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Health impacts of water and sanitation insecurity in the Global North: a scoping literature review for U.S. colonias on the Mexico border

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ABSTRACT

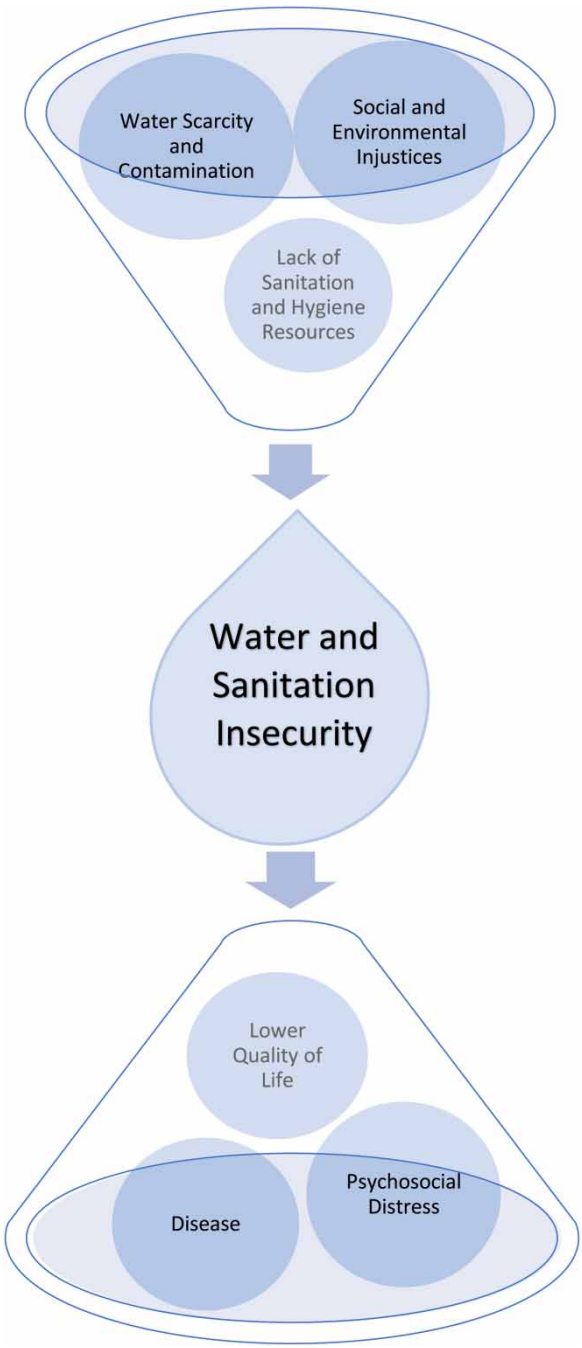
U.S. border colonias are peri-urban settlements along the U.S.–Mexico border. Residents often face substandard housing, inadequate septic and sewer systems, and unsafe or inadequate household water. As of 2015, an estimated 30% of over 5 million U.S. colonia residents lacked access to clean drinking water, suggesting health complications. This scoping review identifies a very limited existing set of research on water and sanitation insecurity in U.S.–Mexico border colonias, and suggests value in additional focused research in this specific context to address health challenges. Preliminary health data indicates that due to water insecurity, colonia residents are more likely to contract gastrointestinal diseases, be exposed to carcinogenic compounds from contaminated water, and experience psychosocial distress. These widespread health issues in colonias are exacerbated by historical and ongoing socioenvironmental injustices in the U.S.–Mexico border region and their relation to the poor health outcomes.

Key words: colonias, health, mental health, sanitation, scoping review, water insecurity

HIGHLIGHTS

- Highlights significant water and sanitation health issues in the U.S.–Mexico border region.
- Explores the developing field of research on disadvantaged rural communities in the Global North.
- Comprises the first scoping review of physical and psychosocial health issues related to water and sanitation insecurity.

GRAPHICAL ABSTRACT



INTRODUCTION

Access to adequate safe drinking water and sanitation is imperative to human development, health, and wellbeing, and is an internationally accepted human right (World Health Organization 2015). Also, with environmental degradation, political and social instability, and climate change, water and sanitation issues are expanding challenges globally (Al-Weshah *et al.* 2016).

One common myth is that water and sanitation challenges are a feature of the Global South (Jepson 2014; Meehan *et al.* 2020; Wutich *et al.* 2022). Recent research has identified that significant water and sanitation challenges are found in many locations throughout the Global North, aligned with social, political, and economic inequalities within higher income

countries (Meehan *et al.* 2020; Roque *et al.* 2021; Wilson *et al.* 2021). One such context is the colonias in the U.S.–Mexico border region, where residents have historically struggled with water and sanitation challenges. U.S. colonias are defined by the United States Department of Housing and Urban Development (HUD) as communities within Arizona, California, New Mexico, and Texas, within 150 miles of the U.S.–Mexico border with poor living conditions, inadequate basic services such as running water, sewerage and drainage, and rudimentary housing (Figure 1) (Mukhija & Monkkonen 2007).

Colonias have predominantly Hispanic populations, with significant structural barriers to delivery of adequate government services, including water (Moya 2017). By this definition, some one million people in this zone could lack adequate sanitation and/or potable water (Mukhija & Monkkonen 2007). In 2015, an estimated 30% of 840,000 colonias' residents lacked access to safe drinking water (RCAP 2015). Conditions in colonias frequently mirror those of rural communities in developing countries facing similar water and sanitation issues, but the severity of the water-related public health issue in colonias is complicated by socio-political and environmental injustices the U.S.–Mexico border regions experience (Hargrove *et al.* 2015). In addition to inadequate water and sanitation services, the border region is characterized by high rates of poverty, unemployment, lack of educational facilities, and increased environmental pollution, all of which contribute potentially to the public health issue (Lusk *et al.* 2012; McDonald & Grineski 2012). Therefore, in the context of these injustices, the scope, form, and especially the consequences of the water and sanitation challenges within borderland colonias must be more clearly described.

In this scoping review, we evaluate the current literature regarding water and sanitation in U.S.–Mexico border colonias, with particular consideration of potential physical and mental health impacts on residents. For the purposes of this review, we differentiate household water insecurity as defined by a lack of access to safe, affordable, clean water (Jepson *et al.* 2017), while inadequate sanitation is characterized by the absence of working of facilities such as toilets and treatment systems so that hygiene practices are compromised (World Health Organization 2015).

Water, sanitation, and health

The relationship between water and sanitation and physical health has been well-defined by scientists, and there is also a growing body of literature that identifies potential impacts detailing how water insecurity and inadequate sanitation might impact psychosocial health and emotional distress (Wutich 2009; Stevenson *et al.* 2012; Bisung & Elliott 2017; Hargrove 2018; Wutich *et al.* 2020). The purpose of this review is to comprehensively analyze the scope and severity of both physical and psychosocial health impacts associated with water and sanitation insecurity in U.S. colonias. The objectives are to scope

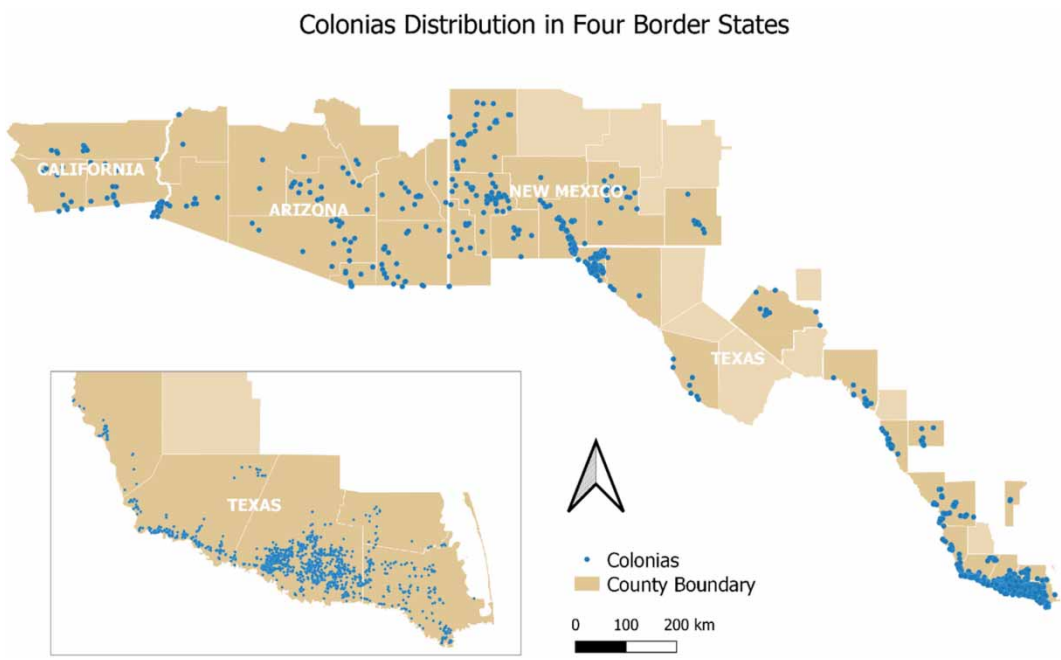


Figure 1 | Distribution of U.S. colonias along the U.S.–Mexico border.

available academic literature to (1) map the scope and severity of health impacts related to water and sanitation insecurity in U.S. colonias; (2) examine the exacerbating factors and barriers; and (3) identify existing gaps in the literature as a guide to future areas for research. As water scarcity and inadequate sanitation issues continue to escalate globally, a better understanding of the relationship between water, sanitation, and *all* facets of human health, is crucial to advising possible solutions in all marginalized communities, including those like these borderland colonias that are potentially overlooked because they are located within the Global North.

METHODS

The methodology for this scoping review was outlined by Arksey & O'Malley's (2005) framework and informed by advancements from Levac *et al.* (2010) and Pham *et al.* (2014). A scoping study was chosen because it can usefully synthesize diverse studies with different designs and methods (Arksey & O'Malley 2005), map literature pertaining to the broad topic and emphasize gaps in the research (Levac *et al.* 2010) and summarize information in research areas that have not previously been comprehensively reviewed (Pham *et al.* 2014). Our scoping review included the following five key steps: identifying the research question, identifying relevant studies, study selection, charting of the data, and collating, summarizing, and reporting the results.

Research question

The design of this scoping review was guided by the following research questions: How does water and sanitation insecurity affect the health of U.S. colonias residents? What is the scope of water and sanitation insecurity? Also, what additional gaps exist in the literature?

Search strategy

The search strategy for this review was implemented through systematic screening of three databases: Scopus, ScienceDirect, and PubMed. The search was limited to published peer-reviewed articles from 1995 to December 2020, and the language of the studies was restricted to English. Keywords from the following three domains were developed prior to the literature search: (1) physical and mental health impacts; (2) water and sanitation; and (3) U.S. border colonias (Table 1). Titles, abstracts, and keywords were searched in all three databases, with searches conducted from 15 to 30 April 2021. Reference lists of initially included articles determined by keyword searches were also explored further for relevant citations, which were then subject to the same selection criteria.

Inclusion criteria and screening

All published peer-reviewed literature documenting health impacts of water and sanitation insecurity in U.S. colonias were initially selected for inclusion, meaning no methodological restrictions were applied. The removal of methodological restrictions was important for identifying a potentially diffuse range of evidence related to water and sanitation insecurity and health. However, then, articles focusing only on the engineering aspects of water quality with no relation to health were

Table 1 | Keyword search terms

Database	Colonias	Water and sanitation	Health impacts
Scopus	*Keyword terms*: 'colonia' or 'U.S.–Mexico border' or 'marginalized community' or 'border community', or 'disadvantaged community'	*Keyword terms*: 'water supply' or 'water *security' or 'water access' or 'access to water' or 'sanitation' or 'toilet' or 'hygiene' or 'open defecation'	*Keyword terms*: 'health' or 'public health' or 'community health' or 'mental health' or 'distress' or 'emotion'
ScienceDirect	*Keyword terms*: 'colonia' or 'U.S.–Mexico border' or 'marginalized community' or 'border community', or 'disadvantaged community'	*Keyword terms:* 'water supply' or 'water *security' or 'water access' or 'access to water' or 'sanitation' or 'toilet' or 'hygiene' or 'open defecation'	*Keyword terms*: 'health' or 'public health' or 'community health' or 'mental health' or 'distress' or 'emotion'
Pubmed	*Keyword terms*: 'colonia' or 'U.S.–Mexico border' or 'marginalized community' or 'border community', or 'disadvantaged community'	*Keyword terms:* 'water supply' or 'water *security' or 'water access' or 'access to water' or 'sanitation' or 'toilet' or 'hygiene' or 'open defecation'	*Keyword terms*: 'health' or 'public health' or 'community health' or 'mental health' or 'distress' or 'emotion'

excluded (e.g., Rios-Arana *et al.* 2004). Additionally, articles that discussed broad environmental or public health issues without identifying any specific health outcomes related to water and sanitation were excluded (e.g., Akland *et al.* 1997; Lusk *et al.* 2012). Studies that analyzed colonias on the Mexico side of the U.S.–Mexico border were also excluded as the focus of the study was on U.S. colonias (i.e., those geo-politically located in the Global North).

A hierarchical procedure adapted from the Preferred Reporting Items for Systematic Reviews' and Meta-Analyses' flow diagram helped guide data management and extraction (Figure 2). First, all titles and abstracts were screened for relevant keywords after the preliminary search by keywords and the removal of duplicates. Second, 12 full-text articles determined from abstracts fulfilling all three keyword combinations in each domain were obtained and screened. The references of the 12 resulting articles were then searched for relevant literature using the snowballing technique, and four more peer-reviewed articles were included. In total, 16 articles were reviewed in this study.

Data management and extraction

Titles and citations were extracted from the three databases and exported into the Reference Manager software Mendeley. Full-text articles of selected literature were then managed in Excel, where extracted data from the selected articles included author(s), year of publication, title, design, type, and location (Table 2).

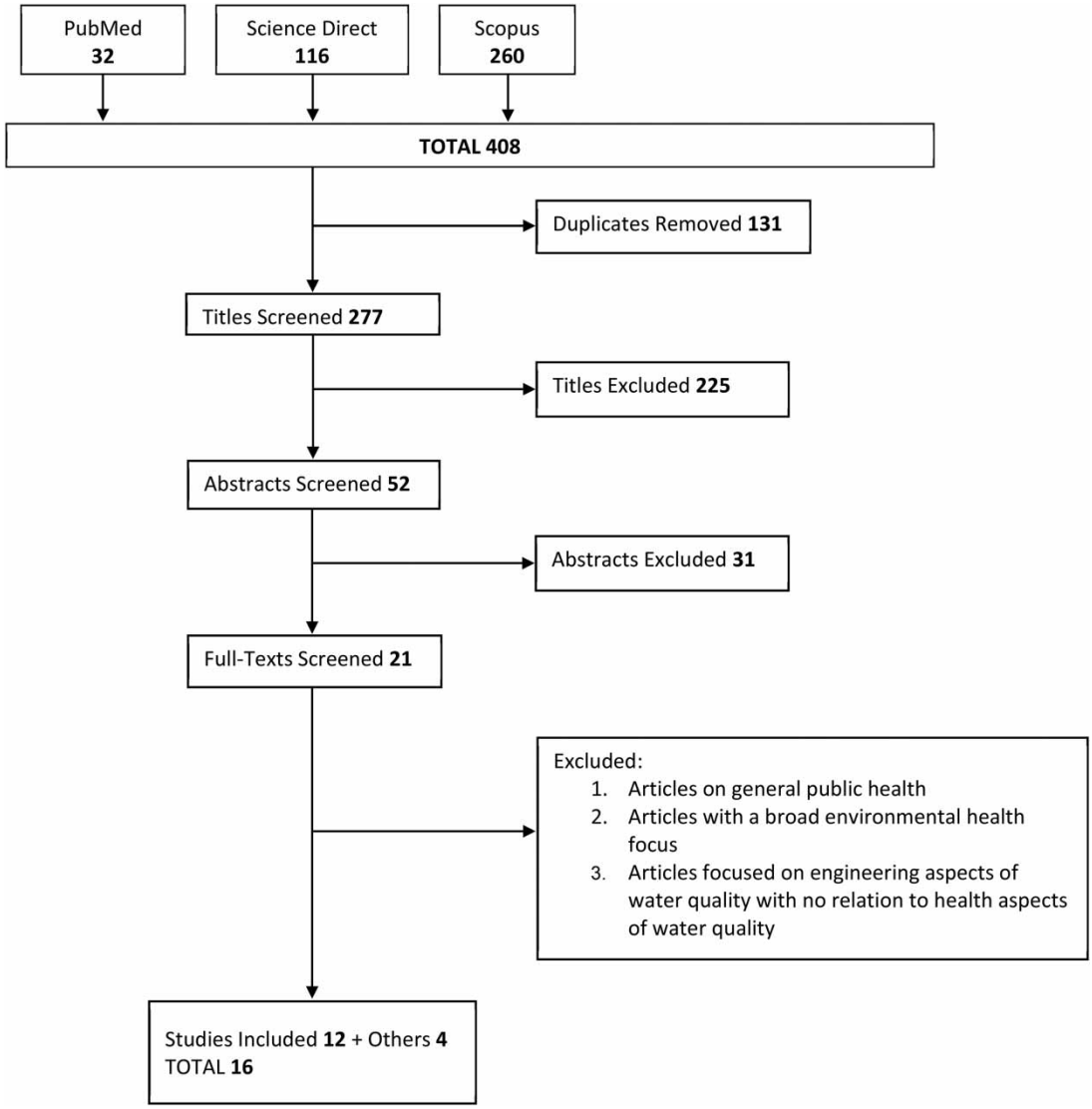


Figure 2 | Flow diagram.

Table 2 | Articles identified in the scoping search meeting all inclusion criteria

Author (year)	Study objective	Location (U.S. colonias)	Method	Examples of health impacts
Balazs *et al.* (2011)	Analyze the relationship between nitrate concentrations in community water systems and characteristics of residents	San Joaquin Valley, CA	Quantitative: water sampling	Over-application of fertilizer for agriculture contributes to excessive nitrate found in water systems in the Rio Grande Valley.
Berry *et al.* (1997)	To evaluate possible health effects on the communities in the Lower Rio Grande Valley from environmental conditions	Cameron County, TX Hidalgo County, TX	Quantitative: water sampling	Distress surrounding water quality and pollution were related to concerns about the groundwater quality of wells in the Valley.
Cardenas *et al.* (2010)	Assess the prevalence of GI infections in El Paso, TX	El Paso County, TX	Mixed-methods: household interviews, environmental sampling	Handwashing had a protective effect on the prevalence of *H. pylori* infection.
Garcia *et al.* (2016)	To quantify and compare water-related perceptions and practices of colonia residents	NM, TX	Mixed-methods: key informant interviews, surveys	Many residents perceive their water supplies to be non-potable. Financial burden of obtaining potable water reduces residents' quality of life.
Hargrove *et al.* (2018)	To explore how water and sanitation infrastructure can address water injustice in the border region	Presidio County, TX El Paso County, TX	Mixed-methods: key informant interviews, surveys, focus groups	Average costs of obtaining drinking water presents a financial burden for households. Households reported stress related to hauling water. Complaints of failing septic tanks among residents were also widespread.
Laware & Rifai (2006)	Examine sources of fecal coliforms in the Rio Grande	Rio Grande, TX	Quantitative: water sampling, model development	Segments of the Rio Grande are unsafe for recreational use due to elevated levels of fecal coliforms. Wastewater flushed from colonias causes contaminated runoff into the Rio Grande.
Leach *et al.* (1999)	Investigate the prevalence of Hepatitis A infection and risk factors for disease along the U.S.–Mexico border	Hidalgo County, Texas	Mixed-methods: serologic testing, questionnaires	Use of bottled water was protective against Hepatitis A infection. Improved sanitation in early childhood may reduce the prevalence of Hepatitis A infection.
Leach *et al.* (2000)	Examine the epidemiology of *C. parvum* infection in children living in colonias	Hidalgo County, Texas	Mixed-methods: serologic testing/ questionnaires	Risk factors for *C. parvum* infection included consumption of municipal water. Within colonias, *C. parvum* infection was associated with the source of water supply.
Moya (2017)	To expose the health and social impacts of water scarcity and contamination in the Southwest border region	San Elizario, TX Sunland Park, NM	Qualitative: focus group discussions, household interviews	Salient environmental and health conditions include water pollution, groundwater depletion, soil contamination, illegal outdoor burning, and infectious diseases.
Mier *et al.* (2008)	To research colonia residents' health-related quality of life and advise possible solutions for health professionals and policymakers	Hidalgo County, Texas	Mixed-methods: household interviews, surveys	Colonias populations are worse off in terms of physical health to the general U.S. population. Most residents perceived health problems as caused by physical environmental problems like polluted water.

(*Continued.*)

Table 2 | Continued

Author (year)	Study objective	Location (U.S. colonias)	Method	Examples of health impacts
Moore *et al.* (2011)	Examine nitrate contamination of California's groundwater	San Joaquin Valley, CA	Quantitative: water sampling, surveys	Exceedances of the nitrate MCL were found in the San Joaquin Valley posing a major health concern for colonias.
Pierce *et al.* (2019)	Identify and define how mistrust of tap water originates between the water source and the water tap	Los Angeles County, CA	Qualitative: focus group discussions, participant observation	Mistrust in tap water discourages plain water intake and leads to greater intake of sugar-sweetened beverages, contributing to obesity as well as decreased oral health
Rios & Meyer (2009)	To develop and test an environmental health ecological framework between the quality of infrastructure, utilities, and resident health	Nueces County, TX	Mixed-methods: household interviews, surveys	Industrial agriculture exposes residents to toxic chemicals through contact with the Rio Grande. Most septic tanks and sewage treatment systems built by residents do not adhere to public health codes.
Rowles *et al.* (2020a)	To develop a model to assess the relationships among water, sanitation, and health	El Paso, Starr, Nueces, TX	Quantitative: household surveys	Measured water quality directly influences household health and indirectly influenced perceived water quality. Connections to sewer were found to positively influence household health.
Rowles *et al.* (2020b)	Determine how well-water quality varies seasonally between arsenic and bacterial contamination	Nueces County, TX	Quantitative: water sampling	During droughts, higher levels of arsenic are found in well water. Microbial water-borne diseases can be exacerbated by flooding events and lead to contamination of wells by fecal pathogens from poorly built septic systems.
Travis *et al.* (2010)	Investigate if access to treated water and sanitary systems reduces *H. pylori* incidence rate	El Paso, TX	Quantitative: water sampling	Bottled/vending water and connection to municipal sewer were protective against water-borne transmission of *H. pylori*.

RESULTS

Characteristics of studies

The final sample included 16 full-text articles: two qualitative, nine quantitative, and five mixed-methods studies. Eleven of the studies were conducted solely in Texas colonias; three studies were conducted in California, and two studies were conducted in New Mexico and Texas. None of the included studies were conducted in Arizona. Nine of the included studies focused on water quality (Leach *et al.* 1999, 2000; Laware & Rifai 2006; Rios & Meyer 2009; Cardenas *et al.* 2010; Travis *et al.* 2010; Balazs *et al.* 2011; Moore *et al.* 2011; Rowles *et al.* 2020b). Four studies examined environmental health (Berry *et al.* 1997; Mier *et al.* 2008; Moya 2017; Rowles *et al.* 2020a), and three studies focused on mental health of water and sanitation insecurity (Garcia *et al.* 2016; Hargrove *et al.* 2018; Pierce *et al.* 2019).

Scoped finding on water insecurity in colonias: scarcity

Based on the scoping review, we identified that water scarcity is not a new struggle for colonias residents. As of 2018, it was estimated that over 134,000 people living in 604 U.S. colonias still lacked access to safe drinking water and sewer service (Hargrove *et al.* 2018). Without access to clean, potable water, residents are not only unable to perform daily household tasks, but also cannot practice hygienic activities such as handwashing, putting residents at higher risk of infection and disease from diarrheal pathogens.

Beyond the physical health impacts, one of the most reported psychosocial health impacts of water scarcity was the fear of running out of water (Hargrove *et al.* 2018). Furthermore, residents expressed a general sense of hopelessness regarding the

lack of piped water. In interviews conducted with residents of the Texas colonia Presidio, many were frustrated by the promise of piped drinking water that had never been fulfilled through local water governance mechanisms (Hargrove *et al.* 2018). Water is only one of many issues that are frequently left neglected and unresolved in colonias, and external stakeholders would prefer to allocate their time and resources into more developed and central areas, further marginalizing border communities (Moya 2017).

Scoped finding on water insecurity in colonias: water quality

Based on the scoping review, water quality is a common problem in U.S. colonias, with supplies frequently contaminated due to issues associated with environmental pollution, water storage, and unsafe water use practices.

Chemical contamination

One of the key factors contributing to the chemical contamination of water is environmental pollution due to the physical location of colonias. In Texas, many colonias are near agricultural operations in the Rio Grande Valley, meaning that the industry's heavy use of pesticides exposes residents to toxic chemicals (Rios & Meyer 2009). A study of the Rio Grande and its tributaries revealed the presence of toxic chemicals and fish contamination downstream of colonias in El Paso, Texas. Although some of these metals like arsenic are naturally occurring in groundwater, other sources of contamination could be man-made including prior research evidencing wind deposition of smelting residues in the Rio Grande (Rios-Arana *et al.* 2004; Rowles *et al.* 2020b). These heavy metals such as arsenic, copper, nickel, lead, and zinc, have also been found in sediments of the Rio Grande (Rios-Arana *et al.* 2004). Additionally, colonia residents' well water has been found to be contaminated with high enough concentrations of sulfates, chlorates, manganese, and molybdenum to make it unsuitable for drinking (Rios & Meyer 2009). Moreover, blood and urine testing data of the local households indicated high levels of polychlorinated biphenyls, low levels of arsenic, small amounts of pesticides, and low levels of bromoform, suggesting ingestion of contaminated water (Rios & Meyer 2009). It is also important to note that well water is susceptible to seasonal weather events such as droughts which exacerbate contamination of arsenic because of decreased groundwater flows (Rowles *et al.* 2020b). Higher levels of arsenic are present during dry periods. This presents a direct health risk to residents as arsenic is carcinogenic and can cause cardiovascular disease (Saint-Jacques *et al.* 2018; Sanders *et al.* 2019).

In California, nitrate-contaminated groundwater poses a major health concern for colonias within the San Joaquin Valley. In 2007, over 75% of the nation's nitrate maximum contaminant level (MCL) exceedances were found in San Joaquin Valley water systems, most likely due to the over-application of fertilizer for agriculture (Moore *et al.* 2011). Exposure to excessive nitrate via water harms the respiratory and reproductive systems, causes spleen, kidney, and thyroid dysfunction, and is also associated with an increased risk of cancer (Balazs *et al.* 2011; Moore *et al.* 2011).

Bacterial contamination

Colonia residents have also struggled historically with water-borne infectious diseases such as gastrointestinal (GI) disease. While the prevalence of disease in colonias has been well-documented, more research still needs to be done focusing on the relationship between water quality and disease prevention. A major contributing factor to bacterial contamination in residents' water supply is unsafe water storage. To address water scarcity, many residents rely on water delivery trucks and store their water in storage tanks (Moya 2017). Yet these water storage tanks frequently contain insufficient amounts of chlorine and high levels of coliform bacteria in the water. Coliform bacteria are typically found in the feces of animals and humans, and typically do not cause disease directly, but their presence in water indicates the possibility of other infectious pathogens (Gruber *et al.* 2014).

A series of diseases, including *Cryptosporidium parvum*, viral hepatitis A, and *Heliobacter pylori*, have been linked to poor water quality in colonias (e.g., Leach *et al.* 1999, 2000; Travis *et al.* 2010). Consumption of bottled water, as opposed to spring or municipal water, has been found to be protective against the incidence of all three diseases in colonias. This suggests that bottled water quality was higher than that of spring and municipal water, and demonstrates a direct relationship between drinking water quality and prevalence of infectious diseases. Bacterial contamination issues are even further compounded by the lack of sanitation infrastructure and poor sanitation practices in colonias, allowing infectious diseases to spread more easily.

Water and sanitation nexus

The water–sanitation nexus has been less reviewed in colonias literature, yet it is a crucial domain to fully understand the public health crisis in border communities. Challenges surrounding the water and sanitation nexus primarily manifest in two forms: (1) inadequate sanitation due to water scarcity and (2) lack of piped water and sanitation infrastructure. For example, the lack of ability and resources to perform hygienic activities such as handwashing due to the scarcity of water facilitates the transmission of water-borne infectious diseases such as *Heliobacter pylori* via the fecal–oral route (Cardenas *et al.* 2010). Furthermore, the lack of sanitation infrastructures such as sewer systems and indoor toilets leads to other public health issues. Rios & Meyer (2009) found in Nueces County, TX, a small proportion of residents were connected to the municipal sewer, with most utilizing septic tank systems, and even some using outhouses and holes for sewage. However, some septic tanks in colonias are built by residents themselves and do not meet standard health and construction codes (Rios & Meyer 2009). Sewage issues can also be complicated by seasonal changes including increased precipitation, flooding, and droughts. In the case of flooding, the lack of pluvial drainage in many colonias can cause cross-contamination between shallow wells and septic tanks and lead to sewage backup in toilets (Rowles *et al.* 2020b).

The lack of sanitation infrastructure in colonias also has implications for the water quality of surrounding water bodies that residents use. Human waste from colonias residents is contributed to nearby watersheds through improper disposal, resulting in significant contamination of groundwater and runoff into the river. In the Rio Grande Valley, segments of the river have been classified as impaired waters due to high levels of coliform bacteria found exceeding the MCL, thereby making it unsafe for recreational use by local colonias (Laware & Rifai 2006).

A plethora of other health problems such as skin infections, eye infections, and respiratory illness have also been found in colonias lacking adequate sanitation infrastructure, yet these issues have yet to be investigated in relation to the water–sanitation nexus (Hargrove *et al.* 2015).

Water and sanitation distress

Water and sanitation distress in colonias manifest in the following three main domains: (1) water affordability and accessibility; (2) water quality and sanitation; and (3) concerns surrounding the safety of the physical environment.

Water affordability presents a significant obstacle to residents due to the two-fold problem of water accessibility and low household income. Since potable drinking water is largely unavailable to colonia communities, residents often must resort to more expensive bottled water options or spend large amounts of money to have water delivered. Hargrove *et al.* (2018) found that the average costs of obtaining drinking water for colonia residents of Presidio, TX presented a significant financial burden for households as most were under the federal poverty level. Furthermore, residents also reported stress related to hauling water as they had heard of their neighbors getting seriously injured in water-hauling accidents (Hargrove *et al.* 2018). Throughout colonias, mistrust of the tap water was also widespread as residents perceived the water quality to be questionable and unsafe for consumption (Garcia *et al.* 2016). Mistrust in tap water has been shown to have indirect health consequences by discouraging plain water intake, thereby leading to greater intake of sugary beverages, which contributes to obesity and decreased oral health (Pierce *et al.* 2019; Rosinger 2022). Households who mistrust tap water must also pay significant time and financial costs to obtain alternatives.

Perceived health concerns related to water and sanitation insecurity were also found to impact the residents' mental health. Residents expressed widespread concern over chemical contaminants in the water (either well/container water) and reported that they believed that they had experienced acute GI disease from water use (Garcia *et al.* 2016). However, residents also reported continued usage or consumption of the water, despite having concerns, suggesting that residents experienced additional stress due to pressure to consume water perceived to be unsafe. Health-related sanitation concerns surrounding the dysfunction of septic tanks were also prevalent. Some residents complained of smelling sewage from drainage pipes and spotting free-standing water near failing septic tanks (Hargrove *et al.* 2018). Many residents were even unsure if their septic tanks had ever been pumped or not, presenting a public health crisis as tanks need to be pumped regularly to prevent clogs and wastewater backup into the house.

In some colonias, mental health was also found to be correlated to worries about the perceived security and safety of residents' physical environment (e.g., Mier *et al.* 2008; Garcia *et al.* 2016; Pierce *et al.* 2019). Specifically, distress surrounding water quality and pollution was related to concerns about the groundwater quality of wells (Berry *et al.* 1997; Mier *et al.* 2008). Rowles *et al.* (2020a) discovered that decreased satisfaction with the dwelling environment corresponded with increased perceived health risk from current living conditions in TX colonias across three counties. This demonstrates

that living conditions determined by the residents' their physical environment have a significant impact on the residents' distress water and sanitation-related.

DISCUSSION

The purpose of this scoping review was to summarize available peer-reviewed literature on the health impacts of water and sanitation insecurity in U.S. colonias. The identified sources particularly focused on the physical and emotional health impacts of water insecurity in colonias. Four main domains relating health to water and sanitation insecurity were identified: water scarcity, water quality, water and sanitation nexus, and water and sanitation-related distress. The following sections discuss key theoretical, methodological, and definitional challenges for advancing this field of research; establishes strengths and limitations of our review; and suggests some areas for future research.

Key challenges and considerations

Theoretical considerations

Most studies analyzed the health impacts of water and sanitation insecurity either utilizing the household (Garcia *et al.* 2016) or the population as a unit (Leach *et al.* 2000). However, water and sanitation insecurity manifests in much more complex ways at both the household and community levels. Individual households can face specific challenges caused by water and sanitation insecurity, but when many households start to share common health concerns, the problem is escalated into a public health issue. For example, resident perceptions of well water being unsafe to drink were indicative of widespread distrust in the quality of living at the community level (Garcia *et al.* 2016). In this situation, collective household concerns about water quality contributed to a community-wide public health issue. Likewise, community concerns can be exacerbated at the household level for families who lack resources and strategies to cope with the larger community concern. For example, Hargrove *et al.* (2018) described how residents' fears of getting hurt in accidents related to hauling water were founded in stories of multiple neighbors becoming seriously injured in such events. Such findings demonstrate how community concerns can be exacerbated at the household level. Thus, more research needs to be conducted to comprehensively integrate health concerns at the household level into the larger framework of community-wide public health issues.

Methodological challenges

A significant methodological challenge was distinguishing measured versus perceived water quality. Most studies either focused on one or the other, with some studies only examining measured water quality using quantitative methodologies, and other studies only discussing perceived water quality using more qualitative methodologies (e.g., Moya 2017). However, Rowles *et al.* (2020a) found that the relationships between perceived and measured water quality suggest that assessments of health and water quality should include measured data and not rely solely on resident perceptions. As differences in education level, resource wealth, and social capital vary from resident to resident, individual perceptions should be considered alongside quantitative data that can support or contrast those perceptions. That said, resident perceptions, even when unaligned with measures of water quality, contribute unique and valuable information that informs our understanding of psychosocial distress, water use behaviors, and willingness to pay and engage in collective action to improve perceived water quality.

Definitional challenges

The term 'colonias' is used in various, sometimes conflicting, ways across the literature. The term was first popularly utilized in Texas in the 1980s to describe unregulated housing subdivisions with poor living conditions, inadequate physical infrastructure, and lack of access to services such as water and sewage (Monkkonen & Angeles 2019). In the decades following, colonias were also designated by the U.S. Department of Housing and Urban Development using similar criteria in three other border states, Arizona, California, and New Mexico. However, from state to state, colonias still differ greatly on all fronts (Wutich *et al.* 2022). While some colonias might predominantly use pits or holes for sewage disposals, other colonias communities might be connected to sewer systems. Even within colonia communities, material conditions and resource access can differ significantly. Because of this heterogeneity in colonias, which are misleadingly referred to in a uniform sense, it is difficult to accurately assess the water and sanitation-related health challenges residents face. Additionally, it is even harder to identify and prioritize high-need households or communities as conditions can differ immensely even

within a small geospatial area. While considerable progress has been made on these definitional challenges, any directly comparative research on U.S. colonias will need to take this into account.

Strengths and limitations

This scoping review, to the best of our knowledge, is the first study to comprehensively assess the relationship between water, sanitation, and both physical and psychosocial health outcomes in U.S. border colonias. By utilizing a search strategy informed by Arksey & Malley (2005), it was possible to analyze a broad range of literature with inclusive and relevant search terms. The inclusion of both quantitative and qualitative studies in the review also added to the depth of evidence examined.

The restriction of the location of studies to colonias on the U.S. side of the border was made under the assumption that colonia residents on either side of the two countries would have starkly different experiences. However, it would be difficult to verify this assumption without conducting a review of the health impacts of water and sanitation insecurity in both U.S. and Mexico border colonias, in which the language of included articles could no longer be restricted to those published in English. Finally, the heterogeneity of studies included, despite adding to the comprehensiveness of reviewed literature, limited our ability to make direct comparisons. As the number of studies assessing water and sanitation-related health impacts in U.S. colonias increase in the future, it will be possible to synthesize evidence across more diverse sources and effectively compare studies of similar design.

Gaps and directions for future research

Holistic health and intersecting influences

In most of the included studies, health was evaluated either at the household or community level and was categorized either as physical health impacts or psychosocial health impacts. However, few researchers attempted to address these categories together, highlighting the need for more research to be conducted that views health as a holistic and integrative phenomenon. This conceptualization of health as binary is a gross simplification of the multidimensionality and inter-relatedness of health challenges. Because of the complexity in defining and assessing health status at different demographic levels and as influenced by variable factors, it is difficult to accurately quantify ideas related to health status. For the purposes of evaluating health impacts due to water and sanitation insecurity in colonias, it is necessary to study how physical and mental health impacts at the household level manifest at the community level impacting the entire population. Such ideas of health must also be cross analyzed through the lens of environmental health to determine the driving factors behind health issues. Leading tools currently utilized to evaluate water insecurity such as the Water Poverty Index do little to capture resident perceptions on health and water quality, which have clearly been shown to influence health decision-making and mental health status (Korc & Ford 2013). On the other hand, tools that capture both quantitative health and water standards while considering resident perceptions can advise where there is a need for educational or infrastructure-related interventions in communities (Rowles *et al.* 2020a). Thus, the development of tools and metrics to address health holistically as it pertains to water and sanitation comprises an innovative field of research. Furthermore, future research that focuses on how social differentiations and structures (including wealth, landholding, gender, legal status) shape water access and use of sanitation facilities can enrich the scientific evidence and corroborate what is already known (Bisung & Elliott 2017).

Socioenvironmental justice and water governance

The colonias along the U.S.–Mexico border have historically been viewed as peripheral communities by decision-makers in the capitals of both countries, meaning that programs and policies designed by absentee authority figures often do not address the real needs of the communities (Lusk *et al.* 2012). This social injustice is further compounded by environmental injustices linked to the rise of maquiladoras (industrial factories), agricultural industry, and cross border trade, all whose activities involve pollution of the environment in which colonias reside (Moore *et al.* 2011; Lusk *et al.* 2012). The historical precedent of neglect and apathy for U.S. colonias has translated into significant water, sanitation, and health problems that are burgeoning out of control with increased population growth.

In the context of water and sanitation, environmental injustice emerges from poor management and water governance. Due to the social, political, and physical isolation of colonias, the delivery of piped water is an expensive operation and residents must endure lengthy waits to receive potable water. Furthermore, the decision to deliver water is controlled by local water boards, which are quasi-government entities that provide services to neighborhoods in designated areas (Moya 2017).

Since colonia communities comprise less developed and clustered populations, water delivery is less likely to be expedited. As colonia populations continue to grow, the water crisis is expected to deteriorate even further, making the role of water governance and environmental injustice an urgent priority for research on water access issues.

Beyond the well-established relationship between water and physical health, recent scholarly work has demonstrated that mental health indicators are particularly sensitive to perceptions of injustice and unfairness in water distribution as well as other nonmaterial aspects (Wutich *et al.* 2020, e.g., Brewis *et al.* 2019; Brewis *et al.* 2021). This means that not only is there a need for more detailed research into the mechanisms linking water insecurity to mental health outcomes, but also the link between perceptions of socioenvironmental injustice as well as other nonmaterial dimensions of water insecurity and psychosocial health (Wutich *et al.* 2020). By tracking colonia residents' perceptions of injustice or unfairness as potential sources of emotional distress and mental health indicators, the efficacy of subsequent water interventions could be greatly increased. Mental health monitoring in the context of water security could also serve additional applications to poverty alleviation, economic development, and climate change mitigation (Wutich *et al.* 2022).

CONCLUSION

This scoping review identifies significant negative impacts of water and sanitation insecurity on both the physical and mental health of U.S. colonias residents. While much high-quality research on water and sanitation insecurity has been conducted in the Global South, more research in the Global North is greatly needed (Meehan *et al.* 2020). To address the challenges of water and sanitation insecurity for colonia communities and residents, clear information on health impacts can communicate why intervention (such as provision of improved services) is necessary and needed. Evidence from this review can also help advise the development and validation of future tools to evaluate water and sanitation insecurity and wellbeing in understudied, marginalized Global North communities like the border colonias. Above all, this scoping review identifies clearly that water and sanitation insecurity, exacerbated by socioenvironmental injustices, has substantial negative impacts in U.S. border communities, and likely similarly disadvantaged communities elsewhere in the Global North, and focused interventions are warranted.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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