potable water supply. 3. Not platted.
Medium health risk	Yellow	Platted *colonias* with potable water supply and adequate wastewater disposal, and satisfy at least one of the following: 1. Either all or some lots lack solid water disposal (trash collection). 2. Not all roads are paved. 3. Not all roads are passable in all weather conditions. 4. It floods during precipitation event.
Low health risk	Green	All lots satisfy all of the following criteria: 1. Platted. 2. Have a potable water supply. 3. Have adequate wastewater disposal. 4. Have solid waste disposal. 5. All roads are paved. 6. All roads are passable in all weather conditions. 7. It does not flood during a precipitation event.

1.2 Water Issues in *Colonias*

1.2.1 Water Capacity and Quality

In *colonias* unconnected to piped drinking water systems, residents collect their own water using available containers, purchase drinking water from a store, and/or rely on water delivery trucks to fill large containers. These drinking water sources are inconvenient, expensive, and susceptible to contamination during transport to and storage at private dwellings. In addition, inadequate sanitation systems may cause discharges of untreated waters to surface water and groundwater. For example, Graham and VanDerslice (2007) measured water quality at different points between collection by water delivery trucks and delivery to 2,500 gallon closed storage tanks in four contiguous *colonias* of El Paso County. The study found that 30 percent of the samples collected immediately after water was delivered to homes had fecal bacteria (fecal coliforms) above the World Health Organization (WHO) guidelines of 10 CFU/100 ml and mean free chlorine levels dropped from 0.43 mg/l, where the trucks filled their tanks to 0.20 mg/l inside the households' storage tanks immediately after delivery. The minimum free chlorine required for water haulers in Texas before delivering water to homes is 0.5 mg/l.

A *colonia* resident in El Paso County may pay about US$ 50 per 2,500 gallons of water delivered by truck whereas a resident of the city of El Paso that is connected to a water line system may pay the same for about 10,000 gallons. A *colonia* household can spend between 15 and 25 percent of its monthly income on drinking water (*Colonia* Revolución community meeting, personal communication, March 23, 2010).

Colonia residents often find themselves in a no-win situation with respect to accessing safe and affordable water sources. Even when water lines and sewer systems are in place, they may not be able to access the services because their homes do not meet building codes.

Residents cannot afford the repairs or improvements necessary to comply and they cannot access government aid funds until they are connected to a water line system.

1.2.2 Water and Health

Access to inadequate drinking water and sanitation services may be associated with adverse health outcomes. Common diseases that can be spread through contaminated water are cryptosporidiosis, *Escherichia coli* infection, giardiasis, viral Hepatitis A, cholera, shigellosis, salmonellosis, and typhoid fever (CDC, n. d.). For example, *Cryptosporidium parvum*, the etiologic agent of cryptosporidiosis and *Giardia lamblia*, the etiologic agent of giardiasis are two widespread protozoan intestinal parasites that may be spread through fecal-oral transmission including person-to-person, animal-to-person, water-borne, and food-borne transmission. They are human pathogens that may cause mild to severe enteritis and have been responsible for recent outbreaks (Eisenstein, Bodager, & Ginzl, 2008; Yoder & Beach, 2010). Onset of illness is most common among younger children because their immune systems are not yet fully developed. Preventive measures against disease transmission include adequate personal hygiene practices, disposition of feces in a sanitary manner, and boiling drinking water supplies for at least one minute. Disinfection of water by chlorination may not provide adequate protection for these parasites, especially for *Giardia lamblia*, due to low free chlorine residuals and limited contact time (Roach, Olson, Whitley, & Wallis, 1991; Sauch, Galvin, Berman, & Jacobowski, 1991).

There is little data available regarding parasite prevalence in *colonias* on the U. S. side of the border with Mexico. Leach et al. (2000) reported 89% prevalence of infection with the intestinal parasite *Cryptosporidium parvum* among children ages six months to 13 years living in seven border *colonias* located in south Texas. The infection was associated with older age, lower household income, and consumption of municipal water. The association with consumption of

municipal water indicated that the water sources within these *colonias* were intermittently or regularly contaminated with *Cryptosporidium parvum*. *Colonias* without municipal water sources primarily consumed bottled water. According to Heymann (2008), in industrial countries, prevalence of infection with *Cryptosporidium parvum* ranges from 1% to 4.5% of individuals surveyed by stool examination. In developing regions, prevalence ranges from 3% to 20%. A 2003 study conducted by the Office of Border Health of the Texas Department of Health (Escobedo et al., 2003) found high prevalence of parasites in first-grade school children living in five border communities in west Texas. The study reported 22% prevalence of infection with parasites in Canutillo independent School District and 25% prevalence in Presidio Independent School District. The high prevalence was believed to be associated with poor hygiene practices and food contamination.

Little is known about the complexity of drinking water and sanitation services in border *colonias* of Texas. In particular, there is a pressing need to assess water services in border *colonias* focusing on communities that experience the highest levels of poverty and are at greatest risk of reduction in health and quality of life associated with inadequate water and sanitation services. Physical, social, economic, and environmental issues may impact the ability of *colonia* residents to access safe water and sanitation services. In general, these issues have been treated and analyzed separately. This study will examine them in an integrated manner by developing and applying the Water Poverty Index (WPI) in border *colonias* of west Texas.

1.3 The Water Poverty Index

The WPI is a multidimensional measure that links household welfare with water availability and indicates the degree to which water scarcity may impact human population (Lawrence, Meigh, & Sullivan, 2002). It provides a means of understanding the complexities of

water issues by integrating physical, social, economical and environmental aspects, and by linking water issues to socioeconomic variables that reflect poverty (Sullivan, 2002; Sullivan et al., 2003). It is a tool that informs and orients policy-making, enabling decision makers to target crosscutting issues in an integrated way.

The core theoretical framework of the WPI encompasses five key components:

- Resources (R): the physical availability of surface- and groundwater, taking into account quantity, seasonal and inter-annual variability, and quality or water resources.
- Access (A): the ease and reliability of access to water for human use, including domestic, irrigation, and industrial use.
- Capacity (C): the people's ability to purchase and manage water.
- Use (U): different uses of water, including domestic, agricultural, and industrial.
- Environment (E): the environmental impact of water management including environmental regulations.

This multidimensional approach to water poverty has been discussed extensively and applied at various geographic scales in a number of countries, such as United Kingdom, China, South Africa, Sri Lanka, Zimbabwe, Tanzania, and Slovenia (Sullivan, 2002; Feitelson & Chenoweth, 2002; Molle & Mollinga, 2003; Sullivan & Meigh, 2003; Sullivan et al 2003; Sullivan, Meigh, & Lawrence 2006; Qiang, Kachanoski, Dong, & Zilong, 2008; Komnenic, Ahlers, & van der Zaag, 2009; Sullivan & Meigh, 2007; Cho, Ogwang, & Opio, 2010; Giné & Pérez-Foguet, 2010).

The WPI components are combined using a weighted arithmetic average method to create the following general expression:

$$WPI_j = \sum_{i=1}^{i=n} w_i X_{ij} / \sum_{i=1}^{i=n} w_i, \quad (1)$$

where WPI_j is the WPI value for a location *j*, X_{ij} refers to a component *i* of the WPI structure for a location *j*, n is the number of WPI components, and w_i is the weight applied to a component *i*. Weights can be constrained to be non-negative and sum to one (see Equation 2). Each of the components is made up of a number of sub-components, and these are first combined using the same method in order to obtain the components.

$$\sum_{i=1}^{i=n} w_i = 1. \quad (2)$$

There is a built-in flexibility in the choice of sub-components, albeit at the cost of comparability. Sullivan and Meigh (2007) suggested that WPI sub-components should be defined through stakeholder participatory processes to make sure they reflect the stakeholders' main interests when expressing the index. In addition, Sullivan and Meigh (2003) encouraged the use of existing data to reduce costs and promote the calculation of the index as part of regular decision-making processes. The weightings are applied to indicate the importance of a particular component or sub-component of the WPI structure. However, to avoid problems of subjectivity, Sullivan and Meigh (2007) suggested that the WPI should be first calculated with weightings set equally. For the five key WPI components listed above, Equation (1) becomes:

$$WPI_j = w_r R_j + w_a A_j + w_c C_j + w_u U_j + w_e E_j \text{ where } w_r + w_a + w_c + w_u + w_e = 1. \quad (3)$$

Recently, Cho, Ogwang, and Opio (2010) suggested that a simplified WPI with three sub-components (i.e., Access, Capacity, and Environment) with unequal weights, or a even more simplified WPI with two sub-components (i.e., Capacity and Environment) with equal weights, would be more cost-effective to construct without significant loss of information.

In addition, Giné and Pérez-Foguet (2010) suggested that a weighted geometric function for the aggregation of WPI components and sub-components (see Equation 4) would be more suitable than the original weighted arithmetic average method (see Equation 1) for the assessment of the index at local scale.

$$WPI_j = \prod_{i=1}^{i=n} X_{ij}^{wi} \tag{4}$$

Index components and sub-components can be normalized to fall in the range 0-1 using the following formula:

$$(X_{ij} - X_{imin})/(X_{imax}-X_{imin}), \tag{5}$$

where X_{ij} refers to the value of a component *i* of the WPI structure for a location *j*, X_{imin} refers to the lowest value of a component *i* in the sample, and X_{imax} refers to the highest value of a component *i* in the sample. Thus, the final WPI value depends on the sample it is calculated for and ranges between 0 and 1. The highest value, 1, is taken to be the best situation, while 0 is deemed to be the most unfavorable condition.

Chapter 2: Overall and Specific Aims

The overall aim of this study was to investigate the quality of drinking water and sanitation services in border *colonias* and other rural areas of west Texas.

The specific aims of this study were to:

1. Adapt and apply the Water Poverty Index in *colonia* Revolución in El Paso County, Texas and three areas of Fort Hancock in Hudspeth County, Texas.
2. Assess and prioritize the drinking water and sanitation services needs in *colonia* Revolución and three areas of Fort Hancock.
3. Compare the distribution of Water Poverty Index values and individual components of the Index between *colonia* Revolucion and three areas of Fort Hancock.

Chapter 3: Methods and Procedures

The University of Texas at El Paso Institutional Review Board approved this study.

3.1 Study Areas

The study included *colonia* Revolución in El Paso County (see Figure 3.1) and the three drinking water and sanitation service areas of Fort Hancock in Hudspeth County (see Figure 3.2): an area identified as *colonia* Villa Alegre, an area serviced by the public Fort Hancock Water Control & Improvement District (FHWCID), and an area serviced by the private Esperanza Water Service Company (EWSC). Table 3.1 describes the demographic characteristics of each area (Korc, Orozco, Corona, & Murtaza-Rossini, 2011).

Table 3.1 Demographic characteristics of *colonia* Revolución in El Paso County and three areas of Fort Hancock in Hudspeth County.

Demographic characteristics	*Colonia* Revolución	Fort Hancock		
		Colonia Villa Alegre	FHWCID service area	EWSC service area
Population	130	60	760	1,000
Number of households	29	12	270	240
Hispanic or Latino (of any race)	100%	100%	97%	100%
Speak Spanish at home	89.7%	100%	77%	88%
Average annual household income	$15,000	$6,000	$14,000	$12,000
Households below poverty level	76%	100%	69%	85%

Colonia Revolución is located in a mixed industrial/residential area in East Horizon City, El Paso County, Texas. The average annual household income is about $15,000 for an average household of 4.5 people, significantly less than the 2011 U. S. Department of Health and Human Services (HHS) poverty guidelines for a family of four of $22,350 (U. S. Department of Health and Human Services, 2011). It is a "red" *colonia* that lacks piped drinking water and sanitation services. About a third of the *colonia* households collect their own water using available containers and two thirds rely on water delivery trucks certified by the Texas Commission on

Environmental Quality (TCEQ) to fill large containers. All households use septic tanks for sanitation (Korc, Orozco, Corona, & Murtaza-Rossini, 2011).

Figure 3.1: Map of *colonia* Revolución in El Paso County, Texas (the map reflects the residential and industrial areas of the *colonia*).

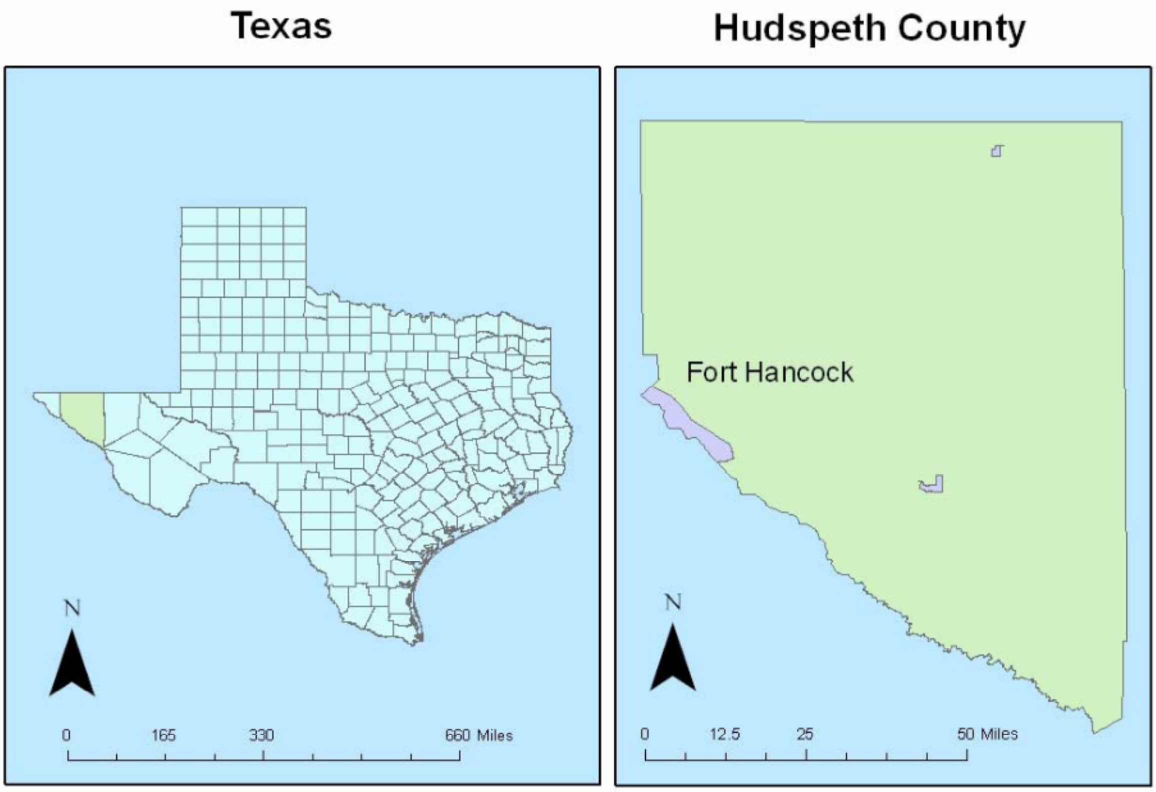


Figure 3.2: Map of Fort Hancock, Hudpseth County, Texas (University of Texas at El Paso, 2005).

Fort Hancock is a town in rural Hudspeth County, Texas east of El Paso County. The average annual household income is about $12,000 for an average household of 3.7 people, significantly less than the 2011 HHS poverty guidelines for a family of four. *Colonia* Villa Alegre is a "red" *colonia* that lacks piped drinking water and sanitation services. All *colonia* households collect their own water using available containers and use septic tanks for sanitation. The area serviced by FHWCID has piped drinking water and sanitation services, similar to the characteristics of a "green" *colonia*. The area serviced by EWSC has piped drinking water services but does not have piped sanitation services, similar to the characteristics of a "yellow" *colonia* (Korc, Orozco, Corona, & Murtaza-Rossini, 2011).

3.2 Developing a Water Poverty Index for Border *Colonias* of West Texas

The development of a composite index such as the WPI involved three key stages and eight steps (Nardo et al., 2005). Figure 3.3 shows the step-by-step procedure for developing the index.

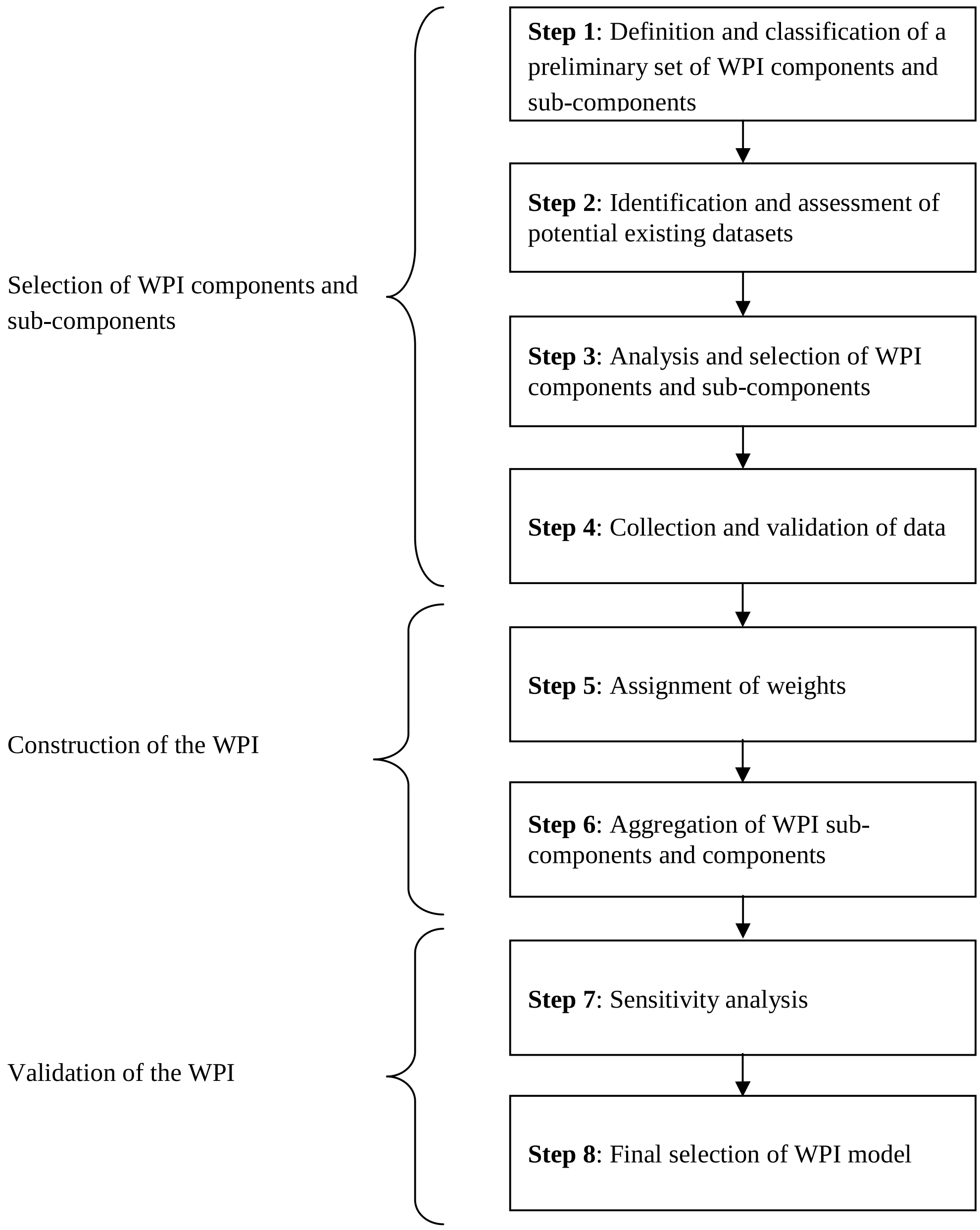


Figure 3.3: Step-by-step procedure to apply the WPI.

3.2.1 Step 1: Definition and Classification of a Preliminary Set of WPI Components and Sub-components

The first step defined a preliminary set of components and sub-components based on a review of the literature. As suggested by Feitelson and Chenoweth (2002), the proposed WPI components and sub-components met the following criteria: available (measurable at no/reasonable cost), understandable (exactly defined to be easily accepted by those who are likely to use it), accurate (supported by reliable information), scalable at different administrative levels, relevant (responsive to changes), regularly updatable, and integrative among physical, social, economical, and environmental aspects.

Once defined, the preliminary set of sub-components was classified based on the WPI conceptual framework (see Table 3.2). Two variables were defined for the resource component, three for the access component, three for the capacity component, one for the use component, and two for the environment component of the index.

Table 3.2: A preliminary set of variables for application of the WPI in border *colonias* of west Texas.

WPI Component	WPI sub-component
Resources (R)	Capacity of water systems in an area/*colonia* (R1). Water quality of suppliers in an area/*colonia* (R2).
Access (A)	Access to drinking water in an area/*colonia* (A1). Access to sanitation in an area/*colonia* (A2). Institutional or technical capacity of water suppliers in an area/*colonia* (A3).
Capacity (C)	Cost of water in an area/*colonia* (C1). Household annual income in an area/*colonia* (C2). Drinking water tank maintenance in an area/*colonia* (C3).
Use (U)	Domestic water consumption rate in an area/*colonia* (U1).
Environment (E)	Septic tank certification in an area/*colonia* (E1). Septic tank maintenance in an area/*colonia* (E2).

3.2.2 Step 2: Identification and Assessment of Potential Existing Datasets

As Sullivan and Meigh (2003) suggested, the study employed secondary data to calculate the values of the WPI sub-components. In this step, an identification and assessment of potential existing datasets was performed to understand whether the proposed sub-components were appropriate. The study identified potential datasets from the following sources: the *Colonia* Initiatives Program of the Office of the Texas Secretary of State, the 2010 Texas Department of State Health Services (TDSHS) community-based survey in border *colonias* of west Texas (Korc, Orozco, Corona, & Murtaza-Rossini, 2011), the U. S. EPA Safe Drinking Water Information System (SDWIS), the U. S. EPA National Pollutant Discharge Elimination System, Enforcement, and Compliance History Online, the 2005-2009 American Community Survey of the U. S. Census Bureau, and the TCEQ water supplier inspections. Datasets were assessed for appropriateness, spatial and temporal representativeness, and completeness. Based on these criteria, the datasets of the 2010 TDSHS community-based survey in border *colonias* of west Texas, the U. S. EPA SDWIS, and the TCEQ water supplier inspections were deemed the most suitable for the study.

3.2.3 Step 3: Analysis and Selection of WPI Components and Sub-components

The third step used the Delphi method (Linstone & Turoff, 2002) to analyze the proposed WPI components and sub-components and select the final set of variables. A stakeholder panel that included representatives of Texas state agencies that have participated in the *Colonia* Initiatives Program of the Office of Texas Secretary of State (see Table 3.3) was interviewed individually twice from August, 2010 through March 2011. During the first round of interviews, the researcher presented the goals of the study and asked the stakeholder panel to review the preliminary set of variables and if necessary, propose new variables based on the criteria defined

in Step 1. In addition, the panel was asked to review the datasets identified in Step 2 and if necessary, identify other datasets to measure the proposed variables. During the second round of interviews, the stakeholders were encouraged to revise their earlier answers in light of the replies of other members of the panel. The researcher provided an anonymous summary of the stakeholders' analysis from the previous round as well as the reasons they provided for their judgments. The stakeholder panel suggested the removal of the use component from the WPI because they considered it irrelevant for this region and difficult to acquire data at the household level.

Table 3.3: The stakeholder panel of the study.

Texas state agency	Office or Program within the agency
Office of the Texas Secretary of State	*Colonia* Initiatives Program
Texas Commission on Environmental Quality	Office of Water Intergovernmental Relations Division /Border Affairs
Texas Department of State Health Services	Office of Border Health Public Health Improvement Program
Texas Department of Housing and Community Affairs	*Colonia* Initiatives Program
Texas Health and Human Services Commission	Office of Border Affairs
Texas Water Development Board	Program Development

Table 3.4 shows the final set of variables, the indicators to measure them, the data sources, and periodicity of data collection.

Table 3.4: The final set of variables for application of the WPI in border *colonias* of west Texas, the indicators to measure them, the data sources, and periodicity of data collection.

WPI Component	WPI Sub-component	Indicator	Source of data	Periodicity of data collection
Resources (R)	Capacity of water systems in an area/*colonia* (R1).	Proportion of households in an area/*colonia* serviced by a water supplier whose provided production, elevated storage, and total storage is greater than or equal to the required amounts by state regulations.	Most recent TCEQ water supplier inspection report	Every three years
	Water quality of suppliers in an area/*colonia* (R2).	Proportion of households in an area/*colonia* serviced by a water supplier that had less than or equal to 10 health violations over a 10 year period.	U.S. EPA SDWIS	Yearly
Access (A)	Access to drinking water in an area/*colonia* (A1).	Proportion of households in an area/*colonia* serviced by a public or private water distribution system.	2010 TDSHS survey in border *colonias* of west TX	2010 cross-sectional study
	Access to sanitation in an area/*colonia* (A2).	Proportion of households in an area/*colonia* serviced by a public or private piped sewer system.	2010 TDSHS survey in border *colonias* of west TX	2010 cross-sectional study
	Institutional or technical capacity of water suppliers in an area/*colonia* (A3).	Proportion of households in an area/*colonia* serviced by a water supplier with less than or equal to 10 technical or monitoring violations over a 10 year period.	U.S. EPA SDWIS	Yearly
Capacity (C)	Cost of water in an area/*colonia* (C1).	Proportion of households in an area/*colonia* with annual water expenditures less than or equal to 6% of annual household income.	2010 TDSHS survey in border *colonias* of west TX	2010 cross-sectional study
	Household annual income in an area/*colonia* (C2).	Proportion of households in an area/*colonia* above 2011 Health and Human Services poverty guidelines.	2010 TDSHS survey in border *colonias* of west TX	2010 cross-sectional study
	Drinking water tank maintenance in an area/*colonia* (C3).	Proportion of households in an area/*colonia* that clean water tank once a month or more, or have piped water service.	2010 TDSHS survey in border *colonias* of west TX	2010 cross-sectional study
Environment (E)	Septic tank certification in an area/*colonia* (E1).	Proportion of households in an area/*colonia* with piped sewer system or septic system certified by a regulated company.	2010 TDSHS survey in border *colonias* of west TX	2010 cross-sectional study
	Septic tank maintenance in an area/*colonia* (E2).	Proportion of households in an area/*colonia* with piped sewer system or septic system maintained by a regulated company.	2010 TDSHS survey in border *colonias* of west TX	2010 cross-sectional study

3.2.4 Step 4: Collection and Validation of Data

In this step, data were collected and validated. As indicated above, the 2010 TDSHS community-based survey in border *colonias* of west Texas dataset, the U. S. EPA SDWIS of water suppliers, and the TCEQ inspection reports of water suppliers were deemed the most suitable for the study. In order to minimize unnecessary errors and uncertainties, all values in the data sets were reviewed. Suspicious data values were evaluated with the source.

The 2010 TDSHS community-based survey was a cross-sectional water, sanitation and safety study of 131 households in border *colonias* of west Texas. Its dataset contains information for all the inhabited households of *colonia* Revolución (29 households) and *colonia* Villa Alegre (12 households), and a representative sample of households for the FHWCID service area (40 households) and the EWSC service area (50 households). It contains demographical data (people per household, age, household income, ethnicity, and language spoke at home), water service data (type of service, treatment, consumption patterns, system maintenance, and cost), sanitation service data (type of service, maintenance, and cost), and perception of safety in the community data. The U. S. EPA SDWIS contains yearly updatable information about public and private water suppliers and their violations of U. S. EPA's drinking water regulations for the past 10 years, as reported to U. S. EPA by the states. These statutes and accompanying regulations establish maximum contaminant levels, treatment techniques, and monitoring and reporting requirements to ensure that water provided to customers is safe for human consumption. The TCEQ inspection reports contain regularly updatable information about the capacity of a state certified public or private water supplier to provide enough water to their customers. According to TCEQ regulations, the system capacities for the water suppliers in this study include water production, elevated storage, and total storage.

For the calculation of the WPI sub-components and components in Table 3, each household of the TDSHS community-based survey dataset was matched with its water supplier whose information was obtained from the U. S. EPA SWIDS dataset and TCEQ inspection reports. About a third of the households of *colonia* Revolución purchase their water from unregulated water providers using their own containers and two thirds rely on Lujan Trucking, a regulated trucking company that delivers treated water purchased from the Lower Valley Water District. All the households of *colonia* Villa Alegre purchase their water from FHWCID using their own containers. FHWICD and EWSC provide piped water services to all the households of their respective areas.

The privacy and confidentiality of the information was maintained. The household level data of the TDSHS community-based survey was kept anonymous and was stored in a locked and secure place.

3.2.5 Step 5: Assignment of Weights

Weights should reflect the relative importance of each of the WPI components and sub-components. Different methods to determine weights have been developed, including statistical techniques and judgment-based opinions (Booysen, 2002). Both methods have strengths and limitations. Statistical methods can be more objective but may not reflect priorities of decision-makers. Judgment-based opinion methods can be more subjective but may reflect more accurately priorities of decision-makers. Since an objective method that reflects priorities of decision-makers does not exist, Sullivan and Meigh (2007) suggested that the WPI should be first calculated with weightings set equally.

In this study, two different approaches were applied:

1. Setting equal weights as suggested by Sullivan and Meigh (2007) to avoid problems of subjectivity. Its main advantages are simplicity and transparency to non-technical audiences.
2. Setting weights using judgment-based opinions to reflect priorities of decision-makers at the expense of being more subjective. The study used the Delphi method (Linstone & Turoff, 2002) to set weights. The stakeholder panel identified in Step 3 was surveyed individually twice regarding the weights of each index component and sub-component. During the first round, a list with the final set of variables was provided to each stakeholder and was asked to assign a zero or positive weight to each of the four WPI components such that the sum of weights was equal to one. Within a specific WPI component, a stakeholder was also asked to assign a zero or positive weight to each sub-component such that the sum of the sub-component weights for each WPI component was equal to one. During the second round, stakeholders were encouraged to revise their earlier answers in light of the replies of other members of the panel. The researcher provided an anonymous summary of the stakeholders' analysis from the previous round as well as the reasons they provided for their judgments. After the second round, the opinions were averaged to determine the final set of weights. Table 3.5 shows the average weights for each WPI component and sub-component.

Table 3.5: Final set of variables with their corresponding average weights for application of the WPI in border *colonias* of west Texas.

WPI Component	WPI Component Average Weight	WPI Sub-component	WPI Sub-component Average Weight (Range)
Resources (R)	0.32	Capacity of water systems in an area/*colonia* (R1).	0.45 (0.20 – 0.50)
		Water quality of suppliers in an area/*colonia* (R2).	0.55 (0.40 – 0.80)
Access (A)	0.30	Access to drinking water in an area/*colonia* (A1).	0.47 (0.30 – 0.60)
		Access to sanitation in an area/*colonia* (A2).	0.32 (0.20 – 0.40)
		Institutional or technical capacity of water suppliers in an area/*colonia* (A3).	0.21 (0.10 – 0.40)
Capacity (C)	0.18	Cost of water in an area/*colonia* (C1).	0.27 (0.20 – 0.40)
		Household annual income in an area/*colonia* (C2).	0.35 (0.30 – 0.50)
		Drinking water tank maintenance in an area/*colonia* (C3).	0.38 (0.30 – 0.50)
Environment (E)	0.20	Septic tank certification in an area/*colonia* (E1).	0.53 (0.30 – 0.70)
		Septic tank maintenance in an area/*colonia* (E2).	0.47 (0.30 – 0.70)

3.2.6 Step 6: Aggregation of WPI Components and Sub-components

Several aggregating methods have been applied in the construction of composite indexes such as the WPI. The method most commonly used has been the weighted arithmetic average method presented in Equation 1. Less common, has been the use of multiplicative (geometric) and other non-linear aggregations such as the one presented in Equation 4. The major virtues of the arithmetic aggregation method are simplicity and transparency. However, the method assumes total independence among variables. This may be an unrealistic assumption since synergies or conflicts may exist among the index sub-components. Furthermore, Nardo et al. (2005) suggested that for arithmetic aggregation methods, weights may fail to indicate the importance of the variable associated and compensability among different individual components is implicit. Giné and Pérez-Foguet (2010) suggested a geometric aggregation method (see Equation 4) for the application of the WPI index at local scale. However, when a geometric aggregation method is applied, poor performance of an index component or sub-component is penalized more heavily.

In this study, the values of the WPI and its underlying components were calculated using the arithmetic aggregation approach of the original index (Sullivan, 2002) and the geometric aggregation approach suggested by Giné and Pérez-Foguet (2010) with equal weights and judgment-based weights. Values were calculated for and compared among *colonia* Revolución, *colonia* Villa Alegre, the Fort Hancock area serviced by FHWCID, and the Fort Hancock area serviced by EWSC.

Demographic variables and WPI sub-components were compared between areas or *colonias* using non-parametric tests (chi-squared test and Fisher's exact test) using the 0.05 level of significance. Statistics were calculated using SPSS software (PASW Version 18, SPSS Inc, and IBM Company, Chicago, IL).

3.2.7 Step 7: Sensitivity Analysis

The WPI construction involves three stages where subjective judgment was made: selection of variables, attribution of weights, and choice of aggregation model. A sensitivity analysis helped assess the robustness of the WPI with regard to underlying assumptions made in its construction. In this step, the researcher changed systematically the attribution of weights and the choice of aggregation model to determine the effects of such changes in the WPI results. The four WPI values calculated using equal and judgment-based weights and arithmetic and geometric aggregation approaches were compared. This study did not analyze the sensitivity of changes in selected variables (i.e., the researcher did not change systematically the choice of indicator of a sub-component to determine the effect of such a change in the WPI results).

3.2.8 Step 8: Final Selection of WPI Model

This step judged the most appropriate WPI construction with regard to attribution of weights and choice of aggregation model based on the following criteria (Swamee & Tyagi,

2000; Sullivan et al., 2003; Giné & Pérez-Foguet, 2010): 1) the most appropriate WPI construction should be free of or minimize overestimation (ambiguity) and underestimation (eclipsing); and 2) when competing approaches produce similar results with respect to underestimation and overestimation, the most appropriate method should be the simplest and most transparent.

Overestimation issues or ambiguity problems arise when a composite index exceeds a critical level without any of its components and sub-components exceeding the critical level. Underestimation issues or eclipsing problems arise when a composite index does not exceed a critical level, despite one or more of its components or sub-components exceeding a critical level (Swamee & Tyagi, 2000). For example, Giné and Pérez-Foguet (2010) used a critical level of 0.3.

Chapter 4: Results

Table 4.1 shows the values of the WPI sub-components for each service area/*colonia* and the town of Fort Hancock as the aggregate of colonia Villa Alegre, the FHWCID service area and the EWSC service area. The values range from 0 (worst) to 1 (best). With the exception of cost of water in a service area/*colonia*, Villa Alegre has the worst WPI sub-component values in all the studied areas. The FHWCID service area has the best values for most sub-components, excluding the resources sub-components and the cost of water in a service area/*colonia*.

Table 4.1: Values of WPI sub-components for each area or *colonia*.

WPI Sub-component	Indicator	*CR*	*CVA*	FHWCID	EWSC	Ft. Hancock[1]
Capacity of water systems in an area/*colonia* (R1).	Proportion of households in an area/*colonia* serviced by a water supplier whose provided production, elevated storage, and total storage is greater than or equal to the required amounts by state regulations.	0.66	0.00	0.00	1.00	0.49
Water quality of suppliers in an area/*colonia* (R2).	Proportion of households in an area/*colonia* serviced by a water supplier that had less than or equal to 10 health violations over a 10 year period.	0.66	0.00	0.00	1.00	0.49
Access to drinking water in an area/*colonia* (A1).	Proportion of households in an area/*colonia* serviced by a public or private water distribution system.	0.00	0.00	1.00	1.00	0.88
Access to sanitation in an area/*colonia* (A2).	Proportion of households in an area/*colonia* serviced by a public or private piped sewer system.	0.00	0.00	0.98	0.00	0.38
Institutional or technical capacity of water suppliers in an area/*colonia* (A3).	Proportion of households in an area/*colonia* serviced by a water supplier with less than or equal to 10 technical or monitoring violations over a 10 year period.	0.66	0.00	1.00	1.00	0.88
Cost of water in an area/*colonia* (C1).	Proportion of households in an area/*colonia* with annual water expenditures less than or equal to 6% of annual household income.	0.31	0.25	0.21	0.30	0.26
Household annual income in an area/*colonia* (C2).	Proportion of households in an area/*colonia* above 2011 Health and Human Services poverty guidelines.	0.24	0.00	0.31	0.15	0.19
Drinking water tank maintenance in an area/*colonia* (C3).	Proportion of households in an area/*colonia* that clean water tank once a month or more, or have piped water service.	0.21	0.58	1.00	1.00	0.95
Septic tank certification in an area/*colonia* (E1).	Proportion of households in an area/*colonia* with piped sewer system or septic system certified by a regulated company.	0.25	0.00	0.98	1.00	0.51
Septic tank maintenance in an area/*colonia* (E2).	Proportion of households in an area/*colonia* with piped sewer system or septic system maintained by a regulated company.	0.39	0.09	1.00	0.23	0.53

Abbreviations:
CR – *Colonia* Revolución
CVA – *Colonia* Villa Alegre
FHWCID – The Fort Hancock Water Control & Improvement District (FHWCID) service area
EWSC – The Esperanza Water Service Company (EWSC) service area
1 Fort Hancock is the aggregate of *colonia* Villa Alegre, the FHWCID service area, and the EWSC service area.

As summarized in Table 4.2, there are statistically significant differences between services areas/*colonias* for all WPI sub-components with the exception of the variable "cost of water in a service area/*colonia*". In addition, for the variable "household annual income in a service area/*colonia*", there are only statistically significant differences between *colonia* Revolución and Fort Hancock and between *colonia* Villa Alegre and the FHWCID service area.

Table 4.2: Associations between study areas for each WPI sub-component.

WPI Component	WPI Sub-component	Study area comparisons						
		CR – CVA	CR – FHWCID	CR – EWSC	CR – Ft. Hancock[1]	CVA – FHWCID	CVA – EWSC	FHWCID – EWSC
Resources (R)	Capacity of water systems in an area/*colonia* (R1).					NA		
	Water quality of suppliers in an area/*colonia* (R2).					NA		
Access (A)	Access to drinking water in an area/*colonia* (A1).	NA						NA
	Access to sanitation in an area/*colonia* (A2).	NA		NA			NA	
	Institutional or technical capacity of water suppliers in an area/*colonia* (A3).							NA
Capacity (C)	Cost of water in an area/*colonia* (C1).							
	Household annual income in an area/*colonia* (C2).							
	Drinking water tank maintenance in an area/*colonia* (C3).							NA
Environment (E)	Septic tank certification in an area/*colonia* (E1).							
	Septic tank maintenance in an area/*colonia* (E2).							

Abbreviations:
CR – *Colonia* Revolución
CVA – *Colonia* Villa Alegre
FHWCID – The Fort Hancock Water Control & Improvement District (FHWCID) service area
EWSC – The Esperanza Water Service Company (EWSC) service area
NA – Not applicable. No statistics were computed because the WPI sub-component was a constant
$p \leq 0.05$ for chi-squared or Fisher's Exact tests, as appropriate.
1 Fort Hancock is the aggregate of *colonia* Villa Alegre, the FHWCID service area, and the EWSC service area.

Four different types of WPI values were calculated using equal and judgment-based weights, and arithmetic and geometric aggregation approaches (see Tables 4.3 and 4.4). The WPI values calculated using the judgment-based weights and arithmetic aggregation approach are the highest and the values calculated using the equal weights and geometric aggregation approach are the lowest for each service area/*colonia*. To make calculations informative and avoid loss of detail for the geometric aggregation approach, a minimum value of 0.0001 was used for WPI sub-components that have null values.

Table 4.3: Values of the WPI and its components for each area/*colonia* using equal and judgment-based weights and an arithmetic aggregation approach.

WPI Component	Equal weights and arithmetic aggregation approach					Judgment-based weights and arithmetic aggregation approach				
	CR	CVA	FHWCID	EWSC	Ft. Hancock[1]	CR	CVA	FHWCID	EWSC	Ft. Hancock[1]
Resources (R)	0.66	0.00	0.00	1.00	0.49	0.66	0.00	0.00	1.00	0.49
Access (A)	0.22	0.00	0.99	0.67	0.71	0.14	0.00	0.99	0.68	0.73
Capacity (C)	0.25	0.28	0.51	0.48	0.47	0.25	0.29	0.55	0.49	0.50
Environment (E)	0.32	0.05	0.99	0.22	0.52	0.32	0.04	0.99	0.22	0.52
WPI value	0.36	0.08	0.62	0.59	0.55	0.36	0.13	0.60	0.65	0.57
WPI ranking	3	4	1	2		3	4	2	1	

Abbreviations:
CR – *Colonia* Revolución
CVA – *Colonia* Villa Alegre
FHWCID – The Fort Hancock Water Control & Improvement District (FHWCID) service area
EWSC – The Esperanza Water Service Company (EWSC) service area
1 Fort Hancock is the aggregate of *colonia* Villa Alegre, the FHWCID service area, and the EWSC service area.

Table 4.4: Values of the WPI and its components for each area/*colonia* using equal and judgment-based weights and a geometric aggregation approach.

WPI Component	Equal-weights and geometric aggregation approach					Judgment-based weights and geometric aggregation approach				
	CR	CVA	FHWCID	EWSC	Ft. Hancock[1]	CR	CVA	FHWCID	EWSC	Ft. Hancock[1]
Resources (R)	0.66	0.00	0.00	1.00	0.49	0.66	0.00	0.00	1.00	0.49
Access (A)	0.00	0.00	0.99	0.05	0.67	0.00	0.00	0.99	0.05	0.67
Capacity (C)	0.25	0.03	0.41	0.36	0.36	0.24	0.02	0.44	0.37	0.38
Environment (E)	0.31	0.00	0.99	0.21	0.52	0.31	0.00	0.99	0.22	0.52
WPI value	0.10	0.00	0.08	0.25	0.50	0.06	0.00	0.05	0.25	0.52
WPI ranking	2	4	3	1		2	4	3	1	

Abbreviations:
CR – *Colonia* Revolución
CVA – *Colonia* Villa Alegre
FHWCID – The Fort Hancock Water Control & Improvement District (FHWCID) service area
EWSC – The Esperanza Water Service Company (EWSC) service area
1 Fort Hancock is the aggregate of *colonia* Villa Alegre, the FHWCID service area, and the EWSC service area.

The sensitivity of these results was analyzed. Two analyses were performed. First, the study compared geometrically and arithmetically aggregated WPI values. As shown in Tables 4.3 and 4.4, the geometrically aggregated WPI values are usually significantly lower than the arithmetically aggregated values. These differences are probably inflated because all service areas/*colonias* have at least one WPI sub-component with a null value. For example, the equal weights and arithmetically aggregated WPI value for the FHWICD service area is 0.62 whereas the geometrically aggregated value is 0.08 because the resources sub-component has a null value. In addition, the geometrically aggregated WPI values for the town of Fort Hancock (0.50 for equal weights and 0.52 for judgment-based weights) were higher than the geometrically aggregated values of each of its three service areas/*colonias* (0.00 through 0.25). The Fort Hancock WPI sub-components do not have null values whereas the service areas/*colonias* values had null values. Second, the study compared equal and judgment-based weights WPI values. As shown in Tables 4.3 and 4.4, the use of judgment-based weights do not change WPI values and rankings significantly with exception of the arithmetically aggregated WPI value for the EWSC service area that has a 10% increase from 0.59 for equal weights (Rank = 2) to 0.65 for judgment-based weights (Rank =1).

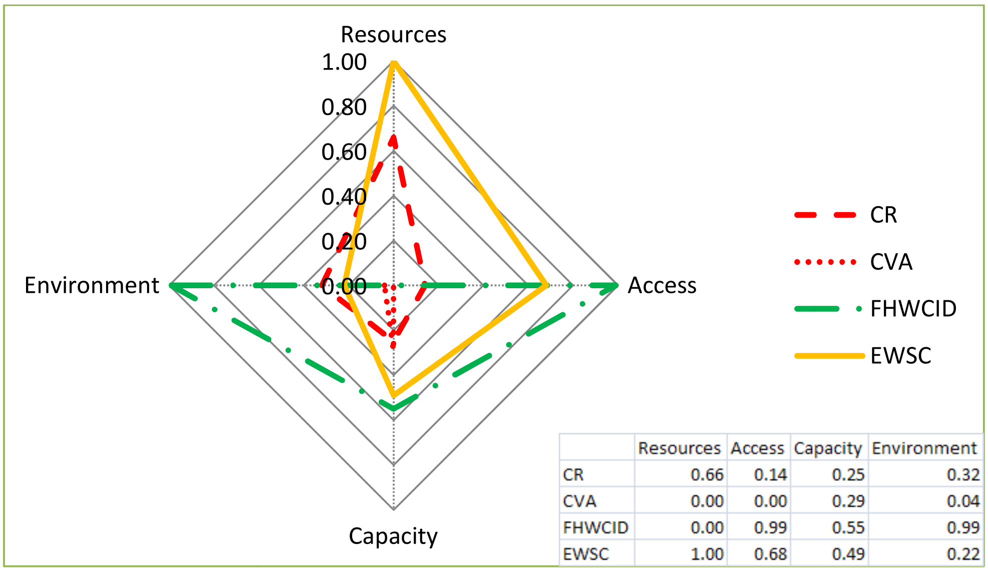
Overestimation (ambiguity) and underestimation (eclipsing) issues of WPI values were also analyzed. Following the criteria defined in Step 8 of the methodology and assuming a critical WPI value level of 0.3 as suggested by Giné and Pérez-Foguet (2010), none of the cases that exceeded the critical value produced overestimation issues. The weighted arithmetic and geometric mean aggregation approaches are ambiguity free functions (Singh, et al., 2008). However, all the cases that did not exceed the critical value produced underestimation issues. These issues were more pronounced for geometrically aggregated values.

Chapter 5: Discussion

The first specific aim of this study was to adapt and apply the WPI for border *colonias* of west Texas. The WPI was developed as a holistic tool designed to contribute to more effective water management in water poor countries and to the best of our knowledge, it has not been previously applied in the U. S. As indicated by Sullivan, et al. (2003), the WPI was not intended to provide unexpected or new results, but to be an integrated, systematic, and transparent indicator of the water situation in a geographical area. This study showed that the WPI can be an effective tool in integrating physical, social, economical, and environmental information and for determining priorities associated with the water situation in *colonias*. It integrated information regularly available from TCEQ and U.S. EPA databases and from a survey that could be easily replicable on a representative sample of border *colonias* every three to five years. This could appeal to policy-makers for its simplicity and completeness. This finding is consistent with those reported by Sullivan, et al. (2003) and Sullivan and Meigh (2007) for the application of the WPI at the community level in South Africa, Tanzania, and Sri Lanka. Based on the results of the sensitivity analysis and the criteria established in Step 8 of the methodology, our results suggest that the most appropriate WPI construct for this case is judgment-based weights and an arithmetic aggregation approach. The use of judgment-based weights promotes political discussion and consensus. An arithmetic aggregation is probably more suitable than a geometric one because of the presence of null values for several WPI sub-components and the production of less underestimation issues. This finding differs from that reported by Giné & Pérez-Foguet (2010) that suggested a weighted multiplicative function as a more suitable aggregation method. Therefore, the choice of aggregation approach cannot be generalized. To adapt and apply the WPI for border *colonias*, the study used a consultative approach using the Delphi method. A

stakeholder panel of Texas state agencies members of the *Colonia* Initiatives Program of the Office of Texas Secretary of State participated in personal interviews to learn about and help develop the index. At the end of this process, the panel agreed that the WPI and its underlying components and sub-components provided a more complete reflection of the water situation in the *colonias* than just using the current methodology based solely on infrastructure information (see Table 1.2).

The second specific aim of this study was to assess and prioritize the drinking water and sanitation services needs in *colonia* Revolucion and the areas/*colonias* of Fort Hancock (see Figure 5.1 and Table 5.1). Our results identified *colonia* Villa Alegre as the neediest community and indicated that improvements in any of the four major components of the index would be beneficial with the highest priorities on improving resources, access, and environmental impact (i.e., index values of zero or close to zero). In addition, our results identified the need to improve the water resources in the FHWCID service area, the access to water and sanitation services in *colonia* Revolucion; the access to sanitation services in the EWSC service area; the capacity of the community in all areas/ *colonias*, and the environmental impact in *colonia* Revolucion and the EWSC service area.   The study provided a 'snapshot' of the situation at one point in time. However, the information used in this study for the WPI calculations could be updated at reasonable intervals agreed with stakeholders to monitor progress.



Abbreviations:
CR – *Colonia* Revolución
CVA – *Colonia* Villa Alegre
FHWCID – The Fort Hancock Water Control & Improvement District (FHWCID) service area
EWSC – The Esperanza Water Service Company (EWSC) service area

Figure 5.1: Pentagram presentation of the WPI component values for *colonia* Revolución, *colonia* Villa Alegre, the FHWCID service area, and the EWSC service area using the judgment-based weights and arithmetic aggregation approach. *Colonia* Revolución and *colonia* Villa Alegre are shown in red, indicating "red" *colonias*, the EWSC service area is shown in yellow, indicating the characteristics of a "yellow" *colonia*, and the FHWCID service area is shown in green, indicating the characteristics of a "green" *colonia*.

Table 5.1: Priorities of drinking water and sanitation services needs in *colonia* Revolución, colonia Villa Alegre, the FHWCID service area and the EWSC service area.

Priority	*Colonia* Revolución	*Colonia* Villa Alegre	FHWCID service area	EWSC service area
1st	Access to drinking water and sanitation services (A1 and A2).	Capacity and water quality of water supplier (R1 and R2).	Capacity and water quality of water supplier (R1 and R2).	Access to sanitation services (A2).
2nd	Drinking water tank maintenance (C3).	Access to drinking water and sanitation services (A1 and A2).	Cost of water and household annual income (C1 and C2).	Septic tank maintenance (E2).
3rd	Cost of water and household annual income (C1 and C2).	Septic tank certification and maintenance (E1 and E2).		Cost of water and household annual income (C1 and C2).
4th	Septic tank certification and maintenance (E1 and E2).	Cost of water and household annual income (C1 and C2).		

The third specific aim of this study was to compare the distribution of WPI values and individual components of the index among *colonia* Revolucion and the areas/*colonia* in Fort Hancock. The results show that *colonia* Revolución and the three areas/*colonias* of Fort Hancock have different water needs and priorities (Table 5.1). The FHWCID service area needs improvement of resources whereas the EWSC service area needs improvement of access and environmental impact, and *colonia* Villa Alegre needs improvement of resources, access, and environmental impact. The community capacity component should be improved in all areas/*colonias*. In addition, the results show water poverty differences between 'red' *colonias*. *Colonia* Villa Alegre is more water poor than *colonia* Revolución. *Colonia* Revolución has better water resources, better access to services, and less environmental impact than *colonia* Villa Alegre. These examples highlight the need to assess the water situation at the community level and the need to classify the water needs of *colonias* using a more comprehensive but simple water assessment tool that integrates several factors and is not based solely on infrastructure.

5.1 Limitations

There are several limitations of this study that need to be noted. First, the WPI is not universal and cannot be employed for comparison among studies (Sullivan et al., 2003; Feitelson & Chenoweth, 2002). Variables representing the key components of the WPI structure and their weightings are subject to biases and individual judgments because they were based on consultations with a panel of stakeholders representing different Texas state agencies. Not all the components of water poverty were included in the index (e.g., water usage). Second, the use of three datasets from different sources to calculate the WPI may affect the quality of the results. However, to minimize inconsistencies, suspicious data values were evaluated directly with each source. Third, findings of this study may be generalizable only to other border *colonias* with

similar socio-demographic and physical environmental characteristics. It is a tool that informs and orients policy-making, enabling decision makers to target crosscutting issues in an integrated way.

5.2 Implications

This study offered relevant insights of the complexity of drinking water and sanitation services in one of the most underserved areas of the U. S.-Mexico border region.

Currently, policy decisions regarding investment on drinking water and sanitation services in border *colonias* of Texas use primarily the classification criteria described in Table 1.2 based on the status of infrastructure. They take limited consideration to other factors such as sustainability. The current *Colonia* Initiatives Program database (The *Colonia* Initiatives Program of the Office of Texas Secretary of State, 2006) only contains information on infrastructure and financial availability. It does not include variables such as water systems capacity, water quality, and technical capacity of potential suppliers, capacity of the community to manage water issues, and potential environmental impacts. For example, the FHWCID service area would be classified as "green" by the *Colonia* Initiatives Program because it has piped drinking water and sanitation services. However, the study showed that this area was more water poor than the EWSC service area that would be classified as "yellow" because of its limited water system's capacity and poor water quality. Including these variables in the *Colonia* Initiatives Program database and applying the WPI would provide information that can be used to advance more equitable and sustainable rural drinking water and sanitation policies and programs and help reduce health disparities associated with water-borne diseases along the Texas side of the border with Mexico.

References

Anders, R. L., Olson, T., Robinson, K., Wiebe, J., Digregorio, R., Guillermina, M., . . . Ortiz, M. (2008). A health survey of a *colonia* located on the west Texas, US/Mexico border. *Journal of Immigrant and Minority Health*. Retrieved from www.springerlink.com/whalecom0/content/fn877530331u234p/fulltext.pdf

Banerjee, S., Carlin, B. P., & Gelfand, A. E. (2004). Hierarchical modeling for univariate spatial data (pp. 129-170). *Hierarchical Modeling and Analysis for Spatial Data. Monographs on Statistics and Applied probability 101*. Boca Raton, Florida: Chapman & Hall/CRC.

Booysen, F. (2002). An overview and evaluation of composite indices of development. *Social Indicators Research. 59*: 115-151.

Carter, N. and Ortolano, L. (2004). Implementing government assistance programs for water and sewer systems in Texas *colonias*. *International Journal of Water Resources Development*. *20*(4): 553-564.

Centers for Disease Control (n. d.) *Preventing bacterial waterborne diseases*. Retrieved from www.cdc.gov/ncidod/dbmd/diseaseinfo/waterbornediseases_t.htm

Cho, D. I., Ogwang, T., & Opio, C. (2010). Simplifying the Water Poverty Index. *Social Indicators Research. 97*: 257-267.

Eisenstein, L., Bodager, D., & Ginzl, D. (2008). Outbreak of giardiasis and cryptosporidiosis associated with a neighborhood interactive water fountain--Florida, 2006. Journal of Environmental Health, *71*(3):18-22.

Escobedo, M. A., Homedes, N., Aldana, V., von Alt, K., Serrano, B. N., & Garcia, R. (2003). *Assessment of parasitic disease in children in five communities in the border region of far*

west Texas. Texas Department of Health, Office of Border Health, Publication # 56-11815.

Federal Reserve Bank of Dallas. (1995). *Texas colonias. A thumbnail sketch of the conditions, issues, challenges and opportunities*. Retrieved from http://www.dallasfed.org/ca/pubs/colonias.pdf

Feitelson, E. & Chenoweth, J. (2002). Water poverty: towards a meaningful indicator. *Water Policy, 4*: 263-281.

Giné, R., & Pérez-Foguet, A. (2010). Improved method to calculate a Water Poverty Index at local scale. Journal of Environmental Engineering. Submitted September 16, 2009; accepted April 14, 2010; posted ahead of print April 16, 2010. doi;10.1061/(ASCE)EE.1943-7870.0000255.

Graham, J. P., & VanDerslice, J. (2007). The effectiveness of large household water storage tanks for protecting the quality of drinking water. *Journal of Water and Health*, *5*(2), 307-313.

Heymann, D. L. (Editor). (2008). Cryptosporidiosis (pp. 157-160). *Control of Communicable Diseases Manual, 19th Edition*. Washington, DC: American Public Health Association.

Komnenic, V., Ahlers, R., & van der Zaag, P. (2009). Assessing the usefulness of the Water Poverty Index by applying it to a special case: can one be water poor with high level of access? *Physics and Chemistry of the Earth. 34*: 219-224.

Korc, M., Orozco, Y., Corona, A., & Murtaza-Rossini, M. (2011). *Drinking water, sanitation, and safety as determinants of health in colonias of west Texas*. Texas Department of State Health Services, Public Health Improvement Program.

Leach, C. T., Koo, F. C., Kuhls, T. L., Hilsenbeck, S. G., & Jenson, H. B. (2000). Prevalence of Cryptosporidium parvum infection in children along the Texas-Mexico border and associated risk factors. *American Journal of Tropical Medicine and Hygiene, 62*(5), 656-661.

Lawrence, P., Meigh, J., & Sullivan, C. (2002). The Water Poverty Index: an international comparison. *Keele Economics Research Papers*. Keele University, Keele, Staffordshire, United Kingdom. Retrieved from http://www.keele.ac.uk/depts/ec/wpapers/kerp0219.pdf

Linstone, H. A. & Turoff, M. (2002). *The Delphi method: techniques and applications*. Retrieved from http://is.njit.edu/pubs/delphibook/

Management Sciences for Health & United Nations Children's Fund. (1998). Stakeholder analysis. *The Guide to Managing for Quality*. Retrieved from http://erc.msh.org/quality/ittools/itstkan.cfm

Mier, N., Ory, M. G., Zhan, D., Conkling, M., Sharkey, J. R., & Burdine, J. N. (2008). Health-related quality of life among Mexican Americans living in colonias at the Texas Mexico border. *Social Science & Medicine, 66*, 1760-1771.

Molle, F. & Mollinga, P. (2003). Water poverty indicators; conceptual problems and policy issues. *Water Policy, 5*: 529-544.

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., & Giovannini, E. (2005). *Handbook on Constructing Composite Indicators: Methodology and User Guide*. Organization for Economic Cooperation and Development (OECD) Statistics Working Paper, OECD, Statistics Directorate, Paris.

Olmstead, S. M. (2004). Thirsty colonias: rate regulation and the provision of water service. *Land Economics, 80*(1), 136-150.

Parcher, J. W. & Humberson, D. G. (2009). Using GIS to assess priorities of infrastructure and health needs of *colonias* along the United States-Mexico border. *Journal of Latin American Geography. 8*(1): 129-148.

Qiang, F., Kachanoski, G., Dong, L., & Zilong, W. (2008). Evaluation of regional water security using Water Poverty Index. *International Journal of Agricultural and Biological Engineering. 1*(2): 8-14.

Ramos, I. N., Baker Davis, L., He, Q., May, M., & Ramos, K. S. (2008). Environmental risk factors of disease in the Cameron Park colonia, a Hispanic community along the Texas-Mexico border. *Journal of Immigrant and Minority Health, 10*(4), 345-351.

Roach, P. D., Olson, M. E., Whitley, G., & Wallis P. M. (1991) Waterborne *Giardia* cysts and *Cryptosporidium* oocysts in the Yukon, Canada. *Applied Environmental Microbiology, 59*: 67-73.

Singh, R. P., Nath, S., Prasad, S. C., & Nema, A. K. (2008). Selection of suitable aggregation function for estimation of aggregate pollution index for river Ganges in India. *Journal of Environmental Engineering, 134*(8): 689-701.

Sauch, J., Galvin, M., Berman, D., & Jacobowski, W. (1991). Propidium iodide as an indicator of *Giardia* viability. *Applied Environmental Microbiology, 57*: 3242-3247.

Sullivan, C. (2002). Calculating a Water Poverty Index. *World Development, 30*(7): 1195-1210Texas Secretary of State. (n. d.). *About the colonias program*. Retrieved from http://www.sos.state.tx.us/border/colonias/

Sullivan, C. & Meigh, J. (2003). Considering the Water Poverty Index in the context of poverty alleviation. *Water Policy, 5*: 513-528.

Sullivan, C. A. & Meigh, J. (2007) . Integration of the biophysical and social sciences using an indicator approach: addressing water problems at different scales. *Water Resources Management. 21*: 111-128.

Sullivan, C. A., Meigh, J. R., Giacomello, A. M., Fediw, T., Lawrence, P., Samad, M., . . ., Steyl, I. (2003). The Water Poverty Index: development and application at the community scale. *Natural Resources Forum. 27*: 189-199.

Sullivan, C., Meigh, J., & Lawrence, P. (2006). Application of the Water Poverty Index at different scales: a cautionary tale. *International Water Resources Association. 31*(3): 412-426.

Swamee, P. K., & Tyagi, A. (2000). Describing water quality with aggregate index. *Journal of Environmental Engineering. 134*(8): 689-701.

Texas State Historical Association. (1999). The handbook of Texas online. Retrieved from http://www.tshaonline.org/handbook/online/

Texas Secretary of State. (n. d.). *About the colonias program*. Retrieved from http://www.sos.state.tx.us/border/colonias/

The *Colonia* Initiatives Program of the Office of Texas Secretary of State. (2006). Tracking the progress of state-funded projects that benefit *colonias*. *Final report in response to Senate Bill 827 by Senator Judith Zaffirini and Representative Ryan Guillen. 79th regular session, Texas Legislature.* Retrieved from http://www.sos.state.tx.us/border/forms/sb827_111706.pdf

The *Colonia* Initiatives Program of the Office of Texas Secretary of State. (2010). Tracking the progress of state-funded projects that benefit *colonias. Final report in response to Senate*

Bill 99 by Senator Judith Zaffirini and Representative Ryan Guillen. 82th regular session, Texas Legislature.

U.S. Census Bureau. (2009). 2005-2009 American Community Survey 5-Year Estimates. Retrieved from http://factfinder.census.gov/servlet/CTGeoSearchByListServlet?ds_name=ACS_2009_5YR_G00_&_lang=en&_ts=327416478743

U. S. Department of Health and Human Services (2011). 2011 HHS poverty guidelines. *Federal Register*, *76*(13): 3637-3638.

U. S. Environmental Protection Agency & Secretaria de Medio Ambiente y Recursos Naturales. (2008). *U.S.-Mexico Environmental Program: Border 2012. A mid-course refinement (2008-2012)*. Retrieved from http://www.epa.gov/usmexicoborder/docs/B2012_New_Objectives.pdf

U. S. Government Accountability Office. (2009, December). Rural water infrastructure. Improved coordination and funding processes could enhance federal efforts to meet needs in the U.S.-Mexico border region. *Report to the Chairman, Committee on Agriculture, House of Representatives.* Washington, DC: U.S. Government Printing Office.

United States-Mexico Border Health Commission [USMBHC]. (n. d.). *Healthy Border 2010. An agenda for improving health on the United States-Mexico border*. Retrieved from http://www.borderhealth.org/files/res_63.pdf

University of Texas at El Paso, Institute for Policy and Economic Development. (2005). Fort Hancock, Texas, research background. Technical report No. 2005-03.

Ward, P. M. (1999). Introduction to the border region and to the case study cities (pp. 13 – 64). *Colonias and public policy in Texas and Mexico: Urbanization by stealth*. Austin, TX: University of Texas Press.

Wescoat, Jr., J. L., Theobald, R., & Headington, L. (2008). Water and poverty in the United States. *The encyclopedia of earth, content, credibility, community*. Retrieved from http://www.eoearth.org/article/Water_and_poverty_in_the_United_States.

Yoder, J. S. & Beach, M. J. (2010). Cryptosporidium surveillance and risk factors in the United States. *Experimental Parasitology, 124*(1):31-9.

Vita

Marcelo Korc was born in Montevideo, Uruguay. He received a B.Sc. (Cum Laude) in Chemical Engineering from the Technion-Israel Institute of Technology in 1987 and a Ph.D. in Chemical Engineering from the University of Rochester in 1992.

For the past thirteen years, he has been an environmental health advisor with the Pan American Health Organization (PAHO). The main objective of his work has been providing leadership and overseeing research, technical cooperation, and capacity enhancement programs in healthy environments in several countries of Latin America.

Before joining PAHO, he was a senior air quality analyst with Sonoma Technology, Inc. in California. In 1994, he was an AAAS-EPA Environmental Science and Engineering Fellow at the Office of Research and Development of U. S. EPA in Washington, DC and received the R. C. Barnard Environmental Science and Engineering Award for outstanding Fellow.

Permanent address: 811 McKelligon Drive
El Paso, Texas 79912

This thesis was typed by Marcelo Korc.