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The Effects of Industrial Zone Proximity on Pediatric Asthma and Academic Outcomes in a Predominately Latino, Low Income Community in Southern California

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The Effects of Industrial Zone Proximity on Pediatric Asthma and Academic Outcomes in a Predominately Latino, Low Income Community in Southern California

THESIS

submitted in partial satisfaction of the requirements
for the degree of

MASTER OF SCIENCE

in Biomedical and Translational Science

by

Kelton Alexander Mock

Thesis Committee:
Assistant Professor Kim D. Lu, Chair
Professor Jun Wu
Associate Professor John Billimek

2021

DEDICATION

To

The Madison Park Neighborhood Association

May every young person in Santa Ana grow up to be a doctor, a nurse, an artist, a Dean, a marathoner, a gardener, the president, or whatever it is they most dream of being.

Mi gusto es, con luna llena,
salir a cantar al campo.
A mí nadie me sofrena
y si en un lugar me planto
es para cantar sin pena.

- Arcadio Hidalgo

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ABSTRACT OF THE THESIS

The Effects of Industrial Zone Proximity on Pediatric Asthma and Academic Outcomes in a Predominately Latino, Low Income Community in Southern California

by

Kelton Alexander Mock

Master of Science in Biomedical and Translational Science

University of California, Irvine, 2021

Assistant Professor Kim D. Lu, Chair

Introduction: While there is mounting evidence supporting the association of traffic-related air pollutants and pediatric asthma morbidity, few studies have examined how land use policies, and especially the proximity of industrial zoning to schools and home residences, influences pediatric asthma outcomes among minoritized communities. The goal of this study was to characterize the association between industrial zone proximity and asthma prevalence, physical fitness, and academic outcomes for children in the Santa Ana Unified School District (SAUSD).

Methods: This is a cross-sectional analysis of school records for students enrolled in SAUSD over the 2018-2019 school year, including demographics, school medical records, physical fitness test scores, attendance records, and standardized exam scores.

Results: The study included a total of 44,641 individual student records. The odds of having an asthma diagnosis were 21% greater for children living in the closest tertile of proximity to the nearest industrial zone (range 0.004-0.534 km) compared to children living in the farthest tertile (> 1.051 km) (adjusted OR 1.21, 95% CI 1.10 to 1.33, p<0.001). Among students with asthma, there was increased likelihood of being overweight or obese for children living in the closest tertile of proximity to industrial zones (adjusted OR 1.50, 95% CI 1.04 to 2.17, p=0.029), an increased likelihood of an unhealthy score on the aerobic fitness test (adjusted OR 1.42 per each additional km of proximity, 95% CI 1.13 to 1.83, p=0.005), but a paradoxical decrease in asthma events with each kilometer of increased proximity (adjusted b = -0.027, p=0.020). Associations of industrial zone proximity with absences or standardized test scores were mostly non-significant, as were most associations between freeway exposures and poor academic/health outcomes.

Conclusion: This school-district-based study found that industrial zone proximity was significantly associated with higher asthma prevalence after controlling for available socioeconomic factors, suggesting that city zoning may be an important variable to consider when studying patterns of asthma among school-age children. Within the population of children with asthma, the effects of industrial proximity on health and academic outcomes are not clear but may be confounded and/or mediated by overweight or obese weight status. Overall, these study findings establish the importance of comparing health disparity distributions to city zoning maps and show how the distance-gradient method can be a useful tool to both inform city policy and generate new hypotheses for additional epidemiologic investigation. Future studies should include improved controls for socioeconomic status and health care access, as well as more sensitive exposure variables incorporating air monitoring data as well as trunk road proximity. Additionally, future studies should investigate the possible protective effect of green space and/or other recreational areas on asthma and weight-related outcomes.

SUMMARY FOR CITY AND SCHOOL DISTRICT POLICYMAKERS

Asthma in Santa Ana. Asthma is the most common chronic illness of childhood, and can have major effects on a child's life, both in the very direct sense of requiring emergency room visits and hospitalizations, and because it can lead to missed school days, trouble with exercise, and decreased academic performance. In the City of Santa Ana, State health surveys indicate that asthma rates may be near the state average, although prior studies have suggested that such surveys may miss large numbers of children with asthma, especially in communities of color where access to asthma diagnosis and treatment tends to be unequal to that of white, non-Hispanic populations. When looking at City statistics at the zip code level, asthma burden is not distributed equally; compared to the northern zip code 92701, where 11.6% of children reported ever having asthma (2018), the Madison Park neighborhood of southeast Santa Ana (zip code 92707) has a lifetime asthma prevalence rate of 15.4% and is a leading zip code for asthma-related ER visits for children.

Zoning in the City of Santa Ana. Santa Ana stands out from surrounding cities in Orange County, such as the nearby City of Irvine, in that it has many areas zoned for light and heavy industrial use interspersed very close to residential areas and schools. For example, zip code 92707 is home to an extensive corridor that lies almost directly adjacent to several apartment complexes, as well as Kennedy Elementary School and Century High School. Children living in 92701 attend schools that are on average 797 meters (~1/2 mile) away from industrial zones; for children living in 92707 the average school distance is 583 meters (~1/3 mile). As the City is likely aware, residents of 92707 have raised concerns about the potential health effects of such close proximity on different health conditions such as asthma. This study was inspired by an ongoing partnership with UC Irvine and Madison Park residents and designed to help answer some of those questions.

With the approval of UC Irvine and Santa Ana Unified School District (SAUSD) research ethics boards, we examined SAUSD data for the 2018-2019 school year, with the following findings:

1. **Asthma may be underreported across SAUSD.** 2018-2019 asthma prevalence was approximately 6.7% district-wide, though a search of school records and documented asthma events suggests that 153 students may have been missed, which increased the estimated prevalence to 7.1%. For comparison, a previous study conducted in Orange County estimated the prevalence of asthma to be around 28% among pediatric populations with similar characteristics to SAUSD students.

2. **Children in the City of Santa Ana tend to live and attend school very close to industrial zones, especially in zip codes 92707 and 92705**. Across SAUSD, three schools sit within 100 meters (328 feet) of areas zoned for industrial use, and 33% of children have home addresses within 500 meters (~1/3 mile) of an industrial zone, with some children living as close as 4 meters (13 feet) away from areas zoned for industrial use. Factoring in exposures at both home and school, children in 92707 live and study at an average distance of 642 meters (0.4 miles) from industrial zones; for children in 92705 the average distance is only 599 meters (0.37 miles).

3. **Children living and attending school within 500 m (~1/3 mile) of an industrial zone have a 20% greater risk of having asthma compared to children that live and attend school over 1.5 km (~1 mile) from industrial zones.** For children with asthma who live and attend school within 500 meters of an industrial zone, there is a 50% greater risk of

being overweight or obese, and a 46% greater risk of receiving an unhealthy designation on the State physical fitness test, in comparison to peers with asthma living over 1.5 km away. These differences were not likely to be explained by socioeconomic factors, as our analysis controlled for variables including free and reduced lunch, race, ethnicity, and parents' highest level of education.

Recommendations. Based on our results, we suggest the following actions by the City and school district. Working in conjunction with UC Irvine physicians, SAUSD could implement an asthma screening tool with improved sensitivity over the current medical reporting procedure. Such a tool could be paired with a documented "asthma action plan," to provide continuity of asthma care for students while they are at school. At the City level, council members and other local decisionmakers should consider how zoning patterns may have direct negative impacts on children's health, and investigate potential remediating or protective factors (i.e. increased green space, buffer zones, health care access, etc). Finally, SAUSD and City officials should continue to build resident-centered partnerships directed by local organizations such as the Madison Park Neighborhood Association and involving nearby research organizations such as the University of California, Irvine, through which zoning-related health hazards can be identified, studied, and hopefully remediated. In conjunction with ongoing community air monitoring efforts, additional research is needed to better understand the connections between industrial zoning and health outcomes in Santa Ana.

CHAPTER 1: INTRODUCTION

Overview

Industrial zoning decisions, vital in shaping the visual and economic landscapes of cities, can have powerful impacts on human health, often in patterns that disproportionately harm minoritized groups.[1] Among the many different environmental disturbances caused by industrial activities, air pollution can be especially insidious, and has been associated with severe health effects including increased asthma morbidity among children.[2,3,4] Unfortunately, studying the effects of air pollution directly is often limited by the availability of monitoring data, given that air monitors are costly to maintain, and extant air monitoring data is frequently interpolated from sparse networks of stationary air monitors.[5] Such is the case in Santa Ana, CA, a city that is 78.2% Hispanic/Latino, has a lifetime pediatric asthma incidence of 13.8% versus the national average of around 11.4-11.6%, and contains 17 census tracts labeled "disadvantaged communities" by the State of California.[6,7,8,9] At present, real time air pollutant levels for Santa Ana are interpolated from a single monitoring station over 10 miles away, in the City of Anaheim.[10] Although long standing community concerns about children's health and environmental exposures have led to the acquisition of resources for the development of a community air monitoring network, questions and concerns remain about whether home and school distance to areas zoned for industrial use might be associated with pediatric health outcomes even in the absence of neighborhood-level pollutant data.[11] In the present study, I sought to examine relationships between industrial zone proximity and asthma prevalence and academic/health outcomes for children in the Santa Ana Unified School District (SAUSD).

Pediatric Asthma and Air Pollution

Air pollution and asthma have become increasingly linked through epidemiologic studies. Asthma is a complex respiratory condition that involves inflammation of the lower airways, frequently in response to an environmental trigger. Asthma triggers in children can be grouped into several categories, including viral infections, weather, exercise, strong emotions, medications, allergens and irritants.[12] Included in the irritant category are many air pollutants including particulate matter <2.5 µm ($PM_{2.5}$), carbon monoxide (CO), coarse size particulate matter between 2.5 and 10 µm ($PM_{2.5-10}$), particulate matter <10 µm (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and polycyclic aromatic hydrocarbons (PAH), many of which are strongly associated with asthma symptoms, exacerbations, hospitalizations, and decreased lung function via pathophysiologic processes that have been observed *in vitro*.[13,14] In urban areas, traffic emissions may contribute substantially to certain groups of pollutants (e.g. $PM_{2.5}$, CO, NO_2, and PAH). There is robust evidence of association with asthma symptoms and these pollution subsets, which are known collectively as traffic related air pollution (TRAP).[15] However, many of the same emissions can also come from indoor sources, including cigarette smoke and woodburning stoves.[3]

Although direct emissions from stationary sources, as well as associated vehicle traffic are frequently associated with areas zoned for industrial use, industrial zoning as a broader entity may affect pediatric respiratory health by producing other asthma triggers. These could include non-combustion related operations within the zone, such as dust from construction work, or the generation of aerosolized allergens from certain activities such as chrome and nickel plating.[16,17] Industrial zoning may also produce tradeoffs in land use resulting in reduced greenspace (a possible protective factor against asthma risk) as well as sensory disturbances such as noise, which may play a role in explaining wheezing among infants.[18, 19]

Pediatric Asthma and Physical Fitness

Despite established benefits of exercise, children with asthma may struggle to engage with exercise due to inadequate asthma management and consequently develop comorbidities such as obesity.[20,21,22] The dual syndrome of asthma and obesity can lead to compounded health risk, as both factors can negatively impact each other. Although there are conflicting findings about whether students with asthma have diminished exercise capacity as measured by VO_2 max, exercise training can be an important aspect of treatment for children with asthma and obesity.[23,24,25] Obesity and exercise tolerance thus present important factors to consider when assessing the full burden of children's asthma in relation to environmental triggers.

Pediatric Asthma and Academic Outcomes

Children with asthma may face additional challenges at school compared to their healthy peers. For example, children with asthma have been reported to miss school at a rate at least 1.5 times that of their classmates who do not have asthma.[26] There is conflicting evidence regarding the effect of asthma on academic performance, with large studies in Canada and the Northeastern USA demonstrating significant differences in math and reading scores between school children with and without asthma, while other studies suggest no measurable effect.[27,28,29,30,31] In addition, detrimental academic effects may be seen more prominently when stratifying by race and ethnicity.[32] A study of 395 children in urban settings in the Northeast United States found that Latino and Black students with asthma had worse academic outcomes than non-Latino white students, and that Latino students with asthma generally fared poorest across several domains of academic performance.[33]

Rationale: Industrial Zoning as a Unifying Exposure Variable

Although clear relationships have been established between specific sources of urban pollution and pediatric asthma outcomes, there is a gap in understanding regarding the relationship between broader patterns of industrial zoning and pediatric asthma morbidity.[19,34,35,36] Establishing precise links between industrial zones and specific pediatric health outcomes has historically proven difficult, given the wide range of understudied chemicals that are emitted by different types of industries, a lack of consensus regarding permissible exposure limits for different noxious substances, and unknown synergistic reactions between different types of chemical emissions.[37,38,39] However, by considering industrial exposures based on geographic proximity alone, I hope not only to capture the hypothesized effects of air pollution, but also the effects of any aspect of industrial zone proximity that may influence asthma morbidity and related health and academic outcomes.

Overall Objective: To evaluate the relationships between industrial zone proximity, asthma health and academic outcomes for students enrolled in the Santa Ana Unified School District (SAUSD) for the 2018-2019 academic year.

Specific Aim 1. Assess the association between asthma prevalence and industrial zone proximity to student home and school locations.

Hypothesis: Increased home and school proximity to areas zoned for industrial use is associated with an increased risk of having an asthma diagnosis, when controlling for traditional socioeconomic factors.

Specific Aim 2. Assess the association between health outcomes (weight status, physical fitness test scores, and asthma events) and industrial zone proximity to home and school locations for students with asthma.

Hypothesis: Increased home and school proximity to areas zoned for industrial use is associated with increased obesity, poorer physical fitness test scores, and increased asthma events among students with asthma, when controlling for traditional socioeconomic factors.

Specific Aim 3. Assess the association between school outcomes (absences and standardized test scores) and industrial zone proximity to home and school locations for students with asthma.

Hypothesis: Increased home and school proximity to areas zoned for industrial use is associated with increased school absences and decreased standardized test scores among students with asthma, when controlling for traditional socioeconomic factors.

CHAPTER 2: BACKGROUND

The Unequal Burden of Pediatric Asthma

Asthma is a complex condition, involving lower airway inflammation in response to a variety of triggers, which results in a spectrum of symptoms ranging from mild wheezing and cough to dramatic exacerbations requiring hospitalization.[12] While it affects people of all ages, it is considered the most common chronic illness of childhood, presently affecting around 14% of the global pediatric population and 7-8% of the US pediatric population.[40] Recent asthma prevalence data for the USA, California, Orange County, and City of Santa Ana are shown in Table 1. Based on the California Health Interview Survey (CHIS) and National Health Interview Survey (NHIS), the 2018 lifetime prevalence of asthma (i.e. the percentage of children who report ever having a diagnosis of asthma) for the USA, California, Orange County, and City of Santa Ana was reported at around 11.6, 14.8, 13.6, and 13.8, respectively.[41,42] However, actual rates of asthma may be much higher than reported, given that the disease can present in a myriad of different ways that may not be detected by primary care providers. For example, a multi-cultural community survey administered by a group of physicians in 2004 found a pediatric asthma incidence of 28% in Orange County.[43]

As with many other health conditions in the United States, the effects of systemic racism are clearly visible in the distribution of pediatric asthma burden.[44,45,46,47] Based on the race, ethnicity and nationality data collected in the NHIS, white non-Hispanic children have lifetime and current asthma prevalence rates of 9.5% and 5.6%, respectively, followed by Mexican and Mexican-American children (11.5% lifetime and 6.9% current prevalence). Lifetime and current asthma prevalence for Black children is much higher, at 18.1% and 14.3%, respectively.[48] Similar patterns are apparent based on California-specific data from the Behavioral Risk Factor

Surveillance System (BRFSS), which shows that white, non-Hispanic and Hispanic children experience a markedly lower asthma prevalence in comparison to Black children (Table 1). Unfortunately, national asthma prevalence data for other specific racial and ethnic groups (disaggregated from "Other Non-Hispanic") is limited.

Table 1. Pediatric Asthma Prevalence at National, State, County, and City Levels

	Current Prevalence (%) [a]	**Lifetime Prevalence (%)** [b]	**Current Prevalence (%)**	**Lifetime Prevalence (%)**
Survey	*NHIS 2018* [c]		*BRFSS 2018* [d]	
United States	7.5	11.6	7.2	11.4
White, non-Hispanic	5.6	9.4	6.2	10.0
Black, non-Hispanic	14.2	18.0	12.0	16.7
Hispanic	8.0	12.5	6.4	11.3
Mexican/Mexican American	7.0	11.5	---	---
Other non-Hispanic	7.4	11.9	7.0	10.6
American Indian or Alaska Native, non-Hispanic	---	17.8	---	---
Survey	*CHIS 2018* [e]		*BRFSS 2018* [d]	
California	---	14.8	6.2	10.7
White, non-Hispanic	---	---	5.1	10.5
Black, non-Hispanic	---	---	15.3	19.7
Hispanic	---	---	5.5	10.2
Other non-Hispanic	---	---	6.9	9.7
Survey	*CHIS 2018* [e]		*N/A*	
Orange County	---	13.6	---	---
Survey	*CHIS 2018* [e]		*Present Study* [f]	
Santa Ana*	---	13.8		7.1
White, non-Hispanic	---	---	---	9.8
Black, non-Hispanic	---	---	---	17.4
Hispanic	---	---	---	7.0

Other non-Hispanic	---	---	---	8.5
American Indian or Alaska Native, non-Hispanic	---	---	---	5.0
Zip Code				
92701	---	11.6	---	6.9
92703	---	13.0	---	6.2
92704	---	14.3	---	7.3
92705	---	13.6	---	7.8
92706	---	14.8	---	6.3
92707	---	15.4	---	7.8
92708	---	12.7	---	3.0

[a] Percent of respondents who reported having asthma at the time of the survey
[b] Percent of respondents who reported ever having had asthma
[c] National Health Interview Survey, 2018. Current asthma table available at: https://www.cdc.gov/asthma/nhis/2018/table4-1.htm. Lifetime asthma table available at: https://www.cdc.gov/asthma/nhis/2018/table2-1.htm. American Indian/Alaska Native asthma information available at: https://minorityhealth.hhs.gov/omh/browse.aspx?lvl=4&lvlid=30. "Child" is defined as under 18 years of age for purposes of the NHIS.
[d] Behavioral Risk Factor Surveillance System, 2018. Current asthma: https://www.cdc.gov/asthma/brfss/2018/child/tableC5.html. Lifetime asthma: https://www.cdc.gov/asthma/brfss/2018/child/tableL5.html. "Child" is defined as 17 years or younger for purposes of the BRFSS.
[e] California Health Information Survey, 2018. Available at: https://askchisne.ucla.edu/ask/_layouts/ne/Dashboard.aspx#/.
[f] Per SAUSD nursing staff, diagnoses are updated annually, via questions that ask whether a child currently has asthma, whether they take medication at home or school for asthma, and if they have activity restrictions due to asthma. Because asthma diagnoses are rarely removed from student records, reported asthma diagnoses were taken to represent a "lifetime" prevalence.
[*] The present study estimate of 7.1% asthma prevalence is based on Santa Ana Unified School District data for 2018-2019 (See Chapter 3- Methods). 97.4% of participants reported a home address within the city of Santa Ana; others are residents of surrounding cities in Orange County.

The stark inequities in pediatric asthma outcomes are further reflected in national patterns of asthma-related hospitalization and mortality. While the hospitalization rate for asthma as a percentage of all children under 18 recently decreased from 9.6% (2001) to 4.7% (2013), the hospitalization of Black children with asthma remains 5.2 times the rate for white children (2017), and the hospitalization of Hispanic/Latino children with asthma is currently 1.8 times the rate for white children (2017). While asthma mortality in children overall has remained very low, around 2.57% in 2001 and 2.51% (2017), the pediatric asthma mortality rate for Black children is currently 8.0 times the mortality of white children (2019), while the mortality rate of Hispanic/Latino children remains 1.4 times the mortality rate for white children (2017).[49,50]

The City of Santa Ana has a population of about 335,052 people, of whom 78.2% identify as Hispanic, and a median household income of $54,521. These indicators differ markedly from the State of California, in which 38% of residents identify as Hispanic and the median household income is $75,277.[51,52,53] In 2018, pediatric asthma incidence across the city was 13.8%, which for that year was well above the national incidence rate, but near or below rates for Orange County and the State of California reported from the CHIS (Table 1). However, zip code level analysis reveals a considerable stratification of wealth, resources, and health indicators within the City of Santa Ana (Table 2). Median income by zip code ranges from approximately $52,400 to $108,800 across the city, although it is important to note that the latter value comes from zip code 92705, which includes part of a wealthier, neighboring city (Figure 1).

According to CHIS data for 2018, asthma indicators also vary by zip code, with 3 Santa Ana zip codes exceeding the county average for pediatric asthma lifetime prevalence, and 2 Santa Ana zip codes exceeding the county average for asthma-related pediatric emergency department (ED) visits. Those two zip codes, 92703 and 92707, rank 1st and 3rd worst in the County for pediatric ED visits for asthma (46.9 and 44.8 per 10,000 population under 18 years old). Of note, while 92707 exceeds the county average on both metrics, there is less concordance among asthma prevalence and ER visit patterns for the other Santa Ana zip codes.

Table 2. Selected Zip Code-Level Demographics Within the City of Santa Ana, California

	Median Income (thousands) [a]	**Hispanic/Latino** (%) [b]	**Lifetime Pediatric Asthma Prevalence** (%) [c]	**Asthma-Related ED Visits** (per 10,000 population <18) [d]	**Student's Mean Home Distance to Nearest Industrial Zone** (m) [e]	**Student's Mean School Distance to Nearest Industrial Zone** (m) [e]
Orange County	90.2	35.0	13.6	42.0	---	---
Santa Ana	66.1	76.8 [f]	13.8	---	883	832
Home Zip Code						
92701	52.4	88.7	11.6	42.0	687	797
92703	61.6	78.5	13.0	46.9	866	1,000
92704	69.3	72.9	14.3	37.0	884	836
92705	108.8	44.3	13.6	30.8	593	623
92706	70.2	71.8	14.8	36.6	1,264	1,275
92707	77.5	84.0	15.4	44.8	658	583

[a] *Conduent Healthy Communities Institute. American Community Survey, 2015-2019. OC Healthier Together. Accessed April 16th, 2021. Retrieved from* http://www.ochealthiertogether.org/indicators/index/view?indicatorId=315&localeTypeId=3&periodId=4523&comparisonId=7205.
[b] *Claritas, 2021. OC Healthier Together. Accessed April 16th, 2021. Retrieved from* http://www.ochealthiertogether.org/demographicdata?id=267&sectionId=941#sectionPiece_179.
[c] *California Health Information Survey, 2018. Retrieved from:* https://askchisne.ucla.edu/ask/_layouts/ne/Dashboard.aspx#/.
[d] *California Office of Statewide Health Planning and Development (2017-2019). OC Healthier Together. Accessed April 16th, 2021. Retrieved from* http://www.ochealthiertogether.org/indicators/index/view?indicatorId=137&localeId=267
[e] *Per present study, average home and school distances were calculated among a sample of children attending school within Santa Ana Unified School District for the 2018-2019 academic year, n=44,641 (See Chapter 3- Methods).*
[f] *US Census Quick Facts (2019). Census.gov. Accessed April 23rd, 2021. Retrieved from:* https://www.census.gov/quickfacts/fact/table/santaanacitycalifornia/PST045219#

Pollution, Zoning, and Respiratory Disease

Air pollution, secondary to stationary and mobile sources, appears to have profound impacts on health in the United States. One estimate of economic costs associated with increased morbidity and mortality related to air pollution in the United States placed the economic benefit of reducing $PM_{2.5}$ emissions over the 1999-2013 period at $24 billion per year.[54] Children are thought to be especially susceptible to air pollutants, due to their higher ventilation per minute relative to adults.[55] Although the broad range of other known asthma triggers make it difficult to conclusively establish causal relationships involving specific air pollutants and pediatric asthma, there are growing bodies of research regarding exposures to traffic pollutants and indoor exposures, and a smaller body of research regarding industrial zone proximity, which suggest important links between urban planning and asthma health outcomes.

The Effects of Automobile Traffic on Asthma Health

Some of the most conclusive evidence for pollution-related asthma morbidity comes from literature on traffic-related air pollution (TRAP). A 2017 systematic review and meta-analysis of TRAP and pediatric asthma found significant effects for black carbon, PM_{10}, and $PM_{2.5}$ on the incidence of pediatric asthma, as well as a heterogenous effect of NO_x compounds.[56] Additional reviews have emphasized a variety of strong associations between traffic exposure and increased pediatric asthma morbidity and have attempted to make the case for a causal association.[14,57,58,59,60,61] At the molecular level, numerous possible mechanisms for this association have been hypothesized, including impaired lung development *in utero*, augmented allergen sensitization, airway inflammation, impaired immune response to viral infection, and even bronchospasm directly triggered by pollutant exposures.[62]

Despite the overwhelming evidence supporting a close link between TRAP and asthma outcomes, some studies have suggested that the relationship may not be as straightforward as anticipated. In the 2015 ESCAPE project, for example, investigators found no significant association between traffic-related air pollutants and asthma prevalence in a large, multinational European sample.[63] This project involved meta-analysis of 5 major European birth cohorts and examined the relationship between TRAP and pediatric asthma outcomes for children exposed at birth, age 4, and age 8. In explaining their nonsignificant findings, authors emphasized the heterogeneity of results seen broadly in the TRAP literature and concluded that while pollution may have strong effects on children that are already diagnosed with asthma, there was little conclusive evidence supporting a link between TRAP exposures and asthma prevalence overall.

One important finding emerging from TRAP studies is the delineation of cutoff distances for which exposure to major roads and highways should be considered an asthma risk. Given that individual components of traffic exhaust can be difficult to disentangle from one another, this approach may prove useful for quantifying risk in a form that is useful for urban planning purposes.[64] In a detailed 2010 special report published by the USA nonprofit Health Effects Institute, an extensive literature review conducted by an expert panel concluded that a distance of 300-500 meters from the nearest major roadway constituted an area of high concern for asthma risk.[13]

In 2012, a study examining the dual effects of traffic exposure and regional air pollution in Los Angeles County used historical monitoring data for ozone and NO_x compounds to compare the anticipated effects of lower pollution levels, as well as decreased proximity to roadways on pediatric asthma prevalence and morbidity. Based on an estimated 320,500 cases of pediatric asthma, the group estimated that a 3.6% reduction in the number of children living within 75 m of a major roadway would reduce asthma cases by 5,900 (95% CI: 1,000 to 11,000).[65] In addition, the group estimated that such a scenario would also lead to significant reductions in hospital admissions, ED visits, and school absences. While limited by the nature of its hypothetical design, this study demonstrated how emerging consensus from individual studies of the associations between TRAP and asthma could be applied to examine larger scale impacts of zoning on pediatric asthma health outcomes.

Indoor Exposures and Asthma

Indoor exposures, including pets, tobacco smoke, dust mites, gas stoves, appliances, and other sources, represent another widely recognized group of pollutants that impact asthma outcomes.[66,67,68] While evidence for an association between environmental tobacco smoke and asthma exacerbations was established nearly 30 years ago, other exposures such as mold have more recently gained support as an associated, and perhaps even causal factor in the development of asthma and asthma exacerbations.[69,70,71] Mold, nitrogen dioxide (NO_2) and $PM_{2.5}$ have also been associated with increased asthma morbidity in the context of schools, suggesting that multiple indoor environments may play important roles in determining the risk of exacerbations among children with asthma.[72]

The Effects of Industrial Zoning on Respiratory Disease

In contrast to exposure studies of traffic-related pollutants, the literature involving industrial zoning exposure and pediatric asthma is somewhat less robust. Using industrial zone proximity alone to approximate air pollution exposure comes with significant limitations, including possible misattribution of health effects to the incorrect pollutant source.[73,74] Nevertheless, although direct measurement approaches may better help establish causality in exposure-outcome type studies, indirect approaches that compare health effects to distance from an area of suspected harmful environmental exposures still have value as an initial tool in describing environmental risk, and identifying potential exposures of interest.[75]

Several recent studies have shown significant associations between asthma symptoms and proximity to different types of industrial sources. In 2009, Wichmann and colleagues used distance gradient modeling to estimate the effects on asthma health resulting from proximity to a nearby petrochemical plant in La Plata, Argentina among a sample of 1,212 children.[76] For children living near the industrial zone (n=290), the researchers found a significantly increased rate of asthma prevalence, symptoms, and exacerbations ($p<0.001$). When analyzing pollutants, including both particulate matter and volatile organic compounds specific to the petrochemical plant, the group found significantly decreased lung function for children exposed to higher levels of pollutants, controlling for a wide variety of possible confounding factors including proximity to major roads or other possible pollution sources, presence of cockroaches or pets in the home, family history of allergies or asthma, and general economic/demographic characteristics, among other variables.

In 2010, *de Marco et al.* examined survey data from 3,854 children living near chipboard (wood processing) industries, analyzing irritant effects related to formaldehyde exposure (eye, nose, throat, skin symptoms), respiratory effects (asthma-like symptoms, cough or phlegm), and other health outcomes (general symptoms, lost school days, ED visits, hospitalizations).[77] Using linear regression, the group found that the risk of reporting many types of symptoms, including asthma-like symptoms, decreased significantly for every 2 km increase in distance from the chipboard industry areas. They also demonstrated significant associations between increased distance from the exposure and decreasing school absence rates, ED visit rates and hospitalization rates. Taken together, these results implicated chipboard industries as a significant health hazard for children living within 2 km of the facilities, controlling for traditional socioeconomic factors, including residential area, traffic level near the home, parents' educational attainment, and environmental tobacco smoke. In contrast to other studies, these results were obtained without considering air monitoring data, as this was not available to the research group.

In 2016, Alwahaibi and Zeka investigated the effect of proximity to a petrochemical and heavy metal industrial complex on respiratory disease outcomes in Oman.[78] Exposures were classified into three zones of proximity to the industrial zone: <5 km (low), 5-10 km (intermediate) and >20 km (control). Outcomes were defined as health events or health visits involving a range of both respiratory and allergic diseases. The researchers also examined effect modification by sex, age, and SES (education and employment) on exposures. For all outcome measures, and across all subsets, the investigators found a consistent effect of industrial zone proximity within 10 km on health events and frequency of doctor's visits. Although the study was limited by a lack of air sampling data, it provided a high-level association between industrial zoning and respiratory/allergic disease across socioeconomic, sex and age boundaries.

In 2018, Bergstra and colleagues conducted a cross-sectional study of Dutch school children living near an area of heavy industry. [79] To measure exposures, the research team used geocoded home and school addresses, weighting each time average by hours spent at home or school during the year, and then multiplied by pollutant exposures as estimated by dispersion model estimates of $PM_{2.5}$, PM_{10}, SO_2, and NO_x. Cases with a home distance less than 100 m from major (trunk) roads were excluded from analysis. Outcome variables included pulmonary function test values (FVC-forced vital capacity, FEV_1-% predicted 1-s forced expiratory volume, and PEFpeak expiratory flow) as well as parent-reported symptoms (wheezing, wheezing during exercise, asthma, or dry cough).

In unadjusted analysis, the group found that $PM_{2.5}$ and NO_x were associated with reduced PEF; NO_x exposures also correlated with lower FVC and FEV_1. When adjusting for age and sex, only the former association remained significant. And when adjusting for parents' highest level of education, molds, passive smoking, allergy, ventilation, fireplace, pets, proportion time exposed and family history of asthma predisposition, no association between exposures and lung function results remained significant. When using reported symptoms as the outcome variable, the investigators found that only the association between $PM_{2.5}$ and "dry cough" was significant, after adjusting for all controls. While these results stood out in that they involved objective measures of lung function in conjunction with distance measures and pollution data, the loss of significance with adjustment for confounds suggested that household factors may have played an important role in affecting lung function and reported symptom frequency among study participants.

Asthma, Exercise and Obesity

Children with asthma may face difficulties related to exercise tolerance, especially if their asthma is triggered by exercise.[80] However, studies comparing exercise capacity in children with asthma against healthy controls have found no consistent differences in kinetic measures such as VO_2 max, suggesting that any observed exercise limitations among children with asthma are less likely related to physiologic restrictions and may be due instead to external barriers such as improper pre-medication, fear of having an asthma attack, or a lack of encouragement from parents or other mentors.[81,82,83] Neighborhood walkability is another external barrier to exercise that may interact significantly with asthma risk. A population-based cohort study of over

300,000 children in Toronto, Canada, demonstrated a significant association between increased asthma morbidity and lower neighborhood scores on a validated walkability index, after controlling for other atopic conditions, neighborhood income, sex, obesity, and preterm birth.[84]

Comorbid obesity also plays a major role in patterns of asthma morbidity—among the 18% of children in the United States who are obese, there is a nearly one-third increased likelihood of having asthma in comparison to healthy weight children.[85] Given that obesity prevalence can be much higher among Hispanic and non-Hispanic Black children (~24-26%), it is possible that these groups of children may face compounded risks for the development of the dual condition of asthma and obesity, although the magnitude of risk may vary greatly by sex.[86,87] The mechanism for increased rates of asthma among obese children may involve a variety of factors, ranging from altered lung physiology in obese children, to immunomodulatory and metabolic effects of obesity on atopy and airway inflammation.[88] It is also possible that the causal link between asthma and obesity is bi-directional, as additional studies have shown that having asthma increases both the likelihood of obesity and the likelihood of decreased physical activity.[89, 21] In summary, while the links between asthma, decreased exercise and obesity are not yet fully characterized, these three factors can have important overlapping effects on health outcomes among children with asthma.[90] Physical activity and obesity therefore must be considered when assessing asthma health outcomes in school-age children, especially among children from minoritized racial and ethnic groups.

Asthma and Academic Outcomes

While a significant body of research literature has linked asthma to increased school absenteeism, results have been mixed regarding differences in academic outcomes among children with and without asthma.[31] Using health records for 92 students in Rochester, Minnesota, *Silverstein et al.* found a significant difference in absenteeism (2.21 additional absences, 95% CI, 1.41 to 3.01) between students with asthma and students without asthma, but found no evidence of decreased GPA or standardized test scores among children with asthma.[29] Similar associations involving absences, but not academic outcomes, were demonstrated by *Moonie et al.* across two samples in Missouri, including a group of 3,812 students and a group of 9,014 students, as well as a sample in Clark County, Nevada including 300,881 students.[91,92,93] Across these studies, absenteeism findings for students with asthma included approximately 3 more yearly absences among students with persistent asthma versus students with mild persistent asthma, approximately 2-3 more absent days among elementary and middle school students with asthma versus students without asthma, and increased odds of missing >10 days of school for children with asthma versus children without asthma.

Other studies have demonstrated associations between asthma and worsening standardized test outcomes. In a study of 8,914 children aged 7 to 15, Dr. Dafna Kohen demonstrated associations between children having moderate or severe asthma and decreased math test scores (OR moderate asthma 1.90, 95%CI 1.34 to 2.68; OR severe asthma 1.62, 95%CI 1.17 to 2.25). For reading tests, an effect was found only for students with moderate asthma (OR 1.73, 95%CI 1.28 to 2.32).[28] In 2013, *Crump et al.* studied 22,730 students in San Jose, California, and found a significant association between poorer English and math test scores (unadjusted English test failure OR 1.30, 95%CI 1.18 to 1.43; unadjusted math test failure OR 1.30, 95%CI 1.18 to 1.44).[94] However, each of these associations lost significance after adjusting for absenteeism, suggesting that school attendance was likely responsible for the majority of the observed association between asthma and decreased standardized test scores.

Asthma and Industrial Zoning in the City of Santa Ana

Santa Ana, California is home to 17 census tracts listed as "disadvantaged communities," a designation defined by the State of California for communities that are "disproportionately affected by environmental pollution and other hazards that can lead to negative health effects, exposure, or environmental degradation."[95] A comparison of these "disadvantaged communities" with a zoning map for the City of Santa Ana demonstrates that these tracts are loosely associated with areas where residential and industrial zones come into contact (Figure 2, Figure 3).[96] For several commonly measured air pollutants used in the "disadvantaged" determination, including $PM_{2.5}$, PM_{10}, and NO_2, air quality measurements for the City of Santa Ana are presently determined from a single monitoring station over 10 miles away.[97] Given the lack of high-resolution local air monitoring data, community concern about detrimental health effects of industrial zones interspersed throughout the city, and evidence of zip code level economic and health disparities, epidemiologic investigation of the association between asthma and industrial zones is warranted (Table 1, Table 2, Figure 2, Figure 3).[11]

This study aims to answer the question of whether industrial zoning proximity is associated with health and academic outcomes observed in school district records. If such an association is found, this may provide important guidance both for asthma management at the school district level, and zoning considerations at the City level. It would also provide a basis for a cost-effective approach to relating school record data to geospatial data in disadvantaged communities, where a need exists for information about the health impacts of city zoning patterns, but for which detailed exposure-outcome studies may be cost-prohibitive.

CHAPTER 3: METHODS

Study Design

To examine the association between home proximity to industrial zones and asthma prevalence, I performed a cross-sectional analysis of all children enrolled in the Santa Ana Unified School District (SAUSD) for the 2018-2019 school year. To test the effects of industrial zone proximity on health and academic outcomes among students with asthma, I performed a subset analysis among all children with a presumed diagnosis of asthma. Across all outcomes, I compared results for industrial zone exposures against the effect of freeway exposures.

Conceptual Models

Hypothesized conceptual models are shown in Figure 5. For Specific Aim 1, proximity to industrial zoning is used as a proxy for increased exposure to air pollution, which I hypothesized would lead to increased asthma prevalence (Figure 5, Model A). For Specific Aims 2 and 3, I hypothesized that increased industrial exposure would lead to increased symptoms and poorer asthma control among students with asthma, resulting in fitness test failure, increased absences, and decreased academic achievement (Figure 5, Model B). Age and sex were included as controls for all adjusted models, as both are known to influence asthma morbidity, BMI, and aerobic fitness results.[98,99,100]

Confounding variables for Model A are proxies for indicators of socioeconomic status, and include race, ethnicity, parents' highest level of education, and free and reduced lunch. These variables were included due to the known associations between race, ethnicity, and parental educational attainment on asthma morbidity, via mechanisms related to decreased healthcare access.[101, 102, 103] Zip code was included in each adjusted model to capture additional SES stratification by neighborhood.[104] Importantly, each of these markers of SES was also thought to have an important effect on the likelihood of living near areas zoned for industrial use. This hypothesized effect is based on reports throughout the environmental justice literature detailing multiple mechanisms whereby low SES communities have been historically pushed to less-desirable areas of cities, through a combination of deliberate practices such as redlining and market-based mechanisms.[105,106,1]

Study Population

Study population selection is shown in Figure 6. The Santa Ana Unified School District (SAUSD) is the 10th largest school district in the State of California and the 2nd largest school district in Orange County.[107] In accordance with both the UC Irvine Institutional Review Board and the SAUSD Research and Evaluation Department, K-12 student data from SAUSD were obtained, including demographic information, student medical records, physical fitness test data, and standardized academic testing data for the 2018-2019 school year. Of 48,823 total student records, 992 students who were enrolled for 159 days or less were excluded, to ensure that all students were enrolled for a significant portion of the school year. 2,827 students who attended 12 non-traditional schools (head start programs and remedial programs for adults) were also excluded, due to non-standard hours of operation and populations outside of the age range of interest for studying pediatric asthma.

After additional exclusions during geocoding (see below), the final sample included 44,641 students at 51 schools. These included 35 elementary schools (n=22,043 students), 9 middle schools (n=9,665 students), and 7 high schools (n=12,933 students). Within the final sample, 3,877 (8.7%) students were 18 years old or older as of January 1st, 2019 but were maintained in the study set given their attendance of traditional schools with comparable hours of attendance to other students. Additionally, 1,571 (3.5%) students had addresses listed outside of the City of Santa Ana but were maintained in the data set given their attendance at schools within City limits.

Demographic and Socioeconomic Status (SES) Variables

Race, ethnicity, free and reduced lunch status, parents' highest level of education, sex, and age information was extracted and re-coded to facilitate statistical analysis. Race data was re-coded to reflect the following broad categories: Hispanic only, American Indian/Alaska Native (AI/AN), Asian/Pacific Islander, Black/African-American, and white. Ethnicity was coded as either Hispanic or non-Hispanic. Per conversations with the SAUSD Research and Evaluation Department, the majority of Hispanic students (34,087) had their race recorded as AI/AN due to a combination of automatic reporting system factors and possible difficulties among parents in selecting corresponding racial descriptors consistent with Latinx identities. To account for this, I combined all students identifying as both Hispanic and AI/AN into a fifth, "Hispanic only" race category, and placed all students not identifying as Hispanic but identifying as AI/AN in the "American Indian/Alaska Native" category. Although this approach potentially obscured any students with dual AI/AN and Hispanic identity, it was carried out to achieve concordance with prior District reporting.

Free and reduced lunch was used as a proxy for home income. All families are invited to apply to receive free/reduced lunch, but only those who submit qualifying income information are granted free/reduced lunch status. Qualifying income levels are set by the State of California and correspond to poverty status, i.e. <130% of federal poverty line (free lunch), 130-185% of federal poverty line (reduced lunch). Qualifying tables for 2018-2019 can be found at https://www.cde.ca.gov/ls/nu/rs/scales1819.asp.[108,109] Students not submitting an income form were coded as NA (missing). For all others, lunch status was coded as “1” for free or reduced lunch and “0” for a denied application. Parents’ highest level of education was self-reported at the time of registration. For the present study, parent education information was consolidated into a binary variable, where “0” = at least one parent completed high school and “1” = neither parent completed high school. Sex data was available only in male and female categories, and was coded accordingly, with “1” = male and “0” = female. Age was calculated using the student's age on January 1st, 2019.

Determination of Students with Asthma

Asthma diagnosis, total number of diagnoses, medical events at school, and medical or health-appointment-related absences were extracted from SAUSD records for the 2018-2019 school year. Per SAUSD nursing staff, diagnoses are updated at variable time points by different schools in the district, with a series of questions that ask whether children currently have asthma, whether they take medication at home or school for asthma, and if they have activity restrictions due to asthma. However, given that asthma diagnoses are rarely removed from student records, SAUSD asthma rates were taken to represent a value comparable to “lifetime” asthma prevalence.

For the purposes of this study, children were primarily defined as having asthma based on their diagnosis in school records. However, for sensitivity analysis this definition was expanded to include all students with evidence of albuterol or inhaler use at school, or evidence of an asthma-related event at school, in their school medical record. First, a search was performed of all medical records for the text string “albut-,” “Albut-,” or “inhaler.” This yielded 165 additional students presumed to have an asthma diagnosis. I then searched for all students with at least one documented asthma event during the 2018-2019 school year. This yielded 37 additional students presumed to have an asthma diagnosis. Overall, the inclusion of both Albuterol use and documented asthma events increased the number of students with a presumed asthma diagnosis from 2,987 to 3,173, which increased estimated district-wide asthma prevalence from 6.7% to 7.1%. The final number of students presumed to have asthma was 3,173, or 7.1% of the total sample population of 44,641.

Total student absences were imported from SAUSD records for the 2018-2019 school year. Medically related absences were defined as any type of absence linked to health needs, including absences coded as “health appointments,” “illness” or “medical absence.” Of note, absence codes were not reliably associated with asthma symptoms, and may better relate to overall student health as opposed to asthma morbidity alone.

Fitness Testing and BMI Data

Physical fitness test data were obtained from FITNESSGRAM physical fitness tests carried out for grade levels 5, 7 and 9 in Winter or Spring, 2019. Of the study sample, 10,996 of 11,180 students in grades 5, 7, and 9 had a documented physical fitness test score. Briefly, the physical fitness test involves assessments in 6 domains including abdominal strength/endurance, upper body strength/endurance, trunk extensor strength/flexibility, body composition, overall flexibility, and aerobic capacity. Given the known relationship between severe asthma and diminished aerobic capacity, FITNESSGRAM results for aerobic capacity (including “healthy fitness zone” indicators) were extracted for each student for whom data was available.[110,111] Additional FITNESSGRAM scoring method information is available through the California Department of Education.[112]

Based on the aerobic testing results, a binary variable was created for "failed fitness test," grouping all students who scored in the "Healthy" fitness zone as a "0" and all children failing to attain this score as a "1." For Body Mass Index (BMI), each calculated BMI value was transformed to a nation-based percentile using the CDC "BMI Percentile Calculator for Child and Teen" (available at: https://www.cdc.gov/healthyweight/bmi/calculator.html). I then created a binary variable for "overweight/obese" weight status, placing children with BMI values in the overweight (BMI ≥85 percentile, <95th percentile) or obese (BMI ≥ 95th percentile) categories into a "1" group, and all other children (including normal and underweight children, BMI ≤5th percentile) into the "0" group.

Academic Testing Data

Among all standardized academic testing data available for the 2018-2019 school year, the statewide Smarter Balanced (SB) assessments for mathematics and English/language arts were selected as academic outcomes indicators, given that results for these assessments were available for the largest number of students (n= 21,938 and 21,931, respectively) across grades 3-8 and grade 11. Details of the SB assessment are available through the California Department of Education. Briefly, the assessments are designed to test students' knowledge levels based on grade-level standards. Students are given both a scale score and an "achievement level," indicating whether their grade-level standard of knowledge was "exceeded," "met," "nearly met," or "not met." [113] For study purposes, results were simplified into a binary "pass" (met or exceeded) or "fail" (nearly met or not met) variable.

Distance Calculation

Home and school addresses were geocoded using ArcGIS Pro ™ (Redlands, CA). Students for whom only a PO box home address was available (n=239), for whom the residential address fell outside of Orange County (n=87), and for whom the geocoding was of low accuracy (i.e. geocoding matching score < 85; n=19) or otherwise incompatible (n=18) were excluded. Among 44,641 student records, 363 total students were ultimately excluded from exposure analysis due to an unmatched or ineligible residence address. Home and school proximities to areas of industrial zoning were then calculated by Dr. Jun Wu, using geocoded addresses with latitudinal and longitudinal coordinates.

Exposure was estimated based on a composite of home and school distance to the nearest industrial zone or freeway. Industrial zones were demarcated according to the City of Santa Ana Zoning Map, corresponding to areas zoned for either heavy or light industrial use (Figure 3). Freeways were defined as Interstate or State Highways. The shortest home or school distance to the nearest freeway or boundary of an industrial zone polygon was then calculated using ArcGIS Pro. The unit of distance was expressed in kilometers.

Using distance values, a weighted composite distance variable was created using a crude estimate for proportion of average time spent at home and school. To create this variable, I estimated a school exposure time of 7 hours per day, 5 days per week, or 21% of all hours in a week, and a residential exposure time for all other hours of the week, or 79%. I then multiplied the composite distance value by -1, to transform it into a "proximity" variable for ease of interpretation:

Composite Proximity to Exposure = -1 * (0.21*school distance + 0.79*home distance)

Time spent in other locations, including travel to and from school and holidays, was not included in the calculation.

Statistical Modeling

Raw SAUSD data files were imported for processing with R Studio, version 1.3.1093. To test the hypothesized relationships between industrial zone or freeway proximity and asthma outcomes, logistic or linear regression were used for unadjusted and adjusted models, depending on whether the outcome was categorical or continuous, respectively. For each hypothesized association, only complete cases across exposure, outcome, and control variables were included. I then assessed beta-values and/or odds ratios (ORs) to determine the strength and likelihood of the association between industrial zone or freeway proximity and the outcome variables described in the S*pecific Aims*. Results were considered significant at a level of $p<0.05$.

To control for potential confounding from effects related to socioeconomic and demographic risk factors, adjusted models included sex, age, race, parents' highest level of education, free or reduced lunch status, and zip code. As described above, zip code was added as a dummy variable in the model to attempt to account for possible unmeasured socioeconomic factors that were not captured in the free/reduced lunch or parents' highest level of education variables. Linear and logistic regression were performed to assess the effect of proposed confounds on the exposure variable (composite proximity to the nearest industrial zone, Appendix A, Table S1), and outcome variables (Appendix A, Table S2), respectively. Given that each proposed confounding variable had at least one significant relationship to either the exposure or primary outcome variable ($p<0.05$), each was retained in the final multivariate adjusted models across all Specific Aims. To assess for multicollinearity, variance inflation factor was calculated for all control variables used in the adjusted model. Variance inflation factor was <5 for every control variable, suggesting only mild collinearity (Appendix A, Table S3).

CHAPTER 4: RESULTS

SAUSD Demographics 2018-2019

Demographics of the full sample, plus the subgroups of children with and without asthma for the 2018-2019 school year are displayed in Table 3. Total asthma prevalence was 7.1%, and 10% of all students reported having at least one non-asthma diagnosis. Mean age was 12.2 years ± 3.7, 82% of the student population received free or reduced lunch, and 45.3% of students came from households in which neither parent completed high school. Most students had home addresses within the City of Santa Ana, with only 799 students reporting a home address outside of the City.

There were several significant differences between the population with and without asthma. Among students with asthma, 22.2% had at least one non-asthma diagnosis, as opposed to 9.8% of the population without asthma ($p<0.001$). The population of students with asthma had a higher proportion of males (58% vs. 50%, $p<0.001$), and a higher mean age (12.4 years vs. 12.2 years, $p<0.001$). Among students with asthma, 80.8% received free or reduced lunch, in comparison to 82.1% of the population without asthma ($p<0.001$). Parents' highest level of education tended to be higher among students with asthma (57.1% achieved high school or beyond, vs. 51.2% of the population without asthma, $p<0.001$). With respect to race and ethnicity, Black and white students were more frequently diagnosed with asthma, while students identifying as Hispanic were less often diagnosed, in comparison to their shares of the total school population ($p=0.002$).

Table 3. Sample Characteristics (Santa Ana Unified School District 2018-2019)

	All Students, n (%) *(n=44,641)*	**Students without Asthma**, n (%) *(n=41,468)*	**Students with Asthma** [a], n (%) *(n=3,173)*	**p-value** [c]
Asthma prevalence, [a] n (%)	3,173 (7.1)	---	3,173 (100)	---
Number of students with a diagnosis besides asthma, n (%)	4,470 (10.0)	4,064 (9.8)	706 (22.2)	<0.001
Males, n (%)	22,590 (50.6)	20,749 (50.0)	1,841 (58.0)	<0.001
Mean age, years +/- SD	12.2 ± 3.7	12.2 ± 3.7	12.4 ± 3.4	<0.001
Number receiving Free/Reduced lunch, n (%) [b]	36,623 (82.0)	34,058 (82.1)	2,565 (80.8)	<0.001
***Highest level of education of either parent**, n (%)*				
Less than high school	20,224 (45.3)	18,937 (45.7)	1,287 (40.6)	
High school or beyond	23,029 (51.6)	21,217 (51.2)	1,812 (57.1)	<0.001
Declined/Unknown	1,388 (3.1)	1,314 (3.1)	74 (2.3)	
***Ethnicity**, n (%)*				
Hispanic	42,880 (96.1)	39,866 (96.1)	3,014 (95.0)	<0.001
Non-Hispanic	1,759 (3.9)	1,600 (3.9)	159 (5.0)	
***Race**, n (%)*				
Hispanic only	33,975 (76.1)	31,632 (76.3)	2,343 (73.8)	
White, any ethnicity	8,646 (19.4)	7,984 (19.3)	662 (20.9)	

Asian, Pacific Islander	1,382 (3.1)	1,264 (3.0)	118 (3.7)	
Black, any ethnicity	197 (0.4)	166 (0.4)	31 (9.8)	0.002
American Indian/Alaska Native, any ethnicity	120 (0.3)	114 (0.3)	6 (0.2)	
Other/Decline to state	321 (0.7)	308 (0.7)	13 (0.4)	
Children per zip code, *n (%)*				
92701	9,339 (20.9)	8,690 (21.0)	649 (20.4)	
92702	3 (0.01)	3 (0.01)	---	
92703	7,658 (17.2)	7,183 (17.3)	475 (15.0)	
92704	11,689 (26.2)	10,831 (26.1)	858 (27.0)	0.076
92705	1,132 (2.5)	1,044 (2.5)	88 (2.8)	
92706	3,686 (8.3)	3,455 (8.3)	231 (7.3)	
92707	10,097 (22.6)	9,306 (22.4)	791 (24.9)	
Non-Santa Ana	1,037 (2.3)	956 (2.3)	81 (2.6)	

[a] *Includes all students with documented asthma diagnosis as well as "presumed" asthma diagnosis (see Methods)*
[b] *Binary Free/Reduced Lunch Variable: Free OR reduced vs. Denied (NA values excluded)*
[c] *P-values derived from comparison between asthma and non-asthma groups, with either Welch T-test (for continuous variables) or Chi-square test (for categorical variables)*

SAUSD Physical Fitness and Academic Outcomes

Physical fitness and academic outcomes are shown in Table 4 and Table 5. Outcomes for physical fitness tests administered during the 2018-2019 school year showed a district-wide mean BMI percentile of 73, with 50.6% of students classified as being overweight or obese (Table 4). 43.9% of students failed to meet "Healthy Fitness Zone" standards for aerobic fitness. BMI was significantly higher among students with asthma compared to students without asthma, with 35.9% of students with asthma being classified as obese compared to 29.4% of students without asthma ($p<0.001$). Additionally, students with asthma had slightly lower average estimated VO_2 max scores (42.4 vs. 42.9 mL/kg/min, $p=0.028$) and a smaller number of students with asthma managed to achieve the "Healthy Fitness Zone" designation based on aerobic performance (48.6% vs. 55.2%, $p<0.001$), in comparison to their peers without asthma.

Students with asthma had a higher average number of total recorded absences (7.0 days vs. 5.0, $p<0.001$) and medically related absences (5.1 days vs. 3.2, $p<0.001$) for the 2018-2019 school year (Table 5). However, mean standardized math and English test scores were statistically similar among students with and without asthma. The majority of SAUSD students tested in math and English domains on state standardized exams during the 2018-2019 school year did not meet expectations. For the Smarter Balanced math assessment, 74.5% of tested SAUSD students failed to achieve scores that met expectations. For the Smarter Balanced English/Language Arts assessment, 67.8% of tested students did not meet expectations.

Industrial Zone and Freeway Exposures

Zip code population distributions were similar among populations of students with and without asthma, as assessed by chi-squared goodness of fit test ($p = 0.076$, Table 3). However, the average distance to the nearest industrial zone or freeway differed significantly between the two groups, as shown in Table 6. For most measures of distance to industrial and freeway exposures, including composite proximity, home distance, and school distance, students with asthma on average tended to live significantly closer to the exposure source than their classmates without asthma. When dividing all students into tertiles of composite industrial zone proximity, the closest 33% of students lived and attended school at an average distance of between 4 meters and 500 meters from areas zoned for industrial use. For freeway proximity, the closest 33% of students lived and attended school at an average distance of between 72 meters and 1.6 kilometers from the nearest freeway.

Table 4. Physical Fitness Test Outcomes (Santa Ana Unified School District 2018-2019)

	All Students, n (%) *(n=10,665)*	**Students without Asthma**, n (%) [a] *(n=9,802)*	**Students with Asthma**, n (%) *(n=863)*	**p-value** [c]
BMI Percentile, mean ± SD	73 ± 28	73 ± 28	78 ± 26	<0.001
BMI Category (%)				
Obese	3,188 (29.9)	2,878 (29.4)	310 (35.9)	
Overweight	2,212 (20.7)	2,019 (20.6)	193 (22.4)	<0.001
Normal Weight	5,001 (46.9)	4,652 (47.5)	349 (40.4)	
Underweight	264 (2.5)	253 (2.6)	11 (1.3)	
Estimated VO_2 Max [c] (mL/kg/min)	42.9 ± 6.3	42.9 ± 6.2	42.4 ± 6.4	0.028
Aerobic Score				
Healthy Fitness Zone	5,827 (54.6)	5,408 (55.2)	419 (48.6)	
Needs Improvement	3,077 (28.9)	2,808 (28.6)	269 (31.2)	<0.001
Health Risk	1,600 (15.0)	1,438 (14.7)	162 (18.8)	
Incomplete Test / Missing	161 (1.5)	148 (1.5)	13 (1.5)	

[a] *Includes all students with documented asthma diagnosis as well as "presumed" asthma diagnosis (see Methods)*
[b] *P-values derived from comparison between asthma and non-asthma groups, with either two-tailed Welch T-test (continuous variable) or Chi-square test (categorical variable)*
[c] *Estimated VO_2 max was calculated by SAUSD test administrators based on age, sex, BMI and walk time ± heart rate for an aerobic task. For example, the 1-mile run equation is: VO2Max = (.21 * age * sex) – (.84 * BMI) – (8.41 * time) + (.34 * time * time) + 108.941. Full details of VO_2 calculation can be found in the 2020 California PFT Reference Guide available at https://pftdata.org/files/Reference_Guide.pdf.*

Table 5. Academic Outcomes (Santa Ana Unified School District 2018-2019)

Absences	**All Students**, n (%) *(n=44,641)*	**Students without Asthma**, n (%) *(n=41,468)*	**Students with Asthma** [a], n (%) *(n=3,173)*	**p-value** [c]
Total Absences recorded for 2018-2019, mean ± SD	5.2 ± 7.4	5.0 ± 7.2	7.0 ± 9.4	<0.001
Total Medically Related Absences recorded for 2018-2019, mean ± SD	3.4 ± 4.7	3.2 ± 4.5	5.1 ± 6.9	<0.001
Math Test Scores	**All Students** *(n=23,794)*	**Students without Asthma** *(n=22,031)*	**Students with Asthma** [a] *(n=1763)*	**p-value** [c]
Mean SB Math Test Raw Score	2473 ± 102	2472 ± 102	2476 ± 104	0.107
# Not Meeting Expectations	17,717 (74.5)	16,432 (74.6)	1,285 (72.9)	0.122
English Test Scores	**All Students** *(n=23,724)*	**Students without Asthma** *(n=21,956)*	**Students with Asthma** [a] *(n=1,768)*	**p-value** [c]
Mean SB English Test Raw Score	2475 ± 104	2475 ± 104	2477 ± 103	0.484
# Not Meeting Expectations	16,091 (67.8)	14,889 (67.8)	1,202 (68.0)	0.901

[a] *Includes all students with documented asthma diagnosis as well as "presumed" asthma diagnosis (see Methods)*

Table 6. Distribution of Exposure Variable (Santa Ana Unified School District 2018-2019)

	All Students, n (%) *(n=44,641)*	**Students without Asthma**, n (%) *(n=41,468)*	**Students with Asthma** [a], n (%) *(n=3,173)*	**p-value** [b]
Composite proximity to nearest industrial zone, mean +/- SD (m)	873 ± 779	875 ± 780	843 ± 769	0.028
Farthest Tertile (m)	1,052 - 20,026			
Middle Tertile (m)	535 - 1,051			
Closest Tertile (m)	4 - 534			
Average Home Distance, mean +/- SD (m)	884 ± 932	886 ± 932	855 ± 923	0.069
Average School Distance, mean +/- SD (m)	832 ± 590	834 ± 591	802 ± 571	0.002
Composite Proximity to Nearest Freeway (m) (+/- SD)	2,220 ± 1,063	2,224 ± 1,063	2,170 ± 1,057	0.005
1st Tertile	2,701 - 4,596			
2nd Tertile	1,641 - 2,700			
3rd Tertile	72 - 1,640			
Average Home Distance, mean +/- SD (m)	2,218 ± 1,157	2,222 ± 1,156	2,176 ± 1,163	0.033
Average School Distance, mean +/- SD (m)	2,227 ± 1,062	2,234 ± 1,062	2,146 ± 1,057	<0.001

[a] *Includes all students with documented asthma diagnosis as well as "presumed" asthma diagnosis (see Methods)*
[b] *P-values derived from comparison between asthma and non-asthma groups, with either Welch T-test (continuous variable) or Chi-square test (categorical variable)*

Results by Specific Aim

Specific Aim 1: Assess the association between asthma prevalence and industrial zone proximity to student home and school locations.

Hypothesis: Increased home and school proximity to areas zoned for industrial use is associated with an increased risk of having an asthma diagnosis, when controlling for traditional socioeconomic factors.

Results: Specific Aim 1 results are shown in Table 7. The unadjusted OR (uOR) for asthma diagnosis with increasing industrial zone proximity was 1.04 (95% CI 0.99 to 1.10, p=0.152) for 40,194 complete cases. Adjusted OR (aOR) for asthma diagnosis with increasing industrial zone proximity was 1.06 (95% CI 1.00 to 1.12, p=0.043).

Comparing students living in the closest versus the farthest tertile of distance from the nearest industrial zone, the adjusted OR was 1.21 (95%CI 1.10 to 1.33, p <0.001). For students with composite exposures in the middle distance tertile, the adjusted OR was also 1.21 (95% CI 1.10 to 1.33, p <0.001). The effect of freeway exposure on the likelihood of having asthma was also significant, both for the continuous variable of composite freeway exposure (adjusted OR 1.05, 95% CI 1.01 to 1.09, p=0.011) and for children living in the closest tertile of proximity to the nearest freeway (unadjusted OR 1.10, 95% CI 1.00 to 1.20, p=0.046). However, adjusted models for the likelihood of having asthma among students in the closest and middle tertiles of distance from the nearest freeway were not significant (p>0.05).

Table 7. Effect of Industrial Zone and Freeway Proximity on Asthma Prevalence (n=40,194, Specific Aim 1)

	Unadjusted OR (95% CI) [a]	**p-value** [b]	**Adjusted OR** (95% CI) [c]	**p-value**
Industrial Zone Proximity (km)	1.04 (0.99, 1.10)	0.152	1.06 (1.00, 1.12)	0.043
Closest Tertile [d] *0.004-0.534 km*	1.18 (1.07, 1.30)	0.001	1.21 (1.10, 1.33)	0.0001
Middle Tertile [d] *0.535-1.051 km*	1.21 (1.10, 1.32)	0.0001	1.21 (1.10, 1.33)	0.0001
Proximity to Nearest Freeway (km)	1.05 (1.02, 1.09)	0.004	1.05 (1.01, 1.09)	0.011
Closest Tertile [e] *0.072-1.640 km*	1.10 (1.00, 1.20)	0.046	1.08 (0.98, 1.18)	0.109
Middle Tertile [e] *1.641-2.700 km*	1.04 (0.94, 1.14)	0.456	1.01 (0.92, 1.11)	0.793

[a] *Determined using logistic regression*
[b] *P-values for logistic regression were determined using Wald's test*
[c] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[d] *As compared to farthest Tertile, >1.051 km away from nearest industrial zone*
[e] *As compared to farthest Tertile, >2.70 km away from nearest industrial zone*

Specific Aim 2. Assess the association between health outcomes (weight status, physical fitness test scores, and asthma events) and industrial zone proximity to home and school locations for students with asthma.

Hypothesis: Increased home and school proximity to areas zoned for industrial use is associated with increased obesity, poorer physical fitness test scores, and increased asthma events among students with asthma, when controlling for traditional socioeconomic factors.

Results: Obesity. Specific Aim 2 results are shown in Table 8, Table 9, and Table 10. Industrial zone proximity was associated with a significantly higher likelihood of being overweight or obese among children with asthma (adjusted OR 1.39, 95% CI 1.11 to 1.78, p=0.005, Table 8). Odds were highest for children living in the middle distance tertile (adjusted OR 1.56, 95% CI 1.09 to 2.23, p=0.015), followed by children living in the closest tertile (adjusted OR 1.50, 95% CI 1.04 to 2.17, p=0.029). There were no significant associations for either the unadjusted or adjusted freeway exposure models.

Physical Fitness Test Outcomes. Among children with asthma, there was a significantly increased likelihood of receiving an unhealthy FITNESSGRAM score with increasing composite industrial zone proximity (adjusted OR 1.42, 95%CI 1.23 to 1.83, Table 9). When comparing tertiles, there was an increased likelihood of receiving an unhealthy FITNESSGRAM score only among children in the closest tertile (adjusted OR 1.46, 95%CI 1.02 to 2.10, p=0.041). No significant associations were observed for either the unadjusted or adjusted freeway exposure models.

Asthma Events. Among children with asthma, there was a statistically significant, weakly negative association between the number of recorded asthma events at school and increasing proximity to the nearest industrial zone in kilometers (adjusted b= -0.03, p=0.020, Table 10). There were similar, slightly stronger negative associations for asthma events among children in the closest (*b*= -0.05, p=0.026) and middle (*b*= -0.05, p=0.045) tertiles of composite exposure, when compared to children in the farthest tertile. No significant associations were observed for either the unadjusted or adjusted freeway exposure models.

Table 8. Effect of Industrial Zone and Freeway Proximity on Likelihood of Being Overweight or Obese Among Children with Asthma (n=810, Study Aim 2)

Overweight or Obese	**Unadjusted OR** (95% CI) [a]	**p-value** [b]	**Adjusted OR** (95% CI) [c]	**p-value**
Industrial Zone Proximity (km)	1.28 (1.05, 1.60)	0.019	1.39 (1.11, 1.78)	0.005
Closest Tertile [d] *0.004-0.534 km*	1.39 (0.97, 1.97)	0.069	1.50 (1.04, 2.17)	0.029
Middle Tertile [d] *0.535-1.051 km*	1.46 (1.04, 2.07)	0.031	1.56 (1.09, 2.23)	0.015
Proximity to Nearest Freeway (km)	0.91 (0.79, 1.04)	0.153	0.90 (0.78, 1.03)	0.131
Closest Tertile [e] *0.072-1.640 km*	0.76 (0.53, 1.07)	0.113	0.77 (0.54, 1.11)	0.163
Middle Tertile [e] *1.641-2.700 km*	0.87 (0.61, 1.24)	0.442	0.91 (0.63, 1.30)	0.606

[a] *Determined using logistic regression*
[b] *P-values for logistic regression were determined using Wald's test*
[c] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[d] *As compared to farthest Tertile, >1.051 km away from nearest industrial zone*
[e] *As compared to farthest Tertile, >2.70 km away from nearest freeway*

Table 9. Effect of Industrial Zone and Freeway Proximity on Likelihood of Unhealthy Fitness Zone Score Among Children with Asthma (n=798, Study Aim 2)

Unhealthy Aerobic Fitness Score	**Unadjusted OR** (95% CI) [a]	**p-value** [b]	**Adjusted OR** (95% CI) [c]	**p-value**
Industrial Zone Proximity (km)	1.32 (1.07, 1.67)	0.015	1.42 (1.13, 1.83)	0.005
Closest Tertile [d] *0.004-0.534 km*	1.44 (1.01, 2.06)	0.042	1.46 (1.02, 2.10)	0.041
Middle Tertile [d] *0.535-1.051 km*	1.20 (0.85, 1.69)	0.307	1.25 (0.88, 1.79)	0.2131
Proximity to Nearest Freeway (km)	1.03 (0.90, 1.18)	0.645	1.01 (0.88, 1.16)	0.829
Closest Tertile [e] *0.072-1.640 km*	1.06 (0.75, 1.49)	0.752	1.03 (0.72, 1.46)	0.891
Middle Tertile [e] *1.641-2.700 km*	0.75 (0.53, 1.06)	0.101	0.78 (0.55, 1.11)	0.171

[a] *Determined using logistic regression*
[b] *P-values for logistic regression were determined using Wald's test*
[c] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[d] *As compared to farthest Tertile, >1.051 km away from nearest industrial zone*
[e] *As compared to farthest Tertile, >2.70 km away from nearest freeway*

Table 10. Effect of Industrial Zone and Freeway Proximity on Asthma Events Among Children with Asthma (n=2,918, Study Aim 2)

	Coefficient (Unadjusted) [a]	**p-value**	**Coefficient (Adjusted)** [b]	**p-value**
Industrial Zone Proximity (km)	-0.03	0.023	-0.027	0.020
Closest Tertile [c] *0.004-0.534 km*	-0.051	0.025	-0.051	0.026
Middle Tertile [c] *0.535-1.051 km*	-0.047	0.038	-0.046	0.045
Proximity to Nearest Freeway (km)	-0.004	0.644	-0.003	0.690
Closest Tertile [d] *0.072-1.640 km*	-0.004	0.867	-0.002	0.945
Middle Tertile [d] *1.641-2.700 km*	0.028	0.209	0.033	0.138

[a] *Beta-value determined using linear regression*
[b] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[c] *As compared to 3rd Tertile, >1.05 km m away from nearest industrial zone*
[d] *As compared to 3rd Tertile, >2.70 km m away from nearest freeway*

Specific Aim 3: Assess the association between school outcomes (absences and standardized test scores) and industrial zone proximity to home and school locations for students with asthma.

Hypothesis: Increased home and school proximity to areas zoned for industrial use is associated with increased school absences and decreased standardized test scores among students with asthma, when controlling for traditional socioeconomic factors.

Results: No significant association was found between industrial zone or freeway proximity and the number of total absences or medically related absences among students with asthma (Table 11, Table 12). The same was found for math test results, although the association between industrial zone proximity and increased likelihood of failing the standardized math exam approached significance for students living in the middle tertile of composite industrial zone distance (adjusted OR 1.31, 95%CI 0.99 to 1.74, p=0.055, Table 13). Paradoxically, there was a significant association between increasing math test scores and living in the middle tertile of distance from the nearest freeway (adjusted b= 14.6, p=0.013).

There was no significant association overall between increasing industrial zone proximity and standardized English test scores among students with asthma (Table 14). However, for the freeway exposure, there was a significant association between increased English scores and living in the closest or middle distance tertile compared to the farthest tertile of distance from the nearest freeway (adjusted b_{middle}= 13.2, p=0.019; adjusted $b_{closest}$=13.3, p=0.016). A similarly paradoxical effect was seen for children living in the closest tertile of freeway distance, who had a decreased likelihood of failing the standardized English exam compared to students in the farthest tertile (adjusted OR 0.72, 95%CI 0.55 to 0.94, p=0.016).

Table 11. Effect of Industrial Zone and Freeway Proximity on Number of Total Absences Among Children with Asthma (n=2,929, Study Aim 3)

	Coefficient (Unadjusted) [a]	**p-value**	**Coefficient (Adjusted)** [b]	**p-value**
Industrial Zone Proximity (km)	-0.18	0.411	-0.13	0.538
Closest Tertile [c] *0.004-0.534 km*	-0.08	0.856	0.04	0.918
Middle Tertile [c] *0.535-1.051 km*	-0.14	0.742	-0.04	0.917
Proximity to Nearest Freeway (km)	-0.08	0.604	-0.11	0.480
Closest Tertile [e] *0.072-1.640 km*	-0.14	0.727	-0.19	0.654
Middle Tertile [d] *1.641-2.700 km*	0.27	0.512	0.34	0.419

[a] *Beta-value determined using linear regression*
[b] *Adjusted for sex, age, nonwhite race, free/reduced lunch status, parents' highest level of education, zip*
[c] *As compared to 3rd Tertile, >1.05 km m away from nearest industrial zone*
[d] *As compared to 3rd Tertile, >2.70 km m away from nearest freeway*

Table 12. Effect of Industrial Zone and Freeway Proximity on Number of Medical Absences Among Children with Asthma (n=2,929, Study Aim 3)

	Coefficient (Unadjusted) [a]	p-value	Coefficient (Adjusted) [b]	p-value
Industrial Zone Proximity (km)	-0.16	0.319	-0.08	0.627
Closest Tertile [d] *0.004-0.534 km*	-0.14	0.661	0.01	0.973
Middle Tertile [d] *0.535-1.051 km*	-0.11	0.719	0.03	0.926
Proximity to Nearest Freeway (km)	-0.002	0.984	-0.04	0.715
Closest Tertile [e] *0.072-1.640 km*	0.02	0.959	-0.02	0.941
Middle Tertile [e] *1.641-2.700 km*	0.20	0.522	0.28	0.362

[a] *Beta-value determined using linear regression*
[b] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[c] *As compared to 3rd Tertile, >1.05 km m away from nearest industrial zone*
[d] *As compared to 3rd Tertile, >2.70 km m away from nearest freeway*

Table 13. Effect of Industrial Zone and Freeway Proximity on Math Test Scores Among Children with Asthma (n=1,662, Study Aim 3)

Math Scale Score	**Coefficient (Unadjusted)** [a]	**p-value**	**Coefficient (Adjusted)** [b]	**p-value**
Industrial Zone Proximity (km)	-0.66	0.843	0.89	0.780
Closest Tertile [c] *0.004-0.534 km*	1.60	0.800	0.59	0.920
Middle Tertile [c] *0.535-1.051 km*	-3.93	0.531	-8.38	0.15
Proximity to Nearest Freeway (km)	1.96	0.407	0.04	0.984
Closest Tertile [d] *0.072-1.640 km*	10.5	0.090	4.17	0.471
Middle Tertile [d] *1.641-2.700 km*	23.6	0.0002	14.6	0.013
Likelihood of Not Meeting Math Test Expectations	**Unadjusted OR** (95% CI) [e]	**p-value** [f]	**Adjusted OR** (95% CI) [g]	**p-value**
Industrial Zone Proximity (km)	1.01 (0.98, 1.06)	0.636	0.99	0.861
Closest Tertile [h] *0.004-0.534 km*	1.03 (0.95, 1.11)	0.480	1.11 (0.84, 1.47)	0.455
Middle Tertile [h] *0.535-1.051 km*	1.06 (0.99, 1.15)	0.086	1.31 (0.99, 1.74)	0.055
Proximity to Nearest Freeway (km)	1.00 (0.98, 1.03)	0.813	1.03 (0.93, 1.15)	0.572
Closest Tertile [i] *0.072-1.640 km*	0.99 (0.92, 1.07)	0.841	1.01 (0.76, 1.33)	0.968
Middle Tertile [i] *1.641-2.700 km*	0.98 (0.91, 1.05)	0.533	0.97 (0.73, 1.29)	0.858

[a] *Beta-value determined using linear regression*
[b] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[c] *As compared to 3rd Tertile, >1.05 km m away from nearest industrial zone*
[d] *As compared to 3rd Tertile, >2.70 km m away from nearest freeway*
[e] *Determined using logistic regression*
[f] *P-values for logistic regression were determined using Wald's test*
[g] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[h] *As compared to farthest Tertile, >1.051 km away from nearest industrial zone*
[i] *As compared to farthest Tertile, >2.70 km away from nearest freeway*

Table 14. Effect of Industrial Zone and Freeway Proximity on English Test Scores Among Children with Asthma (n=1,666, Study Aim 3)

SB English Test Scale Score	**Coefficient (Unadjusted)** [a]	**p-value**	**Coefficient (Adjusted)** [b]	**p-value**
Industrial Zone Proximity (km)	0.43	0.896	0.98	0.748
Closest Tertile [d] *0.004-0.534 km*	2.18	0.728	-0.27	0.961
Middle Tertile [d] *0.535-1.051 km*	2.46	0.692	-3.23	0.561
Proximity to Nearest Freeway (km)	5.73	0.014	4.01	0.06
Closest Tertile [e] *0.072-1.640 km*	20.1	0.001	13.3	0.016
Middle Tertile [e] *1.641-2.700 km*	21.5	0.001	13.2	0.019

Likelihood of Not Meeting English Test Expectations	**Unadjusted OR** (95% CI) [a]	**p-value** [b]	**Adjusted OR** (95% CI) [c]	**p-value**
Industrial Zone Proximity (km)	1.01 (0.97, 1.06)	0.781	0.98 (0.85, 1.14)	0.821
Closest Tertile [d] *0.004-0.534 km*	1.01 (0.93, 1.10)	0.715	1.06 (0.81, 1.38)	0.669
Middle Tertile [d] *0.535-1.051 km*	1.05 (0.96, 1.14)	0.275	1.19 (0.92, 1.56)	0.189
Proximity to Nearest Freeway (km)	0.97 (0.94, 1.00)	0.039	0.90 (0.82, 1.00)	0.053
Closest Tertile [e] *0.072-1.640 km*	0.90 (0.83, 0.98)	0.011	0.72 (0.55, 0.94)	0.016
Middle Tertile [e] *1.641-2.700 km*	0.94 (0.86, 1.01)	0.113	0.84 (0.64, 1.10)	0.204

[a] *Beta-value determined using linear regression*
[b] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[c] *As compared to 3rd Tertile, >1.05 km m away from nearest industrial zone*
[d] *As compared to 3rd Tertile, >2.70 km m away from nearest freeway*
[e] *Determined using logistic regression*
[f] *P-values for logistic regression were determined using Wald's test*
[g] *Adjusted for sex, age, race, ethnicity, free/reduced lunch status, parents' highest level of education, zip*
[h] *As compared to farthest Tertile, >1.051 km away from nearest industrial zone*
[i] *As compared to farthest Tertile, >2.70 km away from nearest freeway*

CHAPTER 5: DISCUSSION

Summary

Results of this study of 44,641 students in the City of Santa Ana, California indicate that industrial zone proximity is significantly associated with higher asthma prevalence after controlling for available socioeconomic factors. Among children with asthma, there was an increased risk of being overweight or obese, and an increased risk of lower physical fitness test scores for those living and attending school at locations within 1.6 km of an area zoned for industrial use. For other health and academic outcomes, including asthma events and medical absences, results were either non-significant or significant but in the opposite direction of the anticipated effect, suggesting that the relationship between industrial zoning and student outcomes is likely more complicated than hypothesized.

Demographics, Asthma Prevalence, and Exposure Variable

Demographic analysis of students in the Santa Ana Unified School District highlights a population of children who may face structural challenges to healthy living and academic thriving.[114] This is reflected across zip code level information from publicly available demographic databases, as well as SAUSD demographic records, which show that students face lower levels of educational attainment among their parents and a high rate of poverty (indicated by the high proportion of students receiving free or reduced lunch, Table 2, Table 3). It is also reflected in high levels of obesity, as approximately 30% of students who took the physical fitness test in 2018-2019 were classified as obese and 21% were classified as overweight (Table 4). These values are significantly higher than the 2017-2018 United States national averages of 25.4% (obese or severely obese) and 16.1% (overweight).[115]

This collection of factors would seem to predict a higher-than-average asthma prevalence rate, as was suggested by the 28% rate previously reported among similar populations in Orange County.[43] However, the 2018-2019 asthma prevalence calculated for SAUSD was 7.1%, even after adding 186 students with a presumed diagnosis based on documented school asthma events or inhaler use records. This suggests that many students with asthma are not being recorded, possibly as a result of district and community-level factors. Currently, SAUSD records ask whether children have a "Current Problem with Asthma," whether they have a medication at home or school for asthma, and if they have activity restrictions or limitations due to asthma. However, they do not ask more simply about whether students have an inhaler at home, or whether students frequently experience wheezing symptoms. It is also possible that asthma is simply under-recognized and underdiagnosed at the community level, either due to limited health care access, or insufficient evaluations by primary care providers. Finally, some degree of underreporting could be influenced by patterns of health literacy, regardless of healthcare access. This may be reflected by the fact that parents of children whose asthma was officially documented by the School District had, on average, higher levels of educational attainment compared to the parents of children without documented asthma (Table 3).

Another striking outcome of SAUSD demographic analysis was the finding that the average home and school distance from an industrial zone in the City of Santa Ana is less than 1 kilometer, with 33% of students having a composite distance of less than 535 meters from the nearest industrial zone (Table 2, Table 6). The distribution of student homes in relation to industrial zones is visible on a home residence density map for the City of Santa Ana (Figure 4). In addition, distance analysis showed that school locations frequently fell within 1 kilometer of the nearest industrial zone, with three schools located less than 100 meters from an area zoned for industrial use (data not shown). These observations are all consistent with historical concerns raised by Santa Ana residents regarding the extraordinarily close proximity of residences and schools to areas zoned for industrial use.[116]

Specific Aim 1- Asthma Prevalence

Results of the adjusted logistic regression model suggest that for every 1 kilometer closer a child's home and school address comes to an area zoned for industrial use, there is a 6% increase in the risk of that child having asthma. Interestingly, this effect became significant only in the adjusted model, suggesting that some of the control variables likely had a protective effect on the likelihood of having asthma. This was confirmed by logistic regression analysis of control variables, which showed a significantly decreased odds of asthma diagnosis associated with Hispanic ethnicity (OR 0.61, 95% CI 0.64 to 0.90, p=0.001), parents' highest level of education less than high school (OR 0.79, 95% CI 0.74 to 0.86, p <0.001), and receiving free or reduced lunch (OR 0.77, 95% CI 0.69 to 0.85, p<0.001; see Appendix A, Table S1). Given what is known about asthma risk factors nationally, and in the context of possible underreporting of asthma across SAUSD, asthma may be especially underdiagnosed in families facing overlapping barriers of structural racism, low educational attainment, or poverty. However, it is also possible that these variables might decrease asthma risk through more nuanced mechanisms, i.e. varying patterns of allergen sensitization or indoor pollutant exposures.

Dividing the exposure distance into tertiles allowed for a more simplified approach to risk estimation and revealed a 21% increased risk of having asthma for children in either the closest (4 m - 534 m) or middle (535 m - 1.05 km) tertiles of composite proximity to the nearest industrial zone, when compared to children living in the farthest tertile. Contrary to the expected relationship of increasing risk with increased proximity, the equivalent risks estimated for closest and middle tertiles suggest that the effect of industrial zone exposure on asthma risk is likely a non-linear relationship, potentially mediated by additional factors such as wind or traffic patterns. The presence of such mediators may also explain the unexpected pattern observed for the freeway exposure variable, which was associated with a significant risk of asthma overall, but not for children in the closest or middle distance tertiles, after adjustment for available socioeconomic factors. Another factor possibly explaining this effect pattern could be exposure to street traffic on larger "trunk roads," which were not accounted for in the present study, but which have been previously linked to increased asthma prevalence.[117]

Given that some of the largest industrial zones in Santa Ana are loosely co-located with freeway corridors, the effect of controlling for freeway proximity in the adjusted model for Specific Aim 1 was tested. When including composite freeway exposure alongside the other controls, the association between composite industrial zone proximity and presumed asthma diagnosis lost significance (adjusted OR 1.05, 95% CI 1.00 to 1.11, p = 0.67). For tertile-based analysis, however, the association was only slightly weakened from the original, tertile-based models (adjusted OR for the closest tertile was 1.18, 95% CI 1.07 to 1.30, p=0.0010). Overall, results for Specific Aim 1 suggest that children with a composite industrial zone proximity of less than 1 km have a significantly increased risk of having asthma, which was not explained by freeway exposure or available indicators of socioeconomic status.

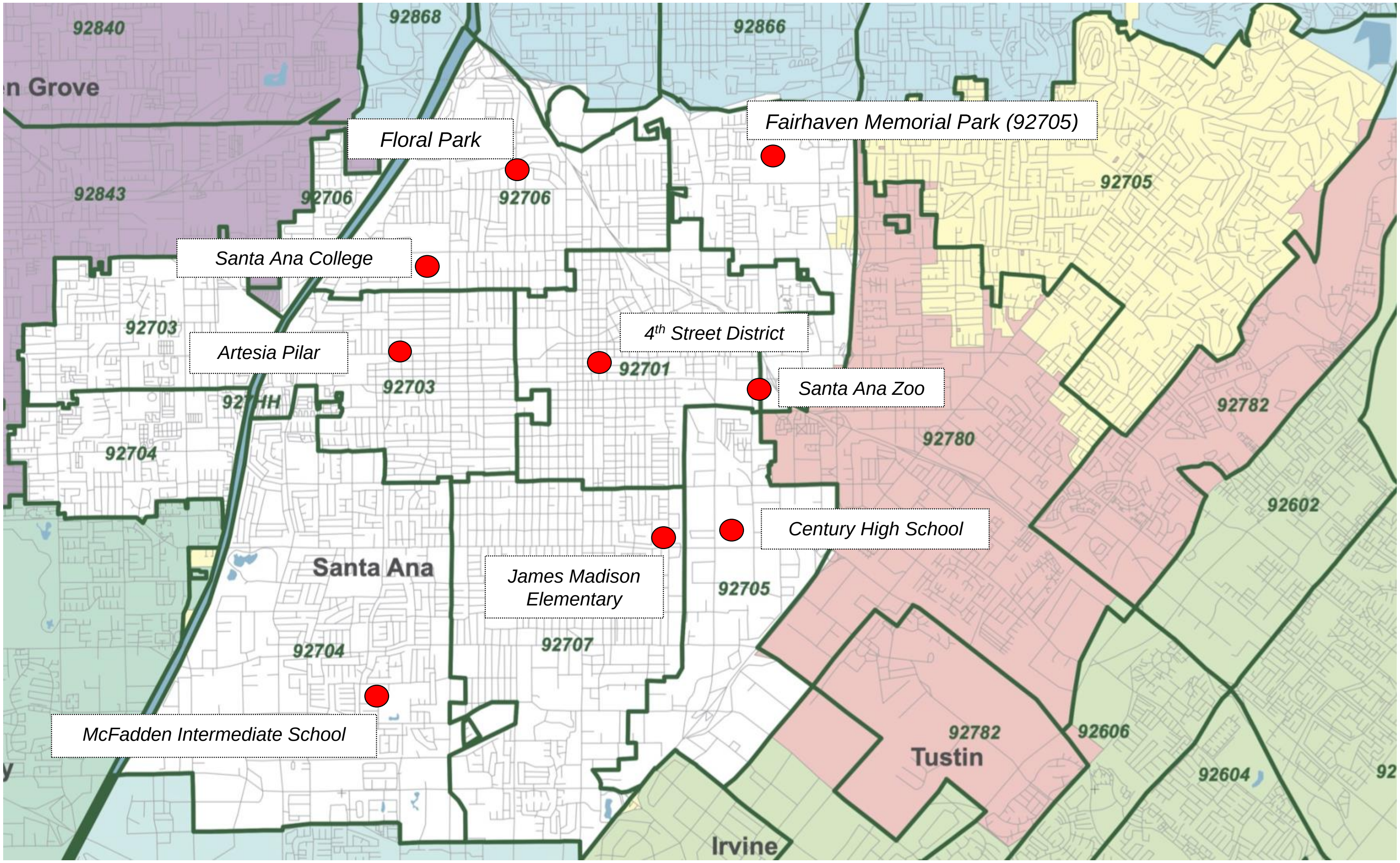


Figure 1. Zip code map for the City of Santa Ana, California (white). Of note, zip code 92705 contains a large portion that encompasses the neighboring region of North Tustin (yellow). City landmarks added by the author. Map was purchased and reproduced with permission from Digital Vector Maps (https://digital-vector-maps.com/).

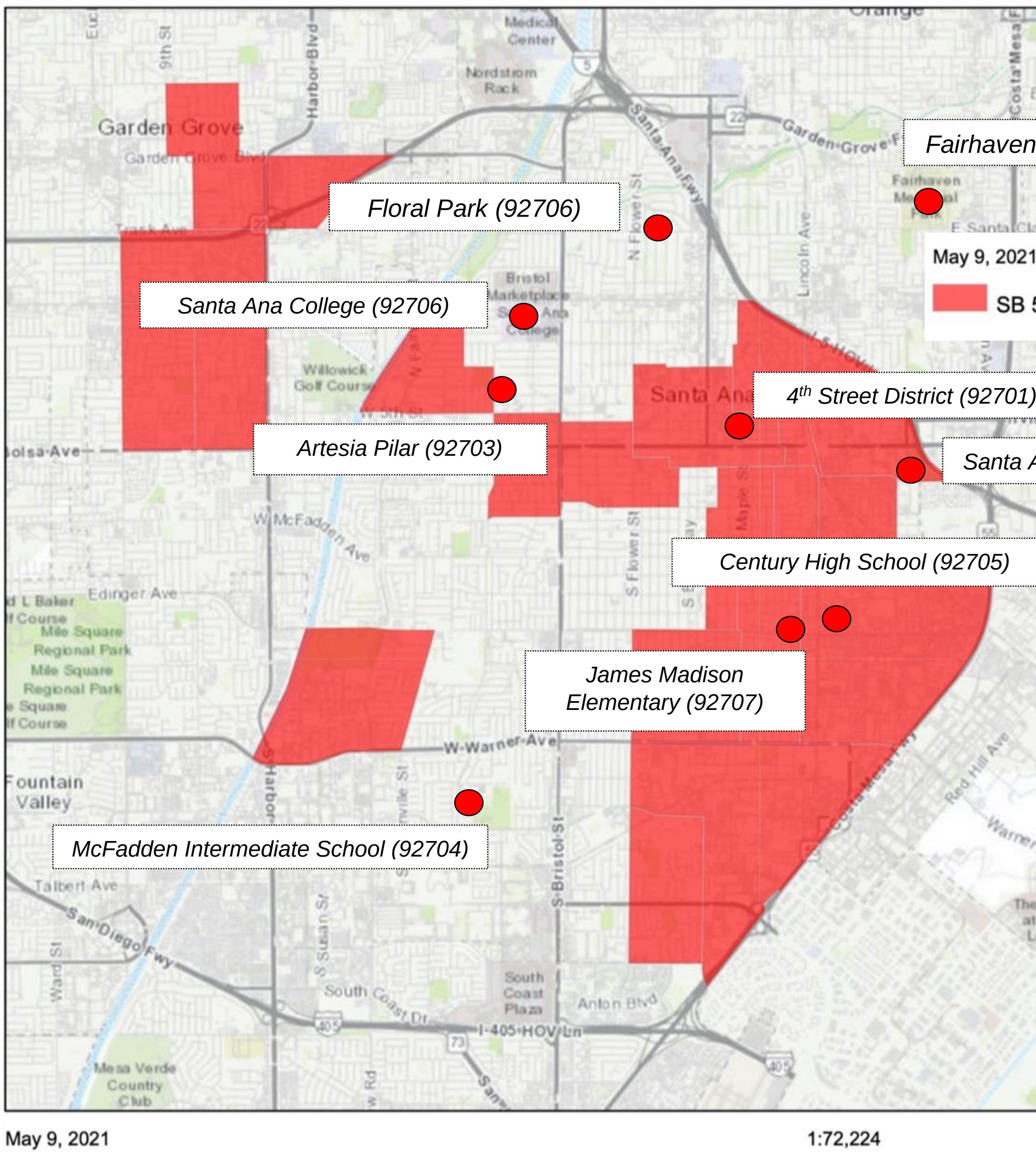


Figure 2. Census tracts labeled as "disadvantaged communities" by the California Office of Environmental Health Hazard Assessment (OEHHA), indicated in red. Other City landmarks added by author. Per OEHHA, "disadvantaged communities" are defined as census tracts scoring in the highest 25% on the Cal Enviro Screen 3.0. Scored items fall into the categories of pollution burden (air quality, water quality, environmental hazards, etc.) or population characteristics (asthma emergency department visits, poverty, linguistic isolation, etc). A full explanation of scoring metrics can be found in the Designation of Disadvantaged Communities report, available at: https://calepa.ca.gov/wp-content/uploads/sites/6/2017/04/SB-535-Designation-Final.pdf.

Image accessed May 9, 2021 at: https://oehha.ca.gov/calenviroscreen/sb535.

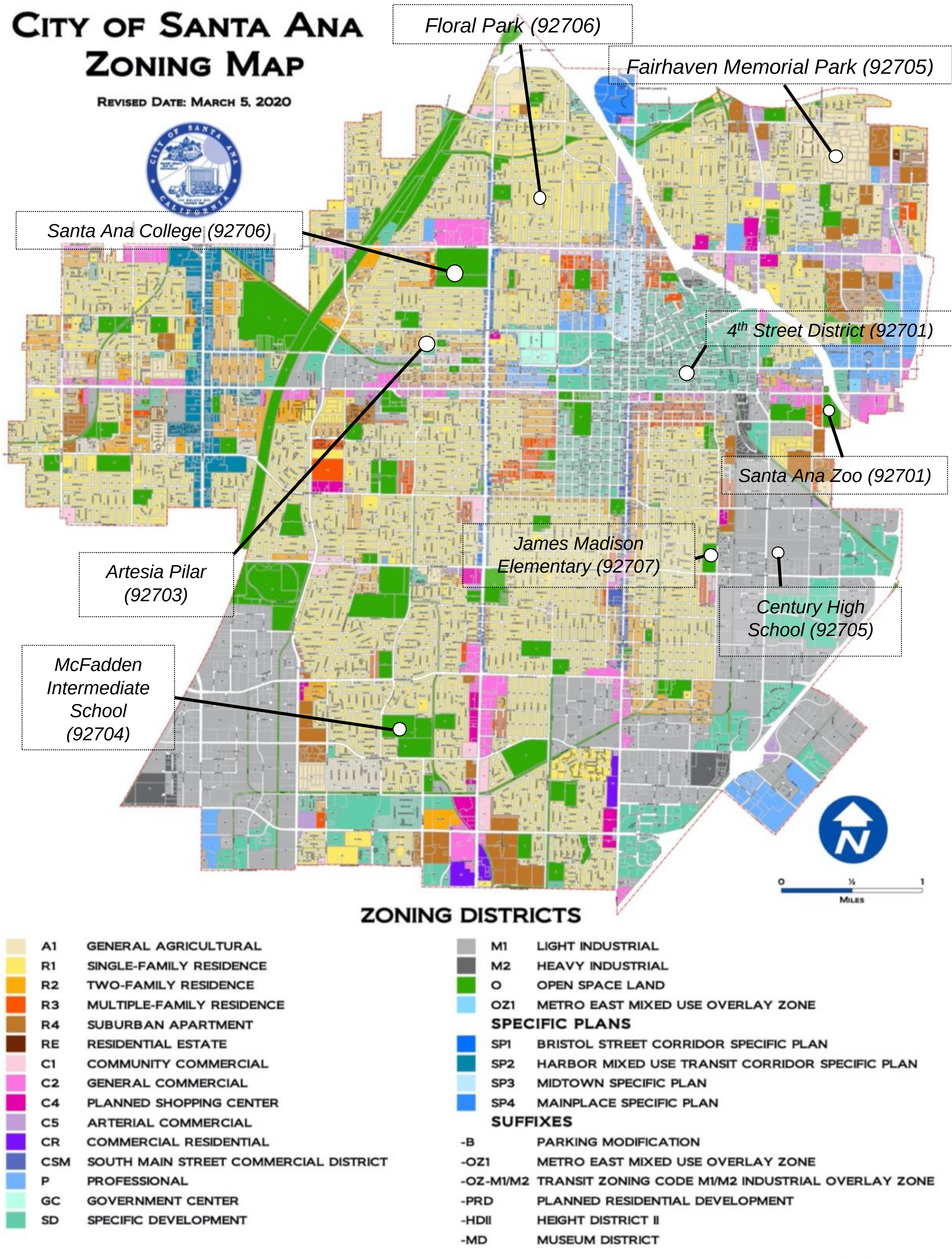


Figure 3. Zoning map for the City of Santa Ana, with areas zoned for industrial use indicated in light gray (light industry) or dark gray (heavy industry). City landmarks added by author. *Accessed April 21, 2021 at: https://gis-santa-ana.opendata.arcgis.com/datasets/b9605d5895d347e1b02d7c25d5e108c6*

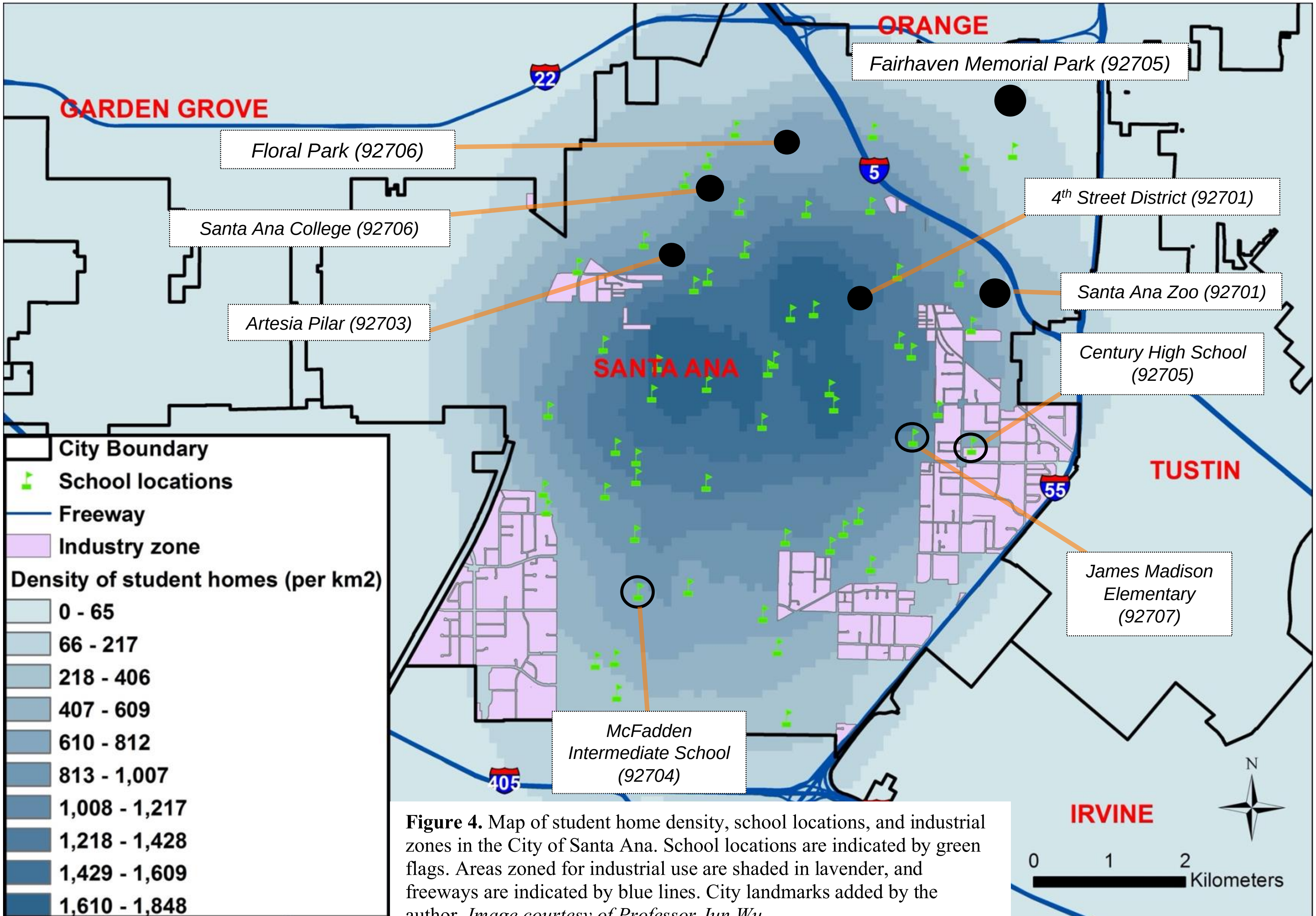
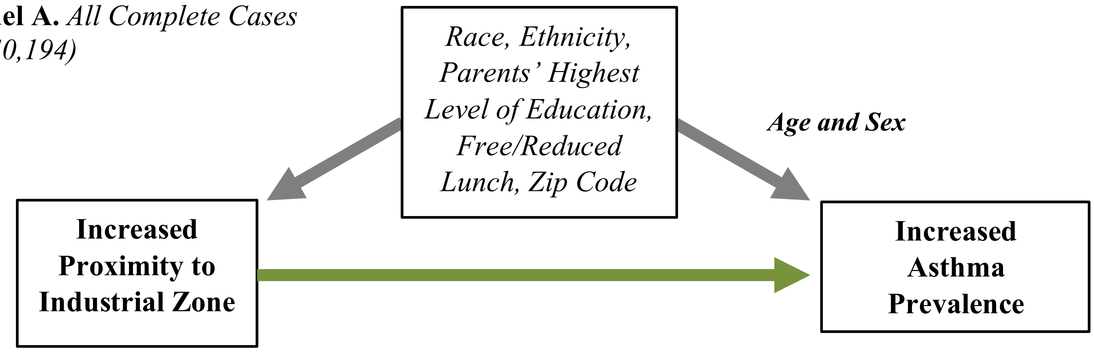


Figure 4. Map of student home density, school locations, and industrial zones in the City of Santa Ana. School locations are indicated by green flags. Areas zoned for industrial use are shaded in lavender, and freeways are indicated by blue lines. City landmarks added by the author. *Image courtesy of Professor Jun Wu.*

Model A. *All Complete Cases (n=40,194)*



Model B. *Children with Asthma – Complete Cases*

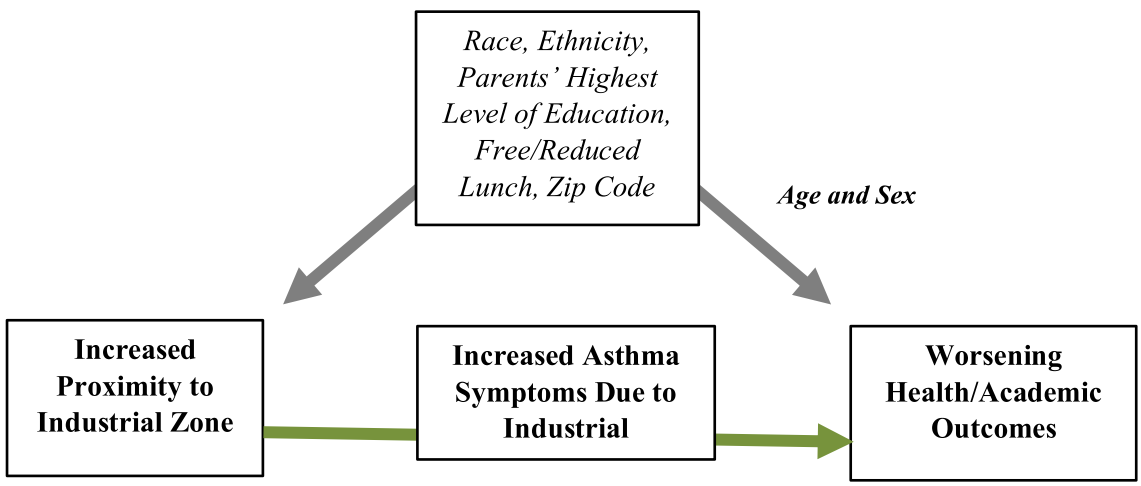


Figure 5. Conceptual models for the effect of industrial zone proximity on (A) asthma likelihood among all study subjects for whom complete files were available, and (B) poor health and/or academic outcomes among all study subjects with asthma for whom complete files were available. Exposure variable was increased proximity to industrial zone, and controls included race, parents' highest level of education, free/reduced lunch, zip code, age, and sex. Because age and sex are hypothesized not to have a significant effect on industrial zone proximity, I included them as controls to reduce their potential magnifying or dampening effect on the relationship between the exposure and outcome.

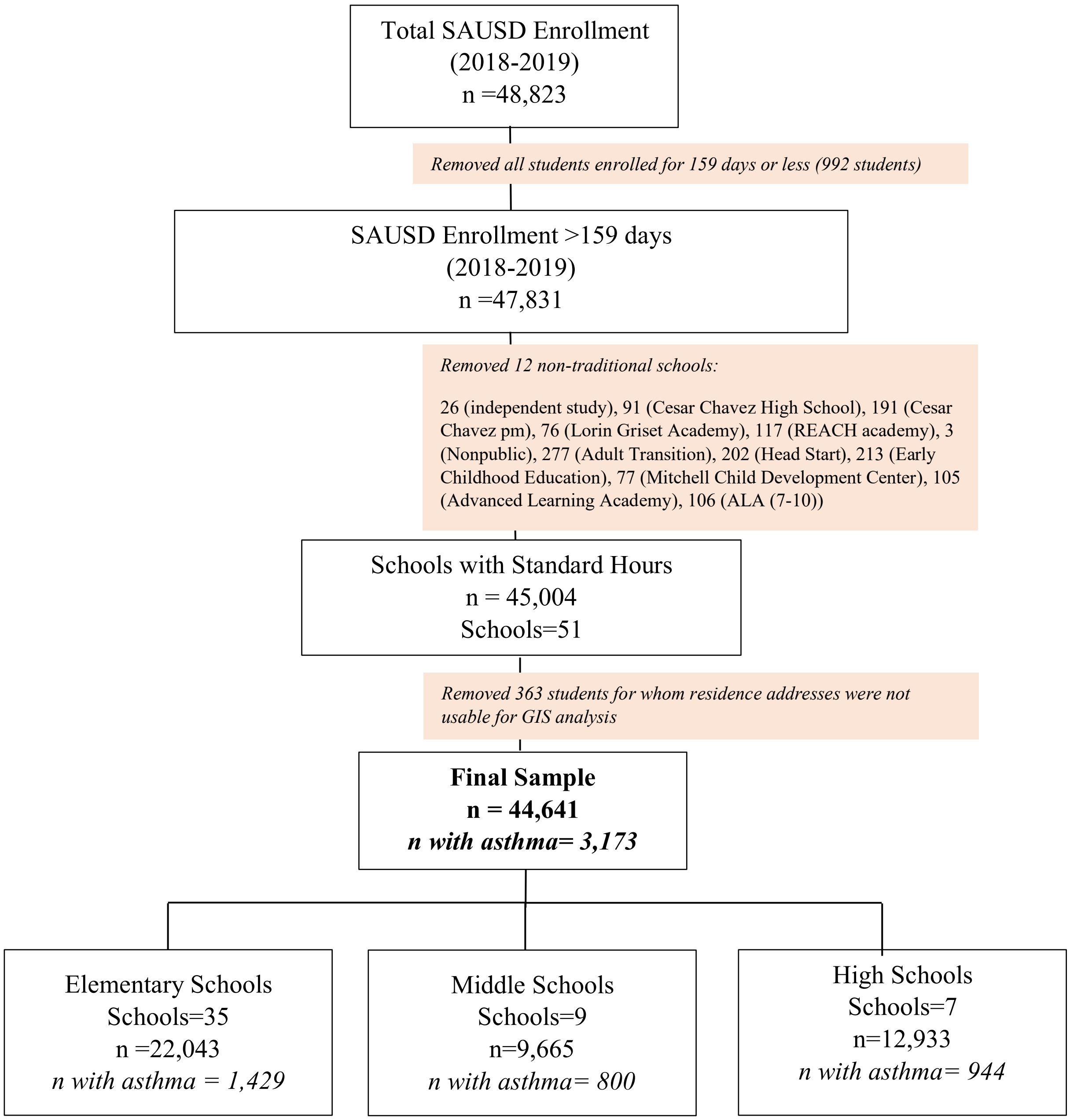


Figure 6. Sample Selection. Of 48,823 total student records, I removed 2,827 students, who attended 12 non-traditional schools, including remedial schools for adult students and head start programs. I then removed 363 additional students for whom residence addresses were not usable for GIS analysis. The final sample included 44,641 students at 51 schools. These included 35 elementary schools (n = 22,043 students), 9 middle schools (n =9,665 students), and 7 high schools (n =12,933 students).

Children with Asthma – Complete Cases

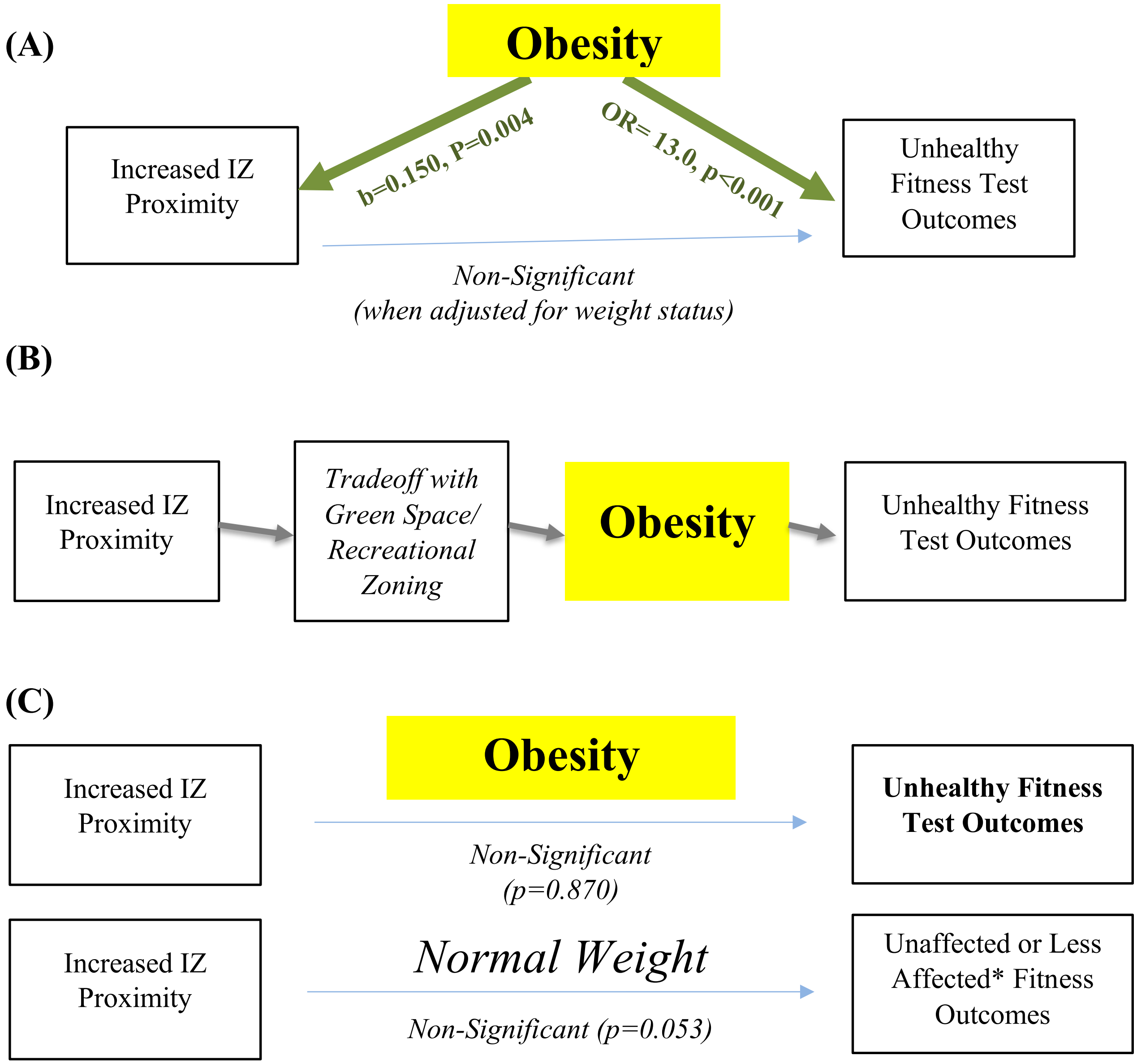


Figure 7. Revised conceptual models explaining the relationships between industrial zone proximity, elevated weight status, and unhealthy fitness test outcomes among children with asthma. In Model A, being overweight or obese was strongly associated with increased industrial proximity (adjusted b= 0.150, p=0.004), and failed fitness test (adjusted OR 13.0, 95%CI 9.1 to 18.8, p<0.001). In Model B, weight status mediates the relationship between industrial zone proximity and unhealthy fitness outcomes. Model B is not assessed in the present study. In Model C, weight status is hypothesized to modify the effect of industrial zone proximity on unhealthy fitness outcomes, via increased susceptibility to pollutants among overweight or obese children with asthma. However, among overweight children with asthma (n=503), there was no significant association between fitness test failure and industrial exposure (adjusted OR 0.96, 95%CI 0.62 to 1.48, p=0.870). * Of note, among normal weight children with asthma (n=360) there was an unexpected positive association between fitness failure and industrial exposure that approached significance (adjusted OR 1.82, 95%CI 1.05 to 3.44, p=0.053).

Specific Aim 2 –Obesity, Physical Fitness and Asthma Events

In analysis of results for Aim 2, I uncovered important associations between industrial zone proximity, likelihood of being overweight or obese, and physical fitness test results among children with asthma, suggesting that the overlapping conditions of obesity and asthma might disproportionately affect students living closest to industrial zones. The effect of industrial zone proximity on weight status was particularly striking, with the odds of being overweight or obese approaching 40% per every kilometer of composite proximity. A significant association was also found between industrial zone proximity and the likelihood of receiving an unhealthy fitness zone score, both with each kilometer of composite proximity (OR 1.42) and when comparing children in the closest and farthest tertiles (OR 1.46). Unexpectedly, however, the adjusted linear regression model for asthma events showed a paradoxical *decrease* in asthma events with increased industrial exposure. This suggests that the effects of industrial zone proximity on physical fitness may not be mediated by increased asthma symptoms as originally anticipated, but instead may be explained by a different conceptual model involving obesity (Figure 7).

To clarify the hypothesized relationships shown in Figure 7, weight status was added to the adjusted model of industrial zone proximity and unhealthy fitness test outcomes (Figure 7A). With the addition of weight status, the model lost significance for both the standard adjusted model (OR 1.27, 95%CI 0.94 to 1.80, p=0.153) and when analyzing by tertiles (OR_{middle} 0.98, 95%CI 0.64 to 1.49, p=0.921; $OR_{closest}$ 1.24, 95%CI 0.81 to 1.91, p=0.32). These results suggest that weight status may act as a confounding variable on the relationship between industrial zone proximity and decreased fitness scores among children with asthma. In this conceptual model, obesity among children exposed to industrial zones could be the result of other socioeconomic factors that are associated with industrial zoning but not necessarily consequences of it, such as the relegation of high-density, low rent housing to less-desirable, more industrial parts of the City. This could result in a concentration of children facing socioeconomic risk factors for obesity and asthma (e.g. decreased ability to afford healthy food, limited health care access), who incidentally live and attend school near industrial zones.

It is also possible that weight status may serve as a mediator for the relationship between industrial exposure and decreased fitness scores among children with asthma. Potential pathways could include additional intermediaries related to zoning policy (Figure 7B). For example, it is possible that increased industrial zoning is associated with decreased green space availability, neighborhood walkability, availability of healthy food options, or other neighborhood-level factors that can further promote obesity among children who have asthma, and may already be more hesitant than their healthy peers to engage in exercise activities.[118,119]

A third pathway of consideration is based on an interaction of specific pollutants and obesity described by *Lu et al.* in 2013 (Figure 7C).[120,121] Investigators conducted a 1-year longitudinal study among 148 children stratified by BMI, comparing the effect of indoor $PM_{2.5}$ and NO_2 levels on asthma-related symptoms. Results demonstrated higher risks for asthma symptoms among children in overweight/obese categories, but not among normal weight children, with increasing pollutant exposures. Similarly, *Permaul et al*. in 2020 found a significant association between classroom NO_2 exposure and asthma symptoms among obese, but not normal weight students. Results of these studies suggest an inflammation-driven pathway, whereby children with obesity are rendered more susceptible to the irritating effects of air pollutants, either due to higher baseline levels of inflammatory activation, or increased minute ventilation.

To investigate this model, I first tested whether there was a stronger relationship between industrial zone exposure and asthma prevalence among overweight children as opposed to non-overweight children. Among overweight children (n=5,400), there was a significantly increased risk of asthma with increasing kilometer proximity to the nearest industrial zone (adjusted OR 1.26, 95%CI 1.07 to 1.50, p=0.008), while among non-overweight children (n=5,265) there was no significant increase in risk (adjusted OR 0.97, 95%CI 0.85 to 1.10, p=0.593). Next, I tested whether there was a stronger relationship between industrial zone exposure and failed fitness tests among overweight children with asthma as opposed to non-overweight children with asthma. Among overweight children with asthma (n=503), there was no significant association between fitness test failure and industrial exposure (adjusted OR 0.96, 95%CI 0.62 to 1.48, p=0.870), while among normal weight children with asthma (n=360) there was a positive association between fitness failure and industrial exposure that approached significance (adjusted OR 1.82, 95%CI 1.05 to 3.44, p=0.053). These results, in combination with asthma event findings, further suggest that asthma exacerbations are unlikely to explain the relationship between industrial exposure and poor fitness test outcomes.

Results of this post-hoc analysis suggest that the poorer physical fitness test outcomes observed among children living close to industrial zones may be better explained by comorbid obesity than by increased asthma exacerbations. This result is not altogether unexpected, considering some prior findings indicating that functional exercise capacity may be more closely linked with obesity as opposed to pulmonary function in urban minority children.[122] However, taking into account the findings for Specific Aim 1, the association between weight status and industrial zoning among children with asthma is a provocative finding, which may give new insight into the social patterning of pediatric health disparities across the City of Santa Ana. Interestingly, freeway proximity showed no significant effects on asthma events, weight status, or unhealthy fitness scores, further suggesting that land use patterns, as opposed to pollutant emissions alone, likely play an important role in explaining asthma, obesity, and failed fitness test outcomes.

Specific Aim 3 – Absences and Academic Outcomes

The observed effects of industrial zoning on absences and decreased standardized test performance were either non-significant, or contrary to the direction hypothesized. In the case of school absences, these results suggest that while students with asthma may have a higher number of average absences than their peers (Table 5), the pattern of absences among students with asthma is not clearly associated with industrial or freeway exposures. Similar results were observed for math and English scores, which did not reflect a straightforward relationship with increasing industrial zone or freeway proximity. Taken together, these results suggest that there is no clear impact of industrial zone proximity or freeway proximity on academic outcomes for students with asthma.

Scientific Impact

The present study expands upon the distance-gradient method of exposure analysis, a simple and frequently used technique in environmental health research.[75] Rather than searching for specific point sources of emissions, or identifying particular industries as exposures of interest, a broad approach was used, outlining all areas zoned for industrial use across the City of Santa Ana as potential exposures. While this approach lacks the specificity of point-source studies, it has the advantage of allowing for the detection of unanticipated effect pathways, i.e. zoning effects on fitness scores that are not purely mediated by air pollution and respiratory irritation. This is illustrated in findings for Specific Aim 2, where the initial construct (Figure 5B) was replaced by a revised construct in which weight status, not increased asthma symptoms, appeared to mediate the effect of industrial zoning on poorer fitness scores among children with asthma (Figure 7A-B). Although the exact mechanism of this effect is not known, it suggests different pathways for future research, which might have been missed had industrial zone proximity been considered strictly as a proxy for air pollution exposure.

With respect to freeway exposures, the present study did find evidence of a 5% associated risk of asthma with each kilometer of composite home and school proximity. However, tertile-based analysis failed to replicate the highway risk zones seen in prior studies, previously demarcated in distances of 75-500 meters.[65,13] This suggests that previously documented freeway risk zones may have limited applicability across different cities, especially if they do not account for the effects of smaller roads, traffic associated with industrial activity, and stationary sources of emissions that may be co-located with freeways.

Examining industrial exposures from the perspective of city zoning maps has an advantage of being highly translatable to local political change. Rather than extrapolating out from a small sample, this study analyzed an entire school district, along with every major industrial corridor for the City of Santa Ana. As a result, conclusions of this study give a detailed picture of the pediatric asthma health landscape of Santa Ana and provide evidence for increased health risks associated with living close to industrial zones.

Limitations and Future Directions

A principal limitation of this study was a lack of air quality information, which restricted the establishment of air pollution as a causal mechanism for the observed associations.[73] Data on in-home exposures, such as smoking, cleaning products, cockroaches, etc, were also not available. As demonstrated by *Bergstra et al*, the addition of this information, together with distance-based analysis, can allow for a significantly more robust and conclusive analysis about the effects of industry on pediatric respiratory health.[79] Future studies across the City of Santa Ana and beyond could integrate the findings of soon-to-be-established community air monitoring networks with zoning data to create a real-time picture of City-wide exposure risk that is accessible to all residents.

Another significant limitation of the present study is its cross-sectional design, which prevents conclusions regarding causal pathways. True assessment of the risks involved with industrial zone exposure would require longitudinal assessment of children in SAUSD, including ongoing measures of asthma incidence that account for the years lived at a single residence within the City. Such a study could monitor new student enrollments, track new asthma diagnoses, record asthma events and physical fitness test results among students who have already been diagnosed, and relate this data both to neighborhood-level air quality data and home/school address information.

School based data also have important limitations, especially with respect to health information. When requested from a single parent during registration, a students' diagnosis and treatment regimens may be inadequately reported depending on the frequency of access to primary care providers, as well as the health literacy of the respondent. For the 2018-2019 school year, I estimated at least 186 cases of likely missed asthma diagnosis, through searches of asthma events and student medication records, which increased the estimated SAUSD asthma prevalence from 6.7% to 7.1%. By revisiting school workflows and considering the addition of higher-sensitivity questions assessing symptoms such as wheezing or coughing, asthma reporting, and consequently asthma management, could be improved across the district.

Other limitations that should be addressed in future studies include the addition of industrial zoning data from surrounding cities and trunk road data, which would add important possible sources of exposure, and could help explain inconsistencies in the observed patterns (e.g. greater risk observed for the middle distance tertile, as opposed to the closest tertile, for asthma prevalence and obesity outcomes). The addition of these exposures could prove particularly important for the 1,571 children who listed home addresses outside of the City of Santa Ana. Future studies could also incorporate measures of external validity, by testing distance-gradient exposure models on cities with similar baseline characteristics, to examine whether industrial zone proximity can successfully predict asthma or other health risks. Such models could be expanded to include possible asthma-protective factors, such as green space or recreational areas.

Conclusion

This school-district-based study found that industrial zone proximity was significantly associated with higher asthma prevalence after controlling for available socioeconomic factors, suggesting that city land use policy may play an important role in explaining asthma burden among school-age children. Among students with asthma, there was no effect of industrial proximity on academic achievement, but there was a strong association between industrial proximity, obesity, and decreased fitness outcomes, which requires further study. These findings present important areas of intervention for city and school district policymakers, and help provide important context for ongoing, community-led environmental justice efforts. Overall, this study demonstrates a simplified approach to environmental risk factor identification, in which industrial zones are seen not just as potential sources of air pollution, but as dynamic entities whose effects on population health can be quantified and managed, even in the absence of sophisticated and expensive sampling equipment.

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APPENDIX A

Table S1. Effect of control variables on composite proximity to the nearest industrial zone (km)

Independent Variable	b-value	p-value [a]
Male Sex	0.014	0.062
Age	0.005	<0.001
Race		
Hispanic only	*Reference*	*Reference*
White	-0.104	<0.001
Asian/Pacific Islander	0.009	0.694
Black	-0.414	<0.001
American Indian/Alaska Native	-0.218	0.002
Hispanic Ethnicity	0.080	<0.001
Parents' Highest Ed Level < H.S.	0.099	<0.001
Free/Reduced Lunch	0.155	<0.001
Zip Code	0.00005	<0.001

[a] *P-values for logistic regression were determined using Wald's test*

Table S2. Effect of each control variable on the likelihood of having a presumed diagnosis of asthma

	Unadjusted OR (95% CI)	**p-value**
Male Sex	1.38 (1.27, 1.48)	<0.001
Age	1.02 (1.01, 1.03)	<0.001
Race		
Hispanic only	*Reference*	*Reference*
White	1.12 (1.02, 1.22)	0.014
Asian/Pacific Islander	1.26 (1.03, 1.52)	0.019
Black	2.52 (1.68, 3.65)	<0.001
American Indian/Alaska Native	0.71 (0.28, 1.48)	0.415
Hispanic Ethnicity	0.61 (0.64, 0.90)	0.001
Parents' Highest Education Level < H.S.	0.79 (0.74, 0.86)	<0.001
Free/Reduced Lunch	0.77 (0.69, 0.85)	<0.001
Zip	1.00 (1.00, 1.00)	0.544

Table S3. Variance Inflation Factors for control variables, Specific Aim 1, Adjusted Model*

Control Variable	Variance Inflation Factor (VIF)
Sex	1.00
Zip Code	1.00
Age	1.02
Race	2.89
Ethnicity	2.86
Parents' Highest Ed Level	1.10
Free/Reduced Lunch	1.10

***** *Logistic regression of composite industrial zone proximity on likelihood of having an asthma diagnosis*