Environmental Injustice and Well Water Contamination in North Carolina
ENEC 698 Final Report

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Outline

I. INTRODUCTION

Private wells play an essential role in supplying water to North Carolinians. It is estimated that about a third of the state's population, or over three million people, depend on private wells for safe drinking water [1]. Private well owners are responsible for the testing and safety of their well due to the fact that private wells are outside of the scope of the Safe Drinking Water Act, which was originally passed in 1974 by the Environmental Protection Agency (EPA) [2]. Fortunately for the state of North Carolina, the state's general assembly enacted a statute that, starting in 2008, required all newly constructed wells to be tested for contamination. These tests are accessible to the public through the North Carolina Department of Health and Human Services, as long as the owners of the wells submitted their test results to the local health department.

With so many North Carolinians depending on private wells for their water needs, it is imperative that the water quality meets contaminant level standards set out by the EPA, known as maximum contaminant levels (MCL). Contaminated drinking water raises serious public health concerns, as elevated levels of toxins such as lead or arsenic can be dangerous when consumed in large quantities [3]. To investigate whether or not private wells were safe to drink from, well water tests were analyzed from the following counties: Wayne, Stokes, Union, and Robeson. These counties were chosen based on the presence or absence of coal ash pits, diverse geographical locations across the state, and other factors.

This study aimed to examine whether Socioeconomic Status (SES), or Environmental Justice metrics such as race, education, and income, predict private well contamination (natural or anthropogenic), test frequency, and test protocols. Results of this study will provide insight into whether private well contamination can demonstrate areas/factors of environmental injustice.

II. LITERATURE REVIEW

In order to determine a research question that was both manageable in the relatively short amount of time that a semester offered us and novel enough compared to past research, a literature review was conducted. To begin, we examined the writings of Dr. Robert Bullard. Considered to be the father of the environmental justice movement, Dr. Bullard investigated various cases of environmental injustice. One of his books, *Dumping in Dixie*, investigated the efforts of several African American communities to seek justice when confronted with environmental problems that disproportionately impacted them, He found that race was the most significant predictor of environmental injustice, even when socioeconomic class was considered [3]. This finding inspired the inclusion of environmental justice metrics in our analysis. Based on the idea that race and other factors like socioeconomic status, education level, and income could potentially be predictors of environmental injustice, we decided to include them in our study.

Dr. Rebecca Fry's research group in the UNC Gillings School of Public Health conducted a study that was published in 2014 regarding heavy metal exposure through private wells and the prevalence of birth defects in the study population in North Carolina. Arsenic, cadmium, manganese, and lead were examined in this study because all of them are "known developmental toxicants" which can cause developmental harm on an unborn baby if the mother is exposed while pregnant [5]. The study was semi-ecologic, and used a cohort of babies (20,151) born between 2003 and 2008. The North Carolina Birth Defects Monitoring Program monitored cases based on 12 different birth defects that were considered to be important consequences of heavy metal exposure according to the CDC. Census data was used to match the cases to the child's address at birth; this location was also compared to existing mapped information about the location of wells throughout the state. Manganese was found to be associated with heart defects in children. Arsenic was only mildly associated with defects, but there was a measured effect of both arsenic and manganese present in well water. In the analysis described in the subsequent sections, several of the approaches that were used by Saunders et al. were utilized. We included these metals in our study based on the significant health effects they are known to have and their inclusion in the Saunders study. Additionally, this study informed our use of census data and some of the other mapping techniques that our group used.

In a study conducted by a team of researchers at Virginia Tech, the Flint water crisis was examined through the lens of environmental justice. This research team included Dr. Kelsey Pieper, who was instrumental in the early stages of our own analysis. This study examined the role that weaknesses of public health policies and federal regulation of drinking water quality play in perpetuating environmental injustice [4]. Specifically, the study examines how public misunderstanding and inadequate lead monitoring can actually serve to undermine the original purpose of the EPA's Lead and Copper Rule. For the purposes of our analysis, this study contained important background information about the shortcomings of federal regulation of drinking water safety, which is likely carried over into state policies.

Dr. Pieper was the lead author of another study that examined water samples from the "ground zero" home in Flint, Michigan. This was one of the studies that brought waterborne lead poisoning to the forefront of national news and public attention. In this study, the researchers deduce that the cause of the elevated lead levels in drinking water was a result of the "destabilization of lead-bearing corrosion rust layers that accumulated over decades" within the piping that fed into homes [10]. The analysis of the samples from this ground zero home eventually lead to the declaration of a state of emergency in Flint, and likely prevented further exposure to lead (although the problem is far from resolved). It should be noted that the water crisis in Flint disproportionately impacted minority populations and areas known for lower socioeconomic status. This is clearly an incident of environmental injustice, and further emphasizes similar cases need to be investigated.

Miguel de Franca Doria devoted time to investigating how people perceive their water quality. In a 2009 study, conducted in the UK and Portugal, Doria looks into the factors by which surveyed people evaluate the quality of their drinking water and the rate at which surveyed people use bottled water instead of tap water in the household. The methods of this study consisted of focus groups and a survey. The survey, being the qualitative component of the study, asked participants to rank their agreement with statements such as "My tap water is usually of high quality," "I trust my tap water company," and "I am happy with the odor of my tap water" [11]. These results were analyzed using both structural equation models and generalised linear models, with results suggesting that "perceptions of water quality and risk result from a complex interaction of diverse factors." The most significant findings of this study give that flavor and peer opinions are the most important factors in consumer evaluation of risk.

This is significant because many harmful metals, including arsenic and lead, can’t be detected by taste, smell, or appearance. Without testing, it is very possible that contamination could go undetected, resulting in negative health effects in households and communities.

Dr. Sarah Flanagan published an influential three-paper series discussing arsenic in private well water. The first part discusses an investigation of arsenic contamination in relation to socio-economic status, henceforth abbreviated as SES. Because of the prevalence of naturally occurring arsenic due to geologic formation, findings suggest one cannot predict the concentration of arsenic with SES. In the third part of this paper, though, Flanagan discusses the ways SES and education level affect the detection of and response to contaminants in well water. People of higher SES and with higher levels of education are much more likely to know how to get their water tested and be able to afford the tests. They are also more able to respond to detected contamination, finding and buying alternate sources of water in the meantime and finding and affording the resources, such as filters and more intensive repairs, that would alleviate the problem [12]. This, combined with the increased vulnerability of low-SES people shows the importance of well water contamination as a social justice issue.

III. METHODS

The counties used in this study- Stokes, Wayne, Union, and Robeson -were chosen for analysis based off location in order to obtain a geospatial distribution of the state of North Carolina. Individual well tests were obtained through the North Carolina State Laboratory Public Health database of inorganic chemistry, where all new wells since 2008 are required to be tested and reported in the database[5]. Over the course of 6 weeks, well test results were selected from this database based on the specified counties. From 3732 well permits, 2625 valid reports were manually recorded.

The following data points were extracted from the well test results: name of system, street address, well identification, date collectected, date received/report date, collected by/reported by, sample type, sample source, sampling point, and results in mg/L for arsenic, cadmium, chromium, lead, manganese, and mercury. When values were not present in the well test results, values were recorded as "NA", and contaminant values that were under the detectable limit were recorded as "ND". Initial manual recording for data points such as sample type/sample point/sample source into the spreadsheet was not standardized, meaning the same text provided in the well test result was entered into the spreadsheet. Finalization/ standardization of the spreadsheet was completed during later statistical analysis. However, street addresses were standardized in the spreadsheet to use in geospatial geocoding before statistical analysis.

Through the use of the geospatial analysis program Esri ArcMap, the locations of the individual well test were geocoded and plotted using the geocoding tool. Geocoding requires a streetline shapefile to match the list of addresses to the well test results spreadsheet to a streets database provided by the streetline shapefile. This shapefile, the integrated statewide road network (ISRN) was downloaded via the North Carolina Department of Transportation website[6]. Additionally, county boundaries were downloaded from this website. Census data, which was required to map environmental justice metrics such as race, income and educational attainment were downloaded from the American Fact Finder, a online search engine for the Census.gov website [7]. A shapefile for census block groups polygons were downloaded via the

Geospatial Data Gateway, an online geospatial portal by the USDA [8]. Using Arctools in ArcMap, maps were generated relating census data and well contaminants in order to determine any significance between geographical location, race, income, and education. Statistical programs such as SPSS and R were also used in order to determine any significance between sample point of collection, age of well, types of contaminants, and occurrence of contaminants.

IV. ANALYSIS

A. Descriptives

Initial analysis began with compiling the test results extracted from the 2625 valid reports. Contaminant level was compared to the state-determined maximum contaminant level (MCL) and by county:

Wayne					
Contaminant	Number of wells tested	Maximum	Average	MCL	Wells above MCL
Arsenic	214	0.005	0.005	0.01	2
Cadmium	214	0.001	0.001	0.005	1
Lead	214	1.6	0.117	0.015	13
Manganese	214	0.18	0.053	0.05	52
Mercury	214	0	0	0.002	0
Union					
Contaminant	Number of wells tested	Maximum	Average	MCL	Wells above MCL
Arsenic	1716	0.172	0.024	0.01	309
Cadmium	1716	0.006	0.004	0.005	1
Lead	1716	0.48	0.022	0.015	34
Manganese	1716	5.9	0.357	0.05	545
Mercury	1716	0.0014	0	0.002	0
Robeson					
Contaminant	Number of wells tested	Maximum	Average	MCL	Wells above MCL
Arsenic	75	0	0	0.01	0
Cadmium	75	0	0	0.005	0
Lead	75	0.038	0.0155	0.015	3
Manganese	75	0.08	0.0538	0.05	5
Mercury	49	0	0	0.002	0
Stokes					
Contaminant	Number of wells tested	Maximum	Average	MCL	Wells above MCL
Arsenic	598	0.108	0.0114	0.01	7
Cadmium	598	0.0018	0.0001	0.005	0
Lead	598	0.111	0.0097	0.015	80

Manganese	598	1.5	0.131	0.05	294
Mercury	594	0	0	0.002	0

The contaminant with the most hits above the MCL was manganese, with 52 in Wayne County, 545 in Union County, 5 in Robeson, and 294 in Stokes. lead and arsenic were second to manganese.

In Wayne and Robeson counties, the average contaminant level for both lead and manganese is higher than the set MCLs. In Union County, lead, manganese and arsenic all have average contaminant levels above the MCL. Stokes County has average contaminant levels of arsenic and manganese higher than their respective MCLs.

B. Contaminant Co-occurrence

The following table lists the number of double occurrences throughout the 2625 analyzed well tests. Note the table lists co-occurrence of contamination at any level, not above the MCL.

Contaminants	# of wells
Arsenic & Cadmium	4
Arsenic & Lead	57
Arsenic & Manganese	214
Cadmium & Chromium	1
Cadmium & Lead	1
Cadmium & Manganese	8
Chromium & Lead	14

Chromium & Manganese	18
Chromium & Mercury	1
Lead & Manganese	124
Manganese & Mercury	1

The highest level of co-occurrence was seen with Arsenic and Manganese, at 214 out of 2625 well tests (8.15%). Further analysis would examine co-occurrence in reference to sampling point and age of the well.

C. Sampling Point

Each county's well test database listed a variety of choices for sampling point of the water tested. Our initial database of 2625 well tests contained over 20 options for 'sampling point,' which were reduced to 6 options: inside, outside, well, port, unspecified/no response, and miscellaneous.

Sampling Pt.	Arsenic	Cadmium	Chromium	Lead	Manganese	Mercury
Inside	0.004071925091	0.006	0.035	0.002311460302	0.1093898724	0
Misc.	0.005701492537	0	0	0	0.07341985816	0
Outside	0.00443696789	0	0	0.002063247897	0.1071192183	0
Port	0.005	0.001	0.015	0.005391254315	0.02498698413	0
Well	0.004034820593	0	0.03921724138	0.002690089147	0.1047519838	0.0014
Unspecified/ NA	0.004082626421	0.0005785	0.02252444444	0.002704187867	0.1055584769	0

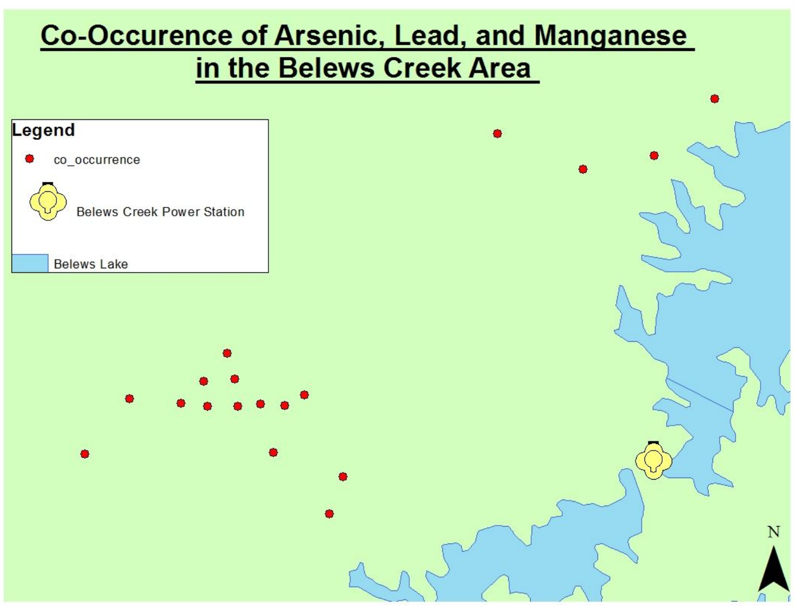
Above is a table of average contaminant values compared to sampling point listed on the well test. There is slight variation throughout each of the contaminants' averages according to sampling point, but no statistical significance was found amongst contaminant level and sampling point.

D. Environmental Justice Metrics and Belews Creek

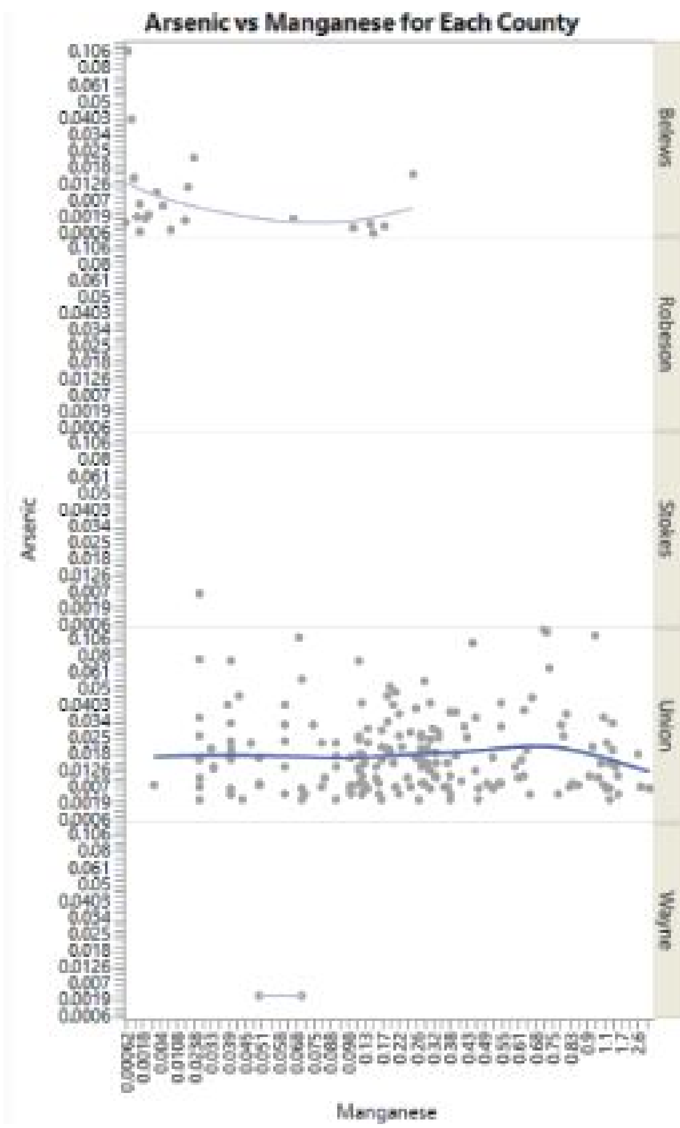
There were three environmental justice metrics that were explored in our analysis of private well water contamination: race, education, and income. (1) The four sub-groups used to qualify racial composition were non-hispanic white, non-hispanic black, American indian, and hispanic/latino. (2) Education level was assessed in a binary fashion, so the only education threshold considered was the achievement of a bachelor's degree. (3) Lastly, private well contamination was looked at in the context of income, with which block groups were divided into those with populations above and below 65% of the median income in North Carolina (approximately $31,000).

While racial composition was considered as an environmental justice indicator for each of the four counties, the random distribution of contaminants in Wayne and Union counties and limited sample size in Robeson county made it difficult to make any conclusions about race and other environmental justice metrics. For example, in Union County, census block groups with populations of 20-45% non-Hispanic Black had only 4.8% of all arsenic contamination in the county, and 5.5% of manganese. Wayne county had a random distribution as well. Census block groups with 28-99% of non-Hispanic Black residents, contained 9.6% of manganese and 2.4% of lead contaminants in the county. Due to the small number of well results racial GIS analysis was omitted for Robeson county. Education and Income GIS results were also omitted for Wayne, Robeson, and Union counties.

Of the four considered, Stokes county displayed interesting findings with respect to using environmental justice metrics as predictors of well-water contamination. For this reason, GIS results for each environmental justice metric are included for Stokes county. Stokes is different from the three other counties because there is a significant pattern of contaminant occurrence. This deviation from the random well-water contamination distribution is seen in the southeastern corner of the county, which is also the location of a coal ash pit belonging to Belews Creek Power Station.

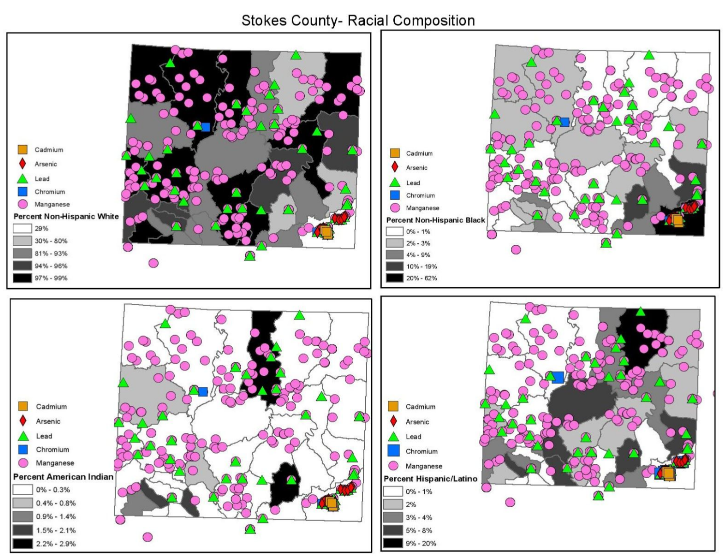


Manganese appears to naturally occur throughout Stokes county. For this reason, natural co-occurrence of the metal is expected to and does occur occasionally throughout the county. Without taking into account the block group containing Belews Creek, there is only one well with a naturally occurring metal that is not manganese-- this metal being chromium. Furthermore and still excluding the same block group, there is no example of triple co-occurrence of any three metals. The map of the Belews Creek area above illustrates a surprisingly different distribution from the rest of the county. While it does not happen in any other Stokes county block group, co-occurrence of arsenic, lead, and manganese contamination is found in 18 different wells on the county-facing side of the Belews Creek Power Station. As if this were not already a significant difference from the rest of the county, the multiple cases of arsenic, cadmium, and chromium in this block group--neither of which appearing to naturally occur in Stokes county--makes the cluster of contaminated wells even more interesting.

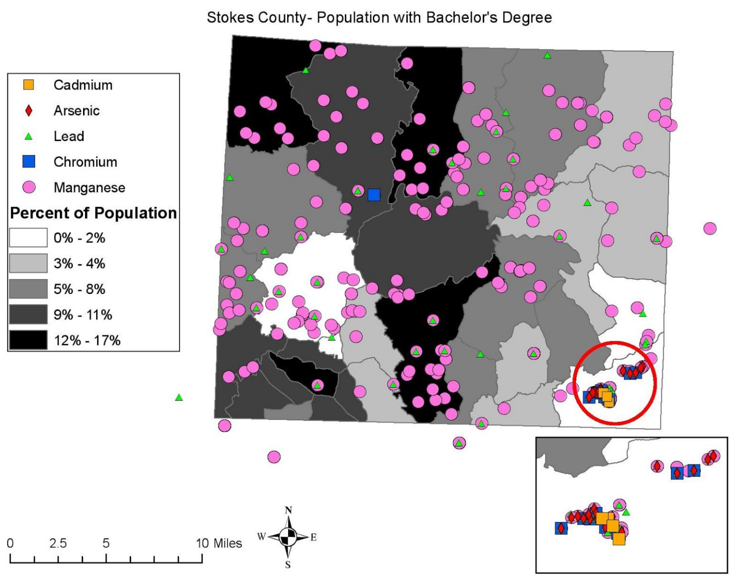


Belews Creek presents the opportunity to explore several environmental justice metrics as possible predictors of well contamination. If wells in Belews Creek are so different, can we find population characteristics that are unique to that area in order to explore a causal relationship between the two?

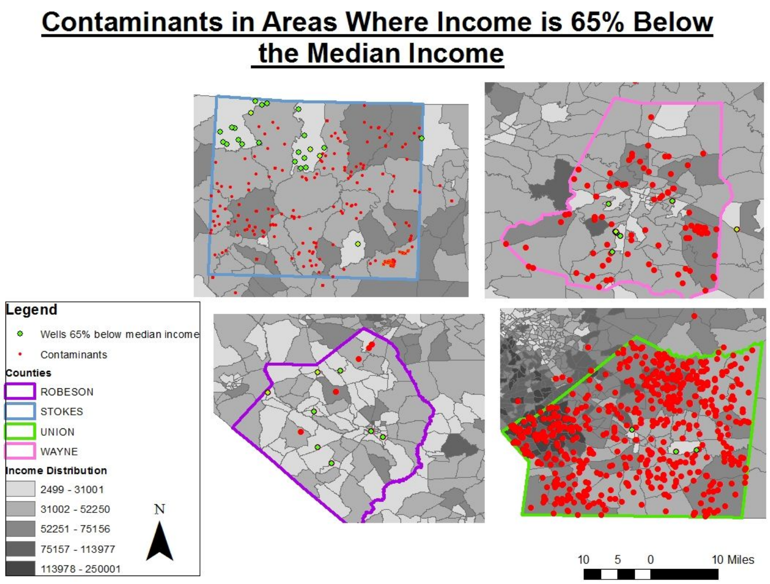
In the GIS map below, there is a significant pattern of racial composition of the Belews Creek block group compared to the rest of the county. The block group has a 20-62% non-hispanic black racial composition. In addition, 100% of arsenic and cadmium well contaminants were located in this census block group. A problem with concluding any causality here is the lack of gradient with the racial composition and contamination of other block groups. While there is still significant racial variability throughout the county, the distribution of contaminants like manganese and lead are still distributed randomly, regardless of the block group.



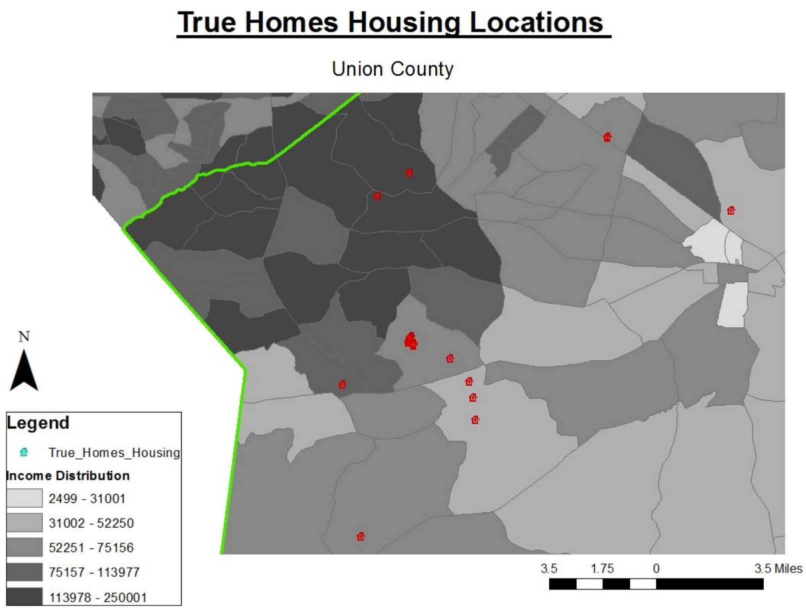
When looking at education level, the cluster falls in the Belews Creek census block group with less than two percent of its population having attained a bachelor's degree, despite having all cadmium and arsenic contaminants in the county. In order to prove any relationship between well water contamination and education level, similar levels of contamination would need to be found in other block groups with equally undereducated populations, but in the map below, the block groups directly to the North of Belews Creek and farther to the West (both are filled with white) do not show levels of contamination that are anywhere near what is seen in Belews Creek.



The final environmental justice metric considered was income. Using GIS, mapping of contaminants was done as was seen previously, except instead of racial composition or education level, block groups were characterized as being either above or below 65% of the median income in North Carolina. Since Belews Creek is the only seemingly non-random cluster of contaminants in the county, a true correlation between contamination and level of income would suggest that block groups with similar income level should have a similar level of contamination. Since this is not the case, it was concluded that income, like race and education, is not a significant predictor of private well water contamination in Stokes county or any of the other three counties.



One last analysis performed through ArcMap was the location of wells tested by the True Homes contractors in relation to contaminants and income. As seen below, the areas where True Homes is present are areas of higher income that do not fall below 65% of the median income. From the combined True Homes well locations, 17% contained chromium, 6% contained lead, 5.8% contained manganese, and 1.2% contained arsenic. The idea that environmental injustice can be detected based off income is negated because all of the True Home locations are above the 65% of the median income threshold, but still contain some detection of contaminants within the wells. This suggests it is possible wealthy communities may be placed on areas where naturally occurring contaminants are present within the ground. These results further support income is not a significant indicator of well water contamination.



V. CONCLUSION

In this project, we sought to evaluate the extent to which traditional environmental injustice metrics, including minority prevalence and socioeconomic status of a region, could predict the presence of contamination in private wells used for residential drinking water. To investigate this relationship, we extracted data from the North Carolina State Laboratory Public Health database of Environmental Inorganic Chemistry, which has well test data on private wells, and compared it to information from the census about race and education across 4 North Carolina counties: Stokes, Wayne, Union, and Robeson. Although we did not find support for a link between environmental injustice predictors and well contamination, we acknowledge that other studies have found evidence to the contrary. Though our study does not add to this body of evidence for environmental injustice in North Carolina, we postulate that patterns of contamination may be linked to the metrics herein or others in ways that could not be elucidated in a study of this scale. For example, a lack of publicly available test data in Robeson County (75 tests in DHHS database) may limit our ability to observe patterns. Importantly, Robeson County is 25th in North Carolina counties (USGS) for the number of people using well water, suggesting that the majority of people who use well water are not having their wells tested by the state, if they are being tested at all.

No clear patterns between racial composition and well results were found in any of the four counties examined. However, this was difficult to evaluate given the fact that we only mapped contaminated wells. Though the contaminated well results do not appear to cluster in any meaningful way, it appears as though certain census tracts do have more hits than others, possibly reflecting a greater reliance on wells. This in and of itself could constitute an environmental injustice, if those who are served by presumably cleaner municipal water differ in significant demographic ways from those relying on well water.

A similar possibility exists for the lack of patterns in education and income. However, as seen previously in Union county, certain naturally occurring contaminants like arsenic may be less likely to have a disproportionate impact on low SES regions. However, we cannot ignore the fact that either synergistic or antagonistic effects may be occurring to some degree: in other words, can race and SES together explain a greater amount of variability in well results, or do they actually have a negative effect on each other, making it harder to tease apart the factors contributing to contamination? Understanding the relative influence of these and other factors will be paramount to evaluating to the extent to which environmental injustice may be occurring in well water across North Carolina.

In our study, manganese was by far the most common contaminant. Given the relatively small amount of attention that has thus far been given to manganese as a human health threat, we emphasize the importance of continued studies on the impact of this metal on North Carolinians. Arsenic was also found to be exceptionally common, despite well known negative health impacts. Furthermore, we found these two contaminants together more frequently than any other combination in the study (214 instances). Co-occurrence of contaminants was also a notable problem in Belews Creek, near the Belews Creek Power Station. We believe this may be due to the coal plant's coal ash pit nearby, but we cannot be sure without additional studies, including species tracking to distinguish the contaminants from natural versus industrial sources.

Our study was limited in scope primarily by the small pool of tests from which our data was extracted. The state database contains only information on publicly tested wells, meaning no data could be obtained from wells for which owners chose to hire private companies to test the water. Additionally, wells constructed prior to 2008 are not covered by General Statute 87-97, meaning owners are not required to test the wells for contaminants. This may be playing a significant role in Robeson county in particular, as the DHHS databases was particularly lacking in tests despite the county's high reliance on well water. Wells in Robeson may also be generally older than those in other counties, which are experiencing significant development. Age of wells will be an important factor to consider in future studies, especially given the fact that older wells, legally, need not be tested at all.

To fully understand the relationship between environmental injustice metrics and well contamination in North Carolina, future studies must not only consider well age, but the temporal variability that may exist over time for any given well. Geographic factors like regional topography and well depth may also influence the presence of contaminants. Crucially, evaluating these large-scale variations will require expanding beyond the four counties examined herein. However, small-scale studies will also be needed to understand what is happening on a meaningful level in places like Belews Creek, where industrial contamination may be driving high prevalence of contamination, and the True Homes developments, where these factors may be less relevant. Perhaps most importantly, future studies should consider ways to get at data from privately tested wells. There is no way to be certain just how much data is missing, though we can safely assume that private tests represent a reasonable fraction of the data collected in North Carolina. No analysis will be complete without incorporating these results. Ultimately, the work has only begun and we strongly advocate for increased attention to the contaminants common to NC, the patterns of contamination that may exist, and the nuances of these patterns.

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