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Original Paper

Air Pollution Burden and Three Population Health Indicators in 58 Counties Comprising the State of California, USA

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Abstract

Air pollution is a major risk factor in human health causing premature death disease and ranks fifth among the top five leading causes of death worldwide. In California, air pollution attracts significant attention due to increased pollution from fossil fuel burning, industry, transportation, and the state's drought record and fire-proneness. Data used in this analysis was obtained from the CalEnviroScreen pollution monitoring tool. There is significant variation in air pollution across counties and racial groups. Hispanic populations, followed by Caucasians, predominantly occupy areas with the highest pollution levels above 40%. Most counties had low average scores in population parameters that determine population health. Pollution burden predicted asthma and CVD prevalence but not low-birth-weight babies. Asthma was closely associated with traffic density, $PM_{2.5}$*, cleanup sites, and ozone levels; low-birth-weight babies were associated with traffic density and release of toxic substances; and CVD was associated with* $PM_{2.5}$*, toxic release, and cleanup sites. Low HPI scores (<40%) were associated with incidences of asthma and CVD but not low-birth-weight babies. The increased population health compromises in California caused by the effects of air pollution call for a paradigm shift in the way population health is evaluated and effects of air pollution mitigated.*

Keywords

air pollution, CES, pollution burden, HPI, population characteristics, asthma, CVD, low-birth-weight babies

1. Introduction

Outdoor and indoor air pollution is an established risk factor to human health worldwide and ranks fifth among the five leading risk factors for death globally after diet, hypertension, smoking and elevated fasting blood glucose levels (GBD, 2017). The air pollutome is a complex mixture of gases (NO_x, O_3, SO_2, NH_3 and CO), volatile droplets (quinones and polycyclic aromatic hydrocarbons), and primary and secondary particulate matter (Pier et al., 2019). In 2017, it was estimated to cause more than 5 million deaths worldwide with a reported 2.9 years loss to life expectancy in 2015 (Lelieveld et al., 2020; Santos et al., 2021). Early concerns about air pollution focused on industrialization and the use of coal and the resulting emission of gases and particles. After World War II, the accelerated development of industries and expansion highway systems increased traffic to urban and industrial centers from expanding suburbia adding a new dimension to air pollution, one that was less sooty but more chemically reactive driven by photochemical transformation of auto exhaust, yielding secondary oxidants that caused eye and throat irritation (Stanek et al., 2011). Air pollution increases morbidity and mortality in the general population, and studies report that adverse fetal, infant, and childhood growth and development are associated with increased risk for disease development in adulthood (Swanson et al., 2009). Ambient and air traffic-related air pollution and exposure to different levels of particulate matter (fine [$PM_{2.5}$], coarse [$PM_{2.5\text{-}10}$], and large [$PM_{>10}$]) in young children leads to lower health outcomes with increased cardiovascular morbidity, asthma development, wheezing, respiratory infections, allergies, and adverse neurodevelopmental effects (Gheissari et al., 2022). Globally, WHO reports that 93% of children under the age of 15 years live in environments with higher than the recommended levels of environmental air pollutants (WHO, 2018). Dondi et al. noted that even low levels of air pollution can affect children's lung function and growth and increase the frequency and incidence of respiratory diseases such as asthma, bronchiolitis, respiratory infections, and bronchitis (2023).

Air pollutants have been implicated in cancer etiology, premature mortality, asthma, chronic obstructive pulmonary disease, cardiovascular disease; aggravate existing chronic conditions like type-2 diabetes; and raise risks of Alzheimer's disease and dementia (Apte et al., 2015; Erickson & Jennings, 2017; Erickson, 2017; Liu et al. 2021). Unfortunately, the ambient air pollution disease burden is not equitably distributed across individuals, communities, countries, regions, or demographic groups. Past studies indicate higher-than-average air pollution exposures for racial/ethnic minority populations and lower-income populations in the United States leading to disparities in attributable health impacts (Liu et al. 2021). Historically, the immigrant status, race and ethnicity have been closely associated with economic opportunity, education access, affordable housing, food security, transportation, and healthy, safe environments (Mir et al., 2013; Matsui et al., 2020). Race and ethnicity have been found to influence health through the harmful effects of discrimination, racism, exclusionary policies, and segregation (Morello-Frosch et al. 2001; Balazs et al., 2011). In California, air pollution is a big public health concern as there are various types of pollutants coming from the burning of fossil fuels, and industrial and transportation activities. Air monitoring shows that over 90 percent of Californians breathe unhealthy levels of one or more air pollutants during some part of the year. These pollutants chiefly include ozone, $PM_{2.5}$ and PM_{10}, oxides of nitrogen (NO_x), carbon monoxide, oxides of sulfur (SO_x), lead, and hydrogen sulfide (ARB, 2023).

In the United States, air pollution was associated with ~100,000 annual premature deaths in 2017 (Stanaway et al., 2018). The Emission Inventory Improvement Program (EIIP) was established in 1993 by the United States Environmental Protection Agency (EPA) to promote the development and use of standard procedures for collecting, calculating, storing, reporting, and sharing air emissions data. It was designed to promote the development of emission inventories that have targeted quality objectives, are cost-effective, and contain reliable and accessible data for end users (EPA, 2023). The EIIP inventory and materials are available to states and local agencies, the regulated community, the public, and other stakeholders. Although California outdoor air quality has made tremendous improvements in the last 2-3 decades, the pollution reduction and resulting health and environmental benefits are not uniformly distributed across the state, within a region, or among all population segments (CalEnviroScreen, 2023).

In the state of California, a pollution monitoring tool (CalEnviroScreen) was developed to analyze air pollution levels and human health effects in 58 counties in the state of California. The California Communities Environmental Health Screening Tool (CalEnviroScreen 4.0) released in October 2021, is the latest iteration of the California Communities Environmental Health Screening Tool. It was developed following consultation with government, academic, business, and nongovernmental organizations and 12 public workshops in 7 regions of the state that resulted in more than 1000 oral and written comments on 2 preliminary drafts (Alexeeff & Mataka, 2014). The CalEnviroScreen tool purposefully relies on publicly available data sets for transparency and relatively simple methods so that it can be understood by a general audience (Cushing et al., 2015). The CalEnviroScreen original and subsequent versions were developed by CA's Environmental Protection Agency's (CalEPA) Office of Environmental Health Hazard Assessment to evaluate the cumulative existence of multiple pollutants and stressors in communities (OEHHA, 2023).

The Health Places Index (HPI) is a project of the Public Health Alliance of Southern California, a coalition of the executive leadership of 10 local health departments in Southern California, representing more than 60% of the state's population. The HPI maps data on social conditions that drive population health (e.g., education, employment, clean air/water, neighborhood conditions, social resources, and health care access) composed of 25 indicators organized into eight policy domains. The overall HPI score is a sum of weighted domain scores, with the economy and education taking the lion's share (50% of total weights). Such social determinants of health indicators are often used by research institutions, policy makers and other stakeholders to evaluate health and well-being of communities, identify health inequities and quantify factors that influence health (Healthyplacesindex.org, 2023). The HPI is a tool that ranks communities at the census-tract level based on factors known to shape health outcomes

(Maizlish et al., 2019). The HPI was designed to help prioritize marginalized and disadvantaged communities in public policy and investments. It is composed of various social determinants of health indicators with weighted community-level attributes, and gives economic factors the most weight while housing, healthcare access, and environmental exposures are given less weighted (Cleveland et al., 2023).

Many communities in California experience a disproportionate burden of pollution from local sources like traffic and industry, but also from dispersed pollution in multiple media including air, water, soil, and farm produce. Most of these communities experience the additional socioeconomic stressors and health conditions that make them more vulnerable to the impacts of pollution (CalEnvironScreen, 2023). To address the cumulative effects of both pollution burden and these additional factors, and to identify which communities might need policy, financial, educational, or programmatic interventions, OEHHA developed and maintains and updates the CalEnviroScreen tool on behalf of CalEPA. Ferguson et al. use the term *triple jeopardy* to refer to the three-tiered conundrum facing low-socioeconomic status (SES) communities. They include exposure to greater environmental hazards, increased susceptibility to poor health outcomes due to pre-existing health burdens (e.g., chronic stress, poorer health status, less opportunity to choose health-promoting behaviors), and resultant health disparities across SES groups (2021).

The current study sought to explore and analyze both the CalEnviroScreen 4.0 and HPI data to explore how pollution levels in the state: a) varied across the 58 California counties; b) varied across the state’s racial groups and age categories; c) how pollution burden was associated by three indicators of health (asthma, low-birth-weight babies and cardiovascular prevalence); d) how individual pollutants were associated with people’s health; and lastly, e) how the HPI was associated with three population health indicators (prevalence of asthma, low-birth-weight babies, and cardiovascular conditions).

2. Method

2.1 CalEnviroScreen 4.0 Model

The CalEnviroScreen model evaluates the cumulative pollution burden and vulnerabilities in California on a geographical basis. The model considers 21 indicator variables in its assessment for each of California’s approximately 8000 census tracts. These indicators are divided into two main categories (pollution burden and population characteristics) and four subcategories (exposures, environmental effects, sensitive populations, and socioeconomic factors) as shown in Table 1. Each of the indicators was quantitatively measured for each census tract and was converted to a percentile rank relative to all other California census tracts. For each census tract, the score of each subcategory was determined by taking a mean average of the percentile values of its indicators. Pollution Burden was calculated by taking a 2:1 weighted average of exposures and environmental effects, respectively. Population Characteristics was calculated by taking a 1:1 average of sensitive populations and socioeconomic factors. Lastly, the CES 4.0 score for each county was calculated by applying min-max normalization on a scale of 0 to 10 for Pollution Burden and Population Characteristics separately and then multiplying them for a total CES score out of 100.

2.2 Data Transformation

The data used in this study comes from three publicly available data sources: CalEnviroScreen 4.0 tool, the CalEnviroScreen Race Analysis tool, and the California Health Places Index 3.0 tool. Statistical analysis was performed on these datasets using R (version 4.2.2) and using the native analysis packages that belong to base R. For each of the three sources, all census tracts were grouped by county that they belong to. For each of the 58 California counties, a mean average was taken for all reported metrics. This analysis done in the current study is performed on this county-level overview of the data.

Table 1. Components of CalEnviroScreen 4.0 Model

Pollution Burden		Population Characteristics	
Exposures	Environmental Effects	Sensitive Populations	Socioeconomic Factors
Ozone concentrations	Cleanup sites	Asthma emergencies	Housing-burdened low-income
PM2.5 concentrations	Groundwater threats	(ER visits)	households
Diesel PM emissions	Hazardous Waste	Cardiovascular Disease	Linguistic Isolation
Drinking H2O contaminants	Impaired water bodies	(ER visits for heart attacks)	Poverty
Lead risk from housing	Solid waste sites	Low-birth-weight infants	Unemployment
Pesticide use			Educational attainment
Toxic releases from facilities			
Traffic impacts			

2.3 Statistical Analysis

Using the three main metrics of the CalEnviroScreen model (Pollution Burden, Population Characteristics, and combined CES 4.0 score), we define counties to be high risk in that category if the county has a score greater than the 40th percentile. Using demographic breakdown for each county provided by the Race Analysis report, age group and race/ethnicity profiles were generated independently for the group of counties above and below the 40th percentile threshold for each of the three metrics. Race was reported by the CalEnviroScreen tool as seven categories: Caucasian, Asian American, Native American, African American, Hispanic, and other/multiple. Age groups were defined as under 10 years old, 10-64 years old, and over 64 years old. To determine how HPI is associated with the three indicators of community health (asthma, low-birth-weight-babies, and cardiovascular disease prevalence), a simple linear regression t-test was performed. Likewise, the association of each of the three health indicators with HPI and with Population Characteristics were independently investigated in the same manner.

To further study these associations and how individual factors were associated with people's health, multiple regression analysis was also performed on the group of indicator variables that make up the pollution burden and population characteristic scores. For pollution burden, the three health indicators were tested against eight pollutants (traffic volume, $PM_{2.5}$, ozone, toxic releases, pesticides, diesel particulate matter, hazardous waste, and hazardous cleanup sites). For population characteristics, the three health indicators were tested against five socioeconomic factor indicators (education, housing burden, linguistic isolation, poverty, and unemployment). To investigate possible associations between individual indicator variables, we performed a series of spearman correlation tests. The correlation of poverty with each of the other four socioeconomic factor indicators was studied as well as the correlations of unemployment with either linguistic isolation or education level. Lastly, individual correlation tests were performed on CES 4.0 score with each of the six reported race/ethnic groups.

3. Results and Discussion

The distribution of CES scores for all counties in the state are shown below (Fig. 1). Most of the counties (24) had CES percentile scores over 40%, 19 had scores between 31-40%, and 15 had CES scores less than 30%. Excluding population characteristics (health conditions, education, language barriers, employment, poverty level and housing), the pollution burden percentile rankings had 18 counties over 40%, 18 between 31-40%, and 22 below 30% (Fig. 2). As noted by Cushing et al. (2015), there is an uneven geographic distribution of the CES percentile scores across the state. California population distribution is skewed and concentrated in a few major urban regions: Sacramento, Fresno, Bakersfield, San Francisco, San Diego, and Los Angeles. Only 35.7% of California cities met the World Health Organization (WHO) target for annual $PM_{2.5}$ exposure of 10 $\mu g/m^3$, as compared to the national average of 81.7% (IQAir, 2023). Consequently, the top five cities with reported worst $PM_{2.5}$ and ozone levels in the country are in California and include Los Angeles-Long Beach, Visalia, Bakersfield, Fresno-Madera-Hanford, San Francisco-San Jose. In 2019, 11 of the 15 most polluted US cities were located within 50 miles of Los Angeles, while best air quality was found in the state's more sparsely populated interior cities, where vehicular and industrial emissions are relatively sparse, and wildfires are infrequent (IQAir, 2023). Information analyzed in this study also indicates that the 24 CES highest percentile scores greater than 40% are in those primarily urban counties that comprise of Los Angeles (67%), Alameda (12%), and Fresno (Fig. 1). Those with scores less than 40% were topped by San Diego (21%); Solano/Sonoma (17%) and both Santa Barbara and Santa Clara (12.5% each). Although some of those lower than 40% areas have major cities like San Diego and San Jose, it appears that a significant number of census tracts included in the database are away from the urban centers, and therefore have relatively cleaner and better-quality air.

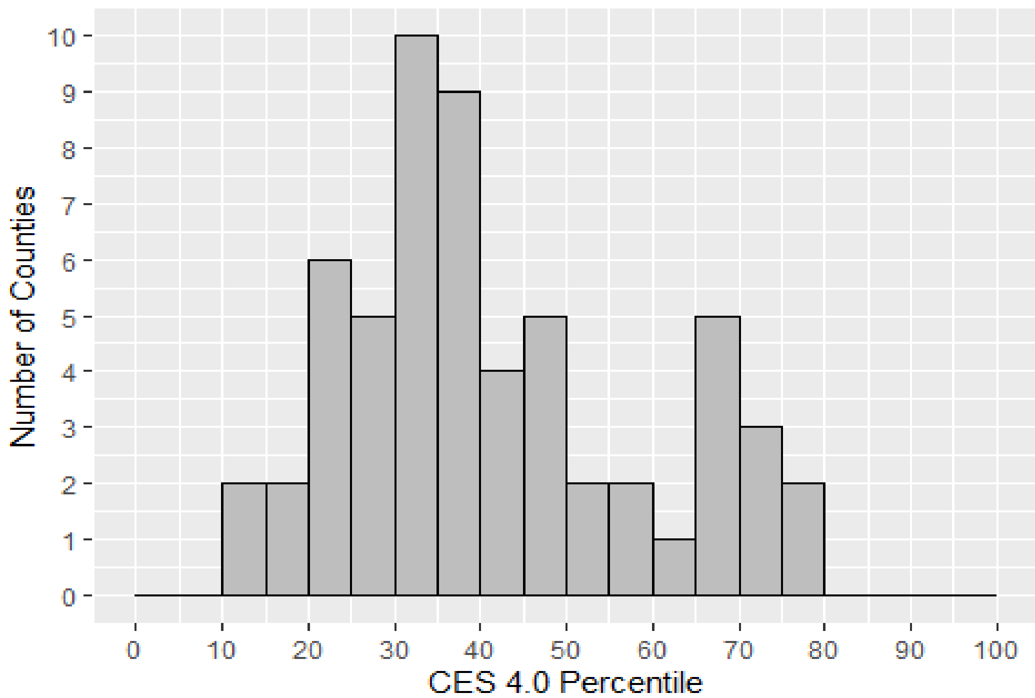


Fig. 1. Distribution of CES Percentiles Rankings in California

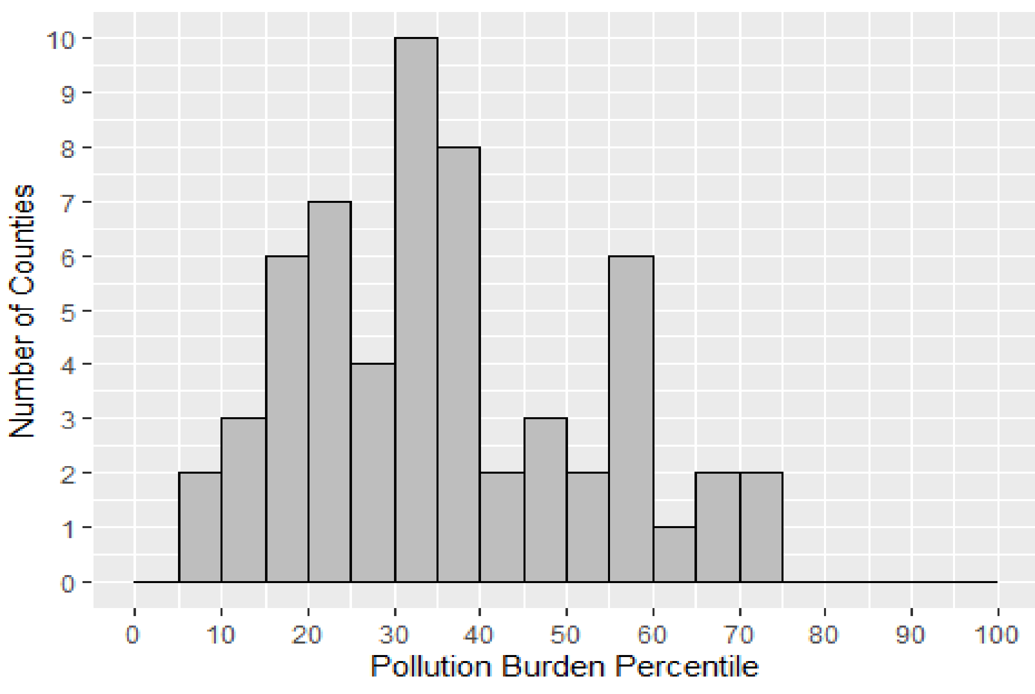
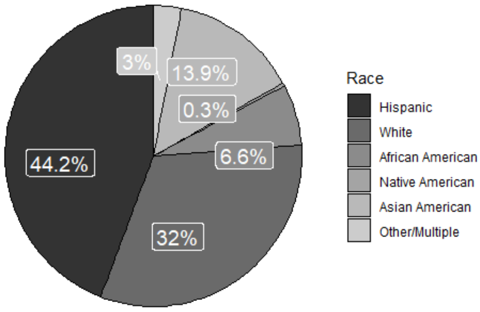


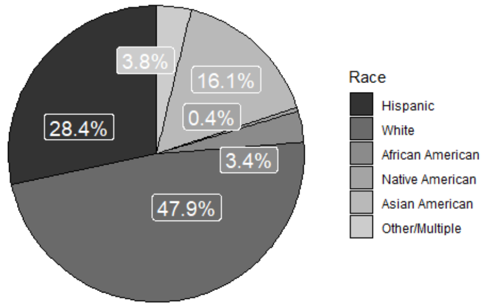
Fig. 2. Distribution of Pollution Burden Percentiles Rankings in California

Combined race profiles for the state shows that CES percentile scores greater than 40% were predominantly highest in counties occupied by Hispanic populations (44.2%), followed by Caucasian

(32%), Asian American 13.9% and African American 6.6%. Areas occupied by other races (Native Americans, multiple, and others) had low CES percentile scores of 3% or below. CES percentile scores less than 40% were highest in areas occupied by Caucasian populations (47.9%, followed by Hispanic (28.4%), Asian American 16.1% and African American 3.4% (Fig. 3a, 3b).

Although racial and ethnic diversity in California is high, it often is associated with distinct socioeconomic disparities, health disparities and disproportionate burdens of environmental pollution (Conroy et al., 2018). Mathiarasan and Huls noted that the intersection of both outdoor and indoor air pollution with socioeconomic conditions can result in many adverse health outcomes including respiratory (asthma, bronchitis, infections, and sleep disordered breathing), neuropsychological (developmental delays, structural alterations in the brain, slower working memory, and mental health issues), and a myriad of other health outcomes (2021). As stated by Bell et al., public health professionals, policy makers and healthcare practitioners consider racial health inequities to be crucial in understanding health outcomes in people of color (2020). In California, about 44% of the people in the state speak a language other than English at home (versus national: 21.6%) with 28% of people speaking Spanish, and 9.8% Asian and Pacific Islander languages. In 2020, approximately 39% of the population living in California were Hispanic, 35% Caucasian, 15% Asian or Pacific Islander, and 4% African American (PPIC, 2023). California has the largest population of Hispanics and the third largest percent Hispanic population nationwide. Comprising a total of 45% of California’s population of 39 million residents, Southern California has a higher percentage of Hispanics with approximately 10.6 million Hispanic residents, (US Census Bureau, 2023). California has a 12.3% poverty rate (versus national: 12.8%) with a median household income of about $84,907 (versus national: $69,717). Regarding educational attainment, only about 36.2% of the population have a bachelor’s degree or higher, and around 21% have a high school diploma (data.census.gov, 2020). The results in this study that people of Hispanic origin dominate in areas with a higher pollution burden (44.2%) than Caucasians and other traces (Fig. 3). These findings seem consistent with previous studies indicating that communities of color across the United States often live in places with worst air quality, more environmental hazards, and fewer health promoting environmental amenities like parks, trails, and open space (Cushing et al., 2015; Huang et al., 2018). In California, people of color experience more adverse health conditions (like asthma, cancer, bronchitis, preterm births, and cardiovascular disease) due toxic air contaminants from industry, live closer to hazardous waste sites and traffic, and in areas with significant water pollution (Balazs et al., 2011; Morello-Frosch et al., 2001). Studies from the northeastern United States report that the annual particulate matter (both PM_{10} and $PM_{2.5}$) was consistently higher in lower socioeconomic areas compared to areas of high socioeconomic areas; and that $PM_{2.5}$ concentrations were associated racial composition and were higher in areas with racial minorities (Brochu et al., 2011). Race and socioeconomic status are reported to be closely associated with a disproportionate level of disease in populations of color and many of the disparities in access to healthcare (Mathiarasan & Huls, 2021).

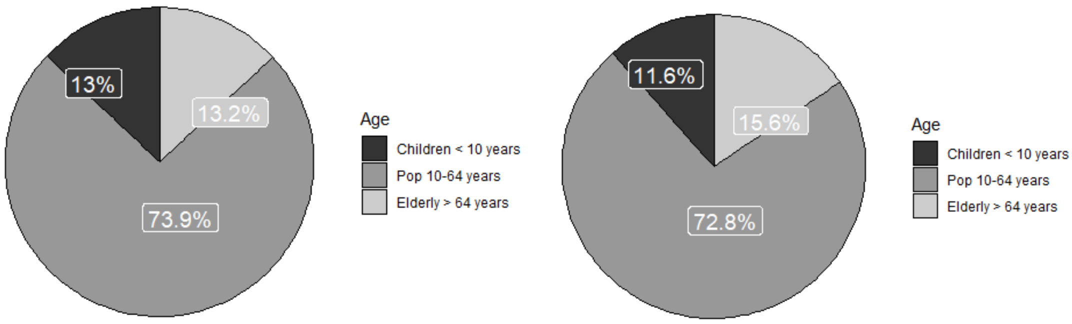




a) CES >40% b) CES <40%

Fig. 3. Combined Race Profiles of CES Percentiles Rankings in California

Combined age profiles for CES percentile scores greater or less than 40% are very similar. Most people living in those areas were respectively between 10-64 years of age (73.9% and 72.8%), seniors 64 years (13.2% and 15.6%), and children 10 years and under (13% and 11.6%) (Fig. 4a, 4b). The population of children in this study (11.6-13%) is small but significant because children are still in their early body and organ developmental stages making them more vulnerable to the effects of air pollution. Both intrinsic and extrinsic factors increase the vulnerability and/or susceptibility of individuals to the adverse effects of air pollutants. Past panel studies of children with and without asthma have noted that child lung function is a subclinical marker of acute pollution health effects, with short-term decrements in lung function observed with short-term increases in ambient air pollution. Short-term increases in air pollution are related to increases in adverse clinical events including ED or urgent care visits and hospitalization for respiratory illnesses (Spektor et al., 1988; Raizenne et al., 1989). Long-term childhood air pollution exposures have been demonstrated to likely shift the entire population distribution of childhood lung function and lung function growth downward (Garcia et al., 2021).



a) CES >40% b) CES <40%

Fig. 4. Combined Age Profiles of CES Percentiles Rankings in California

Studies on older adults report that this age-group is especially vulnerable to hazards in their immediate environment; and traffic-related pollution exposure has been shown to result in worse cognitive function among those living in more polluted areas (Ailshire & Clarke, 2015). Of particular concern to population health is when fine particulate matter ($PM_{2.5}$) is inhaled, the small particles are reported to cause damage to organs such as the brain (Peters et al., 2006). In a study of its kind, demonstrating an association between air pollution and cognitive function in a racially diverse sample of older U.S. men and women, living in areas with higher levels of $PM_{2.5}$, Weuve et al. showed that there was more rapid cognitive decline in the adults 55+ years over a 2-year period (2012). Markers of neuroinflammation and neuropathology associated with neurodegenerative conditions such as Alzheimer's disease have been linked to living in areas with high levels of air pollution especially of $PM_{2.5}$ (Peters et al., 2006). In this study, older adults were a significant proportion of the state's population making 13-15.6% of the total (Fig. 4a, 4b). With advancing age, pre-existing chronic disease in older adults (like asthma, COPD, pulmonary fibrosis, arrhythmias, hypertension, ischemic heart disease, diabetes, autoimmune diseases, and obesity) makes them more vulnerable to the combined health effects of air pollution. Older adults are also likely to experience immune-senescence, progressive decline in lung function, and greater incidences of hospitalizations due to air pollution exposure (Santos et al., 2021).

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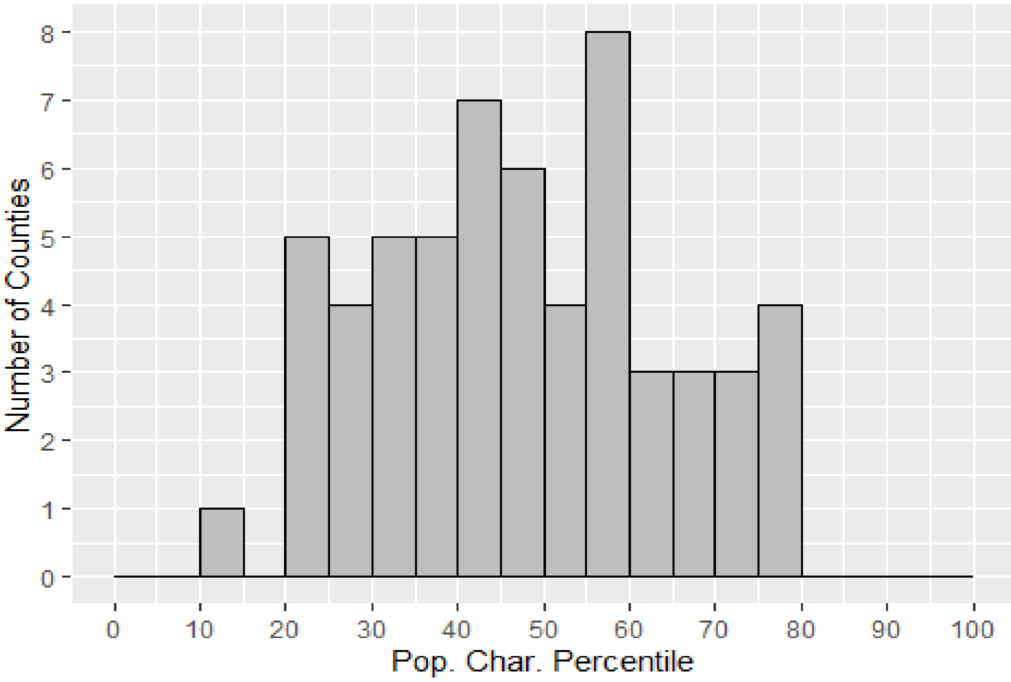


Fig. 5. Distribution of Population Characteristics Percentiles Rankings in California

The distribution of population characteristics (health conditions, education, language barriers, employment, poverty level, and housing) in California show that a slight majority of the counties (57%) had lower population percentile averages than the rest (Fig. 5). The relationship between asthma, low-birth-weight babies and CVD levels and population characteristics (poverty, race, housing, linguistic isolation, and unemployment) was also investigated. Multiple regression indicates that only poverty and linguistic isolation were significant for asthma; none of the characteristics were significant for low-birth-weight babies; and CVD was predicted by housing conditions, unemployment, and linguistic isolation, but only marginally associated with poverty levels (Table 2).

Table 2. Probability Values between Population Characteristic Percentiles and three Health Indicators

Population characteristic	Asthma	Low-birth-weight babies	CVD
Poverty	0.038*	0.09	0.051
Linguistic isolation	0.033*	0.77	0.02*
Unemployment	0.28	0.33	0.01*
Housing burden	0.41	0.82	0.02*

**Indicates significance*

Life course characteristics like socioeconomic status, level of education, existing health conditions, and employment contribute to differential air pollution exposure levels/risk and increases the susceptibility of people living in those conditions. Such susceptibility can be brought about by poor health status, addictions, other pollutant exposure, family history, psychological stress, and poor nutrition. Cushing et al. found that in California, there was significant evidence that cleanup and solid waste sites, concentrations of ozone and diesel particulate matter, and pesticide use are disproportionately located in communities with higher levels of poverty (2015). Several studies in China found that people with lower socioeconomic status normally experienced a higher health risk from air pollution, while people in middle or high socioeconomic levels had lower risks presumably because they had more ways and means to mitigate air pollution (Jiao et al., 2018). However, research on how life course characteristics influence the health effects of air pollution produced mixed results (Jiao et al., 2018 provides a good review). As part of the socioeconomic status of an individual, a study of 20 cities in the United States reported that individual education significantly modified the relationship between coarse particulate matter (PM_{10}) and mortality—specifically, the higher education level of the individual, the lower the effect of PM_{10} on mortality in (Zeka et al., 2006). People of low socioeconomic status usually lack a good education, and therefore lack the knowledge regarding health and environmental pollution in addition to the health effects caused by air pollution. As a result, they are more likely to have a lower level of awareness and means of self-protection (Jiao et al., 2018). Laurent et al. (2007) provided an alternative argument that the modification effect of socioeconomic status on air pollution health effects depended on the regional level at which socioeconomic characteristics were measured. When socioeconomic characteristics were measured at coarser geographical resolutions (like city, regional or statewide), there was no modification effect. When measured at community level, the results were mixed, but when individually measured socioeconomic characteristics were used, the result indicated disadvantaged people tend to be more affected by the effects of air pollution. Several reasons make people of low socioeconomic status more vulnerable to the effects of air pollution: most are in relatively poor health due to lack of resources, have poor diet, live in overcrowded households, have poor access to health services, are employed in jobs that expose them to more outdoor and indoor air pollution, and live in areas with less opportunities for physical activity and exercise.

A simple regression analysis of: a) pollution burden and asthma prevalence indicates a significant relationship [$F\ (1,56) = 4.71$, $p=0.034$, Fig. 6a]; b) pollution burden and low-birth-weight babies prevalence (Fig. 6b) indicates no significant relationship [$F\ (1,56) = 2.57$, $p=0.115$], and c) pollution burden and cardiovascular disease (CVD) prevalence (Fig. 6c) indicates a significant relationship [$F\ (1,56) = 5.67$, $p=0.021$].

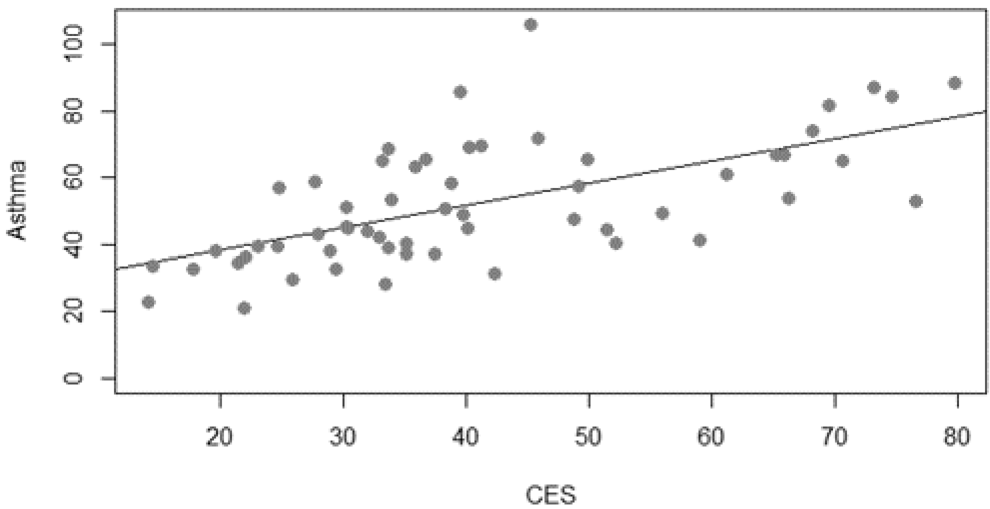


Fig. 6a. Relationship between Pollution Burden and ~~a~~Asthma Prevalence (p=0.034)

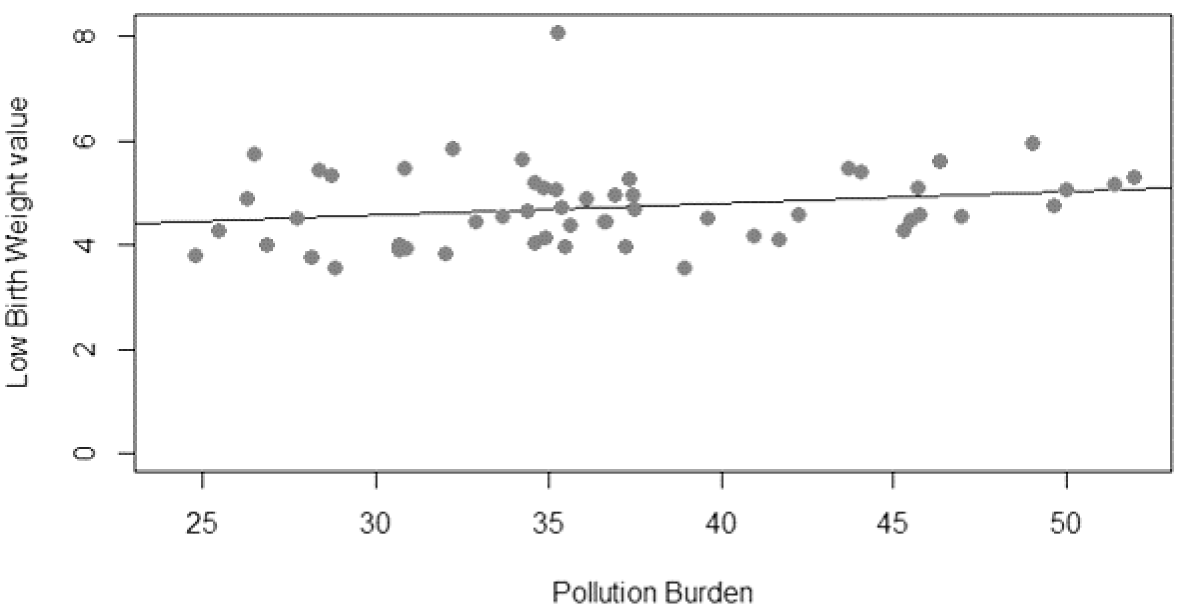


Fig. 6b. Relationship between Pollution Burden and Low-birth-weight Babies Prevalence (p=0.115)

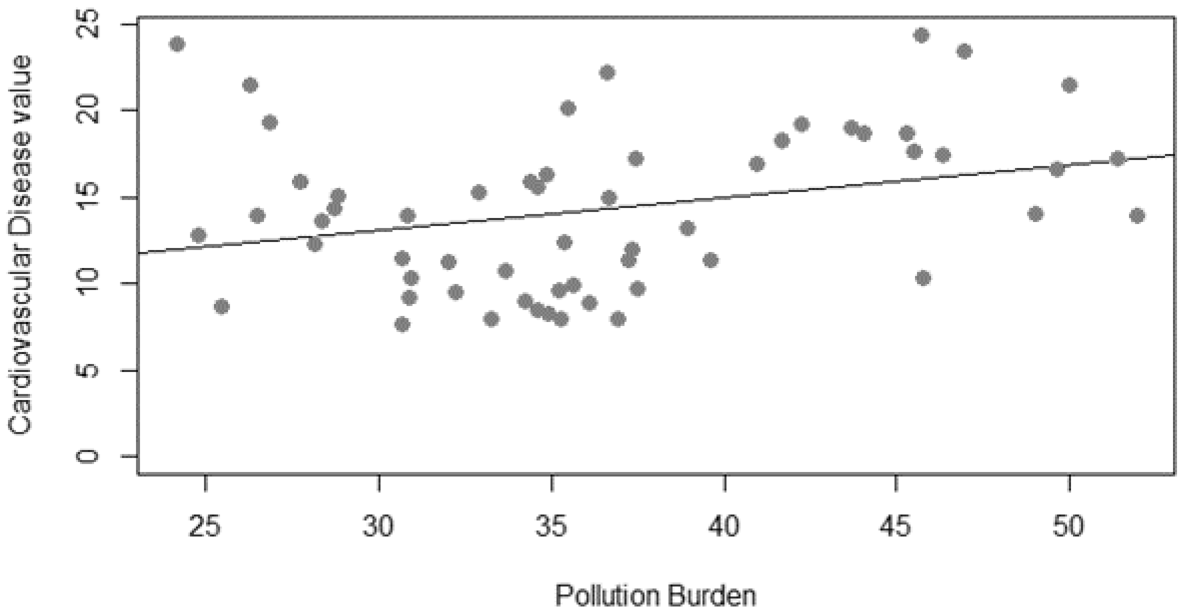


Fig. 6c. Relationship between Pollution Burden and Cardiovascular Disease (CVD) Prevalence (p=0.021)

Among the eight pollution level percentile indicators reported on the CalEnviroScreen database (ozone, $PM_{2.5}$, diesel PM, pesticides, toxic release, traffic, clean-up sites and hazardous waste) we were interested in finding out which pollutants were mostly associated with the prevalence of asthma, low-birth-weight babies, and CVD. Multiple regression analysis suggests that asthma was closely associated with traffic density, $PM_{2.5}$, cleanup sites, and ozone levels. There was no association between asthma and diesel PM, toxic release, hazardous waste, and pesticide levels. For low-birth-weight babies, only two indicators were associated: traffic density and toxic release. CVD was only associated with three indicators: $PM_{2.5}$, toxic release and cleanup sites (Table 3).

Table 3. Pollution Level Percentile Indicators versus Asthma, Low-birth-weight-babies, and CVD Prevalence

Pollution Factor		P-values	
	Asthma	Low-birth-weight-babies	CVD
Traffic density	0.02*	0.018*	0.07
PM2.5	0.002*	0.58	0.001*
Cleanup sites	0.007*	0.33	0.04*
Diesel PM	0.19	0.128	0.49
Hazardous waste	0.09	0.56	0.48
Ozone	0.04*	0.41	0.47

Toxic release	0.28	0.033*	0.05*
Pesticides	0.94	0.25	0.52

Indicates significance

With reference to particulate matter levels reported in this study, McConnell et al., more than twenty years ago studying 3,676 children from 12 locations in the state of California, showed that children with asthma who were exposed to air pollution from three pollutants (NO_2, PM_{10}, and $PM_{2.5}$) had a higher prevalence of respiratory symptoms and a greater need for medication than did children without asthma (1999). Current research indicates that there is a consistent relationship between exposures to ambient air pollution or traffic-related air pollution and childhood asthma (or wheeze) in early-childhood (Zhu et al., 2017). The development of eczema and allergic symptoms in children has been closely associated with postnatal exposure to ambient PM_{10}, NO_2, and O_3 (Liu et al., 2020). Several studies demonstrated that the risk of respiratory infections (e.g., pneumonia, rhinitis, or bronchitis) in infants and children was associated with increased short-term exposure to ambient PM_{10}, O_3, NO_x, and SO_2 (Gheissari et al., 2022). Particulate matter, especially fine ($PM_{2.5}$), can penetrate deep into the lower respiratory tract, escapes host defense and alveolar clearing mechanisms, and may reach the bloodstream and organs (including the placenta and the brain) through translocation across biological membranes (Mannucci et al., 2019). The effects of air pollution appear to be more marked during the first years of life, including during the intrauterine period when mothers inhale air pollutants.

Although no significant relation was found in this study between pollution burden and low-birth-weight babies, specific single factors like the levels of traffic pollution and toxic substances released in the air were associated with asthma prevalence. Research on prenatal exposure to ambient air pollution (especially $PM_{2.5}$, O_3, NO_x, and SO_2) has consistently been associated with reduced or low-birth-weight babies across various populations and geographic locations (Ebisu et al., 2012; Vinikoor-Imler et al., 2014). Gheissari et al. report that birth weight is inversely correlated with prenatal exposures to certain chemical constituents present as pollutants in air (like zinc, sulfur, elemental carbon, silicon, titanium, and aluminum) (2022). In areas in California with significant wildfire smoke, its exposure has been associated with preterm birth and low-birth-weight babies. Expectant women who lived in wildfire-prone areas were at a greater risk of preterm birth or low newborn birth weight than those living in non-wildfire zones (Abdo et al., 2019).

Epidemiological studies indicate that increased pollution from wildfire smoke is linked to increased cardiovascular events (hypertension, angina, and cardiac arrest) particularly among the elderly. Proximity to wildfire has strongly been associated with increased respiratory symptoms, medication use, or hospital visits in adults (Martin et al., 2013). Most regions in California suffer from significant air pollution from wildfires especially north of Sacramento, central Valley, and southern regions (Los Angeles/San Bernardino mountains) are frequent wildfire zones. Studies in ambient and traffic-related air pollution have linked air pollution exposures in neonates and children with increased cardiovascular morbidity (Ghessari et al., 2022). Experimental studies have demonstrated that increased morbidity through inflammation, oxidative stress, and transcription regulation can result from early-life air pollutant exposure. During pregnancy maternal inflammatory cytokines induced by air pollutants have been found to cross the placenta and induce fetal inflammation and oxidative stress that can last through childhood (Tillett, 2012; Gheissari et al., 2022). Abnormal immune profiles in newborns and children exposed to air pollution in utero have been reported in recent studies (Black et al. 2017). Early postnatal exposure to air pollutants like $PM_{2.5}$ can generate reactive oxygen species (ROS) and inflammatory stress in addition to inducing developmental dysfunction and epigenetic alterations (Møller et al., 2014).

In this study cardiovascular disease was also associated with three specific pollution indicators ($PM_{2.5}$, cleanups, and toxic release). Several studies have explored the relationship between air pollution and cardiorespiratory diseases, but from a global perspective less appears to be known about the health risks across regions and populations. The air pollution—health relationship is greatly complicated by “effect modifiers” such socioeconomic status, level of education amongst individuals, energy use, sources of pollution, distances from polluting sources, and prevailing weather conditions during peak pollution times of day among others (Requia et al., 2018). Long-term air pollution studies have projected mixed opinions in the relationship between particulate matter ($PM_{2.5}$) and increased risk of all-cause mortality, and significant risks in both cardiopulmonary and cardiovascular disease (Lipsett et al., 2011). Atkinson et al. also showed that associations for respiratory causes of death were larger than for cardiovascular causes. For example, one study reported that for PM_{10}, each increment of 10 micrograms per cubic meter was associated with an increase in obstructive pulmonary disease mortality in China, United States, and the European Union (Song et al., 2014). A relationship was also reported between heart failure and increases in CO, SO_2, NO_2, PM_{10}, $PM_{2.5}$ (Shah et al., 2013). Another study stated that a 10 microgram per cubic meter increment in $PM_{2.5}$ was associated with a small increase in the risk of death for cardiorespiratory diseases (Atkinson et al., 2014). Lastly, Requia et al. reported a small increase in hospital admissions and mortality attributed to cardiorespiratory diseases per 10 microgram per cubic meter increment in $PM_{2.5}$ (2018).

Although the actual microgram levels of particulate matter in this study were not available, nevertheless, the study found that incidences of asthma and cardiovascular disease could be predicted from the CES or pollution burden percentile scores. This observation provides excellent opportunities for the implementation of pollution reduction intervention strategies by policy makers, industry, educators, research agencies, non-profit organizations, community activists, and local citizens in improving environmental quality in areas with high CES percentile scores. Considering that communities living in such areas are not likely (or are unable) to relocate, interventions might include educating populations on ways to reduce individual exposure to pollutants, especially for children and older individuals. This can be achieved using social media, cell phone text alerts when air quality is poor, distribution of fliers, billboards and posters, community activism, and community education sessions. As noted by Gheissari et al., determining and identifying detrimental air pollutants from the pollution exposure mixture and finding out the detrimental chemical components within those pollutants (in situations where specific drivers of toxicity are identifiable), will help formulate community intervention targets and pollution exposure reduction strategies in high CES score areas (2022).

Most counties in California (about 30) had a HPI higher than 40%, and the rest (26) had a HPI lower than 40% (Fig. 9). By race category, almost equal numbers of Caucasian (38%) and Hispanic (35.5%) populations live in areas with higher HPIs (40-100%), and so do 17.1% of Asian Americans. In areas with lower HPIs (10-39%) about half of the people are of Hispanic origin (49.8%), about 34.8% are of Caucasian heritage, and 7.1% Asian Americans (Fig. 10 a, b). The relationship between Healthy Places Index (HPI) and prevalence of asthma, low-birth-weight babies, and CVD was tested and was found to be predictive. In areas where the HPI falls below 40%, asthma and CVD prevalence were significantly higher [$F(1,54) = 19.29$, $p<0.001$; $F(1,54) = 55.39$, $p<0.01$ respectively] but it was not the case for low-birth-weight babies [$F(1,52) = 1.54$, $p=0.22$] (Fig. 11a,b,c).

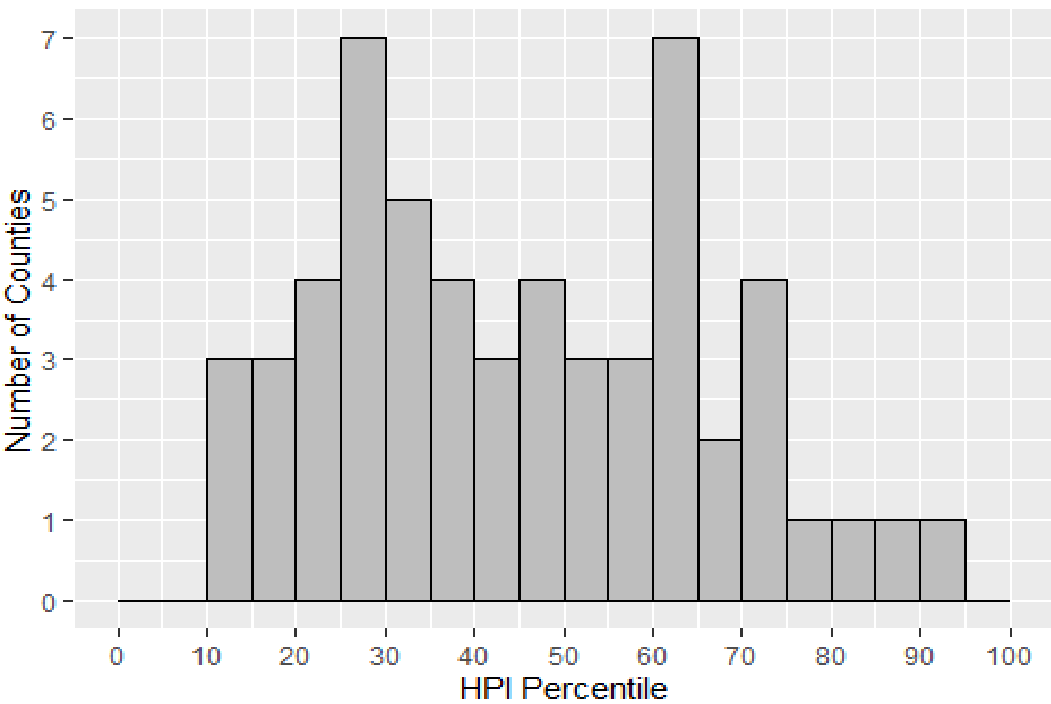
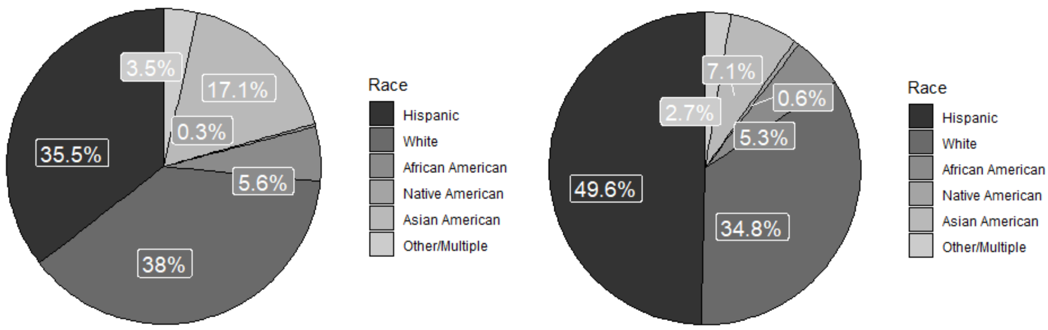


Figure 9. Distribution of Healthy Places Index Percentiles in California Counties



a) HPI >40% b) HPI <40%.

Figure 10. Combined HPI Percentile Profile for California by Race

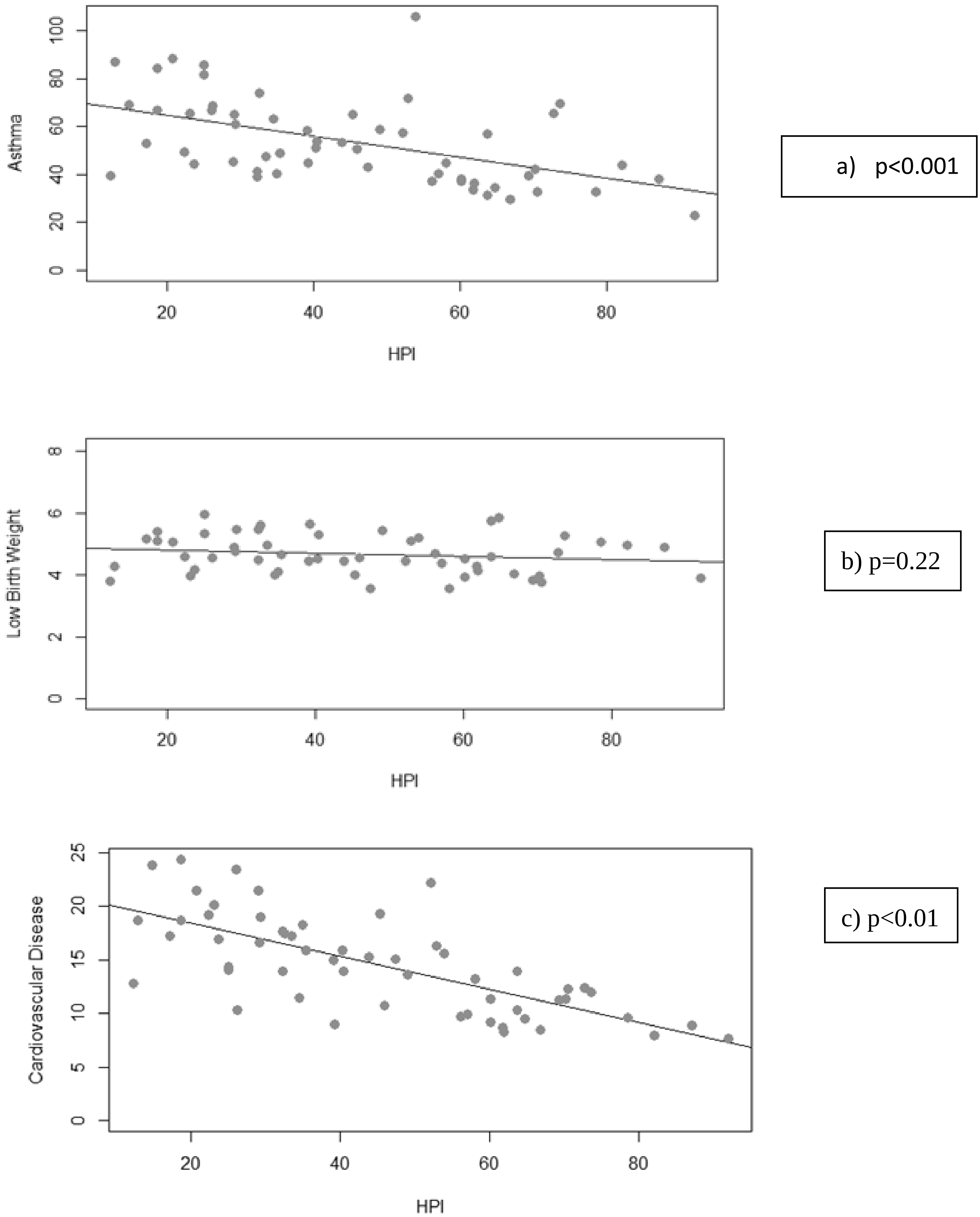


Fig. 11. Relationship between Healthy Places Index (HPI) Scores and three Health Indicators a) Asthma b) Low-birth-weight babies c) CVD

Consistent with what was found in this study where half of Hispanics in California live in regions with low HPIs, Cleveland et al. observed a similar pattern for 10 counties in Southern California—counties with higher proportions of Hispanics were associated with lower HPIs (2023). The study also found that cities with a higher proportion of Hispanic residents had higher rates of adult and childhood obesity and adult diabetes cases and lower HPI percentile scores. The HPI score was found to explain the highest proportion of the variability in the percentile of adult obesity, adult diabetes, and childhood obesity, which underlines the fact that social determinants of health are strongly associated with poor metabolic health. Cleveland et al. also found that a lower HPI score was strongly associated with poor physical and mental health, lower life expectancy, and a greater prevalence of smoking, asthma, and heart attacks (2023). It is therefore no coincidence in this study that areas where the HPI scores fell below 40% were predictive of the prevalence of asthma and CVD in those communities. In California, communities of color are likely to live near areas with significant traffic and diesel particulate matter, toxic releasing industries that use fossil fuels, hazardous waste generating and processing sites, less open space lacking developed areas for physical activities like walking, bicycling, and other park activities. Such communities are also likely to be less educated, have little or no health insurance, their children walk or use public transport to get to school, and may have coexisting health conditions that increase their vulnerability to air pollution-related detrimental health effects. Living conditions in low socioeconomic areas cause social and psychological stress, which makes the body more susceptible to infections and diseases; stress also increases the risk of developing negative health outcomes with exposure to air pollution (Mathiasaran & Huls, 2021). Williams reported that socioeconomic status and race are closely tied together, and they can be attributed to disproportionate levels of disease in populations of color and many of the disparities in access to healthcare due to racism (1999).

The state of California currently focuses on reducing pollutant emissions to meet policy mandates in the face of climate change. There is a glaring lack of risk management policies related to air pollution resulting in people of lower socioeconomic (for example, children, seniors >65 years of age, and people with existing health conditions) failing to receive the related public services. The formulation of public policy to mitigate the negative impact of air pollution exposure becomes critical for the regions with more serious air pollution. Public policy makers must advocate and lobby the government to rev up financial investment that will provide protective and air purification equipment, and information consulting services for marginalized populations. The government must also continue improving existing health care policies, enhance access to essential and appropriate medical services to the disadvantaged populations, and minimize the health effects arising from air pollution.

4. Conclusion

With the climate change predictions projected this century, disadvantaged and minority residents in many parts of California will continue to face escalating levels of both outdoor and indoor air pollution that will continue to affect their health and well-being. Climate change will intensify dry conditions in fire-prone California causing more intense fires, toxic release, and smoke inhalations. It will also increase the risk of disease due to changing and extreme weather patterns, which are also associated with the increase in allergens as well as disease vectors. These conditions will greatly raise the prevalence of respiratory conditions and diseases, such as asthma. Disadvantaged communities will be hit hardest with fewer available resources, are less educated, lack healthcare access, subsist on poor nutrition, face aggravated stress levels due to poor living conditions, and have less ability to evacuate from affected areas. Since so many people's health is compromised by the effects of air pollution in California, there needs to be a paradigm shift in the way population health is evaluated and effects of air pollution mitigated. We need more interdisciplinary research to understand the complexity of the in-built environments where marginalized people live, and the synergistic interactions in many environmental phenomena and how they affect people's health. More information is also needed to identify specific ways that cumulative impact assessment can be most effectively used to reduce environmental inequalities. We need viable and actionable solutions like increased investment in education, infrastructure, and in the physical spaces where people live. We need policies and practices that promote urban revitalization, modifying the built environment in ways that create enterprising zones, shifting of available resources (like job creation and food outlets), assessing the impacts of the social determinants of health, expanding urban housing, and capacity building through deliberate community engagement. The lives of marginalized communities will need better focused approaches from national, regional, and local governments, private corporations, private entrepreneurs, educational institutions, and the community at large to deconstruct the socioeconomic dilemmas facing them, characterizing issues of racism and discrimination, leveling of environmental injustices experienced, and addressing rampant health disparities and inequities.

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