Toxic Air Pollution is Linked to Higher Cancer Rates among Impoverished Communities in Louisiana

Short Title: Toxic Air Pollution and Cancer in Louisiana

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Abstract

Despite the intense debate surrounding Cancer Alley and environmental racism in Louisiana, there is a lack of environmental health research in this state. The few studies that exist of cancer and toxic air pollution in Louisiana have been industry-funded and/or limited in statistical power by small population size. These limitations reduce (or may reduce) the likelihood of detecting any cancer-pollution link that exists. We investigated the relationship between toxic air pollution and cancer among Louisiana census tracts using the most recent cancer incidence rates available from the Louisiana Tumor Registry (2008-2017). To account for cancer latency, we used historical pollution data, specifically, Cancer Risk (due to toxic air pollution), from the U.S. Environmental Protection Agency's 2005 National Air Toxics Assessment (NATA), and we excluded census tracts with substantially changed boundaries between the 2005 and 2008-2017 datasets. We used Cancer Risk values for point sources, which are industrial plants, electrical utilities, large waste incinerators, and other sources with a specific point location of emissions, but excludes airports and homes, as well as fires, vehicles, and other mobile sources. Our analysis included 5-year estimates (2011-2015) of race (% Black) and poverty from the U.S. Census Bureau's American Community Survey. Using linear regression and stepwise AIC model selection, we evaluated cancer rates among census tracts (n = 750) relative to each variable and to all combinations of variable interactions. The top-performing model included the direct effects of race (% Black) and poverty, in addition to interactive effects between race and poverty and between pollution and poverty. Further analysis found that higher pollution levels were linked to higher cancer rates among the most impoverished census tracts (i.e. top quartile; $r = 0.25$, df = 187, $P = 0.0004$), but not among the other census tracts. A simple correlation test between pollution values and cancer rates was non-significant, meaning that the link between pollution and cancer was apparent only when poverty was considered. Our analysis provides evidence of a statewide link between cancer rates and toxic air pollution in Louisiana and suggests that toxic air pollution is a contributing factor to the state's cancer burden. These findings validate the firsthand knowledge of Louisiana residents from impoverished and industrialized neighborhoods who have long maintained that their communities are overburdened with cancer.

Introduction

Clients of the Tulane Environmental Law Clinic, including residents of Cancer Alley, Mossville, and other industrialized communities, have long maintained that their communities are overburdened with cancer and other health problems from chronic pollution exposure. While continually dismissed by industry,[1] state decision-makers,[2] and local politicians,[3] these concerns are not baseless. More pounds of industrial toxic air pollution are released each year in Louisiana than in any other state in the nation.[4] Our clients who live in industrialized communities have firsthand experiences with higher-than-normal cancer prevalence among their family members, friends, and neighbors. Yet, despite this basis for concern, neither the Department of Environmental Quality (LDEQ) nor the Louisiana Department of Health (LDH) has ever published a systematic evaluation of pollution and cancer risk across Louisiana. Understanding this relationship is essential to environmental justice because Black communities in Louisiana are overburdened by both pollution and cancer.[5]

The LDEQ has repeatedly used data from the Louisiana Tumor Registry – the state cancer database – to justify further industrial development in Louisiana's industrialized communities. Specifically, LDEQ has dismissed concerns about toxic air pollution in particular communities on the basis that the local cancer rate is not statistically higher than the Louisiana average.[6] This approach is scientifically flawed for multiple reasons. Most fundamentally, the approach fails to include any measure of pollution exposure or to recognize that industrialized communities across Louisiana are represented in the state average, which itself is abnormally high. Louisiana has the 7th highest cancer rate in the United States.[7] While multiple factors contribute to cancer disparities, there is no scientific reason to exclude Louisiana's extreme industrial pollution from the list of potential causes. Further, LDEQ's approach to public health inappropriately puts the burden of proof on the community rather than the polluter. In other words, there is no evidence that it is *safe* to locate industrial plants near communities, yet LDEQ maintains there is no

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[1] For example, see Formosa Plastics (FG LA LLC) Environmental Assessment Statement to LDEQ. January 27, 2019. Page 8. Doc ID 11457119.
[2] For example, see LDEQ Basis for Decision and Response to Comments regarding Formosa Plastics air permit approval. January 6, 2020. Pages 17, 18, 49, 54, 65, 118, 121, 122. Doc ID 11998452.
[3] For example, see the letter from Louisiana parish presidents (Ascension, St. James, and St. Charles parishes) to President Joseph Biden. June 2, 2021.
[4] Based on 2017 – 2019 values for TRI Pounds of air releases, from EPA Risk Screening Environmental Indicators Database. Available at https://edap.epa.gov/public/extensions/EasyRSEI/EasyRSEI.html#
[5] Terrell, K. and W. James, 2021. Racial Disparities in Air Pollution Burden and COVID-19 Deaths in Louisiana, USA, in the Context of Long-Term Changes in Fine Particulate Pollution. *Environmental Justice.* September 2, 2020. https://doi.org/10.1089/env.2020.0021.
[6] LDEQ Basis for Decision and Response to Comments regarding Formosa Plastics air permit approval. January 6, 2020. Pages 17, 18, 49, 54, 65, 118, 121, 122. Doc ID 11998452. *See also* LDEQ Response to Comments. Pin Oak Terminal. 2580-00051-V0. AI 144688. Doc ID 11078480. Page 6.
[7] Louisiana ranked 7 out of 52 for age-adjusted incidence of cancer (all sites) from 2013-2017. Louisiana rate: 481.0. U.S. rate: 448.7. Rates are per 100,000 population. National Cancer Institute. Incidence Rates Table. Accessed June 18, 2021.

evidence that this practice is *unsafe*.[8] Scientists (including co-author Terrell) have informed LDEQ that there are many reasons why an effect of pollution exposure can go undetected, particularly in small populations.[9] Yet the agency has not corrected its approach to industrial permitting.

The Louisiana Tumor Registry itself has adopted questionable practices with respect to Louisiana's industrialized communities. Specifically, the Registry's annual reports provide cancer rates for the "Industrial Corridor," a subjectively defined area in southeast Louisiana that corresponds to West Baton Rouge, East Baton Rouge, Iberville, Ascension, St. James, St. John, and St. Charles parishes. (Louisiana parishes are equivalent to counties). This definition omits the neighboring parishes of Jefferson, Orleans, St. Bernard, and Plaquemines, which are similarly impacted by industrial pollution and are typically considered to be part of "Cancer Alley."[10] The definition also ignores heavily industrialized communities in other parts of the state, including Mossville, Lake Charles, Shreveport, and Alexandria. In fact, of the 10 parishes in Louisiana with the highest Cancer Hazard from industrial pollution, only four are included in the Tumor Registry's definition of the Industrial Corridor.[11]

Like LDEQ, the Tumor Registry lacks any measure of pollution exposure in its analyses. Instead, the Registry simply reports region-wide cancer rates for the so-called Industrial Corridor.[12] Because these values are not statistically elevated compared to the corresponding state averages, the report implies that industrial pollution is not a significant driver of cancer in Louisiana – a baseless and potentially dangerous conclusion. In fact, the LDEQ has copied and pasted these findings into air permitting decisions.[13] The misuse of cancer data by industry, LDEQ, and the Registry itself has resulted in profound distrust of the Louisiana Tumor Registry by many residents and environmental advocates. Yet, despite the widespread misuse of Louisiana cancer data, the dataset itself is scientifically sound and represents a valuable resource for public health research and advocacy.

We evaluated the relationship between cancer rates and toxic air pollution in Louisiana using data from the Louisiana Tumor Registry and the Environmental Protection Agency, as well as demographic data from

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[8] LDEQ Basis for Decision and Response to Comments regarding Formosa Plastics air permit approval. January 6, 2020. Pages 17, 18, 49, 54, 65, 118, 121, 122. Doc ID 11998452. *See also* LDEQ Response to Comments. Pin Oak Terminal. 2580-00051-V0. AI 144688. Doc ID 11078480. Page 6.

[9] Letter from Edward Peters and Kimberly Terrell to LDEQ Secretary Chuck Carr Brown. RE: LDEQ Approval of Formosa Plastics Plant Contradicted Basic Public Health Principles. March 4, 2021. Doc ID 12606364.

[10] Wesley James, Chunrong Jia, and Satish Kedia. "Uneven Magnitude of Disparities in Cancer Risks from Air Toxics." International Journal of Environmental Research and Public Health 9 (Dec 2012): 4365–4385. See also An Environmental Justice Assessment of the Mississippi River Industrial Corridor in Louisiana, Using a Gis-Based Approach." Applied Ecology and Environmental Research 11 (2013): 681–697.

[11] Cancer Hazard is a measure of the amount of cancer-causing pollution released by industrial facilities, as reported by the Environmental Protection Agency's Toxic Release Inventory. In 2019, the top 10 parishes were: Iberville, Ascension, Caddo, St. Bernard, Jefferson, East Baton Rouge, St. Mary, St. James, Ouachita, and Calcasieu.

[12] Maniscalco L, Yi Y, Zhang L, Lefante C, Hsieh MC, Wu XC (eds). Cancer in Louisiana, 2013-2017. New Orleans: Louisiana Tumor Registry, 2020. Vol. 35.

[13] LDEQ Response to Comments. Pin Oak Terminal. 2580-00051-V0. AI 144688. Doc ID 11078480. Page 6. *See also* LDEQ Basis for Decision and Response to Comments regarding Formosa Plastics air permit approval. January 6, 2020. Page 65. Doc ID 11998452.

the U.S. Census Bureau. Our goal was to better understand the drivers of cancer rates in Louisiana and to determine whether the firsthand experiences of industrialized communities are supported by Tumor Registry data. Because we relied entirely on publicly available datasets compiled by state or federal institutions, our analysis can be independently reproduced. The combined dataset and R code are available upon request.

Methods

Mapping

We mapped each dataset using QGIS Version 3.18 to visualize the geographic patterns of cancer (Fig. 1), toxic air pollution (Fig. 2), and race and poverty (Fig. 3) among Louisiana census tracts. Each dataset is broken down by percentile. Additionally, we mapped smoking and obesity data at the finest geographic resolution available (i.e. parish level; Fig. 4), since those factors are commonly cited as explanations for Louisiana's cancer burden.

Cancer Incidence Rates

We obtained 10-year average annual cancer rates for all malignant tumors combined from the Louisiana Tumor Registry's most recent annual report, published in 2021 and reflecting cases diagnosed in 2008-2017.[14] Cancer incidence rates were available for 932 of 1,148 census tracts in Louisiana (Fig. 1). These rates are age adjusted and presented per 100,000 population. For simplicity, we subsequently refer to cancer incidence rates as "cancer rates."

Pollution Levels

We used estimates of pollution-related cancer risk from the Environmental Protection Agency (EPA)'s 2005 National Air Toxics Assessment (NATA), which reflects pollution levels in 2005 (Fig. 2). Because EPA updates its methodology each time it publishes the NATA (typically once every 3 years), the 2005 NATA provided more refined methodology compared to previous NATAs (1996, 1999, and 2002), while still allowing a reasonable time gap relative to the cancer rate dataset (2008-2017) to help account for cancer latency.[15] Additionally, in selecting the dataset, we considered that changes in census tract boundaries occur during each decennial census (e.g. 1990, 2000, and 2010). To account for these changes, we excluded significantly-changed census tracts from our analysis, as described below.

We used NATA's Point Source Cancer Risk because the Industrial Corridor/Cancer Alley is characterized by a high density of point sources of pollution (i.e. chemical and petrochemical facilities). The NATA Point Source category represents stationary sources for which locations are known, including industrial plants, electric utilities, and large waste incinerators.[16] This NATA category does not include airports, homes,

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[14] Maniscalco L, Yi Y, Zhang L, Lefante C, Hsieh MC, Wu XC (eds). Cancer Incidence in Louisiana by Census Tract, 2008-2017. New Orleans: Louisiana Tumor Registry, March 2021.

[15] Diana L. Nadler, Igor G. Zurbenko, "Estimating Cancer Latency Times Using a Weibull Model", *Advances in Epidemiology*, vol. 2014, Article ID 746769, 8 pages, 2014. https://doi.org/10.1155/2014/746769.

[16] EPA. An Overview of Methods for EPA's National-Scale Air Toxics Assessment. January 31, 2011. Page 19. Available at https://www.epa.gov/sites/production/files/2015-10/documents/2005-nata-tmd.pdf. Note Footnote b in Exhibit 2-1. *See also* EPA. 2014 NATA Technical Support Document. August 2018. Page 10.

wildfires, vehicles, or other mobile or diffuse sources of pollution. For simplicity, we subsequently refer to Point Source Cancer Risk as "pollution level" or "toxic air pollution." Because our analysis relies on historical pollution values, but there is significant interest in current pollution levels, we also mapped Point Source Cancer Risk from the most recent (2014) NATA (Fig. 2). Importantly, the results of different NATAs are not directly comparable due to methodological changes over time.[17] We did not use the 2014 data in any statistical analysis; rather, we mapped the data for visualization only.

Demographic and Health Indicators

As demographic predictors of cancer rates, our analysis included the percentage of Black residents (i.e. African-American alone or African-American mixed with another race) and the percentage of residents living below the federal poverty threshold, from the U.S. Census Bureau's 2011-2015 American Community Survey (Fig. 3). While smoking and obesity are also important risk factors for cancer, to our knowledge, these data are not available at the census tract level for Louisiana. To explore the potential for geographic patterns in smoking and obesity that could confound our analysis, we mapped parish-level smoking and obesity data from the 2011 Louisiana County Health Rankings.[18] These rankings use 2003-2009 smoking data from the U.S. Centers for Disease Control (CDC)'s Behavioral Risk Factor Surveillance System and 2008 obesity data from the CDC's National Center for Chronic Disease Prevention and Health Protection. We use historical smoking and obesity data because current cancer rates reflect historical risk factors. Because the data were not available at the census tract level, we could not include smoking or obesity in our statistical analysis; rather, we mapped the data for visualization only (Fig. 4).

Data Exclusions

Our analysis excluded census tracts for which cancer rates were not available from the Louisiana Tumor Registry (n = 216 out of 1,148 total). Additionally, we excluded tracts that the Tumor Registry designated as containing military bases (n = 27), because military personnel are likely to have different exposure histories compared to permanent residents. We also excluded census tracts (n = 155) with geographic boundaries that had changed substantially between the 2000 Census and 2010 Census, as identified by the U.S. Census Bureau.[19] This exclusion was necessary because we used a pollution dataset that was based on the 2000 Census and a cancer dataset that was based on the 2010 Census. After these exclusions, there were 750 census tracts remaining in the final dataset. Estimates of cancer risk from EPA's 2005 National Air Toxics Assessment were available for all of these tracts.

Statistical Analysis

We performed all analyses in R Statistical Software. We used Tukey's Ladder of Powers to evaluate data normality and to identify transformations for non-normal data (transformTukey function in the *rcompanion* package). With the exception of cancer rates, all variables in our datasets were non-normally distributed and were transformed for analysis (Figs. A1 & A2). After transformations were applied to

[17] EPA. 2014 National Air Toxics Assessment Technical Support Document. August 2018. Table 1-1. Pages 5-6.
[18] University of Wisconsin Population Health Institute. 2011 County Health Rankings. Available at https://www.countyhealthrankings.org/app/louisiana/2021/downloads.
[19] Available at https://www.census.gov/geographies/reference-files/2010/geo/relationship-files.html#par_textimage_19960473. Accessed Feb 18, 2020.

pollution ($X^{0.125}$), poverty ($X^{0.4}$), and race ($X^{0.4}$) data, more normal distributions were achieved (Fig. A1). To reduce multicollinearity, data were then centered on zero by substracting the mean from each value.[20]

We evaluated the performance of alternate linear models for predicting census tract-level cancer rates using the stepAIC function in the MASS package of R Statistical Software.[21] This function performs stepwise AIC model selection through an iterative process that adds and removes variables sequentially to identify the best fit model. After identifying the best fit model, we performed a linear regression to determine significance values for each variable. To better understand the observed interaction effects, we divided our transformed dataset into quartiles by poverty. We then used a Pearson's Correlation to evaluate relationships between cancer incidence rates and pollution levels and between race and pollution levels. We then created scatterplots of the raw (i.e. untransformed) data to visualize these comparisons. These plots included linear regression lines with 95% confidence intervals, calculated using the geom_line function in ggplot2 in R Statistical Software.

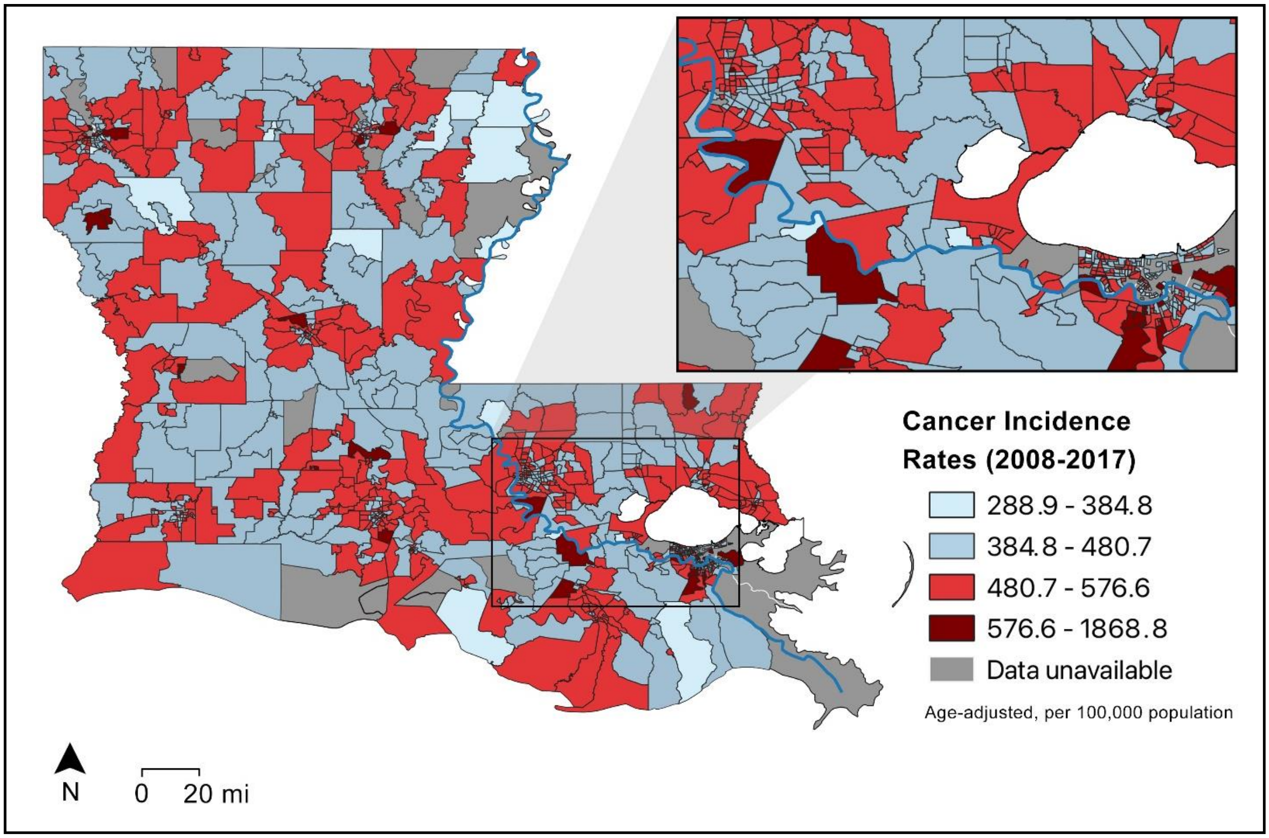

Figure 1. Age-adjusted annual cancer incidence rates, averaged from 2008-2017, as reported by the Louisiana Tumor Registry. Inset depicts the Industrial Corridor from Baton Rouge to New Orleans.

[20] Iacobucci, D., Schneider, M.J., Popovich, D.L. et al. Mean centering helps alleviate "micro" but not "macro" multicollinearity. Behav Res 48, 1308–1317 (2016). https://doi.org/10.3758/s13428-015-0624-x
[21] R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

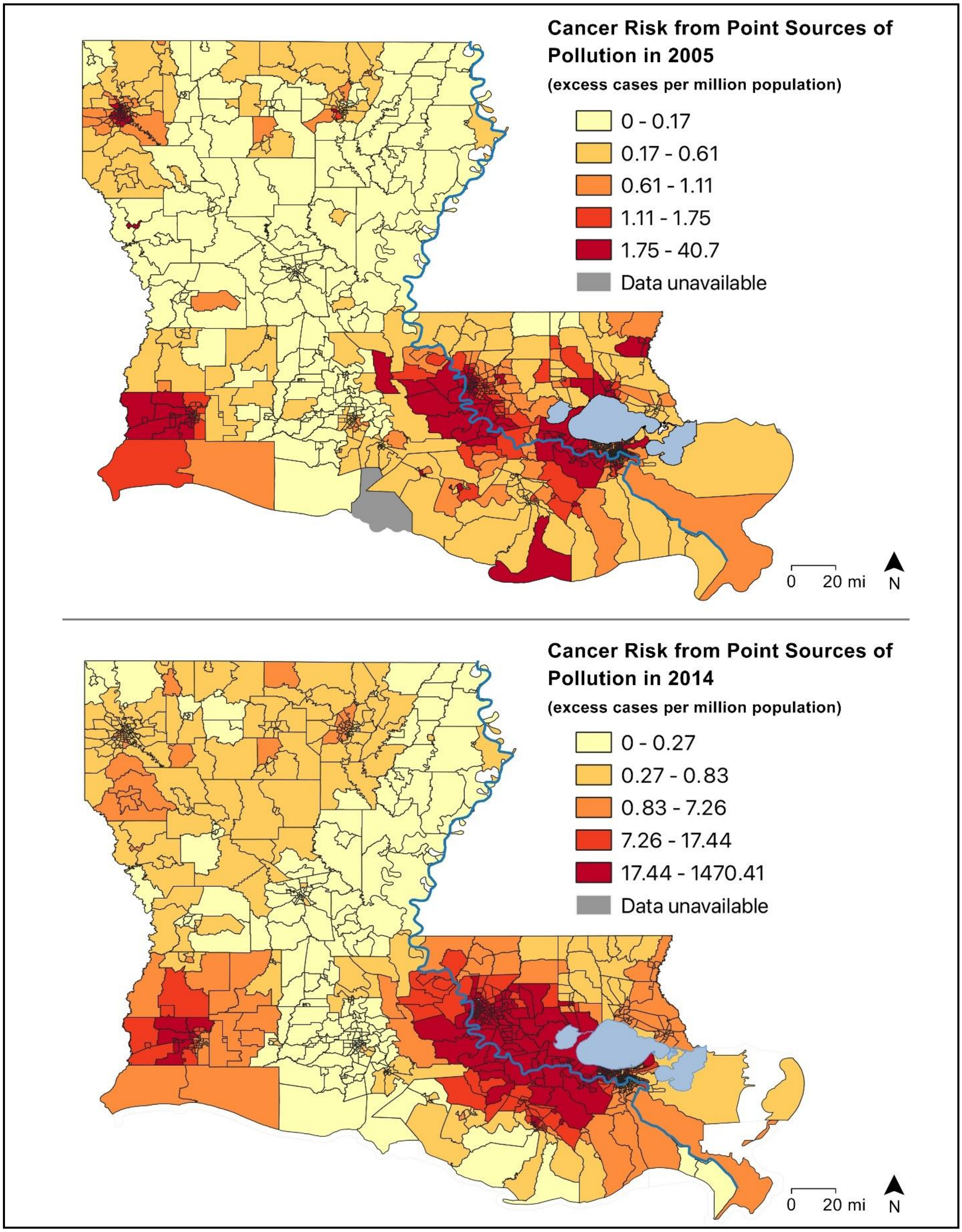

Figure 2. Cancer Risk from Point Sources of Pollution, broken down by percentile, as reported in the Environmental Protection Agency's 2005 (*top*) and 2014 (*bottom*) National Air Toxics Assessment (NATA). Note that the methodology differed between these two assessments, so the resulting data are not directly comparable. The Mississippi River is shown in dark blue.

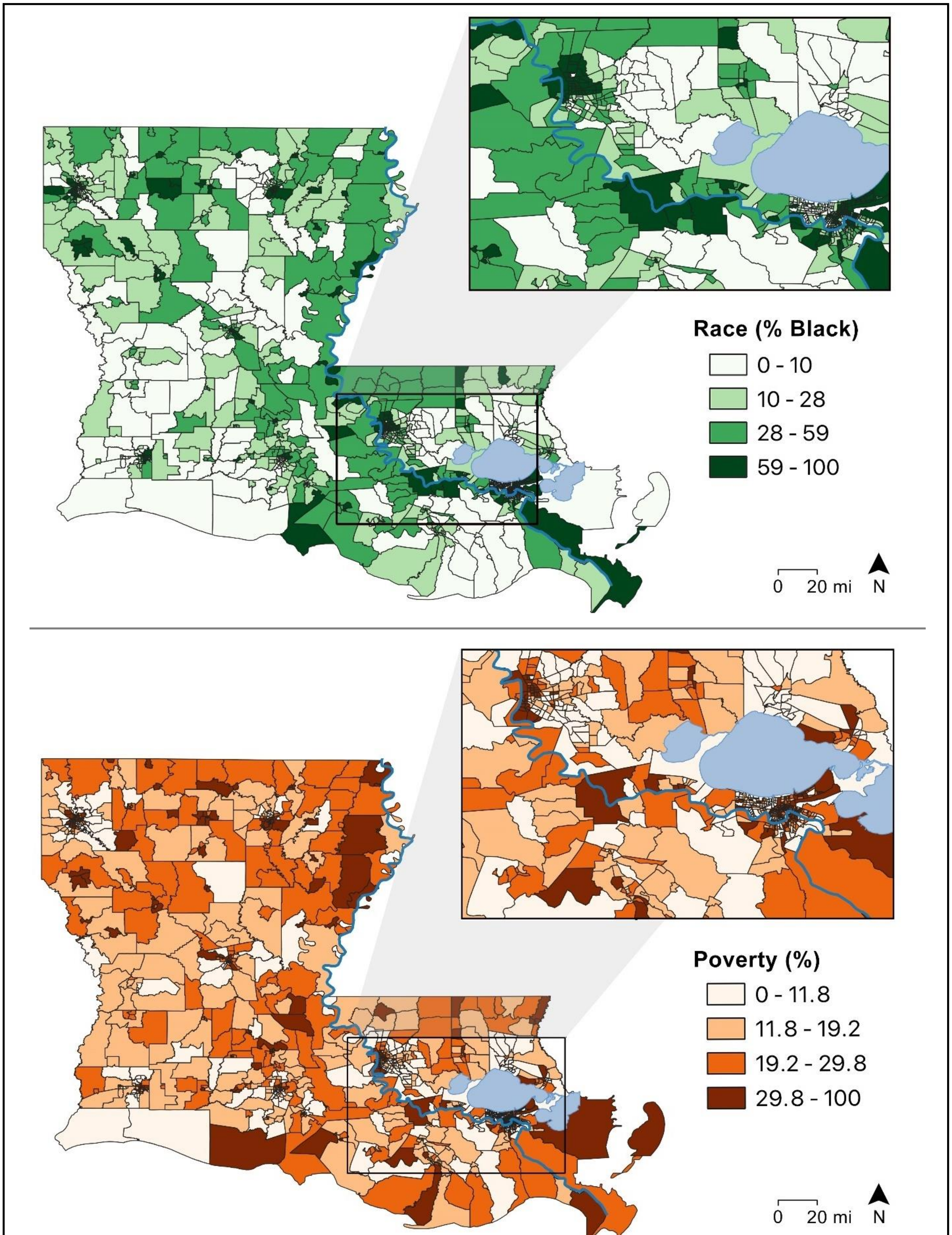

Figure 3. *Top*: Race (% Black). *Bottom*: Poverty (% living below threshold). The inset in each panel depicts the Industrial Corridor from Baton Rouge at the northeast corner to New Orleans. The Mississippi River is shown in dark blue. Data are 5-yr estimates (2011-2015) from the U.S. Census Bureau's American Community Survey.

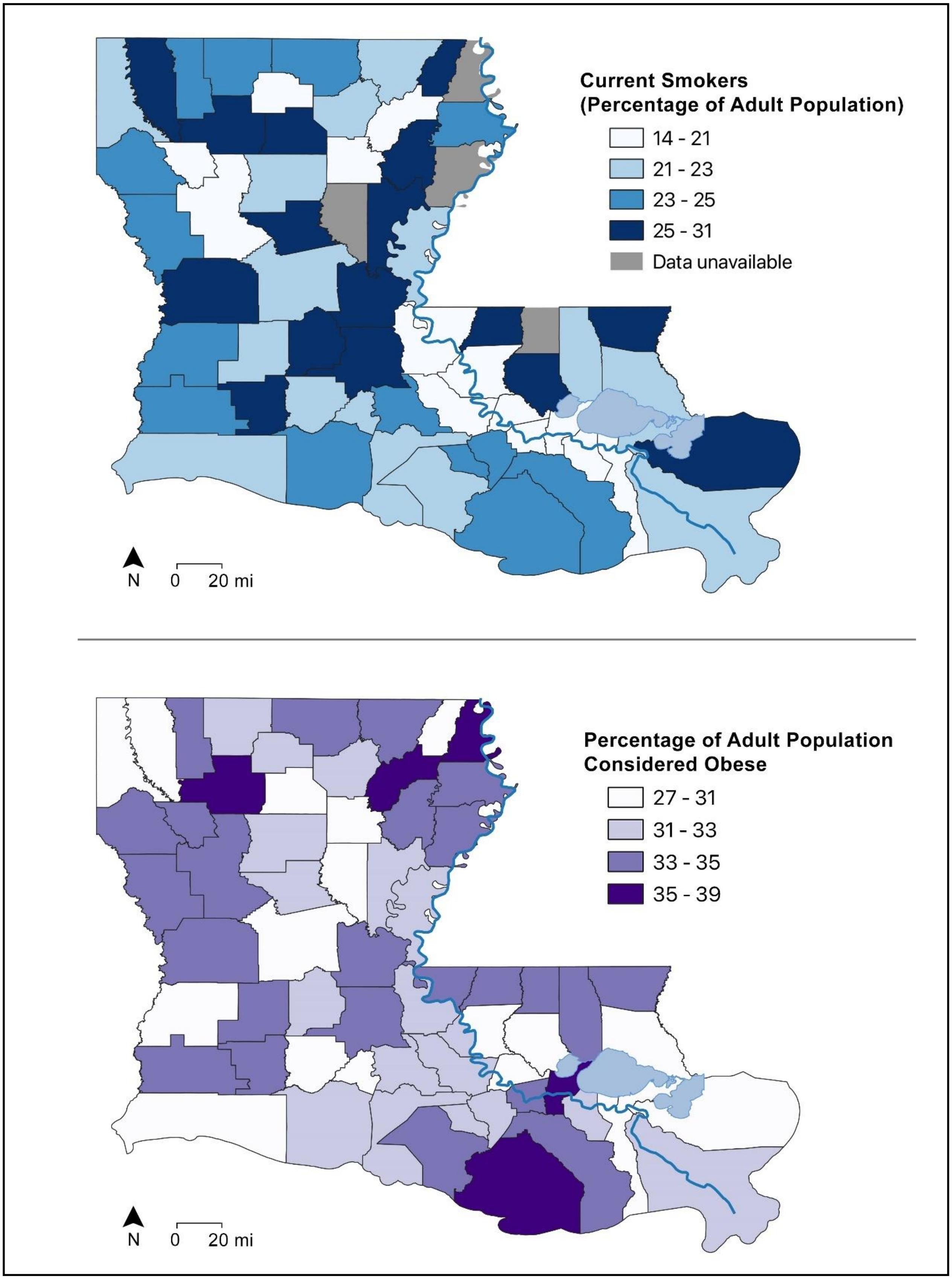

Figure 4. *Top*: Percentage of adult population that currently smoke tobacco products. *Bottom*: Percentage of adult population that is considered obese. Both datasets are from the 2011 County Health Rankings, which use 2003-2009 smoking data and 2008 obesity data. The Mississippi River is shown in blue.

Results

Quality Assurance and Data Exclusions

After excluding census tracts with incomplete or unreliable data (see methods), data distributions were generally unchanged (Table 1). The one notable exception was maximum cancer rate, which was lower in our analysis compared to the full dataset. The latter contained three outlying census tracts that were excluded for containing military bases: 22015010900 (Bossier Parish, 1,868.8 cancer cases per 100,000 people), 22115950702 (Vernon Parish, 1,301.6 cases), and 22115950704 (Vernon Parish, 1,125.4 cases). However, there was no significant difference in cancer rates between census tracts that were excluded (n = 182) or included (n = 750) in our analysis (t = -1.71, df = 193.11, P = 0.088). If the three outlying tracts are ignored, there is even less statistical support for a difference in cancer rates between census tracts that were included versus excluded from our analysis (t = -0.549, df = 236.05, P = 0.583). Thus, our final dataset was representative of cancer, pollution, race, and poverty in Louisiana.

Table 1. Sample Sizes and Summary Statistics for Each Census Tract-Level Variable Analyzed

Variable	Dataset	# Census Tracts	Minimum Value	1st Quartile	Median	3rd Quartile	Maximum Value
Cancer rate*	All available	932	288.9	443.6	481.4	514.1	1,868.8
	Analyzed	750	288.9	442.8	480.7	513.7	845.5
Pollution Level**	All available	1,105	0.001	0.25	0.97	1.47	40.70
	Analyzed	750	0.001	0.22	0.91	1.57	30.90
% Black	All available	1,128	0	10.8	28.7	60.2	100
	Analyzed	750	0	10.6	27.6	55.3	100
% Poverty	All available	1,127	0	12.1	19.5	30.2	100
	Analyzed	750	0.9	11.9	18.3	27.9	62.0

*Age-adjusted annual incidence, per 100,000 population.

**2005 NATA Point Source Cancer Risk, reported as estimated excess cancer cases per million population.

Relationship between Pollution Levels and Cancer Rates

The direct effects of race, poverty, and pollution were retained in all models returned by the stepwise selection (Table 2). In both of the top models (ΔAIC < 2), poverty interacted with pollution and with race to predict cancer rates (Table 2). However, the second-highest ranking model (ΔAIC 1.7) included a significant interaction between race and pollution (Table 2). Because there was not clear support for this interaction, we omitted it from the final model (Table 3). Regression analysis of the final model determined that cancer incidence rates were significantly related to poverty, race, and the interaction of poverty with pollution and, separately, with race (Table 3; Figure 5). Mapping parish-level smoking and obesity data (the finest resolution available) revealed no evidence to suggest that these lifestyle factors were responsible for the putative link between pollution and cancer rates (Figure 4).

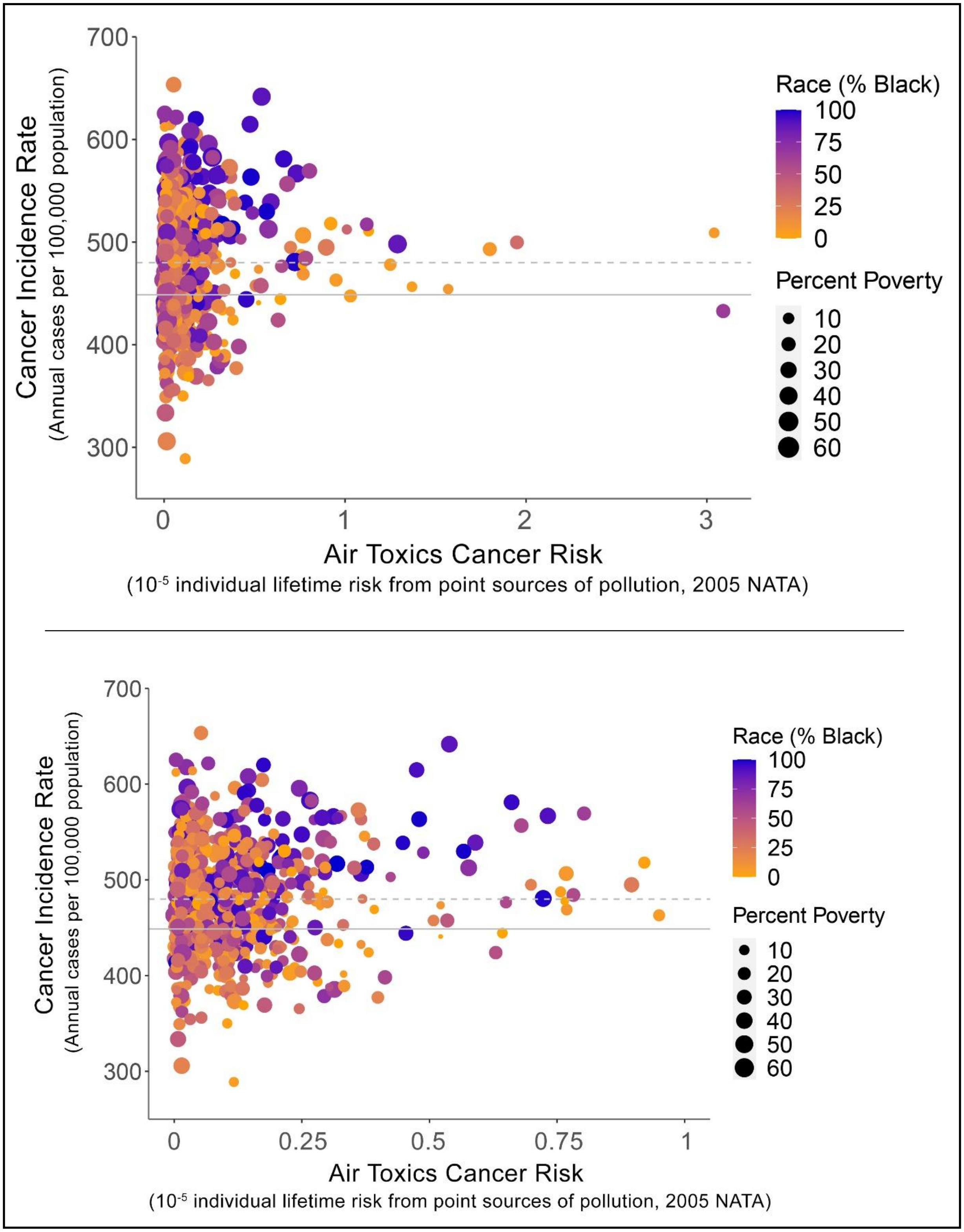

Figure 5. Relationships among toxic air pollution, cancer rates, poverty, and race for Louisiana census tracts (n = 750). The same dataset is presented in both panels, with a smaller scale on the bottom panel to better distinguish data points. Solid gray line indicates U.S. average cancer rate (448.7); dashed gray line indicates Louisiana average (481.0).

Analysis by Poverty Quartiles

Higher pollution levels were correlated with higher cancer rates for the most impoverished quartile of the dataset, but not for the other quartiles (Table 4; Fig. 6). Similarly, race (% Black) was correlated with cancer rates for the most impoverished quartile, but not for the other quartiles (Table 5, Fig. 7). For the overall dataset (n = 750 tracts), a simple correlation test between pollution and cancer incidence rates was non-significant (t = 1.18, df = 748, P = 0.240). This result indicates that the relationship between pollution and cancer incidence rates was only apparent when accounting for poverty.

Table 2. Results of Stepwise Model Selection for 2008-2017 Census Tract-Level Cancer Rates.*

Main Effects	Interaction Terms	AIC	ΔAIC	Rank
Race Poverty Pollution	**Race × Poverty** **Poverty × Pollution**	**5910.6**	**0**	**1**
	Race × Poverty **Poverty × Pollution** **Race × Pollution**	**5912.3**	**1.7**	**2**
	Race × Poverty Poverty × Pollution Race × Pollution Race × Poverty × Pollution	5914.3	3.7	3
	Race × Poverty Race × Pollution	5915.9	5.3	4
	Race × Pollution Poverty × Pollution	5918.8	8.2	5

* See methods for data sources and transformations. The best-supported models (ΔAIC < 2) are emphasized in bold text.

Table 3. Significance of Predictors from Final Model (2008-2017 Census Tract-Level Cancer Rates).

Variable*	Coefficient Estimate**	t	*P*
(Model Intercept)	477.59	210.34	<0.0001
Race (% Black)	6.57	4.03	<0.0001
Poverty (% Below Poverty Threshold)	-0.07	-0.02	<0.0001
Pollution (2005 NATA Point Source Cancer Risk)	19.75	0.29	0.77
Race × Poverty	4.64	2.86	0.0044
Pollution × Poverty	313.03	3.62	0.0003

*Data were transformed and mean-centered (see Methods).

**These coefficients do not provide meaningful "real-world" information because they correspond to transformed data. To illustrate the relationships among these variables, scatterplots of raw data are presented in Figs. 5 & 6.

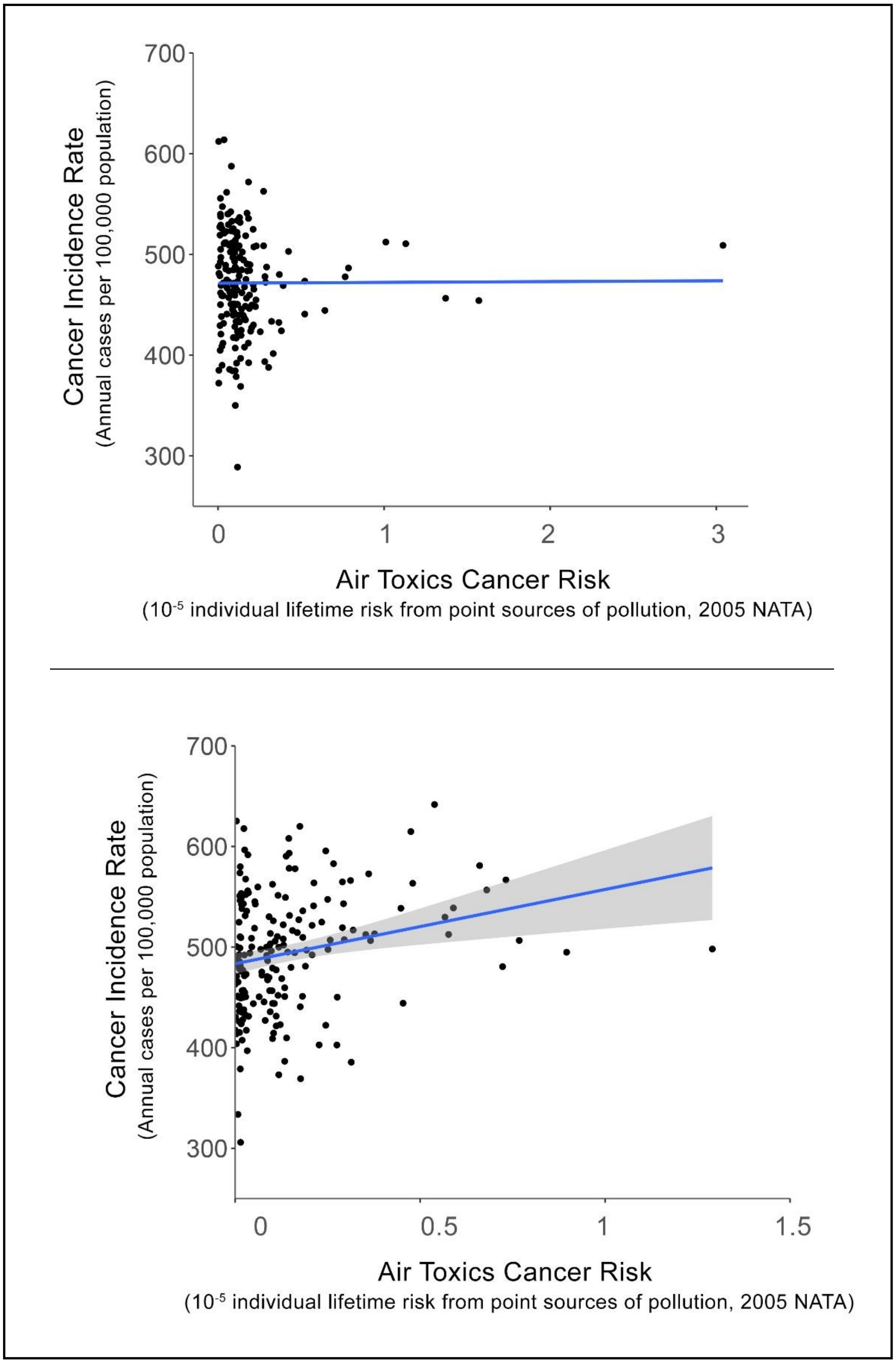

Figure 6. Comparison of pollution versus cancer rates for the most affluent (*top panel*) and most impoverished (*bottom panel*) census tracts. See Table 4 for quartile breaks and test statistics. Blue line represents a linear regression of untransformed data. Confidence intervals (95%) are included for regressions where $P < 0.05$.

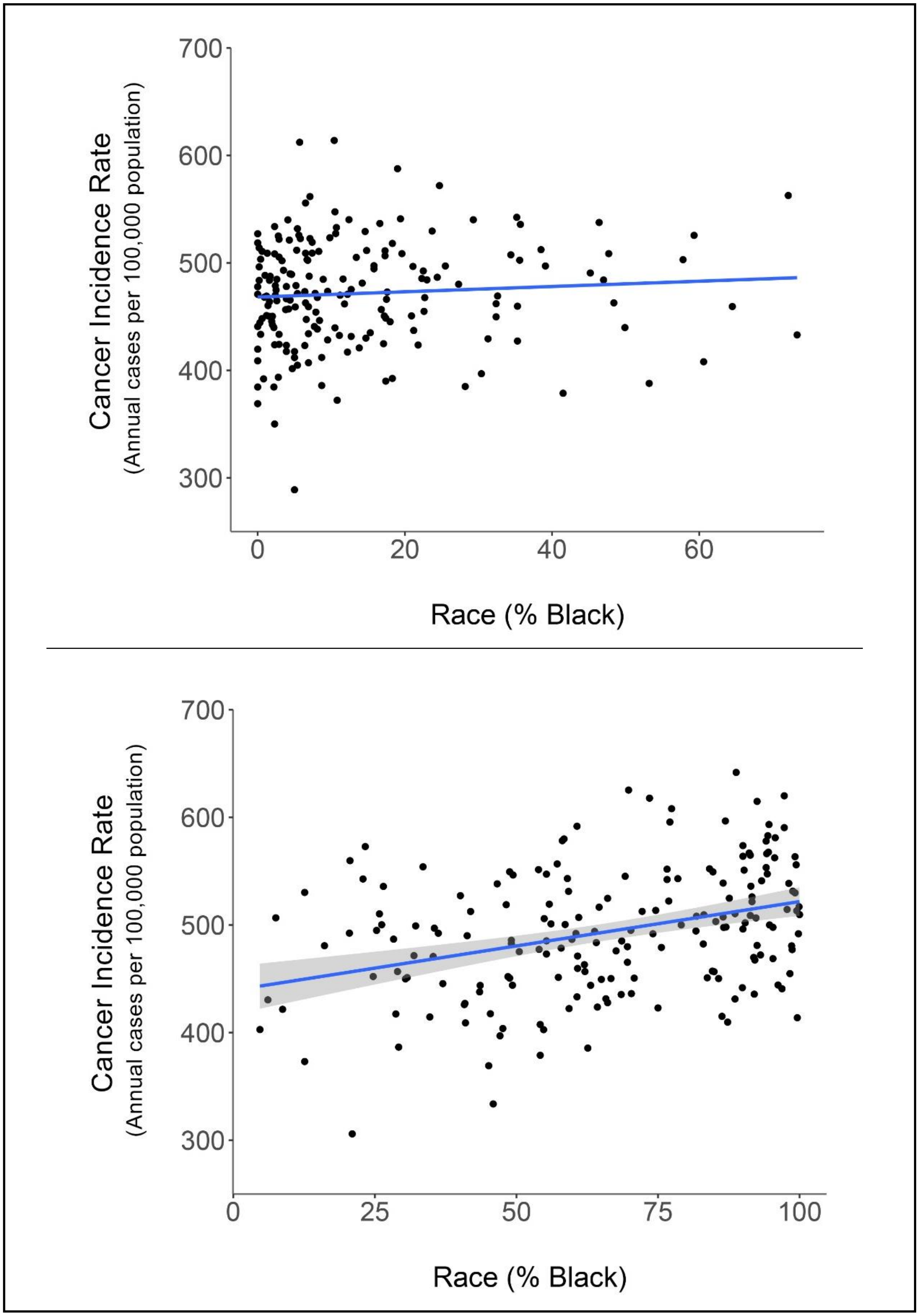

Figure 7. Comparison of the proportion of Black residents versus cancer rates for the most affluent (*top panel*) and most impoverished (*bottom panel*) census tracts. See Table 5 for quartile breaks and test statistics. Blue line represents a linear regression of untransformed data. Confidence intervals (95%) are included for regressions where $P < 0.05$.

Table 4. Pollution Levels versus Cancer Incidence Rates by Poverty Quartile*

Poverty Quartile	Raw Data			Transformed Data			Link between Pollution and Cancer Rates?
	r	t	*P*	r	t	*P*	
1 (most affluent)	NA	0.06	0.949	NA	-1.42	0.157	No
2	NA	0.74	0.462	NA	0.38	0.705	No
3	NA	-0.52	0.604	NA	-0.25	0.805	No
4 (most impoverished)	**0.23**	**3.28**	**0.001**	**0.25**	**3.59**	**0.0004**	**Yes**

*Poverty range: 0.90% - 62.00%. Quartile breaks: 11.90%, 18.25%, 27.90%. NA, not applicable (no significant correlation). Bold text emphasizes significant correlation.

Table 5. Race (% Black) versus Cancer Incidence Rates by Poverty Quartile*

Poverty Quartile	Raw Data			Transformed Data			Evidence of Racial Disparity?
	r	t	*P*	r	t	*P*	
1 (most affluent)	NA	0.06	0.949	NA	1.53	0.128	No
2	NA	0.74	0.462	NA	0.14	0.891	No
3	NA	-0.52	0.604	NA	1.20	0.232	No
4 (most impoverished)	**0.23**	**3.28**	**0.001**	**0.34**	**4.89**	**<0.0001**	**Yes**

*See Table 4 footnote.

Discussion

To our knowledge, this analysis represents the first statewide assessment of the relationship between cancer incidence rates and toxic air pollution in Louisiana. We found that higher levels of toxic air pollution were linked to higher cancer rates among Louisiana's most impoverished communities. Poverty may increase health risks from toxic air pollution, for example, by reducing access to preventative medical care, or by increasing pollution exposure for people who live in older/rundown buildings, where air pollution may enter through gaps in walls or windows. Additionally, we found that predominantly Black, impoverished communities generally had higher cancer rates than predominantly White, impoverished communities. Collectively, our findings illustrate that race, poverty, and toxic air pollution interact in complex ways to affect health outcomes in Louisiana. These findings are consistent with the firsthand experiences of Black residents from impoverished, industrialized neighborhoods who have long maintained that their communities are overburdened with cancer from toxic pollution.

It is important to recognize that the lack of a statistical relationship between two factors is *not* evidence that those factors are unrelated. In this case, the lack of a statistically significant relationship between toxic air pollution and cancer rates among more affluent communities does *not* imply that pollution is safe for these communities. Rather, based on the current dataset, we cannot determine whether pollution levels are linked to cancer among more affluent communities. This concept relates to fundamental principles of statistics, namely that the null (i.e. default) hypothesis is *no effect*. In the analysis presented here, the default hypothesis was *no link* between pollution levels and cancer rates. The statistical test determined whether or not there was sufficient evidence to reject the default hypothesis and conclude that a link exists. Typically, a P-value above 0.05 indicates that the default hypothesis *cannot* be rejected and we *cannot* conclude that a link exists. This threshold corresponds to only a 5% chance of a false positive if we concluded that a link exists. Thus, a conclusion of "insufficient evidence for a link" can be made, even when there is more support *for* a link than *against* it. A solid understanding of statistics is important to interpreting cancer rate data and to understanding why the default assumption should be that industrialization of communities is *unsafe*, especially because there is no safe level of exposure to cancer-causing toxic air pollutants.[22] In this case, our dataset may not have been adequate to detect a link between pollution and cancer among more affluent communities. For example, people living in more affluent communities tend to move around (relocate) more, potentially making it harder to connect cancer rates to environmental exposures in these communities.

Our findings highlight some of the many problems with relying solely on annual reports from the Louisiana Tumor Registry to make conclusions about health risks from industrial pollution. Not only do Louisiana Tumor Registry reports lack pollution data, but they also lack poverty data. Our study determined that the link between pollution and cancer was only apparent among the most impoverished communities. Because poverty rates and other cancer risk factors vary widely across the Industrial Corridor (Fig. 3), it is not surprising that average cancer rates in this area also vary widely (Fig. 1). Similarly, even though virtually all census tracts in the Industrial Corridor face higher-than-average cancer risk from toxic air pollution (Fig. 2), there is still substantial variation in pollution exposure within the Industrial Corridor. There are well over 100 industrial facilities across this region, each of which emits a unique combination of pollutants, with large clusters of facilities near some neighborhoods, and no facilities near other neighborhoods. Further, as discussed above, some of the most heavily industrialized communities in Louisiana (e.g. Mossville) occur outside the so-called Industrial Corridor. Given these collective realities, the LDEQ's practice of pointing to Industrial Corridor cancer rates as evidence against pollution-related cancer risk is naïve and scientifically unsound.

Overall, our analysis provides compelling evidence that toxic air pollution is a significant driver of cancer rates in Louisiana. There is no evidence that lifestyle factors contributed to this finding. In fact, many industrialized parishes in Louisiana have a relatively low prevalence of smoking, while obesity is a problem throughout the state (Fig. 4). Analogous to pollution exposure, smoking and obesity are likely to vary within parishes; but there is no apparent reason why these factors would be more prevalent among industrialized census tracts, especially given that our analysis accounted for poverty and race. Certainly, smoking and obesity are important risk factors for cancer; however, these factors do not adequately explain the *geographic pattern* of cancer in Louisiana (i.e. census tract averages). We found that this geographic pattern is partly explained by the racial composition, poverty status, and the burden of toxic air pollution in a given community (i.e. census tract). Our analysis contributes to the growing body of evidence that Black and Brown communities in Louisiana are overburdened with the negative effects of

[22] U.S. Centers for Disease Control, National Institute for Occupational Safety and Health. NIOSH Evaluation of its Cancer and REL Policies. Available at https://www.cdc.gov/niosh/topics/cancer/policy.html. Accessed June 20, 2021.

toxic air pollution from petrochemical facilities and other sources. Environmental justice requires that LDEQ acknowledge the health risks of toxic pollution and address the disproportionate burden of heavy industry on impoverished and black communities in Louisiana.

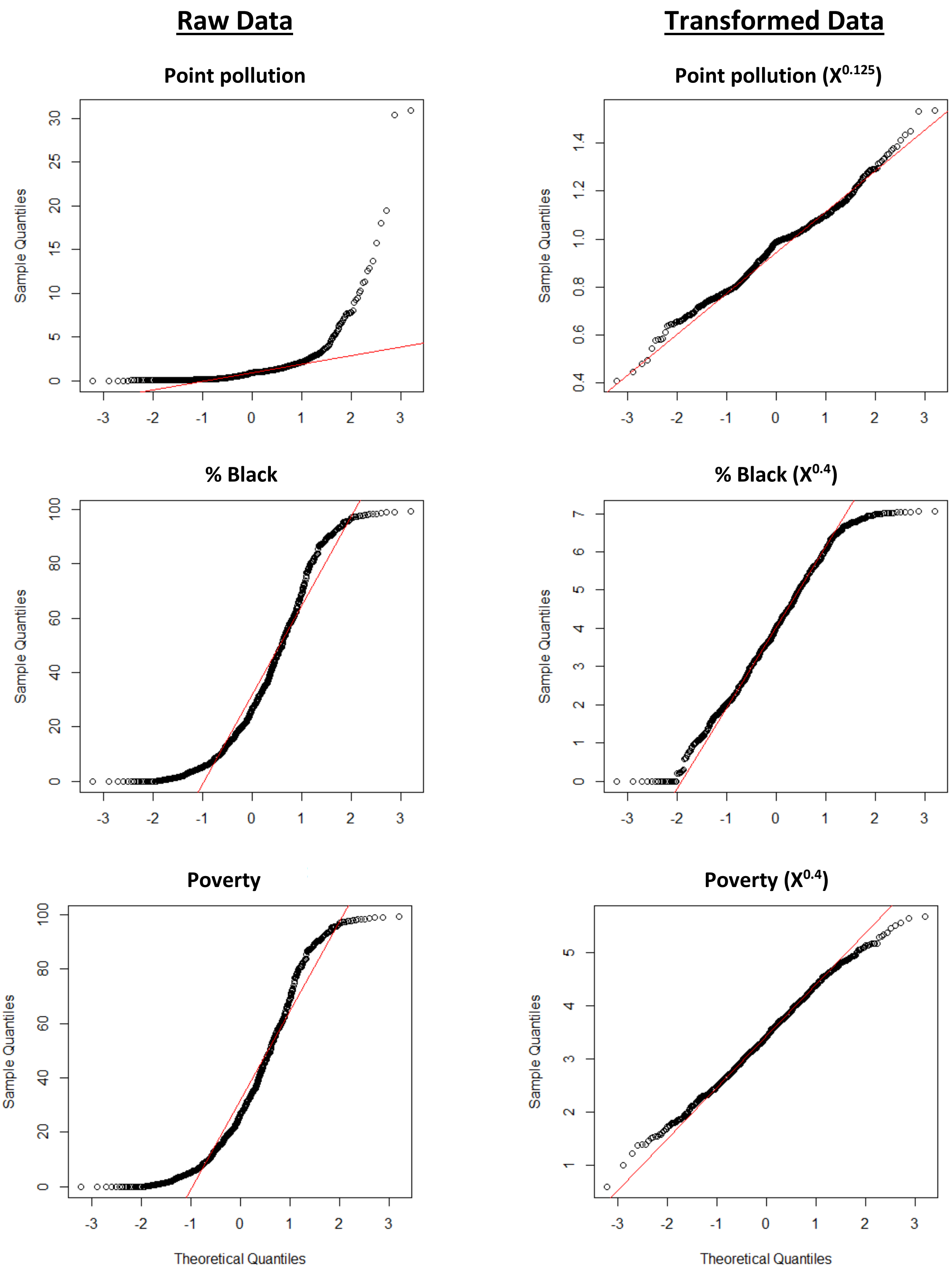

Figure A1. Quantile-quantile plots for raw and transformed variables. See methods for data sources. X-values correspond to data transformations.

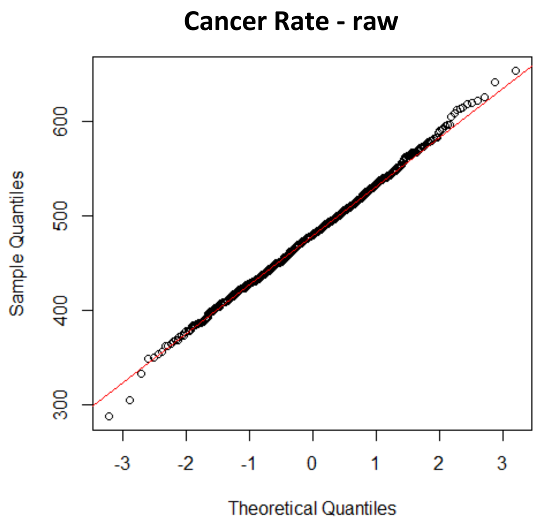

Figure A2. Quantile-quantile plots for cancer incidence rates. See methods for data source.