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## **The Effect of Community Connectivity on Water and Sanitation Systems in Rural Panama**

M.C. Moritz

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THE EFFECT OF COMMUNITY CONNECTIVITY  
ON WATER AND SANITATION SYSTEMS IN RURAL PANAMA

By

M. C. Moritz

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Civil Engineering

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This thesis has been approved in partial fulfillment of the requirements for the Degree of  
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Department of Civil and Environmental Engineering

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## **Preface**

Dr. Mark Rouleau aided in the preparation of section 5.1, titled *Descriptive Statistics*, and section 5.2, titled *Regression Analysis*. This aid included suggestions for SPSS Data coding, regression model input recommendations, help with independent variable selection, and guidance on interpreting statistical results. Material from chapters 1 - 5 will be submitted in the near future for publication in a journal.

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Allison Gokbudak	Oswaldo Galicia	Kimberly Pearson
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Finally, I thank my office mate, classmate, travel companion, fellow volunteer, emergency contact, voice of reason, and friend: Leigh Miller.

## Abstract

The world has yet to realize universal access to water and sanitation. Various academic and professional fields provide frameworks for understanding water and sanitation access, but none directly consider the impact of community connectivity. Community connectivity refers to the infrastructures linking rural communities with urban centers. These infrastructures fall under the broad categories of transportation, energy, and telecommunication. This paper examines 23 rural Panamanian communities and compares connectivity measures with the functionality of the communities' rural water and sanitation systems (RWSS). Community connectivity was evaluated with the Community Connectivity Analysis Tool (CCAT), while the water and sanitation systems were evaluated with the *Sistema de Información Sobre Agua y Saneamiento Rural* (Rural Water and Sanitation Information System, SIASAR). Statistical analysis revealed that commutes with more time spent in automobiles and on foot were linked with lower water system functionality. Infrastructure projects can have many goals from expanding markets to increasing access to education. By understanding what kinds of infrastructure make the biggest impact on RWSS, state and local governments can make wiser investments to better serve rural populations.

## 1. Introduction<sup>1</sup>

### 1.1 Infrastructure Challenges

Of the 663 million people worldwide who lack access to an improved water source, 80% live in rural areas (WHO/UNICEF 2015). Although this means roughly one in every 11 people do not have water access, this number is down after numerous efforts by the United Nations (UN) to spur international action. In the last 40 years, the UN has created the International Drinking Water Decade (1981 – 1990), the International Decade for Action (2005 – 2015), and the Millennium Development Goals (2000 – 2015) in an effort to achieve universal water and sanitation access. In 2012 the World Health Organization (WHO) and the UN Children’s Fund (UNICEF) reported meeting one of the Millennium Development Goals by halving the portion of people without access to safe drinking water (UNICEF 2012).

Since 1990, over 2.6 billion people have gained access to an improved water source (WHO 2015). Most of these people are first-time users connected to newly built systems. This means that the challenge facing universal water access is shifting from *building* infrastructure to *maintaining* it (Moriarty et al. 2013). The WHO/UNICEF Joint Monitoring Programme (JMP) reported that 427 million people in sub-Saharan Africa alone have gained access to an improved water source in the last 25 years (WHO/UNICEF 2015). But it is clear that these newly built systems face maintenance challenges. For example, nearly 35% of all sub-Saharan rural water systems area are not functioning (Harvey and Reed 2006).

Before the world can maintain sustainable RWSS, it must face sobering economic realities. In rural Tasmania, local governments rely on the revenue generated by charging rural water users a monthly fee at municipal rates. However, rural populations are smaller and simply cannot generate the same revenue stream as their urban neighbors. In a recent study, twelve local Tasmanian government representatives identified their rural location as a significant hindrance in fulfilling their responsibility to meet regulatory requirements and provide safe drinking water (Whelan and Willis 2007). When the cost of operations and maintenance (O&M) must be paid by a small population the fee per user can be exorbitant. Researchers in Uganda found the same problem and cited these high per-user costs as a likely cause of O&M failure (Quin et al. 2011). Another economic reality is that many people without access to water in rural areas are considered “poor”. Quantifying exactly *how* poor is challenging because household incomes for the rural poor are complex, dynamic, and notoriously hard to measure in monetary terms (Cohen and Sullivan 2010). The rural poor are not completely without resources, but livestock and land are not liquid assets and cannot be easily used to pay monthly water user fees.

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<sup>1</sup> Material contained in this chapter is in preparation for submission to a journal.



Routine monitoring, reporting, and evaluation (MRE) for urban systems is far easier than for RWSS. A 2010 study from Colombia found that there was no water quality information for nearly one third of nation's population because rural areas are difficult to access (Wright et al. 2014). Although incomplete, the data from this study indicate a disturbing disparity between rural and urban systems where only 60% of rural systems passed the water quality tests compared to 100% compliance for urban systems (Wright et al. 2014). This trend of non-compliance was seen again in rural Sudan where results showed fecal coliform counts far higher in rural and nomadic communities than in the peri-urban community (Musa et al. 1999).

The lack of routine water quality testing is due in part to the physical isolation of rural communities and the scarcity of testing facilities. When ice is unavailable to preserve the water sample, the WHO recommends a transportation time of two hours or less between the sample location and the testing facility. This leaves few options for rural areas that lack the climate and/or electricity to make ice. The WHO also recommends one sample per month for all piped drinking water systems and additional samples for systems that serve populations greater than 5000. The Panamanian regions considered in this paper, Bocas del Toro and Nökríbo, have no testing facilities whatsoever, and none of the service providers in this study conduct monthly quality testing.

### *1.2 Community-based Management Challenges*

In the 1980s, the community-based management (CBM) framework gained momentum in the developing world for several reasons. Firstly, water users were unsatisfied with government management of RWSS. Secondly, many non-government organizations (NGOs) structured their projects so that community members would manage O&M of the system after the NGO provided the initial capital investment and training. Additionally, a Western idealization of communities in low-income countries fueled a belief that small rural populations could manage their water systems independent of institutionalized assistance. Researchers studying RWSS in Ghana, Kenya, Uganda, and Zambia noted that “Rural water systems in high-income countries are not generally managed successfully by communities, so why should there be an automatic expectation that they can be in low-income countries?” (Harvey and Reed 2006, p. 367). Ideally, remote communities would form water committees to collect user payments, inspect the system, test water quality, and make repairs when necessary. However, the CBM framework had unrealistic expectations for what can be achieved by community members volunteering their time informally (Moriarty et al. 2013). Subsistence farming often involves time-consuming, back-breaking labor. The added responsibility of managing a water system, even if that responsibility falls to a committee, can be a heavy burden.

The CBM framework also assumes that the water committee will be properly trained to carry out all financial and technical operations for the design life of the system (Harvey and Reed 2006). As a U.S. Peace Corps volunteer, the author facilitated robust training programs for rural water committees. However, this knowledge is often lost or degraded

over time. Key leaders in the community may die, move to another town, or take on other responsibilities. Communities with small populations (i.e. 300 people) may face leadership burn-out when the same small group of people volunteers for committees and workdays. Without access to digital media communities must rely on printed paper materials, which have an alarmingly short lifespan in tropical climates. As discussed in the previous section, the community will most likely be unable to generate sufficient funds to cover major repairs even with the leadership of a well-trained water committee. Cost-efficient construction methods, such as ferrocement storage tanks, can ease the financial burden. But if the original water source dries up, becomes contaminated, or is outstripped by population demands, most rural communities will not have sufficient funds to develop a new or expanded system.

The global community has made substantial efforts to increase water and sanitation access. However, many projects constructed RWSS in locations where regular maintenance is economically unfeasible or routine water quality testing is physically impossible. CBM, once touted as the solution for managing RWSS, has not been a panacea. The UN recognizes the access to safe and clean drinking water and sanitation as a human right (UN 2010). But if rural spaces are to be included in the pursuit of universal water and sanitation access, it is important to examine *community connectivity*, the way goods, information, and people move to and from these remote places.

### *1.3 Community Connectivity*

The gap between urban and rural development is common across the globe. A study on Chinese poverty reduction efforts in the 1980s found that geographically isolated regions were less conducive to rapid poverty reduction programs and were essentially abandoned by the state (Cohen and Sullivan 2010). These isolated rural regions may lack roads or navigable rivers, or else travel along existing roads and rivers may be prohibitively expensive for local communities. In such remote communities there may also be no reliable electricity to charge a cell phone nor cell signal strong enough to justify the effort. With regards to RWSS O&M in such spaces, “it is difficult to see any viable medium-term solution other than self-supply, but self-supply that is recognized and supported by the state and its agencies” (Moriarty et al. 2013, p. 337).

This state and/or agency support is only possible if rural areas are physically accessible, or accessible via telecommunications. There are many kinds of connective infrastructure that can be divided into the broad categories of transportation, telecommunication, and energy. These types of infrastructure projects can be expensive, but states must be willing to invest in rural infrastructure to close the gap between the urban and rural standards of living (Tang et al. 2016). Rural infrastructure is unlikely to create direct economic returns (Shen et al. 2011), however, a more holistic approach takes into account the benefits of a healthier, more productive population that can share resources more efficiently. Enhanced connectivity has the power to reduce poverty, increase economic growth, create equitable access to information, and even mitigate conflict and promote peace (Bhattacharyay 2012).

The costs of constructing RWSS should include the cost of the connective infrastructure necessary for adequate O&M. This paper will show how all three types of connective infrastructure influence RWSS functionality. Ideally, every rural water committee would be able to take a water sample to a testing facility in under two hours. The water committee would be able to call their local health ministry for support and, when the problem was too extensive for a quick repair, the health ministry or other authority would be able to travel to the rural community and address the issue. By understanding *what kinds* of connective infrastructure make the biggest impact on the functionality of RWSS, state and local governments can make wiser infrastructure investments.

## **2. Existing Frameworks and Models<sup>2</sup>**

The concept of community connectivity intersects many formal academic and professional disciplines. As a result, existing frameworks from economics, ecology, and sociology brush against the concept of connectivity, but do not address it directly as it relates to water and sanitation access. Similarly, a diverse array of professions, from urban planning to transportation engineering, have developed methodologies for maximizing the efficiency of connective systems, but again not with the explicit intention of improving RWSS functionality. This is a critical gap in the global conversation on universal water and sanitation access. When the UN recognized water access as a human right, it called upon states and international organizations to scale up efforts to provide safe, clean, accessible and affordable drinking water and sanitation (UN 2010). This resolution acknowledges both the need for institutional support and the responsibility of states to provide that support. This human rights framework builds the case for developing connective infrastructure, albeit indirectly.

The MDG were developed based on a human rights framework, however, the MDG metrics for assessing access to water and sanitation are limited. A study from Cambodia and Viet Nam noted that simply looking at water system ‘coverage’ does not capture a realistic picture of safe domestic water provision (Guppy 2014). Other researchers have come to the same conclusion by pointing out that water system coverage as reported by the WHO/UNICEF Joint Monitoring Programme does not address the water quality or level of service (Moriarty et al. 2013).

As discussed previously, CBM has proven to be an ineffective framework for RWSS O&M. This shortcoming is due, in part, to the fact that CBM only indirectly considers community connectivity. One aspect of CBM includes choosing an appropriate technology that is in line with a community’s financial, technical, and management capabilities (Bouabid and Louis 2015). This paper will argue that all these components of a community’s capacity are directly linked to its level of connectivity. Another aspect of CBM is the idea of community participation as a critical component to sustainability.

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<sup>2</sup> Material contained in this chapter is in preparation for submission to a journal.

Community participation empowers local stakeholders; however, it should also give communities the space to decide *not* to be in charge of their own fee collection, water testing, and infrastructure maintenance, especially if there is another option (Harvey and Reed 2006).

The Demand-Responsive Approach (DRA) was designed so communities could demand the kind of services they need and the appropriate NGO or state institution would respond accordingly. The idea was to encourage communities to be proactive and foster a sense of ownership of the RWSS. Meanwhile, the institutions would be forced to consider stakeholder input when designing a solution. However, the DRA framework is also defective, firstly because a sense of ownership does not necessarily translate to better O&M (Harvey and Reed 2006), and secondly because it does not consider community connectivity. In order to make a demand, the rural community needs to be able to contact the appropriate organization. This is a tall order in locations without roads, cell signal, or electricity. Similarly, the service-delivery framework asserts that rural water services should be provided by clearly identified service providers operating under standards that are enforced by a legitimate authority (Moriarty et al. 2013). Again, this framework assumes that the authoritative body will have access to the community and fails to provide a solution for isolated rural spaces – the spaces with the least access to water and sanitation.

The water poverty index (WPI) is another holistic framework aimed at understanding water and sanitation access. The WPI framework takes into account the physical water supply, the household access to the supply, the capacity for households to manage their water access, and the environmental impact of a given system. Although these components paint a more complete picture than a simple metric of “coverage”, the WPI fails to take into account the isolation of the rural community. When the WPI was applied to a study in Cambodia and Viet Nam, it was concluded that these WPI measure had relatively little connection to how water was actually being used by respondents in the village (Guppy 2014). The term “water poverty” attempts to illuminate a closed-loop connection between societal well-being and water access, where a lack of water access decreases human productivity, impoverishing the society to a level at which it is unable to improve access to water. However, it has been argued that water-induced poverty is different from economic poverty (Komnenic et al. 2009). Komnenic et al. went on to state that “the WPI does not assess the capacity to address water issues, i.e. it does not express the social resources within the society to counter water scarcity” (Komnenic et al. 2009, p. 220). The social resources within a community are closely related to the concept of community connectivity.

The Water, Economy, Investment and Learning Assessment Indicator (WEILAI) is yet another framework that builds on the methodology of the WPI and the basic needs framework for poverty alleviation (Cohen and Sullivan 2010). Although it considers water access from a household level instead of a community-wide level, the factors concerning water resource management capacity only evaluate the presence of a water committee, the household participation in water management, and the speaking abilities and education

levels of the head of the household. Again, the concept of community connectivity is notably absent from this framework.

The capacity factor analysis model (CFA) attempts to quantify a community's needs and abilities in order to recommend appropriate water and sanitation interventions (Bouabid and Louis 2015). The eight factors are listed and defined in Table 1. Of the frameworks discussed, this framework most closely resembles the community connectivity studied in this paper. The technical factor, for example, includes a metric regarding the supply chain and the availability of services. In this paper, the supply chain is evaluated by quantifying a round trip from the remote community to the nearest urban center in terms of time, monetary cost, mode of transportation, and the effect of inclement weather. The energy factor in the CFA and electricity access in this study are nearly identical, although the CFA incorporates a measure of energy reliability while this study only quantifies what kinds of electrical sources are available in a given community. The CFA framework aims to measure a community's capacity, while this study measures a rural community's connectedness to the nearest urban center. Stronger urban-rural links result in rural communities more capable of managing a RWSS.

Table 1: Capacity Factors from Bouabid and Louis 2015, p. 337

	<b>Capacity Factor</b>	<b>Definition</b>
1	Service	Quantity, Quality, Accessibility (distance form user)
2	Institutional	Policies (laws, regulations), Programs (administration, jurisdiction), Processes (permits, performance)
3	Human Resources	Professional, Skilled Labor, Unskilled Labor - Literate and Illiterate
4	Technical	Operations, Maintenance, Adaption, Supply chain: Spare parts, Supplies, Services
5	Economic/Financial	Private Sector %, Bonds Rating, User Fees, Budget, Asset Values
6	Energy	Grid Electricity Access, Other electricity access, % of budget, reliability factor (annual hours / 8766)
7	Environmental/Natural Resources	Annual Withdrawal % of (stock + recharge), Background quality
8	Social/Cultural	Community, Stability, Castes/Clan/Ethnicity/Women Participation

Surprisingly, some of the most useful frameworks for understanding community connectivity do not come from the social sciences. Recent research on human movement behavior used network analysis to examine spatially distributed infrastructure (Wu et al. 2016). Wu et al. found that administrative regions are often based on cultural and geographical environments. This division effects the construction of connective infrastructure, but may not always be consistent with the actual human movements of the population (Wu et al. 2016). The need for interregional and international collaboration becomes clear when human movements are taken into consideration.

Social Network Analysis (SNA) provides useful insights into community connectivity. SNA uses mathematical formulas to explain how individual units (i.e. cars or bits of

information) move through a network of edges and nodes. When used by civil and construction engineers, the edges and nodes may symbolize roadways and intersections. When used by social scientists, the nodes typically represent people and the edges represent their interpersonal relationships. A recent study used SNA to improve transportation planning in Mississippi by investigating which streets and intersections were most vital for the effectiveness of the whole road network (El-adaway et al. 2016). Similarly, this paper examines the different kinds of connections between rural communities and local centers of commerce. Is reliable cell service more important to RWSS functionality than road access? Is having inexpensive transportation more important than having rapid transportation? Just as SNA can decrease the cost of transportation planning and provide a more holistic approach to evaluating a population's transportation needs, evaluating the impact of community connectivity on RWSS O&M can help decrease the costs of future connective infrastructure projects.

The human rights framework is fundamental in studying water and sanitation access for two reasons: it establishes universal access as a human right and places the responsibility for providing access on institutions as opposed to individuals. This chapter discussed various means to achieve this end including community-based management, demand-responsive approach, and the service-delivery model. These approaches, however, are difficult to apply in rural settings because water committees are isolated from the services and facilities found in urban centers such as banks, hardware stores, water quality testing labs, and health department offices. The water poverty index (WPI) and the Water, Economy, Investment and Learning Assessment Indicator (WEILAI) attempt to understand how and why certain populations continue to lack access to water and sanitation, but neither framework considers the isolation of rural communities. The difficulty of making a phone call or purchasing a sack of cement are not addressed in the various WPI and WEILAI indicators.

Capacity factor analysis, on the other hand, *does* consider some of these elements of rural living by including measures of the local supply chain and access to reliable electricity. Human movement behavior and social network analysis offer insights into how rural areas interact with urban centers. This study seeks to build on these frameworks by measuring rural community connectivity and showing the relationship between connectedness and RWSS functionality.

### **3. Panamanian Context<sup>3</sup>**

Panama is a narrow isthmus connecting North and South America. The Panama Canal, which cuts through the provinces of Colón and Panamá, has served as a strategic shipping lane since its completion in 1904. As a result, the Panama City-Colón metropolitan corridor, which is located next to the canal, is home to more than half of the country's population (Guitierrez 2010). This highly developed region stands in stark contrast to the less developed rural areas of Panama, especially the four *comarcas*, or indigenous

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<sup>3</sup> Material contained in this chapter is in preparation for submission to a journal.



provinces. These provinces, shown in Figure 1, are the Comarca Ngäbe-Buglé, the Comarca Kuna-Yala, and the two distinct regions of the Comarca Embera-Wounaan.



Figure 1: Provinces and Comarcas of Panama. Author: Hanna5974, Wikipedia Commons, Creative Commons, CC-BY-SA-3.0

A portion of the Comarca Ngäbe-Buglé is included in this study, and it is important to note that this region of Panama has its own semi-autonomous government operating within the larger national government. This comarca was formed in 1997 after considerable pressure from indigenous groups concerned about natural resource exploitation and degradation of their ancestral lands. The current boundaries of the comarca include land previously belonging to the provinces of Bocas del Toro, Chiriquí, and Veraguas.

Figure 2 illustrates the Cordillera Central, a mountain range that runs through the center of the country. The highest point, Volcán Barú, is located near the northern border of the Chiriquí province and reaches an elevation of 11,395 ft (Smithsonian Institution 2013). Until the late 1990s, this mountain range separated the Bocas del Toro province and the Caribbean side of the Comarca Ngäbe-Buglé (called Ñökribo) from the rest of Panama. Today these regions are connected by a single two-lane road, Route 10, shown in Figure 3.

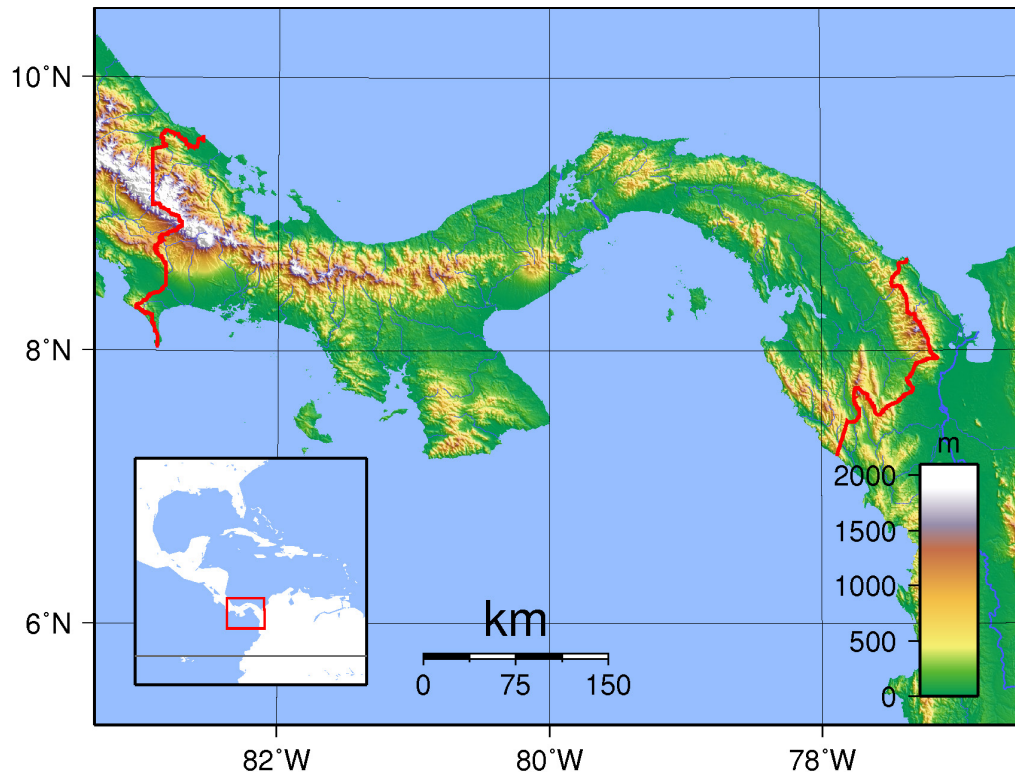


Figure 2: Panama Topography. Author: Sadalmelik, Wikipedia Commons, Creative Commons, CC-BY-SA-3.0

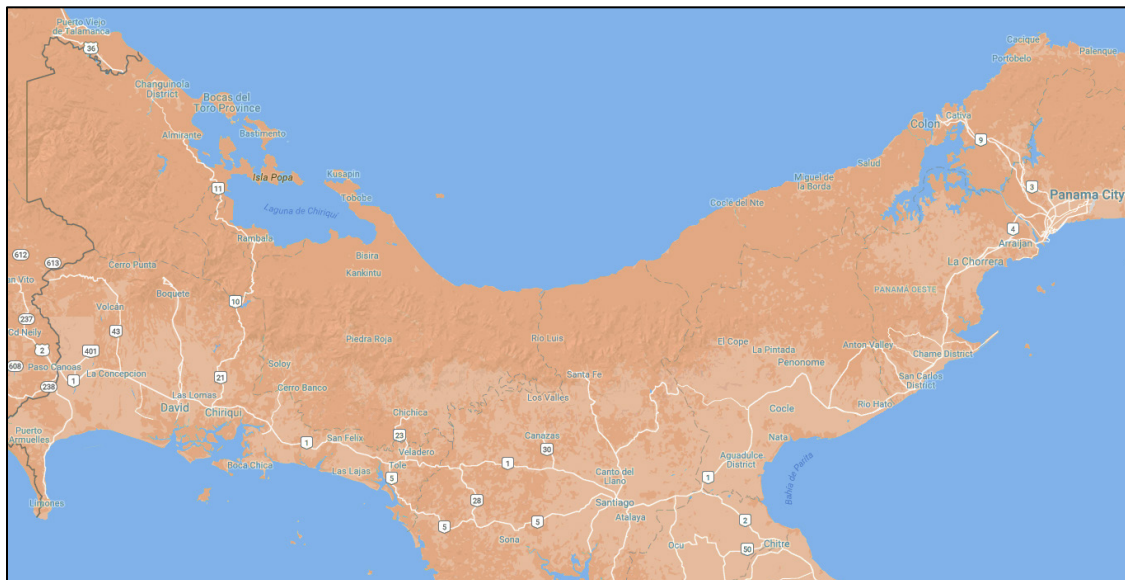


Figure 3: Major Routes in Western Panama. Source: Google Maps 2016



Partially as a result of this geographic isolation, Ñökribo and the province of Bocas del Toro remain less densely populated than the more connected Pacific side of Panama. Other large rural areas include the southern part of the Azuero Peninsula and the eastern portion of the country near the Colombian border. The most densely populated areas are in the Panama City-Colón metropolitan corridor and near the Pan-American Highway which runs along the Pacific coast of the country.

While the national population of Panama has more than doubled in the last 40 years, the rural population has grown much more slowly as shown in Figure 4. This shift in the population distribution partially accounts for the improvement in access to water and sanitation at the national level.

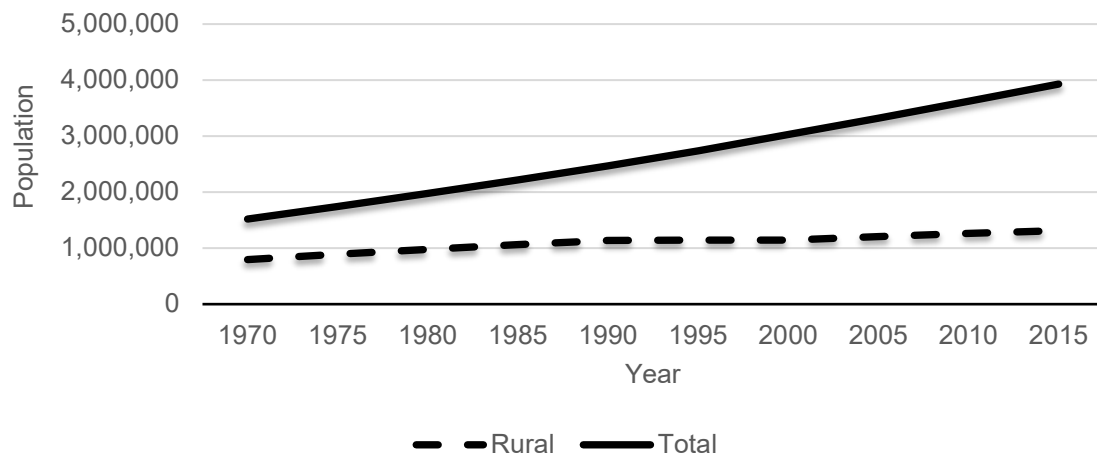


Figure 4: Panama Population Data. Data from “World Development Indicators” by The World Bank Group.

Like many other countries, Panama’s rural population has historically lagged behind the country’s urban population in terms of access to water and electricity, as shown in Figure 5 and Figure 6. The last 25 years have seen dramatic improvements in water and electricity access in rural areas, but in order to reach universal access the country will have to invest in connective infrastructure in extremely remote regions.

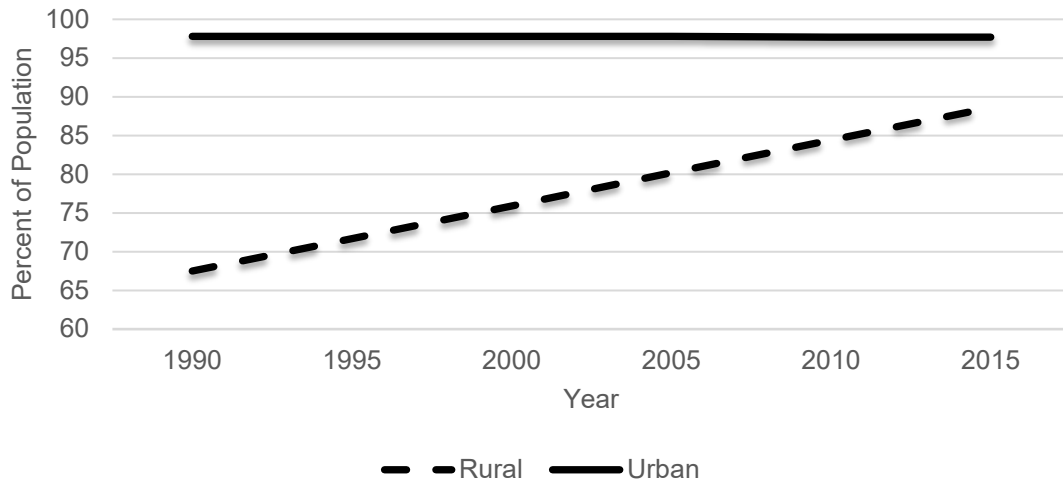


Figure 5: Access to Improved Water. Data from “World Development Indicators” by The World Bank Group.

Access to electricity is an important component of community connectivity. Computers and cell phones obviously require electricity, but in most rural communities this electricity comes from either gas / diesel generators or solar power. Figure 6 shows the improvement in electricity access in rural areas but also the persistent gap between urban and rural access.

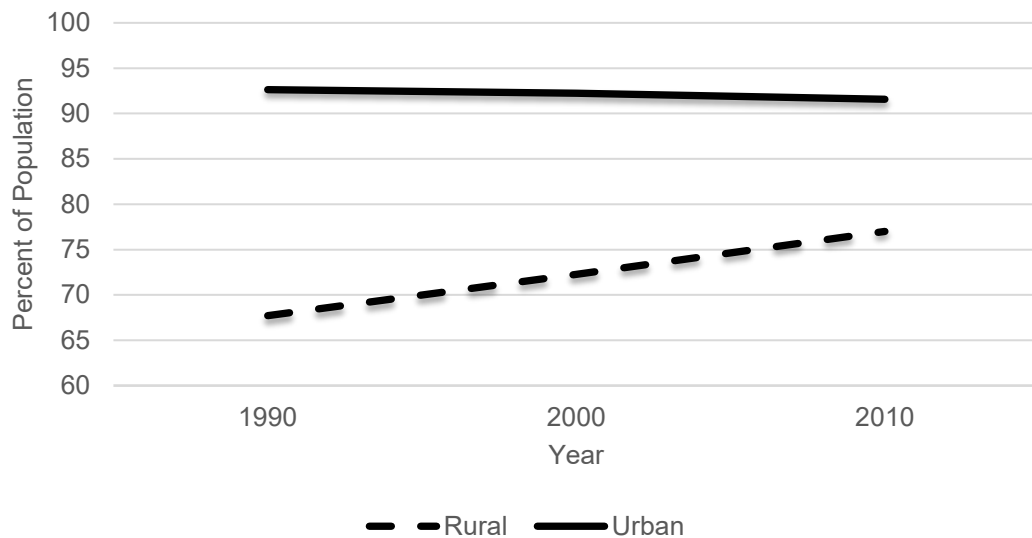


Figure 6: Electricity Access Data. Data from “World Development Indicators” by The World Bank Group.

The vast majority of energy produced in Panama comes from its 31 hydroelectric power plants (Schneider 2015). The western half of the country has steep mountains with numerous rivers which are easily accessible from the Pan-American Highway. Figure 7 shows the relatively small portion of power produced from oil and coal.

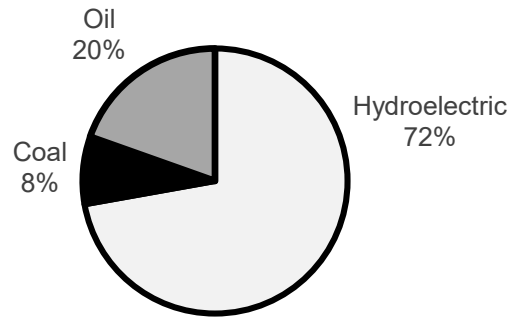


Figure 7: Panamanian Energy Production in 2013. Data from “World Development Indicators” by The World Bank Group.

The last ten years have seen an increase in the number of internet users and a sharp rise in the number of mobile cellular subscriptions. Figure 8 compares the United States and Panama in terms of number of internet users and cell subscriptions per 100 people. In 2015, the number of Panamanian cell subscriptions was approximately 150% the number of U.S. cell subscriptions per 100 people. This is due, in part, to the geography of Panama and the scarcity of cell towers. Cell users, especially rural cell users living in mountainous areas, may use multiple service providers to take advantage of the nearest tower.

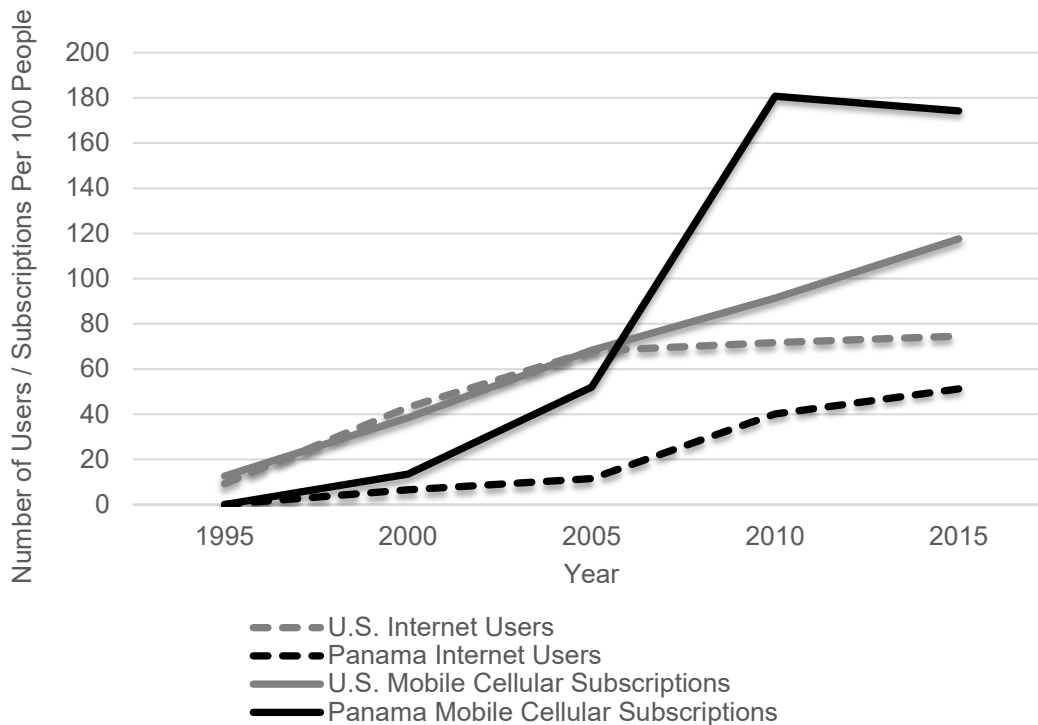


Figure 8: Internet and mobile cellular user data. Data from “World Development Indicators” by The World Bank Group.

As stated previously, the communities in this study are located in the Bocas del Toro province and Ñökribo, the portion of the Comarca Ngäbe-Buglé located on the Caribbean side of the Cordillera Central. It is important to note that these areas are especially rural and undeveloped in comparison to the rest of Panama. The Cordillera Central kept these areas geographically isolated from the rest of Panama until the construction of Highway 10 in the late 1990s. Falling within the boundaries of the Comarca Ngäbe-Buglé, the Ñökribo region faces the added challenge of political isolation from the larger Panamanian national government. This study focuses on Bocas del Toro and Ñökribo because these added factors of inaccessibility make managing RWSS especially challenging. The country's geography and energy production profile shed light on the difficulties of providing electrical grid access to these rural areas. Additionally, the growing urban and stagnant rural populations helps explain the lack of political will to address the gap between the rural and urban standard of living. Panama is a democracy where the rural electorate has been shrinking for the last 45 years.

#### **4. Methodology and Hypotheses<sup>4</sup>**

##### *4.1 The Community Connectivity Analysis Tool*

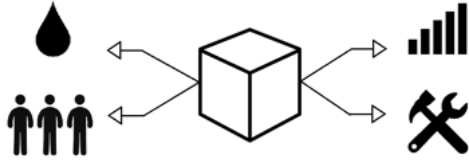
Connective infrastructures can be broadly categorized as relating to transportation, telecommunication, and energy. Rural communities do not often interact with each other; however, these communities have frequent exchanges of people, goods, money, and information with urban centers. (Wu et al. 2016). For this reason, the Community Connectivity Assessment Tool (CCAT), developed for this study, evaluates the round trip from the community to the nearest center of commerce and also considers the community's energy and telecommunication infrastructure. Herein, a "center of commerce" refers to a town large enough to have a hardware store that sells cement. The CCAT was not designed to generate a single connectivity score. Instead, the different aspects of connectivity are considered separately as they relate to water and sanitation system functionality.

The CCAT was applied in the field by U.S. Peace Corps volunteers. The first page of the two-page survey, shown in Figure 9, asks for the volunteer's name, the community name, the province, and the date of the assessment. The next section collects information about the accessibility of the community and the water system by using the water storage tank as a reference point. Volunteers filled out how many minutes it takes to get from the storage tank to the water source, the monetary cost of travel (if applicable), and the mode of transportation used. Volunteers also rated the effect of inclement weather on each leg of the journey. The same parameters were used to assess the journey from the storage tank to the nearest hardware store. These fields evaluate the connective infrastructures related to transportation.

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<sup>4</sup> Material contained in this chapter is in preparation for submission to a journal.

Volunteer Name				
Community				
Province				
Date				



This tool evaluates community accessibility and connectivity. The **water storage tank** is the point of reference for all relevant fields. Fill in one line for each leg of the journey.

Use the comments box to describe important aspects of the journey (i.e. dramatic elevation changes, rough terrain, or transport that is only available on certain days)

		Time (Minutes)	Cost (USD)	Transport Mode	Effect of Inclement Weather
From Storage Tank to Water Source	Leg 1				
	Leg 2				
	Leg 3				
	Leg 4				
From Storage Tank to Hardware Store	Leg 1				
	Leg 2				
	Leg 3				
	Leg 4				
Comments				Write the number corresponding to the mode of transportation	Write the number corresponding to the effect of inclement weather
				1. On foot 2. Pickup truck (Chiva) 3. Bus 4. Boat	1. No effect 2. Increases time 3. Increases time and cost 4. Can make travel impossible

Figure 9: Page 1 of the CCAT

The next portion of the CCAT, shown in Figure 10, examines the community's locality by asking volunteers to count how many communities are within a 30, 60 and 90-minute walk from the water storage tank. Volunteers provided basic water system information by selecting the type of water source and the water storage tank material. The final sections of the CCAT focus on the telecommunications and energy infrastructures by asking if an *infoplaza* (a public internet access location) is present in the community, if phone cards are sold in the community, and how far a person must walk from the water storage tank to find cell service. *Infoplaza* fees generally range from \$0.25 - \$0.50 per 30 minutes of computer time. Phone cards are also an important aspect of telecommunications because the vast majority of Panamanians purchase small data, calling, or text packages as opposed to signing a contract and paying a monthly fee. Service varies by cell provider, but generally 100 texts could be purchased for \$1.00. Lastly, volunteers were asked to indicate the number of homes with solar panels, generators, and wired electricity. These fields were designed to establish the level of electricity access in the community.

	Number of communities within 30 minute walk		Number of communities within 31 - 60 minute walk		Number of communities within 61 - 90 minute walk	
	Neighborhood Comments					

Check one box to indicate water source	Spring (ojo)		Check one box to indicate storage tank material	Plastic		Aqueduct Comments
	Creek			Concrete Blocks		
				Ferrocement		

Infoplaza present? (Y or N)	
How far does one have to walk from the storage tank to find cell phone signal? (number of minutes)	
Phone cards sold in this community? (Y or N)	

Check one box to indicate number of homes with solar panels		
None	Less than half	More than half
Check one box to indicate number of homes with generators		
None	Less than half	More than half
Check one box to indicate number of homes with wired electricity		
None	Less than half	More than half
Cell Signal and Electricity Comments		

Figure 10: Page 2 of CCAT

#### 4.2 *Sistema de Información Sobre Agua y Saneamiento Rural (SIASAR)*

*Sistema de Información Sobre Agua y Saneamiento Rural* (Rural Water and Sanitation Information System, SIASAR) is a joint initiative launched by the governments of Panama, Honduras, and Nicaragua (SIASAR User Manual, 2012). As stated in the 2012 SIASAR User Manual, the objective of this project is to create a tool to evaluate rural water and sanitation systems in order to:

- Support various actors in planning and coordinating water and sanitation projects
- Monitor the coverage, quality, and sustainability of rural water and sanitation services
- Record the performance of service providers
- Make rural water and sanitation data public for use by states, NGOs, and all other interested parties

Since its inception in 2012, the SIASAR project has expanded to include data from the Dominican Republic, Costa Rica, Mexico, and Peru. Data are gathered by various actors including community health extension workers, U.S. Peace Corps volunteers, community leaders, health ministry officials, and other persons trained on the use of the SIASAR survey. The survey can be completed either on paper or via the SIASAR mobile application. In Panama, the results are uploaded onto the SIASAR website by staff from the *Ministerio de Salud* (Health Ministry, MINSA).

The SIASAR survey evaluates the status of water and sanitation (watsan) in a given community by examining four components: the community, the system, the service provider, and the technical assistance available. Each of these four components receives a classification of either A, B, C, or D, with A representing the highest level of functionality and D representing the lowest. Table 2 defines each classification level.

Table 2: Classification system for watsan components

Component	Classification			
	A	B	C	D
<b>Community</b>	The community has a healthy environment and adequate watsan coverage	The watsan coverage in the community is not complete	The community has serious deficiencies in watsan coverage	The community has serious environmental problems and very low watsan coverage
<b>System</b>	The system functions correctly	The system has deficiencies that can be addressed by the service provider	The system has serious deficiencies that cannot be addressed by the service provider	The system does not function
<b>Service Provider</b>	The service provider is well organized and ensures sustainability	The service provider is somewhat organized and sustainability is likely	The service provider is not well organized and sustainability is unlikely	The service provider is inactive and the systems is at risk of failing
<b>Technical Assistance</b>	The technical assistance provider works appropriately and has sufficient resources	The technical assistance provider is not fully supportive and has scarce resources	The technical assistance provider barely fulfills its roles and/or lacks resources	The technical assistance provider is not fulfilling its roles and does not have the necessary resources

Each individual component also has its own scoring system. On the SIASAR survey there are 33 questions that feed into the 8 criterion for the community component. The hygiene criteria score, for example, is determined by the answers to three questions regarding handwashing, latrine usage, and grey water management. The community scoring system is explained in Table 3. Note that only a score of 4, 3, or 1 is possible for the environment and hygiene criterion.



Table 3: Community Scoring

Community Criterion	Score			
	4	3	2	1
Improved drinking water coverage	Greater than 80%	65-80%	50-65%	Less than 50%
Improved sanitation coverage	Greater than 80%	65-80%	50-65%	Less than 50%
Sustainable water coverage (SWC)	Greater than 80%	60-80%	50-60%	Less than 50%
Sanitation coverage with flush toilets	Greater than 30%	20-30%	10-20%	Less than 10%
Social care centers with improved drinking water	100%	80-100%	50-80%	Less than 50%
Social care center with improved sanitation	100%	80-100%	50-80%	Less than 50%
Environment	Good	Regular	-	Bad
Hygiene	Good	Regular	-	Bad

Importantly, the sustainable water coverage (SWC) criterion in Table 3 is calculated with Equation 1 which includes weighting factors based on the service provider and system classifications (shown in Table 4). For example, a service provider classification of “B” would result in a weighting factor of 0.66. A system classification of “A” results in a weighting factor of 1.00. These values are then used to calculate the SWC. In this way the community component of the SIASAR survey is tied to the service provider and the system components.

$$SWC = \frac{\left( \frac{\text{number of households connected to the system}}{\text{number of households in the community}} \right) \times (system_{wf}) \times (service\ provider_{wf})}{1} \quad (1)$$

Table 4: SWC weighting factors

Classification	SWC Weighting Factor
A	1.00
B	0.66
C	0.33
D	0.00

After calculating the scores from the eight community criterion, the scores are averaged to determine the community classification by using the scale shown in Table 5.

Table 5: Calculation for community classification

Average	Classification
3.5 - 4.0	A
2.5 - 3.49	B
1.5 - 2.49	C
< 1.49	D

A similar procedure is followed to determine the SIASAR classification for the service provider and system components. The system component takes survey answers from 37 questions and again uses these responses to assess 8 criteria related to the water system. Table 6 shows the scoring system for these indicators. The calculation of the system classification is a simple sum of the scores for each indicator, as shown in Table 7.

Table 6: Scoring for system component

Criterion	Score			
	4	3	2	1
Flow rate	Supply $\geq 1.5 \times$ Demand	$S \geq 1.0 \times D$	$S \geq 0.8 \times D$	$S < 0.8 \times D$
Water catchment	Good condition	Requires maintenance	Requires minor improvements	Requires reconstruction
Conduction line	Good condition	Requires maintenance	Requires minor improvements	Requires reconstruction
Storage tank	Good condition	Requires maintenance	Requires minor improvements	Requires reconstruction
Distribution network	Good condition	Requires maintenance	Requires minor improvements	Requires reconstruction
Storage capacity	Capacity $\geq 1.35 \times$ Required	$C \geq 1.0 \times R$	$C \geq 0.8 \times R$	$C < 0.8 \times R$
Micro watershed	No deforestation	Little deforestation that does not affect the system	Some deforestation that has a small effect on the system	Severe deforestation that affects the system
Residual chlorine (mg / L)	$1.0 \leq RC < 1.5$	$0.2 \leq RC < 1.0$	-	$RC < 0.2$

Table 7: Calculation for system classification

Sum	Classification
25 or more	A
17 - 24	B
16 - 9	C
8	D

There are 39 survey questions to evaluate the quality of the service provider. In this context, the term “service provider” refers to the organization responsible for the O&M of the RWSS. For all 23 communities included in this study, the service provider is a water committee consisting of 1–7 elected community leaders. This is typical of RWSS in Panama, especially in the Bocas del Toro and Ñökribo areas. The scoring system for service providers is shown in Table 8, and the classification calculation is shown in Table 9.

The technical assistance component is designed to capture information about supportive institutions. This component is not tied to one community in particular, and classifications of this component are not included on the SIASAR map at this time. Some of the institutions under consideration include health ministry offices, water quality testing facilities, and engineering firms with departments dedicated to RWSS support. Technical assistance classifications are beyond the scope of this paper because these data are not tied to a specific community, nor does the information have a geographic component. For example, a single health department office may serve several hundred communities, and the quality of technical assistance provided to each of these communities may not be equal.

Table 8: Scoring for service provider

Criterion	Score			
	4	3	2	1
Watsan committee management: score given by the number of criteria with affirmative responses	1. Committee is legalized	Three criteria fulfilled	Two criteria fulfilled	One criteria fulfilled or none
	2. All positions are filled			
	3. Meets 4 times every 6 months			
	4. Tracks finances			
User Fees: score given by the number of criteria with affirmative responses (these criterion only apply to gravity-fed or electric pump systems)	1. User fees established	Three criteria fulfilled	Two criteria fulfilled	One criteria fulfilled or none
	2. User fees cover system costs			
	3. More than 80% of users pay			
	4. Fee is determined by consumption rates			
Financial Strength: score given by the number of criteria with affirmative responses	1. Committee has a bank account	Two criteria fulfilled	One criterion fulfilled	No criteria fulfilled
	2. Committee has financial records			
	3. Revenues are higher than costs			
Operation and Maintenance: score given by the number of criteria with affirmative responses	1. Funding exists for the extent of the design life	Two criteria fulfilled	One criterion fulfilled	No criteria fulfilled
	2. Preventative and corrective maintenance provided			
	3. System has a designated operator / plumber			
Micro watershed care	Good: community maintains a clean water source and has a reforestation program	Regular: community is actively reforesting and protecting the water source	Bad: community is not taking measures to protect the water source or the catchment device	Failed: community is doing nothing to protect the water source

Table 9: Calculation for service provider classification

Average	Classification
3.5 - 4.0	A
2.5 - 3.49	B
1.5 - 2.49	C
< 1.49	D

### 4.3 Hypotheses and Analysis

The Bocas del Toro and Nökríbo areas fall under the same organizational region for Peace Corps Panama. At a regional meeting on May 31, 2016, the premise for this research was presented to a group of roughly 40 volunteers. Paper copies of both the CCAT and the SIASAR survey were distributed with instructions to return the completed forms to the regional leader's house by June 30, 2016. At the end of the month, 17 volunteers had completed both forms with information from 23 communities where they live and work. The sample consists of 12 communities from the Bocas del Toro province and 11 communities from Nökríbo.

When examining community connectivity in southwestern Amazonia, a recent study found that paved roads accelerated population growth via migration in previously isolated communities (Perz et al. 2011). This study expects to find a similar correlation between available transportation modes and RWSS functionality. Because roads significantly reduce transportation time and mitigate the effects of inclement weather, this study anticipates that communities with this kind of accessibility will have higher SIASAR community, system, and service provider scores. Bus and truck transportation increases the round trip costs in monetary terms; however, the savings in time and the ease of transporting materials is expected to outweigh this monetary cost. Additionally, where buses and trucks are not available, the only viable alternative is often boat transport, a relatively expensive option. For this reason, communities with boat access are expected to have lower RWSS functionality than communities with road access.

When studying rural and urban communities in western China, a study found that "urban service points extensively collaborate with numerous rural service points, while rural service points collaborate with only a few urban service points" (Wu et al. 2016, p. 6). The study went on to show that rural communities do not often collaborate with other rural communities. For this reason, this study does not expect that the neighborhood indicators will have any significant correlation with the functionality of the RWSS.

In the author's experience, spring water sources are much easier to maintain than surface water sources (streams). This is because the catchment device for a stream can become clogged with organic matter and is more susceptible to erosion along the banks and the streambed. The author has also observed that ferrocement and plastic water storage tanks are less expensive to maintain than concrete block tanks. RWSS with spring sources and

plastic or ferrocement tanks are therefore expected to score higher on the SIASAR survey than RWSS with stream sources and concrete tanks.

The presence of an *infoplaza*, cell signal, phone cards, and reliable electricity all facilitate telecommunications from the community. Electricity from generators or wired electricity is considered more reliable than solar power because the pervasive rainy season offers little direct sunlight. Higher scores in these categories will likely result in higher SIASAR categorization.

Quantitative analysis was performed with Statistical Package for Social Sciences (SPSS) 24 (IBM 2015). The input method was backwards stepwise, meaning that all the independent variables are initially included in the model. The software then removes an independent variable if doing so improves the model. This process is repeated until removing additional independent variables would weaken the model. Three separate multiple linear regressions were performed. First the community component of the SIASAR survey was the dependent variable. Then the service provider component and finally the system component were made the dependent variables. The independent variables included all the indicators from the CCAT survey *and* the two SIASAR scores not serving as the dependent variable. This was done to try to capture as much of the dependent variable's variance as possible. Although the hypothesis of this study concerns the effect of connective infrastructure on RWSS functionality, other variables likely contribute. Regression analysis was chosen precisely because it can calculate the influence of individual independent variables in the model. For example, the community score and the service provider score were included as independent variables for the system score because doing so captures more facets of the reality in which the system exists. The adjusted R-squared value associated with each of the three models is reported in addition to the R-squared value because the adjusted value takes into account the number of independent variables included in the model to avoid overfitting.

## 5. Results and Discussion<sup>5</sup>

### 5.1 Descriptive Statistics

For the system component of the SIASAR survey, the average score was 23.13 (classification “B”). The average score for the service provider component was 2.06 (classification “C”) while the average community score was 2.18 (classification “C”). The classifications for each community and each component are shown in Table 10.

Table 10: System, service provider, and community classification for each community

Province	Community	System Classification	Service Provider Classification	Community Classification
Bocas Del Toro	Punta Peña de Risco	B	C	C
Bocas Del Toro	Quebrada Pueblo	B	D	C
Bocas Del Toro	Barriada Guerra, La Soledad	B	C	C
Bocas Del Toro	Quebrada Pastor	A	C	C
Bocas Del Toro	Quebrada Pluma	B	C	B
Bocas Del Toro	Quebrada Cacao (System 1)	B	B	C
Bocas Del Toro	Quebrada Cacao (System 2)	B	B	D
Bocas Del Toro	Valle Junquito	B	B	B
Bocas Del Toro	Renacimiento	B	C	C
Bocas Del Toro	Quebrada Pita	B	C	C
Bocas Del Toro	La Gloria	B	C	B
Bocas Del Toro	Cañaza	B	C	B
Ñökribo	Barriada Trotman #1	A	D	D
Ñökribo	Pumona	B	C	C
Ñökribo	Kankintú	A	C	C
Ñökribo	Calante	B	C	C
Ñökribo	Gualaca	A	D	D
Ñökribo	Kuite	A	C	C
Ñökribo	Drigari	A	C	C
Ñökribo	Cerro Ñeque	A	B	A
Ñökribo	Notente	A	D	D
Ñökribo	Odobate	C	C	C
Ñökribo	Playa Verde	B	D	B

For the telecommunications indicators, only Kankintú has an *infoplaza*; however, 20 of the communities have phone cards available for local purchase. In Ñökribo only four communities have cell signal at the water storage tank, compared to nine communities in Bocas del Toro. The energy indicators are reported in Table 11.

<sup>5</sup> Material contained in this chapter is in preparation for submission to a journal.

Table 11: Energy Source Indicator Responses

<b>Energy Source</b>	<b>Number of Homes in the Community</b>		
	None	Less than half	More than half
Solar Panels	0	13	10
Domestic Generators	9	14	0
Wired Electricity	21	1	1

All 23 communities rely on solar panels to some extent for domestic energy. Generators are less common and wired electricity is found only in Cañaza and La Gloria, both located in Bocas del Toro. The neighborhood profiles for Bocas del Toro and Ñökribo were very similar. The average number of neighboring communities within a 30, 60, and 90-minute walk were two, three, and four respectively.

In Ñökribo, nine out of the eleven communities surveyed use a stream as a water source as opposed to a spring. In Bocas del Toro this number was a little lower, with only six out of twelve communities using a stream. The type of materials used for water system storage tanks were similar in the two areas with seven communities in Ñökribo and six communities in Bocas del Toro using concrete blocks. There were two plastic tanks (both in Bocas del Toro) and five ferrocement tanks (three in Bocas del Toro and two in Ñökribo). Each province had one community where the water system did not use a storage tank and in one Bocas del Toro community the water system used both a ferrocement tank and a plastic tank.

Regarding the transportation indicators, severe storms could make travel more expensive or impossible in three communities in Ñökribo and four communities in Bocas del Toro. The mode of transportation, round trip cost, and total travel time differed considerably for the two regions. All 11 of the communities in Ñökribo have no truck or bus access and require boat travel. These boat rides cost \$10 to \$24 and take two to six hours for a round trip. In contrast, all 12 communities in Bocas del Toro have bus or truck access and none require boat travel. The result is significantly higher travel times and travel costs for communities in Ñökribo as shown in Table 12.

Table 12: Average travel times and cost by region

	<b>Average Time Traveling on Foot</b>	<b>Average Total Travel Time</b>	<b>Average Round Trip Cost</b>
Ñökribo	81 minutes	6.4 hours	\$ 18.36
Bocas del Toro	56 minutes	3.5 hours	\$ 3.51



## 5.2 Regression Analysis

Appendices A and B contain the CCAT responses and the SIASAR scores for all 23 communities. Appendices C and D show the exact formatting used to input the data into SPSS 24 for multiple linear regression analysis. This regression analysis could be affected by collinearity, as some independent variables are correlated. A complete cross-correlation matrix is provided in Appendix E. As described in the methodology section, three models were generated, one for each of the SIASAR scoring categories (system, service provider, and community). Table 13 is the model summary for the system score.

Table 13: System Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
11	0.785	0.616	0.436	2.623

In Model 11, 10 of the original 17 independent variables were removed by the backwards stepwise method. The original 17 variables were discussed in the methodology section and are also listed in Appendix C. An R-squared value of 0.616 indicates that 61.6% of the variance in the dependent variable (the system score in this case) is captured by the model. The adjusted R-squared value, 0.436, takes into consideration the number of independent variables included in the model. Thus, taking into account the fact that this model has seven independent variables, the model explains 43.6% of the variability in the system score. When considering the standard error of the estimate it is important to recall that the system scores could range from 8 point to 32 points.

The analysis of variance (ANOVA) for the system score is shown in Table 14. For this study, the most important information is found in the significance column. Although this study is interdisciplinary in nature, a value of 0.05 or less is generally accepted as “significant” in most fields of study, and the same threshold is applied to these models.

Table 14: System Model ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
11	Regression	165.405	7	23.629	3.434	0.021
	Residual	103.203	15	6.880		
	Total	268.609	22			

Table 15 lists the seven independent variables included in the model along with their respective unstandardized coefficients, standardized coefficients, and significance values. All the variables met the 0.05 significance threshold except for “Water Source”, which has

a significance of 0.057. Recall that this variable refers to the use of either a stream or spring for the water system. The unstandardized coefficients quantify the impact of a variable in terms of the units used to define the variable. For example, the “Minutes on Bus” variable, which refers to the number of minutes spent on a bus during the round trip, has an unstandardized coefficient of -0.066. This indicates that for each additional minute on a bus, the service provider score drops 0.066 points. This model then predicts that a 100-minute bus ride would decrease the system score by 6.60 points. Appendix D shows a table explaining the binary coding used in SPSS for variables without explicit units. The Bocas del Toro province, for example, was coded as “1” while Ñökribo was coded as “0”. The system model in Table 15 shows an unstandardized coefficient of 16.695 for the “Province” variable. This means that moving from “0” to “1” (Ñökribo to Bocas) increases the predicted system score by 16.695 points.

Table 15: System Model Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
11	(Constant)	16.953	3.322		5.103	0.000
	Province	16.695	4.023	2.440	4.150	0.001
	Minutes in Boat	0.058	0.017	2.023	3.492	0.003
	Minutes on Bus	-0.066	0.022	-0.877	-2.991	0.009
	Minutes in Truck	-0.038	0.015	-0.618	-2.502	0.024
	Minutes on Foot	-0.017	0.007	-0.480	-2.425	0.028
	Generators	-3.094	1.435	-0.442	-2.156	0.048
	Water Source	-2.921	1.419	-0.407	-2.058	0.057

The standardized coefficient Beta allows for comparison of the relative impact of the independent variables. The Beta coefficient is not in terms of the units of the independent variables and makes it possible to compare the impact of “Province” (which has no units) to the impact of “Minutes on Bus” (which is reported in minutes). Table 15 shows that the “Province” variable is nearly three times more influential than the “Minutes on Bus” variable.

A separate regression model was developed for the service provider component of the SIASAR score, following the same backwards stepwise method. Table 16 summarizes the

model performance statistics. An adjusted R-squared value of 0.573 indicates that 57.3% of the service provider score variance is captured by this model.

Table 16: Service Provider Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
12	.830	0.689	0.573	0.38314

The significance value reported in Table 17 is well below the 0.05 threshold. Similarly, all the independent variables included in the model have an associated significance below 0.05 as shown in Table 18.

Table 17: Service Provider Model ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
12	Regression	5.206	6	0.868	5.911	0.002
	Residual	2.349	16	0.147		
	Total	7.555	22			

Table 18: Service Provider Model Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
12	(Constant)	-0.045	0.457		-0.099	0.923
	Minutes in Truck	-0.006	0.002	-0.610	-3.054	0.008
	Impact of Weather (1 - 4)	0.442	0.124	0.782	3.567	0.003
	Round Trip Cost (USD)	-0.057	0.015	-0.792	-3.901	0.001
	Solar Panels	0.704	0.208	0.609	3.393	0.004
	Storage Tank Material	-0.928	0.265	-0.803	-3.508	0.003
	Community Score	0.916	0.177	1.072	5.187	0.000

Finally, performance statistics for the regression model for the community component of the SIASAR score are reported in Table 19. This model captured 76.7% of the variance observed in the community score.

Table 19: Community Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
12	0.911	0.830	0.767	0.33117

Table 20 and 21 show that this model and its independent variables meet the 0.05 significance threshold.

Table 20: Community Model ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
12	Regression	8.585	6	1.431	13.046	0.000
	Residual	1.755	16	0.110		
	Total	10.340	22			

Table 21: Community Model Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
12	(Constant)	0.843	0.334		2.521	0.023
	Minutes in Truck	0.006	0.002	0.480	3.386	0.004
	Impact of Weather (1 - 4)	-0.453	0.088	-0.685	-5.131	0.000
	Round Trip Cost (USD)	0.055	0.011	0.653	4.980	0.000
	Solar Panels	-0.585	0.184	-0.432	-3.171	0.006
	Storage Tank Material	1.004	0.172	0.742	5.836	0.000
	Service Provider Score	0.684	0.132	0.585	5.187	0.000

### 5.3 Discussion

To aid in the discussion, the unstandardized coefficients and their associated variables are reported in Equations 2, 3, and 4. The “Water Source” variable is not included in Equation 2 because it did not meet the significance threshold of 0.05. The constant value was also not included in Equation 3 for the same reason.

$$\begin{aligned} \text{System Score} = & 16.953 + 16.695 (\text{Province}) + 0.058 (\text{Minutes in Boat}) \\ & - 0.066 (\text{Minutes on Bus}) - 0.038 (\text{Minutes in Truck}) \\ & - 0.017 (\text{Minutes on Foot}) - 3.094 (\text{Generators}) \end{aligned} \quad (2)$$

Equation 2 shows that being located in the Bocas del Toro Province raises the system score. This is in line with expectations. This model also shows that longer bus rides, truck rides, and longer hikes all lower the system score, which all support the hypotheses of this study. However, the model shows that each minute spent on a boat during the round trip *raises* the system score by 0.058 points. Thus, a 100-minute boat ride is expected to raise the system score by 5.8 points. How could this be?

The towns of Kankintú and Cerro Ñeque, both boat-access sites, have exceptional water systems and are outliers in Ñökribo. In Kankintú, a Spanish missionary group has been actively involved in the development of this remote jungle village for the past 40 years. At 6 hours and \$24, this town has the longest and most expensive round-trip commute out of

all the communities included in this study. And yet, this site has a water system valued at \$800,000. Similarly, Cerro Ñeque has received international support from a German NGO. In 2011 the town received a \$600,000 water system. Cerro Ñeque had the highest system score, earning 29 out of possible 32 points. Kankintú followed close behind at 27 points.

With only 23 communities included in this study, the results are limited by the small sample size. Outliers like Cerro Ñeque and Kankintú would have much less influence on the model if the data included responses from several hundred communities. Unfortunately, gathering data from these remote places is difficult. The sample size was limited by the author's ability to visit the towns in person and by the number of Peace Corps Volunteers participating in the study. The small sample size may also be the cause of the confounding result regarding generators.

$$\begin{aligned} \text{Service Provider Score} = & -0.006 (\text{Minutes in Truck}) + 0.442 (\text{Impact of Weather}) \\ & -0.057 (\text{Round Trip Cost}) + 0.704 (\text{Solar Panels}) \\ & -0.928 (\text{Storage Tank Material}) + 0.916 (\text{Community Score}) \quad (3) \end{aligned}$$

Equation 3 shows that longer truck rides, more expensive travel, and the use of concrete water storage tanks all lower the service provider score. In this model, increasing the community score also increases the service provider score. All of these outcomes were expected and agree with the study hypotheses. It is reasonable that a higher community score is associated with a higher service provider score, because in all 23 communities the service provider was a democratically elected water committee composed of community members. If a community is practicing good hygiene habits and understands the importance of water and sanitation, it follows that their representatives would have the same priorities.

The impact of the “Solar Panels” variable in Equation 3 indicates that having more homes with solar panels increases the service provider score. Since all the communities relied on solar power to some extent, having more solar panels indicates having greater overall access to electricity. This does not necessarily agree or disagree with the hypothesis, since this study expected to find that the presence of generators and wired electricity would raise all SIASAR scores.

The impact of the “Weather” variable, on the other hand, directly contradicts the hypothesis. This contradiction is likely due to the way the question was formatted on the CCAT. Volunteers were asked to rate the effect inclement weather has on each leg the round trip according to a scale shown in Table 22.

Table 22: Excerpt from the CCAT survey

Write the number corresponding to the effect of inclement weather
1. No effect
2. Increases time
3. Increases time and cost
4. Can make travel impossible

What this question fails to capture is the *frequency* of significant inclement weather events. Basic rainfall data is limited, and in any case would likely not help clarify the matter because the communities are all located in a relatively small geographic area and experience similar weather. Volunteers were instructed to write the number corresponding to the worst-case scenario, and results were calculated by using the highest “Impact of Weather” score for a given community. This means that a community that experiences one annual flood event that can make travel impossible appeared equal to a community that experiences numerous annual flood events that can make travel impossible. Bridges and paved roads significantly reduce the negative impacts of flood events and allow for year-round travel. Future studies should still investigate the impact of weather, but should do so in a more nuanced way.

The “Impact of Weather” variable appears again in the community score model, as shown in Equation 4; however, this time a higher “Impact of Weather” value actually lowers the community score. Although this variable may not accurately capture the reality of the community’s accessibility, it does support the hypothesis in this model. As seen in Equation 3, the community score appeared in the service provider model. It follows that the service provider score would also appear in the community score model.

$$\begin{aligned} \text{Community Score} = & 0.843 + 0.006 (\text{Minutes in Truck}) - 0.453 (\text{Impact of Weather}) \\ & + 0.055 (\text{Round Trip Cost}) - 0.585 (\text{Solar Panels}) \\ & + 1.004 (\text{Storage Tank Material}) + 0.684 (\text{Service Provider Score}) \end{aligned} \quad (4)$$

It is important to recall what exactly the community score is measuring. This part of the SIASAR survey asked questions about the coverage of drinking water and sanitation in the community. It also evaluated practices such as trash management, greywater management, open defecation and handwashing. It included a section on domestic water treatment and storage. These indicators, while important for evaluating the hygiene habits of a community, were not directly considered in the hypotheses of this study. For example, the author found no literature linking rural areas to better or worse trash management practices than urban areas. The community score model is included in this study for the sake of completely exploring the information captured in the SIASAR survey and analyzing it in relation to connectivity factors.

It is also worth noting that neither the number of neighboring communities nor the presence of cell signal were included in any of the three models. The literature predicted that nearby communities would not play a significant role in the day-to-day life of their neighbors, but the exclusion of the cell signal variable is surprising. This does not necessarily mean that the presence of cell signal has no effect on RWSS functionality; rather, this particular study may have failed to measure the effect conclusively. This applies to all variables excluded from the final models.

#### *5.4 Policy Proposals and Technical Recommendations*

Equation 2 shows that increasing the amount of time spent traveling to and from an urban center is detrimental to the functionality of RWSS. Equation 2 also demonstrates that living in Bocas del Toro, a province with considerably more paved roads and bridges as shown in Figure 3, predicts higher system RWSS functionality. Paved roads reduce travel time and make a route less susceptible to the effects of inclement weather. Even well maintained gravel roads would be a vast improvement over the single-track dirt footpaths that link many rural communities to the rest of Panama. A straightforward policy proposal is to invest in roads connecting rural areas to urban centers in a way that reduces the travel time for the largest number of people. As stated previously, this infrastructure is unlikely to generate direct economic returns (Shen et al. 2011), but studies like this one can begin to build the case for the broader, more holistic societal benefits of rural infrastructure, such as increasing access to water and sanitation.

Every year, there are fewer and fewer places on Earth left unlinked by roads. The remoteness of these rural communities is part of their beauty, and the people living there still have an intimate relationship with the land that is lost in an urban setting. Still, isolation comes at a cost. This study examined the effects of community connectivity on RWSS, but numerous other researchers have documented the effects of community connectivity on personal health and access to health care (Jones et al. 2009, Stasser et al. 2016, The Lancet 2015). These three studies found that rural populations have higher rates of mortality, disability, and chronic disease than their urban counterparts due in large part to their lack of access to health care. Rural areas simply have not obtained the same standard of living as urban areas. The challenge moving forward will be to connect rural communities to the same public services enjoyed by urban populations, while still maintaining the environmental, cultural, and agricultural integrity of these hinterlands. This study indicates that a policy which favors investing in rural roadways will increase RWSS functionality, but this proposal is put forth with caution. Projects which are inconsiderate of the environmental and cultural impact of roadways may end up doing more harm than good. A holistic design process is critical to minimize the potential damages while maximizing the benefits of new transportation infrastructure.

From a technical viewpoint, the complete lack of water quality testing is a serious shortfall in the functionality of these 23 RWSS. As stated previously, neither Bocas del Toro nor Ñökribo have a testing facility within their borders. The closest lab is located in David, a



3 to 6-hour bus ride from the urban centers considered in this study. Opening lab facilities on the Caribbean side of the mountains should be a top priority. In the meantime, however, inexpensive testing solutions like the Coliscan Easygel© kit should be used to routinely check for *E. coli* and coliforms. Although these kits do not detect all types of harmful pathogens and are not as accurate as the testing performed in a lab, the information available from the samples could help communities identify spikes in contamination levels and monitor the effectiveness of chlorine treatments. Additionally, test kits could be provided to measure chlorine levels in the system.

A further technical recommendation concerns the types of sources used for the water systems in this study. The SIASAR surveys revealed that only 15 out of 23 communities have adequate water during the dry season. Flowrates of potential sources should be measured multiple times during both the dry and rainy seasons before developing a water system. Flowrates of existing systems should also be monitored to detect waning groundwater levels before complete system failure.

## **6. Future Work and Concluding Remarks**

This study directly considers the definition of the term “rural” and attempts to quantify a community’s connection with, or isolation from, the nearest urban center. This study is likely the first to analyze the effects of community connectivity on RWSS functionality. Examining connectivity factors shifts the general conversation on water and sanitation access towards the more specific question of what barriers to universal access exist specifically in rural areas. As discussed previously, 80% of the 663 million people worldwide who lack access to an improved water source live in rural areas (WHO/UNICEF 2015). This study will hopefully be one of many to understand the water and sanitation challenges specific to remote communities.

Future studies should investigate some variables not included in this study. Household income and education levels, for example, were not captured by either the SIASAR or CCAT surveys, but may have a significant effect on RWSS functionality. Future studies should also include a larger sample size that is not limited by the presence of a specific aid organization. All sites included in this study were accessible by U.S. Peace Corps volunteers, and therefore the results exclude some of the more remote towns in the Bocas del Toro and Nökríbo.

The world has not yet achieved universal access to water and sanitation, but significant progress has been made in the last half century. A concentrated global effort helped achieve the MDG for water access by encouraging states and NGOs to build new infrastructure. The challenge has now shifted from *constructing* new systems to *maintaining* existing infrastructure – a challenge that is especially difficult in rural areas. When seeking solutions to increase access to water and sanitation, governments and institutions should look beyond existing frameworks and consider the connectedness of the underserved population. When governments seek to improve the standard of living in rural

areas, they should invest not only in connecting pipes to a tank, but also in connecting rural communities to the institutions and services critical for maintaining RWSS functionality.

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## 8. Appendices<sup>6</sup>

Appendices A – E are found in the separate document titled “MC Moritz Thesis Appendices”. Each tab in the workbook corresponds to one section. The tabs are labeled as follows:

- Appendix A – CCAT data
- Appendix B – Calculated SIASAR data
- Appendix C – Data formatted for SPSS
- Appendix D – SPSS coding for non-scalar variables
- Appendix E – Variable cross-correlations

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<sup>6</sup> The material contained in this chapter is in preparation for submission to a journal.