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Development of Environmental Justice Index for Water Quality in NY State Using Trihalomethanes

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Abstract

Trihalomethanes (THMs), which are likely to cause cancer in humans, are frequently detected as disinfection by-products (DBPs) in public water systems (PWS). A recent study revealed that regions with higher incomes typically had lower THM levels in New York State, potentially suggesting a socioeconomic disparity concerning the quality of drinking water. Expanding on this crucial discovery, our research sought to lead the development of an Environmental Justice (EJ) Index for evaluating drinking water quality, using THM concentrations as the primary metric. Our hypothesis centers on utilizing THM concentration as an environmental indicator to address issues of environmental justice, given the health risks associated with THMs and their susceptibility to socio-economic and environmental factors in communities. The step-by-step creation and practical application of an EJ Index for THMs has been demonstrated, highlighting the suitability of THMs as an EJ indicator. Through this comprehensive approach, our research aimed to initiate the inclusion of a water-quality related EJ index in the current U.S. EPA's thirteen EJ indexes which lack adequate representation of water quality in communities.

Keywords: EJ Index, Trihalomethanes, Disinfection By-Products, Socioeconomic Disparity, New York

1. Introduction

A national assessment spanning over three decades, from 1982 to 2015, examined drinking water quality violations in public water systems (PWS) and discovered that approximately 8.0% of PWS experienced health-based violations during this period (Allaire, 2018). Among these violations, a significant proportion, approximately 25%, were attributed to disinfection by-products (DBPs) (Allaire, 2018). Trihalomethanes (THMs), which belong to the class of DBPs, are known to form as a result of the chemical reactions between natural organic matter and disinfectants, such as chlorine, employed in the treatment of public drinking water (DeMarini, 2020). The U.S. Environmental Protection Agency (EPA) regulates four trihalomethanes including chloroform, bromodichloromethane, dibromochloromethane, and bromoform which are referred to as total trihalomethanes (or THM4) of which federal regulatory level is set at 80 µg/L (U.S. EPA, 2018). One of the key reasons THMs warrant attention is their classification as probable human carcinogens, supported by findings from experimental studies involving laboratory animals (Attias, 1995). Moreover, numerous epidemiological investigations have established associations between exposure to chlorinated drinking water, which often contains THMs, and the incidence of conditions such as rectal, colon, and bladder cancers (Costet, 2011; Hildesheim, 1998). This robust body of evidence underscores the significance of THMs as an environmental indicator for drinking water quality, as their presence not only reflects the prevalence of DBPs but also raises pertinent public health considerations, particularly concerning potential carcinogenic risks associated with long-term exposure.

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Elevated THM levels exceeding federal mandates were observed in the watersheds of three states (Arkansas, Nevada, and Rhode Island) characterized by lower median household incomes compared to the national average, while states with higher median household incomes (Delaware, New Hampshire, and Wisconsin) exhibited notably low THM levels (Karim, 2020). In a THM study conducted in middle Tennessee, it was noted that specific areas within each watershed, marked by lower median household incomes, demonstrated heightened levels of THMs in their drinking water (Guha, 2019). While this previous two studies did not demonstrate a significant correlation between THM levels and socioeconomic factors through data points from either U.S. states or major watersheds in Tennessee, the recent study by Lee and Park (2023) made a noteworthy discovery. It revealed a negative correlation between median household income and THM concentrations at the city (or village) level in the state of New York. This inverse relationship raises an important concern, suggesting the existence of socioeconomic disparities in terms of drinking water quality. As a natural progression from this pivotal finding, our research endeavored to pioneer the development of an Environmental Justice (EJ) Index tailored to assess drinking water quality using THM concentrations as a primary metric.

The primary objective of this article is to demonstrate the suitability of THMs as an EJ indicator for drinking water quality and to develop an EJ index, aiming to shed light on regions within New York State that might bear higher environmental burdens, potentially affecting vulnerable populations. Our methodology aligns with the EPA's established EJ Index development tool in EJScreen, which amalgamates both environmental and socioeconomic indicators to provide a comprehensive perspective on environmental justice (US EPA, 2023).

We hypothesized that the concentration of THMs can be used as an environmental indicator to discuss environmental justice because THMs can pose health risks, and their presence in drinking water can be influenced by a community's socio-economic and environmental conditions. We presented the detailed procedure for developing an EJ Index for THMs and its application. We compared the results of the previous correlation study between THMs and socioeconomic factors with the outcomes of the correlation study applied using the developed EJ index.

2. Materials and Methods

The average concentrations of total trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform) in 2020 were obtained from the New York State Department of Health (NYDH) and used for THM data (NYDH, 2020). All communities investigated in this study were identified using the U.S. EPA Safe Drinking Water Information System (SDWIS) to link THM concentrations, the served communities, and their demographic information (U.S. EPA, 2022). U.S. Census Bureau's American Community Survey (ACS) 2017-2021 5-Year Estimate (ACS 2021) were used for demographic information such as household incomes and race percentages (US Census Bureau, 2023). We retrieved data for 286 PWS that cover over 80% of the NY state population after excluding very small communities of which information is hard to find on the Census Bureau website. Cancer incidence rate by county was obtained from NY Department of Health (NYDH, 2020). Pearson correlation coefficients (r) were used with corresponding p-values to evaluate the association between THM concentrations and demographic index and between THM concentrations and cancer incidence rates. The significance level of the p-value for determining whether to accept or reject the null hypothesis stating "no correlation between the two variables" was established at 5% (0.05). To compute an EJ Index for THMs, we integrated a normalized THM environmental indicator with the demographic index through the following equation.

$$\text{EJ Index for THMs} = \text{Demographic Index} \times \text{Normalized THM Environmental Indicator}$$

The demographic index was derived from the average of two crucial demographic indicators: the percentage of low-income individuals and the percentage of people of color within the studied population. The percent of people of color represents the proportion of all people other than non-Hispanic white-alone individuals within a community. Meanwhile, the percent of low-income individuals accounts for the share of a community's population residing in households with incomes less than or equal to twice the federal poverty level. The normalization process for the THM environmental indicator involved converting THM data obtained from the New York Department of Health into percentiles in NY state.

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3. Results

3.1 Generation of EJ Index for THMs in NY state

Table 1. Communities at or above the 80th percentile of EJ Index for THMs in NY state

Community	Average THM Conc (µg/L)	THM Percentile (NY)	Median Household Income	% Low Income	% People of Color	Demographic Index	EJ Index for THMs	EJ Index for THMs % (NY)
Albany City	54.5	84.5	$48,512	0.414	0.462	0.438	37.0	100
Syracuse City	46.4	73.3	$38,893	0.524	0.466	0.495	36.3	99.7
Potsdam Village	61.9	94.3	$25,850	0.578	0.169	0.374	35.2	99.3
Poughkeepsie City	48.3	76.1	$47,008	0.401	0.514	0.457	34.8	99
Troy City	57.9	90.5	$48,834	0.432	0.337	0.384	34.8	98.6
Rochester City	42.1	63.5	$37,395	0.530	0.546	0.538	34.2	98.3
Peekskill City	47.3	74.3	$66,067	0.296	0.607	0.452	33.6	97.9
Catskill Village	69.1	98.2	$42,200	0.515	0.141	0.328	32.2	97.6
Buffalo City	38.9	58.2	$39,677	0.495	0.529	0.512	29.8	97.2
Geneva City	57.1	88.7	$42,472	0.443	0.223	0.333	29.6	96.9
New York City	41.1	61.4	$70,663	0.347	0.602	0.474	29.1	96.2
Elmsford Village	42.9	65.9	$102,601	0.222	0.629	0.425	28.0	95.8
Monroe Village	63.7	95	$92,744	0.211	0.379	0.295	28.0	95.5
Monticello Village	37.7	52.9	$40,080	0.526	0.528	0.527	27.9	95.1
Port Chester Village	46.1	71.9	$81,586	0.292	0.453	0.373	26.8	94.8
Watertown City	55.8	85.2	$41,918	0.463	0.161	0.312	26.6	94.4
Amsterdam City	45.4	70.8	$40,696	0.467	0.284	0.375	26.6	94.4
Fredonia Village	68.7	97.8	$56,406	0.379	0.159	0.269	26.3	93.7
Schenectady	41.9	62.1	$47,773	0.409	0.435	0.422	26.2	93.4
Wallkill Town	86.9	99.2	$75,825	0.114	0.413	0.264	26.2	93
Newark Village	59.1	91.5	$51,178	0.391	0.176	0.284	25.9	92.7
Oneonta City	66.0	96.1	$55,565	0.392	0.135	0.264	25.3	92
New Paltz Village	50.0	80.7	$75,455	0.457	0.161	0.309	25.0	91.6
Hudson City	38.4	56.1	$36,543	0.528	0.349	0.439	24.6	91.3
Geneseo Village	43.1	66.3	$28,558	0.637	0.104	0.371	24.6	90.9
Utica City	38.2	54.3	$42,624	0.497	0.387	0.442	24.0	90.5
Nyack Village	55.9	85.6	$83,930	0.265	0.291	0.278	23.8	89.8
Lyons Town	56.9	88	$51,354	0.365	0.17	0.268	23.5	89.5
Clarkstown	55.9	85.6	$118,837	0.224	0.324	0.274	23.4	89
Auburn City	48.6	77.5	$43,555	0.416	0.166	0.291	22.5	88.8
Erwin Town	50.0	79.6	$83,773	0.430	0.131	0.280	22.3	88.1
Mount Vernon City	30.9	40.7	$59,291	0.280	0.793	0.536	21.8	87.3
Cortlandt Town	41.2	61.7	$114,347	0.461	0.243	0.352	21.7	86.7
Attica Town	65.4	95.7	$64,093	0.226	0.225	0.226	21.6	86.3
Elmira City	38.4	56.8	$36,543	0.519	0.215	0.367	20.8	86
Fallsburg Town	31.5	41.7	$49,435	0.680	0.306	0.493	20.6	85.3
Syracuse City	31.2	41	$38,893	0.524	0.466	0.495	20.3	85
Rome City	50.5	81.4	$51,752	0.362	0.133	0.247	20.1	84.6
Middle Town City	35.5	47.3	$58,235	0.369	0.473	0.421	19.9	84.3
Binghamton City	36.1	48.7	$35,730	0.536	0.281	0.408	19.9	83.9
Ithaca City	47.3	73.9	$38,019	0.516	0.323	0.419	19.8	83.7
Rensselaer City	56.0	86.3	$56,347	0.258	0.199	0.228	19.7	83.6
New Rochelle City	38.5	57.1	$81,735	0.232	0.45	0.341	19.5	83.2
Medina Village	44.0	68.4	$45,134	0.423	0.134	0.278	19.0	82.9
Seneca Falls	51.9	82.8	$48,961	0.378	0.079	0.229	18.9	82.5
Tupper Lake Village	88.9	100	$42,066	0.300	0.076	0.188	18.8	82.2
Massena Village	57.8	90.1	$45,504	0.352	0.06	0.206	18.6	81.8
Schaghticoke City	73.3	98.5	$94,338	0.321	0.053	0.187	18.4	81.5
Lockport Town	48.6	77.1	$70,060	0.352	0.124	0.238	18.4	81.1
New Paltz Town	39.8	59.2	$75,455	0.457	0.161	0.309	18.3	80.8
Rensselaer city	49.6	78.5	$56,347	0.26	0.199	0.23	17.9	80.1

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As U.S. EPA used the 80th percentile as the initial benchmark for addressing environmental justice, we have identified communities in New York State that meet or exceed the 80th percentile of the EJ Index for THMs in the State (Table 1). For example, Albany city had a THM concentration of 54.5 μg/L, which corresponds to the 84.5th percentile in the state. It also had percent people of color of 46.2% and percent low-income of 41.4%, resulting in a Demographic Index of (0.462 + 0.414)/2 = 0.438. An EJ Index for THMs was calculated by multiplying the state percentile for the THM Indicator by the Demographic Index, resulting in 84.5 x 0.438 = 37.0. Once this calculation was applied to all the communities investigated in this study, the state percentile for the THM EJ Index was determined, allowing for easy comparisons among communities. The EJ Index for THMs of 37.0 for Albany city corresponds to the 100th percentile in the state. When a city (e.g. Attica city, Ithaca city) was served by multiple PWS, a population weighted average THM concentration was used. Because the EJ Index combines three measures (THM level, % low income, and % people of color), the percentile of Albany city's THM EJ Index is greater than that of Potsdam village although Albany city's THM concentration is lower than that of Potsdam village. The population weighted average THM concentration for 286 THM data points in New York state in 2020 was 34.2 μg/L, with a standard deviation of 21.4 μg/L. We conducted a regression analysis to evaluate the association between demographic index and THM concentrations but could not find a linear correlation (p-value = 0.49, Figure 1) while a negative correlation was found between median household income and THM concentration in the previous study (Lee and Park, 2023).

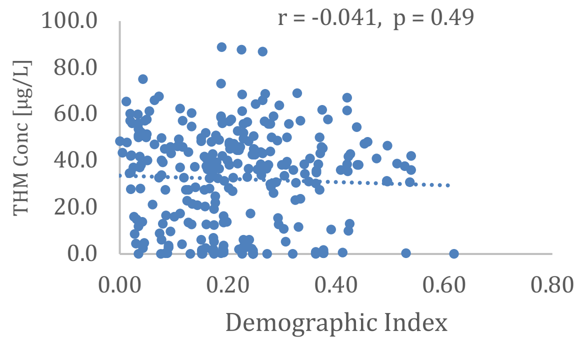

Figure 1. THM concentrations plotted against demographic index at city levels in New York State. THM Conc denotes total trihalomethane concentrations.

Table 2. Communities violated total trihalomethanes standard in NY state in 2020. * denotes cities that violated THM standards multiple times.

County	NY PWS ID	Community	Population	Demographic Index (Percentile in State)
Cayuga	NY0511732	Aurelius (T)*	872	17
Cayuga	NY0530054	Brutus (T)*	1287	6
Cayuga	NY0501718	Fleming (T)	1800	5
Cayuga	NY0501733	Montezuma (T)	490	33
Cayuga	NY0530063	Springport (T)*	52	26
Erie	NY1400397	Akron (V)	3100	45
Essex	NY1500278	Essex (T)*	350	25
Franklin	NY1600012	Tupper Lake (V)*	5500	39
Genesee	NY1800542	Alexander (V)	785	24
Herkimer	NY2102310	Mohawk (V)	2985	41
Jefferson	NY2230022	Champion (T)	650	35
Jefferson	NY2202337	Dexter (V)*	1100	30
Jefferson	NY2202083	Pamelia (T)*	25	45
Jefferson	NY2202346	Watertown City*	27861	54
Jefferson	NY2202352	Watertown (T)*	750	42
Livingston	NY2500701	Caledonia (T)	160	25
Livingston	NY2501014	Leicester (V)*	24	22
Orange	NY3503527	Florida (V)*	2884	47
Orange	NY3503584	Wallkill (T)*	18450	63
Otsego	NY3800154	Oneonta City	15779	41
Steuben	NY5000755	Lindley (T)*	39	21
Tompkins	NY5430047	Ulysses (T)*	400	36
Washington	NY5700124	Whitehall (V)*	2800	54
Wyoming	NY6011605	Castile (T)*	440	40

3.2 State-wide THM Compliance Data

We investigated the THM standard violation history of communities in New York State using drinking water standard violation data from NYDH (NYDH, 2020). In addition to the THM violation data, we included population data from the Census Bureau and Demographic Index data from EJScreen, and generated a combined information sheet (Table 2). Among the communities at or above the 80th percentile of the THM EJ Index, three communities

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(Watertown City, Wallkill Town, and Oneonta City, highlighted in red in Table 1) were found to violate the THM standard in 2020. Of the communities with THM standard violations, 48% were served by small public water systems (serving 501-3,300 people), and 35% were served by very small public water systems (serving 25-500 people).

3.3 Correlation between THMs and Bladder and Colorectal Cancer Incidence Rate

We conducted an investigation into the correlation between THM concentrations and the incidence rates of bladder and colorectal cancer in the state of New York. As cancer incidence rates are reported at the county level in NY state, we computed correlations between cancer incidence rates and the average THM concentrations within each county, rather than at the city-level. Our findings revealed no significant correlations, with p-values of 0.98 for bladder cancer incidence rates and 0.120 for colorectal cancer incidence rates (Figure 2). In the 2016-2020 period, the average incidence rate for bladder cancer in New York State's counties was 25.4 cases per 100,000 individuals, with a standard deviation of 4.5 cases per 100,000 people. In comparison, colorectal cancer had an average incidence rate of 13.0 cases per 100,000 individuals, with a standard deviation of 4.1 cases per 100,000 people.

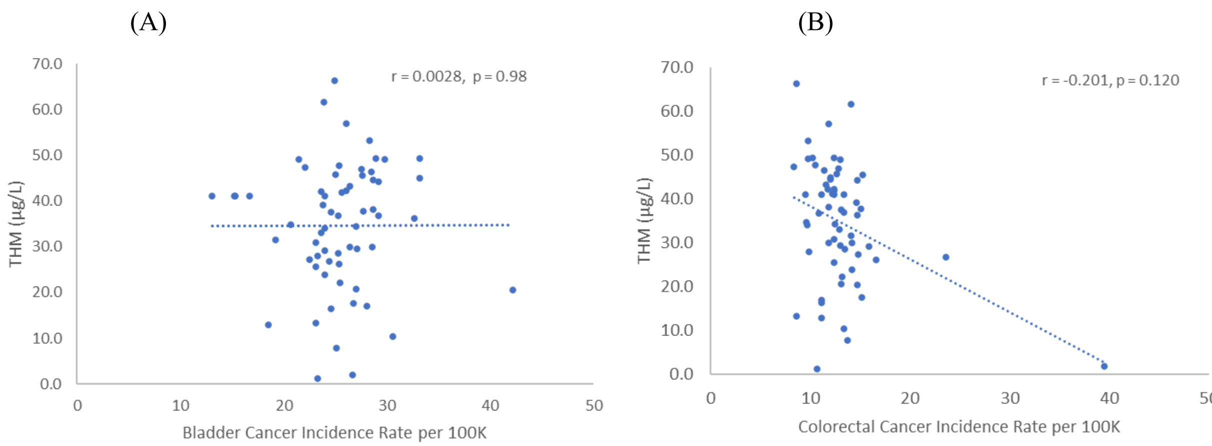

Figure 2. THM concentrations plotted against (A) Bladder cancer incidence rate (B) colorectal cancer incidence rate at county levels in New York State. THM Conc denotes total trihalomethane concentrations.

4. Discussion

Unlike other regulated contaminants in drinking water, DBPs possess unique characteristics as they are by-products formed during a crucial process of inactivating pathogens. They not only form in the final drinking water process at water treatment facilities but continue to form throughout distribution systems. Maintaining low DBPs while ensuring proper pathogen inactivation is a challenging task, contingent on the economic and technical capabilities of communities.

In the U.S. and many other countries, THMs and haloacetic acids (HAA5) are regulated because they serve as indicators of exposure to the complex mixture of DBPs in chlorinated drinking water, although more than 600 DBPs have been identified since the discovery of the first DBPs in 1974. Furthermore, THMs have a more extensive dataset regarding occurrence, carcinogenicity, genotoxicity, and epidemiology than other DBPs, making them suitable for studying correlations with historic socioeconomic factors. Therefore, THMs should be suitable representatives for drinking water quality in EJ studies.

Following a top-down approach recommended by Browne et al. (2022) in a recent EJ study, we developed an EJ Index for THMs in New York State. This process starts with a broad conceptual framework, gradually transitioning to a specific and quantifiable focus, addressing Environmental Justice concerning Drinking Water Quality (Figure 3). In the prior study conducted by Lee and Park (2023), a potential socioeconomic disparity was observed through an examination of the correlation between THM levels in drinking water and median household income in New York

State. To establish a concrete Environmental Justice (EJ) Index, environmental and demographic factors were integrated to encompass the multifaceted dimensions of environmental justice. The final step involves assessing the efficacy of the developed index to ensure that it effectively fulfills its purpose of addressing and rectifying inequalities in access to clean and safe drinking water. This structured approach guarantees a methodical progression from a broad conceptual framework to a practical tool for advocating Environmental Justice.

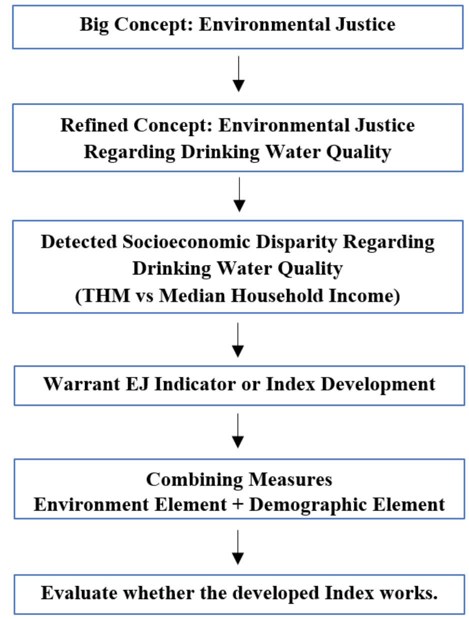

Figure 3. From Concept to Action: Developing an EJ Index for Equitable Drinking Water Quality

Our approach aligns with the guidelines established by the U.S. EPA, which outline key considerations in the selection of environmental indicators, with specific characteristics in mind (U.S. EPA, 2023). First, these indicators should be characterized by a resolution already in existence or readily attainable at the census block group level or a closely related resolution. Second, they should provide broad coverage, with screening level data available or feasible to develop for the entire United States, ensuring comprehensive reach. Third, these indicators should be highly relevant to environmental justice, as they pertain to pollutants or impacts where disparities have been observed between various groups concerning exposures, susceptibility, or health outcomes. Lastly, they should carry significant public health importance, with pollutants or impacts that have the potential for notable effects, raising substantial concerns, even if localized, or demonstrating established links to substantial health impacts on a national scale.

Consequently, we chose THMs as an EJ indicator for several reasons. THM concentrations are typically accessible at the local or regional level through water quality monitoring conducted by various agencies, including state or local environmental agencies. These concentrations are most commonly reported at the community water system level, as community water systems are mandated to monitor and report DBP levels to ensure compliance with federal drinking water regulations, including the total trihalomethanes and haloacetic acids regulations. Nationwide THM concentration data is readily available. As evident in the thirteen EJ Indexes currently utilized by the U.S. EPA (Particulate Matter 2.5, Ozone, Diesel Particulate Matter, Air Toxic Cancer Risk, Air Toxics Respiratory HI, Toxic Releases to Air, Traffic Proximity, Lead Paint, Superfund Proximity, RMP Facility Proximity, Hazardous Waste Proximity, Underground Storage Tanks, Wastewater and Discharge), sets of measurable environmental indicators are essential to comprehend and address unjust exposure to unhealthy environmental conditions. Notably, there is a scarcity of indicators representing water quality, highlighting the need to incorporate more indicators related to water quality.

In the prior study conducted by Lee and Park (2023), an inverse relationship between THM levels and median household income was identified, suggesting a potential socioeconomic disparity in drinking water quality. Elevated DBP concentrations in drinking water have been associated with health concerns, including an increased risk of cancer and other diseases. Communities with higher DBP levels may face health disparities, which can disproportionately affect marginalized or low-income communities. However, we were unable to find such a correlation when we used demographic index instead of median household income for socioeconomic status. While a negative correlation existed between THMs and median household income, there was no observable correlation between THMs and the percentage of people of color. This absence of correlation extends to the demographic index, which incorporates both household income and race factors. The demographic index, comprised of both the percentage of low-income individuals and the percentage of people of color, offers a more robust composite socioeconomic indicator compared to a single metric like median household income or poverty level. This outcome underscores how the definition of demographic factors can profoundly influence the interpretation of environmental justice data in the context of discussions about environmental justice. The THM EJ Index information included here highlights areas across the NY state that have higher THM levels when compared to other communities in the state but it does not indicate whether a selected area is not meeting the federal or state standard for THMs. For example, the federal or NY state regulatory standard, maximum contaminant level (MCL) of THMs is 80 µg/L and most of communities in the Table 1 did not violate the THM standard.

As a final step of EJ index development, we assessed its effectiveness using state-wide THM compliance data and correlational epidemiology. Although only three communities from the communities at or above the 80th percentile of the THM EJ Index are listed in the THM standard-violating community table (Table 2), it does not mean that only small percentage of the high THM EJ Index communities violated the THM standard. When we developed the EJ Index using 286 data points by matching the names of the communities in the THM data with the geographic names in the U.S. Census Bureau data, we often could not find demographic information for small communities with a population of less than 3,300. Thus, many small communities in Table 2 were not included in 286 data used for the EJ study. However, the retrieved data for 286 PWS covering over 16 million people accounts for 81% of the New York State population, which was adequate for statistical analysis.

We investigated the correlation between THM levels and cancer incidence rates; however, no linear correlations were identified (Figure 2). Access to cancer incidence data at a more granular level, such as the city or village level, would have enabled us to explore potential correlations between the THM EJ Index and cancer incidence rates more comprehensively.

5. Conclusion

Our research has successfully culminated in the creation of an EJ Index for THMs in New York State, employing a meticulously structured top-down methodology in line with established standards. The selection of THMs as a key indicator stems from their data accessibility, relevance to environmental justice, and the significant public health implications they carry. The incorporation of a demographic index underscores the profound influence of demographic factors on the interpretation of environmental justice data. While our EJ Index's efficacy was tested using statewide compliance data, our inquiry into the potential correlation between THM levels and cancer incidence rates revealed the absence of linear associations. To deepen our understanding, access to more granular cancer incidence data at the city or village level is recommended, offering a more comprehensive exploration of possible links between the THM EJ Index and cancer rates. This study underscores the persistent urgency of addressing environmental justice issues and emphasizes the nuanced complexity of interpreting environmental data within the framework of equity and public health. Future research endeavors should encompass the development of THMs and EJ data at smaller scales, such as census block levels, and involve a comparative analysis of the THM EJ Index with other EJ indexes, as presented in the EJScreen.

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