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Drinking Water Infrastructure and Environmental Disparities: Evidence and Methodological Considerations

James VanDerslice, PhD

Potable drinking water is essential to public health; however, few studies have investigated income or racial disparities in water infrastructure or drinking water quality.

There were many case reports documenting a lack of piped water or serious water quality problems in low income and minority communities, including tribal lands, Alaskan Native villages, colonias along the United States–Mexico border, and small communities in agricultural areas.

Only 3 studies compared the demographic characteristics of communities by the quality of their drinking water, and the results were mixed in these studies. Further assessments were hampered by difficulties linking specific water systems to the sociodemographic characteristics of communities, as well as little information about how well water systems operated and the effectiveness of governmental oversight. (*Am J Public Health.* 2011;101:S109–S114. doi:10.2105/AJPH.2011.300189)

WATER SUPPLY INFRASTRUCTURE in the United States ranges from large systems serving millions of people to private wells serving a single family. In all, this infrastructure provides piped water to the homes of over 99% of the US population. Despite such high levels of access, there were reports from several parts of the country suggesting race and income driven disparities in access to piped and/or potable water.[1–6] The extent of disparities in the US drinking water infrastructure and drinking water quality, particularly as related to race and income, has not been well examined. An earlier review of the evidence linking income and race to health risk and drinking water quality identified only a few case studies, concluding "...inequities in exposure to contaminants in water may exist."[7] Seventeen years after this review, only a handful of published studies addressed this issue.

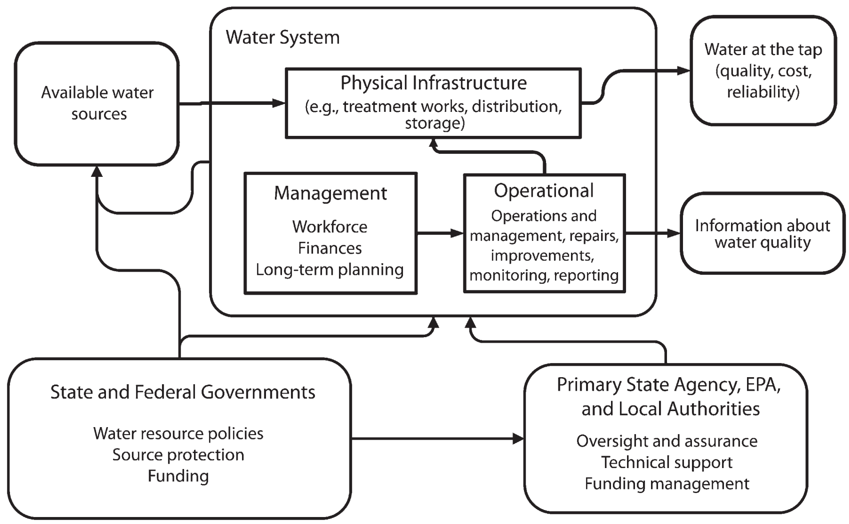
Racial and income disparities in drinking water infrastructure were reviewed with the goal of identifying disparity prone aspects of this infrastructure. As a first step, a framework was proposed that depicted key elements of the drinking water infrastructure in the United States. This framework took a systems approach, thus facilitating identification of aspects of the system that could trigger or enabled disparities, or even limited the mitigation of known disparities. Evidence of infrastructure and concomitant water quality disparities were reviewed using this framework, and the methodological issues that limited the assessment of disparities in water infrastructure were discussed.

FRAMEWORK FOR ASSESSING DISPARITIES

There are many dimensions to the value that consumers ascribe to their water supply: good taste and freedom from odor, low or acceptable health risks, low monetary cost and high convenience, adequate amounts and pressure, high reliability, and reliable information about the quality.[8–11] Disparities in these beneficial characteristics ultimately reflect disparities in the underlying infrastructure. Efforts to reduce these disparities require in-depth understanding of what is disparity prone about this infrastructure; thus, a clear understanding of the elements of a drinking water infrastructure is needed.

The infrastructure that produces water is conceptualized as 4 components: (1) available water sources, (2) the physical infrastructure (e.g., treatment facilities, transmission, and storage), (3) operational/managerial capacity, and (4) government policies and agencies that regulate, assist, and financially support system operators (Figure 1).

Source water quality, location, and reserves drive the technical requirements for water treatment, transmission, and storage. Operation of this system to reliably produce drinking water that meets public health standards at reasonable cost requires adequately trained operators and sufficient administrative capacity to ensure sustainable financial and operational performance. Government serves many roles in this infrastructure: setting policies for water quality regulations and access to sources of water; providing oversight to assure that systems meet water quality, treatment, and monitoring requirements; offering technical assistance and training; and allocating resources to repair and upgrade physical infrastructure.



Note. EPA = Environmental Protection Agency.

FIGURE 1—Framework of the components of drinking water infrastructure.

Each aspect of water infrastructure might ultimately affect water quality, reliability, or cost. To the extent that any of these aspects of the water infrastructure differed as a function of race and income of the communities they served, racial/ethnic or income disparities in water quality, reliability, and cost (as well as the other attributes valued by consumers) might manifest. For example, disparities in the availability of construction funds might lead to fewer improvements in the physical infrastructure, leading to more problems in water quality or reliability. Disparities in the quality of management might impact the level of operator training, the reliability of water treatment, or the level of compliance with sampling requirements. These factors might directly, or indirectly, affect the reliable provision of high quality water. The level of oversight and technical assistance by the primacy agency might impact the management and operations of the utility, and ultimately, the quality, reliability, and cost of the water produced.

There is great variability in water systems and thus, in the manner in which this framework was applied to these systems. Water systems generally fell into 3 categories based on the size and complexity of the physical/operational infrastructure and the degree of governmental involvement. Community Water Systems, as defined by the Safe Drinking Water Act, make up the first category of water systems.[12] These systems serve at least 15 service connections or 25 or more full-time residents, and are subject to comprehensive regulatory requirements. The second category comprises individual systems serving a single residence and shared systems serving multiple residences but which are not large enough to be subject to the SDWA. These systems have simpler infrastructure and less governmental regulation. The final category includes situations in which minimal infrastructure exists, characterized by the absence of piped water.

EXAMINING DISPARITIES IN DRINKING WATER INFRASTRUCTURE

To identify studies on disparities in water infrastructure, a wide collection of databases was searched, including PubMed, the ISI Web of Knowledge, and Scopus, using the terms “disparity,” “environmental equity,” “environmental justice,” and “inequality” in combination with the term “water.” A search through the Internet was also conducted using the same terms, with a particular focus on sites provided by the Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention, Indian Health Service, Government Accountability Office, and the states bordering Mexico. The review was organized by the category of water system as described previously, as each study focused on only a single category of system.

Communities Lacking Piped Water

Using data from the 2007 National Housing Survey,[13] it was estimated that 0.5% to 1% of US residences did not have piped water. These estimates were based on the proportion of residences reporting that they had a kitchen sink and those with hot and cold piped water. However, there were many documented instances of low income and minority communities where the entire community lacked piped water. One of the largest unserved populations resides in thousands of small, unincorporated settlements, known as colonias, along the US–Mexico border.[14,15] Since the mid-1990s over 1.4 billion dollars in state and federal funds have been directed toward assuring the provision of water and sewer infrastructure to residents of these colonias.[16] Despite these efforts, the most recent data available (2006) indicated that 60 000 people in 442 colonias in Texas still remained without water or sewer infrastructure[2] with an estimated 10 000 living in colonias where there were no sources of piped water.[17]

Concerns about water systems and drinking water quality among American Indians and Alaskan Natives have been evident since the 1950s (E. Leopardi, personal communication, April 4, 2007). Overall, an estimated 8% do not have piped water, and 11% do not have safe piped water.[4] There was great variability with the highest proportions found around Tucson, Arizona (34%), rural Alaska (29%), and the rest of the Southwest (22%). A recent assessment in the Navajo Nation found that 30%

were without piped water; more than 70% of water sources used for domestic purposes were positive for total coliforms, 21% were positive for *Escherichia coli*, 12% had arsenic concentrations above the maximum contaminant level (MCL), and 5% had uranium concentration above the MCL.[3,18,19]

Individual and Shared Water Systems

The US Geological Survey estimated that 14% of the US population relied on individual systems serving a single household or "shared water systems" serving fewer than 15 residences.[20] Such systems usually had quite simple physical infrastructure (well, pressure tank, distribution), financed and operated by the owner(s). They were generally subject to few regulations, and the requirements varied by jurisdiction. Typically, system requirements were covered by local building codes, adequate water reserves had to be documented, and water sampling was usually limited to indicators of microbiologic contamination, and only required at the time of construction or when the property was sold. Contamination of private wells appeared to be relatively common nationwide; 23% of the private domestic wells sampled by the US Geological Survey had at least 1 chemical contaminant at concentrations above their MCL or over a health-based guideline, while 34% were positive for total coliforms and 8% for E. coli.[21] State and/or local officials could provide help resolving water quality problems; however, without on-going, comprehensive monitoring, water quality problems will go unnoticed.

Comprehensive data about these systems or who they served was not readily available, precluding an assessment of disparities in water quality among these users. There were several case studies of low income and minority communities in rural agricultural areas that relied on groundwater that had high levels of nitrates or other agricultural chemicals. In the Yakima Valley of Washington State, approximately 25 000 low-income Hispanic residents relied on groundwater, where, based on existing records, 12% of the wells exceeded the nitrate MCL.[5]

The case of migrant worker camps illustrated the issues associated with this category of drinking water infrastructure. Published reports in the 1980s and 1990s documented a high prevalence of diarrhea and parasitic infection, and poor water quality and sanitary conditions in migrant labor camps.[23–25] More recent studies found grossly inadequate water systems, problems with microbial water contamination, and in some instances, nitrate and pesticide contamination of water supplies.[26–29] A study of migrant labor facilities in Michigan found that such problems were persistent.[6]

Community Water Systems

Community water systems reportedly served 96% of the US population.[30] They are not required to compile sociodemographic information about their customers, making it difficult to assess disparities in water infrastructure by the income or racial characteristics of residents. Data were compiled separately for public water systems on tribal lands. These data indicated that in 2007 to 2008, 16% of tribally owned and operated systems had a health-based violation compared with 7% nationwide.[30] Significant monitoring and reporting violations were also higher (42% vs 19%).

There were several reports of predominantly low-income Hispanic communities in the San Joaquin Valley of California that were served by community water systemw with elevated levels of nitrate.[1,22] Of the 44 Community Water Systems in California that violated the nitrate MCL in 2007, 74% (n=29) were located in this region.[31] Ninety-five percent of households surveyed reported using an alternative source of drinking water or a point-of-use filter, the costs of which accounted for 1.5% of their household income.[31]

Only 3 studies explicitly examined differences in water infrastructure by income or race in areas served by community water systems. In each of these studies, US Census demographic data for a geographic area (i.e., census block groups, zip code, county) were linked to aggregated water quality or violation data from the community water systems serving that area.

In California, the Environmental Justice Coalition for Water found that counties with the highest number of drinking water violations had a higher proportion of people of Latino ethnicity than counties with the lowest number of violations (42% vs 16%).[1] There were smaller disparities related to income; 17% of those living in counties with the highest number of violations were living below the poverty line compared with 12% of those in counties with the fewest violations.

Cory and Rahman[32] examined differences in arsenic concentrations in community water systems in Arizona as a means of assessing disparities in the enforcement of the SDWA. Zip codes were classified as having high arsenic if the average arsenic concentration from all community water systems in that zip code was higher than the MCL. Neither high proportions of Black residents nor lower per capita income at the zip code level were associated with high levels of arsenic. The authors concluded that there was no evidence of an environmental disparity in the enforcement of the SDWA.

Balazs et al. used hierarchical longitudinal models to assess the relationship between sociodemographic characteristics at the census block group level and nitrate concentrations in 327 community water systems in central California from 1999 to 2001 (Balazs C, personal communication, August 4, 2010). Block groups were linked to individual water sources based on the reported geographic location of the well or surface water source. For block groups served by a small community water system, the proportion of residents who were Latino and the proportion who rented were significantly associated with increased nitrate levels. They concluded that there was evidence of disparity in water quality levels based on ethnicity and poverty status.

In large water systems there might be significant variability in contaminant levels within a distribution system, which might lead to a disparity between users of the same system. For example, in 2004, high levels of lead were found in some parts of the water system serving the District of Columbia after the utility switched from chlorine to chloramines for disinfection.[33–35] The change in water chemistry resulted in lead being leached from lead service lines. As lead service lines were more common in older neighborhoods, which are often disproportionately low income and minority, the potential for disparities in exposure to lead in drinking water existed.

However, no studies examined this issue.

METHODOLOGICAL ISSUES IN ASSESSING DISPARITIES

Typically, disparity or environmental justice studies are ecologic; groups of people or communities were compared, not individuals. The way the groups are formed (i.e., unit of analysis), and the specific groups included in the analysis (i.e., scope), could both have a major influence on the subsequent results.[36,37] Although the choice of these factors should be guided by the study questions, they are commonly driven by level of aggregation of the available sociodemographic and outcome data. Studies assessing disparities in drinking water infrastructure faced these same challenges.

Studies of Community Water Systems

The population served by each community water system is a logical unit of analysis for assessing disparities in drinking water infrastructure, or the characteristics of finished water, as the outcome measure was associated specifically with a community water system, and thus, with the community they served. Characterizing the demographic attributes of the community, however, was problematic. Water systems did not collect income or race information about their customers. Even their estimates of the total residential population served were unreliable. Although US Geological Survey and American Housing Survey data indicated that approximately 14% of the population were served by individual or shared water systems, the sum of the number of people reportedly served by each community water source equals 96% of the US population.[13,21,30] Further, in many counties, the total reported residential service population was more than the county's population (Wolff, C, VanDerslice J, Kuwabara J, et al. Unpublished, 2006).

State and EPA databases only contained the city where the community water system was located and the county it primarily served. In metropolitan areas, a single community water system might serve several municipalities. Many counties had more than one community water system, and in rural counties, this might account for only a moderate proportion of the population. If the specific area served by each community water system was known, then the demographic characteristics of that area could be estimated from extant census or state data using geographic interpolation techniques.[38,39] Only a handful of states currently have electronic geo-referenced databases of community water system service areas, (e.g., New Jersey, New York, Washington, and Utah). Without such databases, existing geographic aggregations of census data (e.g., county, city, or census tract) could not be precisely attributed to a single community water system, making it difficult to conduct reliable disparity assessments. For example, Cory and Rahman[31] aggregated water quality data from all community water systems serving each zip code, and used the average arsenic concentration from all community water systems serving that zip code as the outcome measure. Clearly, this obscured differences in water quality between water systems, did not account for the population served by each system, and thus masked associations present at the subzip code level.

In large systems, water quality might vary within the distribution system if there were multiple entry points connected to different sources, or when contaminants, such as disinfection byproducts, continued to be formed during transmission. This was recognized as a potential source of disparity worthy of recognition by water system operators.[40] In these situations, different sections of a community water system might need to be considered as separate units of analysis.

Outcome Measure

Most of the studies reviewed used contaminant levels as the outcome, interpreting the levels as a measure of public health risk. For contaminants where the maximum contaminant level goal was zero, it could be argued that any difference in contaminant levels represented a toxicologically important disparity in risk. However, such an interpretation was less obvious if the maximum contaminant level goal or other health-based guideline was greater than zero, and the contaminant levels found in the study communities fell below this level.

Cory and Rahman[31] used arsenic concentrations over the MCL as a proxy for the level of enforcement. However, contaminant levels observed in finished water are highly dependent on the contaminant level in the source water, the treatment train, and even the monitoring locations and frequency. As such, water quality at the tap might be a poor proxy for the managerial, operational, or enforcement aspects of the infrastructure. Differences in contaminant concentration, when the water did meet standards, might indicate a disparity in water quality, but not necessarily a disparity in any other part of the infrastructure other than source water.

Regulatory databases contained general information about a system's physical infrastructure, but no reliable information about its management or operations. Compliance with monitoring requirements depends on good record keeping, organization, and a commitment to meeting regulations, this might be better indicator of good management than water quality violations.

Studies of disparities in enforcement related to the Clean Water Act used the number of enforcement actions taken by state environmental agencies as a measure of the regulatory agency's effectiveness.[41] State regulators and the EPA are known to work collaboratively with water systems having difficulties meeting regulatory requirements, rather than being adversarial. A lower number of citations or fines might be an indicator of an effective collaborative regulatory system, rather than one that was deficient.

Scope of Study

The choice of the geographic extent of the study should be based on the study question. Of the analytic studies reviewed, 2 used state boundaries; the other used a contiguous, primarily agricultural area. As the community water systems were primarily regulated by state agencies, the state would be a defensible choice, particularly when the outcome was a measure of governmental oversight.

Regulatory requirements, physical infrastructure, and management and operations vary substantially with the size of the community water systems. Observed disparities in infrastructure might reflect differences in settlement patterns by race or income (e.g., higher proportion of minority residents in smaller towns). Limiting the scope of the study to community water system of a given size class, or stratifying the analysis by system size, might help uncover underlying disparities.

Studies of Individual and Shared Water Systems

Conceptually, each individual private well, or shared system, would be the appropriate unit of analysis for disparity studies. Disparity assessments on the individual level would be quite difficult to conduct. In general, water quality data from individual and shared systems was collected at the local level and not readily available. Even if such data were available, sociodemographic data would need to be collected from individual households. Although water quality would be the most obvious outcome measure, the provision of technical assistance (e.g., individual consults, educational materials in the user's language) might also be an important outcome to assess.

Available data suggested that specific contaminants (e.g., nitrate, radon) occurred at levels above health-based benchmarks more frequently in individual systems than community water systems.[21,30] This raised the question of whether being served by a community water system in itself could constitute a disparity. Given that a large proportion of individual wells likely produced high quality water, some contaminants (e.g., disinfection byproducts) occurred only in community water systems, and that a majority of well owners had a strong preference for keeping their private well as their water source,[42] it was unreasonable to consider the lack of a community water system as a disparity in and of itself.

CONCLUSIONS

Despite the importance of access to adequate supplies of clean water for health, there have been very few studies examining disparities in drinking water infrastructure. There were several documented instances of low-income, minority communities that lack piped water completely, or relied on poor individual or shared water systems that produced contaminated water. These included tribal communities, residents of border colonias, migrant farm workers, and minority communities in rural areas. Although efforts have been, and continue to be made, significant problems remain. There were few studies that compared some aspect of drinking water infrastructure by race and income levels of the population being served; the results were mixed. This did not mean that there was ambiguity with respect to disparities in water infrastructure; disparities could exist in some regions and not in others.

Most of the studies cited used finished water quality as an outcome. Although water quality data were readily available, such measures might not be good proxy measures of the underlying operational, physical, and regulatory aspects of water infrastructure. Unfortunately, data characterizing these aspects of the water infrastructure are not systematically collected by regulatory agencies. Data on individual and small shared water systems were even more limited because of the low level of regulation of these systems. Although the community served by a community water system was an appropriate and logical choice as the unit of analysis, such studies were hampered by the lack of georeferenced data delineating the area served by each community water system and difficulties accurately characterizing the population served by a given system.

Improving the understanding of disparities associated with water infrastructure will depend primarily on the availability of the sociodemographic data needed to characterize populations served by each community water system. Geo-referenced data describing the areas served by each community water system would be a step forward. Only a handful of states currently have such data. Other states should be encouraged and provided support to obtain this information. There is also a need to improve the collection of, and access to, data describing not only the physical condition of water systems, but indicators of good management and operation, as well as measures of the effectiveness of oversight and regulation. Such information is necessary to move from identifying disparities, to taking actions to correct them. ■

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