

**The potential for COVID-19 to exacerbate
Environmental Injustice faced by Oakland Communities.**

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ABSTRACT

Communities exposed to higher air pollutant concentrations are at risk of health conditions such as asthma, lung disease, and cancer, many of which increase the severity of COVID-19 infection. In Oakland, pollution is concentrated along freeway I-880, which virtually all Port of Oakland traffic travels through. The harmful emissions from diesel trucks, industrial sites, and port facilities along I-880 have exposed adjacent communities to disproportionate levels of air pollutants, specifically PM 2.5, black carbon, and nitrous oxide. This increased exposure is a legacy of discriminatory policies like redlining, urban renewal, and highway construction. The health burden associated with air pollution and a legacy of disinvestment and displacement create a landscape of inequality on which the coronavirus pandemic acts upon. To understand how COVID-19 has heightened existing vulnerabilities across Oakland, I compared coronavirus case rates over the course of the pandemic in zip codes containing I-880 to case rates in other zip codes to see how distributions of community health hazards overlap. Communities along the I-880 Corridor, including those in West Oakland, East Oakland, Fruitvale, and Chinatown, were found to have a significantly higher COVID case rate over the course of the pandemic. Additionally, communities along I-880 may have had vaccine access compromised, given that they had significantly lower vaccination rates during the initial vaccine rollout. These findings demonstrate how COVID-19 enacts greater harm on lower income communities of color in Oakland, reinforcing nationwide studies that show how the pandemic has a disproportionate impact on those most physically and socioeconomically vulnerable.

KEYWORDS

Air pollution, pandemic, freeway/highway, vaccination, exposure

INTRODUCTION

The global spread of COVID-19, a respiratory illness, has prompted an enormous response to ensure that people are breathing healthy air, yet less attention has been paid to who gets clean air access to begin with. Air pollution remains a significant problem across the United States, but it is not distributed evenly. People of color are exposed to higher levels of particulate matter pollution, even when factors like income, which might determine where someone lives, are controlled for by researchers (Tessum 2021). The propensity of non-white households to be closer to sources of pollution is tied to a history of structural inequality in the United States, one that continues to expand during the current pandemic. COVID-19 attacks the lungs, meaning inequalities that expose people to more highly contaminated air have an even larger role during this current era of disease transmission. Therefore, the pandemic presents an opportunity to further research how existing health risks associated with air pollution have been aggravated by the spread of coronavirus.

Air pollution poses significant health risks, often harming communities that are already marginalized. Particulate matter (PM) pollution has a well-documented history of adverse health effects, including asthma, respiratory inflammation, elevated cancer risk and mortality, as well as increased severity of both respiratory and cardiopulmonary disease (Xing 2016). In the Bay Area alone, PM concentrations in the air are linked to over 3,000 deaths and over 5,500 childhood asthma cases annually, and this burden is not distributed evenly. Local monitoring revealed that more polluted areas in Alameda county had a disproportionate number of deaths due to air pollution, almost 15% higher than the county-level data (Southerland 2021). Low income communities of color are subject to these elevated health risks, as census-tract level analysis reveals (Bourzac 2021). Due to the variation in health impacts across space, county-level studies can no longer be enough to account for public health inequities that take place across American cities and neighborhoods.

The unequal health risks posed by air pollution have been magnified since the onset of the coronavirus pandemic. The Centers for Disease Control [CDC] found, supported by either meta-analysis or systematic review, that certain cancers, chronic lung diseases, and heart conditions all increase the chance of a severe case of COVID-19; a “severe” case involves

hospitalization, admission into the ICU, intubation, mechanical ventilation, or death (Williamson 2020, Zhou 2020). Asthma may also increase one's chance of a severe coronavirus case, though evidence is mixed (Williamson 2020). These health conditions are more common among people exposed to nitrous oxide or particulate matter pollution, displaying an implicit link between hazard exposure and COVID-19 severity. Researchers in the Harvard Graduate School of Biostatistics sought to make this link explicit through a nation-wide study. Controlling for a variety of population factors, they found that counties with higher levels of air pollution experienced a higher mortality rate from COVID-19 (Wu 2020). Although their research has unveiled this connection, more detailed analysis must be made, given that recent advances in air quality monitoring technology can differentiate air quality differences at the hyperlocal level. Applying this principle to a single locality can prove that COVID-19 is worsening an existing case of environmental injustice, demonstrating the link between the two hazards.

The potential for COVID-19 to disproportionately impact communities with greater exposure to air pollutants follows a body of research dedicated to exposing compounded vulnerabilities as a result of the pandemic. Multiple research teams have analyzed COVID-19 data across U.S. counties using the CDC's social vulnerability index [SVI], which is based on census variables in four categories: socioeconomic status, household composition and disability, minority status and language, and housing and transportation (Hallisey 2014, Freese et al. 2021). They found that coronavirus disproportionately affected communities with a higher social vulnerability rating, exploiting physical and economic susceptibilities (Wilson 2020, Gaynor 2020, Dasgupta 2020). Many of these susceptibilities have emerged as results of structural racism against Black people and other people of color, which disadvantages these communities in areas such as housing choice, employment, and access to health care (Wilson 2020). A study investigating the interaction between extreme heat waves and COVID-19 found that the pandemic has worsened this existing environmental hazard for vulnerable groups across the country, demonstrating that vulnerabilities to environmental stressors are magnified as well (Wilhelmi 2021). Studies that link COVID-19 to existing vulnerabilities have been conducted using county-wide data at the national level; refining the scale to the city of Oakland can identify the specific hazards that burden susceptible communities, and can lead to specific interventions to protect those most at risk.

In my study, I investigate how air pollution and COVID-19 act as compounded hazards against vulnerable communities across Oakland. My research is guided by the following question: *How have pandemic-era health disparities between communities in Oakland manifested as a combination of air pollution, coronavirus exposure, and the state's pandemic response?* Integral to answering this question is a disaggregated analysis of air pollution, COVID-19's impact, and the distribution of health and prevention services across the city of Oakland. To address the main research question, I ask a series of subquestions. First, *which neighborhoods are most affected by air pollution in Oakland?* I focus on specific sites defined by their history and by air pollution levels, defined by NO_x, PM 2.5, and BC levels, as the sites facing environmental injustices. I hypothesize that West Oakland and East Oakland will be important areas to study due to their proximity to freeways and industrial sites, which are usually sites of pollution. Next, I must ask, *how do areas experiencing higher levels of air pollution compare to neighboring areas in terms of COVID exposure?* I seek to define the specific hazard posed by the pandemic, and data about COVID infection rates can support answering the question as to whether or not these hazards compound. Finally, I must ask, *how were health and COVID-19 prevention services distributed across Oakland?* Communities living in neighborhoods exposed to higher levels of air pollution are facing environmental injustice as a consequence of city and state officials deprioritizing their health, which may reflect in the same entities' COVID responses. Through responding to these questions, I aim to unveil the need to consider an area's ongoing health risks as a vital determinant in a just response to the global pandemic we continue to face.

Site Description

West Oakland

Across the bay from San Francisco lies West Oakland, whose network of large polluting infrastructure has resulted from a series of deliberate actions to disenfranchise the diverse community who call the area home. Perhaps the most important local complex is the Port of Oakland, the fourth largest container port in the United States (Harris 2007). Although the amount of freight moving through this area has reached unparalleled levels, West Oakland has

been a nexus for transportation and shipping for centuries. The transcontinental railroad's western terminus was built in Oakland, and immigrant communities quickly settled around the feet of the train tracks (Soliman 2015). The Beaux-Arts Wood Street Train Station anchored the growing manufacturing economy in the 20th century, which accelerated with the naval shipbuilding industry during the second World War (Harris 2007). The WWII shipbuilding industry supported continued immigration until postwar suburbanization led to associated economic and spatial changes that devastated West Oakland.

After World War II, the state did not recognize the importance of Black and immigrant communities that worked in West Oakland, and sought to disrupt the thriving working class neighborhood through a combination of employer relocation and "renewal" policy. The Metropolitan Oakland Area Program (MOAP), which was tasked to expand development and capital extraction in the region, distributed opportunities to Oakland's periphery, catering to the predominately white, middle-class homeowners moving to suburbs in southern Alameda county (Harris 2007). Manufacturing jobs dwindled, new jobs were coordinated elsewhere, and West Oakland was left to deteriorate. The city began to cater to white suburbanites, beginning a trend of sidelining the prosperity and well-being of West Oaklanders. This trend continued through an "urban renewal" agenda that manifested in freeways and mass transit being built during the 1950's and 1960's. In 1957, the Nimitz Freeway (known as I-880, and includes I-80 East) cut through West Oakland to connect East Bay to San Francisco. In this process, the community had blocks of their homes demolished, their access to downtown cut, and their lungs filled with drastically increased vehicle emissions. The Macarthur and Grove-Shafter Freeways (I-580 and CA-24 freeways, respectively) expanded on the Nimitz freeway and its associated spatial and environmental consequences (Harris 2007). Policymakers' decisions to force highways across West Oakland attempted to box in the community, as West Oakland is now surrounded by freeways that create artificial boundaries due to their difficulty to traverse. This spatial injustice is tied to a history of disinvestment, and an active reproduction of its legacy in the high air toxic contamination present in the freeway air.

The loss of jobs and vehicle pollution caused by these changes to West Oakland were furthered in the transformation of the adjacent port. Container shipping reduced the demand for longshoremen, who were put off of work. Rather, this new method required massive infrastructure development and, more importantly, the constant flow of trucks, whose exhaust

fumes pollute West Oakland to this day (Soliman 2015). Research from government and nonprofit agencies have found that the major sources of pollution in West Oakland are the major highways, stationary sources such as industrial facilities, truck trips generated by the Port and other West Oakland facilities, exclusively port-related sources, as well as other construction and local sources (BAAQMD 2019). These major polluters are inextricably tied to systemic violence against what was once a thriving neighborhood, and have had major effects on the population living in West Oakland.

Historic trends have persisted as inequalities today, apparent in the demographics of West Oakland. In 2007, West Oakland was home to 30,000 residents, two-thirds of which identified as African American. During the same year, one-third of residents lived below the poverty line, and over 60% of residents lived below two-times the poverty line (Harris 2007). Ten years later, in 2017, the total population dropped to 25,000, the African American population dropped to 42%, and the number of residents living below two-times the poverty line decreased to a still significant 52% (BAAQMD 2019). These demographic changes reveal the displacement of low income people and Black residents in the district, emphasizing the importance of protecting vulnerable populations that are actively being pushed out. Since its early beginnings, West Oakland served as a haven for Black migrants experiencing discrimination in the South as well as in other Bay Area communities; the bustling district provided employment and affordable housing opportunities for the Black working class (Harris 2007). The history of West Oakland follows along a narrative of Black working class pride, despite institutional trauma inflicted upon people in the area through policy and land use decisions.

Residents of West Oakland are working, living, and organizing against forces that either seek to remove them from their homes for land speculation, or forces that injure their health and threaten their livelihoods to preserve the flow of capital. West Oakland residents have a life expectancy that is, on average, about 7 years below that of the Alameda County average life expectancy, and Black/African-American West Oakland residents have a life expectancy 5 years lower than the average resident in their area. Contributing to these disparities are elevated rates of cancer, stroke, heart disease, and severe asthma emergency visits and hospitalizations (BAAQMD 2019). Although life expectancy estimates result from an innumerable combination of factors, life-threatening conditions that result from exposure to high levels of air pollution are present to a greater degree in this community, indicating the threat environmental degradation

imposes. A 2016 study by the Alameda County Department of Public Health reported that asthma hospitalization rates were the most severe in this community, at 1.6 times higher in West Oakland than Alameda County as a whole, meaning a total of over 174 adults and 623 children per 100,000 are hospitalized for asthma symptoms each year (CAPE 2018). Inequality, especially in the air that West Oaklanders breathe, has been noticed long before institutional recognition, and environmental justice efforts are currently being led from community-based organizations. West Oakland Environmental Indicators Project [WOEIP], has published numerous reports highlighting the consequences of these major pollutant sources. Only recently have their efforts been recognized by policymakers, yet the call for clean air and just treatment in West Oakland should always be understood as coming from the community before any governing body claims these goals as part of their agenda. It is in this landscape of unequal health outcomes, disregard of community well-being by monied institutions, and cumulative environmental burdens that the COVID-19 pandemic has reached West Oakland, threatening those already most vulnerable.

East Oakland

Although East Oakland is not bounded by freeways to the extent West Oakland now is, a similar history of vibrant culture and perseverance links the community of East Oakland. Residents have different takes on where East Oakland actually lies in the city, but most agree that Deep East Oakland refers to the flatlands bordering San Leandro to the south. In this part of Oakland, community members, especially the prominent Black community in the area, have been cut off from the city's resources, and have had to endure the systemic injustices from redlining, the War on Drugs, and police brutality (Darden 2018). Consistent in East Oakland's history is the state's wielding of structural and physical violence to dismantle people power in one of the most politically active districts in the Bay Area, which is done through harm to human health and bodies.

Structural violence has extended past direct state action, and manifests in the financial hardships that households in East Oakland may experience. Commercial interests have taken advantage of this history of disinvestment and harm, burdening East Oaklanders with rising prices in a wave of gentrification (Darden 2018). As a result of structural discrimination, East Oakland has endured hard times in recent years. In the aftermath of the 2008 Recession, census

tracts in East Oakland had some of the highest rates of mortgage delinquency, as well as densification of middle-to-lower income households, suggesting financial strife as families struggled to make ends meet and may have had to move in with relatives to support themselves (Hwang 2021). The economic conditions across East Oakland are directly related to numerous other factors, especially displacement. Foreclosure rates remained at the highest in East Oakland, compared to surrounding neighborhoods, for years after the Recession (Hwang 2021). Based on these indicators, financial instability is demonstrated to be highest in the East Oakland neighborhood during recession periods. Although finances are not directly tied to health outcomes, the concentrated instability in this part of the city suggests that a history of disinvestment continues along today's crises, and systemic inequalities have yet to be rectified across Oakland.

East Oakland has a constellation of organizations and coalitions dedicated to fights for justice and equality in the region. The Black Cultural Zone [BCZ] in East Oakland is a present reminder of how powerful community solidarity organizing can be. From their website, the BCZ describes their history and role in the city: "Since 2014, the East Oakland Black Cultural Zone Collaborative Partners has worked with a coalition of residents, government agencies, churches, and grassroots organizing and community groups to help keep Black folks in East Oakland. Through our strategy of building power, securing land, and directing more dollars to community driven projects we can secure a foothold in East Oakland that finally allows our neighborhoods to thrive" (BCZ 2021). Acknowledging the work of generations that continue to strive towards economic sustainability, liberation, and culture in Black East Oakland underscores links to reclaiming the health of those living in the area. Communities for a Better Environment is one such group that explicitly advocates for East Oakland's environmental justice in their local chapter. They have organized against crematorium construction, neglect of hazardous material building in abandoned lots, and for addressing the effects of climate change in East Oakland (Communities for a Better Environment 2021). The network of Black power, grassroots organizing, and cultural connection is vast and interconnected, and has worked to address and undo structural damages that institutional interests fail to combat, and in some cases, have directly implemented.

Endeavors led by community based organizations have shown how the history of institutional neglect for the livelihoods of East Oaklanders is consequently mirrored in the

problematic levels of air pollution. An air monitoring team deployed by the Communities for a Better Environment set up air quality monitoring across East Oakland in a variety of locations. They found that pollutant levels exceeded the Alameda County average concentrations (over 4 times for 3 of the four flatlands sites), the average concentrations in the adjacent Oakland Hills (by 2.5 times), and far exceeded both federal and state standard concentrations. Although their study did not pinpoint the exact sources of pollution, the sites situated next to diesel traffic corridors and industrial sites had the highest levels of pollution (Communities for a Better Environment 2010). Pollutant sources consequently impact the health of East Oakland households, displaying the lack of attention paid to those living in East Oakland, and the active deprioritization of their health compared to that of more affluent communities in the hills.

Measuring Air Pollution

Quantifying the amount of pollution in a portion of the airshed requires detection of specific contaminants set by regulatory agencies. The Environmental Protection Agency [EPA] continually must re-evaluate its standards for air pollutant concentration as more research links hazardous substances to health impacts (US EPA 2014). While the Clean Air Act defines 187 air toxins, certain substances are of this study's concern due to their overstated presence in air pollution literature. Nitrogen oxides, such as NO and NO₂, are air toxins that result from burning fuel. Not only do they affect respiratory health on their own, they also aid in reactions that form other toxins, such as particulate matter (US EPA 2021a). Particulate matter describes a broad class of solid and liquid substances that can enter the respiratory system through suspension in air. PM 10 corresponds to particles less than 10 micrometers in diameter, and PM 2.5 are "fine inhalable" particles with a diameter of less than 2.5 micrometers. These toxins pose a serious threat due to their ability to enter the lungs, and for the fine particles, the bloodstream (US EPA 2021b). Black carbon, also referred to as "BC" in some studies, is considered a type of fine particulate pollutant. Resulting from the burning of fossil fuels, such as through diesel and gas engines, sooty BC particles constitute a large share of PM 2.5 pollution, especially in areas linked to these activities (US EPA 2011). PM 2.5 concentrations, and specifically black carbon concentrations when available, will be paramount to understanding how freeways and other industrial uses in Oakland have polluted their surroundings.

Despite a history of disinvestment and violence towards marginalized groups in Oakland, people in these communities have fought tirelessly to be heard; recent calls for environmental justice and addressing of systemic racism from across Oakland have increased access to air pollution data and policy for some communities. California Assembly Bill No. 617 [AB 617], filed on July 27th 2017, is the state's biggest policy step towards expanding air pollution data under an environmental justice framework. The legislation designates specific communities with sensitive populations that have been impacted by cumulative burdens of air pollution, and mandates that air pollution data be recorded and made available to these communities for inspiring solutions (Garcia 2017). West Oakland was selected for the AB 617 Community Air Protection program in 2018, and groups like WOEIP are continuing to study the polluting operations of the port, mobile sources, and industry in the area (CARB 2018). The California Air Resources Board supports their selection by citing the numerous emissions sources, disadvantaged areas of the community, and number of sensitive receptors like schools and daycare facilities (CARB 2018). Given the legislature involvement in West Oakland, this community has increased data availability and emissions mitigation planning.

Policy support of environmental justice in West Oakland has culminated in important deliverables about the topic. On October 2nd, 2019, *Owning Our Air: The West Oakland Community Action Plan* was officially adopted as a partnership between the Bay Area Air Quality Management District and the West Oakland Environmental Indicators Project to spearhead the AB 617 research initiative (BAAQMD 2019). In the most recent 2021 cycle, East Oakland was also selected to be included in the Community Air Protection program. This neighborhood's location along a major commercial corridor was the main reason for inclusion into the program. AB 617 legislation highlights the role that I-880 plays in harming Oakland residents' health, and calls for further research and community-based action to address the environmental injustices in these areas.

Monitoring air quality can be achieved through a variety of methods, though serious drawbacks compromise their efficacy. Traditionally, detection of air toxics has been done through stationary monitors, which capture concentrations with regulatory-grade efficiency. Although the detection mechanisms are accurate, these monitors cannot account for changes on the hyperlocal scale, say within a district (Southerland 2021). Glossing over local variations may

misattribute the role of certain facilities as polluters, and obscures which sources may be responsible for pollution in different areas.

Overcoming limits of stationary monitoring requires a proliferation of sensing across space, which has led to innovations in air quality detection. Recently, consumer-driven monitoring has advanced the practice. Air quality studies are taking advantage of mobile monitoring practices, which attach air quality monitors to moving vehicles to capture changes across space. What results is a highly specific reading that shows how air quality varies over distances as short as city blocks (Southerland 2021). Mobile monitoring expands the capabilities for local air quality studies, because disparities that normally would not be picked up by the existing network of stationary monitors are now visibilized. This practice is thus favorable for city-wide studies, which require high-resolution air quality data across the local scale.

Data collected by Southerland et al. provided a comprehensive set of highly localized air quality measurements through mobile monitoring practices across Oakland census tracts. The authors of this study used a health impact model to estimate air toxic concentration in terms of asthma incidence, asthma ER visits, CVD [cardiovascular disease] incidence, CVD mortality, and all-cause mortality across age groups. I chose to only focus on all-cause mortality to provide a comprehensive baseline for comparison across geographic areas (Southerland 2021). Although they measured data at different scales, their intracity collection only focused around West Oakland, East Oakland, and Downtown Oakland. These areas have a history of higher air contamination because of port and industrial activities, as well as I-880 that runs through these parts of the city. The research team's focus on vulnerabilities in these areas shaped my decision to include the former two groups in my analysis.

The Environmental Defense Fund, a leading nonprofit in environmental research, also found that a significant disparity exists in the air pollution levels that communities adjacent to Oakland's freeways face. A team of researchers deployed cars equipped with mobile air quality monitoring equipment, and found that both black carbon and nitrogen oxide exposure were higher at nearly every point along I-880 compared to I-580 (Figure 1). On average, BC exposure was 80% higher along I-880, NO₂ exposure was 60% higher, and NO exposure along I-880 was double that along I-580 (Apte et al. 2017). These disproportionate levels of air pollutants indicate that I-880 presents a major threat to the air quality and lung health of Oakland residents.

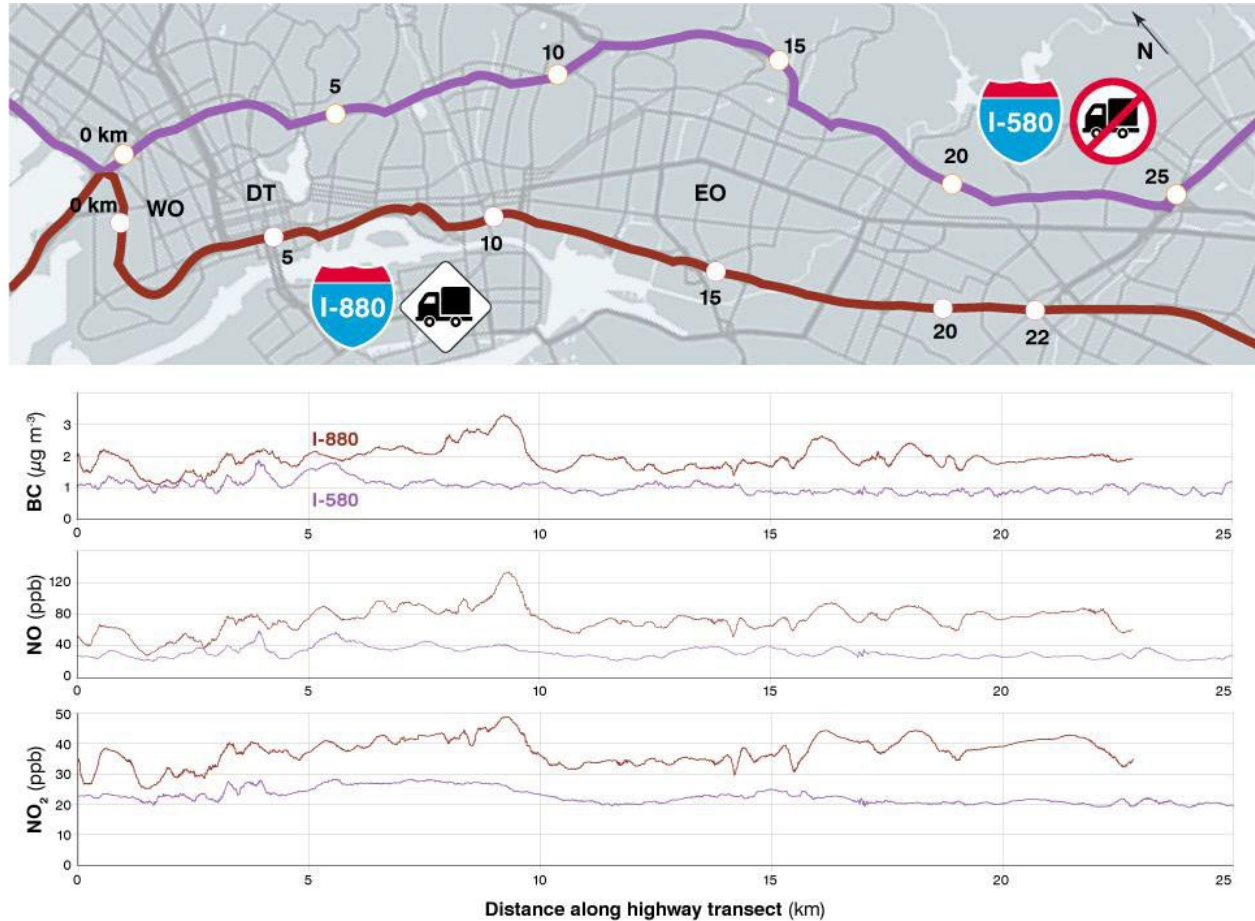


Figure 1. Air pollutant concentrations across Oakland’s two major freeways. Research teams at the Environmental Defense Fund used mobile monitoring along I-880 and I-580, the latter which does not allow heavy trucks to pass through. Because of this distinction, I-880 exposes adjacent communities to consistently higher levels of air pollution compared to I-580 (EDF 2021).

Introducing the Impact of COVID-19

The COVID-19 brought about what was undoubtedly the most severe recession in the 21st century, which has furthered socioeconomic inequality. Lockdown and disease radically shifted markets, causing global supply chain failures, massive increases in unemployment, and contraction of global trade volume. When compared to the Great Recession in 2008, the financial devastation is both more severe and wider spread, across Western countries as well as manufacturing centers in the Global South (Ibn-Mohammed 2021). The global economic downturn consequently created economic distress in the city of Oakland. Trends from the 2008

Recession show that East Oakland had been hit with the highest rates of financial instability, and parts of West Oakland also stood out as areas expressing financial strife. Predictive models and data from the COVID-19 pandemic show that these trends continued during the 2020 Recession; for example, unemployment remained highest in these areas, even as more affluent parts of the city began to rebound in the months following the initial landing of coronavirus in March (Hwang 2021). Evidently, impacts of financial recession are not felt equally, and it is often the most vulnerable that are further harmed in times of crisis.

The wealth gap widening effect of the pandemic and consequent quarantine has presented major obstacles for equity and justice-based initiatives. In the city's Economic Recovery Plan, made in response to the pandemic-era recession, they highlight how the pandemic thwarted Oakland's goal for more equitable wealth distribution in specifically Black and Latino households, and that Black and Latina women were most likely to face unemployment as quarantine came into effect (Economic & Workforce Development Department 2021). These groups are likely most vulnerable due to the nature of their work and their families; COVID-19 has increased obstacles for working mothers that could previously look outside the home to ease the demands of childcare. Additionally, nation-wide studies have found that Black, Latino/Latina, Native American, and low-income workers were more likely to be employed in "essential" positions that require in-person attendance (Wilson 2020). This propensity for in-person work increases exposure to COVID-19 through workplace interaction among low-income workers of color, demonstrating further vulnerabilities by race and occupation. When responding to the pandemic's economic effects, Oakland officials tried to direct aid to these groups, and gave about 86% of CARES Act grant funding to people of color (Economic & Workforce Development Department 2021). Equity-oriented recovery represents a targeted strategy that may mitigate the inequality caused by COVID-19, at least in an economic policy sense, though it is important to note that the city's attention to marginalized groups has come about after decades of organized protest and resistance. Although the bridge in economic inequality caused by the pandemic has been at least addressed by policy, COVID-19 is a transmissible virus, meaning it has caused disparities in health outcomes and infection as well.

The bulk of health and prevention services geared towards combating the coronavirus pandemic are administered by the federal and state governments, leaving the potential for unjust distribution given that these actors do not have local knowledge of Oakland. The Governor's

Office in California responded to the pandemic with a variety of policy: the state leased hospital facilities to increase availability for COVID patients, they released reserves of facemasks and other medical gear, coordinated the closure of restaurants, schools, and digitized mass gatherings, increased the availability and access to free COVID tests, and directed millions of dollars in funding for other healthcare infrastructure (Office of the Governor Gavin Newsom 2021). The multi-pronged policy framework pursued at the state level worked to mitigate the hazard posed by the virus, though its limits were reached as cases surged.

Regardless of how valuable other policy approaches have been, the most important component of the United States COVID-19 response has been vaccination. According to the CDC, the COVID-19 vaccine can prevent severe cases of coronavirus, almost eliminating the risks of hospitalization or death, and can mitigate the spread of disease as well (CDC 2021a). Vaccination became the cornerstone of pandemic mitigation after the United States saw surging cases throughout 2020; government officials were unable to unilaterally protect public health through limiting interactions and providing adequate services for a comprehensive shelter-in-place order. Therefore, federal and state administrations shifted tactics towards vaccinating their populations to prevent the spread of disease while maintaining their refusal for implementing a total and well-coordinated quarantine. Initially, the vaccines were offered to the elderly and those designated as “frontline workers,” who were valorized for their work in-person during the pandemic while simultaneously being undersupplied with critical sanitary gear (AJMC Staff 2021, Ankel 2020). Vaccination expanded greatly throughout 2021, as the United States purchased 600 million doses, enough for 300 million adults, in February of the year (AJMC 2021). In theory, this should account for nearly the entire adult population in the United States, but this potential has yet to be realized.

Despite the massive investment towards vaccination, the effort was stalled due to administrative mismanagement leading to wasted doses, contentious politicization of the pandemic, skepticism surrounding the vaccines’ development, and disparities in vaccine access. During the early months of 2021, Black Americans had about one-third to one-half the rates of vaccination of white Americans, despite the fact that COVID mortality was 3 times higher among Black, Latino, and Native American populations. The CDC eventually confirmed that counties with higher proportions of “vulnerable” populations were underserved vaccination resources (AJMC 2021). Already in the early months of vaccination, disparities emerged that

built upon existing socioeconomic inequalities in the context of this deadly virus. On April 19th, 2021, all adults residing in the United States became eligible for the vaccine. This change sought to elevate the vaccination approach to the general population after those identified to be more vulnerable to disease either due to physical or occupational factors were protected. Disparities in vaccination persisted within California, as Black and Latino residents had lower vaccination rates due to a variety of social, economic, and geographic characteristics (Greene 2021). The imbalance of vaccinated people thus continues, calling into question how committed authorities are to protecting those most vulnerable to disease exposure.

Notably, the Bay Area had been ahead of other areas in California in terms of vaccination. The availability of vaccines has drastically increased since the initial rollout, since chain pharmacies, like CVS and Walgreens, now have doses to administer (CDC 2021c). Nevertheless, these pharmacies are not distributed evenly across cities or counties, which could problematize their central role in vaccine administration. As the COVID-19 virus continues to spread, it has the ability to mutate, which may call into question the efficacy of existing vaccines (CDC 2021a). Studying the initial vaccine rollout, and specifically analyzing its use of equitable and effective distribution, could prove useful if another major vaccination campaign needs to be reinstated.

METHODS

Characterizing Air Pollution Distribution

Community groups, research teams, and government-affiliated organizations have published a wealth of knowledge on air pollution within Oakland, which I used to determine the boundaries of my study groups. Areas surrounding I-880 were consistently found to contain higher concentrations of NO₂, PM 2.5, and BC than other parts of the city. This increased exposure is also significantly different from areas surrounding other freeways. Therefore, I decided to group together zip codes that span I-880 in a group called “I-880 Corridor” to test for difference. The I-880 Corridor encompasses West Oakland, Chinatown, Clinton, San Antonio, Fruitvale, and East Oakland (zip codes 94607, 94606, 94601, 94603/94621, respectively). Due to chronic and prolonged exposure to higher air toxic concentrations from the freeway and industry,

which tend to be located in the flatlands of Oakland, I used the I-880 Corridor group as a variable to account for environmental injustices when sorting through other data.

To understand how communities most affected by air pollution in Oakland might be exposed to COVID-19, I compared employment characteristics between Zip Code Tabulation Areas [ZCTA] in the 2020 American Community Survey. I used responses about employment to estimate the proportion of workers required to report to work in-person. Respondents to the 2020 ACS self-reported as working from home; I retrieved these total estimates and percentages for each zip code for analysis. I grouped these together by geography using the I-880 Corridor distinction described above, then graphed these distributions as box plots using the ‘ggplot’ package in R. Because the ACS relies on point-in-time analysis, I also used statistics on employment by industry and occupation to infer jobs that would most readily require employees to work in-person. I defined industries likely to be in person by grouping together the following ACS-designated categories: Agriculture, forestry, fishing and hunting, and mining; Construction; Manufacturing; Wholesale trade; Retail trade; Transportation and warehousing, and utilities; Educational services, and health care and social assistance; Arts, entertainment, and recreation, and accommodation and food services (ACS 2020). I added the total estimates and percentages for each zip code, then followed the same grouping by geography and box plot analysis. Next, I repeated the process with occupations I thought likely to have an in-person component: Service occupations; Natural resources, construction, and maintenance occupations; Production, transportation, and material moving occupations (ACS 2020). Because industry and occupation are reported separately, there is no error due to occupational overlap in these categories.

I found it important to understand who is most affected by air pollution from I-880, so I organized demographics data between Zip Code Tabulation Areas [ZCTA] in grouped box-plot analyses. I used median household income measures from the 2020 ACS 5-Year Estimates, which I subsequently compared using box plots in R. Given the history of freeways being used to fracture Black neighborhoods, and discriminatory housing policy impacting the ability for families of color to purchase homes in the Oakland hills, I also used statistics on race to inform my understanding of the I-880 Corridor. The 2020 ACS uses the following distinctions: Hispanic (includes anyone who identifies as Hispanic, regardless of other racial identities they may have reported), Black (includes people who identify as Black only), White (includes people who identify as White only), and Asian (includes people who identify as Asian only) (2020 ACS).

There are limits to these distinctions; namely because they do not acknowledge Black Hispanic people as Black, and that they use an aggregated measure of “Asian,” which invisibilizes the unique circumstances of different Asian peoples in Oakland. To avoid these errors, I looked at the percentage of white residents in each zip code for my analysis, so that the contributions of systemic racism and displacement to air pollution exposure can be seen in comparisons between white residents and residents of color. This comparison also allows me to see if people of color tend to work jobs that require in-person interaction, and thus are more likely to be exposed to COVID in the workplace, based on whether or not these analyses correlate with one another.

COVID-19 Exposure and Severity

To characterize the impacts of coronavirus across Oakland, I used data from the Alameda County Department of Public Health [DPH]. These data provided the cumulative number of cases across Oakland zip codes since March 2020. I found it important to date cases back to the beginning of the pandemic because case rates have changed drastically in response to vaccines and stay-at-home orders. My first step in understanding the geography of coronavirus in Oakland was to index these case rates by zip codes. Each zip code approximately corresponds to a neighborhood or series of neighborhoods (Figure 2). In areas like Fruitvale, West Oakland, and East Oakland, the demarcations most closely resemble the neighborhood boundaries, which makes zip codes a useful unit of analysis for comparative study.

Zip Code	Area
94601	Fruitvale
94602	Dimond/Lower Hills
94603	East Oakland
94605	Eastmont/South Hills
94606	Clinton/San Antonio
94607	West Oakland/Chinatown
94608	Emeryville/Clawson

94609	Temescal/North Oakland
94610	Grand Lake/Lower Hills
94611	Piedmont/Upper Rockridge/Hills
94612	Downtown
94618	Rockridge/Claremont
94619	Lower Hills/South Hills
94621	East Oakland
94705	North Hills/Elmwood

Figure 2. Associations between Oakland zip codes and neighborhoods. Neighborhood boundaries vary by understanding, and are not exactly defined by zip code boundaries, but naming is for purposes of this study.

In my analysis, zip code and date were explanatory variables and cumulative cases per capita was the response variable. Case rates, which correspond to a unique person’s positive test, were measured every 28 days since the start of the pandemic in March. I used cases per capita to facilitate easier comparison across groups. Although the exact populations might have changed over the course of the pandemic, I assumed that no major changes occurred in each zip code, so that I could use the same zip code population count provided by Alameda County DPH as the denominator in per capita calculations.

I tested the relationship between zip code and cumulative cases per capita over the course of the pandemic by creating linear models and testing them for difference. In R, I graphed the data and found that linear models would be suitable to fit the increasing case numbers. To test for difference, I ran ANOVA, followed by post-hoc tests of pairwise comparison to understand which zip codes have a significant difference from one another.

I followed my zip codes analysis with a grouped analysis to see if cases vary along the I-880 transit corridor. Given that I-880 emits a significant air toxic burden to neighboring communities, this grouped analysis directly addresses my second subquestion: *“how do areas experiencing higher levels of air pollution compare to neighboring areas in terms of COVID exposure?”* I compared these areas to the other parts of the city, which do not experience as high a concentration of air toxics as these areas.

As with the first set of tests, I used ANOVA to test for difference between these groups. Because the test only has two groups, I-880 Transit Corridor and Other, no pairwise comparisons are needed in follow-up analysis.

Vaccine Access

I measured access to COVID-19 vaccination through distribution of vaccination sites and analysis of vaccination rates. To find available vaccine sites (as of November 2021), I used the federal *vaccines.gov* website and searched Oakland zip codes under the “Find COVID-19 Vaccines” search tool. I recorded each individual vaccine site in Microsoft Excel, including the full address and zip code. I then counted the number of sites belonging to each zip code and reflected those values on a map of the city created using Adobe Illustrator. The resulting graphic uses a blue-orange color scale to show which areas of the city have access to vaccination sites within their zip code.

I measured vaccination rates, defined as persons who have received 2 doses of Moderna/Pfizer or equivalent per capita, using the same dataset provided by the Alameda County DPH. Like with COVID cases, I used R to graph vaccination rates across Oakland’s zip codes. I followed this representation with a series of t-tests to determine which areas had significant variation in the rate of vaccination over time.

Next, I performed grouped analyses to understand where vaccination disparities may have emerged. I continued using the same “I-880 Corridor” group to account for areas burdened with increased air toxic concentration. After testing for significance, I then compared vaccination rates between zip codes with different numbers of vaccine sites.

COVID Case and Vaccination Survey

The severity of COVID-19 and effectiveness of vaccination efforts are best understood through the lived experience of people that are living, working, or spending a significant portion of time in Oakland. I measured their experience during the pandemic through a series of questions asking about their experience with COVID-19, their experience getting vaccinated (or choosing not to get vaccinated), and their experience with the booster shot. Respondents also

could provide data about their location (zip code, intersection) to give me the option for spatial analysis, and demographic data to understand how the pandemic affects people across different income levels, age groups, and racial identities.

The first set of questions asked respondents who contracted COVID-19 about their experience to address the subquestion *“how do areas experiencing higher levels of air pollution compare to neighboring areas in terms of COVID exposure?”* I used the ‘display logic’ feature on the qualtrics platform to identify which respondents to question about their experience with COVID-19: only those who had COVID or believed they had COVID, but could not ensure diagnosis with a test, were asked further questions about social and physical comorbidities that may increase the severity of their disease contraction. I am asking these questions to see how the coronavirus interacts with existing geographies of inequality, addressing concerns over how COVID infection may stress already financially vulnerable households, and how the disease may have caused greater harm to people with existing medical conditions related to air pollution exposure. These comorbidities are defined based on CDC materials and approved studies, and include asthma, heart disease, lung disease, stroke, and cancer (Williamson 2020, Zhou 2020).

Next, I asked respondents about their experiences with vaccine and booster shot administration to answer the subquestion *“how were COVID-19 health and prevention services distributed across Oakland?”* Information about vaccination time and location yields insight about how different sites, ranging from the Oakland Coliseum mega-site, to pharmacy distribution, to vaccination drives at community events, provided opportunities for vaccination. Combining these logistical data with respondents’ spatial data may also show how accessible vaccines were to different communities, in terms of time and place.

I included similar questions for those respondents who have received their booster shot to see how vaccine access has changed over time and to see which distribution methods are most effective going forward. Those who got vaccinated also have a chance to reflect on their experience; I included feedback channels for those who had a poor experience with vaccination to see whether complications were imposed by spatial, temporal, or biological obstacles. I also wanted the survey to address concerns of unvaccinated Oaklanders, so those who have yet to be vaccinated were asked about why they have not yet received the COVID vaccine. Response options included lack of time, lack of information, lack of transportation access, and personal

attitudes towards the vaccine, so that I can better understand whether people cannot get vaccines or they simply are refusing to receive it.

I deployed my survey over a variety of platforms to reach the widest variety of respondents. I shared the survey digitally on the Facebook groups “What’s Happening Oakland” and “Oakland Now!” though moderators removed my posts within the same day. In addition to digital distribution, I posted physical copies across Oakland. I made 60 copies and posted them in public locations: outside of BART stations, in commercial corridors, etc. (Figure 3). To incentivize response, I gave people the chance to enter a raffle for a \$175 VISA gift card upon completing the survey. Because I could not compensate everyone who filled out the survey, the raffle provides an opportunity to reward participation at a much lower cost. To retain engagement, I also used built-in features within the Qualtrics platform. The aforementioned ‘display logic’ feature shortens the survey time for those to whom the question does not apply, which ideally retains more users until survey completion.

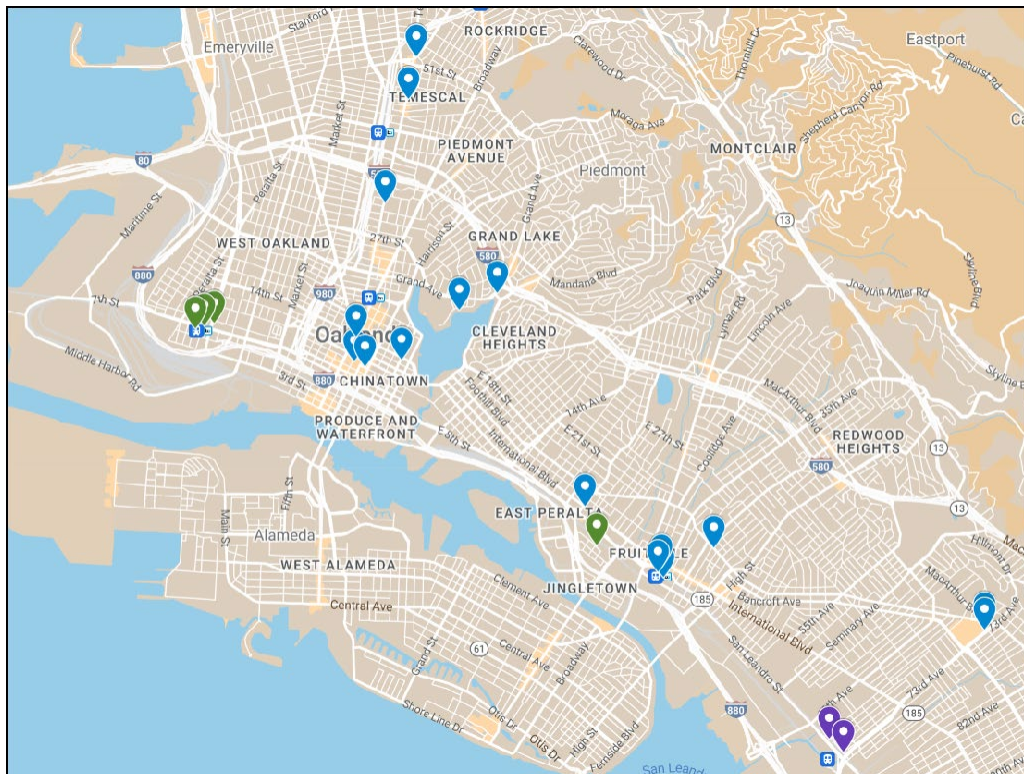
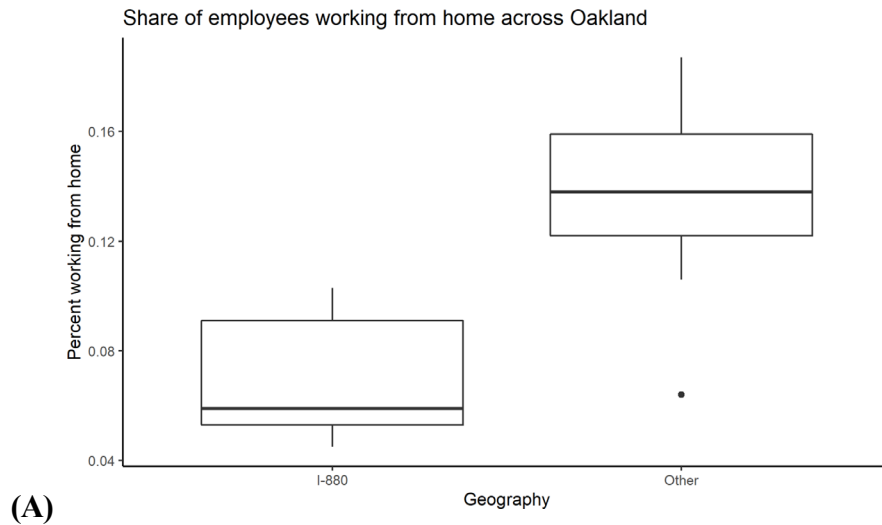


Figure 3. Distribution of paper flyers across Oakland. Flyers were posted at the marked locations across Oakland. Flyers posted on April 15, 2022 are marked in blue; flyers posted on April 26, 2022 are marked in green; flyers posted on May 12, 2022 are marked in purple.

RESULTS

Characterizing Air Pollution Distribution

Workers living in neighborhoods adjacent to I-880 are more likely to be employed in sectors that demand in-person work compared to other areas of Oakland. Average rates of working adults self-reporting as working from home were significantly lower in zip code areas containing I-880, according to 2020 ACS 5-year estimates; communities along the commercial corridor had an average work from home rate of about 6% compared to 14% elsewhere (Figure 4A). Employment by industry and occupation reinforced these results, as an average of 72% of employees living adjacent to I-880 worked within industries likely to demand in-person commitment, and 53% of employees in this area worked in occupations likely to demand in-person commitment (Figure 4B, C). Therefore, residents in zip codes spanning I-880 are more likely to be exposed to coronavirus through their workplace, since a higher percentage of them require employees to attend work in-person.



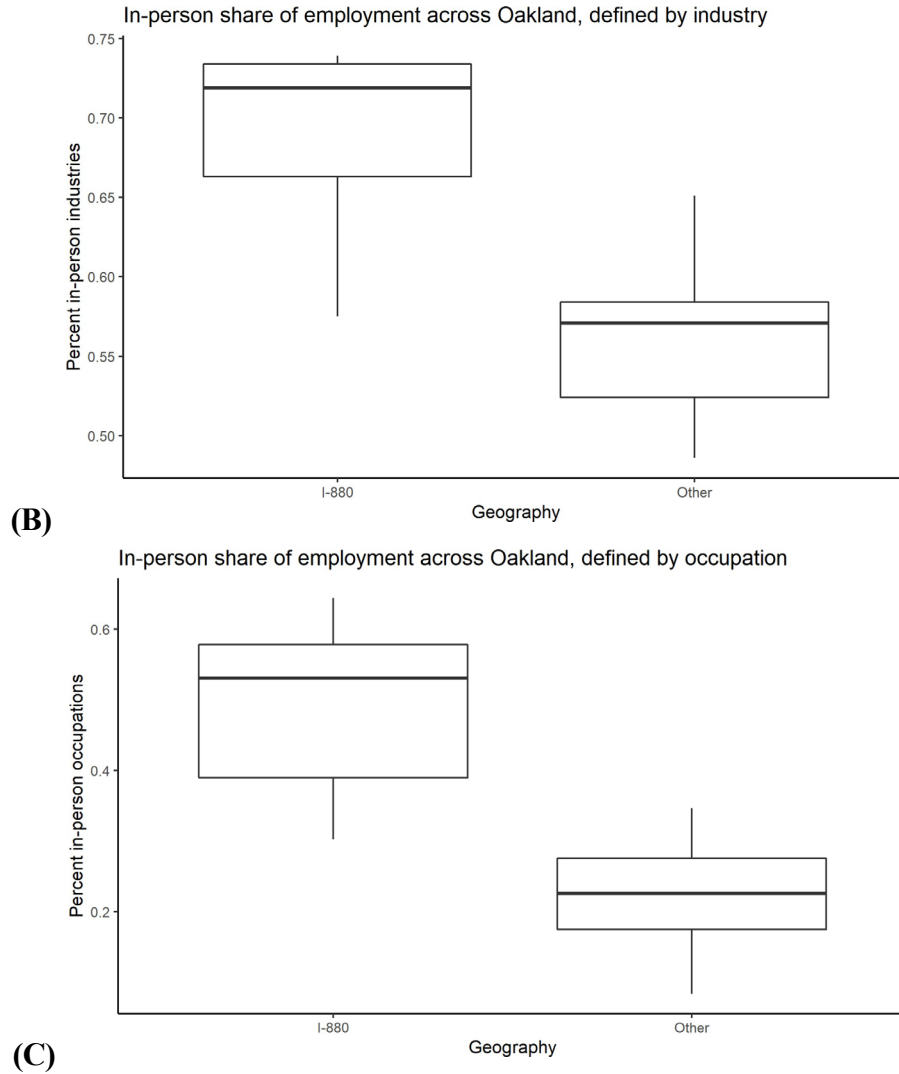


Figure 4. Comparison of in-person workplace commitments between communities most impacted by air pollution (I-880), and others. Significantly less respondents reported working from home (A), and more were employed in industries (B) and occupations (C) likely to require in-person work. (2020 ACS)

Zip codes within the I-880 Corridor group had lower median household income, and tended to be less white. Although median household incomes vary significantly among zip codes, with a minimum of \$40,813 per year (94621) and a maximum of \$169,856 per year (94618), incomes were more concentrated along the I-880 corridor (Figure 5A). Therefore, the average median household income in these zip codes was significantly lower than in other parts of the city. Additionally, zip codes adjacent to I-880 tend to be more diverse than other parts of the city; while both groups are majority non-white on average, communities exposed to the freeway’s pollution are 90% non-white on average compared to 43% elsewhere (Figure 5B).

Overall, zip codes containing I-880 tend to be lived in by lower income communities of color, who are therefore experiencing a disproportionate burden of the freeway’s pollution impacts. These communities also have a higher proportion of employment demanding in-person commitment, which increases their likelihood of being exposed to COVID-19.

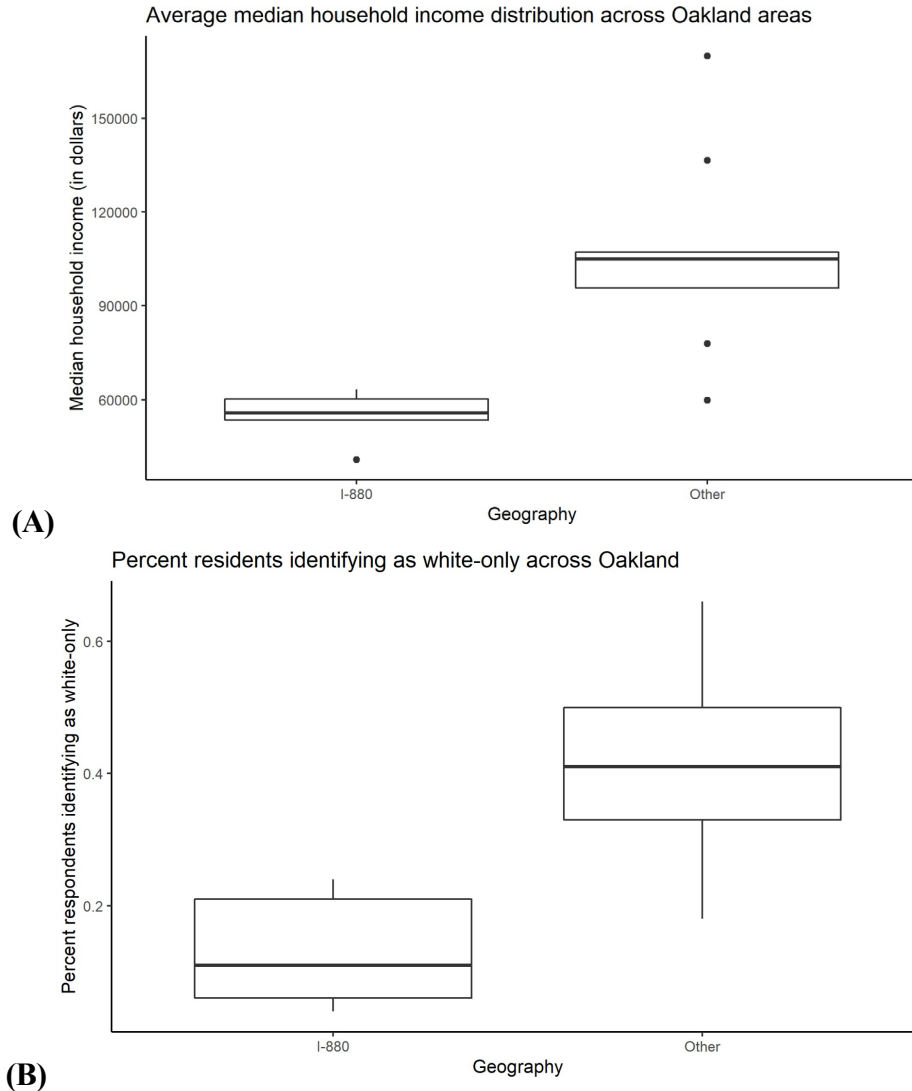


Fig. 5. Socioeconomic demographics of zip codes along I-880 compared to the rest of Oakland. Communities adjacent to the I-880 corridor tend to have a lower average median household income (A), while other parts of the city had generally higher, though more varied, average median household incomes. Communities adjacent to the I-880 corridor tend to be less white than other parts of the city (B), meaning that a higher proportion of people of color (PoC) live near the freeway.

COVID-19 Exposure and Severity

Investigating COVID-19 case rates across Oakland zip codes reveals a canyon of inequality between areas of the city. To date, COVID exposure remains the highest in Fruitvale and East Oakland, corresponding to zip codes 94601 and 94603/94621, respectively. The former has a cumulative per capita case total of about 0.25, meaning about 1 in 4 people have contracted COVID in Fruitvale and surrounding areas. In East Oakland, the cumulative total reaches 0.29, which indicates that about 3 in 10 people have contracted COVID-19 (Figure 6). These values depart significantly from case trends in other parts of the city.

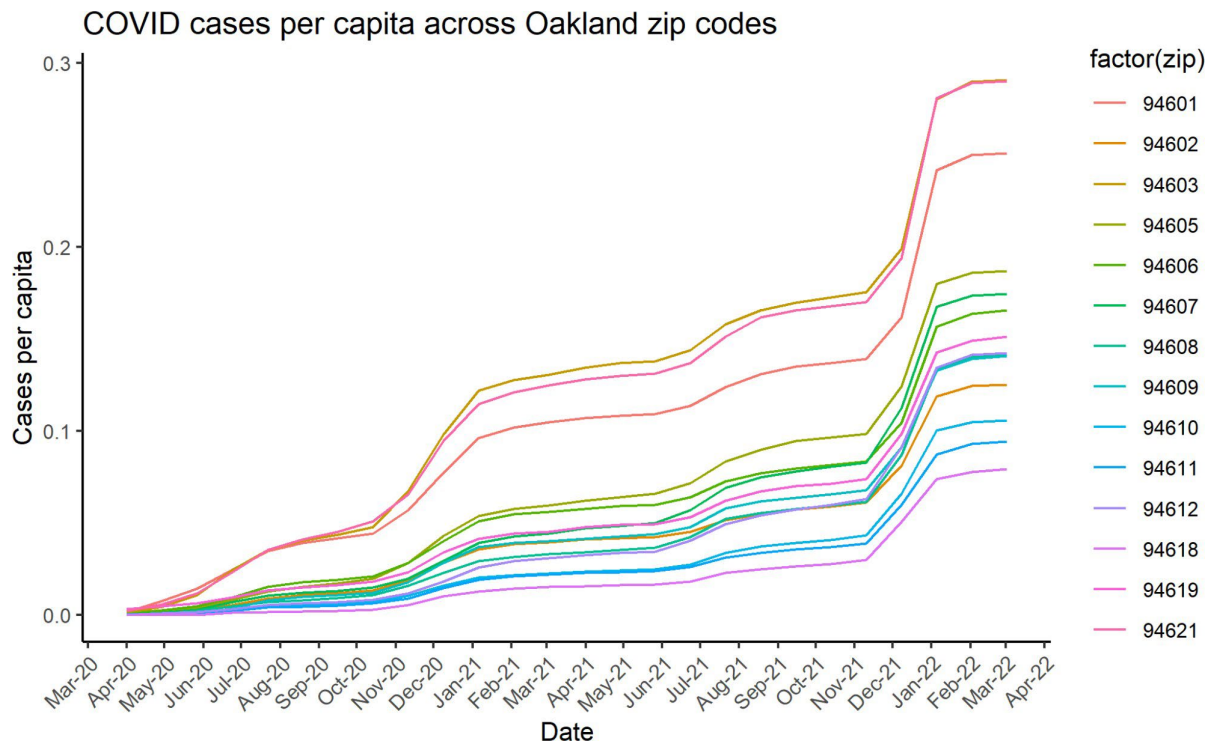


Figure 6. Cumulative cases of COVID-19 per capita across Oakland. Zip codes 94603 and 94621 (East Oakland) have the highest count, followed by 94601 (Fruitvale). Zip code 94613 excluded due to small sample size.

Pairwise comparisons between the different zip codes bunch together areas of the city with similar case rate trendlines. The most exposed group, which diverged significantly from the other zip codes in Oakland, contains 94601, 94603, and 94621 (Fruitvale and East Oakland). On the other hand, the least exposed group contains 94610, 94611, and 94618 (Grand Lake,

Piedmont, Rockridge, Claremont). Among other demographic characteristics, these areas diverge in geography, given that the former three lie along I-880 in the flatlands and the latter three are away from the commercial corridor and tucked in the hills.

Analyzing the COVID exposure in the I-880 Corridor group compared to the rest of the city showed that communities facing this environmental stressor are also experiencing higher rates of coronavirus infection. Grouping together zip codes along the I-880 Corridor shows that these areas have faced a higher number of cases throughout the pandemic; this disparity has widened over time through the present day (Figure 7). The p-value of a t-test comparing I-880 and non-880 groups was 0, proving that this difference is significant.

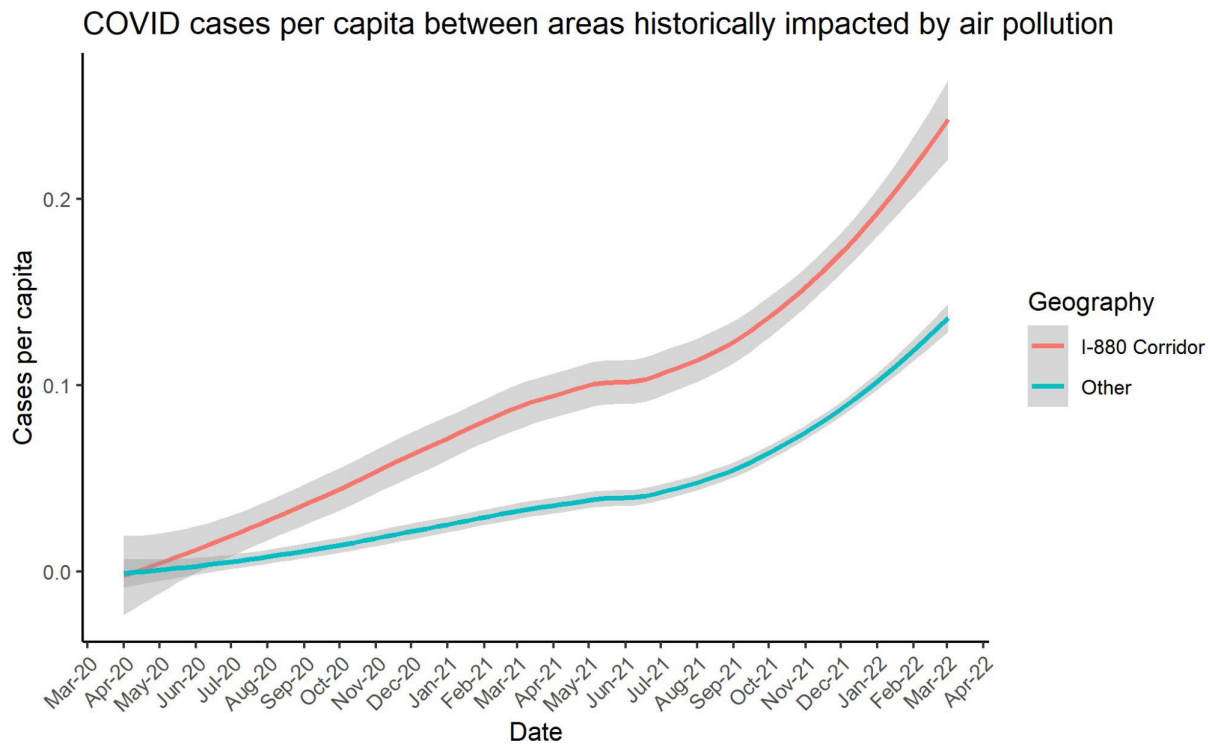


Figure 7. Disparities in COVID cases based on geography of air pollution. Zip codes along I-880 (grouped in red) have a significantly higher rate of COVID cases than those not along I-880 (teal). Gray represents the standard error of each curve; the former has a larger error due to a smaller sample size. Significant differences continue to the current day.

Vaccine Access

Vaccination sites were not distributed evenly across Oakland, especially across the flatlands of the city. Both zip codes in East Oakland did not have a single vaccination site open in November 2021 (far after the closure of the coliseum), and West Oakland only had one vaccination site (Figure 8). East and West Oakland stand out because these zip codes cover a large land area of the edges of the city, presenting accessibility issues for those living at the edge of their area. The zip code with the most vaccination sites was 94611, with 6 in total. For areas adjacent to 94611 with limited vaccination sites, the availability of options in 94611 means that vaccination sites are still accessible.

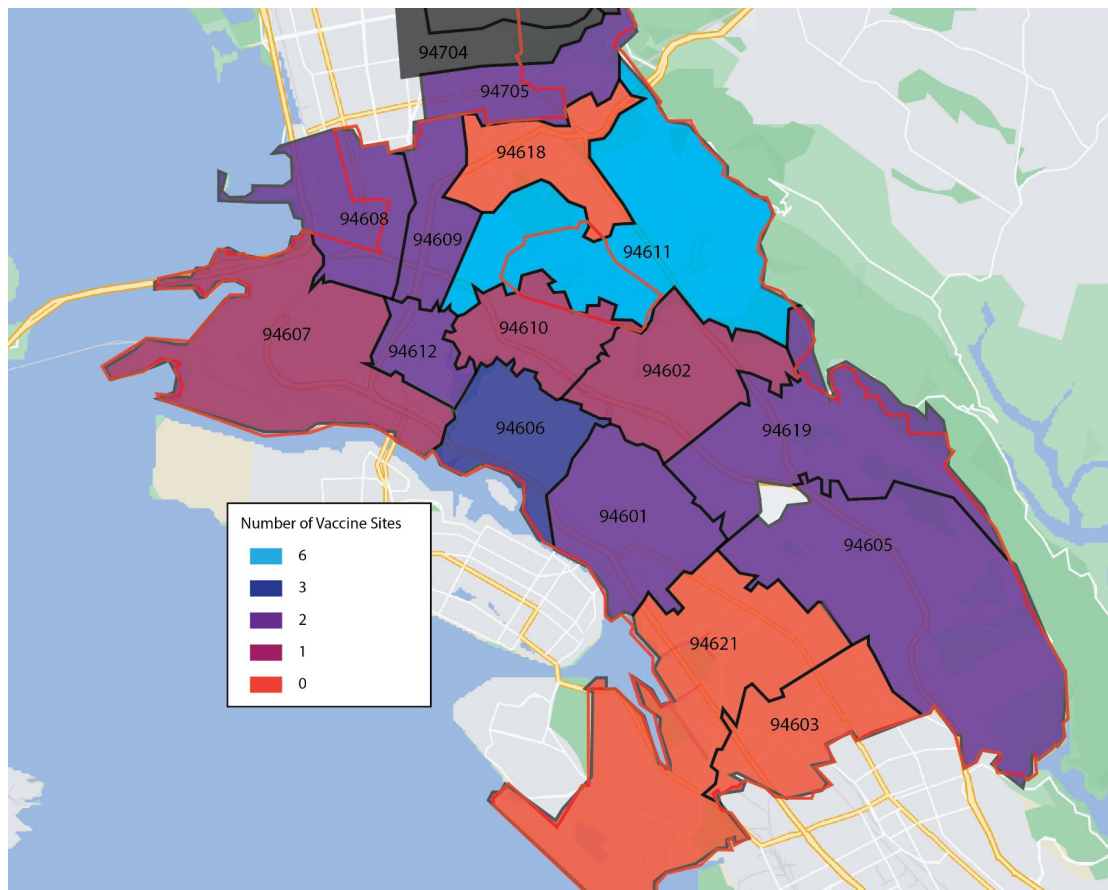


Figure 8. Listed number of vaccination sites in each Oakland zip code, according to the CDC. Vaccine sites in Oakland varied from 0 per zip code to 6 per zip code. Generally, areas in the hills had more vaccination sites, though there are exceptions such as in 94618, where an affluent community had 0 vaccination sites situated within itself.

Although vaccination had occurred unequally throughout the course of the pandemic, the difference did not carry as consistently as differences in COVID-19 case rates. The highest vaccination rates are in the Rockridge, Piedmont, and Claremont areas (zip codes 94611 and 94618), where about 95% of the eligible population is vaccinated. Every zip code in Oakland has a vaccination rate over 75% to date, which exceeds state and national averages. Analyzing vaccination trends over time shows that in the beginning of 2021, when vaccines were first being distributed, people in East Oakland and Fruitvale (zips 94601, 94603/94621) had reduced access compared to more affluent zip codes. By mid-April 2021, when vaccines began to open to the general public, Rockridge districts had vaccination rates over 75%, while the latter areas had vaccination rates below 50% (Figure 9). The range in values has decreased over time, demonstrating that vaccine dispersal proceeded more equally as availability increased.

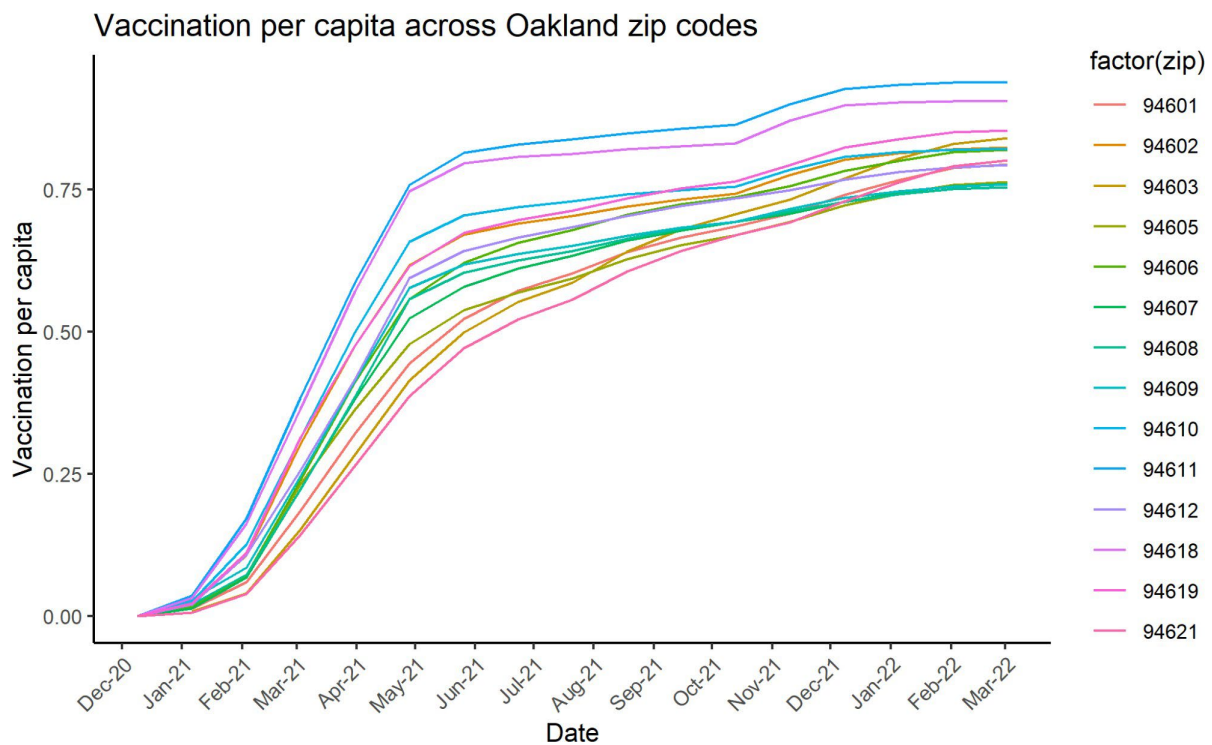


Figure 9. Vaccination rates across each Oakland zip code. Rates varied the most during spring and summer of 2021, and disparities have reduced since. East Oakland and Fruitvale (94603 and 94621, 94601) had the lowest vaccination rates at the start of the pandemic, but then reached and eventually passed vaccination rates in other parts of the city. Zip code 94613 was excluded due to small population sample size.

The disparity in vaccines per capita during the summer of 2021 is present in a comparison between the I-880 Corridor group and the rest of the city. Zip codes containing the I-880 Corridor had lower vaccination rates, though the gap has closed in recent months (Figure 10). Grouped comparison reinforces the trend found in zip code analysis; inequality in vaccine administration has reduced as vaccines have become more widely available.

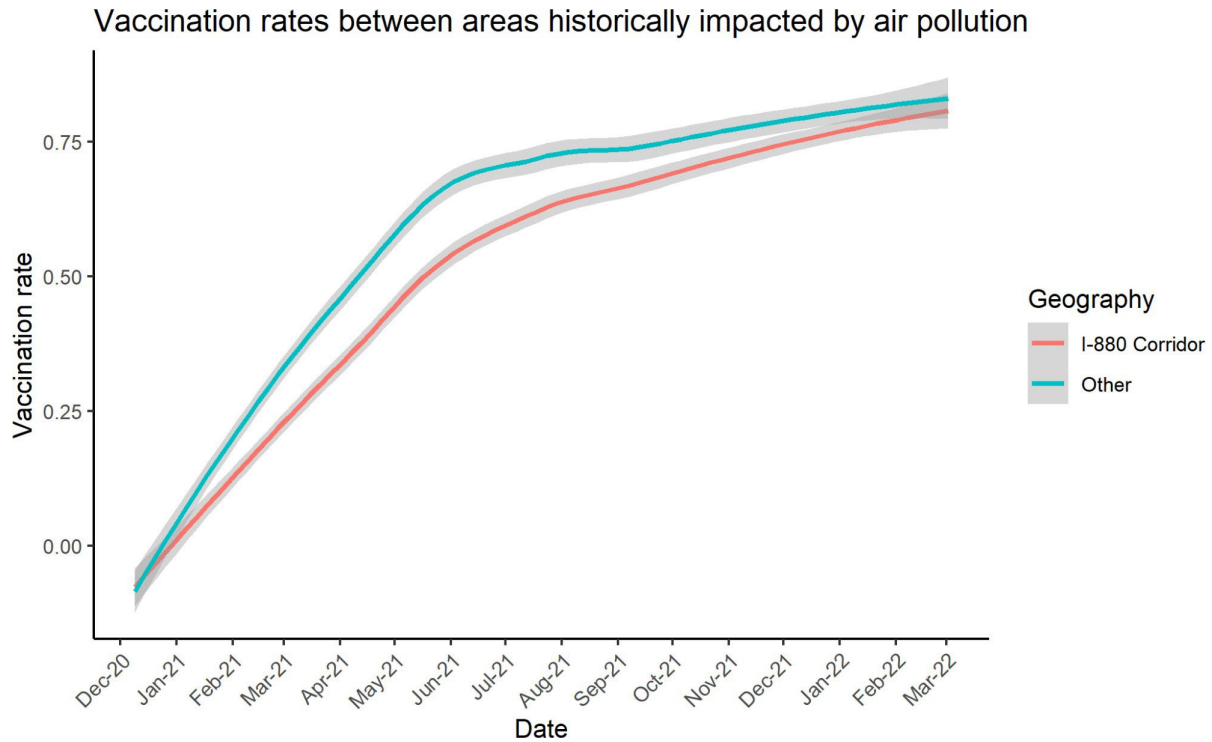


Figure 10. Disparities in vaccines per capita based on air pollution geography. Vaccination rates were lower in zip codes along I-880 (red) than zip codes not containing I-880 (teal); the gray area represents standard error of the vaccination rate curves over time. Vaccines were not distributed evenly amongst different areas of Oakland initially, but the difference has waned to insignificant levels in 2022.

COVID Case and Vaccination Survey

Unfortunately, the Qualtrics survey only received 14 responses, meaning that no statistically significant findings can be derived from the small sample size. However, some results stood out upon review. Of the 3 respondents who indicated that they had COVID-19, one mentioned missing work without pay, and one mentioned losing jobs/contracts as a result of the disease. Additionally, one respondent who had COVID-19 indicated that their asthma worsened

their symptoms or caused concern for their health. Trends cannot be derived from these single responses, but they suggest that coronavirus infection indeed worsen financial and physical vulnerabilities in susceptible populations. Vaccination sites were distributed among almost all available options: Oakland Coliseum (1), CVS/Walgreens (1), Community events (1), Clinic or medical facility (2), and Other: Local church (1). The individual who received their vaccine at the local church received their booster at the same facility, hinting that churches could be leveraged as valuable community resources to drive vaccination. Regarding booster shots, the proportion of respondents who had received their boosters (4) was far lower than vaccines (9); one respondent said they had not been administered their booster due to lack of time, and another said that they had not been administered their booster because they could not get to the vaccine site. These results outline the possibility that accessibility issues continue to this day through booster shot inaccessibility, even though most of the population in Oakland has received two vaccine doses. Overall, the highly limited survey responses indicate where further research can be dedicated towards.

DISCUSSION

Communities along the I-880 Corridor are exposed to greater respiratory trauma due to air pollution exposure and coronavirus incidence than other parts of Oakland. Demographics reveal that these zip codes are more likely to include low-income communities of color. Elevated COVID-19 case rates are likely due to the nature of employment across Oakland; workers living in communities adjacent to I-880 tend to work from home less, or rather are required to work in-person more. These communities were further disadvantaged by limited vaccine access during the initial rollout in 2021. Although the disparity in vaccination has since closed, disparities in COVID case rates between areas impacted by air pollution have continued to this day.

Systemic racism and exposure to air pollution

Demographic analysis of areas experiencing the worst air pollution in Oakland connect to legacies of redlining and disinvestment from communities of color. The I-880 Corridor encompasses West Oakland, Chinatown, Fruitvale, and East Oakland, all of which have living

histories as spaces for communities to resist systemic discrimination inflicted upon them. I-880 itself is a manifestation of the racist planning behind urban highway construction, given that vibrant blocks for Oakland communities were demolished to build the freeway (Harris 2007). This violence is experienced today in the form of elevated PM 2.5, NO₂, and BC pollutant levels that endanger the health of residents living near the freeway. The threat that I-880 specifically poses is greater than other urban highways in Oakland because the traffic going to and from the port in West Oakland, which consists of large diesel-burning trucks, travels almost exclusively along I-880's path (Apte et al. 2017). Structural violence manifests in the air that these residents breathe, which makes them more susceptible to conditions such as asthma, lung disease, heart disease, and cancer (Xing 2016). These illnesses, borne out of inequality, also worsen COVID-19 cases, magnifying the impact of environmental injustice in the current pandemic era.

Demographic analyses of air pollution-vulnerable populations in Oakland reinforce trends in unequal coronavirus burdens found in nationwide studies. Areas along I-880, which have exhibited higher COVID case rates since the onset of the pandemic, have a significantly higher proportion of nonwhite residents than other parts of the city. Working adults in these areas are much more likely to be employed in professions that require in-person work, following national patterns where workers of color are on the frontlines of COVID-19 exposure (Wilson 2020). Therefore, it is no surprise that it is in these same communities that COVID cases have been the highest.

Compounded vulnerabilities between air pollution and coronavirus

Communities living in areas with higher concentrations of traffic-related pollutants are also exposed to higher levels of coronavirus incidence. These compounded vulnerabilities threaten the livelihoods of those living around major polluters like I-880 in Oakland, especially considering the fact that many diseases associated with elevated levels of air toxic exposure are also known to increase the severity of an individual's COVID-19 infection (Williamson 2020, Zhou 2020). Additionally, lower median household income in zip codes containing I-880 can exacerbate the economic impacts caused by coronavirus infection. These results show that COVID acts on an existing landscape of inequality by exploiting financial insecurity and increased chronic illness presence in areas next to the major freeway.

These trends mirror studies at the national level, showing that inequality leads to significantly worse coronavirus infection even within cities. Researchers have demonstrated that COVID affects low income Black and Latino/Latina households more severely than white ones, worsening existing social vulnerabilities across counties. Identifying these drivers of inequality at a much finer resolution creates opportunities for actionable change. In Oakland, implicating I-880 as a pollution corridor signals to city and state administrations which communities are most at risk during the COVID-19 pandemic. These vulnerable communities should lead policy decisions regarding their future because their circumstances are the most pressing.

Efficacy of vaccine distribution

Although the inequality has since been bridged, trends in vaccination show that when vaccines are limited, they are not being allocated to the most vulnerable, nor the most exposed. Zip codes along I-880 had significantly lower vaccination rates as soon as February 2021, when vaccines were limited to “essential workers.” At the same time, data from the 2020 ACS revealed that a higher proportion of workers living within the I-880 Corridor group had work in-person, or worked in occupations likely to require in-person attendance; these employment statistics run contrary to actual vaccination rates, revealing that vaccination efforts did not properly reach communities that had the highest likelihood of exposure. Vaccines were disproportionately administered to residents living away from I-880, who tend to be whiter, wealthier, and more likely to work remotely. These results mirror trends of vaccination across the state of California, given that zip codes with higher proportions of Black and Latino residents received less vaccination doses at the onset of vaccine distribution (Greene 2021). Therefore, this study confirms that disparities in vaccine access attributed to structural inequality are apparent within the limited geography of a single city.

Longitudinal analyses of vaccination rates over time were vital to highlight the uneven administration of doses in Oakland. Vaccination rates over the last 30 days, which are made available for the public by the Alameda County DPH, would show that people all across Oakland have gotten vaccinated at rates higher than state and national averages. These recent figures obscure a significantly lower vaccine presence across Oakland zip codes with lower median household income and more Black and Hispanic residents that lasted until October 2021. Now

that vaccines are widely available across the United States, differences in vaccination rates across Oakland are no longer significant; however, acknowledging disparities that existed when supply was limited recognizes that lower income communities and communities of color were not prioritized in vaccine rollout, despite the fact that they are overrepresented in industries and occupations that demand in-person workers.

Synthesizing and contextualizing case and vaccination rates across Oakland

In the summer of 2021, communities spanning I-880 had significantly lower vaccination rates and significantly higher COVID case rates. It was during this period that the Delta variant became the dominant strain of COVID-19, compromising ongoing efforts to return to “business as usual” (Smith-Schoenwalder 2021). In unvaccinated individuals, coronavirus symptoms generally present more strongly, meaning the disease enacts on disparities in vaccine access by infecting vulnerable people more severely (CDC 2021a). Although vaccination rates have equalized at a value above state and national averages, there is potential for COVID-19 resurgence through a new variant. Public health officials suggest that people get an additional dose, known as a “booster shot,” to mitigate the chance of resurgence (CDC2021a). There is a possibility for this trend to persist with the new push to get booster shots, which some survey respondents have reported as inaccessible due to site access constraints or time constraints. To address potential chasms in booster access before a new variant reaches the general public, the city should work with vulnerable communities to administer booster shots at relevant and accessible locations.

Limitations and future directions

Just as intracity analysis yielded specific results about which areas in Oakland are most vulnerable to COVID-19 and air pollution exposure, refining my study methods to the census tract level could improve accuracy and specificity of data collection. Census tracts are preferable to ZCTAs in terms of census data availability and interpretation, presenting an opportunity for more detailed analysis of geographical inequities within the city of Oakland (UCF 2022). Mobile

monitoring of air toxic levels also reports data at the census tract level, meaning that contemporary air pollution data can be used more effectively with census tract analysis.

Another limit to this study was the yield of survey responses. Despite efforts to reach people through in-person flyering, this method proved ineffective in collecting enough responses for statistical analysis. In the future, centering survey methods as a primary research method will require me to distribute the materials more effectively. Surveys have utility as a participatory research method, given that they rely on self-reported, sometimes anecdotal, evidence from community members themselves. When working on studies about inequality, especially those that are so specific in people and place, these voices should be centered in understanding the problem and framing possible solutions. Further studies on these topics should use community-based, participatory methods to form an empowering, rather than extractive, relationship with the communities being studied.

Conclusion

The ability for Oakland residents to take a deep breath of clean air is threatened both by air pollution and COVID-19, which act on existing structural inequities and harm the city's low income communities of color. The impacts of these compounded hazards are felt most among those with physical or financial vulnerabilities to the virus, such as people with lung conditions, elderly people working in retail, or wage workers living paycheck-to-paycheck. Given the possibility of coronavirus resurgence through a new variant, we must learn from previous shortcomings and address the needs of those most endangered by the risk posed by another full-fledged pandemic. Even if the pandemic subsides, people adjacent to I-880 still are put at risk from air toxic contamination near their homes. Confronting these vulnerabilities requires confronting systems that devalue the lives of Black people and other people of color in Oakland, whether that be through redlining or bulldozing homes to make way for a freeway.

Although the pollution from I-880 disseminates structural violence in particles as fine as 2.5 microns, communities experiencing its impacts resist and reject oppression by carving out a healthier future. Groups like the West Oakland Environmental Indicators Project continually publish research on the harmful impacts of freeway construction and outline interventions to improve livelihoods in their community. The Black Cultural Zone has established itself as a bastion to protect Black businesses and circulate the Black dollar, standing against disinvestment and

displacement in East Oakland. These community-based organizations carry a legacy far more important than that of institutional violence: they continue the story of resistance, and keep hope alive. Policymakers are finally combating the impacts of structural racism through recognizing and amplifying the work that these organizations have been doing in policies like AB 617. Providing funding and jurisdiction for communities to address the impacts of polluting highways like I-880 themselves represents a significant change in government policy. This power is especially important in times of crisis; the overlapping vulnerabilities between coronavirus exposure and air pollution necessitate policy to protect, and more importantly, embolden those most vulnerable. As Dr. Valerie Wilson said when she testified to Congress: “If we are to protect Black, Latinx, and Native American communities from suffering under the same needlessly heavy burden during the next economic or public health crisis that they are suffering under now, we must work diligently to address long-standing underlying racial disparities in economic and health outcomes.”

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APPENDIX

Survey questions

Survey text imported from the Qualtrics Berkeley Platform:

Experiences with COVID-19

Survey Flow

Block: Place-based Questions (3 Questions)

Standard: COVID-19 Exposure (3 Questions)

Standard: COVID-19 Vaccination (6 Questions)

Standard: COVID-19 Boosters (3 Questions)

Standard: Demographics Survey - OPTIONAL (5 Questions)

Standard: Raffle Entry (1 Question)

Start of Block: Place-based Questions

Q22 The following survey should not take more than 7 minutes of your time.

Complete the survey for a chance to win a \$175 VISA Gift Card!

Any information you provide in this survey will be used to help inform a report on how COVID-19 has affected people across Oakland. All responses will be kept anonymous and will only be used for academic purposes.

Page Break

Q1 Do you live, work, or spend a substantial portion of your day in Oakland, California?

Yes (1)

No (2)

Skip To: End of Survey If Do you live, work, or spend a substantial portion of your day in Oakland, California? = No

Page Break

Display This Question:

If Do you live, work, or spend a substantial portion of your day in Oakland, California? =
Yes

Q2 What zip code in Oakland do you live, work, or spend the most time in?
SKIP if you prefer not to answer

End of Block: Place-based Questions

Start of Block: COVID-19 Exposure

C1 Have you had COVID-19?

- Yes (1)
- No (2)
- Likely, but did not confirm with a test (3)

Page Break

Display This Question:

If Have you had COVID-19? = No

C2 How has COVID-19 infection or exposure affected your ability to earn a living or otherwise provide for your household, if at all?

- Missing work without pay (no sick leave) (1)
- Increased childcare needs (2)
- Lost jobs or contracts (3)
- Other (4) _____

- No significant effect/I am not a provider for my household (5)

Display This Question:

If Have you had COVID-19? = No

C3 Did any of the following conditions either worsen your COVID-19 symptoms or cause concern for your health, to the best of your knowledge?

- Asthma (1)
- Diabetes (2)
- Heart disease (3)
- Lung disease (4)
- Cancer (5)
- Stroke (6)
- None of the above (7)
- Other (8) _____

End of Block: COVID-19 Exposure

Start of Block: COVID-19 Vaccination

V1 Have you been vaccinated from COVID-19? *Being "vaccinated" is defined as receiving two doses of Pfizer or Moderna vaccines, or one dose of the Johnson & Johnson vaccine.*

- Yes (1)
- No (2)

Page Break

Display This Question:

If Have you been vaccinated from COVID-19? Being "vaccinated" is defined as receiving two doses of P... = Yes

V2 During what month and year did you become fully vaccinated? *Date of your second dose for Moderna/Pfizer, or first dose for J&J.* (Ex: March 2021)

Display This Question:

If Have you been vaccinated from COVID-19? Being "vaccinated" is defined as receiving two doses of P... = Yes

V3 Where did you get vaccinated?

- Oakland Coliseum (1)
 - CVS, Walgreens, or other drugstore within/near Oakland (2)
 - Community events within/near Oakland (Cultural festivals, farmers markets, etc) (3)
 - Clinic or medical facility within/near Oakland (4)
 - Educational institution within/near Oakland (5)
 - Other within/near Oakland (6)
-

Outside of Oakland (7)

Display This Question:

If Have you been vaccinated from COVID-19? Being "vaccinated" is defined as receiving two doses of P... = Yes

V4 How did you feel about the process of getting vaccinated?

- Extremely dissatisfied (11)
- Somewhat dissatisfied (12)
- Neither satisfied nor dissatisfied (13)
- Somewhat satisfied (14)
- Extremely satisfied (15)

Display This Question:

If How did you feel about the process of getting vaccinated? = Extremely dissatisfied

Or How did you feel about the process of getting vaccinated? = Somewhat dissatisfied

V5 If you were dissatisfied with the vaccination process, which of the following reasons explains why?

- Took too much time (1)
- Hard to access vaccine site (2)
- Recovery was difficult (3)
- Other (4) _____

Page Break

Display This Question:

If Have you been vaccinated from COVID-19? Being "vaccinated" is defined as receiving two doses of P... = No

V2B Which of the following reasons best describes why you have not been vaccinated against COVID-19?

- Lack of information about where and how to get vaccinated (1)

- Inability to get to vaccination sites (2)
- Not enough time to get vaccine (3)
- Beliefs or choice (personal, religious, political, etc) (4)
- Other (5) _____

End of Block: COVID-19 Vaccination

Start of Block: COVID-19 Boosters

Display This Question:

If Have you been vaccinated from COVID-19? Being "vaccinated" is defined as receiving two doses of P... = Yes

B1 Have you received a COVID-19 booster shot? *A booster is defined as getting a vaccination dose after being fully vaccinated (refer to previous pages for a definition of vaccination).*

- Yes (1)
- No (2)

Page Break

Display This Question:

If Have you received a COVID-19 booster shot? A booster is defined as getting a vaccination dose af... = Yes

B2 Where did you receive your COVID-19 booster?

- Oakland Coliseum (1)
- CVS, Walgreens, or other drugstore within/near Oakland (2)
- Community events within/near Oakland (Cultural festivals, farmers markets, etc) (3)

- Clinic or medical facility within/near Oakland (4)
 - Educational institution within/near Oakland (5)
 - Other within/near Oakland (6)
-
- Outside of Oakland (7)

Page Break

Display This Question:

If Have you received a COVID-19 booster shot? A booster is defined as getting a vaccination dose af... = No

B2B Which of the following reasons best describes why you have not received a COVID-19 booster shot?

- Lack of information about where and how to get booster (1)
- Inability to get to vaccination sites (2)
- Not enough time (3)
- Poor experience with previous vaccination (4)
- Beliefs or choice (personal, religious, political, etc) (5)
- Other (6) _____

End of Block: COVID-19 Boosters

Start of Block: Demographics Survey - OPTIONAL

The following few questions are an optional demographics survey to ensure a variety of people are being heard. Please respond to whatever you feel comfortable sharing (none of this information will be used for promotional or marketing purposes).

How old are you?

- Under 18 (1)
- 18-24 years old (2)
- 25-34 years old (3)
- 35-44 years old (4)
- 45-54 years old (5)
- 55-64 years old (6)
- 65+ years old (7)

Which of the following groups do you identify with:

- White (1)
- Black or African American (2)
- Latino/Latina/Latinx (3)
- Asian (4)
- Native Hawaiian or Pacific Islander (5)
- American Indian or Alaska Native (7)
- Other (8) _____

Household: How many people live or stay in this household at least half the time?

Information about income is very important to understand. What would you estimate your entire household income in (previous year) was before taxes?

- Less than \$20,000 (1)
- \$20,000 - \$39,999 (2)
- \$40,000 - \$59,999 (3)
- \$60,000 - \$79,999 (4)
- \$80,000 - \$99,999 (5)
- \$100,000 - \$119,999 (6)
- \$120,000 - \$149,999 (7)
- More than \$150,000 (8)

End of Block: Demographics Survey - OPTIONAL

Start of Block: Raffle Entry

Contact Info If you would like to enter the raffle for a \$175 VISA gift card, please provide your email below (your email will NOT be used for any promotional or marketing purposes).

End of Block: Raffle Entry