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ASSESSMENT OF WATER INFRASTRUCTURE INTERACTION IN US INFORMAL SETTLEMENTS

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Abstract: Informal settlements, specifically *Colonias*, are communities that are often located at the periphery of cities, have high poverty rates, with houses that are built piecemeal and lack access to or receive subpar infrastructure services. In the context of water infrastructure, residents from these communities face problems, such as water pipes breaking and noticing problems with smell, color, or taste. This study seeks to assess the interaction between *Colonia* residents and water infrastructure services. Enabling this study is a survey distributed to residents of a non-border *Colonia* in Central Texas (n=92) in 2018. Statistical inferencing and qualitative analyses were used to explore the perceived conditions of the water services, and identify relationships between the sources of drinking water (i.e., from the system or an alternative source), how residents interact with their system (e.g., tap water uses), and socio-demographic factors. The results show that 42% of respondents have a monthly household income below US$2,000, and 57% of respondents prefer an alternative source of drinking water to the system, and approximately one-third of residents boil or filter the tap water, primarily due to safety concerns. Additionally, it was found that household income is associated with the preferred source of drinking water. This finding may reflect that residents in a better financial position can access alternative sources of water. These findings may assist policy-makers and utility managers in better understanding human-infrastructure interactions in *Colonias*—a foundational step in improving the quality of services rendered and reducing the financial burden placed on residents.

1 INTRODUCTION

In recent decades, there has been a population shift towards urban areas, which is expected to continue in the coming years (United Nations 2014). Notably, since 2007, more people live in urban areas than in rural areas (United Nations 2014); by 2050, 66% of World's population is expected to live in urban areas (United Nations 2014). One of the consequences of urbanization is the development of informal settlements surrounding urban centers due to the increasing demand and prices of housing. Thus, forcing low-income residents to settle at the city's periphery (or further) in often underserved areas lacking access to adequate water, sanitation, and transportation services (Hoornweg and Freire 2013). Despite the challenges posed by informal settlements worldwide in developed and developing economies alike, much of the literature in this domain has been primarily focused on developing economies (Durst and Wegmann 2017; Durst 2015; Gharaibeh et al. 2009). The U.S.—and more specifically the state of Texas—which is the area of interest for this study—has experienced the development of informal settlements, also known as *Colonias* for decades (Ward and Carew 2000). As of 2015, the estimated number of residents in *Colonias* in Texas was approximately 500,000 (Housing Infrastructure 2015), located in both border *Colonias* at the US-Mexico border and non-border *Colonias* located throughout the state (Ward and Peters 2007).

Colonias not only face the lack of adequate infrastructure services but also face challenges to improve the provision of infrastructure services to their residents. For instance, the isolation and prevalence of low-income residents in *Colonias* make the construction of new infrastructure projects prohibitively expensive (Housing Infrastructure 2015). Notably, despite these challenges, some progress has been made regarding the improvement of the built environment conditions in the *Colonias*. For example, *Colonias* classified as having no or limited access to services, such as water infrastructure services, wastewater systems, or paved roads have decreased during the last decade (Housing Infrastructure 2015). Although improvements to existing infrastructure systems have been made in *Colonias*, these improvements have been focused primarily on providing access to physical components of infrastructure systems to the residents (e.g., pipes, sewer, or roads). However, less attention has been given to the quality of services provided to residents. Notably, water quality challenges can lead to limited use of the water infrastructure system; for example, limiting the use for drinking purposes (Jepson and Brown 2014). In this example, residents may seek out alternative sources of water to meet their basic needs, such as bottled water or water from vending machines installed in private stores. Although alternative water sources may solve this particular water quality problem for residents that perceive the drinking water system as inadequate, choosing these sources can pose a challenge for residents in the form of an additional financial burden.

Enabling this study is a survey deployed between March and June 2018 to *Colonia* residents. Questions of interest from this survey pertain to the resident's interactions with their household water infrastructure system, the perceived quality of the services received, and the preferred sources of drinking water. As such, this study seeks to explore the relationships between perceived quality of water services received by residents and the influence of such perceptions on seeking out alternatives sources of drinking water. Understanding these relationships provides insight to decision makers and policy makers regarding how to improve the provision of water infrastructure services in the *Colonias*. The provision of infrastructure services is far more complex than simply providing access to physical infrastructure systems, or even providing water that meets water quality standards. These services go beyond the technical and managerial knowledge of how the infrastructure systems operate; it also involves the interaction with the users (e.g., how users interact with and perceive the services received by these systems). Users must not only receive water at adequate levels of service, but they must also *perceive* that they are receiving adequate levels of service. Furthermore, infrastructure services received hold much more value to the population than the physical system (Little 2002).

2 BACKGROUND RESEARCH

Existing literature in the context of Texas *Colonias* primarily focuses on drivers of their development (e.g., Ward 2010; Ward and Carew 2000), the characteristics of these communities, such as houses that are built piecemeal (e.g., Sullivan and Olmedo 2015; Durst and Ward 2014), and the lack of basic infrastructure services (Gharaibeh et al. 2009; Jepson and Brown 2014). Relevant to this study, this section focuses on literature regarding characteristics of *Colonias* and the provision of water infrastructure services.

Historically, informal settlements have been a by-product of rapid urbanization in a region and lack of regulation of the housing market (Ward 2010). In these areas, developers frequently sold unplatted land lacking adequate infrastructure services to vulnerable buyers (i.e., low-income people; Larson 1995; Ward and Carew 2000; Ward 2010). Houses built on this land are typically constructed piecemeal over multiple decades by the residents, and often do not comply with existing building codes (Cisneros 2001; Durst and Ward 2014; Ward and Peters 2007). For instance, often mobile homes may be adapted as houses and augmented over time (Durst 2018). These communities are further characterized by the lack of some of the most basic infrastructure services such as drinking water, wastewater, electricity, or paved roads (Housing Infrastructure 2015). More importantly, even if residents are connected to basic infrastructure systems, the provision of adequate infrastructure services are not free from challenges such as additional costs, limited accessibility, and low quality of these services (Gharaibeh et al., 2009; Jepson and Brown 2014).

For example, conditions in *Colonias* can lead to excessive energy costs for residents (Gharaibeh et al., 2009). Similarly, in the domain of the water infrastructure services, existing literature has reported the lack of access due to poor household connections, delays with the connection process due to financial restrictions, water poverty conditions faced by residents, and lack of trust in utility providers regarding water

quality (Garcia and Hernandez 2011; Housing Infrastructure 2015; Jepson 2014; Jepson and Vandewalle 2016). Consequently, due to the lack of infrastructure systems or the perceived lack of quality of the services received *Colonia* residents sought out alternatives methods (or substitute products) to meet these services needs (Jepson and Brown 2014). An example of this, in the case of drinking water, which residents have used vending machines or water ATMs as a primary source of drinking water in spite of widespread household connections to the water infrastructure network (Jepson 2014; Jepson and Brown 2014). Much of the existing literature has focused on acknowledging the inadequate provision of infrastructure services in *Colonias*; however, less attention has been given to how these problems impact the interaction between residents and infrastructure systems. Therefore, in this paper, we focus on the relationships between perceived quality of water services received by *Colonia* residents and the influence of such perceptions on preferred alternative sources of drinking water.

3 METHODOLOGY

The study leverages survey analysis, qualitative analysis, and statistical inferencing to explore the human infrastructure interactions in a non-border *Colonia*.

3.1 Survey Development and Deployment

A face-to-face survey was conducted to explore human-water infrastructure interaction between *Colonia* residents, gather demographic information, and ask about how water infrastructure services are used in the household (among other questions relating to health and the built environment out of the scope of this study). Of specific interest to this study were questions pertaining to housing conditions and the interaction between residents with the water infrastructure system including the perceived quality of the service, how residents use tap water, and the preferred sources of drinking water (see Table 1). The survey was conducted in English or Spanish, dependent on the preference of the resident. The survey was distributed to residents from one non-border Colonia located in the region of Central Texas between March and June 2018. The population is predominately Hispanic with high poverty rates. Prior to deployment, subject matter with expertise in public health, nursing, housing, and civil and environmental engineering validated the survey, as well as individuals fluent in both English and Spanish for word choice. Additionally, the survey underwent IRB review at the University of Texas at Austin. The data collection process was done using electronic devices (i.e., IPads), where research team members recorded the survey responses from residents to minimize typing errors during the data collection process. The participation in the survey was voluntary, and the survey took approximately 20 minutes to complete. Ninety-two households, representing 397 individuals comprise the final sample. 61 surveys were performed in English, and 31 in Spanish.

Table 1: Survey questions of interest

Questions	**Alternatives**	
What is the water source to this home for daily use?	1. Water distribution system provided by utility 2. Well 3. Truck delivery service to storage tank	4. House provided by neighbor 5. Rainwater harvesting 6. Other (e.g., bottled water, water ATM)
Is your drinking water different from your primary water source(s) mentioned above? If so, what is your primary source of drinking water?	1. Water distribution system provided by utility 2. Well 3. Truck delivery service to storage tank	4. House provided by neighbor 5. Rainwater harvesting 6. Other (e.g., bottled water, water ATM)
If selected "Other" as a primary source of drinking water. Please describe the drinking water source.	Open-ended response	
Have you ever had pipe bursts/breaks?	1. Yes 2. No	

Do you ever notice problems with smell, color, or taste of your drinking water?	1. Yes 2. No	
Do you ever boil your drinking water?	1. Yes 2. No	
Why do you boil your drinking water? Choose all that apply.	1. For taste 2. For smell 3. For color	4. For safety 5. It is habit 6. Other
Do you typically filter your drinking water?	1. Yes 2. No	
Why do you filter your drinking water? Choose all that apply.	1. For taste 2. For smell 3. For color	4. For safety 5. It is habit 6. Other

3.2 Qualitative Analysis

Responses to the question asking for *alternative/other sources of drinking water* (see Table 1) underwent qualitative analysis (n=46), coded to four categories—(1) bottled water, (2) water in gallons, (3) water from stores, and (4) other sources. The definition of each category is shown in Table 3, and Table 4 shows the frequency of each code. The coding dictionary and coding were validated using intercoder reliability checks (Saldaña 2013).

3.3 Statistical Inferencing

Chi-square tests of independence (Washington et al. 2010) were used to explore statistical relationships between responses from Table 1 and socio-demographic characteristics. Responses in Table 1 represent self-reported behaviors regarding water consumption, perceived problems of the water infrastructure service, and actual problems with the water infrastructure system—e.g., pipe breaks. For example, one test explored whether an association existed with a preferred drinking water source and the household income. Another example is whether residents who boiled their water for drinking purposes perceived problems with the water quality—in regards to smell or taste.

3.4 Limitations

One limitation may be the sample size obtained in this study (n=92). Nonetheless, it is recognized in the literature that challenges to studying informal settlements is receiving a high response rate of surveys or interviews, and thus a small sample is better than no information at all (Ward and Carew 2000).
Notably, the higher percentage of female responding the survey is not unexpected—82% it aligns with existing literature in the context of Colonias (e.g., 73% Durst and Ward 2013; 68% Ward et al., 2003). Reasons to explain these results are that in general in the Colonias women are primary the heads of the household (Jepson 2013), and as such, women are more likely to be available for surveys or interviews (Ward et al., 2003, pp38). Another methodological limitation is associated with using statistical inferential analysis. Although this type of analysis identifies the presence of relationships between the studied variables, the type of relationship between the variables cannot be concluded.

4 RESULTS

Of the survey's respondents, 82% were women, 97% were of Hispanic ethnic background, and the average number of household members was 4.3 persons. Additionally, 76% of residents live in either a trailer or a mobile home, and only 34% of the residents have a monthly household income higher than US$3,000. Shown in Table 2 are descriptive statistics of select demographic parameters.

The results illustrated in Table 4 show the frequency and corresponding percentages of the survey responses to the questions of interest for this study. Table 5 shows the results of the Chi-square tests of independence between *Colonia* residents' characteristics and the preferred primary source of drinking water.

Table 2: Survey sample demographics

Independent Parameter *Unless otherwise indicated, variables are 1 if true, otherwise 0*	**Average**	**Standard Deviation**
Socio-demographics		
Female	0.82	0.39
Monthly household income greater than US $2,000	0.58	0.5
Monthly household income greater than US $3,000	0.34	0.48
Monthly household income greater than US $1,000	0.29	0.46
Ethnicity—Mexican born	0.42	0.50
Ethnicity—Mexican-American born	0.51	0.50
Household characteristics		
Number of Household members *(number, not dummy variable)*	4.32	2.08
Reside in a mobile home	0.24	0.43
Have you lived in your current home* more than 15 years	0.45	0.50
One home on the lot	0.89	0.31
Community resident built home or portion of the home	0.23	0.42
Physical improvements were made to home such as remodel the kitchen or install new appliances	0.64	0.48
Extensions/expansions have been built on home	0.27	0.45
Roof leaks	0.33	0.47
Home has flooded	0.13	0.34
Land or roads around the home has flooded	0.70	0.46
Home has had pipe bursts/breaks	0.41	0.5
Only one member of the household is currently in paid employment	0.34	0.48
Two members of the household are currently in paid employment	0.33	0.47

**home is defined as the structure in which the respondent lives with his/her family; in this case, it can be a house, a trailer, or a mobile home.*

Table 3: Topical codes and categories defined

Category	**Description**
Bottled Water	Statements that indicate the preference for buying bottled water as a primary source of drinking water
Water in gallons	Statements that indicate the preference for buying water in gallons as a primary source of drinking water
Water from stores	Statements that indicate the preference for buying drinking water in stores or in vending machines (e.g., water ATM)
Other sources	Statements that indicate the preference for using alternatives to drinking water different than bottled water, water in gallons, or buying water from stores

Table 4: Frequency of response to the questions of interest of this study (n=92)

Questions	**Alternatives**	**Frequency (Percentage)**
What is the supply of water to the home for daily use?	Water distribution system provided by the utility	91 (99%)
	Hose provided by neighbor	1 (1%)
Is your drinking water different from your primary	Water distribution system provided by the utility	40 (43%)

water source(s) mentioned above? If so, what is your primary source of drinking water?	Other	52 (57%)
You selected "Other" as a primary source of drinking water. Please briefly describe the drinking water source.	Bottled Water	29 (63%)
	Buying Water in Gallons	5 (11%)
	Buying water in a Store	11 (24%)
	Other	1 (2%)
Have you ever had pipe bursts/breaks	Yes	38 (41%)
	No	54 (59%)
Do you ever notice problems with smell, color, or taste of your drinking water?	Yes	29 (32%)
	No	63 (68%)
Do you ever boil your drinking water?	Yes	24 (26%)
	No	68 (74%)
Why do you boil your drinking water? *Choose all that apply*	For taste	1 (4%)
	For smell	0 (0%)
	For color	2 (7%)
	For safety	17 (61%)
	It is a habit	2 (7%)
	Other	6 (21%)
Do you typically filter your drinking water?	Yes	26 (28%)
	No	66 (72%)
Why do you filter your drinking water? *Choose all that apply*	For taste	7 (20%)
	For smell	2 (6%)
	For color	2 (6%)
	For safety	19 (54%)
	It is a habit	5 (14%)

Table 5: Chi-squared results, p-values for statistical association between socio-demographic and household attributes with the preferred source of drinking water

Residents attribute	**Preferred source of drinking water (Distribution of responses: provided by the utilities, alternative source)**
Household income greater than 1,000 USD	0.560
Household income greater than 2,000 USD	**0.031****
Household income greater than 3,000 USD	**0.004****
Gender (Female)	0.195
Ethnicity: Hispanic-Mexican born	**0.032****
Ethnicity: Hispanic-Mexican-American	**0.022****
Household characteristics	
Boiling water	0.219
Filtering water	**0.084***
Having pipe breaks	0.527
Perceiving problems with water quality (i.e., smell, taste, or color)	0.528

Note: * p<0.1; ** p<0.05

5 DISCUSSION

5.1 Existing conditions

The survey sample is consistent with the literature, regarding socio-demographic characteristics in Texas *Colonias*—i.e., residents have a Hispanic ethnic background of and low household income (Bogolasky and Ward 2018; Jepson and Brown 2014; Ward 2010). The survey revealed challenges with access to perceived, adequate water services. One-third of respondents discussed aesthetics issues—i.e., taste, smell, or color— with the drinking water provided by the utilities. Notably, almost all residents are connected to the local water utility service. Interestingly, however, more than half of the residents prefer to use an alternative source for drinking water (see Table 4). Regarding the self-reported behavior of those who consume water, approximately 30% of respondents boil or filter their water prior to consumption for safety concerns (61% boil and 54% filter; see Table 4). These behaviors indicate that residents limit their direct interaction with the service provided by the local water utilities. Many methods used to limit this interaction are additional financial burdens—purchasing of filters or bottled water—in areas that are primarily populated by low-income residents. These results support the notion that although *Colonia* residents may be physically connected to the water system; the water services that residents receive are not perceived as adequate, and as such are not fully utilized. In other words, providing infrastructure services to *Colonias* is not only building the physical infrastructure—e.g., water pipes and tanks—but also building the trust of the service provided. These findings challenge the current measure of access to infrastructure services in the *Colonias,* which defines access as being connected to physical infrastructure systems (Housing Infrastructure 2015), and do not considers neither the actual or perceived quality of the services provided.

Safety was the primary reason that residents limited their interaction with the water provided by the utilities, primarily via using substituted products, such as bottled water (see Table 4). When asked about interactions and experiences in the context of drinking water service responses indicated challenges regarding the perceived quality. (Note, as the water quality was not tested, the authors are stating that this is the *perceived* water quality). Respondent's indicated challenges such as: "[the] *water comes out white from the faucet and when turned off [it] smell like sewer,*" "[the] *tap water smells like sewage,*" or "[it has] *color and little rocks' come out of the pipe.*" Although not all those surveyed indicated similar responses, these quotes are indicative of a potential challenge regarding access to adequate service, whether from the provider or due to household issues. Consequential of the service received at the tap; residents are altering their behaviors and interactions with the systems. Notably, not all those who discussed boiling water indicated aesthetics issues or safety concerns. However, the boiling of water or purchasing of bottled water may be capturing a distrust of the services provided by the utility. This distrust of water services provided has been documented in literature in other contexts as well. For instance, in Kenya, in rural communities, the lack of trust may discourage water consumption (Leclert et al. 2016). Conversely, in an urban context, and as discussed by Jorgensen (2009), the role of trust from users in water authorities is fundamental for the development of water management strategies. As such, if decision-makers and water authorities want to improve not only the access to services but also the utilization of their infrastructure systems the relationship between the consumer and provider should be further explored in these communities.

A common theme identified in the hypothesis testing was the association between income and preference for an alternative source of drinking water, likely capturing that it is a privilege among drinking water sources (Table 5). It may be a privilege for residents in the sense that 42% of the residents have a monthly household income lower than US$2,000, at least four persons live in a household, and 76% of residents live in either a trailer or a mobile home. Thus, buying bottled water for a family living with less than US$2,000 and at least four residents can be simply unaffordable, and thus, inaccessible. Similarly and supporting this finding, Jepson (2014) found a relationship between poverty and limited water access in *Colonia* settlements. Otherwise stated, some residents in these communities may not be able to shoulder the financial burden necessary to seek out alternative products. Another socio-demographic characteristic associated with the preferred source of drinking water was the ethnicity of respondents. This characteristic may likely be capturing the existing relationship between water infrastructure preferences and cultural aspects from the users, as discussed by Kaminsky (2016) and Koehler et al. (2018). As such, this finding may suggest the need to develop and manage culturally appropriate water infrastructure alternatives better suited to match users' preference.

Surprisingly, households that had pipe breaks and perceived problems with the water quality as represented by aesthetic qualities (smell, taste, or color) were not associated with the preferred source of drinking water. The lack of association may highlight that residents do not perceive these aspects from the water infrastructure service as important for them when deciding which alternative to choose for drinking purposes. Water aesthetic issues could arise from chemical and microbial content of natural water, chemicals added or removed during the treatment—e.g., chlorine, or reactions occurring during water distribution and storage (Dietrich 2006; Platikanov et al., 2013). Interestingly to note, aesthetic issues do not always indicate health concerns for drinking water—e.g., residents complained about an unusual odor in drinking water due to zebra mussels in Austin although the water was safe for drinking (Kamath et al., 2019). Similarly, this may be the case for *Colonia* residents, although the water may be perceived as adequate to drink from aesthetic purposes, it is not perceived safe (or desirable) by consumers. This potential disconnect between perceived water quality and actual water quality can pose challenges to service providers who must build trust and communicate with the consumers. Ultimately, to improve access, providers must bridge the frequent disconnect between actual water quality and perceived water quality, after ensuring that the water quality meets the regulatory requirement.

5.2 Challenges for Water Providers and Policy Makers

Notably, the built environment in *Colonias* has improved throughout the years, in part due to public funding and non-profit organizations that have contributed to developing programs to improve existing infrastructure services in these communities (Housing Infrastructure 2015). The role of federal funding has been fundamental to the positive evolution of the built environment among *Colonia* settlements in the state of Texas; for instance, this funding has been used for improved water infrastructure, wastewater alternatives, and paving roads (Housing Infrastructure 2015). Recently, however, the state government has terminated the funding (Vock 2017), posing a financial burden on local officials such as county authorities to continue to improve existing conditions of *Colonia* settlements. Without the federal funding, Colonia residents will likely have to access infrastructure services by their own means (e.g., self-contracting utility services; Sullivan and Olmeado 2015). Interestingly, existing studies have suggested alternatives to limit the influence of federal funding on the development of Colonias. For example, the annexation of Colonias to local municipalities has been suggested as a feasible and sustainable solution (Durst 2015). Nevertheless, it also has been found that Colonias are unlikely to be annexed by local municipalities due to large infrastructure investment required and potential minimal tax revenue collected from Colonia' residents (Durst 2014b; Durst 2015)

Additionally, challenges persist in meeting the same level of infrastructure services as in incorporated areas. The primary problems that residents perceived were not related to operational issues from the water system—e.g., intermittent supply or pressures. Instead, residents highlighted concerns regarding the water quality received at the tap water at the household. Another challenge for water providers highlighted by this study is the heterogeneity of the human-infrastructure interactions across *Colonias*, regarding the water use. For instance, residents with a higher income—in the context of *Colonia*s—may have the capacity to access alternative sources of water that residents with a lower income may not, such as buying bottled water. As such, a "one size fits all" policy may not be the most effective across the entire community for increasing the use of water provided by the system. For example, utilities may enhance existing infrastructure with the support of the residents and local authorities, and public policies of subsidies for low-income families may be adapted to account for the financial heterogeneity within *Colonias*. Similarly, in the context of electric infrastructure, the implementation of alternatives to alleviate the financial burden of residents has been explored. Gharaibeh et al. (2009) reported the successful implementation of passive solar systems as an alternative to reduce the amount spent on electricity bills for *Colonia* residents. Nonetheless, the exploration of financially sustainable alternatives remains a challenge regarding other critical infrastructure systems, such as water, wastewater, or transportation services. Multiple reasons may support the limited number of studies, such as the perceptions that sustainable alternatives are unaffordable for informal settlements (Gharaibeh et al., 2009), the unincorporated and isolated nature of these settlements, or the notion that informal settlements do not exist in countries with developed economies (Durst and Wegmann 2017). However, more research is needed in this regard because as shown by Kuffer et al. (2016), the development of informal settlements is a global issue that does not exclude nations with developed economies. The effects of urbanization and urban spread have been reported in countries with

developed economies, for instance, according to the 2016 Census in Canada, peripheral municipalities—those surrounding urban centers—are growing faster than the urban centers they orbit (Proudfoot 2017).

6 SUMMARY AND CONCLUSIONS

Historically, the study of informal settlements has been focused on developing nations; however, developed nations face this challenge as well. In the United States, the state of Texas has many informal settlements known as *Colonias*. This study explored the human-infrastructure interaction between *Colonia* residents and water services received in the household. Specifically, this study assessed the perceived quality of water services received and their influence on the preferred source of drinking water. The results of this study reaffirm that *Colonia* residents are part of a vulnerable population within the US, facing high poverty rates, isolation from the urban centers, and that lack access or receive subpar infrastructure services. Specifically, in the case of the water infrastructure services, our results showed that a significant portion of *Colonia* residents currently faces challenges with their water services, such as a pipe breaking or noticing problems with the drinking water (e.g., smell, color, or taste). Consequently, it was observed that *Colonia* residents limit their interaction with the tap water for drinking purposes, for instance boiling or filtering the tap water, or buying bottled water, in spite of the financial burden. The primary reason to do so was safety concerns about the quality of the tap water provided received within the household. Additionally, it was found that household income is associated with the preferred source of drinking water.

The findings of this study may be used by utility managers and policy makers to improve their understanding of the interaction between residents and water services. Specifically, given the heterogeneity found among *Colonia* residents, a suggestion is made to avoid “one size fits all” policies, and seek the engagement from local communities to be incorporated during the development of alternatives to improve the quality of infrastructure services in *Colonias*. Future research should seek to match perceptions from Colonia residents with actual data in regards to water quality to provide stronger evidence of the problem existing in these communities. The approach used in this study is transferable to explore human-infrastructure interactions between residents from other types of vulnerable populations around the world with their corresponding infrastructure services as well. For example, those located in Latin-America and African nations.

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