Air Pollution and COVID-19: A Double Whammy for African American and Impoverished Communities in Cancer Alley

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Key Findings

- Black and disadvantaged communities in Louisiana (and in Cancer Alley specifically) are overburdened with air pollutants that can cause respiratory disease and immune suppression.

- Across Louisiana, parishes with more hazardous levels of air pollution have higher per capita COVID-19 death rates.

- Louisiana is losing ground on long-term improvements in air quality, and emissions of fine particulate matter ($PM_{2.5}$, a common air pollutant) from industrial sources are on the rise.

Executive Summary

African Americans in Louisiana are dying in disproportionate numbers from COVID-19, a novel coronavirus that attacks the lungs. There is growing concern about the potential for air pollution to increase COVID-19 susceptibility in Cancer Alley, a heavily industrialized region in southeast Louisiana with high proportions of African Americans. Recent evidence linked long-term exposure to $PM_{2.5}$ (a common pollutant from industrial and other sources) with increased COVID-19 death rates. Yet, $PM_{2.5}$ exposure has not been evaluated within Cancer Alley parishes (i.e. counties), and there are no recent studies of pollution in this region, despite an ongoing wave of industrial expansion that began in ~2014. Here, we explore the relationships among pollution, race, socioeconomic status, and per capita COVID-19 death rates (reported through May 12, 2020) in Louisiana, with an emphasis on Cancer Alley. We use two independent data sources as indicators of pollution burden: 1) long-term (2000 – 2016) average $PM_{2.5}$ concentrations from satellite data, and 2) air pollution-related health risk estimates, specifically, Respiratory Hazard (RH) and Immunological Hazard (IH) from the most recent (2014) U.S. National Air

Toxics Assessment. Additionally, we examine changes over time in industrial versus non-industrial $PM_{2.5}$ emissions since 1990 using the most recent (2017) U.S. National Emissions Inventory, as well as changes in ground-level $PM_{2.5}$ concentrations from 2000 – 2018 satellite data. Our goals were to detect potential disparities in pollution burden or COVID-19 deaths in Louisiana and to identify temporal changes in $PM_{2.5}$ pollution across the state.

Our analyses revealed that higher pollution burdens (measured by $PM_{2.5}$, RH, and/or IH) at the census tract level were associated with larger percentages of African Americans in the population, higher unemployment rates, higher poverty rates, and larger percentages of seniors (aged 65+) living in poverty. An overall similar pattern of disparities was observed when considering Cancer Alley census tracts only. Race and socioeconomic disparities in pollution burden were observed when mobile and non-point sources of pollution were excluded from RH or IH values, indicating that these disparities were not solely the result of vehicle emissions or urbanization. Across Louisiana, higher per capita COVID-19 death rates at the parish (i.e. county) level were associated with increased pollution burdens and with larger percentages of African Americans in the population. These parish-level associations were not driven by diabetes prevalence, obesity prevalence, smoking, age, or socioeconomic factors. Satellite data indicated that concentrations of $PM_{2.5}$ declined dramatically in Louisiana from 2000 – 2015, but subsequently increased throughout much of south Louisiana. Emissions data revealed that industrial sources have become a greater fraction of Louisiana's $PM_{2.5}$ since 1990, as contributions from vehicles have declined by 75% while industrial $PM_{2.5}$ emissions have remained about the same overall (despite large increases and decreases in industrial $PM_{2.5}$ emissions between 1990 – 2017). Further, the data indicate that industrial $PM_{2.5}$ emissions are on the rise in Louisiana, with a 33% increase between 2014 and 2017, concurrent with the ongoing wave of industrial expansion.

Our study provides overwhelming evidence that African American communities in Louisiana are disproportionately impacted by both pollution and COVID-19. Further, our study reveals (through two independent data sources) that $PM_{2.5}$ pollution in Louisiana has steadily increased over the last several years, concurrent with a rapid expansion of petrochemical activity. Collectively, our findings point to the urgent need to reduce industrial emissions impacting Louisiana's African American communities and expand air quality monitoring in the state. Further, based on our study and others, long-term exposure to air pollutants that harm the respiratory or immunological system should be considered a pre-existing condition for COVID-19.

Background

Louisiana has been among the U.S. states hardest hit by the COVID-19 pandemic, with approximately 32,000 cases and nearly 2,300 related deaths reported through May 12, 2020 (*1*). Yet these impacts have not been evenly distributed (*2*); African Americans account for 33% of Louisiana's population, but an alarming 56% of COVID-19 deaths in the state (as of May 11, 2020 [*1*, *3*]). Similarly, disproportionate numbers of COVID-19 hospitalizations/deaths among African Americans have been reported in New York City (*4*) and across a 14-state study area (*5*). In Louisiana, there is growing concern about the potential for air pollution to increase COVID-19 susceptibility in Louisiana's heavily industrialized communities, which are predominantly African American (*6*, *7*). Identifying potential links among race, pollution, socioeconomics, health, and COVID-19 deaths in Louisiana may help elucidate, and ultimately address, the intractable public health disparities in this state.

A growing body of research provides compelling evidence that exposure to common air pollutants (e.g. particulate matter, nitrogen dioxide, and ozone) increases susceptibility to respiratory diseases, including from viral infections (reviewed in *8*). For example, exposure to particulate matter (PM) has been linked to higher rates of chronic cough, bronchitis, and chest illness among U.S. schoolchildren (*9*), as well as increased hospital admissions for pneumonia in both children and adults (*10*). Several studies suggest that even short-term (<7 days) increases in PM can result in higher rates of respiratory infections among children and adults (*11*–*13*). Both short-term and long-term measurements of fine particulate matter ($PM_{2.5}$) exposure were linked to higher death rates from SARS, a coronavirus, during the 2003 outbreak in China (*14*). Experimental studies are beginning to elucidate the mechanisms underlying these associations, with evidence that PM suppresses the early immune response by reducing the activity of key immune cells (reviewed in *8*).

Given the well-established link between air pollution and respiratory disease, there is growing concern that air pollution may increase susceptibility to COVID-19, a novel coronavirus that attacks the lungs, causing respiratory distress and pneumonia (*15*, *16*). Indeed, air pollution exposure is associated with many of the co-morbidities that increase risk of severe illness or death from COVID-19, including asthma, hypertension, diabetes, and chronic obstructive pulmonary disease (*8*, *12*, *17*–*19*). A recent, nationwide analysis from researchers at Harvard University found that a small increase in $PM_{2.5}$ exposure (measured over the short-term or long-term) was associated with a large increase in per capita COVID-19 death rates (*20*). The analysis, currently under peer review, included more than 3,000 counties and accounted for 20 confounding factors (e.g. diabetes, obesity, and days since first reported case [*18*]). Smaller-scale studies in Europe have reported broad geographic patterns that are consistent with an association between air pollution and COVID-19 death rates (*21*, *22*).

Concerns about a possible link between air pollution and COVID-19 have brought national attention to Louisiana's "Cancer Alley," a heavily industrialized area with high percentages of African Americans and high poverty rates (*6*, *7*, *23*–*25*). Also referred to as the "Industrial Corridor," "Chemical Corridor," or "Death Alley," this ~130-mile stretch of land along the Mississippi River encompasses over 200 industrial sources of air pollution from Baton Rouge to New Orleans, including petroleum refineries, chemical facilities, metal manufacturers, and fertilizer plants (*26*). Many of the African American communities in this region were founded by enslaved people after emancipation (e.g., *27*), long before the area became industrialized. For decades, many of these communities have publicly expressed concerns about the health effects of industrial pollution and have organized grassroots movements to engage in environmental governance (e.g. legal challenges to environmental permits) at the local, state, and federal levels (*28*–*31*) . These environmental justice efforts have intensified since ~2014, in response to a wave of rapid industrial expansion in Louisiana and elsewhere, largely driven by increased U.S. production of natural gas (*32*). Although often omitted from discussions of Cancer Alley, southwest Louisiana is another area of extremely concentrated industrial development and environmental justice efforts (*33*).

Despite the well-established negative health effects of $PM_{2.5}$ and other pollutants produced by industrial facilities, there is some debate about the "existence" of Cancer Alley, even within Louisiana's public health agencies (e.g., [*32*]). Much of this debate is fueled by the petrochemical industry itself, which has invested significant resources in characterizing Cancer Alley as a "myth" and in disseminating misleading or inaccurate health statistics (e.g., "*1 out of 3 people will get cancer in their lifetime – regardless of where they live*" [*33*]). Yet data from the U.S. Environmental Protection Agency (EPA) clearly demonstrate that residents of Cancer Alley are overburdened by pollution-related health risks, including cancer (*36*, *37*). For example, the EPA's most recent (2014) National Air Toxics Assessment indicates that, across most of Cancer Alley, residents have a higher risk of cancer from air pollution than ≥95% of Americans and ≥90% of Louisianians (*36*). More recently, the Louisiana Chemical Association (LCA) has disseminated unsubstantiated statistics in response to the link between $PM_{2.5}$ exposure and elevated COVID-19 death rates (*20*), claiming that industrial emissions have declined in the last 30 years and that "*auto emissions have accounted for a lot of particulate matter in the environment*…" (*38*). Additionally, in a Nov 2019 opinion article, the LCA president claimed that a 2017 report demonstrated that "*growing industry is actually causing emissions to go down, not up*." (*39*) In fact, the report only indicated that certain aspects of air quality in Baton Rouge, LA had improved over time (*40*). To our knowledge, there is no clear mechanism by which increased industrial production would decrease emissions, and there are no published studies (including the 2017 report) of changes in emissions from Louisiana's industrial facilities over time.

Prior to the current wave of industrial expansion, research found that African American and low-income communities in Cancer Alley were overburdened with air pollution, based on data from the 2005 National Air Toxics Assessment (*25*). A gradient effect was observed within these groups, with the most extreme pollution burden occurring in the communities with the greatest proportions of African Americans and the highest rates of poverty (*25*). A subsequent study demonstrated that, in many Cancer Alley parishes, toxin-emitting industrial facilities were disproportionately located in African American and low-income communities (*7*). From an environmental justice perspective, the *existence* of a pollution disparity is sufficient to warrant corrective action, regardless of the cause(s) of that disparity. Specifically, according to EPA, environmental justice requires that "*no group of people, including a racial, ethnic or a socioeconomic group, should bear a disproportionate share of the negative environmental consequences from industrial, municipal and commercial operations or the execution of federal, state, local and tribal programs and policies*." (*41*) Yet, despite these studies, no actions have been taken by environmental or public health agencies to address pollution disparities in Cancer Alley. Further, despite a growing focus on Cancer Alley in the national media and a recent increase in permitted industrial emissions (*42*), no study (to our knowledge) has evaluated the existence of pollution disparities in this region since 2013 (*7*, *25*).

Here, we explore the relationships among pollution, race, socioeconomic status, and per capita COVID-19 death rates in Louisiana (up to and including May 12) and examine long-term trends in $PM_{2.5}$ pollution across the state. Currently, COVID-19 death counts are only available at the parish (i.e. county) level in Louisiana, but more robust comparisons between pollution and race/socioeconomics can be made at the census tract level. Thus, we present two parallel disparity analyses, one at the census tract level (excluding COVID-19 data) and one at the parish level (including COVID-19 data). For both analyses, we include two entirely independent sources of pollution data: satellite derived $PM_{2.5}$ values (*43*) and EPA estimates of health risks from the combined effects of all modeled air pollutants (*36*). Specifically, we included EPA's Respiratory Hazard Index (RH) and Immunological Hazard Index (IH), two unitless metrics that are calculated based on the toxicity of individual pollutants and the pounds emitted (*44*).

We chose these particular hazard indices because pre-existing respiratory disease increases susceptibility to COVID-19 (*45*, *46*), and immune dysfunction can be expected to increase susceptibility to respiratory viruses (*8*). Further, we include RH and IH from all pollutant sources, as well as from stationary point sources only, which excludes vehicles and small-scale sources (e.g. residential heating). For the disparity analyses, we predicted that $PM_{2.5}$, RH and IH would be positively correlated with the percentage of African Americans in the population and with measures of economic hardship, both across the state and in Cancer Alley specifically. Further, we predicted that parish-level per capita COVID-19 death rates would be positively correlated with $PM_{2.5}$, RH, IH, percentages of African Americans, and economic hardship. Our goals were to 1) identify any existing disparities in pollution burden and COVID-19 among marginalized and vulnerable communities in Louisiana, and 2) determine whether levels of PM2.5 pollution in Louisiana have changed over the last several decades.

Methods

Data Sources

We obtained parish-level COVID-19 data through May 12, 2020 from the Louisiana Department of Health (*1*). We calculated per capita COVID-19 death rates in Microsoft Excel as the parish death count divided by the corresponding 2019 population estimate (*3*). We report these rates as the number of deaths per 10,000 people. As described above, we used surface-level $PM_{2.5}$ concentrations (at a $1^{\circ} \times 1^{\circ}$ resolution) from vanDonkelaar et al. (*43*), the same source used by Wu et al. in their recent analysis linking long-term $PM_{2.5}$ exposure to increased COVID-19 death rates (*20*). We generated long-term (2000-2016) $PM_{2.5}$ averages at the census tract level using the RasterStats plug-in in QGIS. We used corresponding parish-level $PM_{2.5}$ estimates calculated by Wu et al. (*20*). As described above, we obtained RH and IH data at the census tract level from the U.S. EPA's most recent (2014) National Air Toxics Assessment (*36*). We used these data to calculate the population-weighted mean for RH and IH at the parish level. All demographic and socioeconomic data were obtained at the census tract and parish levels from the U.S. Census Bureau's 2014-2018 American Community Surveys (5-year estimates). We calculated average crude rates of diabetes and obesity prevalence among adults (aged 20+) using the three most recent years of parish-level data (2014-2016) from the U.S. Centers for Disease Control's Diabetes Surveillance System (*47*). We obtained parish-level estimates of smoking prevalence from the U.S. CDC's Behavioral Risk Factor Surveillance System (BRFSS) 2017 survey. We obtained estimates of $PM_{2.5}$ emissions for all available years (1990 and 1996-2017) from the most recent National Emissions

Inventory (*48*). These emissions data are broken down by major categories, based on the pollution source (*49*).

Disparity Analyses

For disparity analyses, we included factors that, based on previous research (*7*, *20*, *25*, *45*), might be related to COVID-19 death rates or pollution burden. These factors included: percentage of whites in the population (one race, including Hispanic), percentage of African-Americans in the population (one or more races), percent of the population living in poverty, percent of the population aged 65 and over, percent of seniors (aged 65+) living in poverty, unemployment rate, percent smokers, percent adult diabetics, percent obese adults, population density, and the number of days since the first reported COVID-19 case in the parish. As described above, pollution estimates included $PM_{2.5}$, RH, and IH. To identify potential disparities related to COVID-19, we evaluated the relationship between the per capita COVID-19 death rate and each of the above factors at the parish level using Pearson's correlation coefficient. As described above, we conducted a parallel analysis to understand pollution disparities at the census tract level. However, certain data were not available at the census tract level and were thus omitted from that analysis, specifically, COVID-19 deaths and the prevalence of diabetes, obesity, and smoking. Analyses at the census tract level were conducted for the entire state and for Cancer Alley specifically. We considered Cancer Alley to represent 11 parishes: Ascension, East Baton Rouge, Iberville, Jefferson, Orleans, Plaquemines, St. Bernard, St. Charles, St. James, St. John the Baptist, and West Baton Rouge (*25*). Correlations were considered significant at the 0.05 level.

Analyses of $PM_{2.5}$ Over Time in Louisiana

We examined both $PM_{2.5}$ emissions and $PM_{2.5}$ ambient (i.e. outdoor air) concentrations in Louisiana using all available years of data in our datasets (i.e. 1990 and 1996-2017 emissions data [*44*] and 2000-2018 ambient concentrations [*40*]). To better understand the relative contribution of Louisiana's industries to $PM_{2.5}$ emissions, we combined emissions data from industrial categories and plotted these values relative to non-industrial categories using Microsoft Excel. Industrial categories included chemical manufacturing, metals processing, petroleum processes, other industrial manufacturing (e.g. paper production), fuel combustion from industrial facilities, and storage and transport of industrial materials. We do not report separate industrial categories, because industry sectors are not fully broken down for each category in this dataset (e.g. "industrial fuel combustion" includes emissions from multiple industries). Non-industrial sources included: vehicles (combined highway and off-highway), fuel combustion from electric utilities, fuel combustion from other sources, waste disposal and processing, solvent use, wildfires, prescribed burns, and miscellaneous sources (e.g. asphalt paving, construction, and human cremation). Note that the non-industrial category includes some relatively minor contributions from industrial-related activity (e.g. waste disposal, construction, or vehicles). Because wildfires and prescribed burns were only reported separately (from miscellaneous) after the 1990s, we included these categories in miscellaneous sources. We included solvent use in the miscellaneous category because its emissions were too small to be visualized in a graph.

Results

Relationships Among Pollution Estimates, Race, and Poverty in Louisiana at the Census Tract Level

Across Louisiana census tracts, increased $PM_{2.5}$ levels were associated with larger percentages of African Americans, higher unemployment rates, higher poverty rates, and larger percentages of seniors living in poverty (Table 1). Increased values for Respiratory Hazard (RH) and Immunological Hazard (IH) were associated with larger percentages of African Americans and higher unemployment rates (Table 1.) Conversely, pollution burdens (measured by $PM_{2.5}$, RH, or IH) were lower in census tracts with larger percentages of whites or larger percentages of senior citizens (Table 1). When considering stationary point sources of pollution only, increased RH was associated with larger percentages of African Americans and higher unemployment rates (Table 1). These disparities were not observed for IH values from stationary point sources only (Table 1).

Table 1. Relationships among Pollution, Race, and Poverty in Louisiana at the Census Tract Level*

DEMOGRAPHIC VARIABLE	POLLUTION ESTIMATE									
	Long-Term $PM_{2.5}$**		Respiratory Hazard†				Immunological Hazard†			
			All Sources		Point Source		All Sources		Point Source	
	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
% Black	0.25	<0.0001	0.14	< 0.0001	0.15	< 0.0001	0.14	< 0.0001	NA	0.87
% White	-0.28	<0.0001	-0.11	0.0001	-0.14	< 0.0001	-0.16	< 0.0001	NA	0.74
% 65 yrs+	-0.10	<0.001	-0.13	< 0.0001	-0.09	0.002	-0.13	< 0.0001	-0.08	0.004
% Unemployment	0.16	<0.0001	0.12	< 0.0001	0.11	0.001	0.09	0.003	NA	0.84
% Poverty	0.09	0.003	NA	0.30	NA	0.41	NA	0.60	-0.06	0.042
% Seniors in Poverty	0.12	<0.0001	NA	0.91	NA	0.94	NA	0.74	-0.08	0.009

*Statistically significant ($P < 0.05$), positive associations are emphasized with red text; r = Pearson's coefficient; *P* = significance value. (Higher r values indicate a stronger relationship, while *lower* P values indicate a more significant relationship.)

**Mean of annual ground-level concentrations from 2000 to 2016; n = 1,079 census tracts.

†From the 2014 National Air Toxics Assessment; n = 1,126 census tracts.

Relationships Among Pollution Estimates, Race, and Poverty in Cancer Alley at the Census Tract Level

Across census tracts in Cancer Alley, increased $PM_{2.5}$ levels were associated with higher unemployment rates, higher poverty rates, and larger percentages of seniors living in poverty, but were not associated with race (Table 2). Increased values for Respiratory Hazard (RH) were associated with the larger percentages of African Americans, higher unemployment rates, and higher poverty rates (Table 2.) The same pattern was observed when considering RH from stationary point sources of pollution only (Table 2). A somewhat different pattern was observed with respect to Immunological Hazard (IH), with larger values associated with higher unemployment rates and larger percentages of seniors living in poverty (Table 2). When considering stationary point sources only, increased IH was associated with larger percentages of African Americans in the population (Table 2).

Table 2. Relationships among Pollution Estimates, Race, and Poverty in Cancer Alley at the Census Tract Level*

DEMOGRAPHIC VARIABLE	**POLLUTION ESTIMATE**									
	Long-Term $PM_{2.5}$**		**Respiratory Hazard**†				**Immunological Hazard**†			
			All Sources		Point Source		All Sources		Point Source	
	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
% Black	NA	0.14	0.18	< 0.0001	0.17	0.0003	NA	0.78	0.09	0.049
% White	NA	0.21	-0.13	0.004	-0.14	0.003	NA	0.38	NA	0.23
% 65 yrs+	0.09	0.065	-0.12	0.010	-0.10	0.035	-0.08	0.095	-0.15	0.001
% Unemployment	0.17	0.0003	0.17	0.002	0.14	0.0023	0.16	0.0006	NA	0.13
% Poverty	0.17	0.0004	0.10	0.020	0.10	0.039	0.08	0.08	NA	0.84
% Seniors in Poverty	0.16	0.0005	NA	0.53	NA	0.61	0.11	0.018	NA	0.28

*Statistically significant ($P < 0.05$), positive associations are emphasized with red text; r = Pearson's coefficient; *P* = significance value. (Higher r values indicate a stronger relationship, while *lower* P values indicate a more significant relationship.)

**Mean of annual ground-level concentrations from 2000 to 2016; n = 441 census tracts.

†From the 2014 National Air Toxics Assessment; n = 470 census tracts.

COVID-19 Death Rates Relative to Pollution Estimates, Race, and Poverty in Louisiana at the Parish Level

Eight of the 10 parishes with the highest COVID-19 death rates in Louisiana through May 12, 2020 are located in Cancer Alley: St. John the Baptist, Orleans, Iberville, West Baton Rouge, St. James, Jefferson, Plaquemines, and St. Charles (Table 3). Among these parishes, COVID-19 death rates were approximately 3 to 6-fold above the state median; by contrast, only two of the 53 parishes outside Cancer Alley were in this top 10 group (i.e. Bienville and East Feliciana; Table 3). We note that Cancer Alley parishes are relatively close to New Orleans (and include Orleans Parish), where the first COVID-19 outbreak in the state was reported on Mar 14, 2020 (*1*). Yet, COVID-19 death rates were comparatively lower in non-Cancer Alley parishes located similarly close to New Orleans (Figs. 1&2), including Assumption (1.6× state median), Iberia (1.2×), Lafourche (2.0×), Livingston (0.6×), St. Helena (0.3×), St. Martin (1.3×), St. Mary (1.7×), St. Tammany (1.8×), Tangipahoa (0.7×), Terrebonne (1.1×), and Washington (1.8×).

Across all parishes, increased per capita COVID-19 death rates were associated with higher Respiratory Hazard (RH) and Immunological Hazard (IH; Table 4, Figs. 1&2). The same pattern was observed when considering RH or IH associated specifically with stationary point sources of air pollution (Table 4, Figs. 1&2). Additionally, increased death rates tended ($P = 0.068$) to be associated with higher long-term (2000-2016) $PM_{2.5}$ concentrations (Table 4, Fig. 2). The only other factors that were positively associated with per capita COVID-19 death rates on a parish level were percentages of African Americans (Fig. 2), population density, and the number of days since the first reported COVID-19 case in the parish (Table 4).

Table 3. Parishes with the 10 Highest Per Capita COVID-19 Death Rates in Louisiana, as of May 12, 2020

Rank	Parish	COVID-19 Deaths Per 10,000 Population	X-Fold Above State Median	Cancer Alley Parish?
-	*State Median*	*3.08*	-	
1	St. John the Baptist	17.74	5.8	Yes
2	Bienville	15.10	4.9	No
3	Orleans	12.23	4.0	Yes
4	Iberville	11.38	3.7	Yes
5	West Baton Rouge	10.58	3.4	Yes
6	East Feliciana	10.45	3.4	No (but adjacent to one)
7	St. James	9.48	3.1	Yes
8	Jefferson	9.36	3.0	Yes
9	Plaquemines	8.19	2.7	Yes

10	St. Charles	8.10	2.6	Yes

Table 4. Correlations with Parish-Level Per Capita COVID-19 Death Rates, as of May 12, 2020*

Factor	**r**	***P***
Pollution-Related		
Long-term mean $PM_{2.5}$	0.23	0.068
Respiratory Hazard – All Pollutant Sources	0.30	0.014
Respiratory Hazard – Stationary Point Sources	0.44	0.0002
Immunological Hazard – All Pollutant Sources	0.45	0.0002
Immunological Hazard – Stationary Point Sources	0.42	0.0006
Demographic		
Percent Black	0.35	0.004
Percent White	-0.39	0.001
Percent 65 yrs +	NA	0.64
Socioeconomic		
People in Poverty (%)	NA	0.16
Seniors in Poverty (%)	NA	0.46
Unemployment Rate (%)	NA	0.82
Health		
Diabetes (% of adults aged 20+)	NA	0.67
Obesity (% of adults aged 20+)	NA	0.79
Smoking (%)	-0.25	0.045
Other		
Population Density	0.28	0.027
Days since first case	0.46	0.0001

*n = 64 parishes; statistically significant ($P < 0.05$) positive associations are emphasized with red text; r = Pearson's correlation coefficient; P = significance value. Higher r values indicate a stronger relationship, while *lower* P values indicate a more significant relationship.

Long-Term Changes in Emissions and Ground-Level Concentrations of $PM_{2.5}$ in Louisiana

According to 2017 NEI data, annual $PM_{2.5}$ emissions (all sources combined) decreased 17% overall from 1990 to 2017 but fluctuated substantially between these two years (Fig. 3A). Overall levels of $PM_{2.5}$ emissions from all industrial sources were similar between 1990 and 2017, though significant variation was observed in the interim (Fig. 3B). Specifically, total industrial $PM_{2.5}$ emissions increased in the late 1990s, decreased in the early 2000s, increased gradually over that decade, declined from 2011 to 2014, and increased from 2014 to 2017, the most recent year for which data are available (Fig. 3B).

Some of this fluctuation may be due to reported changes in EPA's estimation methodology (*49*). Vehicle $PM_{2.5}$ emissions decreased progressively from 1990 to 2017, dropping 75% overall (Fig. 3B). Fuel combustion from electric utilities increased sharply in the late 1990s, then steadily decreased, resulting in an overall increase of 67%, while fuel combustion from other sources (i.e. residential, commercial, and institutional) gradually declined by 68% across the entire time period (Fig. 3B). After the 1990s, industrial sources became a relatively greater fraction of Louisiana's $PM_{2.5}$ pollution, as emissions declined from other sources, particularly vehicles. Specifically, industrial sources accounted for 20% of Louisiana's total $PM_{2.5}$ emissions in 1990, but 25% in 2017 (Fig. 3A). With respect to more recent trends, overall emissions declined by 20% between 2014 and 2017, including a 29% reduction in vehicle $PM_{2.5}$ emissions and an 18% decline in non-industrial fuel combustion (Fig. 3B). By contrast, industrial $PM_{2.5}$ emissions grew continuously from 2014 to 2017, increasing 33% overall (Fig. 3B).

A substantial, statewide decline in surface-level concentrations of $PM_{2.5}$ was observed from 2000 - 2015, based on satellite-derived data (Fig. 4). However, these concentrations increased from 2016 – 2018 across southern Louisiana (Fig. 4). From 2000 to approximately 2015, hotspots of $PM_{2.5}$ pollution were located in Louisiana's major cities (from south to north): New Orleans, Lake Charles, Lafayette, Baton Rouge, Alexandria, Shreveport, and Monroe (Figs. 4&5, note scale differences between figures). As of 2017-2018, a different pattern of hotspots has emerged, with the highest levels of $PM_{2.5}$ pollution occurring over a broader swath of south Louisiana and no longer concentrated in cities (Fig. 4).

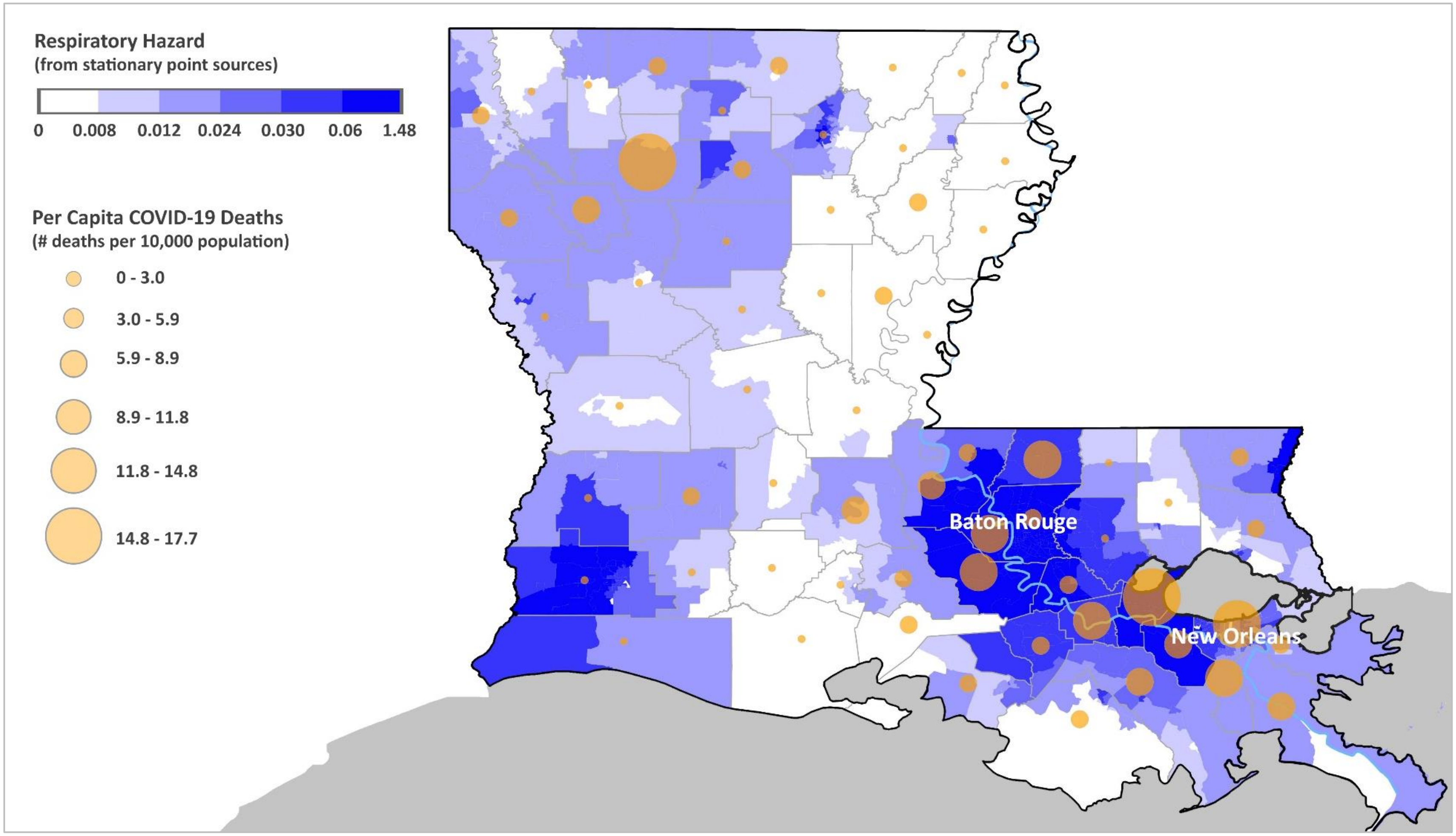

Figure 1. Respiratory Hazard (purple shading) by census tract, relative to parish-level per capita COVID-19 death rates through May 12, 2020 (circles). Hazard values are from stationary point sources of pollution only (i.e. excluding vehicles and other mobile or nonpoint sources). See methods for data sources.

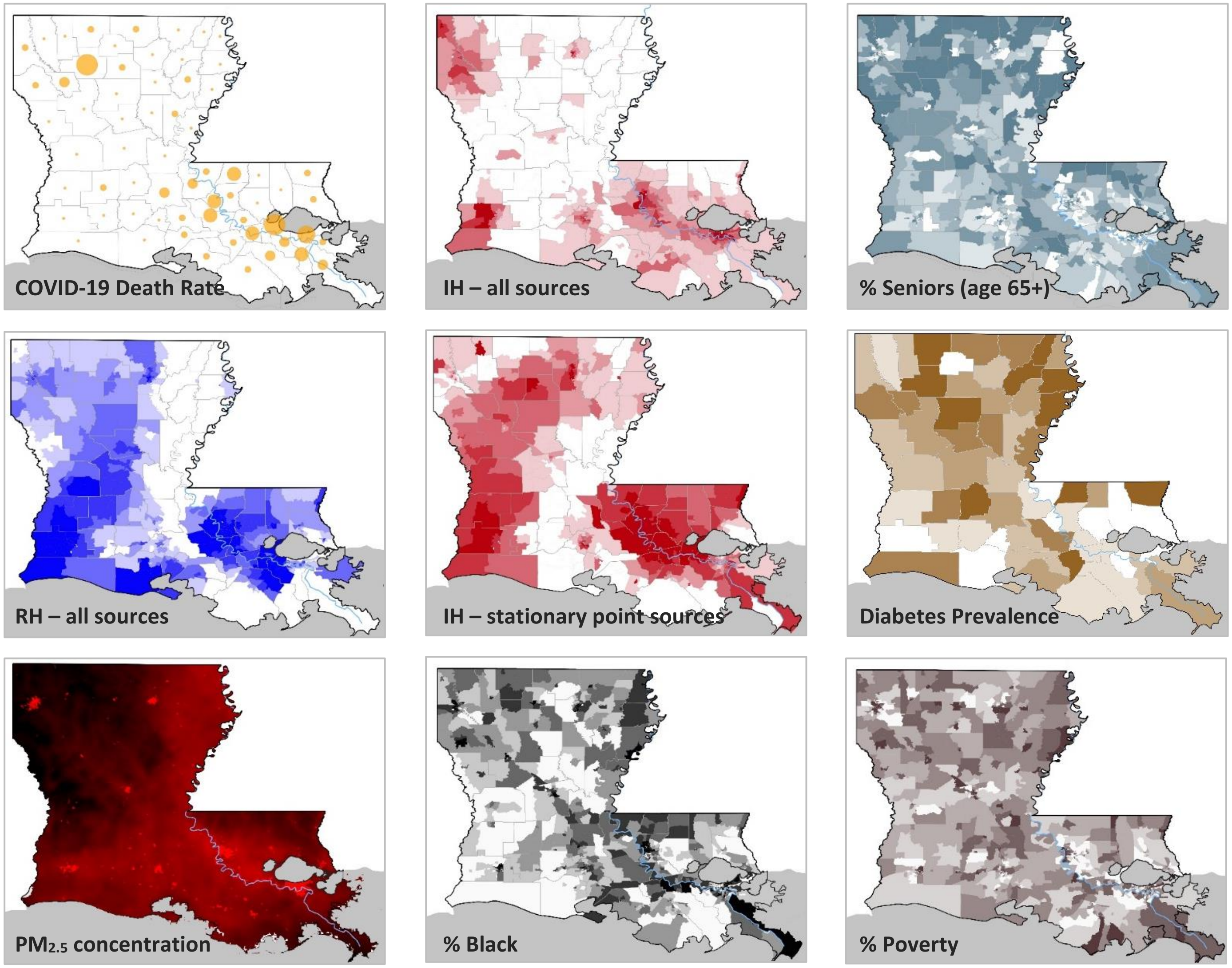

Figure 2. Geographic distribution of per capita COVID-19 death rates, air pollution burden ($PM_{2.5}$, RH and IH), and other relevant factors across Louisiana. See Tables 1&4 for correlation coefficients and significance values. Factors in the right column were unrelated to COVID-19 death rates at the parish (i.e. county) level. RH: Respiratory Hazard. IH: Immunological Hazard.

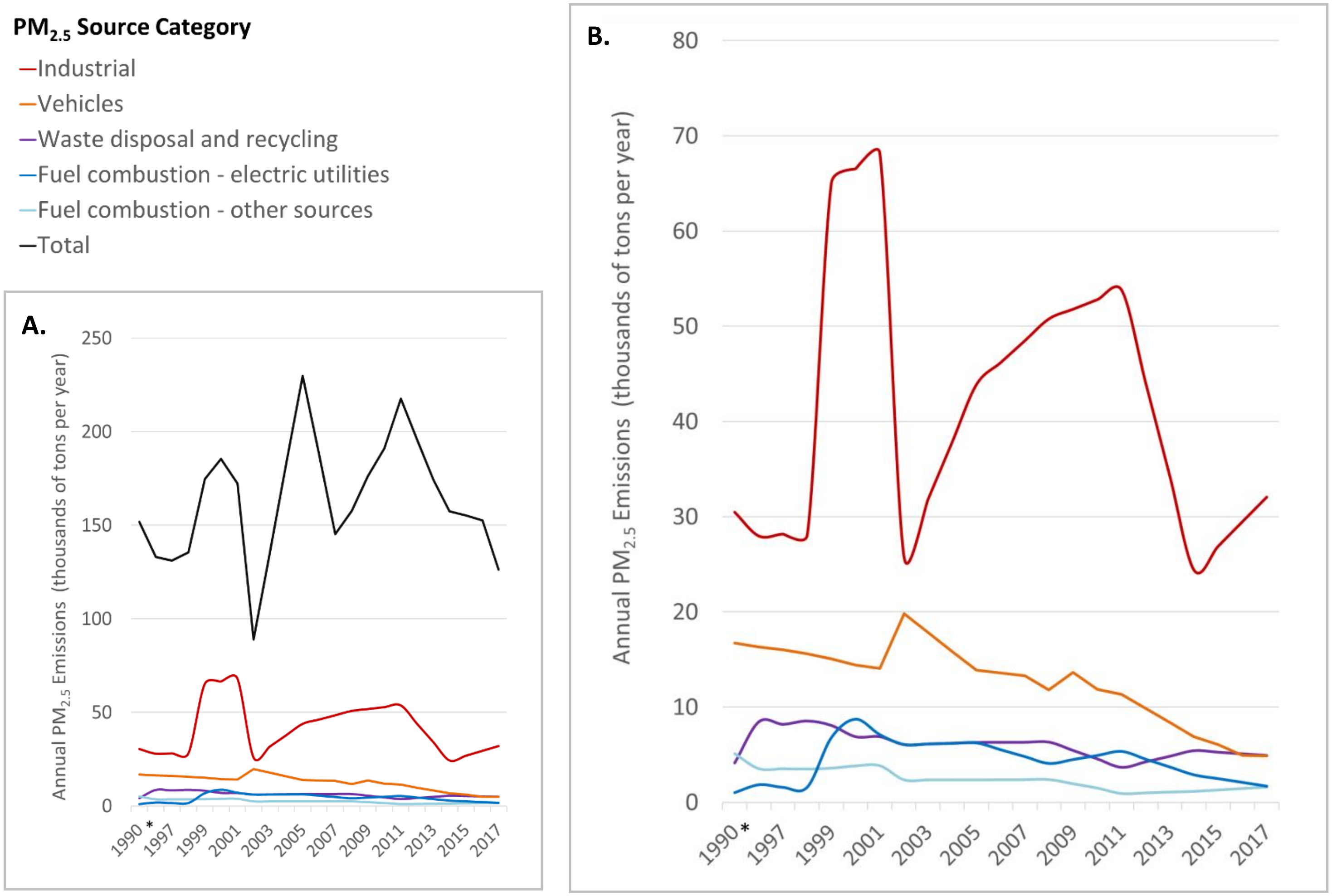

Figure 3. Emissions of $PM_{2.5}$ over time by source category with (A) and without (B) total emissions from all sources included. Miscellaneous sources are omitted from these figures (but included in the calculation of total emissions) to better illustrate the relative contributions of these source categories. See methods for more information on source categories. Values from the 2017 National Emissions Inventory Trends dataset. *Data unavailable for 1991-1995.

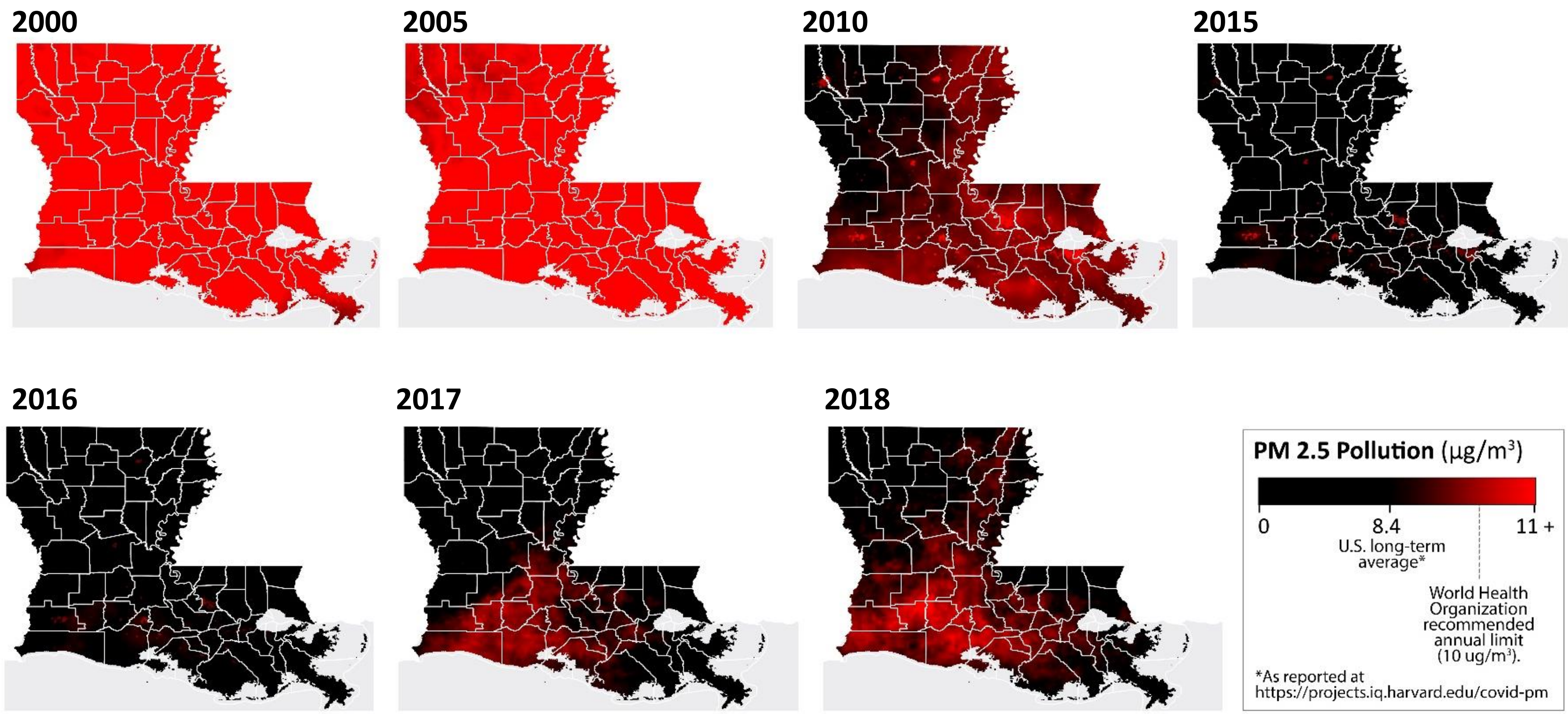

Figure 4. Levels of $PM_{2.5}$ in Louisiana from 2000 to 2018, on a scale of 8.4 - 11.0 µg/m^3 to illustrate changes over time.

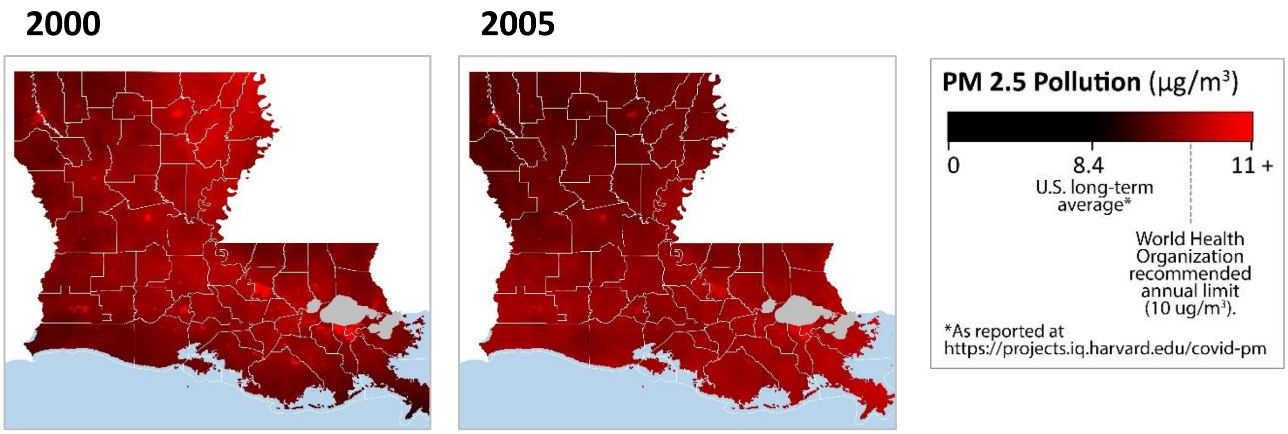

Figure 5. Levels of $PM_{2.5}$ in Louisiana, on a scale of 8.4 - 15.0 μg/m^3 to illustrate hotspots in cities.

Discussion

Our analysis yielded three major findings. First, African American and economically disadvantaged communities in Louisiana, including those in Cancer Alley, continue to be overburdened with pollution and the associated health risks. Second, increased per-capita COVID-19 death rates among Louisiana parishes are associated with larger percentages of black residents and with higher estimates of pollution burden. In other words, Louisiana's communities of color have long been overburdened with air pollution and are now overburdened with COVID-19. This association was not driven by the prevalence of diabetes, obesity, or smoking, as these factors did not correlate positively with per-capita COVID-19 death rates at the parish level. Finally, Louisiana's patterns of $PM_{2.5}$ pollution have changed dramatically over time, with vehicle emissions declining substantially, industrial sources becoming a relatively larger fraction of $PM_{2.5}$, and the state recently losing ground on long-term air quality improvements.

Our findings are consistent with previous research that has demonstrated racial and economic disparities in pollution burden in Cancer Alley, using other datasets. Specifically, James et al. (2012) demonstrated that air pollution in this region disproportionately affects socially disadvantaged and racial minority communities, using Cancer Risk estimates from EPA's 2005 National Air Toxics Assessment (NATA). Perera and Lam (2013) reported that Cancer Alley communities located close to toxin-emitting facilities were disproportionately minority and disproportionately impoverished, using EPA Toxic Release Inventory data. In the present study, we relied on estimates of long-term $PM_{2.5}$ levels from modeled satellite data, as well as Respiratory Hazard Index (RH) and Immunological Hazard Index

(IH) from EPA's most recent (2014) NATA. Thus, there are now at least three independent datasets that provide evidence of racial and socioeconomic disparities in pollution burden within Cancer Alley: 1) EPA's National Air Toxics Assessment , 2) EPA's Toxic Release Inventory, and 3) modeled satellite data for annual $PM_{2.5}$ levels from van Donkelaar et al. (2019).

Understanding temporal changes in pollutant concentrations and the relative contributions of different emission sources is important to addressing pollution disparities. We found that, overall, concentrations of $PM_{2.5}$ have declined substantially in Louisiana overall the last two decades (Fig. 4). This decline has manifested in two ways: the disappearance of $PM_{2.5}$ hotspots from cities and lower $PM_{2.5}$ levels across the entire state (Figs. 4&5). Contributing factors likely include the decommissioning of coal-fired power plants in the broader region (*50*) and the observed 75% reduction in vehicle emissions since 1990 (Fig. 3). By contrast, industrial emissions remained relatively unchanged in 2017 compared to 1990, despite substantial variation in the interim (Fig. 3). Thus, we found no evidence that industrial sources are responsible for the steady decline in $PM_{2.5}$ concentrations observed in Louisiana from 2000 to 2015. Further research is needed to understand the relative contributions of different industry sectors to air pollution in Louisiana, because the dataset used here (i.e. National Emissions Trends Data) is not fully broken down by industry sector.

Notably, improvements in Louisiana's $PM_{2.5}$ concentrations have not been maintained in all regions of the state. In recent years, south Louisiana (including Cancer Alley) has lost ground on the reductions that were observed statewide from 2000 to 2015 (Fig. 4). While fully understanding the reasons for this "lost ground" is beyond the scope of this analysis, we note that industrial $PM_{2.5}$ emissions (from all sources combined) increased by a third from 2014 to 2017, the most recent year for which data are available (Fig. 3). Regardless, our findings directly contradict the Louisiana petrochemical industry's current focus on vehicle emissions as a major source of $PM_{2.5}$ pollution in Louisiana (*38*) and the narrative that "*growing industry is actually causing emissions to go down, not up*" (*39*). Importantly, our study indicates that pollution disparities in Louisiana are not simply the result of vehicle emissions or urbanization, because disparities persisted when pollution data was limited to stationary point sources (e.g., excluding vehicles and residences; Tables 1,2&4). Furthermore, the link between pollution burden (i.e. RH and IH) and COVID-19 deaths remained unchanged when considering stationary point sources of pollution only (Table 4). Collectively, these findings are consistent with well-publicized concerns that toxin-emitting industrial facilities are disproportionately impacting impoverished African-American communities in Cancer Alley (e.g. (*42*, *51*)).

It is noteworthy that eight of the 10 parishes with the highest per capita COVID-19 death rates (as of May 12, 2020) occur in Cancer Alley (Table 3). These rates are exceptionally high and are approximately 3 to 6 times greater than Louisiana's median rate (Table 3). In particular, the per capita COVID-19 death rate for St. John the Baptist Parish, in the heart of Cancer Alley, was reported on Apr 16, 2020 to be among the highest in the nation (*52*). Our findings confirm that St. John the Baptist has remained a hotspot COVID-19 deaths. Specifically, we found that the per capita COVID-19 death rate in St. John is dramatically higher than all other Louisiana Parishes: 6× than the state's median value and 17% greater than Bienville, the next highest parish (Table 3). A cluster of COVID-19 deaths at the Southeast Louisiana Veterans Home (reported as 24 deaths on Apr 23, 2020 (*53*)) in Reserve, LA partially contributed to the per capita death rate in St. John. However, even after excluding these 24 deaths, the COVID-19 death rate in St. John remains unusually high (12.1 deaths per 10,000 people) and approximately equal to that of Orleans, the third highest parish (12.2 deaths per 10,000 people). Furthermore, St. John is not unique, or even unusual, in having a COVID-19 cluster at an assisted living facility. Clusters have been reported across at least 47 nursing homes across Louisiana, including in New Orleans (*54*).

Our analysis supports the notion that COVID-19 and air pollution represent a "double whammy" for African-American communities in Louisiana, particularly for those in Cancer Alley (*23*). It is imperative that Louisiana's public health and environmental agencies develop and implement bold, effective, and efficient strategies to eliminate these disparities. Central to this goal is the need for more extensive air quality monitoring in Louisiana. The current network of monitors operated by the Louisiana Department of Environmental Quality (LDEQ) is grossly inadequate to determine whether air quality throughout the state meets legal standards (i.e. National Ambient Air Quality Standards, or NAAQS). For example, LDEQ monitors $PM_{2.5}$ levels at only 20 sites across the state (an area of over 52,000 square miles) (*55*). The lack of air quality data in Louisiana is particularly conspicuous in Cancer Alley, with only one $PM_{2.5}$ monitor for determining NAAQS compliance along the ~100-mile stretch of the Mississippi River in between Baton Rouge and Jefferson Parish (*55*). Similarly, most communities in Louisiana have little or no information about air quality with respect to the dozens of other harmful air pollutants emitted in this state.

While Cancer Alley communities and their allies have been fighting for environmental justice for decades, the COVID-19 pandemic highlights the urgency of this issue. Louisiana's pollution disparities are evidenced by multiple independent data sources, including those reported here, and it is imperative that environmental decision-makers and public health professionals in Louisiana acknowledge and address these disparities. Long-term exposure to air pollutants associated with respiratory disease or immunological dysfunction should be considered a pre-existing condition for those infected with any virulent respiratory virus, including COVID-19. Framing pollution in this context will help advance public health efforts for communities worldwide, including those in Cancer Alley, that are overburdened with pollution.

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