Air Pollution and Environmental Injustice: Differential Burdens in San Francisco Bay Area Communities

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ABSTRACT

Air quality varies significantly within San Francisco Bay Area. This paper examines trends in the concentrations of nitrogen dioxide (NO_2), ozone (O_3), and particulate matter $\leq 2.5\mu m$ ($PM_{2.5}$) and the association of these pollutants with two demographic traits – the percentage of African Americans and percentage of individuals in poverty – from 1994 to 2013. Scholars have documented spatial inequities related to air pollution at national level but have yet to do so at local levels. Additionally, few researchers have studied how differences in the concentrations of air pollutants are changing with urban redevelopment and gentrification. I found that NO_2 pollution is strongly associated with the percentage of African Americans in a population near air pollution monitoring sites surrounded by large populations of African Americans in the Bay Area. In addition, my results suggest the analogous trend with respect to poverty. Association of O_3 and $PM_{2.5}$ with each demographic were much weaker. A combination of racialized historical planning, new urban redevelopment, and increasing wages that are partially attributed to the tech boom have resulted in gentrification of the Bay, and associated displacement of many poorer, typically non-white residents. To better understand the local dynamics of air pollutant distribution in relation to changes in demographic composition, I identified spatial and temporal trends describing changes in demographics and changes in air pollutant concentrations in the Bay Area.

KEYWORDS

air pollution, environmental justice, Oakland, gentrification, diesel emissions, red-lining

INTRODUCTION

The demographics of the San Francisco Bay Area are changing as more affluent, wealthier, typically white populations migrate in. This process is known as gentrification - defined as, "the transformation of a working-class or vacant area of the central city into middle-class residential or commercial use" (Zuk & Chapple 2015). Though not an explicit part of this processes' definition, displacement typically occurs as a result of gentrification and displaced populations are often poor minorities (Chapple 2015). However, many urban planners herald the new development associated with gentrification as a beacon of progress. Others have found that due to the removal of low-cost housing and increases in costs of living that the process of gentrification is in fact more detrimental than it may superficially appear specifically for low-income residents and people of color (Abel 2011). In the Bay Area especially, the process of gentrification is almost always associated with displacement (Zuk and Chapple 2015). Additionally, it is documented that environmental burdens of gentrification – including eviction, displacement, and community fragmentation – are differentially distributed in Oakland. The greatest burdens often rest on low income, minority-dominated areas of the Bay like West Oakland, this study's central case geography (Fisher et al. 2006). West Oakland is historically one of the poorest neighborhoods with the highest concentration of many criterion air pollutants in the Bay Area (Care & BAAQMD 2014). Since 1990, this neighborhood has experienced a rapid exodus of established, impoverished and African American individuals (Census 2010). For this reason, this paper will analyze the roles that gentrification and displacement may have in shaping air pollution burdens felt by impoverished individuals and African American people. Additionally, I will use migration data in conjunction with the results of recent studies to calculate what neighborhoods West Oakland residents are most likely to move to following gentrification-driven displacement, and to examine relationships between the settlement of displaced peoples and nascent air pollution burdens.

Improvements to environmental quality typically occur first in wealthier neighborhoods and neighborhoods with increasing wealth. Demographic change tends to follow the latter. (Young et al. 2012). No studies have been published to date examining whether gentrification, and related displacement, affects air pollution distribution. Specifically, research tracking the migration of those displaced from gentrification, and studies comparing pollution exposure from

people's former and current residences are lacking. Accordingly, no studies have explored trends in air pollution and demographics, and subsequently combined those trends with migration data to find displacement's impact on air quality burden.

In this paper I will analyze how gentrification in West Oakland correlates with air pollution burden on low-income residents and African Americans in areas that are gentrifying, and areas that are increasingly populated with those displaced by gentrification. This study will provide evidence and insights for equitable air pollution policymaking that might prevent further stratification of environmental burdens. Additionally, I will examine the factors that drove people to move from their former homes and uncover the factors that preferentially draw displaced people to settle in certain Bay Area neighborhoods over others. Similarly, I will test if demographic changes are correlated with changes in air quality each study site which can elucidate issues of environmental justice within air quality policy. Using correlation tests I will observe how closely related migration patterns are to pollutant concentrations, and I will focus specifically on the differences in air quality between the newly settled locations and old residences (Chapple 2015). Lastly, I will visually overlay demographics changes and air pollutant concentration changes over time to spatially present trends. These tests will serve analyze how gentrification affects populations that have historically faced higher rates of environmental injustice in the San Francisco Bay Area, in order to determine if new policies are needed to prevent injustice with regard to air pollution burden. To fight inequality, future policies can prevent increasing air quality burdens on poor and minority populations under the National Environmental Policy Act (Bhatia 2005).

BACKGROUND

White Flight and the Creation of the Suburbs

Post World War II housing and development policies lead to a disinvestment in cities and the creation of the suburbs. Typically white, wealthy families moved into neighborhoods away from central cities and left predominantly lower income, African American populations residing in inner city and industrial districts (Self 2003). Since its founding, Oakland has been subject to policies encouraging segregation. As reported by Self (2003), "By the 1920s real estate interests

had carved [Oakland] into long, narrow strips that marked neighborhoods by income and elevation—Flatlands, foothills, and hills—and embedded a class regime literally into the physical terrain". This act institutionalized segregation into Oakland's landscape by creating sectionalized property values.

A decade later these tracts were used to determine loan value and eligibility. This policy, known as redlining, was used in excluding African Americans from white neighborhoods by leveraging discretionary lending practices (Seitles 1996). Introduced by the Federal Housing Association (FHA) in 1934, redlining constituted the practice of approving and denying home loans based on neighborhood-level qualities, including race (Massey and Denton 1993.) Banks publically justified this policy by claiming that it allowed them to assess the likelihood that homeowners could pay back loans. Neighborhoods that were given priority for loans were "new, homogenous, and in demand in good times and bad", and these new, wealthy, and white regions became Oakland's first suburbs (Seitles 1996). These suburbs were located primarily in the uplands and hills around Oakland, while African American neighborhoods were restricted to the Flatlands adjacent to the city and West Oakland (US Bureau of the Census, 1950). A few years later, in 1946, supplementary housing policies were enacted to ensure that primarily white veterans could buy homes after World War II (Kammen 2015). The combination of these two polices prevented many African Americans from buying homes in wealthier neighborhoods and encouraged white populations to settle in areas at the periphery of cities located away from industry, pollution, and African American populations.

Within a half a decade of the end of World War II new policies began displacing low income African Americans from the city in attempts at achieving "Urban Renewal". After the suburbs were established it became apparent to City officials that Oakland hosted higher concentrations of poverty, crumbling homes and industrial buildings, and a higher occurrence of disease (Self 2003). Renewal, however, did not mean improvement for current residents. It usually meant redevelopment, as the city of Oakland tended to tear down homes with low values and old industrial buildings in primarily black neighborhoods to make way for middle income homes and new industry (Self 2003). However, city officials used renewal and redevelopment synonymously and the entire process became known as "Negro Removal", a term coined by author James Baldwin in the 1960s (Self 2003).

By 1950s and 1960s West Oakland boasted a disproportionally large population of

African Americans relative to the rest of East Bay, many of whom fought in World War II (US Bureau of the Census 1950, 1960; Self 2003). Banks would not grant any loans to residents of West Oakland to buy homes (see redlining in paragraph 1). Additionally, most African Americans could not afford to pay out of pocket for land and homebuilding outside redlined neighborhoods (US Bureau of the Census *Current Population Reports* 1959-1969). As a result, the majority of African Americans ended up renting subdivided homes from owned by whites, who lived in the suburbs (CV 1961).

City officials sought to revitalize the whole of Oakland; however, in practice, revitalization was actualized differently in East Oakland and West Oakland. For East Oakland, it meant restoration of homes, but for West Oakland it meant replacement of older homes and factories with middle class housing and new industry (CV 1959). Oakland demolished many African American homes during in this time, and failed to create as many jobs as they had promised for Oakland residents (Self 2003). Self (2003) recounts an instance in which a member of the U.S. civil rights council addressed the head of the Redevelopment Agency in Oakland and said, "What are you really telling these people [African American Oaklanders]?… We are taking your home and you are not getting a job either?" (Hearing before the U.S. Commission on Civil Rights 1965). At the same time Bay Area Rapid Transit (BART) was in initial building phases, and its planners cited the Oakland portion of its tracks in areas with lower property values. These areas were also home to the last thriving African American communities in Oakland (Self 2003). BART did not create thriving economies around each stop in Oakland as was promised. Instead, it allowed people to "by-pass the city altogether in favor of San Francisco" (Self 2003). African American communities in Oakland were disrupted and divided by transit installation and the promise of urban renewal.

Recentralization and Gentrification

In the past 20 years, urban gentrification has been associated with the reverse trend as white flight and a return of wealthy white individuals and families to Oakland (1990, 2000, 2010 Census). Reinvestment in poorer, formerly industrial areas has resulted in an increased cost of living throughout Oakland. As a result, landlords have been raising rent prices with little pushback from city officials because of Oakland's minimal rent control policies. Most rent

control in California is only applicable to large multiunit apartments and not single unit dwellings (Costa-Hawkings Rental Housing Act 1995). This is forcing out more longtime residents, who are primarily of lower income (Chapple and Zuk 2015).

In this time Oakland also became a more desirable place to live. Co-occurring with rising home values and changes in demographics, environmental conditions have improved drastically in Oakland in the past two decades. The largest environmental improvement in the past 20 years has been in air quality (BAAQMD 2014). Community based organizations that seek to better conditions for their populace such as *Save the Bay* and *Clearing the Air* have improved local air quality, and San Francisco Bay water quality. Improvement in air quality helps increase desirability of property, which likely played a part in increasing interest from investors in Oakland (Harrison and Rubinfeld 1978).

Similarly, financial practices swayed people to move into and invest in cities. Changes in mortgage lending patterns pushed economic focus to be on impoverished city centers rather than suburbs. In a trend now known as "subprime mortgage lending" banks offered a glut of loans to many people regardless of credit scores to encourage middle class families to move into historically impoverished neighborhoods (Wyly & Hammel 2004). Additionally, millennials, unlike their parents, claim that they would prefer to live in cities (US Census Bureau 2010).

Lastly, as investment and desirability for Oakland increased tech companies started and moved to The Bay. As the tech bubble grew, tech companies such as Yahoo! and Pandora began establishing their headquarters further from Silicon Valley like Oakland. Over the past two decades Oakland has experienced increased desirability and low property value. These factors lead to an increase in the number of more affluent, primarily white individuals moving into Oakland since 2000. Today property values continue to increase and the demographics of Oakland continue reflect a more affluent and white population.

Air Quality Change in West Oakland

Air quality has improved substantially as more affluent and white individuals have moved into Oakland - driving gentrification. Many of West Oakland's contemporary air pollution mitigation policies focus on the transportation sector (Meena et al. 2003, Preble et al 2015, Air Resources Board of California 2015). The neighborhood is home to one of the biggest

ports in the world, each year billions of dollars of goods are trafficked through the area on trucks and container ships burning diesel fuel. As a result, West Oakland diesel emissions have burdened local residents and have led to local efforts, such as the *Clearing the Air* campaign, to remove as many pollutants as possible from the air of West Oakland Air (Meena 2003). Since the early 2000s, air quality has significantly improved, but it has not improved for the residents that fought for cleaner air (BAAQMD 2014). In the years that air quality improved (most years between 1990-2015), West Oakland experienced higher levels of emigration of long-time residents (Census 2010). Moreover, levels of ozone and diesel particulates have remained highest in areas with higher density populations of poor, minority families in West Oakland neighborhoods (Rodriguez 2013). And similarly, changes in air regulations in those neighborhoods evolved only as more affluent individuals moved in (Preble et al. 2015). Air quality has improved in West Oakland and many other parts of the Bay, but the beneficiaries are typically not the low income residents that fought for cleaner air. Instead, the beneficiaries are new wealthy residents. As more affluent residents move in to breathe newly clean air, displaced residents are forced to relocate to areas that may have similar comparable air quality problems to those that Oakland boasted decades ago.

LITERATURE REVIEW

As stated prior, in this report "gentrification" is defined as transformation of a working class or vacant urban area into a middle class residential or commercial neighborhood (Zuk & Chapple 2015). Though debated by city politicians, literature supports that gentrification has a negative effect on low income populations, and populations of people of color (Wyly & Hammel 2004; Abel &White 2011; Checker 2011).

Gentrification and Displacement

Gentrification has been proven to correlate with change in neighborhood demographics, however the timing of displacement is debated. In Karen Chapple's project on Urban Displacement (2015), she writes that gentrification can begin with investment in cities, but it can also begin with disinvestment in cities. She defines "disinvestment" the absence of continuing

investment. Disinvestment can lead to businesses shutting down and moving out of once vibrant neighborhoods. The closure of business lead to residents seeking employment elsewhere, which increases their likelihood of moving to a new workplace. On the other hand, she notes that investment can also push lower income people out of these areas by raising rents, disrupting minority communities, and redeveloping low rent houses into higher priced homes.

Previously many scholars and city planners viewed this style of displacement as voluntary because people were choosing to move out of their own neighborhoods instead of being evicted (Friedman 2005; Ellen & O'Regan 2011). However, today most scholars do not distinguish between the two types of displacement, and rather view them both as forced. Zuk and Chapple (2015) site Eunice and George Grier (1978) writing that, "For most residents to move under such conditions is about as 'voluntary' as is swerving one's car to avoid an accident." Forced movement was defined only as legal eviction notices, it did not include coerced movement such as moving to find work or escape rising rent prices (Ellen & O'Regan 2011). It is theoretically possible for gentrifying parts of cities to be able to retain established lower income residents and receive new wealthier residents at the same time, however literature suggests that this typically does not occur (Chapple & Zuk 2015, Checker 2011, and Freeman 2005).

Modern Renewal: Environmental Gentrification

Environmental gentrification is described by Sieg et al. (2004) as projects or policies that which, are proposed with the intention of neighborhood improvement and restoration in low income neighborhoods. Environmental gentrification typically occurs through the provisioning of parks or other environmentally sustainable infrastructure, many times however, these projects end up increasing property values. Increased property values lead to financial struggle and displacement of the very low-income communities that environmental policies and projects were designed to help (Sieg et al. 2004). Studies have found using statistical Geographic Information System (GIS) analysis that the "bulk of the benefits of a policy that successfully cleans up dirtier neighborhoods where the poor live may actually be captured by richer households" (Banzhaf 2004). Without the support of appropriate policy, environmental quality improvements within environmentally burdened neighborhoods can be conducted similarly to urban renewal and

gentrification can result (Checker 2011).

Harlem is a heavily studied case example for gentrification, second only in critical examination to Oakland. Checker (2011) observed and analyzed the trends that lead to an influx of higher income, white individuals to Harlem and found that much the draw was caused initially by "greening the neighborhood" by adding parks, biking routes, and energy efficient buildings. She found that many of these projects were initially led by environmental justice groups that wanted to improve the quality of life in Harlem, however many of their successes caused an increase in property values and, as a result, some long-time residents could not afford to live there anymore. After a few improvements developers took the opportunity to buy and renovate apartments to then sell to wealthier clients. Soon the city became involved in the effort to improve neighborhood conditions and wanted to add more green space, however these projects were primarily slated for gentrifying regions and ignored the poorer regions and resident's requests for removal of toxic release inventories (Checker 2011).

This trend is not isolated to Harlem. To some such as Sieg et al. (2004); Banzhaf (2004); Checker (2011), improving the environment in low income, minority neighborhoods has been appropriated as a modern urban renewal that displaces the very people it tries to help. In Oakland, one can see a similar pattern in the *Clearing the Air* example described previously. Pastor (2012) remarks, "It is not enough to point to the unequal consequences for the poor. We must take on and reverse, the incentive structures that result in environmentally and socially intensive patterns of development". The current paradigm of urban redevelopment and environmental improvement does not do that. It instead places priority on, "elitist visions of "livability" while forcing low income housing and service agencies to fight their own displacement" (Checker 2011). Higher rents force people to move out of their newly remediated neighborhoods into places where rents are low, and low rents are found near areas of high environmental burden (Abel & White 2011).

THEORY AND METHODOLOGICAL FRAMEWORK

Environmental Justice: A Historical Perspective

Environmental justice (EJ) is **"**the fair treatment and meaningful involvement of all people

regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (US EPA 2015). As discussed in this report's Background, racial division was rampant in the development and redevelopment of Oakland, however those events are not confined to Oakland. The US has a history of disproportionally distributing urban environmental burdens on poor minorities. Environmental justice became well known 1982 when a hazardous waste dump was sited for construction in Warren County, South Carolina, a primarily African American neighborhood (Pastor 2012). Subsequently, the Congressional Black Caucus pressured the US General accounting office to study the distribution of landfills in mostly US neighborhoods based on race, and found that the burden of landfills was taken on far more by black neighborhoods (Pastor 2012). Since then the US government and the US EPA have released statements that condemn environmental injustices; however, history repeatedly demonstrates that community action is the agent of change for reducing environmental burdens for low income communities and minorities, not government (Kammen 2015). In this way, the fallout from the Warren County waste site battle lead to the formation of environmental justice groups across the country.

Since the Warren county waste site battle many environmental justice groups have been the driving force that has improved community level environmental quality. Some sought to get rid of toxic release inventories and others sought to monitor pollution levels to ensure they did not surpass legal limits or health thresholds (Pastor 2012). Some of these groups have been successful in gaining enough cohesion and power to change things in their communities for the better. EJ movements received official approval from the California state government in 2000 when enough EJ groups pressured the California state government to adopt Senate Measure 115 which, "directs the state's Office of Planning and Research to coordinate EJ initiatives" (Pastor 2012). Though a victory for EJ groups, the measure was passed without specific goals and gave no group the power to enforce the policy. EJ groups must spearhead and support concrete improvements in mitigating pollution burdens to persuade politicians to address most community level inequities. It should also be noted that EJ organizing takes a combination of time, money, and power, which is scarce in most low-income minority communities.

Environmental Justice: A Contemporary Perspective

The EPA's definition of "fair treatment" (within their definition of EJ) includes the prevention of disproportionate burdens on specific incomes and ethnicities**.** Many studies including Freudenberg et al. (2011); Pastor (2012), Minkler et al. (2015) have found that communities that can gain and maintain power and influence in their respective local politics are most successful at blocking development that would increase pollution that disproportionality effect their communities. Freudenberg et al. (2011) uses community capacity as the metric for community power and influence. According to Freudenberg et al. (2011); Pastor (2012); and Minkler et al. (2015), community capacity is what allows people to prevent environmental burdens such as air pollution. It is a function of the strength of individuals' ties to one and other. Displacement causes communities to lose community capacity. Allowing the process of gentrification-displacement to continue denies low income people and people of color the change to establish themselves and prevent environmental burdens on them. Freudenberg et al. (2011) writes, "Communities that underwent rapid demographic change seemed to have lower community capacities and, thus higher vulnerability to environmental burdens". Each of the EJ scholars mentioned above view increasing community power as the first step towards environmental equity.

Minkler et. al (2008) found that community based research was one of the best ways for communities to gain agency and success in decreasing pollution burden. Using similar markers of community capacity as Freudenberg et al. (2011) this study observed several different community-based participatory research groups. Each case study coalition had great success in finding evidence for environmental injustices. The study analyzed why each case had success stories, and found that in every successful case a community created an organization that reached out to policy makers and researchers and maintained its members over the course of their campaign. According to Rita et al. (2003) and Minkler et al. (2008), community based EJ groups must retain a steady its membership in order to educate others within their organization to organize, lead, and write policy. Change disrupts education within communities and can lead to disruption in a community's ability to act cohesively. Minkler et al. (2008) also writes that although professional policy developers maker and researchers are essential to successful community based participatory research groups, however the community members must direct

their research and their policy. Additionally, unlike politicians, who's actions may be biased by money or votes, community organizations are focused specifically on the betterment of their own neighborhoods. Therefore, it is community organizations that ultimately drive equity. However, most members of communities do not have enough cohesion, connections, time, or money to organize in a way that drives such equity. Thus, to achieve a just urban environment local governments have an obligation to sponsor communities that have been historically marginalized by government. This would manifest in capacity building actions such as connecting communities to professionals, scholars, and giving marginalized communities any other tools they need to gain equitable amounts of power and influence.

Gentrification and Environmental Justice

Gentrification is a modern manifestation of historical institutionalized racism and segregation. From the 1920s until the 1960s local governments in the East Bay pushed minorities and poor communities to settle primarily in the Flatlands. These areas were adjacent to a high number of shipping ports and factories and as a result they were also exposed to a high level of air pollution. This has changed in the past 20 years as increased emissions regulations have lead to cleaner air in all parts of Oakland, especially the wealthier parts. Due to a mix of housing and development policies as described earlier property values have also increased. As a result, minority and poor communities are finding it financially difficult to afford an increasing cost of living.

Gentrification has twofold effects – first, people are forced to move to places that are cheaper than their former homes, which in the context of West Oakland and the East Bay is likely to mean more polluted areas – and second, displacement disrupts community capacity and prevents action against environmental injustices. However, many of the details between gentrification, displacement, and environmental justice are unanswered. As described previously, environmental justice is a loaded term that manifests in complex processes. A decrease in environmental burdens has the potential to cause displacement of the very residents that fought to get rid of those burdens. As demonstrated in the example in which *Clearing the Air* successfully achieved tougher regulations in West Oakland's shipping port however during this time gentrification immigration of affluent individuals was increasing in the area. Current

research still leaves a few questions unanswered. Is the disparity between environmental burdens of the wealthy and white populations and poor and minority populations increasing? What are the conditions of the places to which the displaced move? Are they comparably better or worse than those areas from which residents were displaced? Using air quality as my metric I have investigated these questions in Oakland.

METHODS

I have analyzed how air pollution and demographics have changed since 1990. I have paid particular attention to the recent demographic changes known gentrification with a focus on West Oakland. To compare trends in areas with different demographic compositions, I have also studied trends in Concord, Fremont, Livermore, San Francisco, and San Rafael.

Air Quality Metrics

I have used concentrations NO_2, ozone, and particulate matter of the size 2.5μm or less ($PM_{2.5}$) as of air quality for this study. These indicators of air quality were chosen for this study because they indicate a spectrum of pollution sources. I selected NO_2 because it is an indicator of diesel pollution. In West Oakland NO_2 primarily is emitted at its shipping port from diesel trucks and ships (Preble et al. 2015). In other locations diesel emissions were likely from truck and train shipping. I then selected ozone because it is an indicator of passenger vehicle emissions. Most test sites have major highways running within 2km of them (CARB 2015). Lastly, I chose to measure $PM_{2.5}$ because it is an indicator of fossil fuel combustion in vehicles, factories, and power plants. My data came from the 2015 release of the Air Quality Data DVDs with data collected by Bay Area Air Quality Municipal District, the California Environmental Protection Agency Air Resources Board.

Part of my pilot study was assessing the availability of data, BAAQMD responded and sent 7GB of air quality data from 1984-2013 within a week of my requesting it. Any data missing from the DVD was collected from the California Air Resource board http://www.arb.ca.gov/adam/index.html.

Population Data and Initial Regression

Population data was collected using the US Demography interactive map report creator from Social Explorer at http://www.socialexplorer.com. Using location data from BAAQMD I used Google Earth Pro to best approximate the street address from the coordinates of site locations. I used the create report feature within the Social Explorer map to collect data on the census districts surrounding my test sites. Once I selected create report I entered the approximated address of each test site into the search bar. Using the circle selection tool, I selected all census districts within 2km of the approximated address for each monitoring site. I then generated reports to find total population of African Americans (African American identified alone, individuals) by selecting the essential demographic report and to find the total population of individuals under the poverty line by selecting the poverty report. I repeated this for every test site then copied the percentages of population from each demographic group out of the total population into Microsoft excel.

After all demographic data was collected for a site I compiled it into a CSV file ready for regressions testing with air pollution in R statistics. Using the macros GUI in Microsoft access on the BAAQMD DVD, I generated yearly reports of air NO_2, Ozone, and $PM_{2.5}$. I copied yearly measurements of NO_2, Ozone, and $PM_{2.5}$ into the CSV with demographic data for the years both demographic and air pollution data were available. Those years were 1990, 2000, and 2009-2013. Once each CSV was assembled I used the Rcmdr package in R to find any trends between the two demographic traits and each air pollution metric. For each significant association ($P < .05$) I generated a plot and a least squares trend line for visualization. Plots of statistically significant relationships for West Oakland are included in appendix A.

Measuring Gentrification - Migration Demographics

To see how gentrification and air quality are interrelated I have calculated migration of various demographic groups over yearly intervals for the past 10 years. I have used a slightly modified version of Karen Chapple's migration equation[1] (shown below) to calculate immigration and emigration of people in different income brackets and of different ethnicities.

Modification was essential to find migration across census collection rather than between American Community Survey (ACS) (1-year gaps).

Equation 1. Original and Modified Equations Karen Chapple's Migration Equations and Study-modified

Original:

$$In\ Movers = Total\ number\ of\ persons - lived\ in\ same\ house\ 1\ year\ ago$$

$$Out\ movers = total\ Pop_{2014} - total\ Pop_{2013} - In\ movers$$

$$In - Migration\ Rate = (\frac{Number\ of\ In - Movers\ to\ Tract\ X\ in\ 2014}{Total\ Population\ in\ Tract\ X\ in\ 2013})$$

$$Out - Migration\ Rate = (\frac{Number\ of\ Out - Movers\ to\ Tract\ X\ in\ 2014}{Total\ Population\ in\ Tract\ X\ in\ 2013})$$

Modified:

$$Relative\ Change\ in\ population = \frac{population\ in\ data\ point - population\ in\ previous\ data\ point}{population\ in\ previous\ data\ point}$$

$$Normalized\ Net\ Migration = (\frac{Relative\ Change\ in\ population}{years\ between\ samples}) * 100$$

I have used this data to find migration rates for African American individuals and people below the poverty line in each test area. I then regressed these rates against the rate of change in levels of NO_2, ozone, and over each 5-year interval in the past 20 years up to now. This relationship shows how related migration of people with certain attributes (specific income level and ethnicity) is to changing levels of air quality indicators. Lastly, I have regressed the populations of African Americans for each of the past 20 years separately against levels of NO_2, ozone, and particulates in West Oakland in order to show the relatedness of air quality and population demographics.

Air Pollution Burden

In order to find a relationship between the process of gentrification and the process of air pollution burden for NO_2 I have derived an equation to measure burden on the two demographic groups I have studied. Burden from ozone pollution and $PM_{2.5}$ pollution were not analyzed due to the results of the air quality metric analysis that showed less strong associations between demographic groups and ozone and PM2.5 concentrations.

$$Burden = \frac{[Pollutant] * Population\ in\ target\ Demographic\ in\ a\ census\ tract}{Total\ Population\ of\ target\ Demographic\ in\ all\ areas\ studied}$$

This equation reveals how the disparity between the wealthy and poor and African Americans and Caucasians has changed since 1994 as costs of living in Oakland and San Francisco have sharply risen.

Lastly, I have used the Cal Environscreen 2.0 tool to create a map of diesel particular matter concentration. Diesel particulate matter concentration serves as an analogue for a map of NO_2 concentration because the two pollutants come from diesel pollution.

RESULTS

I compiled air pollution data compiled by Bay Area Air Quality Municipal District (BAAQMD) in conjunction with the California Air Resources Board (ARB) and the California Environmental Protection Agency. I collected population data by census tract for 1990, 2000, 2009-2013 from American Community Survey (ACS) and decennial Census data from the US Census Bureau via socialexplorer.com/explore/maps. Employing this data, I derived burden from NO_2 and Ozone pollution for African Americans and low-income families over each year studied. Gentrifying areas show a reduction in populations of minorities and low income individuals. Places with lower costs of living show an increase in these populations. Pollution in the gentrifying areas is decreasing more rapidly (and is at overall lower levels compared with areas with lower costs of living). Conjunction with burden calculation, the burden gap is increasing between African American populations and Caucasian populations and the poor and more wealthy.
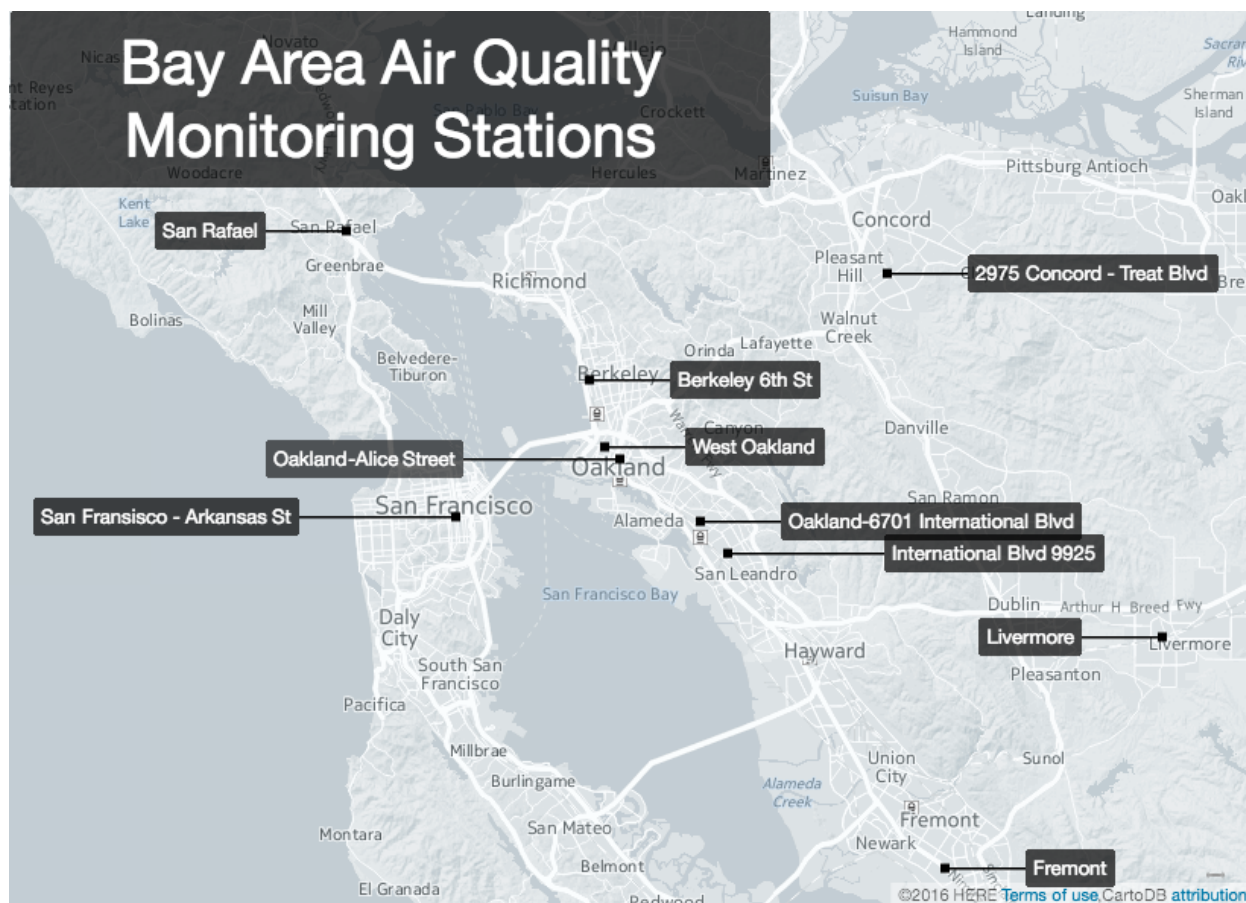
Figure 1. Map of local San Francisco Bay Air Pollution Monitoring Stations. Spatial Data from BAAQMD plotted using CartoDB mapping tools.

Air Quality Metrics

Most study sites exhibited improvement in air pollution overall. I used county wide data to find general trends for the change in air pollution over time at monitoring stations in certain areas of the Bay (Table 1). Only Marin and San Francisco counties experienced diminishing air quality in PM2.5 and ozone respectively.

Table 1. Overall Trends in Air Pollution over time in the San Francisco Bay Area since 1994. Data from BAAQMD and CARB.

County	Pollutant	Reduction Since 1994
Alameda	NO2	27%
Alameda	Ozone	3%
Alameda	PM2.5	20%
Contra Costa	NO2	55%

Contra Costa	Ozone	39%
Contra Costa	PM2.5	37%
Marin	NO2	43%
Marin	Ozone	9%
Marin	PM2.5	-8%
San Francisco	NO2	39%
San Francisco	Ozone	-25%
San Francisco	PM2.5	31%

Alameda, Contra Costa, Marin, and San Francisco counties all showed a significant decline in NO_2 concentrations since 1990 (table 2). Contra Costa county was the only site with a significant association between Ozone and years since 1990. All other counties had no significant R^2 or $P \leq .05$. Lastly, I found statistically significant moderate associations between $PM_{2.5}$ and time since 1990 for Alameda, Contra Costa, and San Francisco. I also found that compared to downtown Oakland, West Oakland has more NO_2 pollution and $PM_{2.5}$ pollution for the years data was available for both sites (2010-2014). NO_2 levels are on average 5ppb higher from 2010 (when testing began for this site) for the West Oakland monitoring site relative to all other Bay Area testing cites. Additionally, since 2009, Particulate Matter has been higher in all Oakland monitoring sites relative to monitoring sites in the city of San Francisco.

Table 2. Trends Over Time in Air Pollution Concentrations Since 1994. Pollution data from BAAQMD and CARB regressed against years since 1990.

Site	Pollutant	Multiple R^2	P-Value
Alameda Co	NO2	0.85	9.88E-09
Alameda Co	Ozone	0.08	0.23
Alameda Co	xx	0.39	0.012
Concord-2975 Treat Blvd	NO2	0.97	1.35E-14
Concord-2975 Treat Blvd	Ozone	0.47	0.001
Concord-2975 Treat Blvd	PM2.5	0.43	0.008
Marin Co	NO2	0.96	4.00E-14
Marin Co	Ozone	0.17	0.7
Marin Co	PM2.5	0.11	0.25
San Francisco Co	NO2	0.97	5.91E-15
San Francisco Co	Ozone	0.005	0.77
San Francisco Co	PM2.5	0.4	0.011

Only certain sites show statistically significant relationships between percent of people in poverty and percent of African Americans out of the total population in a census tract collection for each region (table 3). Data assessed was for the years 1990, 2000, 2009-2013.

Table 3. Summary of Statically Significant Correlations. Air pollution data from BAAQMD & CARB, demographic data from the US Census Bureau collected from Social Explorer.

Site	Pollutant	Demographic	Correlation Coefficient (R^2)	P-Value
Concord	NO2	% African American	0.75	0.007
Concord	NO2	% in Poverty	0.84	0.003
Concord	Ozone	% in Poverty	0.92	0.0007
Fremont	NO2	% African American	0.7395	0.013
San Francisco	NO2	% African American	0.92	0.0006
San Francisco	NO2	% in Poverty	0.85	0.003
San Francisco	Ozone	% in Poverty	0.85	0.003
West Oakland	NO2	% African American	0.8945	0.0012
West Oakland	NO2	% in Poverty	0.0798	0.0173
West Oakland	Ozone	% African American	0.6862	0.0213
West Oakland	Ozone	% in Poverty	0.5355	0.0442
West Oakland	PM2.5	% in Poverty	0.8341	0.0109

Measuring Gentrification - Migrating Demographics

I found yearly rates of migration change for every monitoring district sampled. All tables other than West Oakland are included in appendix B. West Oakland lost African Americans at a rate of about .7 % per year (percent of relative total population of African American individuals) since 1990 (table 4). In addition, the number of people living in West Oakland in poverty as defined by the US Census Bureau increased at a rate of about 1.3% per year since 1990. San Francisco shows even more striking results with poverty increasing at an average rate of 3% per year. According Chapple & Zuk impoverished individuals have been leaving the city in favor of West Oakland, Concord, and Richmond (2015). Similarly, African Americans in the area within 2km of the air monitoring have been leaving San Francisco at an average rate of 1.7% per year since 1990 and are heading to those same locations. Lastly, the areas within 2km of the Concord Monitoring stations have experienced an increase in the population of low income individuals

and African Americans. Populations of low income individuals and African Americans within 2km of monitoring stations have changed less significantly at the other monitoring sites studied.

Table 4. Rates of change in population of Individual African Americans and Impoverished individuals per year in West Oakland. Rate of migration is given in units of $\frac{\%Change\ in\ Population}{years\ between\ samping\ dates} * 100$ and is calculated from US Census data. Immigration is denoted with a positive value and emigration is denoted with a negative value.

Time Frame	Migration of Impoverished	Migration of African Americans
1990-2000	1.3	-2
2000-2009	0.17	0.43
2009-2010	3.3	-4.4
2010-2011	-1.7	-1.6
2011-2012	6.6	5.4
2012-2013	7.6	1.6
Per Year Mean	**1.3**	**-0.7**

Air Pollution Burden

I calculated burden for African Americans and individuals below the poverty line using my burden equation. Nominal burden of NO_2 pollution on both impovereshed individuals and African Americans decreased at all sites except Fremont. However, the share of burden felt by impoverished indivudals and African American people has gone up in the areas to which these groups are moving. Therefore, the disparity of burden between those above the poverty line and those below the poverty line is increasing and the dispartiy of burden between white individuals and Africans American individuals is increasing as well.

Table 5. Burden of NO_2 pollution on Poverty in 1994 and 2013. Values calculated using my burden equation with data from the 1990 US Census and 2013 America Community Survey collected via social explorer.

Site	1994	2013
Concord	1.102	0.711
Fremont	0.963	0.976
Livermore	1.481	0.701
San Francisco	8.774	4.874
San Rafael	2.235	1.801
West Oakland	7.797	4.884

Table 6. Burden of NO₂ pollution on African American people in 1994 and 2013. Values calculated using my burden equation with data from the 1990 US Census and 2013 America Community Survey collected via social explorer.

Site	1994	2013
Concord	0.309	0.288
Fremont	0.734	1.443
Livermore	0.401	0.305
San Francisco	3.749	2.176
San Rafael	0.714	0.649
West Oakland	16.882	10.038

Figure 1: Diesel Pollution. Data collected through CARD and BAAQMD. Map generated as part of Cal-Eniroscreen 2.0. Relative diesel partimmiculative matter concentrations are anaolgous to NO₂ pollution.
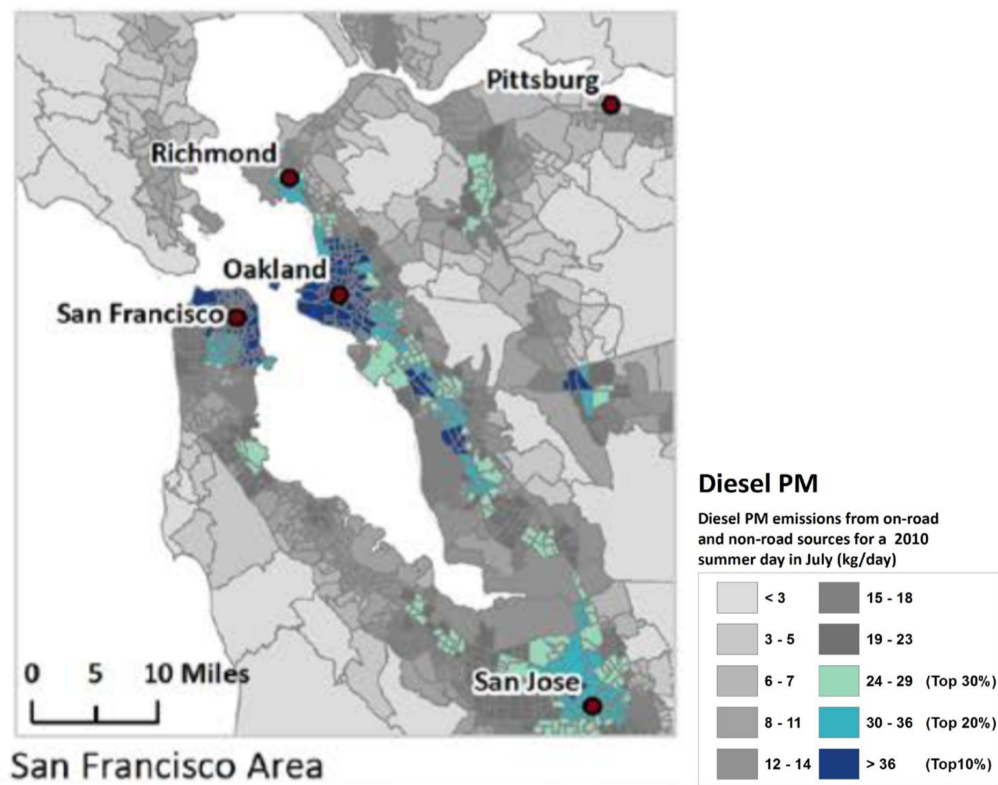
Using the Cal Enviro-Screen 2.0 tool I derived this map that shows diesel particululate matter trends. Burden from NO_2 pollution is higher for African Americans and those in poverty along the Eastern Side of San Francico and highest in West Oakland. NO_2 burden has decreased overall in each location, but it has decreased most signigifacantly in the areas that people are being displaced from and least signifcantly in the areas people are being displaced to. Addtionally, the differences between burden felt by white indivudals relative to African American indivudals has increased and the burden between those under the poverty line and those above the poverty line has increased. African American people and impovereshed individuals face less burden in areas other than San Francisco and West Oakland, however most poor people and African American people live in those areas.

DISCUSSION

My data suggests the San Francisco Bay Area has an environmental justice problem with regards to air pollution. I found that NO_2 concentrations are much higher in areas with larger populations of African Americans. The pollutant NO_2 has rapidly decreased over the last 20 years in the East Bay Area. This is most likely due to stricter regulations on cargo ships and freight trucks in the Port of Oakland that went into effect in the past 12 years. This decrease has been most pronounced in richer areas with larger populations of White individuals. African American individuals face a disproportionally higher amount of NO_2 pollution burden than other groups studied. The areas with the highest populations of African Americans - San Francisco and West Oakland - have much higher levels of NO_2 and the highest correlation between NO_2 concentrations and the population size of African Americans. For example, the percentage of the population of West Oakland of African Americans is highly correlated with NO_2 concentrations observed from 1990 to 2013 ($R^2 = 0.89$, *p < .05*). Analyzed spatial data representing air pollution burden suggests that migration - resulting from gentrification-related displacement - is causing the distribution of air pollution burden to become more stratified across dissimilar demographics.

Burden is disproportionately distributed within two tested demographics. The first demographic is race. Out of the six air monitoring sites testing in the Bay Area, sites with a higher proportion of White individuals and lower population of African American individuals boasted lower concentrations of pollutants of interest. Similarly, areas surrounding monitoring

sites in neighborhoods with high proportions of African American people to White people had higher concentrations of pollutants of interest. The second demographic is income. I identified a similar relationship with respect to wealth and poverty in Concord and San Francisco, but not West Oakland. I found that in Concord and San Francisco the percent of those under the poverty line is highly correlated with NO_2 and Ozone concentration (see Table 3). Additionally, the sites that had the largest decreases in NO_2 concentration since 1994 also had least amounts of poverty and the smallest populations of African Americans relative to the rest of the Bay Area. West Oakland and San Francisco have experienced an increase in the proportion of those in poverty. Similarly, in those areas air pollution concentrations decreased at a much slower rate for NO_2 and have been consistently about 2ppb higher than other regions in the Bay Area. I was unable identify significant changes in levels of $PM_{2.5}$ and Ozone since 1994 in cities other than Concord, San Francisco and West Oakland. In Concord and San Francisco ozone was only correlated only with percentage of individuals under the poverty not race. However, West Oakland Ozone concentration was somewhat related to percent under the poverty line and percent African Americans ($R^2 2$ = 0.54 and 0.68, respectively). Lastly, $PM_{2.5}$ was not found to significantly correlate with any demographic factor at any monitoring site except in West Oakland, where I found it correlated with poverty.

Air Quality Changes since 1994

NO_2 levels in all regions in the greater Bay Area decreased over time, while $PM_{2.5}$ and Ozone may have decreased slightly. NO_2 significantly decreased since 1994 in all Bay Area air monitoring sites observed in this study. The decrease in NO_2 is likely a result of stricter regulation of diesel cars, a ban on cargo ship idling in the port of Oakland, and freight truck emissions regulations following City of Oakland legislation in 2003 (CARB Plan to Reduce Particulate Matter from Diesel-Fueled Engines 2000, Preble et al. 2015). The lack of significant change in $PM_{2.5}$ and ozone concentration since 1994, and of correlation of $PM_{2.5}$ and ozone concentration is surprising. $PM_{2.5}$ was declared a toxic pollutant in California in 1999 and became more strictly regulated with the passage of the Children's Environmental Health Act, yet most the trends in pollutant concentration at each site did not differ significantly from the normal distribution (CARB 2002). One reason why $PM_{2.5}$ did not show any observable trends could

have been due to the location of the monitoring sites used in the study. Many sites were not located directly adjacent to or downwind from highways. Vehicles on highways can contribute to greater levels of $PM_{2.5}$ pollution in areas of high traffic volume (Eeftens et al. 2012). Similarly, the lack of statistically significant change in ozone concentration of the past 20 years could be attributed to ozone's relationship with weather or increasing levels of volatile organic compounds in Bay Area air (Ludwig 1995).

Changes in NO_2 were most dramatic for monitoring stations located in regions with median levels of pollution concentration for 1994 (about 17ppb). This means that air monitoring stations with the worst levels of NO_2 pollution in 1994 were more likely to have the worst air quality in 2013 than other air monitoring stations. In 1994 and in 2013 areas with the highest amounts of air pollution also had the largest populations of African Americans and those living in poverty. NO_2 concentration and year are strongly negatively correlated suggesting that NO_2 concentrations have decreased overall since 1994. I also found NO_2 concentration to positively correlate with the population of African Americans and I found NO_2 concentration to positively correlate with population of those under the poverty line the line for West Oakland.

Gentrification and Migration:

The composition of the populations in each census tract surrounding monitoring stations has changed since 1990. The population within a two kilometer radius of the West Oakland monitoring station has grown since 1990 from about 40,000 to about 56,000 in 2013, but that growth is primarily white individuals and not African American people. In fact, since 1990 the population of African Americans within 2 km of the West Oakland air monitoring station has fallen at a rate of 0.7% per year. Changes in population were notably higher between 2012 and 2013.

Reanalyzing the factors that result in gentrification for each air monitoring site studied is outside the scope of this paper. However, overlaying my demographic and air pollution data with research on gentrification in the Bay Area can provide insight into the social and environmental justice issues associated with gentrification. My measurements are consistent with Karen Chapple's Report on Urban Displacement in supporting that minority populations and low income individuals usually come from downtown San Francisco or downtown Oakland, and are

moving to areas of the East Bay with higher concentrations of NO_2 (Zuk & Chapple 2015). The same trend may be repeating in other areas of the Bay. What I have found supports that hypothesis. The areas within a 2km radius of the Concord, Fremont, and Livermore monitoring stations showed an increase in the population of African Americans and the areas within 2km of the San Francisco and West Oakland monitoring stations showed a decrease in the population of African Americans since 1990. Lastly, the area around the San Rafael monitoring station did not have a statistically significant change in the population of African Americans. The areas within a 2km radius of the Concord, Fremont, West Oakland, San Francisco, and San Rafael monitoring stations exhibited increases in the population of low-income individuals while the area surrounding the Livermore monitoring station showed a decrease in population of low income individuals since 1990.

These demographic trends have a few possible explanations. Chapple and Zuk (2015) found that most people moving maintained their jobs during the move and that primary motivation of moving was to live in an area with a lower cost of living. Maintaining one job attracts many, especially those of low income, to stay near Bay Area Rapid Transit (BART) lines in order to get to work (Zuk & Chapple 2015). West Oakland has a BART stop on its West side, and as a result West Oakland may be seen as a convenient and cheap alternative to living in San Francisco for those employed in the City of San Francisco. Another reason for the observed demographic trend is that many people seek to be part of a greater community where they live. Freudenberg et al. (2011) suggests that displaced individuals and families seek to find cohesive communities, and therefore many African Americans likely seek areas such as such Richmond and Concord that have growing African American communities.

From this information some may claim that people are choosing to live in polluted areas, but that argument ignores the history of urban planning in the Bay Area that restricted African American's settlement to certain neighborhoods. The majority of African Americans that live in the East Bay are still located in areas that underwent redlining in the 1930s (US Census 2010, Massey & Denton 1993). Bay Area cities did not promote opportunities for integration after red-lining was no longer practiced. It is likely that people residing in red-lined areas were also limited by mobility (prior to the construction of BART in the late 1960s). This left them few options for work outside their neighborhoods. As a result, African Americans in West Oakland

were limited to working low paying jobs that hindered them from having the opportunity to move to wealthier, less polluted neighborhoods. (Massey & Denton 1993).

Today many displaced African Americans from East San Francisco and West Oakland are tied to the BART lines for economic livelihood because they use BART to commute to work (Zuk & Chapple 2015). Places with lower costs of living include parts of Concord and Richmond, which have higher concentrations of criterion pollutants than most other areas in The Bay (CARB 1994-2013, Census 2010). African American people and poor people displaced by increasing costs of living have few places to go if they wish to stay in The Bay Area and retain their jobs. As such environmental injustice is perpetuated through the migration and air pollution trends I have found. My data shows that poor people and African American people are being driven to areas with similar or greater concentrations of NO_2 than their home neighborhoods. The process of gentrification is pushing people that are disproportionately affected by environmental hazards, namely poor people and African Americans, to new locations.

Burden and Social Implications:

Air pollution burden has become more inequitably distributed. Relative rates of burden have increased for low-income individuals and African American individuals, while burden has decreased for more affluent individuals and White individuals. The Bay remains highly segregated with most African Americans currently situated in similar locations to those occupied by this demographic in the 1930s during the red-lining era (US Census Bureau 1930, 2010 via Social Explorer). The Flatlands - the land in the East Bay closest to SF Bay - still contains the highest populations of African Americans and those under the poverty line (US Census 2010). The major change in those demographics today are likely a part of gentrification in the East Bay (Chapple & Zuk 2015). Wealthier, predominantly White areas are expanding into neighborhoods formerly occupied by impoverished Black communities. Income and property values in these areas are increasing, but many residents cannot afford increasing costs of living and, as a result, they move into the remaining lower income areas in the East Bay such as West Oakland, Fremont, and Concord (Zuk & Chapple 2015). My findings show that overall, pollution is down in the Bay Area, but the risk of breathing in more polluted air is up for African American and

low-income people relative to the rest of the population. Risks will continue to increase if current trends continue.

This overarching, decreasing trend can conceal disparities if reports on air pollution focus on the overall decreasing trend of air pollution, rather than focus on the spatial and socioeconomic disparities between regions of the East Bay. Ignoring socioeconomic inequities honors a history of racialized development in West Oakland and the rest of the Bay Area. Pollution is not distributed in low income communities and African American communities randomly. BART and highways were sited by the city of Oakland such that they cut directly through economically strong Black neighborhoods. The City of Oakland cited these projects with the intention of spurring new economic growth as part of the city's revitalization plans (Self 2003). Those neighborhoods were primarily African American and low income as a result red-lining, which prevented Blacks and the poor from being allowed to move elsewhere (Massey & Denton 1993). Now historically Black and poor neighborhoods host some of the least expensive properties in a region of increasing costs of living (Elkins 2015). As a result, these neighborhoods are seen as good investments for renovation and revitalization. The changing costs of living are forcing out old residents (Chapple & Zuk 2015). This process is a modern analogue of red-lining likely not borne not from racist intentions but from ignorant urban planning. Though developers unlikely have racist intentions, planning that does not recognize the Bay Area's history can increase racial segregation and displace the poor. Contemporary policies in the Bay Area lack provisions, such as rent control, to prevent coerced movement and lack environmental monitoring at the community level that could expose environmental inequities. The current trend increases burden on the poor and Black relative to the general population, however many policies and community based campaigns have the potential to alleviate overall burden and disparity in burden.

Limitations and Future Directions:

The coarseness of my data limited my study to a census tract-group level analysis rather than a neighborhood-by-neighborhood level analysis. To have a more complete analysis, future studies should collect and analyze data, ideally, at the census block level. This study has done that at a broader level, but much of the literature on gentrification and urban displacement

suggests that demographic change is best analyzed at the community level (Ellen & O'Regan 2011). The use of census blocks would refine my study's level of analysis to the community scale, and is likely to lead to a better understanding the specific processes that make neighborhoods more or less predisposed to demographic transitions such as gentrification.

Additionally, I had similar limitations with my air pollution data. The air pollution data I used was rather coarse. BAAQMD and the CA ARB monitoring stations are spatially limited, not randomly assorted, and some locations provided incomplete data. The six stations I analyzed had the most complete data out of 12 stations that had collected incomplete data in The Bay Area sometime between 1990 and 2013. An ideal study would set up many more monitoring stations at the census block level. This would allow for detailed mapping of pollution burden in the area. Unfortunately, setting up more monitoring stations is difficult because of equipment costs and labor needed to conduct such detailed data collection. It may be possible to effectively engage communities in a study to monitor their own air because they should have an inherent concern for the quality of their environment. Ultimately, by reducing coarseness more statistical tests can be performed with a more refined analysis to get localized trends instead of regionalized trends.

Lastly, my report relied on other studies to find data on the drivers of Bay Area demographic change. Surveying individuals and families that have recently been displaced can provide the most accurate and detailed data on why people are moving. This can circumvent issue of relying on foreclosure data or property value data as proxies for forced movement. Although this study did not provide a community-level assessment of burden, it suggests a strong relationship between race and income with NO_2 levels. I suggest future studies should focus on a community-engaged community level analysis of pollution burden. This study can serve as the framework for other studies and lead to the creation of policies to limit disparities in burden.

Broader Implications:

Ensuring that minority populations are adequately protected and heard in local government can prevent large disparities in burden based on race or socioeconomic class. My study provides foundational evidence, for future research examining demographic change and its relationship with changes in air pollutions burdens. I have created a methodology to examine the relationship between any form of pollution to population dynamics. In addition, the results of my

study suggest that more effort should be devoted to creating policies that prevent environmental burden disparity from increasing. Burdens are currently changing, which means the social dynamics and city-level policies that allow for burden to become inequitable are present now, and should not be viewed only as a relic in city planning.

Programs and policies aimed at building community capacity, as discussed prior, have the potential to create strong and politically engaged communities (Minkler et al. 2015, Freudenberg et al. 2011). These communities can protect themselves from environmental injustices by monitoring air pollution and other sources of environmental burdens. Communities can use the data they collect as evidence for the need of stricter regulations on polluters. The Pacific Institute examined a community based monitoring group that already exists in West Oakland in its report on reducing diesel pollution in West Oakland (2003). It is known as The Coalition for West Oakland Revitalization. This organization has partnered with scientists and policy makers to monitor air quality and lobby for stricter air pollution regulations for the Port Oakland ships and cargo trucks. Individuals and small groups in communities can begin organizations similar to the Coalition for West Oakland Revitalization by reaching out to scientists and policymakers and asking their city, country, or local governments for funding to enable poorer members to become active members. Such organizations can conduct the finest possible analyses of environmental burden and will have an intrinsic motivation for their studies. Study results translate into policies that can lead to a reduction in burden and increased pollution equity. My study has demonstrated the potential of statistical and geospatial analyses to illustrate the dynamics of environmental burden in modern metropolitan areas. Scientists and communities should continue similar studies at finer levels and lobby for policies that promote environmental equity.

ACKNOWLEDGEMENTS

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APPENDIX A: REGRESSION TESTING

Figure A1. Plots of Statically Significant Correlations of NO$_2$ and O$_3$ concentrations in West Oakland. Air pollution data from BAAQMD & CARB, demographic data from the US Census Bureau collected from Social Explorer.
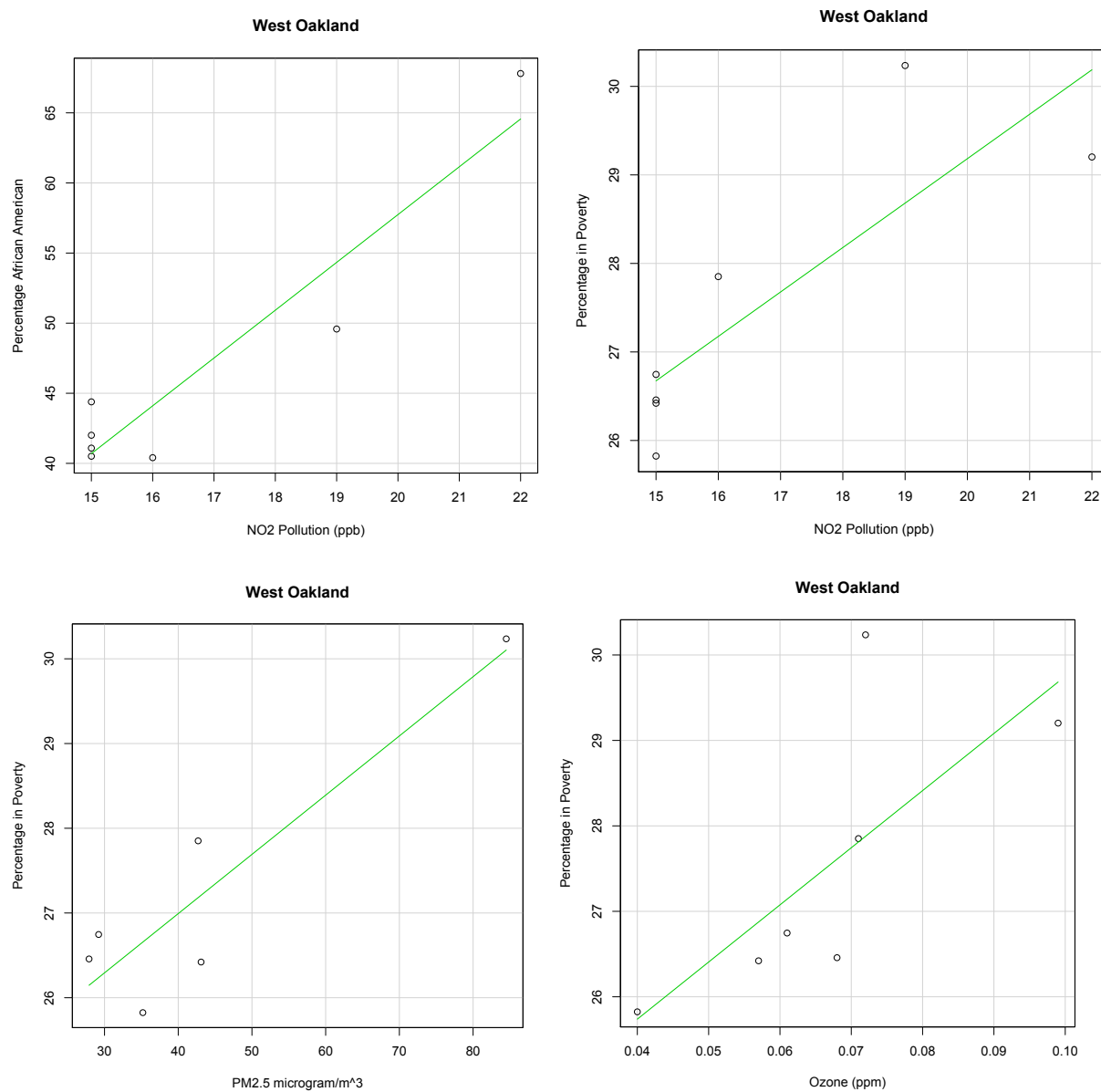
APPENDIX B: MIGRATION RATES

Tables B1-B5. Rates of change in population of Individual African Americans and Impoverished individuals per year in Various Bay Area Cities. Rate of migration is given in units of $\frac{\%Change\ in\ Population}{years\ between\ samping\ dates} * 100$ and is calculated from US Census data. Immigration is denoted with a positive value and emigration is denoted with a negative value.

Table B1: Concord

Time Frame	Migration of Impoverished	Migration of African Americans
1990-2000	0.79	4.49
2000-2009	4.88	-0.1754
2009-2010	2.57	40.29
2010-2011	13.4	-6.67
2011-2012	9.17	20
2012-2013	8.11	-10.4
Per Year Mean	**3.7**	**3.8**

Table B2: Fremont

Time Frame	Migration of Impoverished	Migration of African Americans
1990-2000	7.23	2.02
2000-2009	3.22	5.47
2009-2010	8.31	23.46
2010-2011	-0.74	3.8
2011-2012	4.36	23.74
2012-2013	-1.73	13.71
Per Year Mean	**4.9**	**5.8**

Table B3: Livermore

Time Frame	Migration of Impoverished	Migration of African Americans
1990-2000	-0.16	-0.86
2000-2009	0.65	7.38
2009-2010	-15.56	13.89
2010-2011	30.06	6.68
2011-2012	-1.77	-0.13

2012-2013	13.83	-15.73
Per Year Mean	**1.4**	**3**

Table B4: San Francisco

Time Frame	Migration of Impoverished	Migration of African Americans
1990-2000	3.29	3.28
2000-2009	-0.71	-4.84
2009-2010	18.31	-18.76
2010-2011	9.16	6.35
2011-2012	4.24	-13.21
2012-2013	9.83	-1.48
Per Year Mean	**3**	**-1.7**

Table B5: San Rafael

Time Frame	Migration of Impoverished	Migration of African Americans
1990-2000	5.07	-1.89
2000-2009	-0.1	0.81
2009-2010	-8.08	-20.11
2010-2011	21.25	18.89
2011-2012	-0.224	22.86
2012-2013	20.26	20.91
Per Year Mean	**3.6**	**1.3**