American Journal of Student Research

Research Article

Born Into Risk: How Prenatal Exposure to PM2.5 Shapes Autism Outcomes

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ABSTRACT

Autism spectrum disorder (ASD) has been one of the fastest-growing developmental diagnoses worldwide. While awareness and diagnostic tools have contributed to the rise of case identifications, environmental factors are emerging as significant contributors. Among these factors, fine particulate matter (PM2.5), measured in $\mu g/m^3$, has become of particular interest in the scientific community due to its potential association with changes in brain development during pregnancy. The purpose of this study is to explore the relationship between prenatal exposure to PM2.5 and ASD prevalence in the United States using publicly available datasets from the Centers for Disease Control and Prevention (CDC) and the CDC's Tracking Data Explorer. Results suggest that there is a statistically significant correlation between higher PM2.5 exposure levels and increased ASD rates at the state level. Trends in PM2.5 levels and exposure, particularly in regions impacted by wildfire smoke and industrial activities, show overlaps with regions experiencing some of the most prominent increases in ASD prevalence. These findings suggest that more integrated environmental health policies should be enforced with early childhood development strategies.

Keywords: autism spectrum disorder [ASD]; PM2.5; prenatal exposure; environmental health; air pollution; neurodevelopment; epidemiology

INTRODUCTION

Over the past two decades, a once-rare diagnosis has found its way into countless families across the United States, reshaping their lives. Now, in 2022, Autism Spectrum Disorder (ASD) affects approximately 1 in 36 children (1). Better diagnostic tools and greater awareness explain part of the rise, but not the entire picture, leaving an important question: what influences, besides genetics, could be driving these numbers?

Among the possible factors, environmental pollution has emerged as a significant competitor. Fine particulate matter, known as PM2.5, is a form of air pollution made up of microscopic particles with a diameter of less than 2.5 micrometers (2). These particles are small enough to penetrate deep into the lungs, enter the bloodstream, and cross biological barriers, including the placenta (3).

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Accepted September 16, 2025
https://doi.org/10.70251/HYJR2348.35276281

Once inside the body, PM2.5 can cause inflammation, oxidative stress, and other physiological changes that may disrupt normal neurodevelopment (4).

This raises a significant question in the public health community: How might prenatal exposure to PM2.5 be associated with the likelihood of a child being diagnosed with ASD? While previous studies have looked at both prenatal and early postnatal exposures, the goal of this paper is to explore the prenatal period specifically, using state-level data to identify patterns and associations that may help push for effective policy and preventive interventions.

METHODS AND MATERIALS

Data Sources

Three main datasets were used for this study. I used the CDC Autism Data Visualization Tool to examine yearly state-level prevalence data for ASD from 2000 to 2022 (1), with statistics coming from both Medicaid data and Special Education Child Count data. I also used the EPH Tracking tool, which offered environmental pollution exposure data, including yearly PM2.5 concentration numbers, population demographics, and socioeconomic factors (5). The U.S. Census Bureau Data was also utilized, as it included data on population density, household income, and urbanization rates, which helped to serve as controls in the analysis (6).

Study Design

State-level ASD prevalence data were paired with annual PM2.5 averages. Median household income and population density were included as controls to help account for potential confounding factors. The dataset spanned 23 years, making it possible to examine both long-term trends and more recent shifts in air quality, including periods when earlier improvements began to reverse (7). Missing data years (2014–2015) were excluded from analyses, and trends were calculated using the available data before and after those gaps.

Statistical Analysis

Pearson correlation coefficients were used to identify the strength and direction of associations between PM2.5 concentrations and ASD prevalence, and linear regression models were created through Excel and were then used to test statistical significance while acknowledging and adjusting for socioeconomic and demographic factors (8). All analyses were conducted at the state level, with separate models run for high pollution and low pollution states to observe regional differences. Specifically, we first computed state-level Pearson correlations between ASD prevalence and PM2.5 within each year from 2000 to 2022. We then fit multivariable linear regression models with ASD prevalence as the outcome and PM2.5 as the exposure of interest, adjusting for median household income and population density. Confounders were included simultaneously in the primary models to minimize omitted variable bias. As sensitivity analyses, we added each confounder separately to the unadjusted model and repeated the association using Spearman's rank correlation. We also present a pooled panel model with year fixed effects, and in a secondary analysis, state fixed effects, to utilize all years while accounting for unobserved time trends and time invariant state differences.

RESULTS

Trends in PM2.5 Exposure

From 2000 to 2017, average PM2.5 levels in the United States declined significantly, dropping from about 13.5 $\mu g/m^3$ to around 8 $\mu g/m^3$ (2). However, this downward trend began reversing in the last few years. Wildfire seasons intensified, heat waves increased in frequency, and climate-related shifts contributed to sustained periods of unhealthy air quality (7). By 2022, over 150 million Americans were again living in areas with PM2.5 levels exceeding safe limits, marking the highest exposure in more than a decade. Even in states that weren't impacted as severely by these disasters, they still exceed the 5 $\mu g/m^3$ limit that the World Health Organization (WHO) has established as unsafe (Figures 1 and 2).

ASD Prevalence Patterns

ASD prevalence has risen steadily since the early 2000s. In 2000, the rate was approximately 1 in 150 children. However, by 2022, it had reached approximately 1 in 36 children (1). While diagnostic improvement, awareness, and changes in classification have definitely played a role, the consistency of increases across both high and low-income states suggests that environmental factors may also be at work (3, 4). Year-to-year changes varied by state, but the overall direction was upward. Figure 3 shows where both Medicaid enrollment and special education identification rose steadily from 2000 to 2022, with totals climbing nearly eightfold.

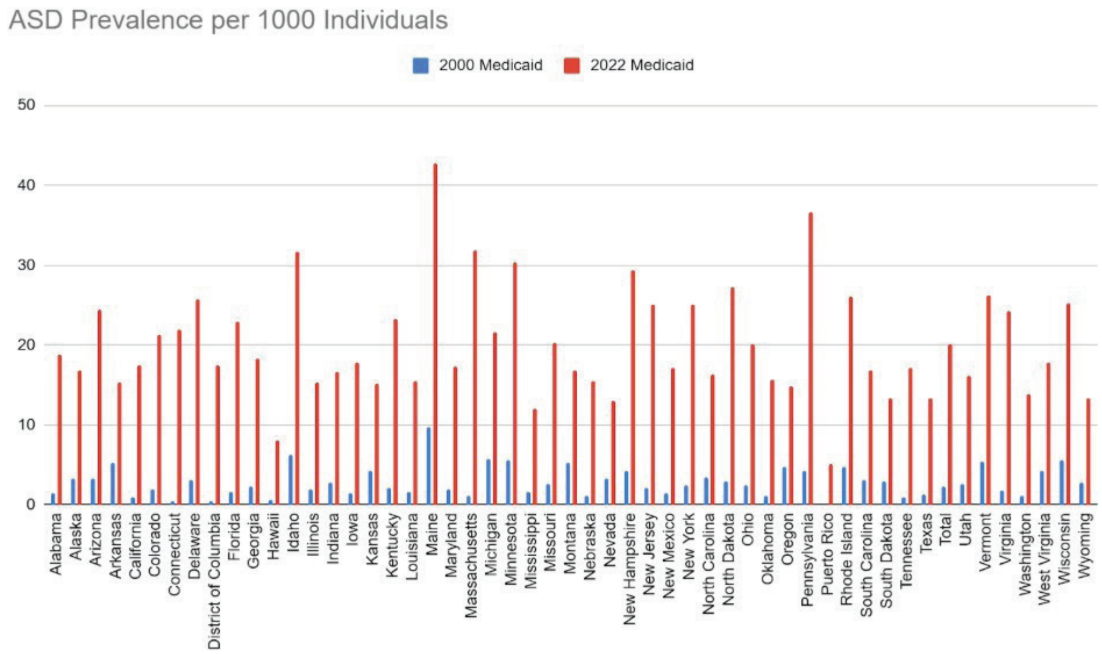

Figure 1. Bar chart of ASD prevalence per 1,000 individuals. This figure compares autism spectrum disorder (ASD) prevalence across U.S. states between 2000 (blue) and 2022 (red) based on Medicaid data. In every state, prevalence rates increased markedly over the two decades, with many states rising from below 10 per 1,000 in 2000 to between 20 and 40 per 1,000 in 2022. The consistent upward trend across states underscores the nationwide growth in ASD identification and reporting over time.

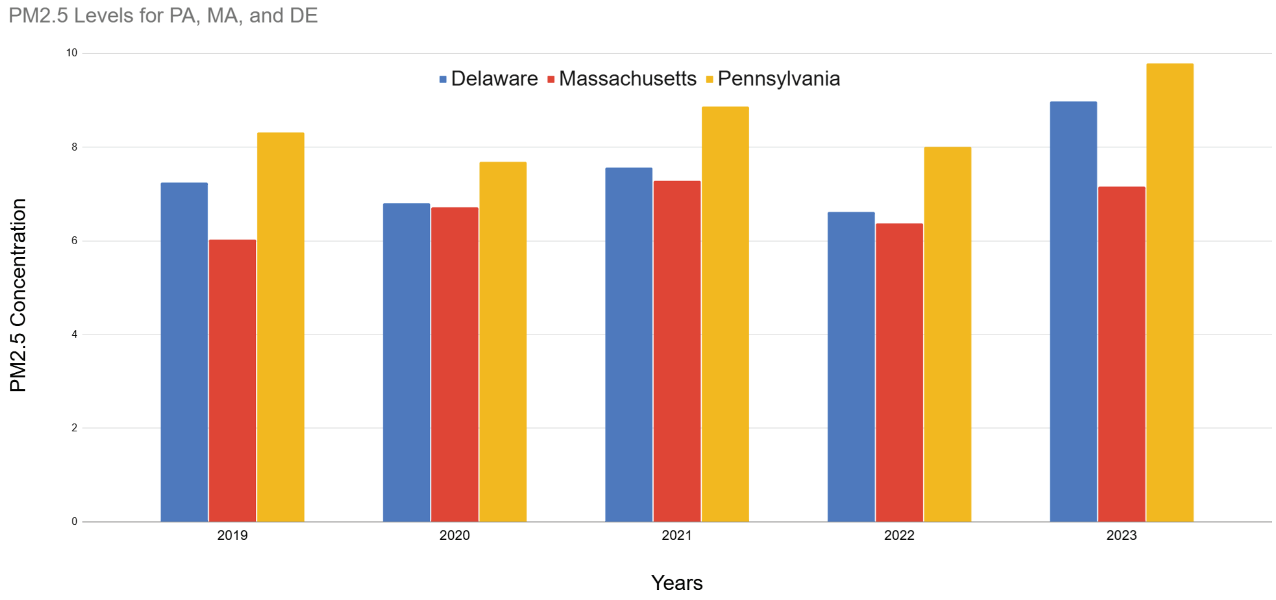

Figure 2. Bar chart of PM2.5 concentrations in Delaware, Massachusetts, and Pennsylvania. This figure presents average PM2.5 levels from 2019 to 2023 across the three states. While all states show fluctuations over time, Pennsylvania consistently records the highest concentrations, reaching nearly 9.5 µg/m³ in 2023. Delaware shows moderate levels with a peak in 2023, while Massachusetts remains the lowest across all years. The comparison highlights regional differences in air quality trends over the five-year period.

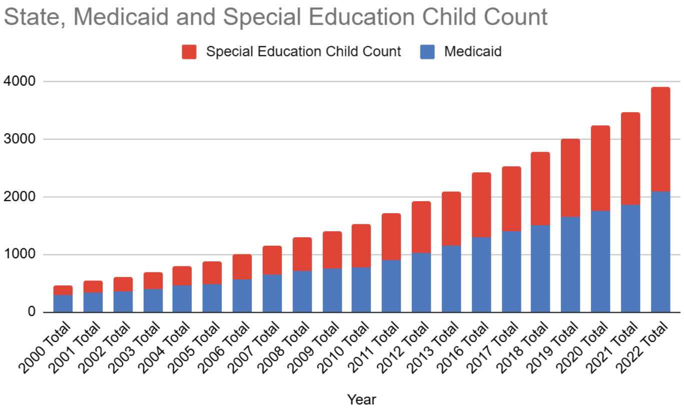

Figure 3. Stacked bar chart of Medicaid and special education child counts. This figure illustrates the yearly totals of children enrolled in Medicaid (blue) and identified in special education (red) from 2000 to 2022. The chart shows a steady and substantial increase in both categories over time, with combined totals rising from fewer than 500 children in 2000 to nearly 4,000 by 2022. The growth highlights both expanding Medicaid coverage and increasing identification of children requiring special education services.

Statistical Correlation

States with consistently high PM2.5 levels tend to have some of the highest ASD rates (5), with this pattern being seen consistently even after accounting for potential confounding variables, like different diagnostic practices and population demographics. Regression analysis revealed a statistically significant association between PM2.5 and ASD prevalence (8). Although it was a moderately strong correlation, it stayed consistent across multiple models, suggesting that for every 1 µg/m³ rise in PM2.5, ASD prevalence tended to be higher, even after adjusting for confounders.

Across states and years, higher annual PM2.5 levels were associated with higher ASD prevalence after adjustment for income and population density. Model fit was statistically significant, and the direction of association was consistent across specifications. In a state-level example using Massachusetts, ASD prevalence tracked annual PM2.5 with a strong linear relationship. The regression explained a large share of variance ($R^2 = 0.893$, $F = 9.169$, $p < .001$), and the positive association remained after covariate adjustment (Figure 4 and Table 1).

Geographic Concentration of Risk

While PM2.5 levels have improved nationwide since 2000, those gains have not reached every region, with some still facing serious pollution problems. Data from 2000 to 2024 show that states such as Pennsylvania, Massachusetts, and Delaware have consistently had higher average PM2.5 levels than the rest of the nation, even in the past five years. From 2019 to 2023, these states held the highest PM2.5 levels in the country, largely because of crowded cities, busy roads, industrial sites, and repeated wildfires from Canada (5). These exposure differences align with the state-level variation observed in ASD identification over time (Figure 5).

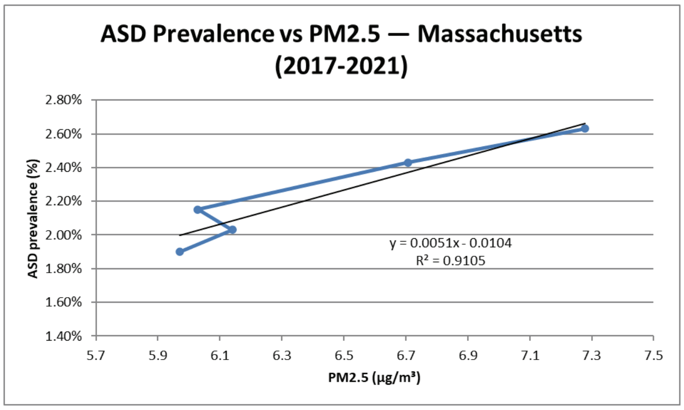

Figure 4. Scatterplot of ASD prevalence and PM2.5 levels. This simple linear regression plot illustrates the relationship between ASD prevalence (%) and average PM2.5 concentration (µg/m³) in Massachusetts from 2017–2021. A strong positive association is evident, with higher PM2.5 levels corresponding to higher ASD prevalence. The fitted regression line ($R^2 = 0.911$) highlights the strength of this association, suggesting that air quality may help explain some of the variation in ASD prevalence over time.

Table 1. Multiple linear regression model predicting ASD prevalence from PM2.5 concentration ($R^2 = 0.893$, $F = 9.169$, $p < 0.001$) for Massachusetts.

State	*ASD Prevalence (%)*	*PM2.5 (µg/m³)*
Massachusetts	*0.019*	*5.969779034*
Massachusetts	*0.0203*	*6.140164637*
Massachusetts	*0.0215*	*6.02828187*
Massachusetts	*0.0243*	*6.708099265*
Massachusetts	*0.0263*	*7.277074419*

The Massachusetts example is shown in the figure panel. See Figure 4.

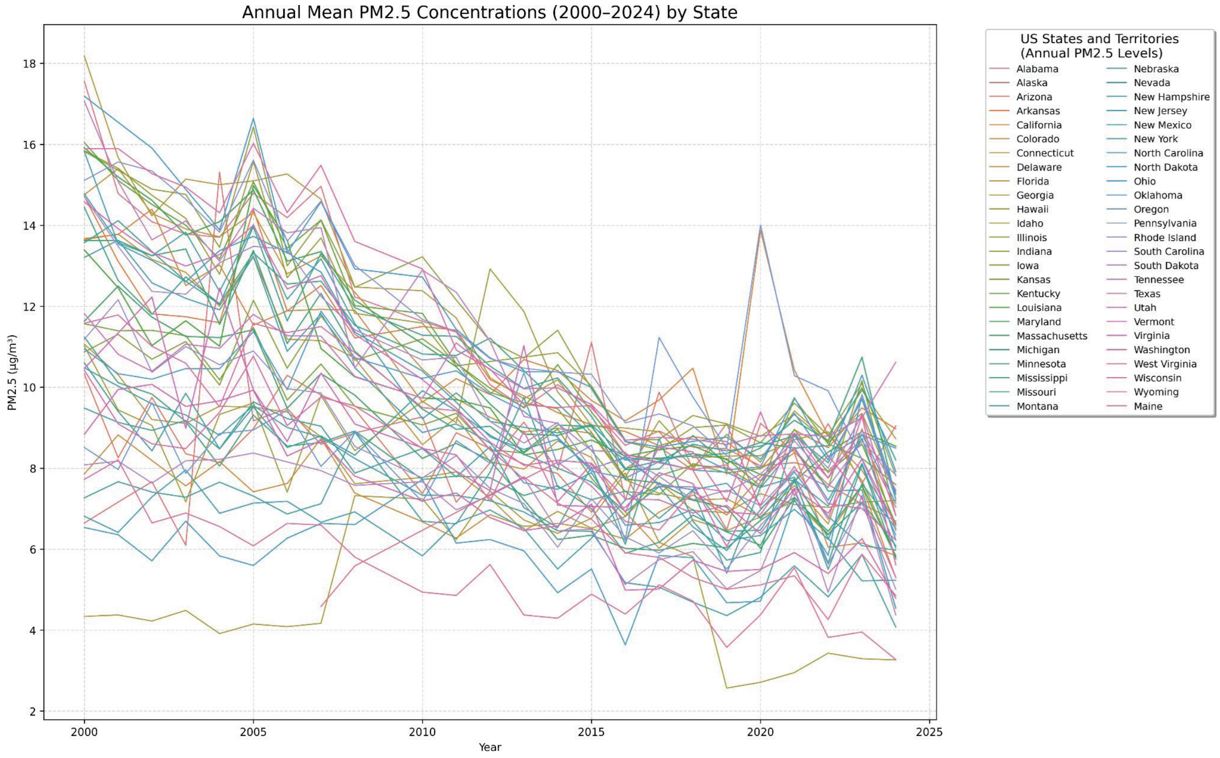

Figure 5. Line chart of annual mean PM2.5 concentrations by state (2000–2024). This figure shows trends in fine particulate matter (PM2.5) levels across all U.S. states and territories over a 24-year period. Most states experienced a marked decline in concentrations from 2000 through the mid-2010s, reflecting improvements in air quality regulations and emission controls. However, variability has remained in recent years, with several states showing temporary spikes and a leveling off of declines after 2017. The chart highlights both the national progress in reducing PM2.5 exposure and the persistence of regional fluctuations.

These gaps are even more concerning when you look at where people live in these states. Many births occur in polluted urban environments, and despite improvements since 2000, these areas often show the fastest rise in autism rates.

The data suggest that the problem is shaped less by national trends and more by everyday realities such as where people live, the pollution sources that are in their communities, and the clustering of pregnancies in high-exposure areas. Although air quality has improved in many places, certain communities still remain exposed to the same risks year after year, and these conditions persist across years in the same communities.

DISCUSSION

PM2.5 particles are small enough to pass through the lungs into the bloodstream, eventually crossing the placental barrier during pregnancy (3). This can lead to inflammation, oxidative stress, and immune activation in both the mother and baby (4). Disruptions during critical periods of brain development may impact synapse formation, myelination, and neural connectivity, which have been associated with a greater likelihood of neurodevelopmental disorders such as ASD. (9).

Studies on animals have also shown that prenatal exposure to particulate matter can result in long-term behavioral changes and structural brain alterations. Epidemiological research in humans has also found a correlation between elevated PM2.5 exposure during pregnancy, particularly in the third trimester, and a higher likelihood of ASD diagnosis in children (8).

The overlap between high PM2.5 exposure areas and elevated ASD rates emphasizes the need for targeted interventions (2). The government should implement policies that focus on reducing the sources of air pollution. especially in densely populated clusters, so that communities near major highways, industrial zones, or wildfire-prone regions face lower exposure risks.. In addition to emissions reduction, community-level interventions such as distributing air filtration systems to high-risk households could help lower exposure levels during pregnancy (7).

Lower-income communities often face greater exposure to environmental pollutants and have less access to quality prenatal care (6). This can amplify the developmental impact of PM2.5.

Reducing these risks requires public health policies that address environmental justice and improve healthcare access for vulnerable populations (2).

CONCLUSION

The results of this study suggest that prenatal exposure to PM2.5 is not only an environmental concern but also a developmental one. While this link does not establish that PM2.5 directly causes autism, the consistency of the association across different states, along with what is already known about its biological effects, underscores the importance of caution. Lowering PM2.5 exposure, particularly for pregnant individuals, could be an important step in reducing autism risk for future generations.

Future studies should look beyond state-level averages and examine exposure at the ZIP code or neighborhood level. This closer view would make it easier to identify the communities most at risk and guide targeted interventions. In the meantime, there is already enough evidence for policymakers, healthcare providers, and environmental agencies to take action. This includes strengthening clean air regulations, investing in community-level mitigation strategies such as air filtration systems in high-risk regions, and enhancing prenatal care guidance to address environmental exposures. By combining research advances with proactive public health measures, it is possible to reduce the developmental risks linked to prenatal PM2.5 exposure.

ACKNOWLEDGEMENT

The author acknowledges the use of publicly available data from the Centers for Disease Control and Prevention (CDC) and the Environmental Protection Agency (EPA) in this study.

CONFLICTS OF INTEREST

The author declares that there are no conflicts of interest related to this work.

FUNDING SOURCES

The author has no funding sources that supported the research and preparation of this article.

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