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Exploring the Spatial Distribution of Air Pollutants and COVID-19 Death Rate: A Case Study for Los Angeles County, California

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Abstract

Objective

Since March 2020, COVID-19 has rapidly spread across the world with over 240 million cases and over 5 million deaths as of November 2021. It has been unclear what role air pollutants may play in exacerbating respiratory illnesses such as COVID-19 due to their interaction with the respiratory system. The association with air pollutants and COVID-19 severity has been explored at the regional and metropolitan area, however it is unclear if such an association is consistent at the neighborhood level.

Methods

Weekly death rates from COVID-19 from March 2020 to November 2021 were compared using one-sided unpaired t-tests across 11 neighborhoods located in Los Angeles County using data collected by the Los Angeles County Public Health department. Air pollutant information was collected from Environmental Protection Agency (EPA) sensors located in the 11 neighborhoods and were also analyzed using a one-sided unpaired t-test between neighborhoods that had a significant difference in COVID-19 death rates.

Results

Out of 23 significant comparisons for COVID-19 weekly death rate, 18 comparisons confirmed that NO_2 levels were higher in neighborhoods that had higher COVID-19 weekly death rates, similarly, 12 out of 19 comparisons confirmed the same relationship with CO levels, 14 out of 23 comparisons confirmed the same relationship with ozone levels, and 6 out of 6 comparisons confirmed the same relationship with PM 10.

Implications

Our study found a positive association with air pollutants and COVID-19 deaths as seen in the literature on a smaller area within Los Angeles County. This association along with biological plausibility suggests a potential causal link, which may serve as an important public health consideration for urban planners and policy makers in terms of reducing urban air pollution.

Keywords

COVID-19, Death Rate, Air Pollution, Statistical Analysis, Environment

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1 INTRODUCTION

SARS-CoV-2, the virus that causes the respiratory illness coronavirus disease 2019 (COVID-19) and was first identified in Wuhan, China, in December 2019, has become incredibly widespread throughout the world. According to a dashboard developed by Dong et al. (2020), roughly over 240 million people worldwide have developed COVID-19, and over 5 million deaths have occurred as a result of COVID-19 as of November 2021 (Dong et al. 2020). As a pandemic, the spread of COVID-19 has led to severe economic and social impacts due to various lockdown measures implemented by countries all over the world. As such, factors that may have contributed to the widespread prevalence of COVID-19 have been under much scrutiny to understand how to prevent future pandemics. Furthermore, the impact of lockdowns and reduced mobility on the environment and the broader shift towards focusing on climate change, has led to a renewed focus on the environment and the interaction between the health of humanity and the health of the shared environment (Soga et al. 2021). Finally, racial and socioeconomic inequalities highlighted by the pandemic have led to an interest in understanding environmental inequalities and how they may be contributing to disparities in COVID-19 case numbers and case fatality rates (Brandt et al. 2020). At the center of these three trends, especially with COVID-19 being a primarily respiratory disease, is air pollution and its relationship to the spread and severity of COVID-19.

2 LITERATURE REVIEW

Several epidemiological studies have been conducted to determine the association between air pollutants and the severity of COVID-19 spread and outcomes within the literature. Copat et al. (2020) completed a literature review and concluded that particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$) and nitrogen dioxide (NO_2) were more closely related to COVID-19 spread and severity. Another literature review conducted by Srivastava (2021) concluded that wind, $PM_{2.5}$, PM_{10}, NO_2, carbon monoxide (CO), and ozone (O_3) are also positively correlated with COVID-19 cases. More broadly, literature reviews conducted by Amnuaylojaroen and Parasin (2021), Rahimi et al. (2021), and Zhao et al. (2021) concluded that there is a generally positive association between both long-term exposure and short-term air pollution and meteorological factors and the spread and severity of COVID-19 cases. Brandt et al.'s findings (2020) support these conclusions by studying Louisiana, Michigan, and New York state and concluding a similar positive correlation but with $PM_{2.5}$, nitrogen dioxide, and carbon monoxide as well. Meo et al. (2021) reached similar conclusions to Brandt et al. (2020) except by studying $PM_{2.5}$, ozone, and CO levels in England. Similar findings were also reported in China with $PM_{2.5}$, PM_{10}, CO, NO_2, ozone in China by Zhu et al. (2020), in England with $PM_{2.5}$, NO, and ozone by Travaglio et al. (2021), in South Korea with NO_2, CO, sulfur dioxide (SO_2) but not with $PM_{2.5}$ and PM_{10} by Hoang and Tran (2020). With a unique focus on long-term exposure in major Chinese cities, Hou et al. (2021) noted that there is a positive association between long-term exposure and increased case fatality rate for COVID-19 and that $PM_{2.5}$ particularly might have a predictive capability. Finally, Zhu et al. (2020) also noted a negative correlation between COVID-19 infection and $SO_{2,}$ which may require further investigation as air pollutants have been positively associated with general morbidity and mortality (Woodby et al. 2021).

A major theme within the literature (Brandt et al. (2020), Travaglio et al. (2021), Hou et al. (2021)) is that there appears to be a positive correlation between air pollutants and COVID-19 spread and lethality. However, due to the nature of the experimental design of these studies where an ecological association is studied, it is hard to separate the role of socioeconomic, racial disparities and other confounding factors which may also correlate with lower air quality (Copat et al. 2020). As such, methodologies focusing on associations are unable to ascertain the precise cause but rather provide more evidence for studying causative factors. In fact, Brandt et al. (2020) noted that racial disparities seem to be a key factor even when controlling for population density and air pollution. Furthermore, with an ecological design, the precise role of air pollution acting on either the spread or other comorbidities is unknown (Sharma and Balyan 2020). Although the literature supports a positive association between air pollutants and COVID-19, further work is needed to determine if the relationship is applicable at finer geographic and time scales as well as to control for socioeconomic and racial disparities.

Although epidemiological studies are limited by being able to mainly comment on associated factors and not causative factors, there are several sources within the literature that hypothesize several biological mechanisms for air pollution to exacerbate the spread and severity of COVID-19. Woodby et al. (2021) explored the biology and biochemical processes behind infection with SARS-CoV-2 and exposure to various air pollutants such as ozone, PM, and nitrogen dioxide. Developing these ideas further, Woodby et al. (2021) suggest several mechanisms by which exposure to air pollutants may exacerbate the risk and severity of COVID-19 infection.

The first mechanism is through pollutants increasing the permeability of the pulmonary epithelium by interfering with the tight junctions between pulmonary cells, which then allows for viral spread and inflammation (Woodby et al. 2020). Additionally, $PM_{2.5}$ and PM_{10} have been suspected to affect the viral entry and surface level of attachment receptors. Exposure to PM has previously been shown to increase angiotensin-converting enzyme 2 (ACE2) receptors which act as SARS-CoV-2 receptors.

Additionally, pollution may facilitate oxidative post-translational modifications of ACE2, which may then alter its surface expression. Furthermore, ACE2 has been noted to help repair lung damage due to $PM_{2.5}$. Therefore, the binding of SARS-CoV-2 to ACE2 may prevent this repair function of ACE2 and further worsen the lung damage sustained due to $PM_{2.5}$ exposure (Woodby et al. 2020).

Several other biological mechanisms that have been suggested by Woodby et al. (2021) include ozone and PM exposure, potentially resulting in increased SARS-CoV-2 infection by skewing immune responses away from viral responses. Other pathways include air pollutants interfering with interferon production, which are signaling molecules released in response to a viral infection, interference with mitochondrial function, autophagy and macrophage, and natural killer (NK) cell functionality. Exposure of macrophages to PM decreased viral uptake, and diesel exhaust particles have been inferred to reduce NK cells' ability to kill virus-infected cells due to reducing NK cells' ability to produce proinflammatory cytokines (Woodby et al. 2021). Pollutant exposure has also been linked to suppression of antiviral responses, as $PM_{2.5}$ has been shown to shift adaptive immune responses to more allergic responses rather than antiviral responses. Finally, pollution exposure has been associated with enhanced virus-induced lung tissue damage and inflammation, especially with PM and ozone exposure.

Wang et al.'s study (2020) corroborates some of the pathways discussed by Woodby et al. (2021) while also providing several other potential mechanisms linking air pollution and COVID-19 spread and severity. Wang et al. (2020) supported the hypothesis that PM could lead to increases in ACE2 receptors and thus result in assisting in SARS-CoV-2 infection. Wang et al. (2020) also discussed the potential for PM to carry viral particles over much greater distances. However, Woodby et al. (2020) disagreed with this perspective, citing the relatively low percentage of viral products in PM-polluted air and indoor transmission being much more prevalent than outdoor transmission. Wang et al.'s study (2020) argues that PM may contribute to the cytokine storm experienced by severe cases of COVID-19 by inducing inflammation and hyper-activating the innate immune system, thus providing another mechanism linking air pollution and COVID-19.

An additional emerging theme within the literature is the spatial analysis of COVID-19 mortality and air pollution. Huang et al. (2021) investigated the long-term effects of air pollution on COVID-19 outcomes across multiple countries by using a spatial model and concluded that there were inconsistent effects for NO_2 and $PM_{2.5}$ across multiple countries. Similarly, Coker et al. (2020) investigated the spatial distribution of $PM_{2.5}$ and COVID-19 mortality and concluded that $PM_{2.5}$ concentration was positively associated with COVID-19-related mortality. Supporting these results, Zhang et al. (2020) analyzed the influence of meteorological factors, including air pollution, on COVID-19 transmission. The results concluded that while air pollution facilitated the spread of COVID-19, this effect was in part counteracted by the presence of higher ambient temperatures. Overall, it is not clear how such findings may be generalized across smaller areas where it is unlikely to have significant variations in ambient temperature. While the literature has investigated the spatial correlation of air pollutants on COVID-19 transmission and mortality across regions, multiple cities, and even countries, there has not been an analysis conducted over an area within a city where it is much more likely that government regulations, climate, and other factors are similar.

Overall, the literature supports a positive association between air pollutants and the spread and severity of COVID-19. Although it is difficult to ascertain causality and whether confounding factors such as socioeconomic factors may contribute to the association, several feasible biological mechanisms may explain air pollution as a potential factor contributing to COVID-19 spread and severity. Beyond just COVID-19, such a relationship highlights the need for a better understanding of the relationship between air pollution and the spread and severity of respiratory illnesses such as COVID-19. With more extensive air pollution monitoring and initiatives taken to help improve air quality, communities and governments can help improve the health of the environment as well as the health of humans.

3 METHODS AND DATA

To study the relationship between air pollution and COVID-19 severity, measures of COVID-19 and air pollution severity were collected from neighborhoods within the greater Los Angeles area. The 7-day death rate was used as a measure of COVID-19 intensity and was collected from the Los Angeles County Public Health department. Air pollution measures were collected from the Environmental Protection Agency's (EPA) sensors located within the neighborhoods. The air pollution sites selected within this study were selected on the basis of maximizing the diversity in the types of communities studied and on availability. Figure 1 illustrates the location of the neighborhoods and the sensors included in this study.

The information collected from each of the EPA sites varies depending on the site, but the specific pollutants studied from each site are listed below in Table 1. Air pollutant types were selected based on the literature and included nitrogen dioxide, ozone, carbon monoxide, sulfur dioxide, $PM_{2.5,}$ and PM_{10}. Air pollutant values were calculated on the basis of taking the 7-day average of each of the days with a reported 7-day death rate average from the LA County Public Health department from March 1st, 2020, to November 5th, 2021.

Our study aims to address the primary research question: do neighborhoods with a higher overall death rate compared to another neighborhood also have a higher concentration of air pollutants; and a secondary research question: is there any pattern in the spatial distribution of air pollutants in Los Angeles County, CA. To answer the primary research question, an unpaired, one-tailed t-test was used to compare between the neighborhoods. In comparisons that had a significant difference in COVID-19 weekly death rates (a = 0.05), an unpaired, one-tailed t-test was conducted between each of the applicable pollutants. An unpaired comparison was made on the air pollutants since not all sensors were active at all the same times, so a paired comparison would not be appropriate.

To answer the secondary research question, spatial analysis was conducted on parameters such as O_3 levels and NO_2, as these parameters were consistently measured across all sensor locations using empirical Bayesian kriging for interpolation. Kriging is a technique that allows for the spatial prediction of a particular value using a statistical model while also allowing for a smaller prediction uncertainty than other prediction models (Krivoruchko 2012). Empirical Bayesian kriging, in particular, generates a spectrum of probable semivariograms, which provides a distinct advantage over other kriging methods (Krivoruchko 2012). Additionally, Moran's I and interpolation was done with both air pollutant variables to determine if there was a spatial relationship in addition to the general trends found in the previous analysis. Although the ultimate goal is to compare the spatial distribution of air pollutants and the spatial distribution of COVID-19 death rates, we were unable to conduct a spatial analysis of COVID-19 death rate as there is no data with regards to how deaths may be distributed within a particular neighborhood. However, to help visualize the relative relationship, Figure 2 displays the average COVID-19 death rates by neighborhood.

Figure 1. Location of Sensors and Neighborhoods Studied.

Table 1 - Pollutants Measured by Neighborhood (Recorded from March 1st, 2020, to November 5th, 2021).

Neighborhood	NO_2	O_3	CO	SO_2	$PM_{2.5}$	PM_{10}
Azusa	X	X	X		X	X
Chinatown	X	X	X	X		X
Compton	X	X			X	
Glendora	X	X	X			X
N. Hollywood	X	X				
Pico Rivera	X	X	X		X	
Playa del Rey	X	X	X	X		X
Pomona	X	X	X			
Reseda	X	X	X		X	
Santa Clarita	X	X	X			X
West LA	X	X	X			

4 RESULTS AND DISCUSSION

Out of all the neighborhoods studied, there were several significant comparisons where one neighborhood had a higher COVID-19 death rate than another neighborhood. Of these comparisons, Azusa had significantly higher COVID-19 death rates and ozone levels during the study timeframe compared to Chinatown, Playa del Rey, Santa Clarita, and West Los Angeles. In a similar trend, for NO_2 and COVID-19 deaths, this relationship was replicated with Azusa and Playa del Rey, Santa Clarita, and West Los Angeles. This relationship was not replicated with ozone, but for CO, it was replicated only between Azusa and Playa del Rey, as well as Azusa and Santa Clarita. The trend was also replicated between Azusa and Chinatown, Playa del Rey, and Santa Clarita.

Chinatown had a higher COVID-19 death rate compared to Playa del Rey. Furthermore, this relationship was replicated between NO_2, O_3, CO, and PM_{10}. Compton had a higher COVID-19 death rate than Glendora, North Hollywood, Playa del Rey, Santa Clarita, and West Los Angeles. This relationship was replicated across all five towns for NO_2 but for CO, only in Glendora, Playa del Rey, Santa Clarita, and West Los Angeles. Finally, for O_3, Compton had significantly higher levels when compared to Playa del Rey.

Glendora, North Hollywood, and Pico Rivera all had a higher death rate than Playa del Rey, Santa Clarita, and West Los Angeles. However, for these three towns, this relationship was only replicated for O_3 between Glendora and Playa del Rey, and West Los Angeles. Additionally, this relationship was replicated across three towns for both Playa del Rey and West Los Angeles. For North Hollywood and Pico Rivera, this relationship was replicated for NO_2. For Glendora and PM_{10}, this relationship was only replicated with Playa del Rey and Santa Clarita, respectively. Pico Rivera had significantly higher levels of CO and COVID-19 deaths compared to Santa Clarita. Pomona and Reseda had a higher death rate than Santa Clarita and West Los Angeles. This relationship was replicated with Pomona and both towns but only with Reseda and Santa Clarita for NO_2. However, this relationship was replicated across both towns for CO and only with West Los Angeles for O_3.

The spatial analysis indicated several interesting features of the spatial distribution of pollutants in Los Angeles County. For example, the higher concentrations of NO_2 in areas closer to downtown Los Angeles such as Chinatown and Pico Rivera, and in areas such as Pomona, makes sense considering that NO_2 is one of the primary air pollutants emitted from the burning of fossil fuels (NASA Scientific Visualization Studio 2020). Additionally, higher levels of ozone are seen around areas such as Pomona and Santa Clarita. However, it is unsure why this may be the case, especially as these neighborhoods are located further from downtown Los Angeles and further from the Pacific Ocean. It is also unclear how these spatial patterns are related to COVID-19 death rates, which may require future analysis. Furthermore, Global Moran's I was calculated for ozone (z= 2.509, p-value = 0.012) and for NO_2 (z = 0.911, p-value = 0.362). The p-value for the Global Moran's I for ozone indicates that there may be some clustering in ozone values but not necessarily for NO_2. Further research will need to be conducted to determine if this finding is rigorous and if similar findings are found for COVID-19 death rates as well.

The higher COVID-19 death rates in neighborhoods such as Compton, Pico Rivera, and Compton are spatially correlated with higher NO_2 values, as seen in Figures 2 and 3. However, Chinatown has a much lower death rate while still being situated in an area with much higher NO_2 values. This association continues with ozone values with just Pomona, Glendora, and Azusa. However, the spatial analysis raises questions with regards to how Compton is situated in an area with lower ozone values yet still has a higher COVID-19 death rate. This could potentially indicate that other factors aside from air pollution may influence death rates. Similarly, Santa Clarita is in an area with much higher average ozone values yet much lower COVID-19 death rates, which may indicate a need for future research to conduct a more rigorous analysis of the relationship between ozone and COVID-19 death rate. Neighborhoods such as Playa del Rey are of particular interest primarily because of relatively low COVID-19 death rates yet being situated in moderate NO_2 levels and low ozone levels, as this may indicate that future research may be required to reconcile these findings with neighborhoods such as Compton and Santa Clarita which present opposing findings.

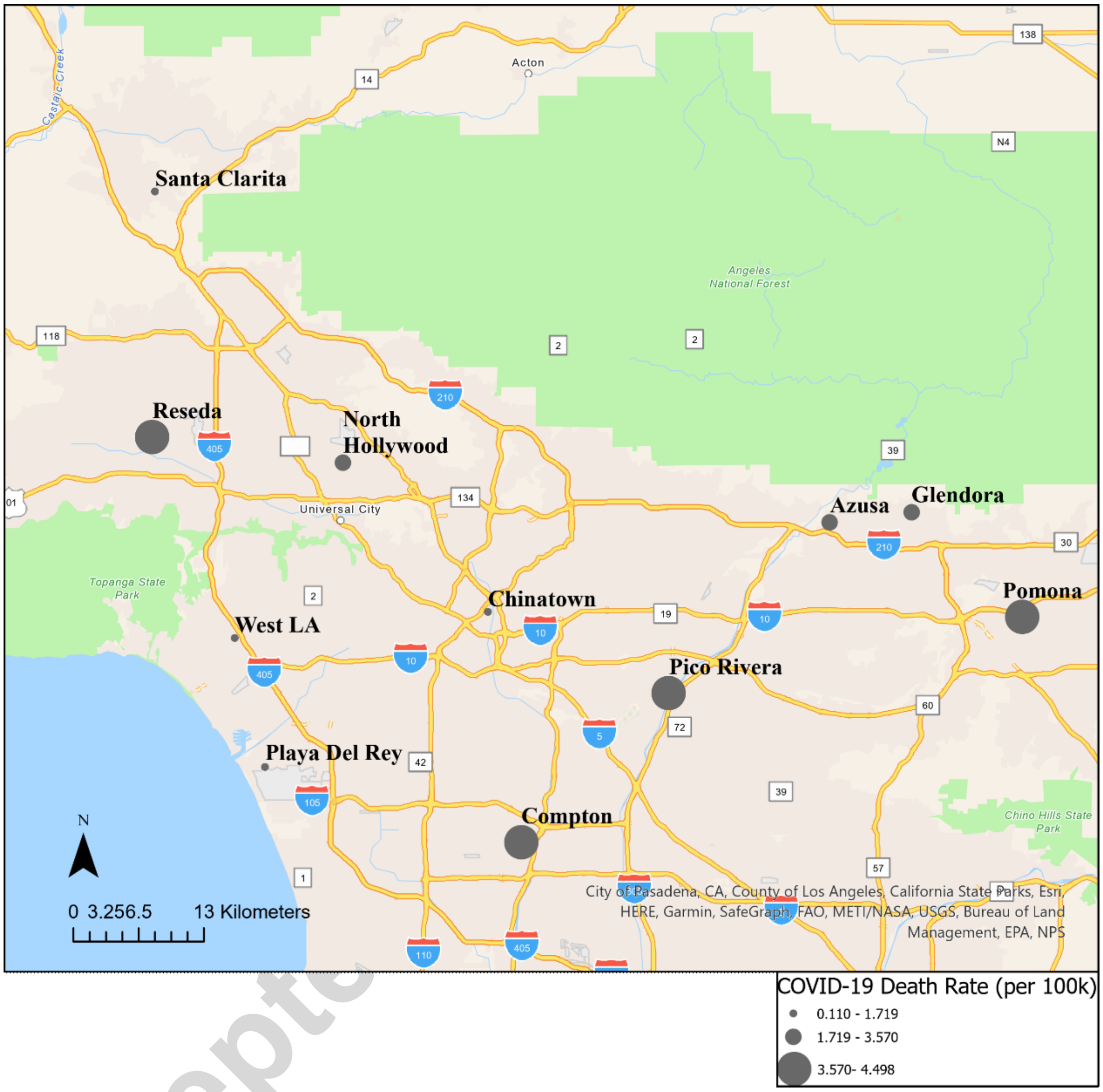

Figure 2. Average COVID-19 7-Day Death Rate (per 100,000) from March 2020 - November 2021.

Figure 3. Average NO_2 Sensor Values (ppb) from March 2020 - November 2021.

Figure 4. Average O_3 Sensor Values (ppm) from March 2020 - November 2021.

The results from our analysis suggest that air pollution is likely to contribute to the difference in COVID-19 death rates across neighborhoods within Los Angeles County. These results are consistent with trends highlighted by other studies conducted on broader scales, such as the study conducted by Brandt et al. (2020), Meo et al. (2020), Zhu et al. (2020), Travaglio et al. (2021), Hoang and Tran (2020) and Hou et al. (2021). The implication of this finding is that the positive association between air pollutant levels and COVID-19 death rates is consistent across smaller neighborhoods. Furthermore, the findings of our research indicate that air pollution could be a significant public health issue for its interaction with respiratory illnesses. Although future work must be done to separate the influence of confounding factors and to determine the extent to which air pollution is associated with death rates, the findings of our research, along with proposed biological mechanisms, indicate that there is a potential causal link between exposure to air pollutants and severity of respiratory illnesses such as COVID-19. However, it must be noted that the Los Angeles County area has managed to keep ozone and nitrogen dioxide levels below the National Ambient Air Quality Standards (NAAQS) set by the EPA of 0.070 ppm and 53 ppb, respectively (US EPA, 2014). Despite meeting the standards, it still remains unclear if the current levels of air pollutants may have a potential interactive effect with COVID-19.

There are several limitations to our ecological approach to understanding the relationship between air pollution and COVID-19 death rates. Chiefly, we cannot extrapolate that air pollution may exacerbate COVID-19 disease severity on an individual level. Additionally, we have not considered long-term exposure to air pollution and have the fundamental assumption that all the death counts were from residents who primarily stayed in that community throughout the 20-month period. Furthermore, the focus on the COVID-19 death rate does not consider other adverse outcomes such as hospitalizations, but this metric can be considered as a proxy since death is the most extreme outcome of COVID-19. Additionally, it is unclear whether air quality is a confounding variable for factors such as socioeconomic status and access to healthcare which could, in turn, explain a greater proportion of the variation in COVID-19 death rates. This is especially important for future research to consider as the poverty status has been linked with respiratory illness hospitalizations and may play a large role in death rates due to a lack of access to healthcare (Brown-Amilian 2020).

Furthermore, a fundamental assumption of this study was that air pollution characteristics tend to remain constant over relatively small areas, and so the air pollution sensor values were extrapolated to the entire neighborhood. Moreover, the air quality data was incomplete in terms of having readings for all the weeks and for measuring all of the pollutants measured across all of the different neighborhoods. A lack of measurement of certain pollutants limited the number of comparisons that could have been made between the neighborhoods.

Moreover, our analysis has not explored the potential relationship between COVID-19 lockdowns, reduced air pollutant levels, and COVID-19 death rates. The decrease in air pollutants as a result of lockdowns can be considered to be a result of lower transportation usage, and the lockdowns themselves may also have resulted in a decrease in the spread of COVID-19 (Sharma and Balyan 2020; Alfano and Ercolano 2020). Future research must be done to determine the influence of the ambient air quality improvement during the lockdown period on the reduction of COVID-19 death rates during the same lockdown period.

Finally, our spatial analysis is limited by the fact that there are a relatively low number of individual air pollution sensors distributed within Los Angeles County that were included in the study. As such, the spatial distribution may not have as high of a resolution compared to an analysis where many sensors located in many different locations are analyzed. Moreover, the lack of multiple air pollution sensors as well as data with regards to the intra-neighborhood distribution of COVID-19 deaths. While more sensors can be deployed in future studies to capture intra-neighborhood air pollution data, finding COVID-19 death data in a smaller area could potentially lead to concerns such as patient privacy as well as requiring more resources to compile.

Implications of our study can influence policy to prioritize increased air quality monitoring and urban design to reduce air pollution levels as it is likely that other respiratory illnesses will emerge in the future alongside existing respiratory illnesses such as influenza. Strategies to improve the air quality in cities globally could be increased investment into public transportation and active transportation to reduce the usage of individual vehicles, which contribute around 70% of environmental pollution (Sofia et al. 2020). Additionally, urban planners can focus on mitigating traffic congestion within cities through redesigning routes and promoting shared mobility. Furthermore, preliminary research has suggested that highly connected and concentrated green spaces may be negatively associated with air pollutants, so urban designers may consider incorporating more connected green spaces within urban areas (Park et al. 2020). Finally, governments can allocate funding to more air pollution sensors to better understand the nature of air pollution within cities and urban spaces and to evaluate the effectiveness of air pollution mitigation strategies.

The equitable distribution of resources and urban planning will become increasingly important due to the rise of more transmissible variants of COVID-19 such as Omicron, as well as the emergence of future respiratory viruses. The findings in our study can be used to guide decision-makers with regard to equitably distributing resources such as vaccine sites, testing sites, and personal protective equipment pickup sites to areas that may have more pollution and more risk from COVID-19. Additionally, the spatial analysis of pollution can guide decision-makers on where to implement strategies to mitigate air pollution through urban green spaces, public transportation, and efforts to reduce traffic congestion as an investment not only for the COVID-19 pandemic but also for potential new illnesses. Our findings with regards to air pollution are considered to be applicable to new strains of COVID-19 and other respiratory viruses through the common method of action of air pollutants on the respiratory system. Overall, our spatial analysis can assist government and public health leaders in developing more equitable localities that are resilient to new strains and potential new respiratory illnesses.

5 CONCLUSIONS

Our findings reaffirm some of the findings found in the literature on a smaller area across neighborhoods. This dual condition of neighborhoods with higher death rates and higher pollutants was often seen with pollutants such as NO_2, PM_{10}, CO, and O_3. Implications for this could be to increase air quality surveillance efforts and the implementation of methods to improve air quality to help mitigate the severity of respiratory illnesses such as COVID-19. Future research should investigate long-term exposure beyond 20 months. Furthermore, it is still unclear whether the relationships found between air pollution and COVID-19 are confounding other factors such as socioeconomic status or inequities such as healthcare access.

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