Original Research Article

# The Influence of Socioeconomic and Environmental Factors on Allergic Sensitization: Population-Level Evidence From the 2005-2006 National Health and Nutrition Examination Surveys (NHANES)

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## ABSTRACT

Allergic sensitization has been an increasingly important topic in public health policy as it can influence individuals' physical and mental well-being. In addition, it can potentially lead to fatal health complications and symptoms. Existing studies have largely examined the influence of individual factors, such as genetics or dietary habits, on allergic sensitization using laboratory data. However, limited research has explored the socioeconomic and environmental factors that may trigger allergic reactions at the population level. Thus, this study aims to identify which socioeconomic and environmental factors of individuals may be associated with allergic sensitization using a large population-level survey: the 2005-2006 National Health and Nutrition Examination Surveys (NHANES). It was hypothesized that higher socioeconomic status (SES), better housing conditions, and the absence of a history of tobacco exposure would be associated with reduced allergic sensitization. Taking the total serum Immunoglobulin E (IgE) as an indicator of allergic sensitization, the regression analysis identified that the family Poverty Income Ratio (PIR), the education level, and the number of people in the household had a strong association with the total serum IgE. This indicated strong evidence for the significance of socioeconomic and environmental conditions in allergic sensitization. These findings imply that living environments should be an important consideration in public health policy, particularly for those with lower SES. They tend to have higher allergic sensitivity, which can interfere with their daily functioning. This study contributes by revealing a strong link between socioeconomic and environmental conditions and allergic sensitization, with implications for public policy.

**Keywords:** Allergic Sensitization; Socioeconomic Status; Housing Environment; Smoking; Public Health; Total Serum IgE; NHANES

## INTRODUCTION

There has been a recent global rise in allergic diseases and immune reactions in both adults and children in developed and developing countries (1). The rate of asthma ranges from 1% to 20%, and allergic rhinitis develops in 1% to 18% of individuals. This trend has been particularly noticeable in children in the past two decades (2). Some of these conditions may have been

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induced by allergic sensitization. It is an outcome in which a healthy immune system becomes hypersensitive to a normally harmless substance, an allergen, by producing specific Immunoglobulin E (IgE) antibodies (3). Heightened allergic sensitization can lead to more allergic reactions, adversely affecting population health.

A biomarker of allergic sensitization is total serum IgE. IgE is a type of antibody produced by the immune system in response to allergens, triggering immediate hypersensitivity reactions. Allergic symptoms manifest as a result. Hence, elevated IgE levels can suggest an allergic condition or a parasitic infection; more pronounced allergic sensitization can also be inferred.

Rather than solely relying on biological factors, immune health is also influenced by socioeconomic and environmental conditions. Particularly, socioeconomic status (SES), education, housing environment, and both second and first-hand smoking are able to shape health outcomes. These factors can influence the degree of exposure to allergens, thereby affecting allergic sensitization. Regardless, most prior literature focuses on either biological mechanisms or social factors; few studies combine both. As a result, there may be a gap in publicly available data linking socioeconomic and environmental determinants to immune biomarkers.

The research objective was to examine how SES, housing environment, and tobacco exposure were correlated with the total serum IgE at a population level. The first hypothesis established was that lower SES was associated with higher total serum IgE. The second hypothesis stated that household environmental exposures, such as mold and cockroaches, were associated with higher total serum IgE. Finally, the third hypothesis theorized that exposure to both active and passive tobacco smoke was associated with elevated total serum IgE.

Lower SES is notably associated with several environmental and social conditions that contribute to chronic stress (4). Psychological strain, which chronic stress contributes primarily to, is known to modify the regulation and capacity of the immune system. As a result, because allergic reactions are a product of an overreaction of the immune system to foreign substances, lower SES can influence allergic sensitization (5-6). In addition, low SES housing may increase allergen exposure, such as to cockroaches and mold, because these individuals may not have the luxury of expending large amounts of resources on the hygiene of their housing environments. This is also tied to the second hypothesis: household environmental exposures, including pets and mold spores, can exacerbate allergic sensitization. Hence, total serum IgE may increase. For the third hypothesis, tobacco smoke has been demonstrated to increase the risk of heightened allergic sensitization in previous literature. The exposure has additionally been shown to worsen asthma and allergic rhinitis symptoms; both allergic rhinitis and asthma can be triggered by allergens, suggesting their relationship with allergic sensitization (7).

To explore the socioeconomic and environmental determinants of allergic sensitization, data from the National Health and Nutrition Examination Surveys (NHANES) taken between 2005 and 2006 were utilized. It was suitable for studying health at the population level because it is a national sample collected by the United States of America (USA) government. Uniquely, the dataset additionally included total serum IgE measurements of the participants.

Understanding socioeconomic, biological, and environmental links in allergic sensitization is important for public health and health inequality research. With accumulated information, organizations monitoring public health may be able to reduce the overall severity of allergic reactions by addressing environmental and social influences alongside medical factors. Furthermore, more effective policies can be implemented with more research.

The remainder of the paper was organized as follows. First, the methodology regarding data collection, organization, and empirical analysis was discussed. Second, the analysis findings were described. Third, the findings and their implications were analyzed. Finally, a conclusion summarizing the previous material concluded with the paper.

## METHODS AND MATERIALS

### Study Design and Data Source

This study aimed to test the association of individual-level socioeconomic and environmental characteristics and allergic sensitization through a cross-sectional analysis. To do so, this study required a population-level dataset containing extensive information on social and environmental factors and allergic sensitization. Due to the unique nature of this combination, many public health datasets do not contain both pieces of information at the individual level. However, this old version of NHANES, conducted between 2005 and 2006, included questionnaire items on individual socioeconomic environments, housing conditions, and laboratory data on allergic sensitization. Therefore, this study used the dataset despite its publication year.

NHANES is a questionnaire conducted periodically since the early 1960s. The target participants are all civilians from the USA. The survey is conducted to better understand individual-level health outcomes and their population-level contributors and can thus be used to inform public health debates and policies. For these purposes, the survey conducts separate surveys and tests. Subsequently, several datasets that represent each survey and test are compiled. In this study, various datasets from the Questionnaire, Laboratory, and Demographic data were used. The data collected included clinical examinations, selected medical and laboratory tests, and self-reported data. The participants were interviewed at home, and health examinations were conducted at a mobile examination center (8).

## Sample Selection

The original data included 10,348 participants from the dataset. However, the final analysis included 6,474 respondents after excluding individuals without responses to key variables, particularly those who did not have their total serum IgE levels measured in the laboratory. Because the socioeconomic background and housing environment of respondents and their laboratory biomarker measures were compiled in separate datasets, the datasets were merged using the sequence numbers. These sequence numbers served as unique individual identifiers.

For each regression model, a complete case analysis was employed. All statistical analyses and multivariable regression modeling were conducted with the use of R (Version 4.5.1) within the RStudio integrated development environment (Version 2025.06.13; Posit Software, PBC, Boston, MA). The precision of parameter estimates was determined at a 95% confidence interval. Participants were only included in a particular model if they did not have a missing response for all explanatory variables required in the analysis. However, due to the absence of data in specific models, the sample size varied across each of the analyses.

## Variables and Measures

To measure the level of allergic sensitization in individuals, this study used total serum IgE, which was included in the Allergen Specific IgE(s) & Total IgE - Serum dataset in the Laboratory data. Total serum IgE is the total amount of IgE antibodies in the blood, measured in kilounits per liter (kU/L). A healthy level is generally considered to be a total serum IgE less than 150 kU/L. Elevated levels suggest an immune response, though it is not specified whether this is due to allergens or other non-allergic conditions. Conversely, a normal total serum IgE result does not exclude allergies, as allergic patients can have normal levels. Furthermore, due to the large differences in total serum IgE, a logarithmic transformation was applied to the variable.

To measure individuals' SES, this study used income, poverty level, education level, and English fluency. All variables were from the Demographics dataset. For Annual Household Income, each value represented a category that increased by 4,999 USD, with 1 corresponding to 0 to 4,999 USD. The numerical value in the variable family Poverty Income Ratio (PIR) represented the value of the family's income relative to the national poverty threshold. An increase in the number indicated a wealthier family. For the education level, 1 represented an education level less than 9th grade. 2 represented an education level between 9th and 11th grade, including 12th grade without a diploma. 3 represented the education level of a high school graduate. 4 represented the education level of someone with a college or AA degree. 5 represented the education level of a college graduate. 7 represented a person who refused to share their education level. 9 represented someone who did not know their education level. English fluency was measured by whether an interpreter was used during the family interview for immigration. 1 was coded for yes and 0 for no to analyze the data. 7 represented someone who refused to answer, and 9 represented someone who did not know.

The hygiene of the housing environment was evaluated using the following indicators: the number of apartments in a building, the year the home was built, the presence of cockroaches in the home, the presence of a mold odor, and the number of people living in a household. Excluding the final indicator, all of these proxies were from the Housing Characteristics dataset in the Questionnaire data. The numerical value represented the number of living units in the building the participant is living in, such as the number of apartments in the building. For the time when the home was built, 1 represented 1990 to present, 2 represented 1978 to 1989, 3 represented 1960 to 1977, 4 represented 1950 to 1959, 5 represented 1940 to 1949, 6 represented before 1940, 77 represented individual who refused to answer, and 99 represented an individual who did not know. For the variables for the presence of cockroaches and a mold odor in the home, 1 was coded for yes and 0 for no analyzing the data. 7 represented someone who refused to answer, and 9 represented someone who did not know. The data regarding the number of people living in a household, or crowding, was retrieved from the Demographics dataset. The numerical value directly represented the number of people living in the household.

Tobacco exposure was measured using variables indicating the typical number of cigarettes smoked at home and the number of cigarettes smoked per day by the responder or the responder's spouse. The proxies were from the Smoking - Household Smokers and the Smoking - Cigarette dataset in the Questionnaire data, respectively. For the former, values between 1 and 39 indicated the participant's answer, while 40 indicated 40 cigarettes or more. For the latter, 1 represented 1 or less, 2 to 90 represented their respective values, 95 represented 95 or more, 777 represented someone who refused to answer, and 999 represented someone who did not know.

The controlled variables were Body Mass Index (BMI), gender, and age. Higher BMI has been demonstrated to be correlated with numerous allergic diseases, and obesity has been shown to be significantly associated with an increased prevalence of allergic rhinitis (9). The BMI data was taken from the Body Measures dataset in the Examinations data. The numerical value represented the participant's weight in kilograms divided by their height in meters squared. From the Demographics Dataset, the variables gender and age were used. 1 represented male, and 2 represented females for gender, while the numerical value in the variable *age* corresponded to the real age of the participant. Determining age and gender as controlled variables was important because men are more likely to have positive skin tests than women, and allergic sensitization decreases with increasing age (10–11).

## RESULTS

The purpose of this study was to investigate the associations between SES, housing environment, and smoking exposure and allergic sensitization at the population level. To do so, this study employed four regression models: SES, housing environment, smoking exposure, and the full model. While the first three models tested the partial association of each factor with allergic sensitization, the full model tested the holistic relationship. Allergic sensitization was measured with the total serum IgE.

As shown in Table 1 (Model 1), the correlation between the annual household income and the total serum IgE was statistically insignificant ($p = 0.923$, $B = -0.0005$). Conversely, the family PIR was found to have a highly significant association with the total serum IgE ($p < 0.001$, $B = -0.0605$). The coefficient highlighted a negative relationship between the explanatory and response variables, for the total serum IgE increased as the family PIR decreased. The same regression model showed that the relationship between the total serum IgE and English fluency was statistically insignificant ($p = 0.447$, $B = 0.141$). On the other hand, education level was found to be strongly associated with total serum IgE. In particular, the high-school dummy had a statistically significant correlation ($p < 0.001$, $B = -0.249$). The coefficient was negative, indicating that as the education level increases, the immune reaction decreases. However, above the high school level, the association between education level and total serum IgE was not statistically significant, with p-values of 0.549, 0.854, and 0.626, respectively.

As seen in Table 1, Model 2, crowding was found to have a significant relationship with total serum IgE ($p = 0.0313$, $B = 0.116$). The coefficient was positive; as crowding increased, the immune reaction increased. In addition, the model showed that the correlation between the number of living units in the responder's apartment and total serum IgE was not statistically significant ($p = 0.715$, $B = -0.0020$).

Furthermore, the differences in the intervals for when the responder's home was built were not significantly associated with total serum IgE. P-values greater than 0.05 were reported in Table 1, Model 2, for each time interval. The association of the number of cockroaches in the responder's home with the total serum IgE was also statistically insignificant ($p = 0.066$, $B = 0.365$). The presence of a mold odor in an individual's house similarly had an insignificant correlation with the total serum IgE ($p = 0.066$, $B = -0.158$).

As shown in Table 1, Model 3, the association between the total serum IgE and the typical number of cigarettes smoked inside the house by a family member or the responder was not statistically significant ($p = 0.896$, $B = -0.0008$). The correlation between the usual number of cigarettes smoked by the respondent or their spouse and total serum IgE was also statistically insignificant ($p = 0.436$, $B = -0.0054$).

The full model results in Table 1 show the regression results that include all predictions in the analysis ($n = 59$). All hypothesized predictors of total serum IgE were found to be statistically insignificant in the full model.

***Table 1.*** *Results from Linear Regression Models Analyzing the Significance of the Relationship of Socioeconomic Status, Housing Environment, Tobacco Exposure, and the Combination of the Three Preceding Factors with the Logarithm-Transformed Total Serum Immunoglobulin E.*

| | **Model 1: SES** | **Model 2: Housing Environment** | **Model 3: Smoking** | **Model 4: Full** |
|---|---|---|---|---|
| Intercept | 4.150** (0.120) | 3.690** (0.360) | 3.560** (0.330) | 3.930** (1.390) |
| Annual Household Income (per $5,000) | −0.001 (0.005) | | | -0.006 (0.159) |
| Family Poverty Income Ratio (PIR) | −0.061** (0.018) | | | 0.212 (0.341) |
| Interpreter Used (Yes=1, No=0) | 0.141 (0.186) | | | -0.718 (1.800) |
| The difference between those who received an education up to 9th Grade and between 9th and 11th Grade | −0.249** (0.064) | | | -0.713 (1.020) |
| The difference between those who received an education up to between 9th and 11th grade and 12th Grade | 0.032 (0.053) | | | 0.366 (0.785) |
| The difference between those who received an education up to 12th grade and college entry | −0.009 (0.050) | | | -0.594 (0.578) |
| The difference between those who received an education up to college entry and those who graduated from college | −0.023 (0.047) | | | 0.509 (0.466) |
| Crowding (number of individuals per living unit) | | 0.116* (0.054) | | 0.394 (0.259) |
| Number of living units in the building | | −0.002 (0.006) | | -0.010 (0.021) |
| The difference between those living in homes built between 1990 and the present and between 1978 and 1989 | | −0.348 (0.195) | | 0.081 (0.658) |
| The difference between those living in homes built between 1978 and 1989 and between 1960 and 1977 | | −0.327 (0.197) | | 0.175 (0.624) |
| The difference between those living in homes built between 1960 and 1977 and between 1950 and 1959 | | −0.088 (0.222) | | -0.999 (0.773) |
| The difference between those living in homes built between 1950 and 1959 and between 1940 and 1949 | | 0.132 (0.235) | | 0.107 (0.891) |
| The difference between those living in homes built between 1940 and 1949 and those built before 1940 | | −0.128 (0.233) | | -0.126 (0.772) |
| Presence of cockroaches in the home | | 0.365 (0.198) | | 0.727 (0.853) |
| Presence of a mold odor | | −0.158 (0.213) | | -0.487 (0.785) |
| Number of cigarettes smoked in the home | | | −0.001 (0.006) | -0.001 (0.032) |
| Number of cigarettes smoked daily | | | −0.005 (0.007) | -0.030 (0.030) |
| Age | −0.005** (0.001) | 0.001 (0.004) | 0.009* (0.004) | 0.022 (0.016) |
| Gender | −0.578** (0.044) | −0.448** (0.146) | −0.760** (0.125) | -0.400 (0.458) |
| Body Mass Index | 0.018** (0.003) | 0.005 (0.011) | 0.023* (0.009) | -0.041 (0.036) |
| # of observations | 4216 | 420 | 535 | 59 |

**$p < 0.05$, ***$p < 0.01$. Cell entries are unstandardized coefficients (B) with the standard errors in parentheses.*

## DISCUSSION

The aim of this study was to investigate socioeconomic and environmental determinants of the severity of allergic sensitization. To assess this, total serum IgE was measured at the individual level (12). While diverse socioeconomic and environmental predictors of allergic sensitization were tested, basic demographic factors and individual health conditions, including gender, age, and BMI, were found to be significantly associated with total serum IgE. Among the independent variables, family PIR, education, and crowding were found to be highly significant, indicating the importance of individual SES and the housing environment in immune response. However, contrary to the findings of some previous studies, both first and second-hand smoking had a limited impact.

In the first hypothesis, the coefficient for annual household income was negative, although the correlation between the variable and total serum IgE was not statistically significant. Income categories may have been too broad to detect subtle effects, as one bracket spans 5,000 USD. It is likely that the effective threshold income for individual health management is within the first bracket ($0 - $4,999). Thus, the differences between income categories may not be significant. Since previous literature finds that overall individual health is closely associated with SES, variation within each income category may have masked the true effect in the current dataset (13).

The family PIR had a significant negative association with total serum IgE. This suggests that a higher SES is correlated with lower allergic sensitization, as the family PIR is a primary indicator of SES. Those of higher SES tend to have more resources to invest in individual health management. Abundant resources enable individuals to access superior nutrition and health services. As a result, those with higher SES may have less chronic stress and reduced allergen exposure from unhygienic environments (14). Moreover, it is implied that while the relationship between household income bracket and the total serum IgE cannot be found, income, measured as a continuous value, serves as a strong predictor of one's health in the immune system.

An insignificant, positive correlation between English fluency and total serum IgE was observed, contradicting expectations. When an interpreter is used, it may suggest that the responder does not have sufficient English proficiency to understand and respond to questions. Fluency in English is an imperative skill in the United States to be employed at a high income. Previous literature has shown that average wages are roughly 8% and 17% higher for men and women proficient in both spoken and written English, respectively (15). Hence, survey participants who used an interpreter in their family interview likely have lower SES. However, the contradiction to the expectation may reflect issues with the sample distribution rather than a true effect on the immune response. 6320 of the 6474 respondents stated that they did not use an interpreter, suggesting that the majority were fluent in English regardless of their SES. This characteristic in the data may have reduced statistical power.

There was a significant negative association between education and total serum IgE, particularly among middle school and high school dropouts. Higher education is generally associated with greater health literacy and better living conditions, as individuals gain more knowledge from school. This can enable them to prevent potential risk factors. They also have a higher likelihood of being provided with valuable opportunities to increase their SES (16). Subsequently, more educated civilians will be able to manage their health more effectively, reducing the severity of their allergic reactions (17). Lower allergic sensitization may be observed in those with higher education as a result. Nevertheless, the low significance of the association between an education level above the high school level and the total serum IgE implies that above a certain level of education, the income and health literacy mechanisms of education may no longer hold. Thus, no significant correlation between education level and allergic sensitization may be found.

For the second hypothesis, crowding showed a statistically significant positive correlation with the total serum IgE. Increased crowding may amplify allergen exposure, as air quality and overall sanitation may be relatively worse because more people are sharing a single space. Trash and dust particles accumulate more rapidly, and items in the home are inadvertently utilized more frequently. Hence, cleanliness can be reduced (18). Reduced sanitation is often associated with more severe allergic reactions; due to increased crowding, more allergens, such as dust particles, can be present in the home.

The number of living units in the edifice where the responder was living had a negative, though insignificant, association with total serum IgE. This may reflect limited variability in building sizes. Conversely, the results may suggest that this measure was not a strong proxy for allergen exposure in households. Regardless of the number of living units in an apartment, those residing in other spaces typically do not interact with the responder's home environment. Therefore, this indicator may be irrelevant to indoor hygiene, as it does not influence exposure to allergens from housing environments.

The time the responder's home was built, the presence of a mold odor, and the presence of cockroaches inside the household had low significance with the total serum IgE. It was predicted that these indicators would have a highly significant association with allergic sensitization; thus, the data utilized may not have been sufficient to detect the effect. Regarding a home's age, it may not be relevant if the household is well-maintained. An old, preserved residence can be more sanitary than a new, contaminated home with greater exposure to allergens like dust particles. Renovations can be implemented in older houses, replacing the ventilation, septic system, and lighting with more modern technology, providing a sanitary environment. Thus, the severity of allergic reactions may not be correlated with this indicator.

Particularly, evident dampness and mold have been positively correlated with multiple respiratory and allergic effects in previous literature (19). An indicator of growing fungi in a home is a mold odor. The insignificant association between mold and total serum IgE may be due to the fact that total serum IgE does not capture all allergic sensitization effects. As a result, there are certain limitations to using the value as an indicator of allergic sensitization associated with dampness and mold. In future research, it may be beneficial to also use the skin prick test (SPT) as an indicator for allergic sensitization. SPT is a reliable test to confirm allergic sensitization, particularly for sensitization triggered by dampness and mold (20).

Regarding the presence of cockroaches in a home, the insignificant correlation between the indicator and total serum IgE may stem from the fact that infestations can occur in clean households. In addition to food waste, the insects are also attracted to warmth and moisture, which are available in clean housing environments as well. Hence, the statistical significance of cockroach allergens may have been masked.

Both of the observed coefficients for the indicators of smoking, the number smoked daily by either the responder or their spouse and the typical number of cigarettes smoked inside the household, were negative. However, the relationships between these indicators and the total serum IgE were not statistically significant. Previous literature demonstrates that both passive and active smoking have been consistently shown to worsen allergic rhinitis, a condition fundamentally caused by allergic sensitization (21). The lack of statistical power of correlations in the current study can be explained by three reasons. First, because the study used a cross-sectional dataset that captures one's environmental conditions and the level of allergic sensitization at a specific point in time, it cannot establish a causal relationship between the two factors. Also, while total serum IgE reflects general allergic sensitization, it is suggested that smoking-related allergic sensitization should be assessed using other specific standards. For example, SPTs are also widely used to test the relationship between cigarette exposure and allergic sensitization (22). Thus, total serum IgE may not have adequately reflected the association between tobacco exposure and allergic sensitization. There may also have been a bias in the self-report for smoking behavior. Smoking is heavily discouraged by society, and this trend has been increasing in recent years; as a result, the respondents might not have responded in a way that reflects their actual environmental conditions.

The severity of immune responses is shaped by social and environmental conditions as well as biological factors; chronic stress, access to resources, education, and living conditions can all influence it (23). The observed results demonstrated that, although some predictors were not significantly correlated, other explanatory variables were significantly correlated with the total serum IgE, an indicator of allergic sensitization.

A limitation of the current study stems from its cross-sectional design. Because all variables were measured at a single point in time, the causal relationship between SES and environmental conditions and allergic sensitization cannot be statistically tested. It is particularly problematic to test the impact of environmental conditions on allergic sensitization because, while SES is often stable over time, environmental conditions can change frequently for a given individual. Hence, the results cannot verify causality. In addition, because the data were collected only between 2005 and 2006, generalizability remains limited. Although the findings may be applicable to the US population during this period, they may not fully apply to the current population; the available medical technology in the country has improved significantly (24). Thus, if a similar test were conducted using more recent datasets, the results would likely differ from the current ones.

The interpretation of the results warrants caution. The small sample size (n=59) within the Full Model was a notable drawback. It indicates that the number of respondents who provided complete answers to the predictor items is relatively small, whereas the number of respondents who partially answered specific predictor items is large enough to test other hypotheses and yield statistically meaningful results. This limitation was due to the lack of participants who responded to all of the explanatory variables involved in the study. Although the study provided valuable insights, it is imperative to consider it as exploration, for the sample size limits its statistical power to detect subtle associations. Therefore, the statistical power of the full model is questionable and thus should not serve as direct evidence of the statistical insignificance of the predictors used.

It should additionally be noted that participant bias could have contributed to this result. Low-income individuals, who tend to have more unsanitary living conditions, may not have answered the surveys. They typically have less time, higher financial stress, and more limited access to the Internet and digital technologies. Furthermore, people with English communication difficulties may have been underrepresented in the sampling process, warranting further investigation into the association between linguistic capability and allergic sensitization.

To address the limited causality explanation, longitudinal data can be utilized. Rather than a single sample taken between 2005 and 2006, repeated measurements of the same participants can be taken across multiple time periods. To verify causality, it is necessary to demonstrate the cause-and-effect relationship across several time points; showing changes in the expected temporal order can provide stronger evidence for causation.

Better SES measures and more detailed environmental exposure data would improve inference. For example, the categories for annual household income may have reduced the precision of the regression test, particularly because of the wide range of incomes of each group. Recording continuous income would preserve the specific differences, permitting more accurate statistical modeling and stronger detection of associations. The environmental indicators can also include other important measures, such as air pollution exposure and the presence of indoor allergens like dust mites.

For future research, it is recommended to consider biomarkers beyond total serum IgE. An example of a biomarker is the number of eosinophils per microliter of blood. Eosinophils are a type of white blood cell specialized in managing inflammatory responses. Therefore, the indicator could provide a more accurate assessment of allergic sensitization among the recorded participants. In addition, future research can utilize diverse measures of allergic sensitization to account for reactions to specific environmental conditions.

While not all predictions were confirmed in the current study, the strong associations between family PIR and high school education and total serum IgE support the idea that socioeconomic conditions are relevant to immune health. The significant relationship between crowding and total serum IgE also supports the theoretical idea that housing environments are correlated with immune health. The insignificant indicators tested do not necessarily refute the theoretical predictions; rather, they highlight data limitations, measurement challenges, and issues with sample composition.

## CONCLUSION

Public health policy and individual healthcare practices are often framed around the impact of individual-level biological and lifestyle characteristics on health outcomes. Admittedly, research findings employing such a perspective are valuable in that they inform individuals of their potential health risk factors and allow them to take precautions against potential health symptoms. However, this framing risks attributing health outcomes only to individual responsibilities.

It should be acknowledged that health outcomes are often shaped by socioeconomic and living environments that individuals may not have strong control over. By shifting the framing from individual to social and environmental factors, public health policy can identify social factors that aggravate public health and thus establish policies that may prevent negative health outcomes at the societal level.

This study provided direct evidence that socioeconomic and housing environments may be relevant to individual-level health outcomes, particularly allergic sensitization. It additionally contributed to public health policy debates on the association between socioeconomic and environmental factors and health outcomes, as well as on preventing negative health consequences. The analysis highlighted the importance of preventive measures in public health policy and their potential value for society as a whole.

## CONFLICT OF INTEREST

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

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