A cross-sectional analysis of associations between environmental indices and asthma in U.S. counties from 2003 to 2012

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Abstract

Background: To capture the impacts of environmental stressors, environmental indices like the Air Quality Index, Toxic Release Inventory and Environmental Quality Index have been used to investigate environmental quality and its association with public health issues. However, past studies often rely on relatively small sample sizes, and they have typically not adjusted for important individual-level disease risk factors.

Objective: We aim to estimate associations between existing environmental indices and asthma prevalence over a large population and multiple years.

Methods: Based on data availability, we assessed the predictive capability of these indices for prevalent asthma across U.S. counties from 2003 to 2012. We gathered asthma data from the U.S. CDC Behavioral Risk Factor Surveillance System by county and used multivariable weighted logistic regression models to estimate the associations between the environmental indices and asthma, adjusting for individual factors such as smoking, income level, and obesity.

Results: Environmental indices showed little to no correlation with one another and with prevalent asthma over time. Associations of environmental indices with prevalent asthma were very weak; whereas individual factors were more substantially associated with prevalent asthma.

Significance: Our study suggests that an improved environmental index is needed to predict population-level asthma prevalence.

Keywords

Air pollution; Environmental index; Asthma; Cross-sectional Study
Introduction

Despite years of attempted intervention, death from chronic lower respiratory diseases remains 4th leading cause of death in the United States\(^1\). In 2013, deaths caused by chronic lower respiratory disease accounted for 5.7% of total mortality\(^2\). It is well-documented that exposure to air pollutants can cause respiratory diseases or exacerbate existing conditions\(^3,4\). However, measurement of individual exposure to the many air pollutants that exist in the environment is resource intensive and often available only for enforcing occupational safety\(^5\) or for isolated research purposes\(^6,7\).

The Behavioral Risk Factor Surveillance System (BRFSS) is a nationwide annual multi clustered survey of U.S. adults older than 18. It collects various pieces of information on chronic disease status and individual behaviors, allowing for large representative samples of the US to be generated for key diseases like cancers, diseases of the kidneys and chronic lower respiratory diseases.

To better understand air quality for the general U.S. population and to promote public health, efforts to publicly provide a comprehensive representation of environmental quality for the entire United States have been developed since the 1980s. These include the Air Quality Index (AQI), the Toxic Release Inventory (TRI), and the Environmental Quality Index (EQI).

The AQI considers measured ambient concentrations of six atmospheric criteria pollutants and uses the most dangerous component to represent the air quality on any given day\(^8\). AQI has been used to demonstrate onset of asthmatic symptoms\(^4\), shown to have an association with other chronic and acute illnesses\(^9\), and led to increased public awareness of air quality and could induce behavioral changes in the event of poor air quality\(^10-12\). The TRI records the annual emissions from stationary sources of more than six hundred toxic chemicals. The TRI has been used to identify disparities in the distribution of harmful air pollutants\(^13,14\), and elevated TRI emissions have been associated with increases in respiratory disease hospitalizations, including acute bronchitis and asthma\(^15\). The EQI is a composite index that consists of five environmental domains: air, water, land, built, and sociodemographic\(^16\). The underlying data, spanning from 2000 to 2005, are summarized by a single value of the EQI for each county in the US. The EQI has shown associations between environmental quality and different health outcomes including asthma, obesity, preterm birth, infant mortality, and cancer\(^16-20\).

Despite advances of using environmental indices to demonstrate the relationship with chronic disease outcomes and environmental pollution, current literature utilizing environmental indices often lack adjustment for the more powerful predictive individual factors such as smoking, obesity, and socio-economic status\(^18,21\). Additionally, most previous studies only estimated associations for a single region or state\(^15,22\).

Asthma is a potentially life-threatening chronic respiratory illness with complex etiology. Both environmental and behavioral factors have been associated with escalated asthmatic symptoms\(^23\). Isolating individual causes in asthma etiology proves to be excessively difficult due to the high volume of potential confounding factors. The goals of this paper are to assess
the AQI, TRI and EQI indices and their relationship with prevalent asthma compared with individual risk factors using a large United States sample and to identify potential areas of improvement for these indices in predicting health outcomes.

Materials and Methods

Data Collection

Ten years of national BRFSS data (2003 to 2012) were obtained and reviewed for suspected factors related to prevalent asthma. Individual factors (behavioral and biological information) including smoking status, smoking frequency, exercise frequency, sex, and body mass index (BMI) status were retained alongside demographic information including total yearly income, ethnicity, education status and locality using state and county codes. Years 2003-2012 were chosen for two reasons: 1) EQI was developed using information between 2000-2005 and is only available for this time period; and 2) the BRFSS shifted away from counties as the geographic unit to metropolitan and micropolitan statistical areas beginning in 2013. Thus, the decade of 2003 – 2012 is best suited to examine EQI, and it offers consistency across time with respect to the surveyed counties. Correspondingly, ten matching years of AQI and TRI data, as well as the single EQI data set, were obtained.

Environmental Index Data

Annual median AQI, annual total air emissions (summation of all recorded chemicals emitted via fugitive and stack to air onsite, without other emissions to water, soil, etc.) from the TRI and the EQI for each county with available data for all three of these indices were sorted into quartiles for statistical analysis. Lower quartiles within each index data set analyzed indicated better environmental quality. Each index was assigned to each individual in the BRFSS dataset matched with county of residence.

Index comparisons

A linear regression and spearman correlation analysis was performed using the proc reg and proc corr procedures using SAS V9.4 (Cary, NC) on ten years of available environmental index data using the median AQI, TRI and the single available source for the EQI to test the interrelated effects between the existing indices.

Individual Factors

Individual factors were categorized following formatting within the BRFSS data by year to minimize possible introduction of bias. Due to the BRFSS containing two different types of smoking questions, including “have you ever smoked at least 100 cigarettes” and a follow-up frequency question, these two questions were combined to represent smoking status as “current smoker,” “previous smoker” and “never smoked.” BMI was analyzed as neither overweight nor obese, overweight, and obese, where neither overweight nor obese BMI range was anything less than 24.9, overweight BMI was between 25 and 29.9 and obese was BMI over 30. Education was categorized into five groups by their highest attained education level including: less than high school, some high school, high school, some college, and college. Exercise status was analyzed dichotomously as “exercise” and “no exercise”. Race was analyzed by self-identified racial identity including: White,
Black, Asian, Native Pacific Islander, American Indian or Alaskan Native, Native Puerto Rican or other. Race and ethnicity questions for years 2006-2012 included information for “multiple race” preferred race identification. These responses were re-categorized into the ‘other’ preferred race response due to inconsistency between years and extremely low counts (N=59). Sex was analyzed by male or female. Total yearly income was stratified into eight different levels, with increasing increments of yearly reported income including: <$9,999, $10,000-$14,999, $15,000-$19,999, $20,000-$24,000, $25,000-$34,999, $35,000 - $49,000, $50,000-$74,999 and $75,000 or more. Age was analyzed by quartile. Individuals who refused to answer, and those with missing data for these individual factors, comprised no more than 1% of the examined population and therefore not shown in the results below.

Statistical Analysis

A weighted multivariate logistic regression model was used to investigate the relationship between prevalent asthma for individuals and collected predictors. Values for individual level data were taken from the BRFSS and pooled into a single dataset covering years 2003-2012, rather than by annum. Weighted data analyses used the effects of strata and cluster effects. Statistical analyses were performed using the PROC SURVEYLOGISTIC in SAS V9.4 (SAS Institute, Cary, NC).

Model 1

\[
\text{Log Odds of Prevalent Asthma} = \alpha + \beta_1 \text{EnvironmentalQualityIndex} + \beta_2 \text{Smoking} + \beta_3 \text{Education} + \beta_4 \text{Exercise} + \beta_5 \text{AgeQuartile} + \beta_6 \text{Race} + \beta_7 \text{Sex} + \beta_8 \text{TotalYearlyIncome} + \beta_9 \text{BMI}
\]

Model 2

\[
\text{Log Odds of Prevalent Asthma} = \alpha + \beta_1 \text{MedianAirQualityIndex} + \beta_2 \text{Smoking} + \beta_3 \text{Education} + \beta_4 \text{Exercise} + \beta_5 \text{AgeQuartile} + \beta_6 \text{Race} + \beta_7 \text{Sex} + \beta_8 \text{TotalYearlyIncome} + \beta_9 \text{BMI}
\]

Model 3

\[
\text{Log Odds of Prevalent Asthma} = \alpha + \beta_1 \text{ToxicReleaseInventory} + \beta_2 \text{Smoking} + \beta_3 \text{Education} + \beta_4 \text{Exercise} + \beta_5 \text{AgeQuartile} + \beta_6 \text{Race} + \beta_7 \text{Sex} + \beta_8 \text{TotalYearlyIncome} + \beta_9 \text{BMI}
\]

The odds ratios and beta for each factor in the models were estimated using the following as reference: lowest quartile for \textit{EnvironmentalQualityIndex},\ 
\textit{MedianAirQuality}, and \textit{ToxicsReleaseInventory}, never smoked for \textit{Smoking}, less than high school for \textit{Education}, no exercise for \textit{Exercise}, lowest quartile for \textit{AgeQuartile}, white for \textit{Race}, female for \textit{Sex}, less than $9,999 for \textit{TotalYearlyIncome}, and neither overweight nor obese for \textit{BMI}.

Additionally, we examined the crude associations between prevalent asthma and environmental index data, without adjusting for individual factors. In these alternative models, the terms for individual factors were removed.
We also performed a sensitivity study by using only the counties that have all three environmental index data simultaneously. The same models described above were used and adjusted for individual factors. This is to eliminate the potential influence from county-specific factors that are not captured explicitly in the data used in this study. We also examined the effect of included areas in this sensitivity study and prevalent asthma by running a series of separate models including the county term.

Results

Baseline characteristics of underlying population

The base characteristics of individuals include 705,632 total individuals over ten years of available data across all US counties from the BRFSS, the AQI, the TRI and the EQI, of which 91,705 were diagnosed with asthma (12.9%). When weighted, our sample contained 42,708,318 individuals who self-reported asthma (13.4%). Individual demographic information of the underlying population including age, gender, education level attained, smoking status, exercise and activity level, preferred race identification, sex, total yearly income, and body mass index can be found in Table 1, weighted by index.

Index Comparisons

The analysis of the distribution of indices and correlation among them can be found in Figure 1. Spearman correlation between EQI and AQI was 0.03 in the positive direction and was statistically significant. The EQI and TRI had a spearman correlation in the positive direction with a value of 0.02 but was not statistically significant. Overall, the correlation between the indices analyzed in this study appear to be very weak.

Temporal Trends

Figure 2 shows the time trend of the environmental index values and asthma prevalence averaged for all counties from 2003 to 2012. Over the ten years, weighted asthma prevalence varied between 12.1% and 13.4%. Over time, the yearly average TRI value decreased from 2003 to 2012. There was no apparent trend between the TRI and prevalent asthma. For the AQI over the analyzed time the trend points downward with spikes in the positive and negative direction. As the yearly average median AQI decreased or increased, prevalent asthma appears to follow a similar trend with both prevalent asthma and average AQI values trending downward in 2012. Since EQI for each county was designed to show how it deviates from the average, the average value for all counties is indeed zero.

Environmental Factors

Figure 3 shows the coverage of counties for each of our models based on data availability from BRFSS and the respective environmental indices. The associations of prevalent asthma with environmental factors represented by the indices are shown in Table 2. After adjusting for individual behavioral factors, our models did not find statistically significant association between AQI/TRI/EQI and prevalent asthma except for marginal significance for the 3rd quartile of the EQI, 4th quartile of the AQI and the 2nd quartile of the TRI. The estimated associations between the indexes and asthma were close to 1.00 (odds ratios ranging between 0.86 and 1.12). When individual factors are not adjusted for (Figure 4),
the estimated associations deviate slightly, but insignificantly from 1.00 (log odds ratios ranging between 0.84 and 1.08). No statistically significant associations were found between EQI/TRI and prevalent asthma. However, a small but statistically significant protective effect was found between all AQI quartiles and prevalent asthma. The sensitivity study included 354 counties that have AQI/EQI/TRI and BFRSS data at the same time. The results showed county-specific factors, if any, were not influential as the log odds ratios were very close to that from the main models results (Table 3). Results of analysis models generated to display the effect of region with respect to prevalent asthma are shown alongside Table 3. The relative difference between the AQI when including the county term was minor. The estimated log odd ratios for TRI increased notably but remained statistically insignificant. The uncertainty of the effect of county on the association between prevalent asthma and the EQI quartiles increased substantially, likely due to the construction of the EQI itself as it incorporates several county related factors in its creation already.

### Individual Factors

Overall, the associations of individual factors with prevalent asthma are consistent for all models in this study (Table 2). Relative to their references, individuals who reported previously or currently smoking, overweight or obese were at significant increased odds of prevalent asthma. Individuals who reported doing physical activity or exercise during the past 30 days outside of their jobs, older ages, male, higher tiers of income were at significant decreased odds of prevalent asthma compared to their respective references. Relative to those who self-identify as white, individuals who self-identify as American Indian or Alaskan Native were at significant increased odds; individuals who self-identified as ‘other’ or Asian were at significant decreased odds; individuals who self-identify as Asian were at significant decreased odds. For individuals who self-identified as native Puerto Rican, native Pacific Islander and Black, no statistically significant increased or decreased odds of prevalent asthma were observed.

### Discussion

This study examined the correlation among three different environmental indices and their capability of predicting prevalent asthma when adjusting for individual factors. Our analysis found little correlation among these indices and weak associations between the indices with prevalent asthma. Methodologically, a major strength of this study was the inclusion of a decade’s worth of individual-level surveillance data incorporated with environmental and individual factors. By using the BRFSS, which consists of a large representative U.S. sample, our estimates had little random error from sampling. Systematic error is an important concern, however, as the BRFSS self-reported survey data are prone to recall bias, misclassification, and omission. Providing that these errors are unrelated to the environmental indices, the direction of the bias will likely to be towards the null. This effect is most likely minimal though, as BRFSS corresponds well with other surveillance programs such as the National Center for Health Statistics, American Heart Association and National Institute on Alcohol Abuse and Alcoholism.30-37
The effect of individual migration may cause a gap between the exposure to the environmental index and prevalent asthma. The individuals who self-report diagnosed asthma who recently migrated into that county may be misassigned an exposure for a county they only recently migrated to, however, we expect that this effect is minor on our results. Approximately 10 million Americans, roughly 3% of the population, migrate each year, and this effect is highly variable by county, so the effect on the associations between prevalent asthma and environmental index exposure is not likely to be substantial\(^3\). 

We observed null associations between the environmental indexes and asthma in our study, and these null findings could be due to measurement errors on the BRFSS survey. We did, however, observe several associations of prevalent asthma with individual-level risk factors in the anticipated direction, which does provide some confidence in the quality of the self-reported survey data. By not adjusting for these individual factors, the crude associations between the indices with prevalent asthma increased marginally but still weak overall. Counterintuitively, based on the crude associations, worse environmental quality indicated by EQI (as represented by higher quartiles of EQI) had a small yet statistically significant protective effect, which was also observed in the full model adjusted for individual factors but to a lesser extent.

Although the three indices all aim to represent the environmental quality, their underlying components are different. The TRI in this study represents the total recorded amount of emission of toxic pollutants to air from stationary sources. As a result, it does not consider any air pollutants from mobile sources, which can be the major sources of the pollutants monitored by the AQI. Meanwhile, EQI includes information from the Air Quality System (which provides the underlying data for composing AQI) and from several sites reported in the Toxic Release Inventory. This information is related to the AQI and TRI data in this study, but EQI also includes many other data sources not related to air quality\(^3\). As a result, it is not surprising to see little correlation among the AQI, TRI, and EQI examined in this study. Essentially, this weak correlation confirms that these indices represent different environmental hazards.

Regarding the associations between asthma and the individual factors, as expected, higher prevalence odds ratios for asthma were found among those who smoked, were obese, did not engage in physical exercise, were female and were Native American Indian, which are consistent with other studies\(^4\)\(^-\)\(^6\). Interestingly, individuals who self-identified as black were not found to have a higher prevalence than white individuals, in contrast with current findings from asthma prevalence research\(^7\). The effect of age and prevalent asthma found in this study showed decreasing odds of asthma with increasing age, which does not seem to be biologically consistent nor does it appear to be consistent with the current body of research\(^8\) and may be explained instead by a misclassification bias within the prevalence data. However, we did observe that the decreased prevalence in the diagnoses of asthma (from 8.2% for first quartile of age to 1.6% of fourth quartile of age). It is likely that misclassification is playing a significant role in the relationship between age and prevalent asthma, a finding which has been observed frequently in previous literature\(^3\)\(^-\)\(^7\),\(^8\),\(^4\),\(^9\).
Environmental pollutants and occupational environment have been heavily implicated as likely causal factor for asthma\textsuperscript{50-52}. However, our study did not find statistically meaningful predictive capabilities for any of the environmental indices regarding prevalent asthma after adjusting for individual factors. This is similar to the finding from a study with over one million people using EQI as an indicator for survival time of end-stage renal disease, after adjusting for multiple individual factors\textsuperscript{53}. This may be explained by multiple reasons outlined below. Due to the underlying data, as of now, the EQI is a static representation of the environmental quality for the period between 2000 – 2005 and has not yet been updated. This hinders its ability to reflect the changing environment over nearly two decades and may have mischaracterized the environmental quality during the period examined by this study. In addition, EQI is composed of five domains (air, water, land, sociodemographic, and built environment), of which not all may be causally related to asthma. Although updated annually, the evidence supporting the predictive power of AQI and TRI for health outcomes is rather limited\textsuperscript{54-56}, which is in agreement with our findings.

The reason why these indices only offered very weak associations with the health outcomes may be three-fold. First, none of the indices were designed to comprehensively capture health-based pollution levels. The EQI uses principle component analysis (PCA) to compile its domain-specific indices and overall EQI\textsuperscript{16}. While useful in treating multidimensional data, PCA does not specifically account for the different persistency, exposure, and toxicity of the many air pollutants covered in the underlying data used by EQI. While the AQI calculations consider the exposure-response effects in determining different breakpoints for each criteria pollutant in its intermediate calculations, the final result only represents the worst value among the criteria pollutants and does not consider any effects of co-exposure\textsuperscript{8}. As for TRI, given that there can be orders of magnitude of difference in toxicity and persistency for different chemicals, a simple summation of the amount of different pollutants cannot lead to a health-based representation of the environmental quality in the region. This limitation was also pointed out in a previous study by Moore and Hotchkiss\textsuperscript{15}.

Second, although exposure to environmental pollutants can lead to negative health outcomes, individual factors also play a critical role in the process as demonstrated in this study and many more discussed so far. The effects of individual factors could have played a much more dominating role. As a result, the existing environmental indices may not predict health outcomes reported by individuals of diverse demographic and behaviors that influence their health. Therefore, it is important to understand the distinct contributions of environmental and individual factors, and caution should be taken when using existing environmental indices alone for the purpose of predicting or representing potential health outcomes.

Third, all three indices focus on regional ambient environmental quality which is only a part of exposure to environmental pollutants for individuals. The quality of indoor air, which is not reflected by these indices, could be a major contributor to the onset and severity of asthma\textsuperscript{57}. Furthermore, these indices cannot reflect the heterogenous distribution of pollutants within counties, which may affect individual exposure differently depending on their more precise locations.
Lastly, a regional effect among available data sources may be one of the driving factors causing a null association to be observed, due to some environmental data not covering as broad a range as the individual factors. The BRFSS encompasses a broad range of the US spatial region and uses a combination of clustered census areas and boroughs, whereas AQI and TRI do not spatially cover as broad a range as the BRFSS. Instead, they are focalized around urban areas, with some rural monitoring, which may be a driving factor in the null association. However, this is a less likely explanation for the null association observed in this study as the sensitivity study did not show substantially different results.

In conclusion, after adjusting for individual factors, our study did only found marginally significant associations between existing environmental indices and prevalent asthma in a 10-year BRFSS dataset. This may be due to the underlying design of these indices not comprehensively reflecting the health effects of multiple pollutants in the environment and the lack of consideration of individual factors in these indices. Considering the constant changing of environmental pollution levels and the need to prevent early death and lowering burden of disease, there is a high need for a more reliable index that better predicts health outcomes and enables better response and intervention.

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Figure 1.
Correlation between environmental indices and their distributions for ten pooled years of available data. The associated r squared of regression analysis for each pair of indices is shown in the bottom right-hand corner.
Figure 2.
Two examined indices from 2003 to 2012 against the yearly prevalent asthma for that year over time. For each index, the prevalent asthma is of all included counties in each year ranging. The average index value is the pooled average value for all counties for that index for any given year. Panel A shows the trend for AQI and panel B shows the trend for TRI. EQI is not included because it has no variation between years.
Figure 3.
Maps showing counties with data available for three models in this study. Panel A shows the counties with both AQI and asthma data, Panel B shows the counties with both EQI and asthma data, and Panel C shows the counties with both TRI and asthma data. Quartiles of each index shown in color gradient. Colorless counties are those without adequate data.
Figure 4.
Prevalent asthma odds ratios and associated 95% confidence intervals for environmental indices by quartile. All indices are relative to the first quartile. A represents the Air Quality Index, E represents the Environmental Quality Index, and T represents the Toxic Release Inventory. Numbers following the letters represent corresponding quartiles.
### Table 1.

Weighted characteristics of persons self-reporting asthma in BRFSS by environmental index

| Characteristic                  | AQI (number of counties: 329) |   |   |   |   | EQI (number of counties: 919) |   |   |   |   | TRI (number of counties: 349) |   |   |   |   |
|---------------------------------|---------------------------------|---|---|---|---|---------------------------------|---|---|---|---|---------------------------------|---|---|---|---|
|                                 | Asthma                          | Total | % of asthma | χ² (df) | p   | Asthma                          | Total | % of asthma | χ² (df) | p   | Asthma                          | Total | % of asthma | χ² (df) | p   |
| Index Quartile                  |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| 1                               |                                 |       |             | 5.81(3)  | 0.12 |                                 |       |             | 24.03(3) | <0.01 |                                 |       |             | 4.24(3)  | 0.24 |
| 2                               |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| 3                               |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| 4                               |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Smoking Status                  |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Current smoker                  |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Previous smoker                 |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Never smoked                    |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Body Mass Index                 |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Neither overweight nor obese    |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Overweight                      |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Obese                           |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Education Level                 |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Less than high school           |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Some high school                |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| High school                     |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Some college                    |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| College                         |                                 |       |             |         |     |                                 |       |             |         |     |                                 |       |             |         |     |
| Characteristic          | AQI (number of counties: 329) | EQI (number of counties: 919) | TRI (number of counties: 349) |
|------------------------|-------------------------------|-------------------------------|-------------------------------|
|                        | Asthma Total                  | Asthma Total                  | Asthma Total                  |
|                        | % of asthma                   | % of asthma                   | % of asthma                   |
|                        | $\chi^2$ (df)                 | $\chi^2$ (df)                 | $\chi^2$ (df)                 |
|                        | $p$                           | $p$                           | $p$                           |
| Exercise Status        |                               |                               |                               |
| Exercise               | 5,732,892 46,742,096          | 8,033,805 65,409,038          | 6,046,877 49,603,987          |
|                        | 12.3%                         | 12.3%                         | 12.2%                         |
| No exercise            | 2,284,298 15,583,955          | 3,388,603 22,694,752          | 2,416,230 16,533,569          |
|                        | 14.7%                         | 14.9%                         | 14.6%                         |
| Race Identification    |                               |                               |                               |
| White                  | 5,755,399 46,002,220          | 8,492,344 67,317,498          | 6,105,007 49,038,030          |
|                        | 12.5%                         | 12.6%                         | 12.4%                         |
| Black                  | 1,463,698 9,562,088           | 1,913,171 12,286,536          | 1,534,843 10,122,672          |
|                        | 15.3%                         | 15.6%                         | 15.2%                         |
| Asian                  | 120,327 1,522,111             | 149,157 1,840,159             | 122,161 1,543,210             |
|                        | 8.5%                          | 8.1%                          | 7.9%                          |
| Native or Pacific Islander | 32,179 158,888               | 36,825 191,997                | 33,283 162,234                |
|                        | 20.3%                         | 19.2%                         | 20.5%                         |
| American Indian or Alaskan Native | 233,748 1,097,862 | 333,353 1,579,269 | 241,633 1,106,862 |
|                        | 21.3%                         | 21.1%                         | 21.8%                         |
| Native Puerto Rican    | 21,535 175,652                | 29,688 210,523                | 22,302 179,794                |
|                        | 12.3%                         | 14.1%                         | 12.4%                         |
| Other                  | 279,281 2,898,095             | 348,904 3,632,775             | 295,760 3,025,448             |
|                        | 9.6%                          | 9.6%                          | 9.8%                          |
| Sex                    |                               |                               |                               |
| Male                   | 3,328,891 30,545,987          | 4,795,928 43,302,890          | 3,520,256 32,469,338          |
|                        | 10.9%                         | 11.1%                         | 10.8%                         |
| Female                 | 4,773,431 32,324,866          | 6,730,583 45,566,776          | 5,025,302 34,224,252          |
|                        | 14.8%                         | 14.8%                         | 14.7%                         |
| Total Yearly Income ($)  | 232.82(9)  <0.01              | 398.41(7)  <0.01              | 238.88(7)  <0.01              |
| Characteristic | AQI (number of counties: 329) | EQI (number of counties: 919) | TRI (number of counties: 349) |
|---------------|-------------------------------|-------------------------------|-------------------------------|
|               | Asthma Total % of asthma $\chi^2$ (df) p | Asthma Total % of asthma $\chi^2$ (df) p | Asthma Total % of asthma $\chi^2$ (df) p | p |
| 18-41         | 3,819,872 27,111,745 14.1% 41.36(3) <0.01 | 5,263,153 36,989,100 14.2% 66.16(3) <0.01 | 4,022,505 28,613,016 14.1% 47.58(3) <0.01 |
| 42-55         | 2,003,560 16,152,924 12.4% 2,841,450 23,136,211 12.3% 2,101,248 17,169,955 12.2% |
| 56-67         | 1,325,575 10,532,325 12.6% 1,993,750 15,437,498 12.9% 1,411,830 11,244,868 12.6% |
| 68-99         | 911,510 8,654,871 10.5% 1,369,931 12,763,150 10.7% 964,044 9,219,619 10.5% |

$\alpha = 0.05$
Table 2.
Adjusted modeled log odds ratios of three environmental indices

| Characteristic     | AQI (number of individuals: 84,284) | EQI (number of individuals: 131,678) | TRI (number of individuals: 87,528) |
|--------------------|-------------------------------------|-------------------------------------|-------------------------------------|
|                    | Log odds ratio | 95% C.I. | β | P-value | Log odds ratio | 95% C.I. | β | P-value | Log odds ratio | 95% C.I. | β | P-value |
| Index Quartile     |                        |          |   |         |                        |          |   |         |                        |          |   |         |
| 1                  | ref |          |   |         | ref |          |   |         | ref |          |   |         |
| 2                  | 0.93 | 0.82 | 1.05 | 0.00 | 0.90 | 1.01 | 0.87 | 1.18 | 0.04 | 0.24 | 1.12 | 1.01 | 1.25 | 0.09 | 0.01 |
| 3                  | 0.93 | 0.83 | 1.05 | 0.00 | 0.97 | 0.86 | 0.74 | 1.00 | −0.12 | 0.00 | 0.99 | 0.89 | 1.11 | −0.04 | 0.29 |
| 4                  | 0.88 | 0.78 | 0.98 | −0.06 | 0.06 | 1.01 | 0.88 | 1.16 | 0.04 | 0.18 | 1.00 | 0.90 | 1.12 | −0.02 | 0.49 |
| Smoking Status     |                        |          |   |         |                        |          |   |         |                        |          |   |         |
| Never Smoked       | ref |          |   |         | ref |          |   |         | ref |          |   |         |
| Current Smoker     | 1.30 | 1.17 | 1.43 | 0.11 | 0.00 | 1.31 | 1.18 | 1.45 | 0.11 | 0.00 | 1.29 | 1.17 | 1.42 | 0.11 | 0.00 |
| Previous smoker    | 1.21 | 1.10 | 1.34 | 0.04 | 0.21 | 1.22 | 1.10 | 1.34 | 0.04 | 0.21 | 1.21 | 1.10 | 1.33 | 0.04 | 0.19 |
| Body Mass Index    |                        |          |   |         |                        |          |   |         |                        |          |   |         |
| Neither overweight or obese | ref |          |   |         | ref |          |   |         | ref |          |   |         |
| Overweight         | 1.08 | 0.98 | 1.19 | −0.04 | 0.48 | 1.08 | 0.98 | 1.20 | −0.03 | 0.54 | 1.08 | 0.98 | 1.19 | −0.04 | 0.45 |
| Obese              | 1.44 | 1.31 | 1.59 | 0.25 | <0.01 | 1.44 | 1.30 | 1.59 | 0.25 | <0.01 | 1.44 | 1.31 | 1.59 | 0.25 | <0.01 |
| Education Level    |                        |          |   |         |                        |          |   |         |                        |          |   |         |
| Less Than High School | ref |          |   |         | ref |          |   |         | ref |          |   |         |
| Some High School   | 1.26 | 0.97 | 1.64 | 0.15 | 0.27 | 1.27 | 0.97 | 1.67 | 0.16 | 0.22 | 1.21 | 0.94 | 1.55 | 0.15 | 0.26 |
| High School        | 1.03 | 0.81 | 1.32 | −0.06 | 0.65 | 1.02 | 0.79 | 1.31 | −0.06 | 0.64 | 0.98 | 0.77 | 1.23 | −0.06 | 0.62 |
| Some College       | 1.06 | 0.83 | 1.36 | −0.02 | 0.84 | 1.05 | 0.82 | 1.35 | −0.03 | 0.82 | 1.02 | 0.81 | 1.29 | −0.02 | 0.90 |
| College            | 1.11 | 0.86 | 1.42 | 0.02 | 0.89 | 1.09 | 0.84 | 1.40 | 0.01 | 0.95 | 1.06 | 0.84 | 1.34 | 0.02 | 0.88 |
| Exercise Status    |                        |          |   |         |                        |          |   |         |                        |          |   |         |
| No Exercise        | ref |          |   |         | ref |          |   |         | ref |          |   |         |
| Exercise           | 0.89 | 0.82 | 0.98 | −0.07 | 0.35 | 0.90 | 0.82 | 0.98 | −0.06 | 0.47 | 0.89 | 0.81 | 0.97 | −0.06 | 0.46 |
| Race Identification|                        |          |   |         |                        |          |   |         |                        |          |   |         |
| White              | ref |          |   |         | ref |          |   |         | ref |          |   |         |

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| Characteristic                        | AOI (number of individuals: 84,284) | EQI (number of individuals: 131,678) | TRI (number of individuals: 87,528) |
|--------------------------------------|-------------------------------------|--------------------------------------|-------------------------------------|
|                                      | Log odds ratio                      | 95% C.I.†                           | p-value‡                           | Log odds ratio                      | 95% C.I.†                           | p-value‡                           | Log odds ratio                      | 95% C.I.†                           | p-value‡                           |
| Native Puerto Rican                  | 1.71 1.34 2.18 0.56                 | <0.01                               | 1.74 1.36 2.23 0.59                | <0.01                               | 1.77 1.39 2.24 0.59                | <0.01                               |
| Native or Pacific Islander           | 0.71 0.45 1.10 −0.33 0.12            | 0.66 0.41 1.05 −0.39 0.08            | 0.65 0.41 1.03 −0.41 0.06          | 0.59 0.35 1.04 −0.34 0.28          | 0.35 0.20 0.59 −0.40 0.36          | 0.40 0.25 0.65 −0.39 0.42          |
| American Indian or Alaskan Native    | 1.05 0.94 1.17 0.07                 | 0.48 0.22                            | 1.04 0.93 1.16 0.07                | 0.04 0.01                            | 1.04 0.93 1.15 0.06                | 0.53 0.38                            |
| Asian                                | 0.68 0.33 1.40 −0.36 0.27            | 0.69 0.34                            | 1.04 0.93 1.16 0.07                | 0.04 0.01                            | 1.04 0.93 1.15 0.06                | 0.53 0.38                            |
| Black                                | 1.65 0.79 3.44 0.52                 | 0.12 0.06                            | 1.67 0.81 3.47 0.55                | 0.10 0.05                            | 1.72 0.84 3.52 0.56                | 0.08 0.04                            |
| Other                                | 0.64 0.50 0.84 −0.42 0.00            | 0.62 0.46                            | 0.82 −0.45 0.00                    | 0.00 0.00                            | 0.67 0.52 0.86 −0.38 0.00          | 0.18 0.01                            |
| Sex                                  |                                     |                                     |                                     |                                     |                                     |                                     |
| Female                               | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   |
| Male                                 | 1.46 1.35 1.58 0.19                 | <0.01                               | 1.46 1.34 1.58 0.19                | <0.01                               | 1.45 1.35 1.57 0.19                | <0.01                               |
| Total Yearly Income ($)              |                                     |                                     |                                     |                                     |                                     |                                     |
| <9,999                               | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   |
| 10,000-14,999                        | 0.74 0.59 0.91 0.19                 | 0.01 0.01                            | 0.73 0.58 0.91 0.18                | 0.02 0.02                            | 0.74 0.60 0.91 0.19                | 0.01 0.01                            |
| 15,000-19,999                        | 0.66 0.55 0.81 0.09                 | 0.18 0.05                            | 0.67 0.55 0.81 0.09                | 0.18 0.05                            | 0.67 0.55 0.81 0.09                | 0.18 0.05                            |
| 20,000-24,999                        | 0.62 0.51 0.75 0.02                 | 0.80 0.54                            | 0.62 0.51 0.75 0.01                | 0.83 0.62                            | 0.62 0.52 0.75 0.02                | 0.78 0.53                            |
| 25,000-34,999                        | 0.57 0.47 0.69 −0.06 0.29           | 0.29 0.15                            | 0.57 0.47 0.69 −0.06 0.29          | 0.30 0.20                            | 0.58 0.48 0.69 −0.06 0.27          | 0.78 0.53                            |
| 30,000-49,999                        | 0.53 0.44 0.64 −0.13 0.02           | 0.02 0.01                            | 0.54 0.44 0.65 −0.13 0.02          | 0.03 0.01                            | 0.54 0.45 0.65 −0.13 0.02          | 0.02 0.01                            |
| 50,000-74,999                        | 0.48 0.40 0.58 −0.24 <0.01          | 0.01 0.00                            | 0.49 0.40 0.59 −0.22 <0.01         | 0.01 0.00                            | 0.49 0.41 0.59 −0.22 <0.01         | 0.01 0.00                            |
| ≥25,000                              | 0.44 0.37 0.52 −0.33 <0.01          | 0.01 0.00                            | 0.44 0.37 0.53 −0.33 <0.01         | 0.01 0.00                            | 0.45 0.38 0.53 −0.32 <0.01         | 0.01 0.00                            |
| Age Quartile                         |                                     |                                     |                                     |                                     |                                     |                                     |
| 18-41                                | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   | ref -- -- -- -- --                   |
| 42-55                                | 0.86 0.78 0.96 0.04                 | 0.19 0.05                            | 0.86 0.77 0.95 0.04                | 0.04 0.01                            | 0.85 0.77 0.94 0.03                | 0.30 0.05                            |
| 56-67                                | 0.83 0.76 0.92 0.01                 | 0.73 0.62                            | 0.83 0.75 0.92 0.01                | 0.79 0.62                            | 0.83 0.75 0.91 0.01                | 0.66 0.52                            |
| 68-99                                | 0.64 0.58 0.72 −0.25 <0.01          | 0.01 0.00                            | 0.64 0.58 0.72 −0.25 <0.01         | 0.01 0.00                            | 0.64 0.57 0.71 −0.25 <0.01         | 0.01 0.00                            |

† C.I. Confidence interval
‡ α = 0.05
Table 3.
Comparison of log odd ratios from main models and sensitivity studies

| Environmental index | Main model | All indices included | Model with county term |
|---------------------|------------|----------------------|------------------------|
|                     | Log odd ratio | 95% C.I.† | Log odd ratio | 95% C.I.† | Log odd ratio | 95% C.I.† |
| AQI                 |             |           |              |          |             |          |
| Q2 v Q1             | 0.93        | 0.82      | 1.05         | 0.90     | 0.79        | 1.02      | 0.98     | 0.77      | 1.25      |
| Q3 v Q1             | 0.93        | 0.83      | 1.05         | 0.93     | 0.83        | 1.05      | 1.08     | 0.80      | 1.46      |
| Q4 v Q1             | 0.88        | 0.78      | 0.98         | 0.88     | 0.77        | 0.99      | 0.92     | 0.66      | 1.28      |
| EQI                 |             |           |              |          |             |          |
| Q2 v Q1             | 1.01        | 0.87      | 1.18         | 1.02     | 0.88        | 1.12      | 0.11     | <0.01     | 15.02     |
| Q3 v Q1             | 0.86        | 0.74      | 1.00         | 0.87     | 0.74        | 1.02      | 0.43     | 0.00      | 45.86     |
| Q4 v Q1             | 1.01        | 0.88      | 1.16         | 1.01     | 0.88        | 1.17      | 0.64     | 0.00      | 153.38    |
| TRI                 |             |           |              |          |             |          |
| Q2 v Q1             | 1.12        | 1.01      | 1.25         | 1.13     | 1.00        | 1.27      | 1.47     | 0.97      | 2.23      |
| Q3 v Q1             | 0.99        | 0.89      | 1.11         | 1.02     | 0.90        | 1.16      | 1.37     | 0.80      | 2.32      |
| Q4 v Q1             | 1.00        | 0.90      | 1.12         | 1.08     | 0.94        | 1.22      | 1.49     | 0.78      | 2.82      |

†C.I. Confidence interval