QUANTIFYING RACIAL DISPARITIES IN WATER AFFORDABILITY

By

Sara Sayed and Hannah Smith

Advisor: Dr. Megan Mullin

April 30, 2021

Master's project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University

Executive Summary

Water systems provide households with a utility that is essential to life, yet people of color and populations of low socioeconomic status do not have the same equitable access to clean water as other communities. People of color face inequitable access to clean water, exemplified by violations of the Safe Drinking Water Act in CWSs with predominantly Black and Hispanic populations. Since clean water is not equitably provided, water affordability, then, could follow the same pattern of unequal burdens placed on people of color.

Over 80% of the population in the United States receives water from a community water system (CWS), with over 50,000 CWSs operating across the country. The revenue for CWSs derives from its customers, and many are small, serving 3,300 households or fewer. In theory, the revenue from the customers should support the water systems to maintain their current operations and support future infrastructure updates. However, small populations and frequently aging infrastructure produce financial issues for many CWSs. As such, water systems face the choice to raise customer rates and decrease affordability or to sustain current rates and risk infrastructure failure.

To assist with revenue shortfalls, water managers have chosen to increase water rates in many CWSs. Rate increases jeopardize customer access to clean, affordable water, yet there is no mandate to ensure equitable affordability in the United States. The only guidance for water affordability exists from the EPA. Under EPA guidance, the metric for water affordability is based on water costs as a percentage of median household income for the entire area served by a CWS. The median household income metric fails to represent low-income households and thereby is an inaccurate depiction of water affordability for a CWS. Recently developed metrics measure water affordability burden with greater attention to low-income households. Specifically, the Household Burden Index (HBI), measures the cost of water as a percentage of low-income households' annual income spent on basic water services.

Along with inadequate affordability measures, limited research exists on water affordability burdens between racial and ethnic groups at the water system scale. Research that highlights inequities to access of clean water can serve as a model for water affordability studies. However, the demographic data that functions as the foundation for exposing racial and ethnic disparities in clean water are not examined at the water system level. Rather, county-level demographic data is roughly attached to water system boundaries, which can be inaccurate and

misleading. The estimated demographic data along with an inaccurate affordability metric such as the percent MHI act as barriers to measuring precise and robust water affordability disparities between racial and ethnic groups.

This study bridges the gap in the research and examines racial and ethnic disparities in the affordability of water services in North Carolina. To address the inaccurate percent MHI metric, we measured affordability based on HBI. HBI is the percentage of annual income that low-income (20^{th} percentile) households pay for basic water services (4,030 gallons per month). The HBI metric highlights the low-income households that struggle to afford water rather than the median-income households who can most often pay their water bills.

Newly digitized water system boundary maps created by a research group at Duke University allowed us to attach demographic data specifically to the water system level rather than making an approximation. In past studies, water systems were roughly attached county-level demographic data; this reflects an inaccurate demographic makeup of a CWS because water systems often span multiple counties or only serve a small portion of a county. This study fits block group level US Census data within water utility boundaries. Multiple block groups compose a water system; therefore, the demographic makeup of CWS is more accurately reflected by the block groups than the county data of previous studies.

By establishing the relationship between HBI and percentage of each racial and ethnic group in a water system, this study concludes there is a modest but significant correlation between unaffordability of water services and higher proportion of Black and Hispanic residents in a block group. Neighborhoods in North Carolina with higher Black populations have a higher HBI.

In short, our novel research reveals a burden of water unaffordability for people of color in North Carolina. Community water systems and researchers should apply our methods to affordability in different states to expose racial disparities in CWSs across the nation. Once the disparities are exposed, policy and finances should be distributed to ensure equitable water affordability.

Introduction

Water is considered a human right, yet access to clean, affordable water is not consistently available for many across the United States (Jones & Moulton, 2016). Most

Americans receive water from a community water system (CWS), which serves its population year-round and earns revenue from its customer base (Jones & Moulton, 2016). CWSs encounter a multitude of challenges that often lead to unclean and unaffordable water for their customers. Oftentimes people of color experience the burden of unclean water, which has been exhibited by multiple studies and national headlines. However, disparities people of color may face for water affordability have not been quantified. Exposing the inequalities of water affordability is an essential step in fixing the inequities of the water sector.

Water Affordability

Water is delivered to most households in the United States through a CWS. The complex nature of the water system requires the nexus of both the physical infrastructure and the managerial operations. Before reaching the tap, water undergoes treatment and then passes through a network of pipes and pumps leading to each household. The responsibility of providing Americans clean water falls to plant managers, engineers, technical, and administrative staff. The systems are typically managed by local governments, private companies or non-profit providers, or private-public partnerships (Greer, 2020). Across the country, there are over 50,000 decentralized community water systems (McBride, 2017). Of these, many are very small, serving 3,300 people or less. Along with a small customer base, most of these systems have physical infrastructure that is past its lifespan (Greer, 2020).

Water system managers are forced to choose to update their infrastructure or keep water affordable for their customers. Revenue for a CWS comes from bills that customers pay to receive their water. This revenue funds the daily operations and the current maintenance of the physical system. However, there is not enough money to replace or build new infrastructure. Replacing infrastructure is an expensive undertaking; it is estimated that over $632 billion will be required to update the aging water infrastructure across the United States (McBride, 2017). In addition, water systems around the country are impacted by the influx and efflux of people, leading to changes in the revenue base. Specifically, in areas that are losing residents, systems are left with shrinking revenues, yet utilities are still expected to maintain and update their aging systems, even with less revenue. This begs the question of who is obligated to cover the cost, the user or the provider, leading to secondary question of how much is too much for individuals to pay for their water. Some utilities have chosen to raise their prices – there has been a 41% increase in water prices in the past decade (Mack & Wrase, 2017).

Systems that serve less than 3,300 people face more problems than larger systems. They have a much smaller customer base, which limits their budget. The reduced revenue allows them to maintain operation, but there is little to no funding for system improvements or to replace physical infrastructure. Smaller systems lack personnel and fiscal and structural capacity, a common occurrence in systems across the nation (Hansen & Mullin, 2018). Utilities with a larger customer base can spread costs over a greater group of customers and have resources to compensate for customers that cannot pay their bills. In small systems, however, the small service population cannot provide the system with the same financial foundation as the larger systems. With no federal regulation guiding community water systems financially, each one chooses a different method to provide customers with clean water. This leads to piecemeal solutions and fragmentation among the CWSs. Some households already struggle to pay monthly water bills with their current income, so any increase in water rates will affect how customers afford their water (Teodoro, 2018).

Each system is responsible for providing the same services including customer service, water testing, and continuous water provision. Yet two systems 5 miles apart could conduct their businesses differently (Duffy, 2002). With the majority of CWSs designated as small systems, the challenge is to prioritize the system's minor budget between operation costs and infrastructure updates.

Environmental Justice and Drinking Water Violations

A recent water crisis in the southern United States created by infrastructure failure in the face of extreme weather provides an example of how aging infrastructure interferes with customer access to clean, reliable water. This water crisis exposes racial injustices in the water sector.

In the winter of 2020, a massive snowstorm covered the southern United States and caused thousands of water mains to burst and fail. In Jackson, Mississippi residents were without clean, running water for over a month (Tatter & Chakrabarti, 2021). Estimates to update the water infrastructure in Jackson alone are over $600 million, but there is no money to fix the infrastructure unless the systems raise the rates of their customers (Tatter & Chakrabarti, 2021).

A city of predominantly Black residents, the failure of the water system reveals a burden of unclean water and potential water affordability issues on people of color (*U.S. Census Bureau QuickFacts*, n.d.).

Disparities among racial and demographic groups exist through sorting (Goddard et al., 2021; Teodoro, 2018). Sorting is a broad term for the segregation of communities by race, ethnicity, and income through processes of residential choice (Hansen & Mullin, 2018). As a result, communities become segregated based on income levels, as the middle to upper classes can both afford to move easily and to areas with more services. Increased revenue in wealthier areas creates a positive feedback loop where these neighborhoods can afford better services while lower income regions sink further into debt. Although water services do not receive funding from taxes, income sorting affects water systems as the revenue and customer bases are determined by the economic segregation. Many community water systems, as stated earlier, often serve small populations; these populations are homogenous due to sorting and small due to fragmentation.

Separate from households' decision-making about services and other amenities, sorting also occurs because of preferences about the racial composition of communities. Historic racial segregation and redlining further contributes to racial segregation across communities (Balazs & Ray, 2014; Leker & MacDonald Gibson, 2018). For example, communities of color were historically excluded from municipal boundaries. As the cities grew around these communities, so did the access to services, such as community water systems (Leker & MacDonald Gibson, 2018). However, communities of color did not reap the benefits of the municipal water systems and were continuously excluded from clean drinking water enforcements (Balazs & Ray, 2014). In many cases, communities that face issues of unclean water are vulnerable due to other structural problems, such as lack of access to healthcare and formal education (Fedinick et al., 2019).

The Safe Drinking Water Act (SDWA) was established in 1974 to create equitable access to clean water despite these historic and systemic conditions. Under SDWA, the United States Environmental Protection Agency (EPA) could enforce water quality standards in public water systems. However, there has been a continued, long-term lack of compliance or enforcement of SDWA, especially in communities of color and low-income populations. The SDWA violations have contributed to unclean water as problems remain uncorrected through the years (Fedinick et al., 2019). Communities of color and low socioeconomic status shoulder the burden of unclean water and the consequences of contamination.

The intent of SDWA was to ensure equal access to clean water across the nation, yet situations continue to expose the inequities of clean drinking water (Fedinick et al., 2019; Leker & MacDonald Gibson, 2018; McDonald & Jones, 2018; Teodoro, 2019). A nationwide examination of SDWA violations revealed as populations of people of color and people in lower income brackets increased so did the number of SDWA violations (Fedinick et al., 2019). Another nationwide study indicated that in large community water systems, initial SDWA violations increased as the population of Black and Hispanic residents increased within that water system (McDonald & Jones, 2018). Minorities in lower socioeconomic classes face the largest number of violations across the US (Switzer & Teodoro, 2018). Specifically in North Carolina, it was found that municipalities with primarily white populations were less likely to extend water lines to surrounding communities with high Black populations (Leker & MacDonald Gibson, 2018). The narrative of these studies highlights the undue burden people of color face in obtaining clean water, an essential human right.

Economic sorting and historic racial segregation have led to many homogenous communities across the United States. Fragmented water systems, then, often serve these homogenous communities. The problem of obtaining clean water persists for the people in these areas because of the historic problems outlined above. Environmental justice is not achieved when some "race, color, national origin, or income" class bears a disproportionate burden of environmental consequences created by "industrial, governmental, and commercial operations or policies." (US EPA, 2015). Based on multiple studies, historically marginalized groups, especially those of low socioeconomic status and communities of color, face environmental injustice in the drinking water sector. The question remains, then, do these communities also face lack of affordability for water services because of economic sorting, racial segregation, and lack of response from the government.

Environmental Justice and Water Affordability

Not only clean water, but the affordability of water must be examined to ensure environmental justice in the water sector. However, water affordability measures vary across the United States, and most considerations of social justice in the water sector continue to focus on violations of SDWA. Studies that do examine water affordability across racial and ethnic categories are limited, especially at a fine resolution of demographic data (Teodoro, 2019). As such, our study focuses specifically on the affordability of water services and how it differs between racial and ethnic groups.

The lack of both standardized affordability measures and regulations of affordability serve as a hurdle to compare water affordability between demographic groups. The only current affordability guidance was developed by the EPA to evaluate potential economic distress to municipalities caused by SDWA enforcement, not to determine affordability thresholds for individual households (Goddard et al., 2021; Jones & Moulton, 2016; Teodoro, 2018). In practice, the percent median household income (MHI), or the 50th percentile of annual income of each CWS, is used to calculate the ability for all households served by a water system to pay an average bill. If a household in the community spends more than 4% of reported MHI on water bills, the water is classified as “unaffordable” by the EPA (Switzer & Teodoro, 2018).

The average bill usage does not account for the variability of water usage across households, which affects the price of water (Teodoro, 2018). Furthermore, percent MHI only considers the 50th percentile of income, and most people at the median level of income can afford the average bill of basic water need (Teodoro, 2018). The same water bill that is affordable for a median household income can be a lasting burden on lower income households. For example, water bills that might cost 4% of the annual median household income might translate to 10% of a lower socioeconomic household’s annual income. Therefore, percent MHI leaves many low-income families out of the affordability assessment for basic water services (Goddard et al., 2021; Mack & Wrase, 2017; Teodoro, 2018, 2019).

To remedy this issue, an alternative metric known as the Household Burden Index (HBI) has been proposed to replace the EPA’s median household income metric. The HBI calculates affordability using the 20th percentile of annual income. Specifically, HBI is the percent of annual income spent on basic water bills for households in the 20th percentile of annual income. The 20th percentile of annual income is considered the lower bounds of the middle class; people in this population often make too much money to receive public assistance, yet they still struggle to financially meet their basic needs (Teodoro, 2018). The HBI metric, therefore, paints a more meaningful and accurate picture of those who are unable to afford water services (Teodoro, 2018).

Additionally, most studies that assess water affordability or drinking water equity more generally analyze county-level demographic data roughly fitted to system boundaries (Goddard et al., 2021; McDonald & Jones, 2018; Switzer & Teodoro, 2018; Teodoro, 2019). Often, water systems are small portions of a county or intersect multiple counties (Gonsenhauser et al., 2020). Service maps are limited for water utilities, thus the boundaries are unknown or inaccurate (Gonsenhauser et al., 2020). As such, past studies have relied on county-level demographic data to roughly estimate the racial makeup of a system. In actuality, the demographic data of water utilities are more nuanced than county-level census data can provide. A group of students at Duke digitized statewide maps of water system services areas across North Carolina, allowing robust examination of a water system's demographic makeup that was unable to be achieved in the past (Gonsenhauser et al., 2020).

Our study utilizes the boundaries provided by the maps to examine racial and ethnic group composition in North Carolina community water systems. We tie the demographic makeup of a water system to water affordability based on the HBI metric. The demographic data and HBI metric together grant a robust investigation of water affordability disparities between racial and ethnic groups at the household level.

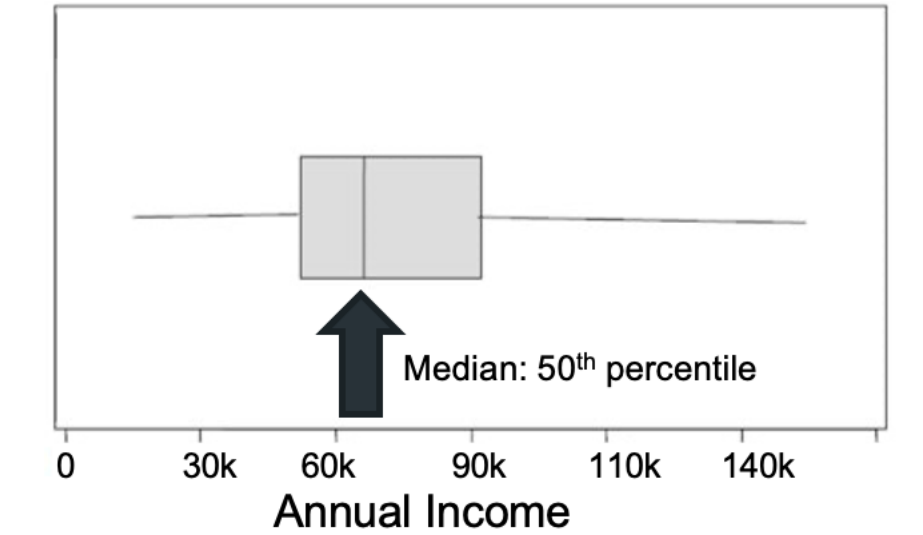
Materials and Methods

Affordability Metrics

The city of Durham, North Carolina serves as example to compare the EPA percent MHI metric to the HBI metric. The median household income, as of 2019, is $60,958 across the city. According to EPA guidance, the average water bill should not exceed 4% of the MHI. This equates to $2,428 per year or $203 per month. Should the average water bill exceed $203 per month, the EPA would deem the Durham CWS unaffordable for its residents. As discussed earlier, this metric considers the households at the 50th percentile (Figure 1) but provides no understanding to the burden a 4% threshold places on lower income households that are more likely to have trouble with paying their water bills.

Figure 1

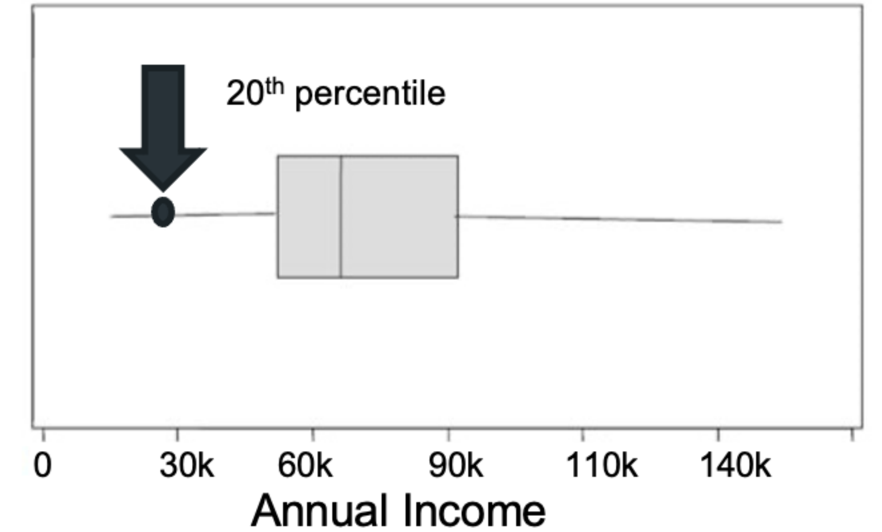
Annual Income Distribution Boxplot



If we turn our attention to the 20th percentile, which is the lower bound of the middle class, we see a drastically different narrative (Figure 2). Durham's 20th percentile income is $22,388. A water bill that is 4% of the MHI translates to 11% of a low-income household's annual income — a level much greater than the EPA recommendation. Thus, the EPA MHI metric ignores large numbers of households that may not be able to afford their water bills.

Figure 2

Annual Income Distribution Boxplot with 20th percentile income highlighted



Applying the household burden index to the City of Durham provides alternative assessment to how affordable the water services are for lower income households. Using Durham's 20th percentile income of $22,388 and Durham's current water rates, the average 20th percentile household pays about 3% annually towards water bills for basic use. By this measure, the Durham water system does not seem to impose a large affordability burden. Our project uses this metric to examine how water affordability varies across racial and ethnic groups in North Carolina.

Previous Work at the Nicholas Institute

Dr. Patterson at the Nicholas Institute for Environmental Policy Solutions and the Internet of Water obtained the cost of water and sewer bills for each system in North Carolina based on Public Water System Identification (PWSID) and newly digitized service area maps (Gonsenhauser et al., 2020). Previously, service area maps were unavailable or difficult to locate for North Carolina; therefore, the exact spatial boundaries for each water service had been impossible to determine. With the new maps, service areas are specifically known and can therefore be tied to more exact demographic data. The rate data for each system included the fixed charge of water and sewage along with any surcharges a user might accrue based on volume used (from 0 to 16,000 gallons per month per household). From there, Dr. Patterson used the cost for 4,030 gallons per month per household to determine HBI, as 4,030 gallons are an estimate to meet the basic needs for the average household (Teodoro, 2019).

Dr. Patterson obtained annual income data for block groups from the US Census Bureau's 2018 American Community Survey (ACS). The 20th percentile of the annual income was determined based on the annual income data for the entire block group. Then, the HBI was calculated as what percent of annual income in this 20th percentile is paying for water bills based on using a standard of 4,030 gallons consumed per household per month for each system in North Carolina.

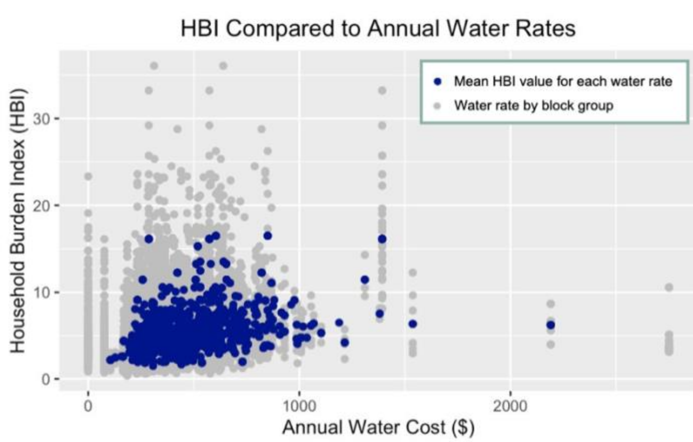
Table 1

Descriptive Statistics of HBI across all block groups

Min	1st Quar	Median	Mean	3rd Quar	Max
0.38	2.57	3.88	4.676	5.8	36.08

Figure 3

Annual water cost for each utility in North Carolina compared to HBI



Note: Mean rate values are in blue

After collecting the data from Dr. Patterson, we calculated HBI summary statistics and compared annual water rates to HBI to determine the relationship (Table 1 and Figure 3, respectively). The maximum HBI is over 36%, which indicates an extremely high affordability burden on some block groups in North Carolina. Furthermore, the overall relationship between HBI and water rates is positive, meaning as water rates increase so does the HBI. However, the relationship is not strictly linear as incomes differ between block groups with the same water rates. For example, the $1,200 annual water rate has a wide range of HBIs, since each block group has a variation of 20th percentile incomes. We expect to see this result as each block group has different income levels and thus varying HBIs even if water rates are the same across the systems.

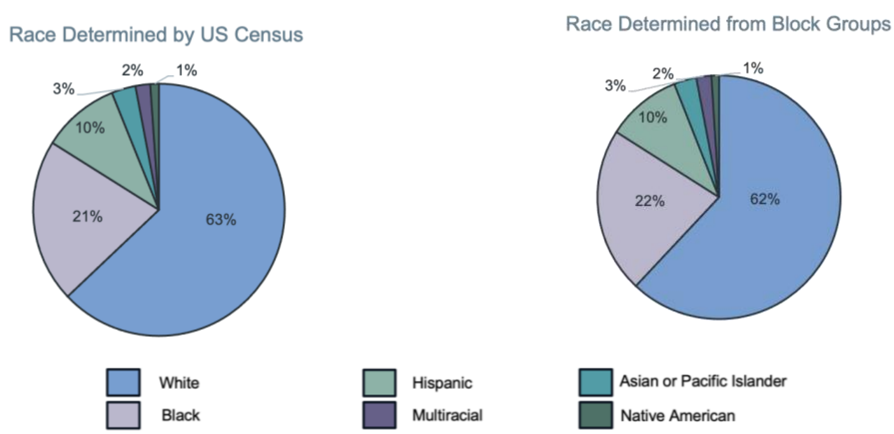
Demographic Data

We obtained demographic data from block groups of the 2018 ACS. Specifically, we used the Census Bureau's API to acquire race (Non-Hispanic Asian, Non-Hispanic Black, Non-Hispanic Multiracial, Non-Hispanic Native, Non-Hispanic Pacific Islander, and Non-Hispanic White) and ethnic (Hispanic) data for each block group in North Carolina. There are 5,739 block groups in North Carolina with unique GEOIDs.

We then calculated percentage of each race and ethnicity by dividing the count of each race and ethnicity population by the block group's total population. We compared the block group data to the census state population data to ensure our data had accurate representations of each racial and ethnic group. The block group data was a percentage point or less different from the state level data (Figure 4).

Figure 4

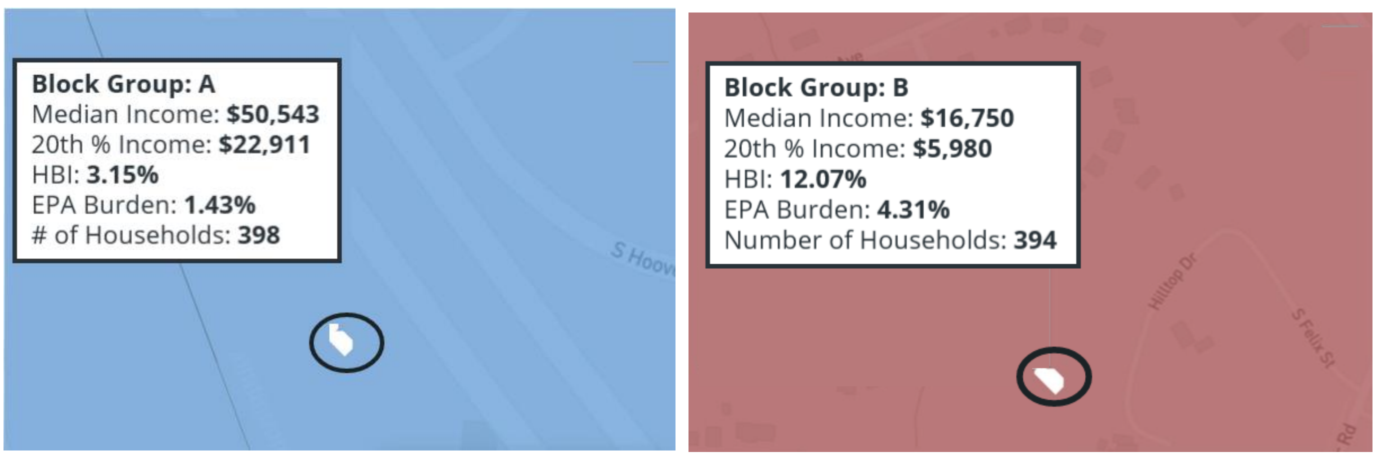
Comparison of State-Level US Population and Block Group Population



Once we obtained the percentage of each race and ethnicity in the block groups, we merged the block group demographic data with the system data based on the GEOID attached to both (once again, the new service maps allowed us to connect those GEOIDs). Therefore, the spatial boundaries of each service area are exactly known and can be tied to block groups. Dr. Patterson, the Nicholas Institute for Environmental Policy Solutions, and the Internet of Water have been working to develop a dashboard of each state to visualize water affordability data at the block group level. An example of block groups within the Durham County, North Carolina utility and the representative affordability data as they appear on the dashboard can be found in Figure 5.

Figure 5

Example of two different block groups on the Nicholas Institute Dashboard



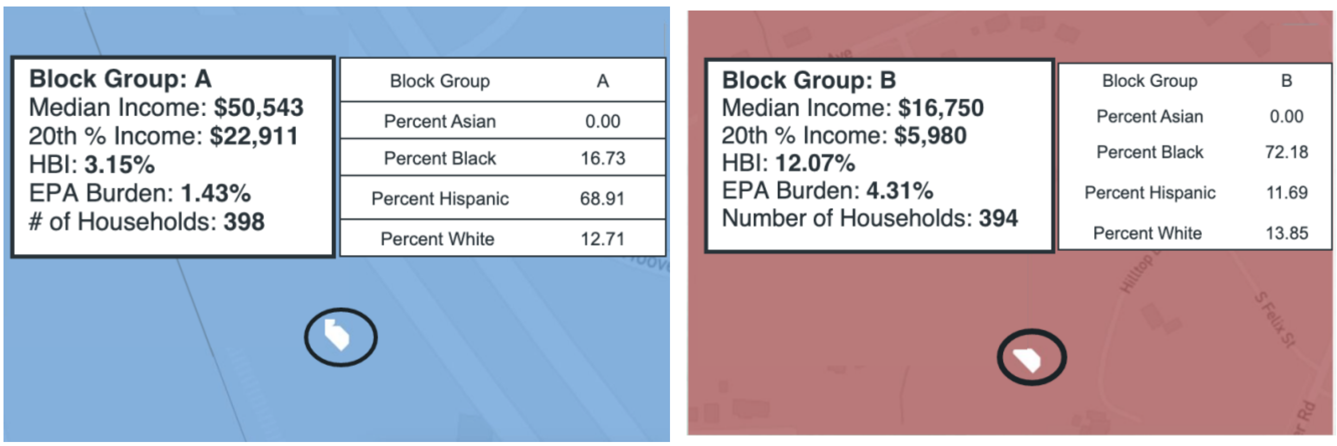
Note: block groups are circled in black within the Durham County water system, made possible by the new system boundary maps

As seen in the Durham County water system (Figure 5), two block groups in the same service area can vary widely. Block Group A has a substantially higher median household income ($50, 543) and 20th percentile household income ($16,750) compared to Block Group B with a median household income of $16,705 and a 20th percentile income of $5,980. The 12.07% HBI of Block Group B is starkly higher than the 3.15% HBI of Block Group A. The visual comparison of the two block groups within the same utility further exemplifies the importance of block group level demographic data to examine affordability disparities.

The GEOIDs for each block group allowed us to then match the existing affordability data from the Nicholas Institute and Internet of Water to the demographic data we obtained from the ACS. Now block groups in each utility have robust demographic and affordability data that was unavailable before (Figure 6).

Figure 6

Example of two block groups on the Nicholas Institute Dashboard with newly added demographic data



Note: block groups are circled in black within the Durham County water system

We chose three control variables for this study: percent of block group that is rural, count of population served by the system, and poverty prevalence index (PPI). Rural CWSs experienced more SDWA violations compared to urban CWSs, so there was a possibility the location of the system could affect the affordability (Statman-Weil et al., 2020). The size of provider was gauged by count of the population served. Similar to rural utilities, small utilities face numerous issues affecting affordability, such as less revenue (Doyle et al., 2020; Mack & Wrase, 2017; Statman-Weil et al., 2020). PPI is percent of households with an income level lower than 200% of the federal poverty level. PPI accounts for broader economic conditions in the block, allowing more precise focus on disparities by race or ethnicity alone.

The rural percentages were obtained from the 2010 Decennial Census data at the block group level. Population served by the system was obtained from the Safe Drinking Water Information System (SDWIS). PPI was calculated by Dr. Patterson using Census data.

Data Analysis

Data was tidied and wrangled in Python using the Pandas and Numpy packages; R was used to conduct the analysis and perform regressions. With a master table of selected variables, utilities, and block groups, we could quickly visualize our data and run linear models. Furthermore, this method makes it easy to add additional variables to the matrix of variables analyzed in this study or possibly develop models for other states.

Since our dependent variables are continuous but truncated, we chose to use an Ordinary Least Squares regression (OLS), deeming relationships to be significant at a threshold of a p-value equal or less than 0.05. We clustered observations at the system level for calculation of standard errors to account for the multilevel observations of the block group and water system levels.

We performed an OLS on HBI against each race and ethnic group using R to create our base model for analysis. We controlled for percent of the block group that is rural, population served by the system, and PPI of the service area to further analyze if racial disparities persist after considering potential confounders. The OLS is used as a descriptive analysis to examine the relationship between HBI and racial composition of water system service areas in North Carolina. Based on the OLS of the percent Black versus HBI, we also conducted a polynomial transformation for that data, using the ggeffects package in R.

Results

Table 2

Descriptive Statistics of Selected Demographic Variables

Variable	N	Min	Q1	Median	Q3	Max	Mean	Standard Deviation
Percent Black	5739	0.00	4.28	15.70	35.49	100.00	23.24	23.40
Percent White	5739	0.00	43.30	67.00	84.50	100.00	61.90	26.90
Percent Native	5739	0.00	0.00	0.00	0.23	90.69	0.75	3.76
Percent Hispanic	5739	0.00	1.46	5.52	13.07	81.39	9.19	10.84
Percent Other	5739	0.00	0.00	0.00	0.00	15.27	0.22	0.95
Percent Multiracial	5739	0.00	0.00	1.20	3.08	28.60	2.12	2.76
Percent Pacific Islander	5739	0.00	0.00	0.00	0.00	11.36	0.05	0.47
Percent Asian	5739	0.00	0.00	0.00	2.65	65.07	2.46	5.26

Table 2 provides descriptive statistics of the percent of each race and ethnicity in North Carolina block groups. We had a large sample size of 5,739 block groups in the state. Based on the summary statistics, the largest racial or ethnic groups represented in North Carolina water system service areas are Black and White, with maximum percentages of block group composition at 100% and mean levels of 23.2% and 61.9%, respectively. Those who designate themselves as Hispanic make up the next largest population, with a maximum of 81.4% and a mean of 9.2% of block group composition. The other populations of Native American, Multiracial, Pacific Islander, and Asian are substantially smaller, with mean percentages of less than 2%. Although we look at all these groups, our analysis will dedicate particular attention to measuring disparities in affordability experienced by Black North Carolinians.

Table 3

Base Model

Variable	Coefficient	Standard Error	P value	Significant?
Percent Black	0.045	0.005	0.000	***
Percent Hispanic	0.008	0.006	0.158	
Percent Native	0.070	0.017	0.006	***
Percent Multiracial	-0.016	0.020	0.421	
Percent Other	0.022	0.045	0.626	
Percent Asian	-0.086	0.014	0.000	***
Percent Pacific Islander	0.032	0.116	0.788	

Note: (*** indicate a significant relationship)

To determine how and where these affordability disparities exist between racial and ethnic groups, we created three models of the descriptive OLS analysis of HBI and racial groups in North Carolina. The first linear model we created was a base model that describes the relationship between census demographic groups and the household burden index (Table 3). Non-Hispanic Whites serve as the base category. Based on this model, block groups with higher percentages of Black and Native populations have significantly higher HBI scores, demonstrated by p-values equal to or less than 0.05. Block groups with higher Asian populations, on the other hand, have a significantly lower HBI. The adjusted R-squared value for the base model is 0.14.

While these relationships are statistically significant, the substantive differences in HBI associated with racial composition are modest. For example, for a 1 percentage point increase in the Black population, there is a 0.045 percentage point increase in HBI. For other racial and ethnic groups, there are similarly less than one-tenth of one percentage point changes in HBI for every 1 percentage point increase in block group composition.

Table 4

Control Model with percent rural and population served

Variable	Coefficient	Standard Error	P value	Significant?
Percent Black	0.052	0.005	0.000	***
Percent Hispanic	0.019	0.005	0.000	***
Percent Native	0.053	0.015	0.013	***
Percent Multiracial	0.000	0.020	0.098	
Percent Other	0.060	0.041	0.190	
Percent Asian	-0.041	0.014	0.016	***
Percent Pacific Islander	0.041	1.153	0.724	
Percent Rural	0.008	0.002	0.000	***
Population Served	0.000	0.000	0.061	

Note: (*** indicate a significant relationship)

In the second model, we controlled for percent of block group that is rural and count of population served by the system (Table 4). With the controls, block groups with a higher percentage of Black and Native populations still have significantly higher HBIs, while block groups with a higher percentage of Asian populations have a lower HBI. Unlike the base model, Hispanics show a significant correlation with HBI when the control was added. The explanatory power for the model with rural percentage and population controls is somewhat higher, with the control model having an adjusted R-squared value of 0.22.

The Native coefficient decreases in the control model (from 0.070 to 0.053, respectively). According to the model with controls for percent rural and populations served, the percentage of Asians is a block group is inversely related to HBI. That is, for every for a 1 percentage point increase in the Asian population, there is a 0.041 percentage point decrease in HBI. Finally, for a 1 percentage point increase in the Hispanic population, there is a 0.019 percentage point increase in HBI.

Table 5

Control Model with percent rural, population served, and PPI

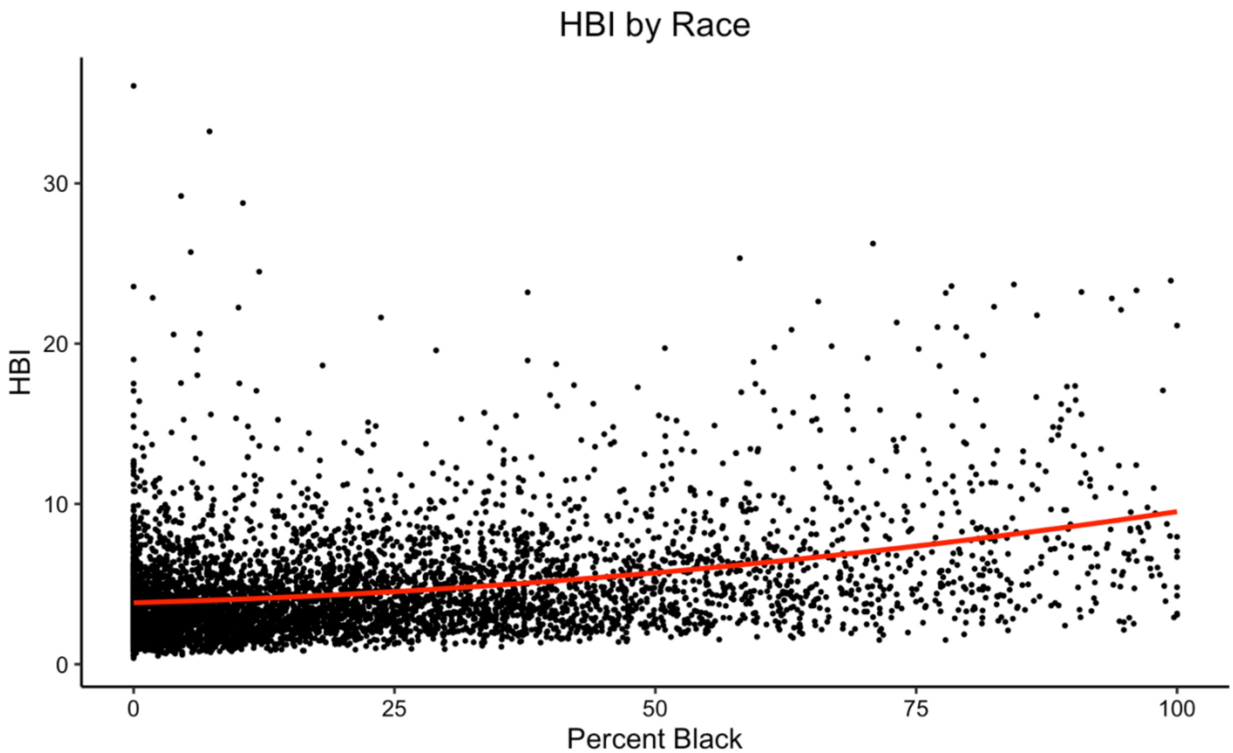
Variable	Coefficient	Standard Error	P value	Significant?
Percent Black	0.024	0.0056	0.000	***
Percent Hispanic	0.024	0.0060	0.030	***
Percent Native	-0.014	0.0135	0.093	***
Percent Multiracial	0.027	0.0191	0.622	
Percent Other	-0.009	0.0407	0.617	
Percent Asian	0.021	0.0081	0.020	***
Percent Pacific Islander	-0.023	0.1004	0.871	
Percent Rural	0.017	0.0020	0.001	***
Population Served	0.007	0.0000	0.047	
PPI	0.000	0.0070	0.000	***

Note: (*** indicate a significant relationship)

Our third model introduces PPI as a control variable in addition to the other controls (Table 5). PPI is included because racial and ethnic composition and affordability burden both are correlated with poverty. The inclusion of PPI allows examination of the direct correlation between HBI and race. Its inclusion also complicates interpretation because income is part of the HBI metric. In controlling for PPI, we see Percent Black, Percent Hispanic, and Percent Asian as statistically significantly related to HBI. However, both Hispanic and Asian are inversely correlated to HBI in this model. The affordability burden associated with larger Hispanic composition therefore appears to be attributable to lower incomes, rather than higher water rates. Increase in percent of population that is Black remains positively correlated with an increase in HBI, but with a lower coefficient compared to the base and other control models (0.024 compared to 0.052 and 0.045, respectively). Introducing PPI as a control variable decreases the coefficient compared to the model without PPI. Still, our results show that even when controlling for poverty prevalence, block groups with larger Black populations have less affordable water.

Figure 7

Bivariate visualization of HBI by Percentage of Block Group Population that is Black with polynomial regression



Note: The red line shows the polynomial relationship between percent of block group that is black and HBI

Table 6

Predicted effects of percent Black on HBI

Percent Black	Predicted HBI
0	3.84
15	4.19
25	4.53
35	4.94
50	5.71
65	6.65
75	7.37
100	9.52

The plot of the raw values of percent of block group population that is Black versus HBI specifically reveals a wider range of HBI values in the higher Black populations, where the scatterplots of other populations did not show the wide variance (Figure 7). The wider range of higher HBI values, specifically in block groups with Black populations 75% or greater, indicates a non-linear relationship between the two. The polynomial regression line (red line in Figure 7) indicates the non-linear, bivariate relationship of HBI and Black population. The non-linear regression is further exemplified in the predicted HBI values based on percent of population that is Black calculated from the raw HBI and Black population data (Table 6).

The polynomial relationship of the percentage Black population compared to HBI signifies a substantial affordability disparity in the block groups with higher Black population. For example, a block group with a Black population of 15% would have a predicted HBI of 4.19%, while a block group with a Black population of 75% would have a predicted HBI of 7.37% (Table 6). A block group that has a population that is 100% Black has a predicted HBI of 9.52%, nearly triple the 3.84% HBI of a block group that has no Black population.

The highest predicted HBI values are related to the highest Black populations (75% and above). The nearly triple HBI of an entirely Black neighborhood compared to a neighborhood with no Black population exposes substantial water affordability disparities in North Carolina neighborhoods of predominantly Black residents.

Discussion and Conclusions

Our results indicate there is a moderate but significant correlation between race and ethnicity and water affordability in community water services of North Carolina. Specifically, people who are non-white Hispanic, Black, and Native American in the 20th percentile of disposable income are more likely to have a higher household burden for their water services. Furthermore, there are substantial affordability disparities between block groups with 75% or more Black populations. The disproportionate burden faced by people of color, specifically those of lower socioeconomic status, to pay for water services in North Carolina is an environmental and social justice issue that is imperative to address as soon as possible. Although water utilities face numerous issues as populations migrate and infrastructure degrades, people of color should not bear the weight via water service costs.

Other studies indicate communities of color continue to face disparities in unclean drinking water based on SDWA violations (Balazs & Ray, 2014; Fedinick et al., 2019; Switzer & Teodoro, 2018). Yet water affordability for different races and ethnic groups remains an elusive metric to quantify. Varying affordability metrics at both the state and national level affect the efficiency of analyzing and reporting undue burdens, if and when they do exist.

Improved affordability metrics beyond percent MHI, such as HBI, aid in receiving more holistic view of the water services burden (Goddard et al., 2021; Teodoro, 2018, 2019). However, these metrics have only been attached to demographic data at broad levels. Therefore, methods such as our study where we analyzed water affordability with robust demographic data are essential in clarifying where water services may fall short. In North Carolina, it seems, water systems fail to provide affordable water to people of color in lower income brackets.

Disparities and burdens should be analyzed at the water system level, if possible, rather than nationwide. Due to fragmentation, water systems are unique in their approaches to providing water to their customers. As such, the demographics of the populations they serve are unique as well. With metrics such as HBI and demographic analysis at the block group level, water systems can analyze the robust data to determine how to provide equitable services to their customers.

Future directions to further this research could include analyzing other states' water systems. Although some studies have looked at nation-wide affordability based on HBI, they have not done so using demographic data at the block group level. Environmental justice in the water sector can be better obtained once each system is able to view affordability disparities with the greatest clarity. To achieve this end, a dashboard for each state, like the one the Nicholas Institute and Internet of Water are creating to highlighting affordability burdens and disparities would create an equitable tool for utilities and customers to easily access the information. Water is an essential human right, and studies such as this are a step to ensure access to clean, affordable water for all people groups.

References

Balazs, C. L., & Ray, I. (2014). The Drinking Water Disparities Framework: On the Origins and Persistence of Inequities in Exposure. *American Journal of Public Health*, *104*(4), 603–611. https://doi.org/10.2105/AJPH.2013.301664

Doyle, M., Patterson, L., Smull, E., & Warren, S. (2020). Growing Options for Shrinking Cities. *AWWA*, *112*(12), 56–66.

Duffy, M. (2002). *Challenges In The Water Industry:* 5.

Fedinick, K. P., Taylor, S., Roberts, M., Moore, R., & Olson, E. (2019). *WATERED DOWN JUSTICE*. 52.

Goddard, J. J., Ray, I., & Balazs, C. (2021). Water affordability and human right to water implications in California. *PLOS ONE*, *16*(1), e0245237. https://doi.org/10.1371/journal.pone.0245237

Gonsenhauser, R., Hansen, K., Grimshaw, W., Morris, J., Albertin, K., & Mullin, M. (2020). Digitizing a Statewide Map of Community Water System Service Areas. *Journal AWWA*, *112*(10), 56–61. https://doi.org/10.1002/awwa.1595

Greer, R. (2020, August 8). *A review of public water infrastructure financing in the United States*. https://onlinelibrary.wiley.com/doi/abs/10.1002/wat2.1472

Hansen, K., & Mullin, M. (2018). *How Local Government Fragmentation Drives Disparities in Water Infrastructure*. 3.

Jones, P. A., & Moulton, A. (2016). *The Invisible Crisis: Water Unaffordability in the United States*. 64.

Leker, H. G., & MacDonald Gibson, J. (2018). Relationship between race and community water and sewer service in North Carolina, USA. *PLOS ONE*, *13*(3), e0193225. https://doi.org/10.1371/journal.pone.0193225

Mack, E. A., & Wrase, S. (2017). A Burgeoning Crisis? A Nationwide Assessment of the Geography of Water Affordability in the United States. *PLOS ONE*, *12*(1), e0169488. https://doi.org/10.1371/journal.pone.0169488

McBride, J. (2017). *The Beleaguered U.S. Water System*. Council on Foreign Relations. https://www.cfr.org/backgrounder/beleaguered-us-water-system

McDonald, Y. J., & Jones, N. E. (2018). Drinking Water Violations and Environmental Justice in the United States, 2011–2015. *American Journal of Public Health*, *108*(10), 1401–1407. https://doi.org/10.2105/AJPH.2018.304621

Statman-Weil, Z., Nanus, L., & Wilkinson, N. (2020). Disparities in community water system compliance with the Safe Drinking Water Act. *Applied Geography*, *121*, 102264. https://doi.org/10.1016/j.apgeog.2020.102264

Switzer, D., & Teodoro, M. P. (2018). Class, Race, Ethnicity, and Justice in Safe Drinking Water Compliance*: Class, Race, Ethnicity, and Drinking Water Compliance. *Social Science Quarterly*, *99*(2), 524–535. https://doi.org/10.1111/ssqu.12397

Tatter, G., & Chakrabarti, M. (2021, March 26). *The Jackson, Mississippi Water Crisis And America's Crumbling Water System*. https://www.wbur.org/onpoint/2021/03/26/the-jackson-mississippi-water-crisis-and-americas-crumbling-water-system

Teodoro, M. P. (2018). Measuring Household Affordability for Water and Sewer Utilities: Measuring Household Affordability for Water and Sewer Utilities. *Journal - American Water Works Association*, *110*(1), 13–24. https://doi.org/10.5942/jawwa.2018.110.0002

Teodoro, M. P. (2019). Water and sewer affordability in the United States. *AWWA Water Science*, *1*(2), e1129. https://doi.org/10.1002/aws2.1129

U.S. Census Bureau QuickFacts: Jackson city, Mississippi. (n.d.). Retrieved April 26, 2021, from https://www.census.gov/quickfacts/fact/table/jacksoncitymississippi/BZA115219

US EPA, O. (2015, February 13). *Learn About Environmental Justice* [Overviews and Factsheets]. US EPA. https://www.epa.gov/environmentaljustice/learn-about-environmental-justice