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Article

Risk factors contributing to Pennsylvania childhood asthma

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SUMMARY

Childhood asthma continues to present a significant clinical and economic challenge in the U.S. Implementing more proactive treatment and comprehensive asthma management programs is imperative to addressing this national financial and health burden. Understanding the importance of various risk factors in asthma hospitalization and diagnosis rates can aid in earlier identification, treatment, and prevention of asthma altogether. In this study, we hypothesized that population density was the greatest predictor of childhood asthma hospitalization rate and diagnosis rate. We examined a total of 18 demographic, socioeconomic, and environmental risk factors at Pennsylvania's county level to identify the risk factors contributing to childhood asthma hospitalization and diagnosis rate. Using a multiple linear regression model, we found "population density" and "percentage of Hispanic population" to be most strongly correlated with both childhood asthma hospitalization rate and diagnosis rates. In addition, "tobacco retail density", "number of high ozone days", and "childhood lead poisoning rate" were important factors associated with asthma hospitalization rate, while "percentage of population living in a rural area" was associated with asthma diagnosis rate. Our study provides a greater understanding of the influence of certain demographic and environmental exposures on Pennsylvania's childhood asthma and emphasizes the importance of prevention.

INTRODUCTION

Asthma is one of the eight most prevalent chronic conditions in the United States (U.S.). Its condition is intricate, influenced by both genetic and environmental factors (1, 2). General signs and symptoms of asthma include shortness of breath, coughing, wheezing, and chest tightness or pain (3). While well-managed asthma may only have minimal effects on daily life, it can be life-threatening if not controlled or treated properly. Currently, asthma affects more than 25 million people in the U.S, with 4.6 million being children (4). Every year, there are 1.6 million emergency department (ED) visits and more than 439,000 hospitalizations associated with asthma attacks (5). Based on a 2015 study, the annual cost of pediatric asthma in the U.S. is $5.92 billion (6, 7). Chronic obstructive pulmonary disease (COPD) and asthma ranked as the 2nd most costly conditions among children aged 0-17 (8). Enhancing asthma education not only alleviates economic burdens but more importantly promotes medication compliance that is crucial to reduce asthma ED visits, hospitalization and mortality rates.

Many risk factors contribute to childhood asthma, including genetic factors, such as gender and family history. Generally, asthma prevalence is greater in boys compared to girls, and children with asthmatic parents are more likely to develop asthma as compared to children with non-asthmatic parents (2, 9–12). Race and ethnicity also play an important role in childhood asthma. Black Americans and American Indians have the highest rates of asthma (10.9% and 12.0%, respectively), while Asian Americans have the lowest asthma rates at 4.0% (10, 11).

Socioeconomic factors such as neighborhood poverty, insurance, provider accessibility, parents' education, etc., are an additional subset of factors associated with childhood asthma. Studies show that children who live in high population density and low-income neighborhoods have higher rates of asthma. Improved health outcomes have been observed after children moved out of these neighborhoods (13). Healthcare provider accessibility, including primary care provider (PCP) and school nurse support, is crucial in reducing ED visits and hospitalization rates, as patients who do not have a PCP are usually lacking the proper education on asthma and self-management at home, oftentimes seeking care in the ED for acute exacerbations (14, 15). Furthermore, many asthmatic patients are managed by their PCPs, who develop specific treatments with regular follow-ups to assess asthma control. Their guidance on identifying triggers, proper use of an inhaler, adherence to medication, recognizing early signs of an attack, and understanding when to seek emergency care is essential to achieving long-term control, thereby reducing ED visits and hospitalization (16–18).

Finally, environmental factors such as air pollution, lead poisoning and tobacco and smoke exposure (second hand smoking and smoking during pregnancy) are also common triggers for childhood asthma (19, 20). Air pollution, specifically ozone concentration, is directly related to asthma attacks and associated ED visits because ozone is very irritating to the lungs and airways (21, 22). Lead poisoning, originating from the paint of aged houses or polluted water, as well as contaminated soil and food, is especially prevalent among urban children in the U.S. As a respiratory irritant, lead exposure can cause asthma and may lead to changes in the lung similar to those seen in COPD (23). Tobacco smoke is also a common trigger of asthma, as more than 40% of children who visit the ED for asthma concerns live with smokers (24–28).

While the average childhood rate of asthma in the U.S. is 7.4%, Pennsylvania (PA)'s childhood asthma rate is 9.9%, causing it to be ranked as one of the five highest U.S. states

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(11). According to Asthma and Allergy Foundation's 2023 report of "asthma capitals" based on asthma prevalence, number of ED visits, and deaths due to asthma, three PA cities are on the list: Allentown (No. 1) in Lehigh County, Philadelphia (No. 8) in Philadelphia County, and Harrisburg (No. 16) in Dauphin County (29). This alarming ranking underscores the need to further investigate underlying factors contributing to PA's high asthma rates. Our analysis focused on identifying the most significant risk factors of childhood asthma using asthma hospitalization and diagnosis rates in PA counties. During the initial examination, we noticed that Philadelphia, Allegheny, Delaware, and Montgomery counties exhibited the highest asthma hospitalization rates. Because these counties were also among the top five most densely populated counties in PA, we hypothesized population density to be the greatest risk factor associated with childhood asthma hospitalization rates and prevalence.

Through our analysis, we found population density and percentage of Hispanic population to be most strongly correlated with both childhood asthma hospitalization rate and childhood asthma diagnosis rate, supporting our hypothesis. In addition, tobacco retail density, number of high ozone days, and childhood lead poisoning rate were important factors associated with asthma hospitalization rate. Percentage of population living in a rural area was associated with asthma diagnosis rate.

RESULTS

We examined the hospitalization rate per 100,000 children under 18 years old due to asthma (i.e., asthma hospitalization rate) (**Figure 1**) and the rate of students medically diagnosed with asthma (i.e., asthma diagnosis rate) (**Figure 2**) across PA counties. Our goal was to identify the risk factors that were most associated with asthma hospitalization rate and diagnosis rate. We collected a total of 18 demographic, socioeconomic, and environmental risk factors at the county level. The demographic risk factors included population density, percentage of Hispanic population, percentage of non-Hispanic Black population, percentage of non-Hispanic White population, percentage of Asian population, and percentage of American Indian and other races. Socioeconomic factors included percentage of population not proficient in English, percentage of uninsured population, percentage of children in poverty, percentage of population living in a rural area, ratio of population to primary care providers, and number of school nurses and supplemental staff per 10,000 students. The environmental factors included number of high ozone days, childhood lead poisoning rate, tobacco retail density, number of conventional oil and gas wells, number of unconventional oil and gas wells, and average daily density of fine particulate matter in micrograms per cubic meter (i.e. PM2.5).

We first individually assessed each risk factor against the hospitalization rate using a linear regression model. Factors that were statistically significant risk factors were population density (p=1.52e-14), percentage of population not proficient in English (p=1.14e-7), percentage of population living in a

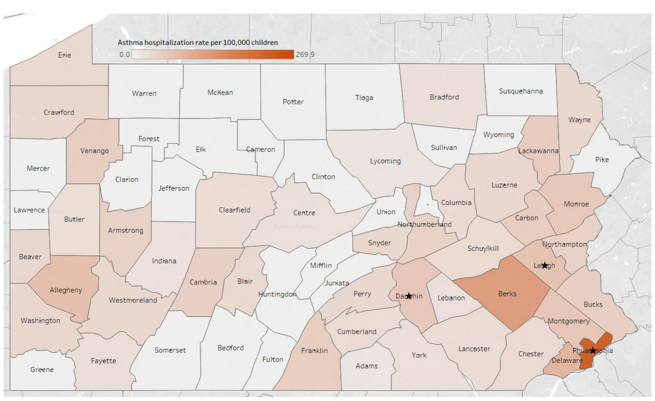

Figure 1. Pennsylvania county asthma hospitalization rate per 100,000 for children under 18 years old (2019–2021). 42 counties (highlighted in shades of orange) had hospitalization rates available, and Philadelphia had the highest hospitalization rate (269.9 per 100,000 children). Stars indicate the counties (Leigh County, Philadelphia County, and Dauphin County) where the three asthma capitals are located.

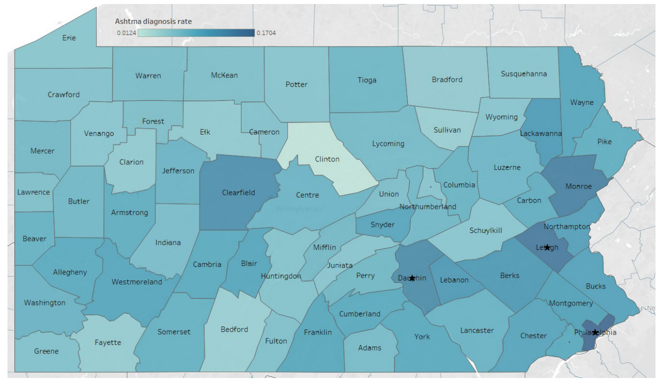

Figure 2. Pennsylvania county percentage of students with a medical diagnosis of asthma (2019–2020). 67 counties had asthma diagnosis rates available, and Philadelphia had the highest diagnosis rate (17.04%). Students are defined as children under the age of 18 enrolled in the county's educational institution. Stars indicate the counties (Leigh County, Philadelphia County, and Dauphin County) where the three asthma capitals are located.

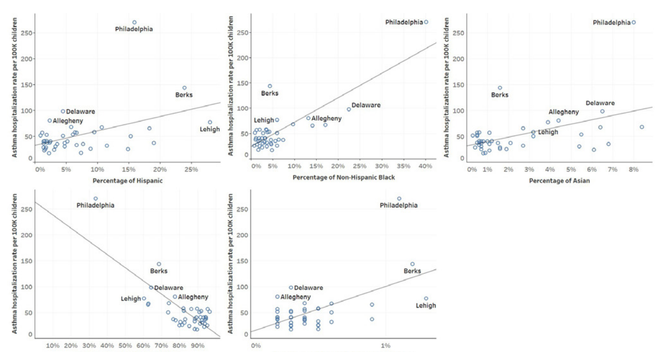

Figure 3. Childhood asthma hospitalization rate and racial and ethnic populations risk factors. Scatter plots showed PA childhood asthma hospitalization rate was positively associated with all racial and ethnic populations ("percentage of Hispanic population" (R^2=19%, p=0.004), "percentage of non-Hispanic Black population" (R^2=66%, p=4.12e-11), "percentage of Asian population" (R^2=22%, p=1.59e-3), and "percentage of American Indian and other races" (R^2=32%, p=8.34e-5)) except for "percentage of non-Hispanic White population" (R^2=60%, p=1.72e-9).

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Risk Factors	Coefficients	Standard Error	t value	*p*-value
Intercept	-18.400	14.184	-1.297	0.203
Population density (in K)	14.540	2.300	6.321	2.92e-7
Percentage of Hispanic	1.309	0.408	3.213	0.003
Number of high ozone days	6.897	2.928	2.355	0.024
Childhood lead poisoning rate (per K)	0.952	0.416	2.287	0.028
Tobacco retail density	24.535	11.526	2.129	0.040

Table 1. Multiple linear regression model for childhood asthma hospitalization rate. Total N=42. Adjusted R^2=0.853.

rural area (*p*=0.008), childhood lead poisoning rate (*p*=0.039), percentage of children in poverty (*p*=7.50e-4), number of high ozone days (*p*=4.21e-8), and all demographic factors were significant risk factors with *p*<0.05. (**Figure 3**, **Figure 4**, **Figure 5**).

Before we applied a multiple linear regression model to evaluate the varying importance of different factors on asthma hospitalization rate, we examined the correlation between these risk factors to reduce multicollinearity. We calculated the variance inflation factor (VIF) score of each risk factor, which indicated the strength of the linear relationship between said risk factor and the remaining risk factors, and found "percentage of non-Hispanic White population" (R^2=0.998, *p*<2.2e-16, VIF=555.556), "percentage of population not proficient in English" (R^2=0.937, *p*<2.2e-16, VIF=15.823), and "percentage of American Indian and other races" (R^2=0.917, *p*<2.2e-16, VIF=12.016) to be highly correlated with other risk factors with VIF>10. Therefore, we removed these three risk factors from the multiple linear regression model.

Because only 42 out of 67 PA counties had asthma hospitalization rates available, we attempted to avoid overfitting by limiting the independent variables using stepwise regression. The final results of the multiple linear regression model indicated that population density was most strongly correlated with asthma hospitalization (*p*=2.92e-7); percentage of Hispanic population (*p*=0.003), number of high ozone days (*p*=0.024), childhood lead poisoning rate

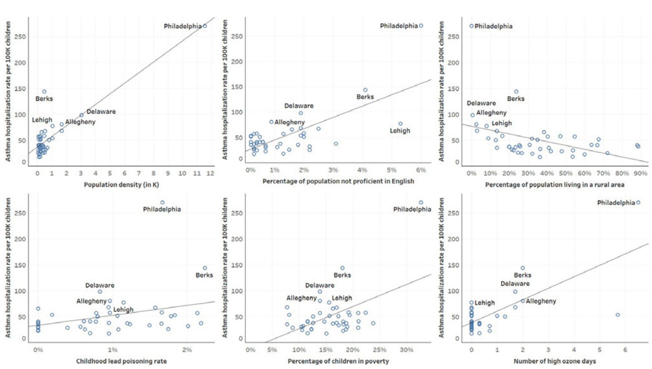

Figure 4. Childhood asthma hospitalization rate and associated risk factors with *p*<0.05. Scatter plots showed PA childhood asthma hospitalization rate was positively associated with "population density" (R^2=78%, *p*=1.52e-14), "percentage of population not proficient in English" (R^2=51%, *p*=1.14e-7), "childhood lead poisoning rate" (R^2=10%, *p*=0.039), "percentage of children in poverty" (R^2=25%, *p*=7.50e-4), and "number of high ozone days" (R^2=53%, *p*=4.21e-8). Childhood asthma hospitalization rate was negatively associated with "percentage of population living in a rural area" (R^2=16%, *p*=0.008).

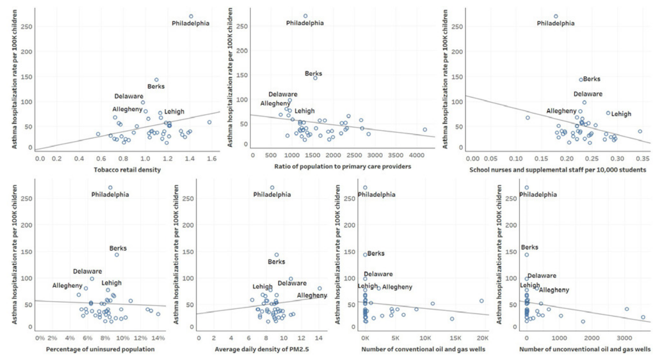

Figure 5. Childhood asthma hospitalization rate and associated risk factors with *p*>0.05. Scatter plots showed PA childhood asthma hospitalization rate has no strong correlation with the following risk factors: "tobacco retail density" (R^2=6%, *p*=0.104), "ratio of population to primary care providers" (R^2=3%, *p*=0.295), "number of school nurses and supplemental staff per 10,000 students" (R^2=6%, *p*=0.111), "percentage of uninsured population" (R^2=0.1%, *p*=0.840), "average daily density of PM2.5" (R^2=0.5%, *p*=0.662), "number of conventional oil and gas wells" (R^2=1%, *p*=0.460), and "number of unconventional oil and gas wells" (R^2=3%, *p*=0.248).

(*p*=0.028), and tobacco retail density (*p*=0.040) were also associated with asthma hospitalization rate (**Table 1**).

It is important to consider the degree to which healthcare accessibility can influence asthma hospitalization rates, as it may create misleading results for the previously mentioned factors. To test this impact, we examined the hospitalization rates of children in PA counties for a variety of other causes including falls, COPD, heart disease, heat stress, pneumonia, anemias, diabetes mellitus, perinatal conditions, poisoning, septicemia, traumatic brain injury, unspecified injury, influenza, and chronic lower respiratory diseases. After excluding asthma and additional related respiratory conditions (COPD, pneumonia, influenza, and chronic lower respiratory diseases), we found that the five counties with the highest hospitalization rates due to the causes listed above were Crawford, Westmoreland, Erie, Schuylkill, and Clearfield. However, these same counties ranked between 12th and 32nd place for children's asthma hospitalization rates. This contrast between asthma hospitalization rates and non-respiratory related hospitalization rates suggests that these five counties were not lacking in healthcare access, and their relatively low asthma hospitalization rates could not be attributed solely to healthcare accessibility.

Furthermore, the occurrence of outliers, specifically Philadelphia County's asthma hospitalization rate, presents another problem that could unfairly influence the fitting of a regression model. Although statistical outliers are generally omitted, Philadelphia County is an integral part of PA and significantly contributes to PA's asthma rate. Therefore, it should be included in any PA-related study. Nonetheless, to understand the impact of Philadelphia County as an outlier, we removed it from the multiple linear regression model, and observed no major changes in our results; all statistically significant variables remained significant.

To study asthma diagnosis rate, we evaluated the same risk factors following the same procedure. We individually assessed each risk factor against the asthma diagnosis rate using a linear regression model (**Figure 6**, **Figure 7**, **Figure 8**).

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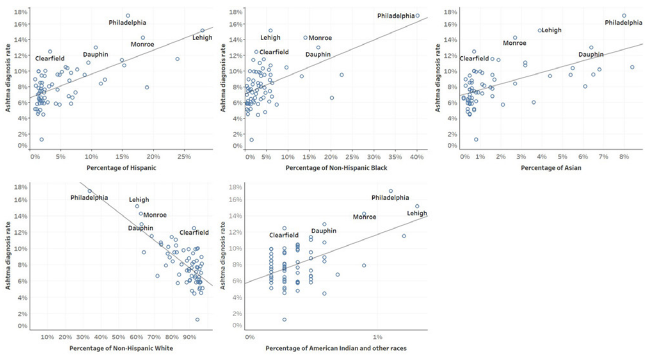

Figure 6. Childhood asthma diagnosis rate and racial and ethnic populations risk factors. Scatter plots showed PA childhood asthma diagnosis rate was positively associated with all racial and ethnic populations ("percentage of Hispanic population" (R^2=43%, *p*=2.28e-9), "percentage of non-Hispanic Black population" (R^2=28%, *p*=3.61e-6), "percentage of Asian population" (R^2=32%, *p*=5.37e-7), and "percentage of American Indian and other races" (R^2=28%, *p*=5.07e-6)) except for "percentage of non-Hispanic White population" (R^2=53%, *p*=2.43e-12).

The final multiple linear regression model identified population density to be the most significant factor associated with asthma diagnosis rate (*p*=2.86e-9); percentage of Hispanic population (*p*=2.92e-5), and percentage of population living in a rural area (*p*=2.72e-4) were also associated with asthma diagnosis rate (**Table 2**).

DISCUSSION

In our study, population density and percentage of Hispanic population were the two most strongly associated risk factors with both childhood asthma hospitalization rate and diagnosis rate. While many studies show that Blacks and American Indians have the highest asthma diagnosis rates compared to other races, an American Lung Association report suggests that rates can vary significantly within a race's subgroup, particularly Hispanics. In fact, Puerto Ricans in the continental U.S. have the highest asthma rate of any racial or ethnic group (11). In our study, Philadelphia had the highest asthma hospitalization and diagnosis rates. Puerto Ricans account for about 70% of all Hispanics in Philadelphia, which suggests linkage with the American Lung Association report. This may be a possible explanation as to why we observed Hispanics, not Blacks or American Indians, to be the race most associated with asthma hospitalization and diagnosis rates.

In our multiple linear regression model, percentage of population not proficient in English was removed to reduce multicollinearity since it was highly correlated with other risk factors. However, English proficiency still plays a role indirectly. Based on recent studies, limited English proficiency is associated with worse outcomes of asthma self-management and increased ED visits and hospitalization rates due to the language barrier in patient-provider communication (30). Another study shows that limited English proficiency was associated with lower adherence rates to medication due to concerns about the side effects and potential addiction to inhaled corticosteroids (31). Therefore, enhancing education on asthma self-management is crucial. Structured asthma education sessions can significantly aid parents and children in maintaining better control over asthma.

Income is another potentially underlying variable tied to a variety of factors like pollution, English proficiency, population density, and ethnicity. While it is difficult to exactly identify underlying variables and their impact, our study attempts to control the effects by including percentage of children in poverty, a representation of income, in our final multiple linear regression model. We did not find significant association of percentage of children in poverty with asthma hospitalization or asthma diagnosis. However, it is still important to recognize its potential influence on other independent variables, as it shares a relatively high correlation with tobacco retail density, percentage of non-Hispanic Black population, percentage of Asian population, and average daily density of PM2.5.

Our study finds some factors to be associated with only one response variable. For example, number of high ozone days, childhood lead poisoning rate, and tobacco retail density are highly correlated to asthma hospitalization rates, but not diagnosis rates. Many studies show that ozone is very irritating to the lungs and airways and could worsen airway inflammation and cause severe asthma attacks (21, 22). Blood lead concentration is associated with increased bronchial hyperresponsiveness (23). Tobacco and smoke are also triggers of asthma flare-ups (24–26). These proven triggers of

Risk Factors	Coefficients	Standard Error	t value	*p*-value
Intercept	8.230	0.465	17.682	<2e-16
Population density (in K)	0.472	0.068	6.911	2.86e-9
Percentage of Hispanic	0.206	0.046	4.507	2.92e-5
Percentage of population living in a rural area	-2.896	0.751	-3.857	2.72e-4

Table 2. Multiple linear regression model for childhood asthma diagnosis rate. Total N=67. Adjusted R^2=0.662. Note, "population density" was rescaled to "population density/1000" allowing for the display of additional digits in "population density" coefficient within the regression table.

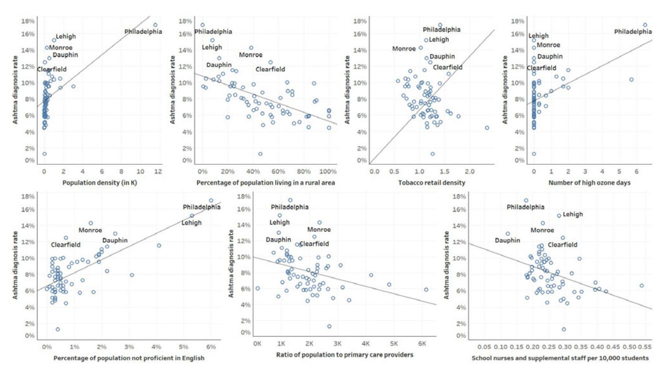

Figure 7. Childhood asthma diagnosis rate and associated risk factors with *p*<0.05. Scatter plots showed PA childhood asthma diagnosis rate was positively associated with "population density" (R^2=26%, *p*=8.39e-6), "tobacco retail density" (R^2=7%, *p*=0.032), "number of high ozone days" (R^2=20%, *p*=1.26e-4), "percentage of population not proficient in English" (R^2=48%, *p*=9.54e-11). Childhood asthma diagnosis rate was negatively associated with "percentage of population living in a rural area" (R^2=32%, *p*=5.11e-7), "ratio of population to primary care providers" (R^2=11%, *p*=0.006), and "number of school nurses and supplemental staff per 10,000 students" (R^2=13%, *p*=0.003).

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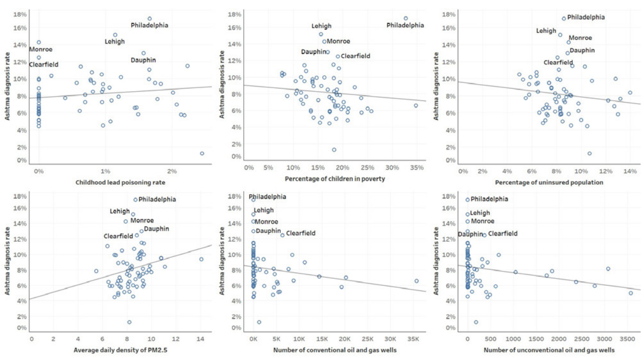

Figure 8. Childhood asthma diagnosis rate and associated risk factors with *p*>0.05. Scatter plots showed PA childhood asthma diagnosis rate has no strong correlation with the following risk factors: "childhood lead poisoning rate" (R^2=2%, *p*=0.268), "percentage of children in poverty" (R^2=1%, *p*=0.433), "percentage of uninsured population" (R^2=2%, *p*=0.308), "average daily density of PM2.5" (R^2=5%, *p*=0.065), "number of conventional oil and gas wells" (R^2=4%, *p*=0.127), and "number of unconventional oil and gas wells" (R^2=5%, *p*=0.068).

asthma will most often result in an ED visit or hospitalization, but not diagnosis because a singular asthma attack induced by ozone, lead poisoning, tobacco, or smoking alone cannot warrant a diagnosis for chronic asthma. So, while these factors undoubtedly play a role in the development of asthma, they are far from the most strongly associated.

Ratio of population to primary care providers and number of school nurses and supplemental staff per 10,000 students were two additional measures that did not show statistical significance in our study. However, healthcare provider accessibility is an important component of asthma treatment and management (16-18). Assistance from PCPs and school nurses created a comprehensive support system for managing childhood asthma and promoting proper asthma control both at home and during school hours. Although our study did not provide sufficient evidence to support statistical significance of healthcare provider accessibility on asthma hospitalization and diagnosis rates, we hope to re-evaluate these risk factors with a larger sample size in future research.

In our analysis, due to a limitation on smoker data available at the county level, we utilized "tobacco retail density", the number of tobacco sale locations per 1000 individuals in each county, as an indicator to estimate the secondhand smoke exposure rate. Due to the significant correlation of tobacco and smoke with asthma hospitalization , it is well worth investigating e-cigarette and vape abundances per county going forward, as such products are much more common and relevant amongst children and teenagers today. Unfortunately, the data on "percentage of high school/middle school students currently smoking cigarettes/using electronic vapor products" provided by the Asthma School Health Data Report is only available at a statewide level. In addition to limitations on smoking data and a relatively small sample size, asthma hospitalization and diagnosis rates used in the study were from 2019-2021 school year data, which includes the COVID-19 pandemic period. Future research aims to utilize post COVID-19 hospitalization and diagnosis data and expand the overall sample size by including more states and counties to build a robust nationwide model.

Asthma is a chronic disease and patients can significantly benefit from their self-management. Early diagnosis and intervention is crucial for ensuring that individuals can effectively manage their condition without experiencing extreme symptoms and avoid unnecessary ED visits and hospitalization. Unfortunately, many individuals with asthma go undiagnosed for years due to the lack of asthma education, leading to life-threatening complications down the line. Our study provides valuable insight into the risk factors associated with childhood asthma, emphasizing the varying factors that influence its pathogenesis.

MATERIALS AND METHODS

The main data was from the "Asthma School Health Data Report by County Asthma Control Program, Bureau of Health Promotion & Risk Reduction" from the Pennsylvania Asthma Control Program (ACP) funded by the Centers for Disease Control and Prevention (CDC). It includes "percentage of student with a medical diagnosis of asthma from 2013–2021" for 67 counties and "asthma hospitalization rate per 100,000 for children under 18 years old (2019–2021) for 42 counties. It also includes additional county demographic, socioeconomic, and environmental data.

In addition to the Asthma School Health Data Report, "childhood lead poisoning rate" was sourced from the Enterprise Data Dissemination Informatics Exchange (EDDIE) run by the Pennsylvania Department of Health (32), which measures the percentage of children tested with a blood lead level above or equal to 10 micrograms per deciliter (μg/dL). "Number of high ozone days" was sourced from the American Lung Association State of Air report card. Pennsylvania land area and population by county were utilized to represent the "population density" of each county (33). The "tobacco retail density", which represents the number of tobacco sale locations per 1000 lives in each county, was sourced from "Tobacco Products Tax Licenses Current Monthly County Revenue" from Opendata PA (34).

All datasets were combined into one file, then imported into R for statistical analysis. Our study was split into two parts: asthma hospitalization rate and asthma diagnosis rate. The first step was to conduct separate linear regression for each risk factor against the dependent variable using the "lm()" function included in R's built-in "stats" package. To reduce multicollinearity, correlation analysis was performed by calculating VIF scores for each independent variable against all other independent variables using the "vif()" function from R's "car" package (35). Any variable with a VIF score greater than 10 was removed from the next multiple linear regression. With the remaining independent variables, multiple linear regression models were then created using the "lm()" function from R's built-in "stats" package. However, to avoid inherent overfitting issues due to the limited number of observations, independent variables with the greatest *p*-value were continuously eliminated through a stepwise regression until the maximum adjusted R^2 and ideal number of 3–7 variables were reached. In the final multiple linear regression model, any independent variables with a *p*-value less than 0.05 were determined to be associated with the dependent variable.

Spatial heat maps for hospitalization and diagnosis rates across PA counties were created using Tableau.

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