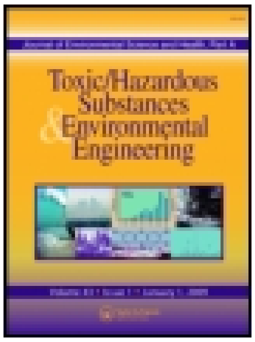

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Racial/ethnic disparities in the association between fine particles and respiratory hospital admissions in San Diego county, CA

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ABSTRACT

Ambient air pollution exposure is associated with exacerbating respiratory illnesses. Race/ethnicity (R/E) have been shown to influence an individual's vulnerability to environmental health risks such as fine particles (PM 2.5). This study aims to assess the R/E disparities in vulnerability to air pollution with regards to respiratory hospital admissions in San Diego County, California where most days fall below National Ambient Air Quality Standards (NAAQS) for daily PM 2.5 concentrations. Daily PM 2.5 levels were estimated at the zip code level using a spatial interpolation using inverse-distance weighting from monitor networks. The association between daily PM 2.5 levels and respiratory hospital admissions in San Diego County over a 15-year period from 1999 to 2013 was assessed with a time-series analysis using a multi-level Poisson regression model. Cochran Q tests were used to assess the effect modification of race/ethnicity on this association. Daily fine particle levels varied greatly from 1 $\mu g/m^3$ to 75.86 $\mu g/m^3$ (SD = 6.08 $\mu g/m^3$) with the majority of days falling below 24-hour NAAQS for PM 2.5 of 35 $\mu g/m^3$. For every 10 $\mu g/m^3$ increase in PM 2.5 levels, Black and White individuals had higher rates (8.6% and 6.2%, respectively) of hospitalization for respiratory admissions than observed in the county as a whole (4.1%). Increases in PM 2.5 levels drive an overall increase in respiratory hospital admissions with a disparate burden of health effects by R/E group. These findings suggest an opportunity to design interventions that address the unequal burden of air pollution among vulnerable communities in San Diego County that exist even below NAAQS for daily PM 2.5 concentrations.

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Air pollution; PM 2.5; vulnerability; social inequalities in health

Introduction

Outdoor air pollution is associated with respiratory illnesses including asthma and chronic obstructive pulmonary disorder.[1–4] Particulate matter (PM) is an outdoor air pollutant that consists of particles and liquid suspended in air.[5] PM 2.5 are fine particulate matter particles that have a diameter of 2.5 micrometers or smaller.[5] PM 2.5 is both naturally occurring as well as anthropogenic. Major sources of PM 2.5 include fossil fuel emissions, wildfires, construction sites, automobiles, and power plants.[5]

Ambient air pollution, including particulate matter, contributes to social inequalities in health through differential exposure and vulnerability, which can act independently or synergistically.[6,7] Socioeconomic status, in interaction with other social determinants of health such as race/ethnicity (R/E), may dictate an individual's level of exposure as well as the effect of fine particles on health.[8] Previous studies have shown that certain R/E minorities such as Blacks and Hispanics suffer greater health risks than others when exposed to environmental hazards due to differential vulnerability.[9,10] To design interventions that reduce health disparities, it is essential to understand which subgroups, within specific socio-demographic contexts, are more affected by ambient fine particles[11,12]

Some large-scale interventions such as the Clean Air Act passed by Congress have largely omitted environmental justice goals,[13] while other policies such as the Congestion Charging Scheme intervention in Central London successfully reduced health inequities through a community-based public health intervention that reduced air pollution levels.[14] Although environmental inequalities can exist even at levels of fine particles below Air Quality Standards, evidence of inequalities in health impacts is lacking at air pollution levels below the current daily National Ambient Air Quality Standards (NAAQS). In 2012, the annual and 24-hour NAAQS for PM 2.5 were set to 12 $\mu g/m^3$ and 35 $\mu g/m^3$, respectively.[5] If some socio-demographic groups are disproportionately affected by the impacts of fine particles even at levels below regulatory guidelines, then stricter interventions could be encouraged to reduce these inequalities. There is a need to disentangle patterns of environmental health vulnerabilities and disparities in specific geographical

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locations to help local public health officials tailor policies that directly intervene on environmental justice issues.

San Diego County is a unique setting in which to study environmental health disparities with days at both very low and elevated levels of fine particles. San Diego is home to many immigrants, refugees, and natives, and has a large number of R/E minorities.[15] The racial/ethnic make-up of San Diego County is 183,523 (5.5%) Black, 1,118,124 (33.5%) Hispanic, 427,224 (12.8%) Asian and Pacific Islander, and 1,535,335 (46.0%) White.[16] In addition to its unique demographic composition, the county's geographic location makes it a microcosm of California with its diverse topography and climate. The geopolitical location of San Diego near the border with Mexico, moreover, impacts the high level of air traffic pollution. An influx of truck-traffic air pollution causes high levels of air pollutants dispersal near the San Diego-Tijuana border and across the county.

Previous studies have shown that air pollution exposure is higher among R/E minorities in California.[17,18] Prior work has considered R/E disparities in regards to the respiratory effects of short-term PM 2.5 exposures in California[19,20]; however, there is a lack of distinct attention given to San Diego County, which is home to 3.3 million people. This is the first study to consider differences in the effect of short-term exposure to PM 2.5 by on respiratory hospitalizations by R/E in San Diego County. Additionally, this research is novel in that it considers environmental health disparities in a region where the majority of days fall below NAAQS for daily PM 2.5 concentrations. By considering differential susceptibility of R/E groups to PM 2.5 exposure in San Diego County, results of this study can be used to inform targeted interventions to protect vulnerable populations during high air pollution episodes. Results of this study can also urge the importance of considering lower thresholds for national standards and highlight the importance of considering the health effects of these lower level exposures in future work on this topic.

The present study aims to assess R/E disparities in fine particles vulnerability in regards to respiratory hospital admissions in San Diego, California. This information may help the County of San Diego develop air pollution control policies that assist the most vulnerable communities, highlighting the importance of acting on air pollution to lower exposures beyond regulatory standards. To assess the R/E vulnerabilities of air pollution in regards to hospital admissions, we analyzed data from a statewide dataset of non-Hispanic white, non-Hispanic Black or African American, Hispanic or Latino, and Asian patients. We hypothesized an increased risk of respiratory hospital admissions among R/E minorities with increasing levels of PM2.5 exposures.

Methods

Health and socio-demographic data

We obtained clinical data for hospitalizations for respiratory diseases (n = 107,005) from the Office of Statewide Health Planning and Development (OSHPD) database of patient discharge data between May and October (6 months) for the 15-year (1999–2013) period. Unscheduled hospitalizations at acute care facilities were included. They include the following ICD 9 codes 460:519 which include pulmonary diagnoses such as asthma, chronic obstructive pulmonary disease (COPD), pneumonia, and interstitial lung disease. Respiratory disorders are among prominent contributors to air pollution-related morbidity and health-care costs.[21,22] The OSHPD dataset includes information on patient characteristics including age, gender, R/E, and zip code of residence. We included OSPHD data on all unscheduled respiratory admissions for all county residents admitted to hospitals in San Diego County. We considered the following R/E groups: non-Hispanic white, non-Hispanic black or African American, Hispanic or Latino, and Asian. Data at the zip-code level was obtained for San Diego County, which includes 110 ZIP Code Tabulation Areas (ZCTAs). Data was then aggregated at the daily level by zip-code and by R/E group for the entire study period.

Environmental data

A daily level of PM 2.5 was assigned to each zip-code using data provided by the California Air Resources Board (CARB). Spatial interpolation using inverse-distance weighting from monitor networks was used to estimate daily levels of PM 2.5 concentrations (μg/m^3) at the zip-code level.[23] There were 500 days of PM 2.5 data unavailable. We used PM 2.5 levels given the strong evidence of its association with respiratory outcomes.[24–27] We also collected daily mean outdoor temperature and ozone (daily maximum 8-hour averages measured in ppm using the same modeling approach as for PM2.5) for the same period (1999–2013). PM 2.5 and mean temperature data were matched to the health data aggregated daily at the zip-code level to constitute time series for the study period.

Statistical analysis

We conducted a time-series analysis using a multi-level Poisson regression model to assess the association between daily PM 2.5 levels and respiratory hospital admissions in the County of San Diego. It is worth mentioning that time-series designs using Poisson regression and case-crossover designs using conditional logistic regression are equivalent in settings of a common exposure like air pollution.[28] To account for time-invariant unmeasured confounders, we used fixed effects at the zip-code level.[29] Cubic B-splines of time with 7 degrees of freedom were used to control for secular trends in the hospitalization time series.[30] This was modeled across weeks of the year (1–52) using a spline with three knots (10th, 50th, and 90th percentiles) to control for seasonal patterns (various analysis were conducted changing splines or degrees of freedom and the final model was decided based on the Akaike information criterion). Sensitivity analyses were conducted by using a different number of degrees of freedom and by including fixed effects on years, months, week of the year, and day of the week (weekend vs. weekday). To ensure that no autocorrelation

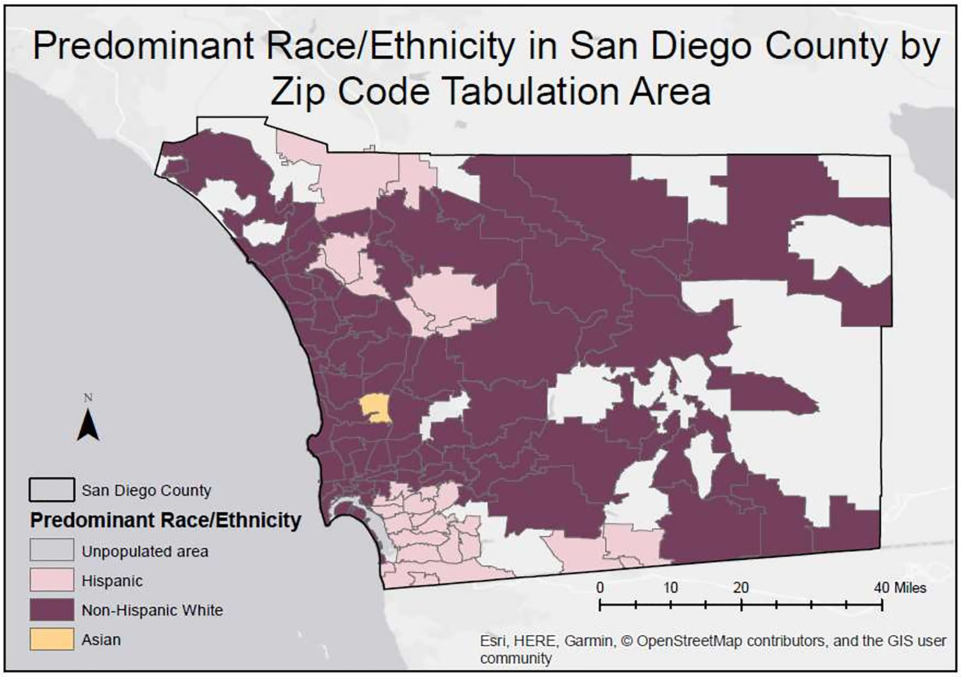

Figure 1. Map showing predominant race/ethnicity by zip code tabulation area in San Diego County.

Table 1. Descriptive statistics for temperature, ozone and PM 2.5.

	Observed (n)	Daily mean	Standard deviation	Daily minimum	Daily maximum
Temperature Celsius	2,760	24.81	3.38	16.49	39.62
Temperature Fahrenheit	2,760	76.6	38	61.6	103.3
Ozone[a] (ppm)	2,191	0.048	0.093	0.015	0.093
PM 2.5 (μg/m^3)	2,191	12.13	6.08	1	75.68

[a]Daily maximum 8-hour average.

remained in the residuals, we visually inspected partial autocorrelation plots and used the white noise statistical test. We considered exposure from previous days by including Lag 0, Lag 1, and Lag 2. The association between PM 2.5 on each lag was estimated separately and then a 3-day moving average PM 2.5 concentrations (Lags 0–2) was estimated, controlling for daily mean temperature. The association (expressed as Risk Ratios: RR) represents an average change in daily hospital admissions per 10 µg/m^3 increase in PM2.5. The overall RR corresponds to an average change in total hospital admissions rates (i.e. all R/E groups together). A specific average change was estimated for each stratified analysis. We estimated 95% confidence intervals (CIs) by bootstrapping (1,000 samples). As a sensitivity analysis, we conducted analyses by restricting the sample to days below the daily NAAQ Standards (35 μg/m^3). An additional sensitivity analysis controlled for daily ozone levels.

The first model estimates included all R/E groups. Further models provided stratified estimates for each R/E group (i.e. non-Hispanic white, non-Hispanic Black or African American, Hispanic or Latino, and Asian). To assess the effect measure modification of R/E on the association between PM 2.5 and hospital admissions for respiratory diseases, we conducted Cochran Q tests,[31] using estimates based on the 3-day moving average exposure to PM 2.5 (Lags 0–2). We a priori considered the presence of heterogeneity at the 10% level of significance.[32]

Results

Figure 1 shows the predominant race/ethnicity in San Diego county for each ZCTA, measures of Zip codes used by the Census bureau. Black was not included as a category, as none of the ZCTAs in San Diego County have a predominance of Black residents. As shown on the map, the majority of ZCTAs are predominantly White, while a large number of ZCTAs near the border and in North county are mostly Hispanic.

Table 1 describes the average temperature ranges and median values of PM 2.5, while Table 2 shows the distribution of respiratory hospital admissions (with the stratification of R/E). A total of 110 ZCTAs were included in this analysis. Out of the 2,760 days observed in the study period, the mean temperature was 24.8 C (76.6 F). PM 2.5 levels had a daily mean of 12.13 μg/m^3 with the highest daily levels reaching 75.86 μg/m^3. Most of the days (99%) during our study period were below the daily (24-hour) NAAQS PM 2.5 standard of 35 μg/m^3.

As shown in Table A1 and Figure 2, we found a positive association between PM 2.5 concentrations and respiratory hospital admissions for the total number of respiratory hospital admissions. The association of the three-day rolling average (Lag 0-2) was greater than any one-day exposure (Table A1). Across all race/ethnic groups, for every 10 μg/m^3 increase in PM 2.5, there was a 4.1% increase in total

Table 2. Descriptive statistics respiratory hospital admissions for the sample population.

	Observed (n) total period	Rate (per 100,000) total period	Daily mean	Daily standard deviation	Daily minimum	Daily maximum
R/E respiratory hospital admissions						
Total admissions	107,005	3,278	38.77	8.39	14	78
White	66,904	4,358	24.24	6.07	7	53
Black	7,975	4,346	2.89	1.79	0	12
Hispanic	20,597	1,842	7.46	3.15	0	22
Asian	7,277	1,703	2.64	1.71	0	12

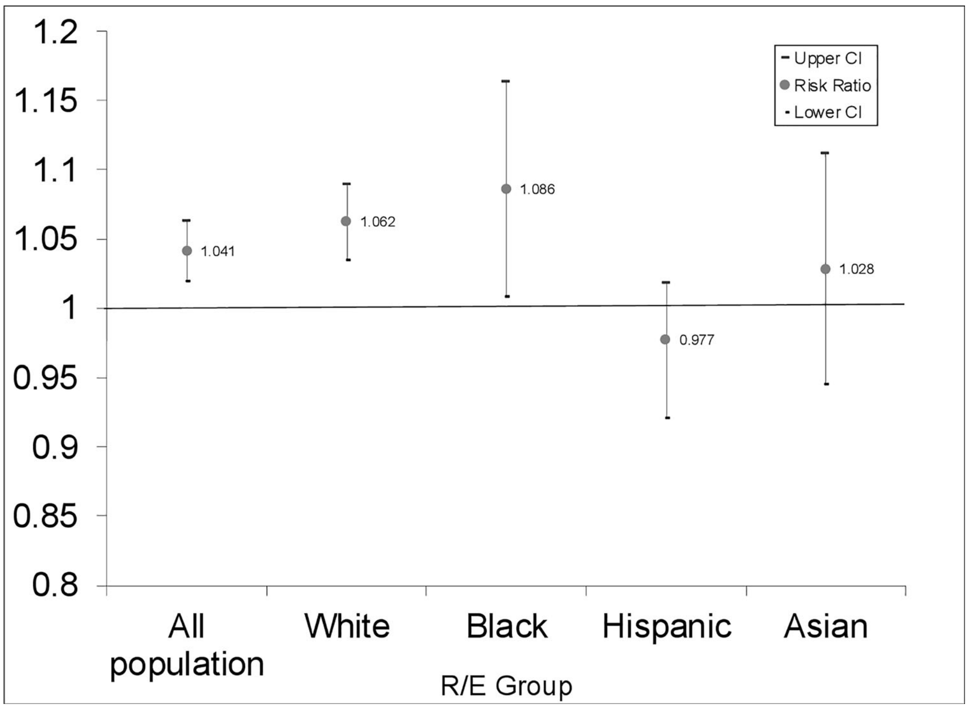

Figure 2. Association between PM 2.5 concentrations and respiratory hospital admission by R/E; *The error bars represent 95% CI for the RR by Racial/Ethnical (R/E) group; All population refers to all hospital admissions for all R/E groups.

Table 3. Summary analysis of the heterogeneity test for Lag 0-2 for PM2.5.

	Risk ratio[a] by R/E strata	95% Confidence interval		Cochran Q test	P-value for heterogeneity
		Lower bound	Upper bound		
White	1.062	1.034	1.089	3.773	0.052
Black	1.086	1.008	1.163		
White	1.062	1.034	1.089	10.792	0.000
Hispanic	0.977	0.920	1.018		
White	1.062	1.034	1.089	2.432	0.119
Asian	1.028	0.945	1.111		
All Population	1.041	1.019	1.063		

[a]For 10 $\mu g/m^3$ increase in PM 2.5.

hospital admissions for respiratory diseases [95% CI = 2.0% to 6.3%]. When restricting the sample to days below daily NAAQ Standards, we found this estimate to be 3.6% [95% CI = 0.7% to 6.6%]. When controlling for daily ozone levels, we found that the association between PM2.5 and total hospital admissions for respiratory diseases was slightly reduced from 1.041 (95%CI: 1.019; 1.063) to 1.032 (95%CI: 1.012; 1.052).

Blacks had a 8.6% increase in respiratory hospital admissions for 10 $\mu g/m^3$ of PM 2.5 [95% CI = 0.9% to 16.3%], while Whites had a 6.2% increase [95% CI = 3.4% to 8.9%]. We did not detect any associations between PM 2.5 and hospital admissions among Asians and Hispanics.

The results of the Cochran Q tests for the association between air pollution and hospital admissions by R/E categories are presented in Table 3. Black individuals were more affected by PM 2.5 than White and Hispanic individuals. Moreover, White individuals were more vulnerable to PM 2.5 exposure when compared to Hispanic individuals.

Discussion

Summary of findings

Most of the observed days were below the NAAQ Standards, with only 17 days in the 14 year study period with PM2.5 levels above these thresholds. Even so, we did find that fine particle concentrations in San Diego County were associated with an increase in respiratory hospital admissions when considering the entire San Diego County population. After stratifying by R/E groups, the strongest association was for Blacks followed by Whites. The association of the three-day rolling average demonstrated an 8.6% higher rate of respiratory hospital admissions for every 10 $\mu g/m^3$ of PM 2.5 for Blacks and a 6.2% higher rate for Whites. We did not detect any impact of PM 2.5 on respiratory hospital admissions among Hispanic or Asian populations. Cochran Q tests indicated that the Black population had a significantly higher risk than White populations, and Hispanic populations had lower risk than the White population. Asian populations did not have significantly different risk than the White population. These results indicate that even at levels below the NAAQS standards, health disparities were observed, and highlights the importance of evaluating potential health equity implications of air pollution exposures below air quality standards.

Comparison with other studies

Our results for air pollution and respiratory hospital admissions are comparable to the findings of several other case-crossover and time-series analyses conducted in the United States. For example, several studies have found that there is an association between PM 2.5 and increased respiratory hospital admissions, emergency department visits, and/or morbidities.[33,34] With respect to effect modification by race, a study in Detroit, Michigan found a heightened disparity of respiratory health effects due to unequal burden of environmental exposures among black communities in this region.[35] Likewise, another study[36] found Hispanic and Black R/E groups to be at higher risk of health effects due to air pollution as compared to White individuals.

In our study, we failed to detect an association among Hispanic and Asian R/E groups. This contrasts a study conducted in nearby Orange County, California, which found a stronger association among Hispanics in regards to ambient air pollution and asthmatic-related hospital admissions as compared to Whites.[35] Our study contributes to a growing understanding of the heterogeneity in regards to the vulnerability of Hispanic communities to air pollution, even within Southern California.[18,37,38]

Mechanisms and social determinants

There are several possible mechanisms for why Black individuals would be more vulnerable to air pollution. As visualized in, ZCTAs in San Diego with higher percentages of Black residents often correspond to low-income areas of the County. Psychosocial stress factors faced by those living in low-income neighborhoods may increase their vulnerability to environmental hazards.[39] Stressors, such as crime, noise, and traffic can lead to acute and chronic changes in the functioning of body systems and increase the effect of toxicants on the biological system.[7]

Social and environmental injustices have long been shown to affect racial minorities and particularly African Americans throughout the United States due to structurally racist and discriminatory factors.[40,41] Communities of color are disproportionately subjected to social deprivation and environmental harms.[12,42] Neighborhoods with a high percentage of Black residents in San Diego County (>20%) often correspond to areas that have a higher cancer risk from inhalation of air toxins and are also subject to other environmental hazards, such as proximity to traffic and hazardous waste.[43] Some areas in San Diego with a higher percentage of Black residents correspond to those with higher cancer risk from environmental toxins as well as a higher air toxics respiratory hazards index, as measured by the National Air Toxics Assessment of the US EPA. Black individuals in San Diego County may have poorer health and consequently, be more vulnerable to PM 2.5 due to being subjected to a range of environmental injustices.

It is interesting that we found a lower risk of association between PM 2.5 and respiratory outcomes in Hispanics and Asians than Blacks and Whites. Despite their lower socioeconomic status (on average), Hispanic populations have similar, if not lower, adult mortality when compared to non-Hispanic Whites.[44] However, this phenomenon is not completely understood.[45] This association could be explained by differential rates of asthma between demographic groups. Air pollution is implicated in the pathogenesis of asthma and also triggers asthma exacerbations.[46] Asthma rates vary by R/E groups, with Hispanics and Asians having lower rates than Blacks and Whites nationally.[47] This may be an important factor in explaining our results, as those with higher asthma rates are likely to be more vulnerable to PM 2.5 exposures.

Implications

Although the majority of days in the study were below NAAQ Standards,[48] we found that certain racial/ethnic groups are disproportionately affected by fine particles even within the existing range of 12 $\mu g/m^3$ to 35 $\mu g/m^3$. This is concerning, as the NAAQS are designed to provide public health protection, especially for vulnerable populations.[48] Our findings suggest that these standards may need to be reevaluated to protect against the respiratory effects of PM 2.5 in diverse populations.

We show that even with fine particulate exposure concentrations below NAAQS, Black communities are still disproportionately affected. There is an opportunity for local policies and intervention efforts that decrease air pollution emissions and concentrations within primarily Black communities.[49] Such policy initiatives could be incorporated into broader environmental justice efforts at the city and county levels in San Diego.[50] Air pollution patterns are quite complex in San Diego County. In addition to air pollution emissions coming from local traffic, there are also heavy amounts of air pollution coming from the San Diego-Tijuana border crossing and the San Diego port.[51,52] There is an opportunity for cross-national collaboration to reduce the impact of air pollution on vulnerable populations.

Increasing accessibility to resources and healthcare for respiratory-related illnesses could also be beneficial in decreasing the health impacts of air pollution on those that are most vulnerable. By revealing the susceptibility of different people to the impacts of air pollution, healthcare professionals could be trained to look for these impacts more readily in these individuals and possibly diagnose and treat air pollution-related respiratory problems more effectively. The recommendation and subsidization of air filtration systems could also decrease exposure to indoor air pollution.[53] Based on the results of our study, interventions to decrease air pollution exposure should be made available and accessible especially in Black communities.

Limitations

Our study has some limitations that need to be acknowledged. We only examined PM 2.5 as a potential air pollutant and did not assess for others including ground-level ozone, sulfur dioxide, and nitrogen dioxide. Prior studies have shown that ozone, in particular, is known to be associated with an increase in respiratory hospital admissions.[54,55] In parallel, SES status is not necessarily correlated with R/E status, and future studies assessing the specific relationship between SES and R/E status to environmental exposures such as air pollution would be important to understand these results. By using estimated daily levels of PM 2.5 concentrations (in $\mu g/m^3$) at the zip-code level, we must assume that all individuals living in one zip code have the same level of exposure. As our data were drawn from monitor networks, we used spatial interpolation using inverse-distance weighting to determine our best estimate of the variation between areas around air monitoring stations, but we acknowledge that using zip codes for our geographical comparison is a limitation to the study. The data was missing information about PM 2.5 levels in 20% of the days in our sample, which has the potential of introducing bias. Some studies conducted in Southern California did not show any strong seasonal pattern between summer and winter months, so such seasonality in PM 2.5 concentration does not affect the interpretation of our results.[56,57] Lastly, throughout the study we only focused on respiratory hospital admissions. Despite respiratory health effects being a prominent effect of air pollutants, there are a wide array of different health outcomes that were not considered. Previous studies have researched various health consequences of air pollution such as cardiovascular diseases.[58–60]

Conclusion

In San Diego, we found that with increasing levels of PM 2.5, there is an overall increase in respiratory hospital admissions despite most of the days being below PM 2.5 regulatory standards. When stratified by R/E, we found that there is an unequal burden of health effects associated with fine particle exposure. Blacks, Whites, and county residents overall had an increase in hospital admission rate per increase in $10\,\mu g/m^3$. We did not find an association between air pollution and respiratory hospital admissions among Hispanic and Asian R/E groups. These results are important as they can help policymakers formulate air pollution control efforts directed toward vulnerable populations in San Diego.

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The authors declare they have no actual or potential competing financial interests. The observational temperature dataset is freely and publicly available from the University of Washington (ftp://ftp.hydro.washington.edu/pub/blivneh/CONUS/). Air pollution data are available from California Air Resources Board (https://ww2.arb.ca.gov). Health data are distributed by the Office of Statewide Health Planning and Development (https://www.oshpd.ca.gov/HID/Patient-Discharge-Data.html).

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Appendix

Table A1. Association between PM 2.5 and respiratory hospital admissions for Lag 0, Lag 1, Lag 2, and Lag 0-2 estimates for PM 2.5.

	Lag day	Risk ratio for 10 $\mu g/m^3$ increase of PM 2.5	95% Confidence interval	
			Lower bound	Upper bound
All population	Lag 0	1.037	1.019	1.055
	Lag 1	1.033	1.015	1.051
	Lag 2	1.018	1.000	1.036
	Lag 0-2	1.041	1.020	1.063
White	Lag 0	1.046	1.023	1.069
	Lag 1	1.049	1.027	1.072
	Lag 2	1.036	1.013	1.059
	Lag 0-2	1.062	1.034	1.089
Black	Lag 0	1.081	1.019	1.145
	Lag 1	1.066	1.002	1.130
	Lag 2	1.033	0.966	1.100
	Lag 0-2	1.086	1.009	1.163
Hispanic	Lag 0	0.996	0.955	1.037
	Lag 1	0.977	0.936	1.020
	Lag 2	0.958	0.915	1.001
	Lag 0-2	0.969	0.920	1.018
Asian	Lag 0	1.028	0.958	1.098
	Lag 1	1.008	0.937	1.080
	Lag 2	1.024	0.954	10.940
	Lag 0-2	1.028	0.945	1.111