Clinical and Socioeconomic Predictors of Childhood Asthma: A Comparative Statistical and Machine-Learning Approach

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ABSTRACT

Background:
Asthma is among the most common chronic physical health conditions affecting children in the United States and represents a significant public health challenge due to its long-term health, educational, and socioeconomic consequences. Childhood asthma is influenced by a complex combination of clinical, sociodemographic, household, and environmental factors, contributing to persistent disparities in diagnosis and management. Nationally representative survey data provide an important opportunity to examine these associations at the population level.

Objectives:
The objective of this study was to examine factors associated with lifetime asthma diagnosis among U.S. children and to evaluate the relative contribution of sociodemographic, environmental, household, and behavioral predictors using both statistical and machine-learning approaches.

Data and Methods:
This study analyzed data from the 2017 National Survey of Children's Health (NSCH), a cross-sectional, nationally representative survey. The analytic sample included approximately 21,600 children aged 0–17 years with available information on lifetime asthma diagnosis. The primary outcome was lifetime asthma diagnosis, derived from NSCH variable K2Q40A and coded as a binary indicator. Analyses included descriptive and exploratory assessments followed by multivariable logistic regression, LASSO regularized regression, and random forest modeling. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC), along with accuracy, precision, and recall.

Results:
Across all modeling approaches, clinical respiratory indicators particularly recent breathing difficulties and allergic conditions were the most influential predictors of lifetime asthma diagnosis. Sociodemographic and household factors, including child age and family socioeconomic status, also demonstrated meaningful associations, while behavioral and environmental variables contributed more modestly. Logistic regression and LASSO models achieved AUC values of approximately 0.84, comparable to the random forest model (AUC ≈ 0.81), indicating similar predictive performance across approaches.

Conclusion:
Lifetime asthma diagnosis among U.S. children is most strongly associated with clinical respiratory symptoms, with additional contributions from socioeconomic and household factors. These findings underscore the importance of early symptom identification and interventions addressing structural determinants of child health. Future research should incorporate multi-year data and subgroup analyses to further elucidate patterns and disparities in childhood asthma risk.

BACKGROUND

Chronic physical health conditions in childhood represent a major public health concern in the United States, with long-term implications for health, educational attainment, and quality of life. Among these conditions, asthma is one of the most prevalent chronic diseases affecting children, requiring ongoing management and posing a substantial burden on families and health care systems.[1] Childhood asthma is associated with increased emergency department visits, missed school days, limitations in physical activity, and elevated health care costs. Because asthma often begins early in life and can persist into adulthood, understanding its risk factors is central to improving child health outcomes and reducing long-term morbidity. [2]

The Physical & Chronic Health category of the National Survey of Children's Health (NSCH) captures a range of conditions that require continuous or long-term management, making it particularly well suited for studying asthma. As a chronic inflammatory disease of the airways, asthma reflects the complex interplay between biological susceptibility, environmental exposures, household context, and social determinants of health. Identifying factors associated with lifetime asthma diagnosis can inform early prevention strategies, targeted interventions, and policies aimed at reducing disparities in pediatric health. [3,4]

National surveillance data consistently demonstrate that asthma remains highly prevalent among U.S. children. According to the Centers for Disease Control and Prevention (CDC), approximately 8–9% of children in the United States have been diagnosed with asthma, with prevalence varying by age, race and ethnicity, and socioeconomic status. [5]Children from lower-income households, racial and ethnic minority groups, and urban environments experience disproportionately higher asthma prevalence and worse asthma-related outcomes. [4] The Health Resources and Services Administration (HRSA) has similarly emphasized asthma as a priority condition due to its impact on child health equity and health care utilization. [6]

Prior epidemiologic studies have identified several key factors associated with childhood asthma. Clinical indicators, such as wheezing, breathing difficulties, and allergic conditions, are strongly linked to asthma diagnosis and severity. Allergic comorbidities, including food and environmental allergies, are known to share underlying inflammatory pathways with asthma and often co-occur. [3]Beyond clinical factors, sociodemographic characteristics, including age, race, household income, and insurance coverage have been shown to influence both asthma risk and access to diagnosis and treatment. [7]

Environmental and household exposures also play an important role. Exposure to indoor allergens, tobacco smoke, and poor housing conditions has been associated with increased asthma risk, particularly among children living in socioeconomically disadvantaged households. At the same time, behavioral and lifestyle factors, such as physical activity, sleep patterns, and sedentary behaviors, have emerged as correlates of asthma-related health and overall respiratory function, although their independent contributions remain less clearly defined. [8,9]

Despite extensive prior research, many studies focus on a narrow subset of predictors or rely on a single analytic approach. There remains a need for comprehensive analyses that jointly evaluate clinical, sociodemographic, environmental, and household factors using nationally representative data and modern analytical methods.

Research Objectives and Hypotheses:

This study uses data from the 2017 National Survey of Children's Health (NSCH) to examine factors associated with lifetime asthma diagnosis among U.S. children. The NSCH allows for the integrated analysis of child demographics, household characteristics, environmental exposures, and health behaviors within a nationally representative sample. The primary outcome of interest is lifetime asthma diagnosis, measured using the NSCH variable K2Q40A, which asks whether a health care provider has ever diagnosed the child with asthma. This measure captures the cumulative burden of asthma across childhood and aligns with the study's focus on chronic physical health.

The objectives of this study are to identify sociodemographic, environmental, and household factors associated with lifetime asthma diagnosis; to evaluate the relative importance of clinical indicators, socioeconomic characteristics, environmental exposures, and behavioral factors in predicting asthma; and to assess the consistency of key risk factors across statistical and machine-learning approaches, including logistic regression, regularized regression, and ensemble methods. Guided by prior research and public health theory, the study hypothesizes that children with recent breathing difficulties and allergic conditions will have substantially higher odds of lifetime asthma diagnosis. It further hypothesizes that socioeconomic disadvantage, reflected by lower household income and related household characteristics, will remain associated with asthma even after accounting for clinical indicators, while environmental and lifestyle factors will demonstrate more moderate associations once sociodemographic and clinical variables are considered simultaneously.

Overall, this study aims to provide a concise, data-driven assessment of factors associated with childhood asthma and to generate insights relevant to both clinical practice and child health policy.

METHODS

1. Study Design and Population:

This study is a cross-sectional observational analysis based on data from the 2017 National Survey of Children's Health (NSCH), a nationally representative survey conducted annually by the U.S. Census Bureau under the direction of the Health Resources and Services Administration (HRSA). The NSCH collects parent- or caregiver-reported information on the physical health, emotional well-being, household context, and social environment of children in the United States.

The analytic sample included children aged 0–17 years who participated in the 2017 NSCH and for whom information on lifetime asthma diagnosis was available. The primary outcome variable, lifetime asthma diagnosis, was derived from the NSCH item K2Q40A, which asks whether a doctor or other health care provider has ever told the respondent that the child has asthma. Children with missing, refused, or "don't know" responses for this item were excluded from regression and predictive modeling analyses. No additional age-based or condition-specific subgroup restrictions were applied in order to preserve sample size and maximize population representativeness.

After applying variable selection and outcome-based exclusion criteria, the final analytic dataset included approximately 21,000 children, exceeding the minimum sample size requirement specified for the project. All selected predictor variables were drawn from domains relevant to sociodemographic characteristics, household environment, neighborhood context, and health-related behaviors.

Survey sampling weights were not applied in the primary analyses. All models were estimated using unweighted data, and results are therefore interpreted as associations within the analytic sample rather than nationally weighted prevalence estimates. This approach was chosen to prioritize model stability, computational feasibility, and comparability across statistical and machine-learning methods.

2. Outcome Definition:

The primary dependent variable for this study was lifetime asthma diagnosis, a chronic physical health outcome aligned with the Physical & Chronic Health category of the National Survey of Children's Health (NSCH). This outcome was derived from the NSCH item K2Q40A, which asks whether a doctor or other health care provider has ever told the parent or caregiver that the child has asthma.

For analytic purposes, responses to K2Q40A were recoded into a binary outcome variable, asthma_diag, where a value of 1 indicated that the child had ever been diagnosed with asthma and a value of 0 indicated that the child had never received an asthma diagnosis. Responses coded as "don't know," "refused," or other non-substantive categories were treated as missing and excluded from regression and predictive modeling analyses. Because K2Q40A is administered to all children in the NSCH, missingness in the outcome was minimal and primarily attributable to nonresponse.

This binary outcome captures the cumulative burden of asthma across childhood and is well suited for both statistical inference and machine-learning–based prediction.

3. Predictor Variables:

Predictor variables were selected to capture a broad range of individual, family, community, and behavioral factors that have been previously linked to childhood asthma in the literature and are

available within the 2017 NSCH. Variable selection followed a hybrid approach, combining theory-driven inclusion based on prior epidemiologic and public health research with data-driven considerations related to completeness, variability, and relevance to the study outcome.

Individual-level factors included child demographic and health-related characteristics. These variables comprised age in years (SC_AGE_YEARS), sex (SC_SEX), race (SC_RACE_R), body mass index percentile category (BMICLASS), and indicators of allergic and respiratory conditions, including ever-diagnosed allergies (ALLERGIES) and frequent or chronic breathing difficulties in the past 12 months (BREATHING). These variables were selected based on extensive prior evidence linking asthma risk to age-related patterns, sex differences, racial disparities, allergic comorbidities, and respiratory symptomatology.[10]

Family-level factors were included to reflect household structure, socioeconomic status, and health-related exposures within the home environment. These variables included family poverty ratio (FPL_I1), number of family members in the household (FAMCOUNT), primary household language (HHLANGUAGE), current health insurance coverage (CURRCOV), household tobacco use (K9Q40), food security status in the past 12 months (FOODSIT), and the presence of mold or water damage inside the home (MOLD). These measures capture multiple dimensions of socioeconomic disadvantage, material hardship, and household exposures that have been associated with asthma prevalence and management in prior studies. [11]

Community-level factors were selected to characterize the broader neighborhood and residential context in which the child lives. These variables included metropolitan statistical area status (METRO_YN) and caregiver-reported neighborhood conditions, such as the presence of poorly kept or rundown housing (K10Q22), litter or garbage on streets or sidewalks (K10Q20), and perceived child safety in the neighborhood (K10Q40_R). These indicators reflect environmental and contextual influences that may contribute to asthma risk through mechanisms such as environmental exposures, stress, and access to resources. [12]

Behavioral and lifestyle factors were included to represent daily routines and health-related behaviors that may influence respiratory health or serve as proxies for broader health and environmental conditions. These variables included the number of days of physical activity per week (PHYSACTIV), average hours of sleep on weeknights (HOURSLEEP), and average weekday screen time (K7Q60_R). While these behaviors are not considered direct causes of asthma, they have been associated with asthma symptoms, disease management, and overall child health in prior research and may capture modifiable correlates of asthma risk. [13]

All predictors were coded in accordance with NSCH documentation. Continuous variables were retained in numeric form, while categorical and ordinal variables were modeled as factors. Together, these predictors provide a comprehensive representation of individual susceptibility, household context, environmental conditions, and behavioral patterns relevant to lifetime asthma diagnosis among U.S. children.

4. Statistical and Machine-Learning Methods:

A combination of statistical and machine-learning methods was used to examine factors associated with lifetime asthma diagnosis and to compare predictive performance across modeling approaches. All analyses were conducted in the R statistical computing environment.

Multivariable logistic regression was first applied as a baseline inferential model to estimate associations between the selected predictors and the binary asthma outcome. Logistic regression was chosen for its interpretability and appropriateness for binary health outcomes, allowing for straightforward assessment of predictor effects through estimated coefficients.

To improve model parsimony and address potential multicollinearity among predictors, a regularized logistic regression model using the Least Absolute Shrinkage and Selection Operator (LASSO) was implemented. LASSO applies an L1 penalty that shrinks weaker coefficients toward zero, effectively performing feature selection. The optimal penalty parameter was identified using internal cross-validation, and the one–standard-error rule was used to favor a more conservative and generalizable model.

To account for potential non-linear relationships and interactions between predictors, a random forest classifier was employed as a tree-based ensemble method. Random forests construct multiple decision trees using bootstrap samples and random subsets of predictors, yielding robust predictions and reducing overfitting. Predictor importance within the random forest model was assessed using mean decrease in Gini impurity.

The analytic dataset was randomly divided into training (70%) and testing (30%) subsets, with a fixed random seed to ensure reproducibility. Model performance was primarily evaluated on the test set using the area under the receiver operating characteristic curve (AUC), along with accuracy, precision, and recall. In addition, five-fold cross-validation was performed for the logistic regression model to assess stability and generalizability across resampled data subsets.

Model calibration was examined by regressing observed outcomes on predicted probabilities to estimate calibration intercepts and slopes. Feature importance and interpretability were assessed using standardized coefficients for logistic regression, non-zero coefficients from the LASSO model, and variable importance rankings from the random forest model. Together, these complementary approaches enabled both robust prediction and meaningful interpretation of factors associated with lifetime asthma diagnosis.

All modeling and evaluation procedures were implemented using established R packages, including stats, glmnet, randomForest, pROC, and caret.

4.5 Model Evaluation Metrics:

Model performance was evaluated using measures of discrimination, overall predictive accuracy, and feature importance. Discrimination was assessed using the area under the receiver operating characteristic curve (ROC–AUC), which quantifies each model's ability to distinguish between children with and without a lifetime asthma diagnosis and is robust to outcome imbalance.

Overall predictive performance was evaluated on the held-out test set using accuracy, precision, and recall at a fixed classification threshold of 0.5. Accuracy reflects the proportion of correctly classified observations, precision represents the proportion of predicted asthma cases that were true cases, and recall measures the proportion of true asthma cases correctly identified by the model.

Model stability and generalizability were assessed using five-fold cross-validation for the logistic regression model, with cross-validated ROC–AUC values summarized across folds. Feature importance was evaluated using standardized coefficients for logistic regression, non-zero coefficients for the

LASSO model, and variable importance rankings based on mean decrease in Gini impurity for the random forest model.

Together, these metrics provided a comprehensive evaluation of model discrimination, predictive performance, and interpretability across modeling approaches.

RESULTS

1. Descriptive Statistics:

The analytic sample included approximately 21,600 children from the 2017 National Survey of Children's Health with information on lifetime asthma diagnosis and selected predictors. The prevalence of lifetime asthma diagnosis was approximately 12%, indicating that about one in eight children had ever been diagnosed with asthma by a health care provider. As shown in Figure 1, the majority of children in the sample had no history of asthma, with only a small proportion of missing or non-response observations.

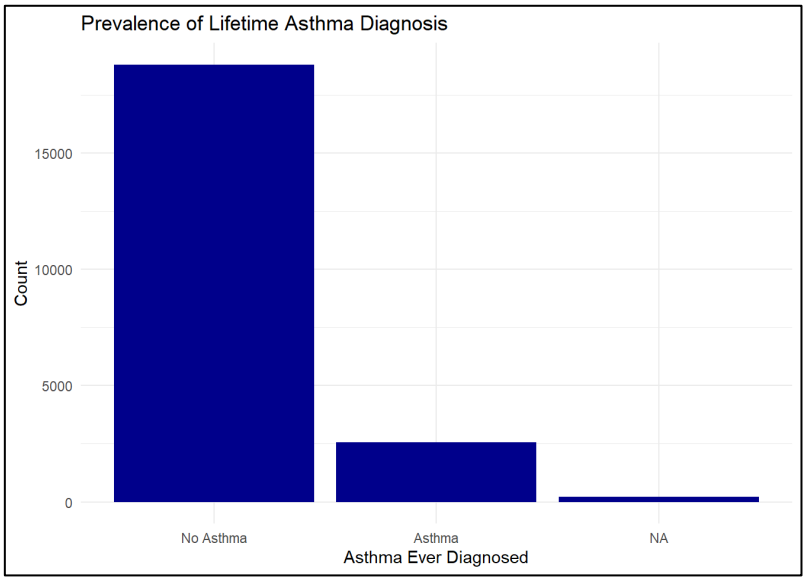

Fig 1: Prevalence of Lifetime Asthma Diagnosis Among U.S. Children (2017 NSCH).

Children ranged in age from 0 to 17 years, with a mean age of approximately 9.4 years, and the sex distribution was nearly balanced. The racial and ethnic composition reflected the nationally representative nature of the survey. A substantial proportion of children reported doctor-diagnosed allergies, while fewer reported frequent or chronic breathing difficulties in the past 12 months.

Household and socioeconomic characteristics varied widely, with family poverty ratios spanning 50% to 400% of the federal poverty level. Most children lived in insured households, although a subset experienced indicator of household hardship, such as food insecurity, tobacco exposure, or mold within the home. Community and behavioral characteristics also showed considerable variation, including differences in neighborhood conditions, physical activity levels, sleep duration, and weekday screen time.

Exploratory analyses were used to examine relationships between predictors and lifetime asthma diagnosis and to assess patterns among continuous variables. Boxplots compared continuous predictors across asthma status, and correlation heatmaps assessed pairwise relationships and potential collinearity. These analyses showed differences in age, household size, and family poverty ratio by asthma status, while correlations among continuous predictors were generally modest, supporting their inclusion in subsequent modeling analyses.

2. Model Performance:

Model performance was evaluated and compared across classical statistical and machine-learning approaches, including logistic regression, LASSO regularized regression, and random forest models. Overall, all three models demonstrated good discriminatory ability, with area under the receiver operating characteristic curve (AUC) values exceeding 0.80.

The logistic regression model achieved an AUC of approximately 0.8373, indicating strong baseline performance and good separation between children with and without a lifetime asthma diagnosis. The LASSO model showed comparable performance, with a slightly higher AUC of approximately 0.8381, while simultaneously performing feature selection by shrinking less informative predictors toward zero. In contrast, the random forest model achieved a slightly lower AUC of approximately 0.8142, though it captured non-linear relationships and interactions among predictors.

Across models, performance metrics such as accuracy, precision, and recall were consistently high, reflecting robust predictive performance. Clinical indicators, particularly recent breathing difficulties and allergies, emerged as the most influential predictors across modeling approaches, while sociodemographic and behavioral factors contributed additional predictive value.

Model	AUC	Key Predictors Identified
Logistic Regression	0.8373	Breathing difficulties, allergies, age
LASSO Regression	0.8381	Breathing difficulties, allergies, age
Random Forest	0.8142	Breathing difficulties, allergies, age

Table 1: Model Performance Summary

Although the random forest model captured non-linear relationships, its predictive performance was similar to that of logistic regression and LASSO, suggesting that much of the signal in the data is well captured by simpler, more interpretable models.

3. Feature Importance and Visualization:

Feature importance was assessed to identify the most influential predictors of lifetime asthma diagnosis using variable importance measures from the random forest model, along with coefficient-based importance from logistic regression and LASSO models.

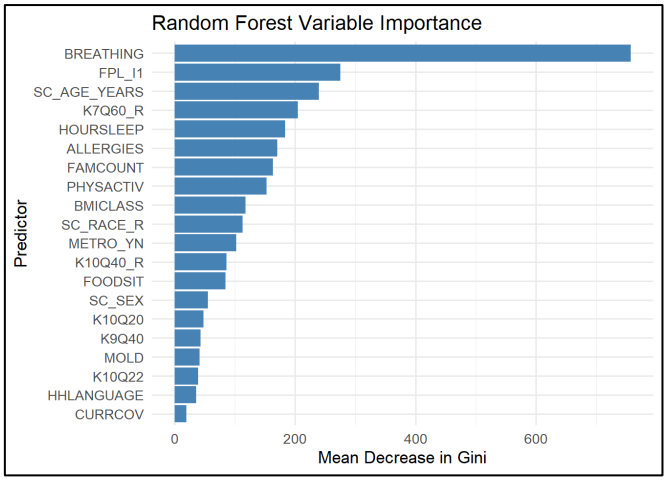

Fig 2: Random Forest Variable Importance for Lifetime Asthma Diagnosis

Figure 2 displays the random forest variable importance plot, with predictors ranked by mean decrease in Gini impurity. Recent breathing difficulties emerged as the most influential predictor by a wide margin, followed by family poverty ratio and child age. Several behavioral and lifestyle factors, including screen time, sleep duration, and physical activity, also ranked among the top predictors, while demographic and community-level variables demonstrated more modest importance.

To facilitate comparison across modeling approaches, Table 2 summarizes the top predictors identified by logistic regression, LASSO, and random forest models.

Rank	Logistic Regression	LASSO Regression	Random Forest
1	Breathing difficulties	Breathing difficulties	Breathing difficulties
2	Allergies	Allergies	Family poverty ratio
3	Child age	Child age	Child age
4	Physical activity	Physical activity	Screen time
5	Sleep duration	—	Sleep duration

Table 2: Top Predictors of Lifetime Asthma Diagnosis Across Models

Across all models, clinical indicators—particularly recent breathing difficulties and allergies were consistently identified as the strongest predictors of lifetime asthma diagnosis, underscoring their central role in asthma-related morbidity. Child age also ranked highly across models, reflecting the cumulative nature of lifetime asthma diagnosis, with older children having had greater opportunity for diagnosis.

Household socioeconomic status, as measured by family poverty ratio, emerged as a prominent predictor in the random forest model, suggesting that socioeconomic conditions contribute meaningfully to asthma risk beyond clinical symptoms alone. Behavioral factors, including physical activity, sleep duration, and screen time, demonstrated moderate importance, indicating potential links between lifestyle patterns and asthma outcomes.

Environmental and community-level variables, such as neighborhood conditions and housing-related exposures, were generally of lower importance but remained contributory, highlighting the broader social and environmental context of childhood asthma.

Overall, the consistent predictor rankings across models indicate that lifetime asthma diagnosis is primarily driven by clinical respiratory indicators, with meaningful contributions from sociodemographic, household, and behavioral factors.

DISCUSSION

This study examined sociodemographic, environmental, household, and behavioral factors associated with lifetime asthma diagnosis among U.S. children using data from the 2017 National Survey of Children's Health. Across statistical and machine-learning approaches, the analysis identified a consistent set of predictors, with clinical respiratory indicators emerging as the strongest contributors to asthma diagnosis, followed by socioeconomic and household characteristics, and more modest contributions from behavioral and environmental factors.

Clinical indicators, particularly recent or chronic breathing difficulties and a history of allergies, were the most influential predictors across all models. This finding is consistent with extensive prior literature characterizing asthma as a chronic inflammatory airway disease closely linked to respiratory symptoms and allergic comorbidities.[14] Epidemiologic studies have repeatedly shown that wheezing, shortness of breath, and allergic sensitization are among the strongest predictors of asthma diagnosis and persistence, supporting the biological plausibility of these results.[3,14]

Sociodemographic and household factors also played a meaningful role. Family poverty ratio and child age were consistently identified as important predictors, particularly in the random forest model. The association between lower socioeconomic status and asthma risk aligns with prior research highlighting disparities in childhood asthma related to housing quality, environmental exposures, access to care, and cumulative stressors. The importance of age likely reflects the cumulative nature of lifetime asthma diagnosis, as older children have had more opportunity for both symptom development and clinical diagnosis. [11,15]

Behavioral factors, including physical activity, sleep duration, and screen time, demonstrated moderate importance. While these factors are unlikely to be direct causes of asthma, previous studies have suggested associations between asthma symptoms and reduced physical activity, sleep disturbances, and increased sedentary behavior. These variables may therefore reflect broader patterns of health, disease management, or environmental exposure rather than causal pathways. [13]

After accounting for clinical and socioeconomic factors, environmental and community-level variables were less strongly associated with asthma diagnosis. This suggests that environmental influences may affect asthma indirectly through respiratory symptoms or socioeconomic conditions, or may not be fully captured by self-reported survey measures.

From a clinical and public health perspective, these findings emphasize the importance of early identification and management of respiratory symptoms and allergic conditions in children. Screening approaches that focus on children with recurrent breathing difficulties or allergies may facilitate earlier asthma diagnosis and intervention. The association between socioeconomic disadvantage and asthma risk further underscores the need for policies that address structural determinants of health, including equitable access to preventive care, housing stability, and reduction of environmental exposures, particularly among lower-income families.

The moderate influence of behavioral factors suggests that comprehensive asthma management may benefit from interventions that extend beyond clinical treatment to include sleep, physical activity, and daily routines. While these factors may not directly prevent asthma onset, addressing them may support improved symptom control and overall quality of life for affected children.

Several limitations should be considered when interpreting these findings. First, the NSCH relies on parent- or caregiver-reported information, which may introduce recall bias or misclassification, particularly for environmental and behavioral measures. Second, the cross-sectional nature of the data limits causal inference, and unmeasured factors such as genetic susceptibility, detailed environmental exposures, or patterns of health care use may confound the observed associations. Third, the use of lifetime asthma diagnosis captures whether a child has ever been diagnosed but does not provide information on current disease activity, severity, or control.

Future research could build on this work by pooling multiple NSCH survey years to enhance statistical power and evaluate trends over time. Stratified analyses by age, race and ethnicity, or socioeconomic status may further elucidate heterogeneity in asthma risk. Additionally, incorporating survey weights or linking NSCH data with external environmental exposure data could strengthen population-level inference and improve contextual understanding of childhood asthma.

CONCLUSION

Using nationally representative data from the National Survey of Children's Health, this study examined sociodemographic, household, environmental, and behavioral factors associated with lifetime asthma diagnosis among U.S. children. Across statistical and machine-learning modeling approaches, clinical respiratory indicators particularly recent breathing difficulties and allergic conditions consistently emerged as the most influential predictors of asthma diagnosis. Sociodemographic and household characteristics, including child age and family socioeconomic status, also demonstrated meaningful associations, while behavioral and environmental factors contributed additional, though comparatively weaker, explanatory value.

These findings have important implications for public health practice and health equity. The prominence of clinical indicators supports the importance of early identification and management of respiratory symptoms and allergic conditions in pediatric populations. At the same time, the persistent role of socioeconomic disadvantage underscores the need for policies that address structural determinants of child health, including equitable access to preventive care, stable housing, and mitigation of environmental risks. The observation that simpler, more interpretable models performed comparably to more complex machine-learning approaches further suggests that transparent analytic methods may be sufficient for informing population-level risk assessment and decision-making.

Future research should build on this work by incorporating multiple years of NSCH data to assess temporal trends and by conducting subgroup analyses to better characterize heterogeneity in asthma risk across demographic and socioeconomic groups. Integrating clinical screening efforts with broader social and environmental interventions may ultimately contribute to reducing disparities and improving outcomes for children affected by asthma.

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