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**TECHNICAL REPORT DOCUMENTATION PAGE**

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Executive Summary

The executive summary should serve as a high-level, standalone project brief (up to two pages) that succinctly describes the problem, the work conducted, and outputs, outcomes, and impacts resulting from the study. Please include the following sections:

1. Problem statement—describe the motivation and need for the project, including a statement of the problem to be solved or the research needed.
2. Technical objectives—describe the technical objectives of the study, including the approach and methodology used to achieve the research goals.
3. Key findings—highlight the key study findings, including relevant outputs and outcomes.
4. Project impacts—describe the impacts of the study on:

* The effectiveness of the transportation system.
* The adoption of new practices.
* The body of scientific knowledge.
* Transportation workforce development.

Acknowledgments

(Optional) Acknowledge any other contributors and sources of project funding other than CARTEEH.

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# Report Guidelines (FOR REFERENCE—Delete This Section)

## Formatting and Content

Follow these guidelines in preparing your report:

* Use only the styles provided in this template if possible:
* Heading 1, Heading 2, Heading 3, and Heading 4.
* Body Text, List Bullet, List Bullet 2, and List Number.
* Figure and Figure Caption.
* Table Caption, Table Header, and Table Text.
* Organize the report into sections or chapters to give a complete description of the project, including data gathered, analyses performed, and results achieved. Use appendices as needed for supplementary materials.
* Heading names (Methods, Results, etc.) in this document are solely for demonstration purposes. Rename or rerrange section headings as necessary, but make sure to include a description of the following required elements:
* The research problem.
* Current literature and the state of the practice.
* The approach and methodology.
* Data collection, analysis, and results.
* Findings, conclusions, and recommendations.
* Research outputs, outcomes, and impacts.
* Technology transfer outputs, outcomes, and impacts.
* Education outputs, outcomes, and impacts.
* Cite your sources using a consistent format.

If you would like information on how to use templates, please visit <http://tti.tamu.edu/group/communications/word-template-instructions/>.

## Review and Publication Process

The principal investigator (PI) should submit the Project Closeout Checklist and draft Final Research Report within **60 days** after the project completion date. CARTEEH leadership will then review the report and determine whether additional edits are necessary prior to its approval. If edits are required, the report will be returned to the PI with comments on requested revisions.

Once revisions are completed, the final documents should be returned to CARTEEH for final approval. After notifying the PI of the final approval, CARTEEH administration will upload the research report to the CARTEEH website and various repositories, per the grant’s requirements.

## Figures

High-resolution images are preferred if possible. Use automatic cross references to mention each figure in the text (Figure 1).



Figure . Sample image with caption. (Use sentence case; end with a period.)

## Tables

Use automatic cross references to mention each table in the text (Table 1). Tables should be created using Word’s formatting if possible.

Table 1. Sample Table Caption (Capitalize Each Word, and Do Not End with a Period)

|  |  |  |  |  |
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| Title 1 | Title 2 | Title 3 | Title 4 | Title 5 |
| The table should be centered on the page. | Headers for the columns should be in Table Header style and shaded 20 percent gray. | Units should be given in the header and not repeated in cells. | All table text should use the Table Text style and be centered. | Tables should not split across the page unless absolutely necessary. |
| Info 1 | Info 2 | Info 3 | Info 4 | Info 5 |

# Sample Level 1 Heading

## Sample Level 2 Heading

In order to use a subheading, you need to divide chunks of information. Therefore, you should have at least two subheadings.

Use **Body Text** style for paragraphs. Use a sentence to introduce bullets:

* Bullet. Use **List Bullet** style.
* Bullet.
* Bullet.
* Sub-bullet. **Use List Bullet 2** style.
* Sub-bullet.
* Sub-bullet.

### Sample Level 3 Heading

Use **Body Text** style. Use a sentence to introduce numbered lists:

1. List element. Use **List Number** style.
2. List element.
3. List element.

#### Sample Level 4 Heading

Use **Body Text** style. Try not to go beyond level 4 headings.

# Background and Introduction

## Asthma

### Definition of asthma

Asthma is a chronic air way disease characterized by episodes of shortness of breath, coughing, wheezing and sputum production, caused by a reversible or partially reversible airway obstruction and hyperresponsiveness with varying degrees of severity ranging from mild self-resolving to sever episodes resulting in mortality (National Heart Lung and Blood Institute, 2007). In 2015, a global burden of disease study estimated that more than 358 million individuals had asthma around the world making it the most prevalent chronic respiratory disease worldwide (Soriano et al., 2017). In the United States (U.S.) the National health Interview Survey in 2017 showed that 19 million adults and 6.2 million children currently had asthma.

### Health and economic Burden of asthma

Each year so and so are hospitalized from asthma

Each year $$$ are spent on asthma

Each year so and so miss school days due to asthma

Children are more vulnerable to asthma

### Causation of asthma

Asthma is a disease with complex causal pathways in which genetic and environmental factors interact leading to multiple sub-phenotypes with different biological, pathological and clinical characteristics (Gowers et al., 2012, Wenzel, 2012). It is well established that asthma can be exacerbated by exposure to ambient air pollution of varying concentrations and sources (WHO, 2005). However, there was debate over whether air pollution can initiate asthma. Studies showed that exposure to general ambient air pollution is not associated with the initiation of new cases of asthma(Anderson et al., 2011). However, new evidence indicates that exposure to a more specific mixtures of air pollutants, most notably, traffic-related air pollution (TRAP), are associated with an increase risk in developing asthma among children (Anderson et al., 2013a, Khreis et al., 2017).

In light of this new evidence, we aim to estimate the childhood asthma burden of disease attributable to the exposure to urban pollutants that are commonly associated with traffic-related air pollution. A full project work plan has been already submitted and approved by CARTEEH. Henceforward, the reports submitted, including this report, will focus on describing the work completed to date, and give clear account of the methodologies adopted to ensure the work is replicable and rigorous. Further, project results will be described as they emerge.

In this report, we will give a summary of what TRAP and TRAP exposure is. Review the evidence suggesting an association between TRAP and risk of developing asthma among children by presenting the biological plausibility of this association and the exposure-response functions. We will review the burden of disease estimation model and discuss some papers that applied it. We will then discuss the methods we used to estimate the exposure of interest and compare it to different modeling techniques. We will present the exposure data collated and analyzed to date. We will overview the US census data and underlying definitions. Finally, we will describe how childhood asthma incidence rates were estimated.

## Traffic related air pollution

Text here ….

### New evidence of traffic related air pollution induced asthma

#### Biological plausibility

#### Asthma is a complex disease with a complex causal pathway (Martinez, 2007). The complexity of asthma can be seen through its various phenotypes and endotypes which can be characterized by the different triggering factors, clinical presentations, pathological features, disease severity and responsiveness to treatment, to name a few (Corren, 2013). Advancement in biological techniques has given us a better understanding how different genetic and environmental factors interact resulting in the different endotypes (Wenzel et al., 2009, Holgate et al., 2000, Holgate et al., 2007, Mauad et al., 2007, Tgavalekos et al., 2007). In particular, advances in genetic techniques showed a wide range of biological mechanisms in which groups of genes control different pathways that result in the susceptibility to the development of asthma. For example, certain groups of genes control airway development, repair and remodeling while another group of genes control the level of response of the immune system to different triggering factors (Martin and Jo, 2008, Nadeem et al., 2008, Ober and Yao, 2011, Holgate et al., 2007). Interactions between genes and environmental factors have been proposed as potential mechanisms that may explain the development of asthma in association with the environment. Some mechanisms include damage to the airways from pollutants through oxidative stress depleting anti-oxidants in the airways, pollutants interacting with airway walls resulting in airway remodeling, influencing the expression of inflammatory mediators and enhancing respiratory sensitization to allergens (Gowers et al., 2012).

#### Significance of association

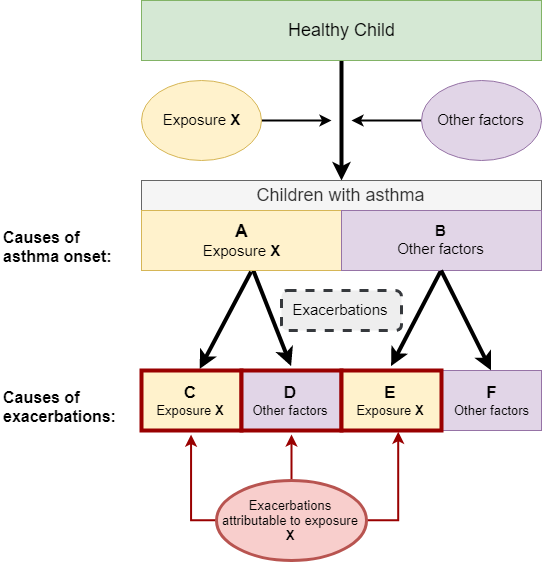
Studies examining the exposure to ambient air pollution at the community level and risk of developing asthma concluded that there is no association. A meta-analysis of cross-sectional studies by Anderson et al. (2011) which included 21 studies examining the community level concentrations of multiple air pollutants (NO2, PM10, Ozone and Sulphur Dioxide) found no association with asthma prevalence at the community’s level. However, studies that examined air pollution concentrations associated with traffic sources showed positive and statistically significant associations with asthma incidence and prevalence. A more recent meta-analysis by Anderson et al. (2013a) of cohort studies included 17 studies examining within-community exposure contrasts dominated by traffic pollution found that NO2, but not PM2.5, concentrations had a significant association with asthma incidence. A more recent meta-analysis by Khreis et al. (2017) examined the associations between exposure to TRAP and risk of developing asthma among children as addressed in case control, cohort, and cross-sectional studies. The meta- analysis included 41 studies and found positive and statistically significant associations between Black Carbon, NO2, PM2.5 and PM10 and childhood asthma incidence and/or prevalence.

## Burden of disease estimation model

The public health and policy relevance of the positive and statistically significant associations between TRAP and childhood asthma incidence is largely unknown as the impact of TRAP exposures on the burden of childhood asthma incidence or prevalence is poorly documented. Due to the ubiquity of TRAP and the high number of exposed children, the relatively small individual risks of TRAP-associated asthma could translate into significant public health impacts with significant health care costs. Yet, this deduction is unconfirmed and is contested as supporting evidence and calculations are scarce.

To estimate the burden of childhood asthma in association with TRAP within the Contiguous United States, we will use standard risk assessment methods that have been previously applied in the context of childhood asthma (Künzli et al., 2008, Perez et al., 2009, Perez et al., 2012, Perez et al., 2013). The aim is to estimate how many new (i.e. incident) childhood asthma cases can be attributable to the exposure of interest, on an annual basis. We will compare these estimates across two years for which we have air pollution exposure data for: 2000 and 2010. The attribution of incident asthma cases to TRAP has substantial implications for the burden of asthma-related exacerbations as well. As air pollution increases the risk of developing new asthma cases, then all future acute exacerbations of these cases, regardless of subsequent (immediate) cause of the exacerbation, should be again attributed to air pollution. This is a conceptual model which has been suggested by Künzli et al. (2008) and is illustrated in Figure 2.

Figure . The burden of asthma exacerbations in children attributable to “exposure X,” assuming a causal role of X in both disease onset and exacerbation. Source: Künzli et al. (2008).



The model illustrated in Figure 2 expands on traditional risk assessment methods. Traditional methods attribute the exacerbations of chronic diseases to exposures of interest that directly induce the episode of exacerbation [direct], while not accounting for episodes of exacerbations induced by different exposures that occur among cases with underlying chronic disease caused by exposure of interest [indirect]. On the other hand, the conceptual model shown in Figure 2 accounts for both [direct] and [indirect] induction of exacerbations. When this model is followed, the burden of disease estimates associated with air pollution are revised to account not only for asthma symptoms that are directly triggered by air pollution (Boxes C and E in Figure 2); but also for asthma symptoms triggered by other causes in children who developed asthma *because* of their air pollution exposure (BoxD in Figure 2). As such, traditional risk assessment methods underestimate the health impacts of exposures that do have a role in the causal pathway of chronic disease.

Certain assumptions are accepted when using the expanded model (Figure 2), first, that the exposure has a causal role in the disease development, second, that the exposure has a causal role in the disease exacerbations, and third, that those who developed the disease due to the exposure wouldn’t have developed the disease without the exposure.

Whilst we focus on the estimation of Boxes A and B in this project, we pave the way forward for future analysis aiming at estimating boxes C, D, E and F.

## Traffic related air pollution exposure modeling

Land-use regression modelling (LUR) is a commonly used empirical-statistical method in air pollution epidemiology. The method has become widely used for estimating within-urban variability in air pollution, typically associated with traffic emissions (Bechle et al., 2015, Anderson et al., 2013b). The method uses least squares regression to combine measured pollutant concentrations with geographical information system (GIS) -based predictor data (reflecting pollutant sources and surrounding land use characteristics) to build a prediction model applicable to non-measured locations (Khreis and Nieuwenhuijsen, 2017). The general pros and cons of LUR models, in comparison to other exposure models, have been previously described in Khreis and Nieuwenhuijsen (2017) and are summarized in Table 2.

Table . Pros and cons of exposure assessment methods used in TRAP and asthma research. TRAP: traffic-related air pollution. Source: Khreis and Nieuwenhuijsen (2017)

Insert table here …

Using land use regression model to assign exposure values has several limitations. The exposure model assumes that pollutant exposure is from ambient outdoor air pollution but does not take into account indoor air pollution. The model also assigns exposure source at one single location and does not take into account time-activity patterns, for example how much of the exposure happens at school or at the playground. Another limitation is exposure misclassification error, the precision of the LUR model varies within urban areas leading to misclassification of exposure in either direction depending the direction of error of the pollutant prediction, for example if the model is over predicting this will lead to overexposure classification but if the model is under predicting the opposite might be true.

# Methodology

## Study area and time period

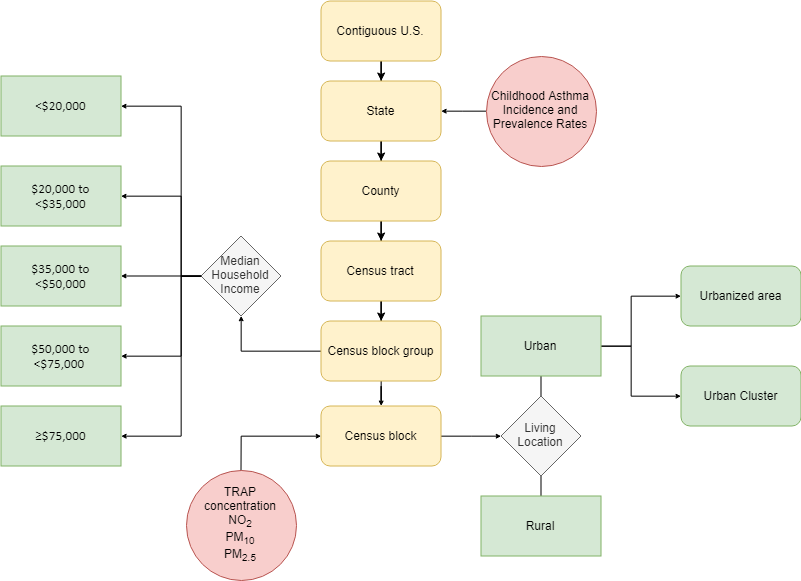
We analyzed data within the contiguous U.S. (48 states and the District of Columbia) for the years 2000 and 2010. When available, we conducted the analysis at the finest geographical level in the hierarchy of census geographic entities within U.S. (Figure 3). Data available at the census block level included population counts, urban or rural living location and air pollution concentration. Data available at the census block group level (one level higher than the census block) included median household income data. Data available at the national and state level included childhood asthma incidence rates. States not within the contiguous U.S., namely Alaska, Hawaii and Puerto Rico, were excluded from the analysis due to the unavailability of air pollution data. Only populated census blocks were included in our analysis. The years 2000 and 2010 were selected for the analysis due to the availability of air pollution concentrations during those periods and the availability of full population counts through the decennial census.

## Census data

### Geographical hierarchy of the US census

The U.S. Census Bureau recognizes multiple geographical hierarchies to address the needs of different users. The “Census Block” is the basic building unit for each of the geographical hierarchies. Census blocks do not cross the boundaries of higher-level hierarchies. Over time the U.S. Census Bureau might add, split or merge census block mainly due to the changing population density within them (US Census Bureau, 1994). The hierarchy used by the census bureau to conduct population counts includes states, counties, census tracts, census block groups and census blocks; we used a similar hierarchy for our analysis. We used a similar hierarchy when conducting our analysis (Figure 3).

Figure : Data hierarchy



### Census data sources and description

We obtained decennial census data for the years 2000 and 2010 for each census block from the National Historical Geographic Information System database (Manson et al., 2018). Each census block contained complete population counts of children <18 years of age and were designated as either urban or rural. Urban designated census blocks were further classified as either urban clusters or urbanized areas based on multiple criteria by the census bureau which include population thresholds, density, nonresidential urban land use (e.g. paved areas and airports), and distance to other urban developed areas (US Census Bureau, 2016). Urban clusters generally have a population threshold of ≥2,500 and <50,000, while urbanized areas have a threshold of ≥50,000 people. Rural designated areas are non-urban areas. Annual median household income, available at the census block group level, was categorized into five categories; <$20,000, $20,000 to <$35,000, $35,000 to <$50,000, $50,000 to <$75,000 and ≥$75,000 (**Error! Reference source not found.**). These five categories were consistent with a previously published study by Clark et al. (2017). Each census block was assigned the median household income category of the census block group, which it resides in. Census blocks with a missing median household income category were assigned as “Not defined”.

## Air pollution exposure

Was based air pollution exposure on the annual average pollutant concentration at the centroid of each census block for the years 2000 and 2010 (Figure 3). We estimated the burden of disease due to exposure of three pollutants; NO2, PM2.5 and PM10. Pollutant concentrations were obtained from satellite-based regression models (LUR) developed by other research teams, Bechle et al. (2015) and Kim et al. (In prep). Air pollution concentrations were available at populated census blocks. The following sections present a description of the modeling method used for each pollutant.

### NO2 model and concentrations

To measure NO2 exposure, we adopt the US-wide LUR model developed by Bechle et al. (2015) which provided annual average NO2 concentration estimates for 2000 and 2010 at the centroid location of each populated census block. The development of the model incorporated two components, a “spatial” and “temporal” component. For the spatial component data were sourced using satellite readings, Environmental Protection Agency (EPA) air quality monitor readings and multiple geographical information systems (GIS) covariates including impervious surfaces, tree canopies, population count, major road length, minor road length, total road length, elevation, and distance to coast. The model had a spatial resolution typical for urban-scale LURs (∼100 m scale) and covered 100% of US Census blocks. For the temporal component, the monthly NO2 average concentrations for 11 consecutive years from EPA air quality monitors were used as a scaling factor for the data to increase the predictive ability of the model. Data from air quality monitors were only included when at least 75% of the hourly values were available. The validation of the spatial model was satisfactory with an R2 = (0.63-0.82) using hold-out cross-validation. The R2 of the model was consistent with other continental-scale NO2 models. For example, Novotny et al. (2011) reported on a US National NO2 LUR model with an R2 = 0.78. Hystad et al. (2011) reported on a Canadian National NO2 LUR model with an R2 = 72%. Beelen et al. (2009) reported on an EU NO2 LUR model with an R2 = 61%, and Vienneau et al. (2013) reported on a Western European NO2 LUR model with an adjusted R2 = 58%. NO2 concentrations were converted from ppb to ug/m3 units by multiplying them with 1.88 (WHO, 2005).

### PM2.5 concentrations and exposure

Annual-average air pollution concentrations for PM2.5 were modeled using 17 years of data (1999-2015) from regulatory air quality monitors. The model was constructed using a universal kriging framework (Kim et al., In prep). The model incorporated hundreds of geographic variables including land use, population counts, and satellite data. The validation of the model was performed using a holdout cross validation with satisfactory performance of 10-fold CV-R2 reaching 0.86 and 0.85 in 2000 and 2010, respectively.

### PM10 concentrations and exposure

Annual-average air pollution concentrations for PM10 were estimated using 27 years of data (1988-2015) using a similar method for PM2.5 (Kim et al., In prep). The validation of the model was performed using a holdout cross validation with satisfactory performance of 10-fold CV-R2 reaching 0.60 and 0.57 in 2000 and 2010, respectively.

## Concentration response function

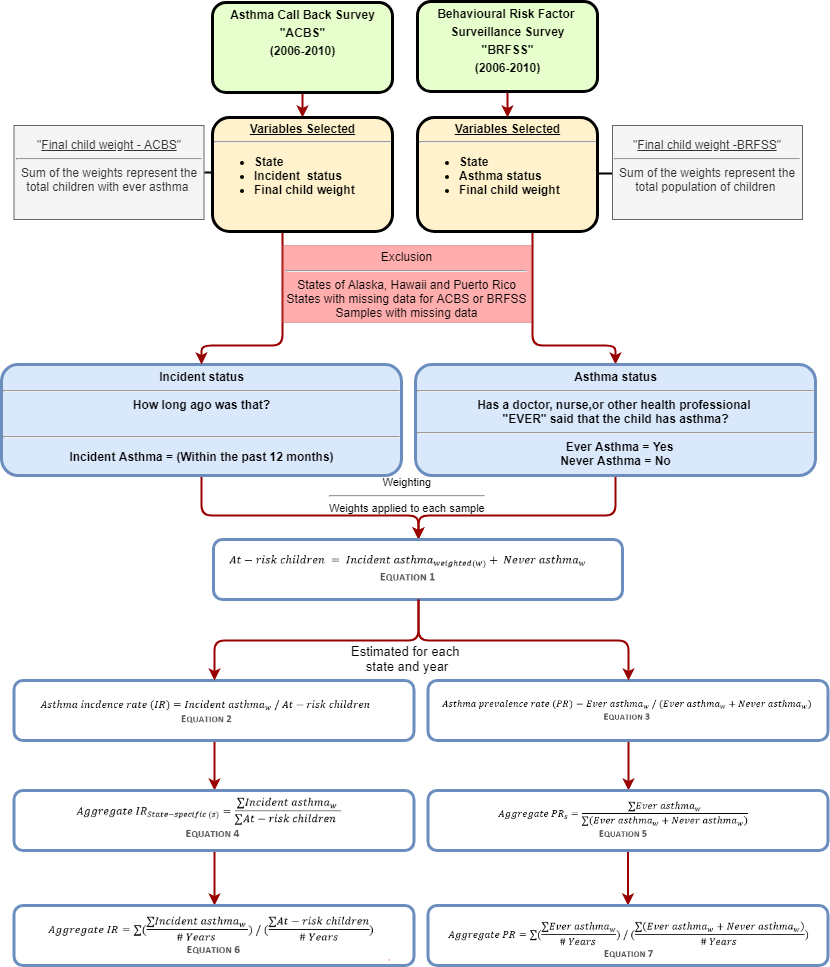
The concentration-response functions (CRF) for the association between exposure to NO2, PM10 and PM2.5 and risk of development of childhood asthma were extracted from a systematic review and meta-analysis study by Khreis et al. (2017). The review included a total of 41 studies examining the association between exposure to traffic related air pollution and risk of developing asthma incidence or life time prevalence among children 18 years or younger. The risk estimates for each pollutant was summarized across available studies using a random-effect meta-analysis. For NO2, the CRF was 1.05 (95% CI=1.02–1.07) per 4 μg/m3 increase based on 20 studies. For PM10, the CRF was 1.05 (95% CI=1.02–1.08) per 2 μg/m3 increase based on 12 studies. For PM2.5 it was 1.03 (95% CI=1.01–1.05) per 1 μg/m3 increase based on 10 studies. The meta-analysis did not adjust for co-pollutants, meaning the number of attributable asthma cases due to either pollutants should not be added up.

## Asthma incidence rate

### Asthma incidence rates used for the analysis

For our initial analysis, we used a single national level childhood asthma incidence rate of 12.5 per 1000 at-risk children (95% CI = 10.5-14.4) obtained from a published paper by Winer et al. (2012). The study extracted data from the Behavioral Risk Factor Surveillance System (BRFSS) and the Asthma Call Back Survey (ACBS) for the years 2006-2008 which included 31 states and the District of Columbia with a sample size of 200,993 children from the BRFSS and 8,437 children from the ACBS. The incidence rate was assigned to the years 2000 and 2010. We then repeated our analysis for the year 2010 using state-specific childhood asthma incidence rates and compared the resulting estimates with the estimated from our initial analysis for the year 2010. We extracted state-specific asthma incidence rate following the methods described by expanding the methods described by Winer et al. (2012) to include the surveys conducted from 2006 through 2010 (2009 and 2010 were added). The following section and diagram (Figure 4), describe how childhood asthma incidence rates were estimated for our repeated analysis.

Figure : Asthma incidence and prevalence estimation



A childhood asthma incidence rate is defined as the number of newly diagnosed asthma cases among at-risk children over a period of time. To obtain the asthma incidence rate of children within the US we used the following surveys; the Behavioral Risk Factor Surveillance System (BRFSS) and the Asthma Call Back Survey (ACBS). The BRFSS is a health-related telephone survey established in 1984 that collects data from US residents regarding health related behavior, chronic health conditions and preventive services (CDC, 2009). The ACBS is a follow up survey of BRFSS respondents established in 2005 which collects detailed data on asthma. While the BRFSS is conducted in all 50 states and the District of Columbia (DC), the ACBS is limited to a number of participating states that differ each year.

Using the BRFSS and ACBS data sets for the years 2006 through 2010, we extracted the following variables; the state, the sample weights, the question that indicates the lifetime asthma status of the respondent “Asthma status” from the BRFSS, and the question that indicates when the asthma was diagnosed “Incident status” from the ACBS.

The BRFSS and ACBS samples are designed to represent the overall population of the state in which it is conducted. To achieve this, survey samples are assigned weights. The weights adjust for disproportionate population sample selection relative to the state’s population, the variability in the probability of selection, and the actual response or non-response rates (Garbe et al., 2011, Korn and Graubard, 2011). For example, if a survey respondent is assigned a weight of 200, then his or her answers to the questionnaires would represent the answers of 200 of the state’s population with similar characteristics based on age, gender, and race. The sum of the BRFSS weights represent the total population within a state and the sum of the ACBS weights represent the total population with “Ever asthma” within a state with some minor discrepancies.

The lifetime asthma status of children “Asthma status” was determined through the BRFSS question: “Has a doctor, nurse, or other health professional EVER said that the [child’s name] has asthma?” if the respondent’s answer was “Yes” the respondent’s child is designated as an “Ever asthma”, if the answer was “No” the child is designated as “Never asthma”.

Respondents with children who answered “Yes” to the previous BRFSS question were asked to participate in the ACBS. The “Incident status” of children was extracted from the ACBS using following question; “How old was the [name of child] when a doctor or other health professional first said [he/she] had asthma? How long ago was that?”, if the answer was “within 12 months” the child is considered an “Incident case”. Sample counts of “Ever asthma”, “Never asthma”, and “Incident case” are then converted to weighted estimates using the weights, or in other words, converted to state-population estimates.

We estimated “At-risk children” by taking the sum of weighted “Incident cases” and weighted “Never asthma”, as shown in .

Equation

We estimated asthma incidence rate (IR) by dividing weighted “Incident cases” by “At-risk children”, as shown in .

Equation

We estimated asthma prevalence rate (PR) by dividing weighted “Ever asthma” by the sum of weighted “Ever asthma” and weighted “Never asthma”, as shown in .

Equation

For states with available asthma data, we summed the weighted “Incident asthma”, weighted “Ever asthma”, weighted “Never asthma” and the at-risk children across all available years (2006-2010), to obtain the state-specific aggregate asthma incidence and prevalence rates, as shown in and . We used the state-specific asthma incidence and prevalence rates for the analysis of the burden of disease.

Equation

Equation

For states that did not have either an asthma incidence (n = 19 states) or prevalence (n = 8 states) available across any of the years (2006-2010), we assigned an overall aggregate asthma incidence (11.6 per 1,000 at-risk children) and/or prevalence (13.1 per 100 children) rates, estimated using all the available data across the states (Table S2). In order to aggregate the rates across the states, we re-weighted state-specific data to account for the number of years with available data. For example, the state of Arizona had available data for two year (2006 and 2007), while the states of Maine had available data for three years (2006, 2007 and 2008). To aggregate each state’s incidence rate, we did the following:

* Arizona; we summed weighted “Incident asthma” across 2006 and 2007 and divided them by two (since we have two years of available data) we then divided the results buy the summed “At-risk children” across 2006 and 2007 divided by two.
* Maine; we summed weighted “Incident asthma” across 2006, 2007 and 2008 and divided them by three (since we have three years of available data) we then divided the results buy the summed “At-risk children” across 2006, 2007 and 2008 divided by three.

The same process is done for the remaining states for the incidence and prevalence rates, as shown in Equation 6 and Equation 7:

Equation

Equation

## Burden of disease methodology

To estimate the burden of disease due to each pollutant we combined the census population count of children with the exposure data, asthma incidence rate and pollutant specific CRF’s. We first calculated the relative risk difference (RRdiff) and the population attributable fractions (PAF) using the CRF, CRF unit and exposure levels (in this case the air pollution concentrations at each census block). We then estimated for each year separately the number of childhood asthma incident cases, the incident cases attributable to each pollutant (attributable cases) and the fraction of attributable cases over the total number of incident asthma cases (attributable fraction). The steps below demonstrate the analysis:

For each year we estimate the total at-risk children at each census block by subtracting the total children within the block by the total children within the block multiplied by the state-specific aggregate prevalence rate, as shown in Equation 8.

Equation

Then we estimated the RRdiff; the risk difference between exposure (air pollution concentration) and counterfactual exposure (zero air pollution concentration), as shown in Equation 9.

Equation

Were RRdiff being the CRF of the pollutants and RRunit being the exposure unit. The population attributable fraction was then estimated using Equation 10.

Equation

The asthma incident cases within each census block were then estimated by multiplying at-risk children with the state-specific aggregate incidence rate, as shown in Equation 11.

Equation

The attributable asthma incident cases within each census block were estimated by multiplying the asthma incident cases with the population attributable fraction, as shown in Equation 12.

Equation

Finally, we summed the attributable cases across all the census blocks to estimate the total number of attributable cases for each pollutant separately. The attributable fraction across any strata (e.g. living location, income and state) was estimated by dividing the total attributable cases over the total incident cases across the strata.

## Counterfactual scenarios

We examined two counterfactual scenarios for our initial analysis. In the first scenario we assumed the air pollution concentrations did not exceed the annual average air quality guidelines by the WHO (WHO, 2005) with the following limits:

* NO2 was 40 μg/m3 (annual average);
* PM10 was 20 μg/m3 (annual average);
* PM2.5 was 10 μg/m3 (annual average).

In the second scenario, we assumed air pollution concentrations did not exceed the lowest modeled concentration by the LUR model in either year for all the census blocks with the following concentrations:

* NO2 was 1.48 μg/m3 (annual average);
* PM10 was 0.72 μg/m3 (annual average);
* PM2.5 was 0.55 μg/m3 (annual average).

We reran the analysis for each year using the above two scenarios and estimated the number of cases due to TRAP that could have been prevented among census block exceeding the air pollution concentrations from the above scenarios.

## Sensitivity analysis

To examine the range of uncertainty in our burden estimates we re-ran the initial analysis using a combination of the upper and lower 95% CI of the CRF and asthma incidence rate. We examined the most conservative estimate, using the lowest CI interval of the CRF and asthma incidence rate, and the most extreme estimate using the upper CI intervals. We also produced a sensitivity analysis matrix combining the lower mean and upper limits of the CRF and the asthma incidence rate.

## Running the analysis

The analysis was conducted using R statistical software (R Core Team, 2018). Data sets were joined using a unique identifier for each census block. The unique identifiers are comprised of a series of numbers starting with the letter G. The numbers are comprised of a state identifier, county identifier, census tracts identifier, block group and block identifier.

We produced open-access interactive maps summarizing the burden results at the county level, and look up tables summarizing the results at the city level for 498 major US cities selected using the CDC’s 500 cities project (CDC, 2017).

The cities of Anchorage, Alaska and Honolulu, Hawaii were excluded from the look-up table since we did not include them in our analysis. The Interactive maps and tables were published at the CARTEEH website at the following link [<https://carteehdata.org/l/s/TRAP-burden-of-childhood-asthma>].

# Results

## Census description

There were more than 5 million and 6 million populated census blocks in 2000 and 2010, respectably, of which urban designated blocks (encompassing urban clusters and urbanized areas) represented 56% and 58% (Table 3). The total population of children were 71,807,328 (26% of total population) and 73,690,271 (24%) in 2000 and 2010, respectively. 79% and 81% of children lived in an urban designated area in 2000 and 2010. The table provides the geographical and population distribution by median household income group for each year. State-specific geographical and demographic characteristics are detailed in Table S1.

## Asthma incidence

For our first analysis we used a single childhood asthma incidence rate of 12.5 per 1,000 at-risk children as published by Winer et al. (2012) for 2000 and 2010. The asthma incidence rate was an average rate across the years 2006-2008 which included samples of 8,437 children from 31 states and the District of Columbia (D.C) throughout the time period.

For our repeated analyses, the state-specific childhood asthma incidence rates were available for 32 states from a total sample of 16,153 from the ACBS, and there were 41 states with available prevalence rates from a total sample of 193,464 from the BRFSS (Table 4 and ). States with missing childhood asthma incidence rates (n = 19 states) were assigned an aggregate asthma incidence rate of 11.6 per 1,000 at-risk children, while states with missing asthma prevalence rates (n = 8) were assigned an aggregate asthma prevalence rate of 13.1 per 100 children. For incidence rate by state, District of Columbia had the highest childhood asthma incidence rate of (IR = 17.1 per 1,000 at-risk children), while Montana had the lowest rate (IR = 4.3 per 1,000 at-risk children) for the period 2006-2010. For prevalence rate by state, District of Columbia had the highest childhood prevalence rate of (PR = 8.4 per 100 children), while Iowa had the lowest prevalence (PR = 4.3 per 100 children)

## Exposure data

### NO2 concentrations

Mean NO2 concentrations across the US for 2000 and 2010 were 20.6 (µg/m3) and 13.2 (µg/m3) with a reduction of 36% (Table 5). By living location, urbanized areas had the largest NO2 mean concentrations followed by urban clusters in both years. NO2 concentrations dropped across all living location by more than 35% between 2000 and 2010. By median household income, the highest and lowest income groups had the largest NO2 mean concentrations compared to other income groups for both years. NO2 concentrations dropped by 28%-47% between 2000 and 2010. The states with the largest and lowest NO2 concentrations were District of Columbia (38.2 µg/m3) and North Dakota (6.8 µg/m3) for 2000, and District of Columbia (26.3 µg/m3) and South Dakota (5.2 µg/m3). The NO2 concentration change across all states between 2000 and 2010 ranged from decrease of 46% (Florida) to a decrease of 21% (North Dakota).

### PM10 concentrations

Mean PM10 concentrations across the US for 2000 and 2010 were 21.5 (µg/m3) and 17.9 (µg/m3) with a reduction of 17% (Table 5). By living location, urbanized areas had the largest PM10 mean concentrations followed by urban clusters in both years. PM10 concentrations dropped across all living location by more than 11% between 2000 and 2010. By median household income, the lowest income groups had the largest PM10 mean concentrations compared to other income groups for both years. PM10 concentrations dropped by 15%-18% between 2000 and 2010. The states with the largest and lowest PM10 concentrations were Arizona (31.5 µg/m3) and New Hampshire (10.4 µg/m3) for 2000, and Iowa (23.7 µg/m3) and New Hampshire (9.4 µg/m3). The PM10 concentration change across all states between 2000 and 2010 ranged from a 7% increase (North Dakota) to a 35% decrease (Idaho).

### PM2.5 concentrations

Mean PM2.5 concentrations across the US for 2000 and 2010 were 12.1 (µg/m3) and 9 (µg/m3) with a reduction of 26% (Table 5). By living location, urbanized areas had the largest PM2.5 mean concentrations closely followed by urban clusters in both years. PM2.5 concentrations dropped across all living location by more than 21% between 2000 and 2010. By median household income, the lowest income groups had the largest PM2.5 mean concentrations compared to other income groups for both years. PM2.5 concentrations dropped by 20%-31% between 2000 and 2010. The states with the largest and lowest PM2.5 concentrations were District of Columbia (15.7 µg/m3) and New Mexico (5.5 µg/m3) for 2000, and Indiana (14.9 µg/m3) and New Mexico (4.5 µg/m3). The PM2.5 concentration change across all states between 2000 and 2010 ranged from a 6% increase (North Dakota) to a 41% decrease (California).

## Burden of disease

### Overall asthma incident cases

Using the national asthma incidence rate of 12.5 per 1,000 at-risk children, the estimated number of childhood asthma incident cases for 2000 and 2010 were 786,300 and 794,900, respectively (Table 6). By living location, the majority of cases lived, 68% and 72%, lived in an urbanized area in 2000 and 2010. By median household income, the majority of cases (31%) lived in an income group of $35,000 to <$50,000 in 2000, while in 2010 the majority (30%) lived in an income group of $50,000 to <$75,000. Among states, California had the largest number of incident cases for both years (>100,000) and the District of Columbia had the least number of cases in both years (Table S4).

### Attributable cases and fraction

The number of attributable cases and their percentage of all childhood asthma incident cases, or attributable fraction, (presented as a percentage) were estimated in 2000 and 2010 as following; For NO2, therewere 209,100 (27%) and 141,900 (18%) attributable cases with a 32% reduction between the two years (Table 7). For PM10 there were 379,400 (48%) and 311,600 (42%) cases with a 13% reduction, and for PM2.5 there were 247,100 (31%) and 190,200 (24%) cases with a 23% reduction.

By state, California had the largest number of attributable cases due to NO2 in 2000 and 2010 with 39,300 (39%) and 25,400 (25%) cases, respectively (Table S5). The states with the largest attributable fractions due to NO2 for 2000 and 2010 were California (39%) and the District of Columbia (27%), respectively. For PM10, California also had the largest number of attributable cases in 2000 and 2010 with 59,700 (59%) and 47,400 (47%) cases, respectively (Table S6). While Arizona had the largest attributable fractions due to PM10 in 2000 and 2010 with 63% and 52%, respectively. For PM2.5, California had the largest number of attributable cases in 2000 and 2010 with 37,700 (37%) and 24,400 (24%) cases, respectively (Table S6). While Georgia had the largest attributable fractions due to PM2.5 in 2000 with 38%, and Ohio in 2010 with 30% respectively. A comparison of change in attributable fraction values by state between the year 2000 and 2010 is presented in Figure S1.

### Attributable cases and fraction by living location

The majority of attributable cases lived in an urban designated area, (Table 7). The attributable number of cases and (fraction) for NO2 were 168,400 (31%) and 117,600 (21%) living in an urbanized area in 2000 and 2010, compared to 24,600 (15%) and 14,500 (10%) in rural areas. For PM10, there were 271,100 (50%) and 246,600 (43%) living in an urbanized area, compared to 70,600 (42%) and 53,300 (36%) in rural areas. For PM2.5, there were 176,400 (33%) and 140,400 (25%) living in an urbanized area, compared to 47,000 (28%) and 32,000 (22%) in rural areas. A comparison of change in attributable fraction values by state and living location between the year 2000 and 2010 is presented in Figure S2 - Figure S4.

### Attributable cases and fraction by median household income

The highest attributable fraction in 2000 and 2010 by median household income were as follows; For NO2, the median household income group of <$20,000 had the highest fraction in both years with 31% and 21%, respectively (Table 7). For PM10, the income group of <$20,000 also had the highest fraction in both years with 51% and 44%, respectively. For PM2.5, the income group of <$20,000 also had the highest fraction in both years with 33% and 26%, respectively. A comparison of change in attributable fraction values by state and median household income between the year 2000 and 2010 is presented in Figure S5 - Figure S7.

Table . Geographical and demographic characteristics

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **Populated Census Blocks** | | **Total Population** | | | **Total Children** | | |
|  | | **2000** | **2010** | **2000** | **2010** | **Change (%)** | **2000** | **2010** | **Change (%)** |
| **Total** |  | 5,280,214 | 6,182,882 | 279,583,437 | 306,675,006 | 10% | 71,807,328 | 73,690,271 | 3% |
| **Living Location** | Urbanized Area | 2,245,602 (43%) | 2,793,824 (45%) | 191,210,242 (68%) | 218,634,292 (71%) | 14% | 49,057,184 (68%) | 52,932,624 (72%) | 8% |
| Urban Cluster | 724,745 (14%) | 796,454 (13%) | 29,630,815 (11%) | 28,899,597 (9%) | -2% | 7,447,648 (10%) | 6,994,464 (9%) | -6% |
| Rural | 2,309,867 (44%) | 2,592,604 (42%) | 58,742,380 (21%) | 59,141,117 (19%) | 1% | 15,302,496 (21%) | 13,763,183 (19%) | -10% |
| **Median Household Income** | Not Defined | 0 | 2,686 (<1%) | 0 | 1,022,300 (<1%) |  | 0 | 13,555 (<%1) |  |
| <$20,000 | 251,146 (5%) | 201,663 (3%) | 15,003,590 (5%) | 11,021,823 (4%) | -27% | 4,055,407 (6%) | 2,614,804 (4%) | -36% |
| $20,000 to <$35,000 | 1,876,701 (36%) | 1,185,560 (19%) | 79,329,475 (28%) | 51,269,356 (17%) | -35% | 20,694,588 (29%) | 12,770,843 (17%) | -38% |
| $35,000 to <$50,000 | 1,829,414 (35%) | 1,978,146 (32%) | 88,439,385 (32%) | 78,430,814 (26%) | -11% | 21,974,042 (31%) | 18,573,954 (25%) | -15% |
| $50,000 to <$75,000 | 984,837 (19%) | 1,860,065 (30%) | 68,510,768 (25%) | 93,716,911 (31%) | 37% | 17,350,990 (24%) | 21,953,876 (30%) | 27% |
| >=$75,000 | 338,116 (6%) | 954,762 (15%) | 28,300,219 (10%) | 71,213,802 (23%) | 152% | 7,732,301 (11%) | 17,763,239 (24%) | 130% |

Table : Childhood asthma survey summary

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **2006** | **2007** | **2008** | **2009** | **2010** | **Total** |
| **BRFSS sample (w)** | 55,094 (50,674,742) | 59,487 (43,661,381) | 61,862 (53,327,550) | 59,821 (47,747,373) | 57,200 (39,975,264) | 293,464 |
| **Ever asthma sample (w)** | 7,168 (6,493,224) | 7,971 (5,763,409) | 8,255 (7,218,400) | 8,126 (6,279,938) | 7,483 (5,158,455) | 39,003 |
| **ACBS Sample (w)** | 2,017 (4,580,870) | 2,797 (5,459,638) | 3,924 (4,343,245) | 4,095 (4,154,076) | 2,196 (3,116,669) | 16,156 |
| **Incident case sample (w)** | 154 (404,276) | 173 (312,917) | 169 (385,818) | 153 (297,546) | 160 (319,743) | 809 |
| **At-risk sample (w)** | 48,080 (30,825,589) | 51,689 (36,050,557) | 53,776 (26,491,259) | 51,848 (25,942,087) | 49,877 (22,900,850) | 255,270 |
| **Incidence rate** | 13.1 | 8.7 | 14.6 | 11.5 | 14.0 | 11.6\* |
| **Prevalence rate** | 12.8 | 13.2 | 13.5 | 13.2 | 12.9 | 13.1\*\* |
| **Number of states in** | 18 | 26 | 20 | 17 | 17 | 32\*\*\* |

*\*Aggregate asthma incidence rate per 1,000 at-risk children*

*\*\*Aggregate asthma prevalence rate per 100 children*

*\*\*Total number of states included in the aggregate asthma incidence rate estimation*

Table . Air pollution concentrations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | **Concentration (µg/m3)** | | |
|  | | **2000** | **2010** | **Change (%)** |
| **NO2** | |  | | |
| **Total** |  | 20.6 | 13.2 | -36% |
| **Living Location** | Urbanized area | 29.7 | 18.4 | -38% |
| Urban cluster | 18.7 | 12 | -36% |
| Rural | 12.4 | 8 | -35% |
| **Median Household Income** | Not defined | NA | 16 |  |
| <$20,000 | 24.2 | 16.1 | -33% |
| $20,000 to <$35,000 | 18.3 | 13.2 | -28% |
| $35,000 to <$50,000 | 19.1 | 11.8 | -38% |
| $50,000 to <$75,000 | 24.3 | 12.8 | -47% |
| >=$75,000 | 28.8 | 16.5 | -43% |
| **PM10** | |  | | |
| **Total** |  | 21.5 | 17.9 | -17% |
| **Living Location** | Urbanized area | 23.4 | 19.1 | -18% |
| Urban cluster | 21.5 | 19.1 | -11% |
| Rural | 19.5 | 16.3 | -16% |
| **Median Household Income** | Not defined | NA | 18.2 |  |
| <$20,000 | 23.4 | 19.2 | -18% |
| $20,000 to <$35,000 | 21.5 | 18.2 | -15% |
| $35,000 to <$50,000 | 21.2 | 17.8 | -16% |
| $50,000 to <$75,000 | 21.6 | 18 | -17% |
| >=$75,000 | 21.1 | 17.7 | -16% |
| **PM2.5** | |  | | |
| **Total** |  | 12.1 | 9 | -26% |
| **Living Location** | Urbanized area | 13.3 | 9.7 | -27% |
| Urban cluster | 11.9 | 9.4 | -21% |
| Rural | 10.9 | 8.1 | -26% |
| **Median Household Income** | Not defined | NA | 8.8 |  |
| <$20,000 | 13.3 | 10.3 | -23% |
| $20,000 to <$35,000 | 11.9 | 9.5 | -20% |
| $35,000 to <$50,000 | 11.9 | 8.9 | -25% |
| $50,000 to <$75,000 | 12.4 | 8.7 | -30% |
| >=$75,000 | 12.7 | 8.7 | -31% |

Table . Incident cases

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | **Incident Cases** | | |
|  | | 2000 | 2010 | Change (%) |
| **Total** |  | 786,300 | 794,900 | 1% |
| **Living Location** | Urbanized area | 537,200 (68%) | 571,000 (72%) | 6% |
| Urban cluster | 81,600 (10%) | 75,500 (9%) | -7% |
| Rural | 167,600 (21%) | 148,500 (19%) | -11% |
| **Median Household Income** | Not defined | 0 | 100 | NA |
| <$20,000 | 44,400 (6%) | 28,200 (4%) | -36% |
| $20,000 to <$35,000 | 226,600 (29%) | 137,800 (17%) | -39% |
| $35,000 to <$50,000 | 240,600 (31%) | 200,400 (25%) | -17% |
| $50,000 to <$75,000 | 190,000 (24%) | 236,800 (30%) | 25% |
| >=$75,000 | 84,700 (11%) | 191,600 (24%) | 126% |

Table . Burden estimates

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **Attributable Cases** | | | **Attributable Fraction** | | |
|  | | **2000** | **2010** | **Change (%)** | **2000** | **2010** | **Change (%)** |
| **NO2** | |  | | | | | |
| **Total** |  | 209,100 | 141,900 | -32% | 27% | 18% | -33% |
| **Living Location** | Urbanized area | 168,400 (81%) | 117,600 (83%) | -30% | 31% | 21% | -32% |
| Urban cluster | 16,100 (8%) | 9,800 (7%) | -39% | 20% | 13% | -35% |
| Rural | 24,600 (12%) | 14,500 (10%) | -41% | 15% | 10% | -33% |
|  | Not defined | 0 | <100 | NA | NA | NA | NA |
| **Median Household Income** | <$20,000 | 13,700 (7%) | 5,900 (4%) | -57% | 31% | 21% | -32% |
| $20,000 to <$35,000 | 59,600 (29%) | 25,800 (18%) | -57% | 26% | 19% | -27% |
| $35,000 to <$50,000 | 60,700 (29%) | 34,500 (24%) | -43% | 25% | 17% | -32% |
| $50,000 to <$75,000 | 50,900 (24%) | 40,500 (29%) | -20% | 27% | 17% | -37% |
| >=$75,000 | 24,100 (12%) | 35,100 (25%) | 46% | 28% | 18% | -36% |
| **PM10** | |  | | | | | |
| **Total** |  | 331,200 | 286,500 | -13% | 42% | 36% | -14% |
| **Living Location** | Urbanized area | 237,400 (72%) | 213,300 (74%) | -10% | 44% | 37% | -16% |
| Urban cluster | 32,700 (10%) | 27,500 (10%) | -16% | 40% | 36% | -10% |
| Rural | 61,100 (18%) | 45,700 (16%) | -25% | 36% | 31% | -14% |
|  | Not defined | NA | 100 | NA | NA% | 1 | NA |
| **Median Household Income** | <$20,000 | 19,800 (6%) | 10,700 (4%) | -46% | 45% | 38% | -16% |
| $20,000 to <$35,000 | 98,300 (30%) | 51,300 (18%) | -48% | 43% | 37% | -14% |
| $35,000 to <$50,000 | 100,800 (30%) | 72,300 (25%) | -28% | 42% | 36% | -14% |
| $50,000 to <$75,000 | 78,700 (24%) | 85,000 (30%) | 8% | 41% | 36% | -12% |
| >=$75,000 | 33,700 (10%) | 67,300 (23%) | 100% | 40% | 35% | -13% |
| **PM2.5** | |  | | | | | |
| **Total** |  | 247,100 | 190,200 | -23% | 31% | 24% | -23% |
| **Living Location** | Urbanized area | 176,400 (71%) | 140,400 (74%) | -20% | 33% | 25% | -24% |
| Urban cluster | 23,700 (10%) | 17,700 (9%) | -25% | 29% | 23% | -21% |
| Rural | 47,000 (19%) | 32,000 (17%) | -32% | 28% | 22% | -21% |
|  | Not defined | 0 | <100 | NA | NA | NA | NA |
| **Median Household Income** | <$20,000 | 14,600 (6%) | 7,400 (4%) | -49% | 33% | 26% | -21% |
| $20,000 to <$35,000 | 71,600 (29%) | 34,600 (18%) | -52% | 32% | 25% | -22% |
| $35,000 to <$50,000 | 74,900 (30%) | 48,300 (25%) | -36% | 31% | 24% | -23% |
| $50,000 to <$75,000 | 59,400 (24%) | 55,700 (29%) | -6% | 31% | 24% | -23% |
| >=$75,000 | 26,700 (11%) | 44,100 (23%) | 65% | 32% | 23% | -28% |

## Counterfactual scenarios

In the following section, we present the number of preventable asthma incident cases had exposure values not exceeded two counterfactual scenarios.

### Scenario (1) WHO air quality guideline levels:

* NO2 exposure level not exceeding 40 ug/m3; the number of incident asthma cases that could have been prevented were estimated to be 11,100 (1% of all asthma cases) and 300 (<1%) in 2000 and 2010, respectively.
* PM10 exposure level not exceeding 20 ug/m3; the number of incident asthma cases that could have been prevented were estimated to be 43,900 (6%) and 14,400 (2%) in 2000 and 2010, respectively.
* PM2.5 exposure level not exceeding 10 ug/m3; the number of incident asthma cases that could have been prevented were estimated to be 53,400 (7%) and 9,500 (1%) in 2000 and 2010, respectively.

### Scenario (2) Lowest modeled air pollution concentrations:

* NO2 exposure level not exceeding 1.48 ug/m3; the number of incident asthma cases that could have been prevented were estimated to be 195,100 (25% of all asthma cases) and 127,700 (16%) in 2000 and 2010, respectively.
* PM10 exposure level not exceeding 0.72 ug/m3; the number of incident asthma cases that could have been prevented were estimated to be 317,600 (40%) and 272,700 (34%) in 2000 and 2010, respectively.
* PM2.5 exposure level not exceeding 0.55 ug/m3; the number of incident asthma cases that could have been prevented were estimated to be 234,500 (30%) and 177,400 (22%) in 2000 and 2010, respectively

## Sensitivity analysis

We estimated the attributable number of asthma cases due to TRAP using the most conservative inputs (lower 95% CI of the CRF and IR), extreme inputs (Upper 95% CI of the CRF and IR) and a combination of the mean, lower, and upper 95% CI of the CRF and IR. We plotted the results into a sensitivity matrix to inspect the change in estimates compared to the mean values of our main analysis, presented in Table 8. With the conservative inputs the estimated attributable cases due to TRAP reduced by 60%-69% (). With the extreme inputs the estimated attributable cases due to TRAP increased by 49%-74%.

Table : Sensitivity Analysis

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Concentration response function | | | | | |  | |
|
| Year 2000 | | | Year 2010 | | |
| NO2 | LL (1.02) | M (1.05) | UL (1.07) | LL (1.02) | M (1.05) | UL (1.07) |
| 79,900 | 175,600 | 227,200 | 52,000 | 119,200 | 158,000 | LL (10.5) | Incidence rate |
| 95,100 | **209,100**\* | 270,400 | 61,900 | **141,900**\* | 188,100 | M (12.5) |
| 109,500 | 240,900 | 311,500 | 71,400 | 163,500 | 216,700 | UL (14.4) |
| PM10 | LL (1.02) | M (1.05) | UL(1.08) | LL (1.02) | M(1.05) | UL (1.08) |  |
| 133,500 | 278,200 | 377,900 | 111,700 | 240,700 | 335,800 | LL (10.5) |
| 158,900 | **331,200**\* | 449,900 | 133,000 | **286,500**\* | 399,800 | M (12.5) |
| 183,010 | 381,600 | 518,300 | 153,200 | 330,100 | 460,600 | UL (14.4) |
| PM2.5 | LL (1.01) | M (1.03) | UL (1.05) | LL (1.01) | M (1.03) | UL (1.05) |  |
| 79,500 | 207,600 | 304,000 | 59,000 | 159,800 | 241,600 | LL (10.5) |
| 94,700 | **247,100**\* | 361,900 | 70,300 | **190,200**\* | 287,600 | M(12.5) |
| 109,100 | 284,700 | 416,900 | 80,900 | 219,100 | 331,300 | UL (14.4) |

\*Grey blocks represent the burden estimated using the mean values of the CRF and IR

\*Dark red block represents the conservative estimates while dark green blocks represent extreme estimates.

## Comparison results

Using state specific asthma incidence and prevalence rates, shown in Table S2, we re-ran the burden analysis due to NO2 for the year 2010 and compared the results with our main analysis which used a flat-national level asthma incidence rate of 12.5 per 1,000 at-risk children.

### Comparison of total asthma incident cases

The total number of childhood asthma incidence cases in 2010 reduced by 6% (47,497 incident cases) when using state-specific asthma incidence rates (Table 9). By living location, the largest relative change in incident cases was among urban clusters with a 6.1% (4,929) decrease, followed by urbanized areas with a 6.1% (34,898) decrease. By income group, the largest relative change was among the highest income group (≥$75,000) with a 7.7% (14,741) decrease in cases, while the lowest income group (<$20,000) had the smallest relative change by a decrease of 1.5% (437) cases compared to other income groups. The states with the smallest and largest change in incident cases, respectively, were California with a 24,500 (24.4%) decrease and Texas with a 25,000 (33.7%) increase (Table S9 ).

### Comparison of attributable number of cases due to NO2

The total number of attributable cases due to NO2 in 2010 reduced by 7.2% (10,192 attributable cases) when using state-specific asthma incidence rates (). By living location, the largest relative change in attributable cases was among urbanized areas with a 7.5% (8,876) decrease, followed by urban clusters with a 6.5% (638) decrease. By income group, the largest relative change was among the highest income group (≥$75,000) with a 9.2% (3,243) decrease in cases, while the lowest income group (<$20,000) had the smallest relative change by a decrease of 1.8% (106) cases compared to other income groups The states with the smallest and largest change in attributable cases, respectively, were California with a 6,200 (24.4%) decrease and Texas with a 3,600 (33.6%) increase (Table S9 ).

### Comparison of attributable fraction due to NO2

The attributable fraction due to NO2 in 2010 had an absolute reduction by 0.3% when using state-specific asthma incidence rates (Table 9). By living location, the largest change was among urbanized areas with a 0.3% reduction. By income group, the largest change was among the highest income group (≥$75,000) with a 0.3% reduction. The attributable fraction across states did change when using state-specific asthma incidence rates, the differences in attributable fractions across states observed are due to rounding errors.

Table . Comparison of results of the burden of disease using state-specific IR

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Results using flat national-level IR** | | | **Results using state-specific IR** | | | **Difference** | | | **Difference (%)** | | |
|  |  | **Incident cases** | **AC** | **AF** | **Incident cases** | **AC** | **AF** | **Incident cases** | **AC** | **AF** | **Incident cases** | **AC** | **AF** |
|  | **Total** | 794,934 | 141,931 | 17.9% | 747,437 | 131,739 | 17.6% | -47,497 | -10,192 | -0.3% | -6.0% | -7.2% | -1.7% |
| **By living location (% of Total)** | **Rural** | 148,470 (19%) | 14,466 (10%) | 9.7% | 140,799 (19%) | 13,788 (10%) | 9.8% | -7,671 | -678 | 0.1% | -5.2% | -4.7% | 1.0% |
| **Urban cluster** | 75,453 (9%) | 9,844 (7%) | 13.0% | 70,524 (9%) | 9,206 (7%) | 13.1% | -4,929 | -638 | 0.1% | -6.5% | -6.5% | 0.8% |
| **Urbanized area** | 571,011 (72%) | 117,621 (83%) | 20.6% | 536,113 (72%) | 108,745 (83%) | 20.3% | -34,898 | -8,876 | -0.3% | -6.1% | -7.5% | -1.5% |
| **By median household income (% of Total)** | **<$20,000** | 28,207 (4%) | 5,892 (4%) | 20.9% | 27,770 (4%) | 5,786 (4%) | 20.8% | -437 | -106 | -0.1% | -1.5% | -1.8% | -0.5% |
| **$20,000 to <$35,000** | 137,765 (17%) | 25,794 (18%) | 18.7% | 132,843 (18%) | 24,699 (19%) | 18.6% | -4,922 | -1,095 | -0.1% | -3.6% | -4.2% | -0.5% |
| **$35,000 to <$50,000** | 200,367 (25%) | 34,549 (24%) | 17.2% | 188,466 (25%) | 32,088 (24%) | 17.0% | -11,901 | -2,461 | -0.2% | -5.9% | -7.1% | -1.2% |
| **$50,000 to <$75,000** | 236,827 (30%) | 40,540 (29%) | 17.1% | 221,334 (30%) | 37,253 (28%) | 16.8% | -15,493 | -3,287 | -0.3% | -6.5% | -8.1% | -1.8% |
| **≥$75,000** | 191,621 (24%) | 35,128 (25%) | 18.3% | 176,880 (24%) | 31,885 (24%) | 18.0% | -14,741 | -3,243 | -0.3% | -7.7% | -9.2% | -1.6% |

# Conclusions and Recommendations

Use **Body Text** style.

# Outputs, Outcomes, and Impacts

**[Delete these section instructions]**

**Outputs**: new or improved processes, practices, technologies, software, training aids, or other tangible products resulting from this activity.

**Outcomes**: changes made to the transportation system, or its regulatory, legislative, or policy framework, resulting from research outputs.

**Impacts:** the effects of an outcome on the transportation system, or society in general, such as reduced fatalities, decreased operating costs, etc.

## Research Outputs, Outcomes, and Impacts

**[Delete these section instructions]**

Please provide a detailed description of all **research** outputs, outcomes, and impacts resulting from this study.

Examples include:

* Peer-reviewed publications.
* Presentations at conferences and technical meetings.
* Changes to policy or regulations, or decisions that were informed by research findings.

## Technology Transfer Outputs, Outcomes, and Impacts

**[Delete these section instructions]**

Please provide a detailed description of all technology transfer outputs, outcomes, and impacts resulting from this study.

Examples include:

* Data sets produced, including digital object identifier (doi).
* Code developed, including links to a repository.
* Software developed, including doi.
* Intellectual property generated, including subject inventions, patent applications, and issued patents.
* Strategic partnerships formed to inform decision-making or drive technology adoption, including public and private sectors.

## Education and Workforce Development Outputs, Outcomes, and Impacts

**[Delete these section instructions]**

Please provide a detailed description of all education and workforce development outputs, outcomes, and impacts resulting from this study.

Examples include:

* Students involved in the project.
* Outreach to students conducted at the K-12 and university level as part of the project.
* Training and educational materials developed, including curricula, lectures, and classroom exercises.
* Innovative educational and outreach methods deployed as a result of the project.

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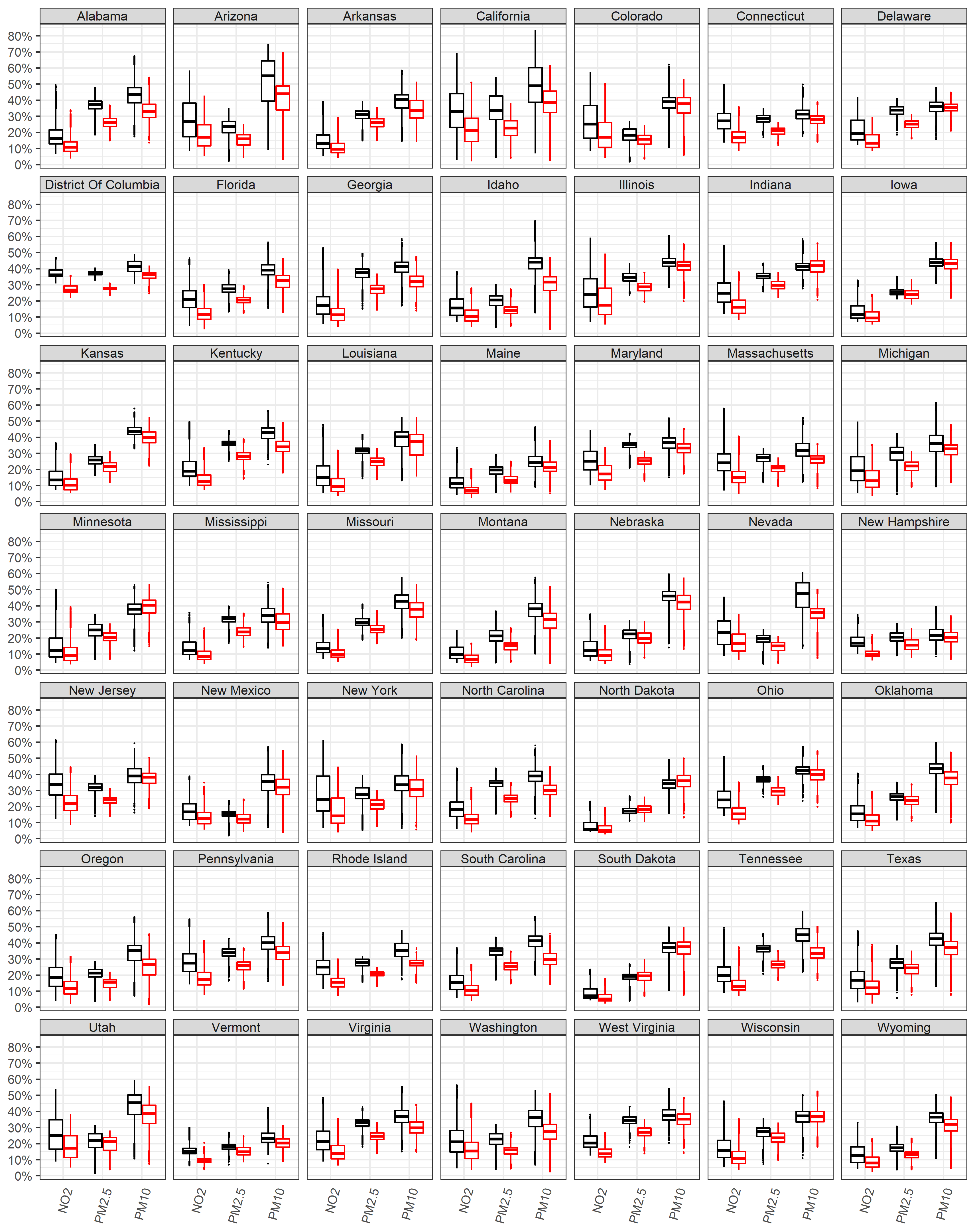
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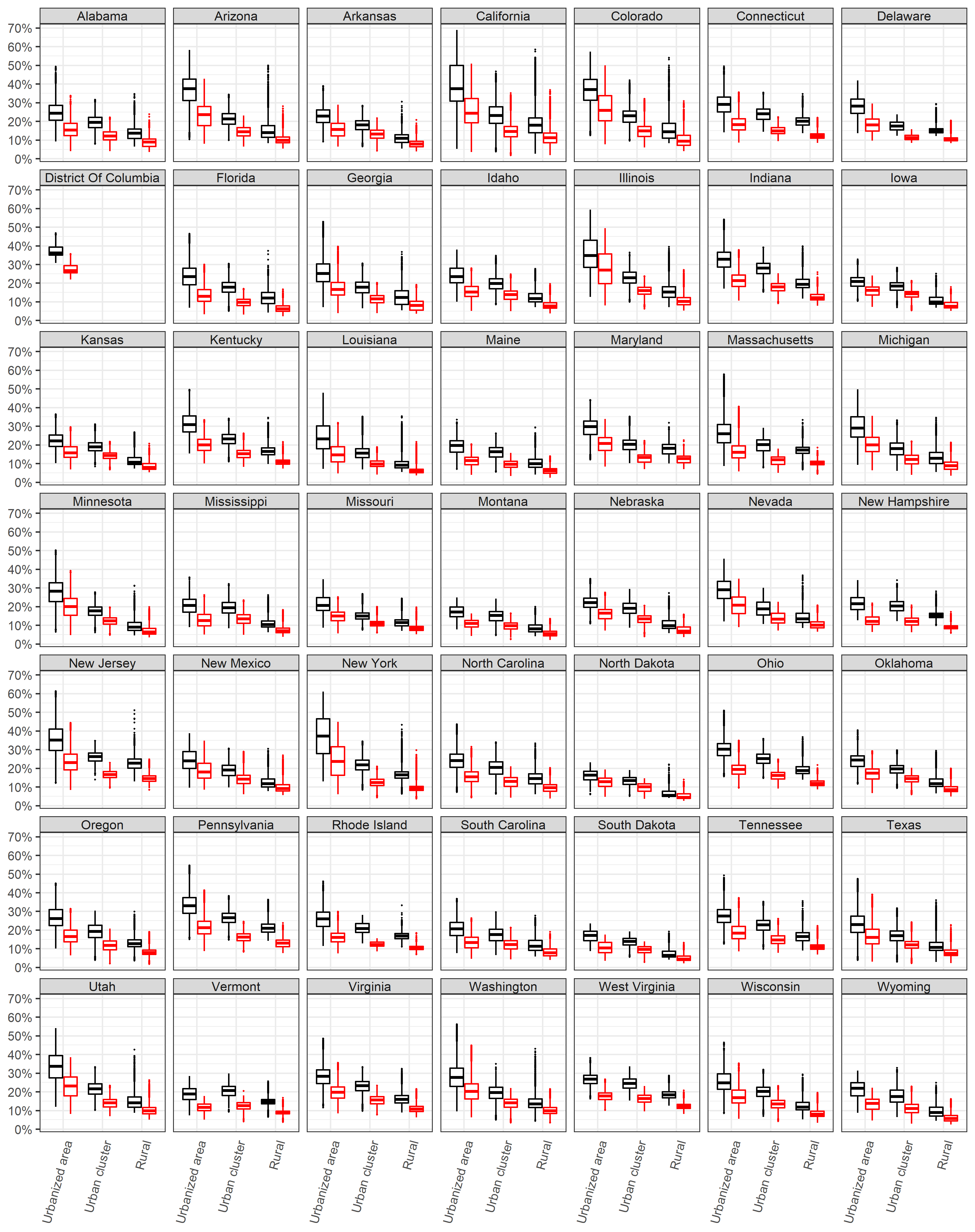
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Figure S. Attributable fraction of TRAP by state and year.



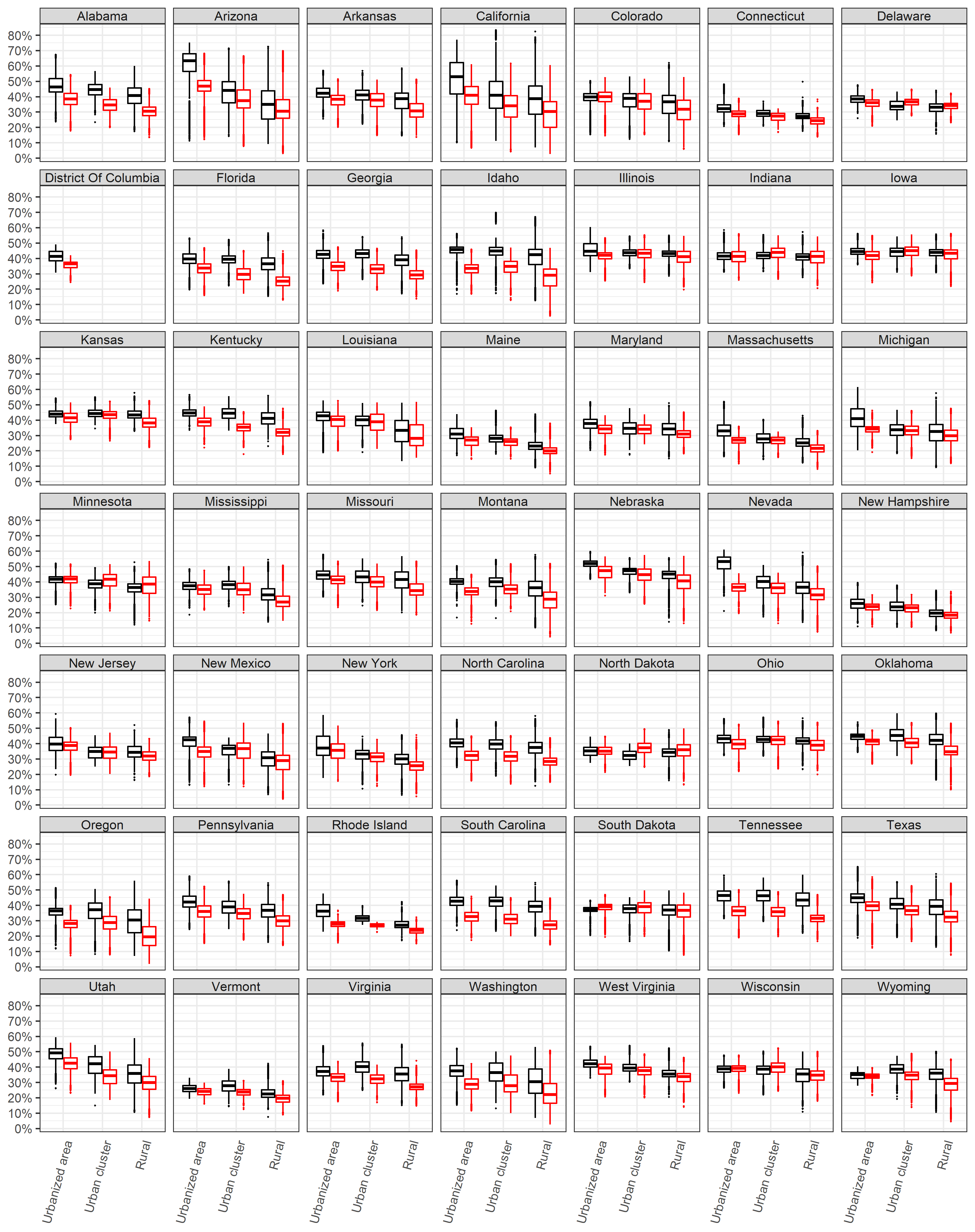
*\*Black box represent year 2000, and red boxes year 2010*

Figure S. Attributable fraction due to NO2 by living location



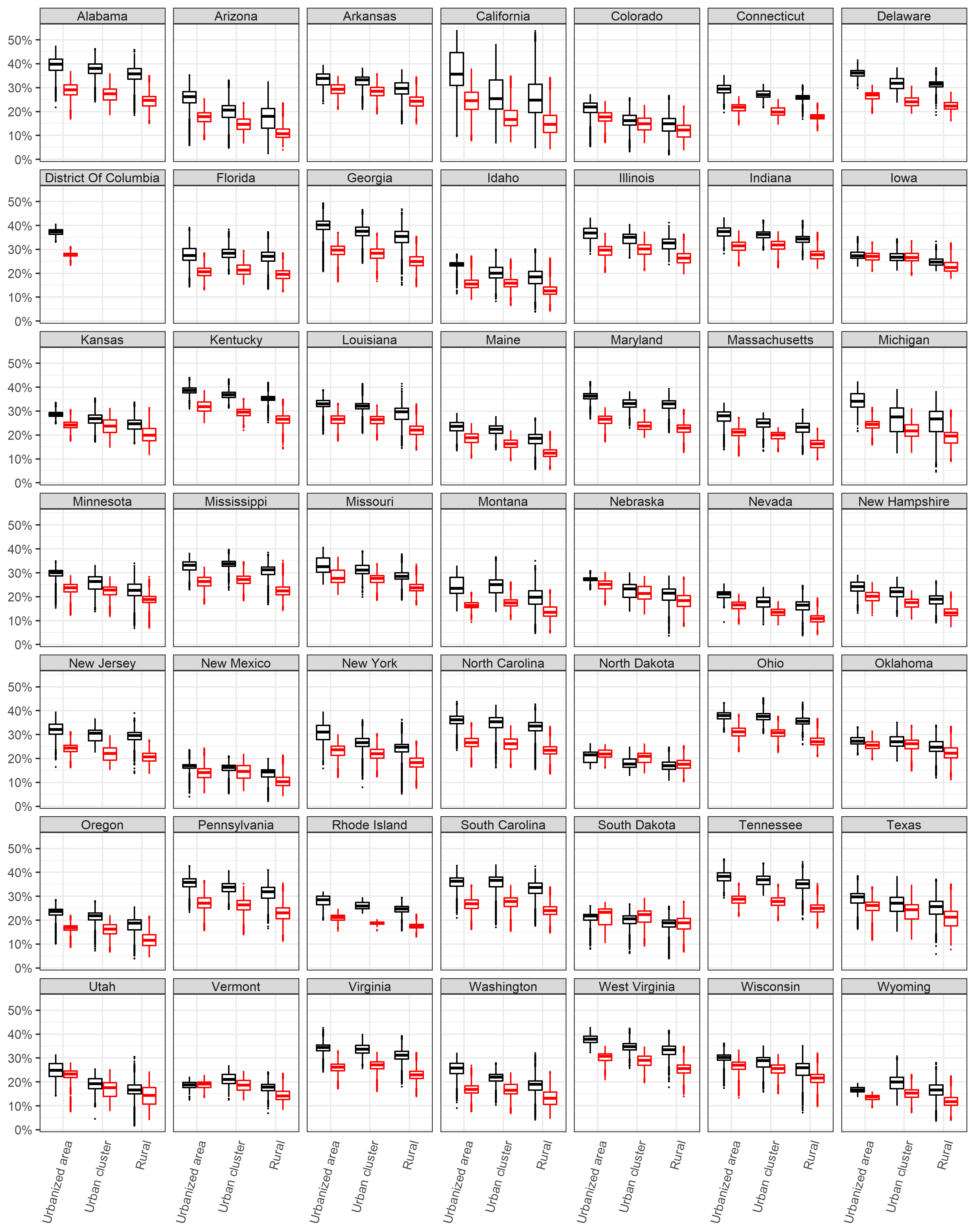
*\*Black box represent year 2000, and red boxes year 2010*

Figure S. Attributable fraction due to PM10 by living location



*\*Black box represent year 2000, and red boxes year 2010*

Figure S. Attributable fraction due to PM2.5 by living location



*\*Black box represent year 2000, and red boxes year 2010*

Figure S. Attributable fraction due to NO2 by median household income

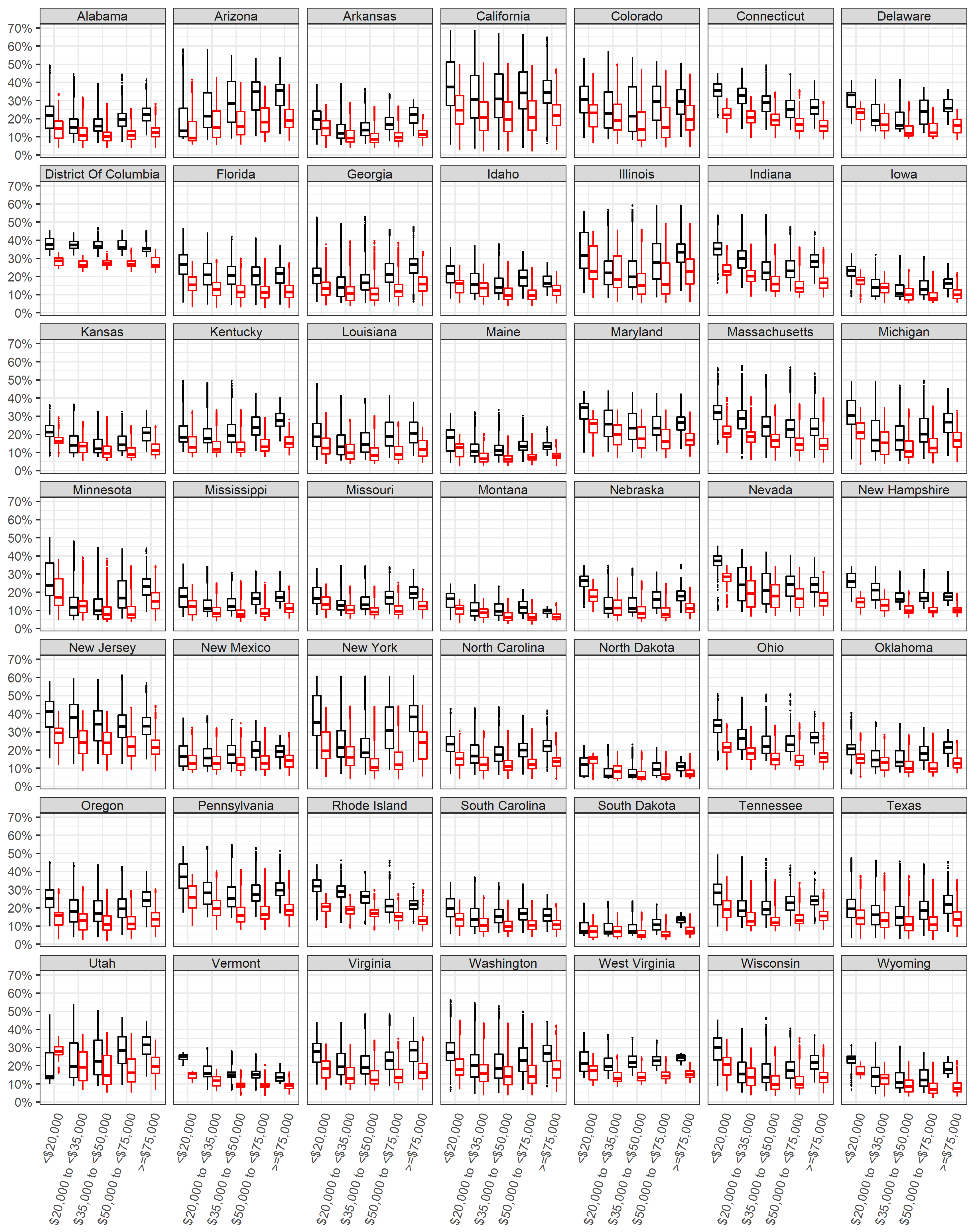
*\*Black box represent year 2000, and red boxes year 2010*

Figure S. Attributable fraction due to PM10 by median household income

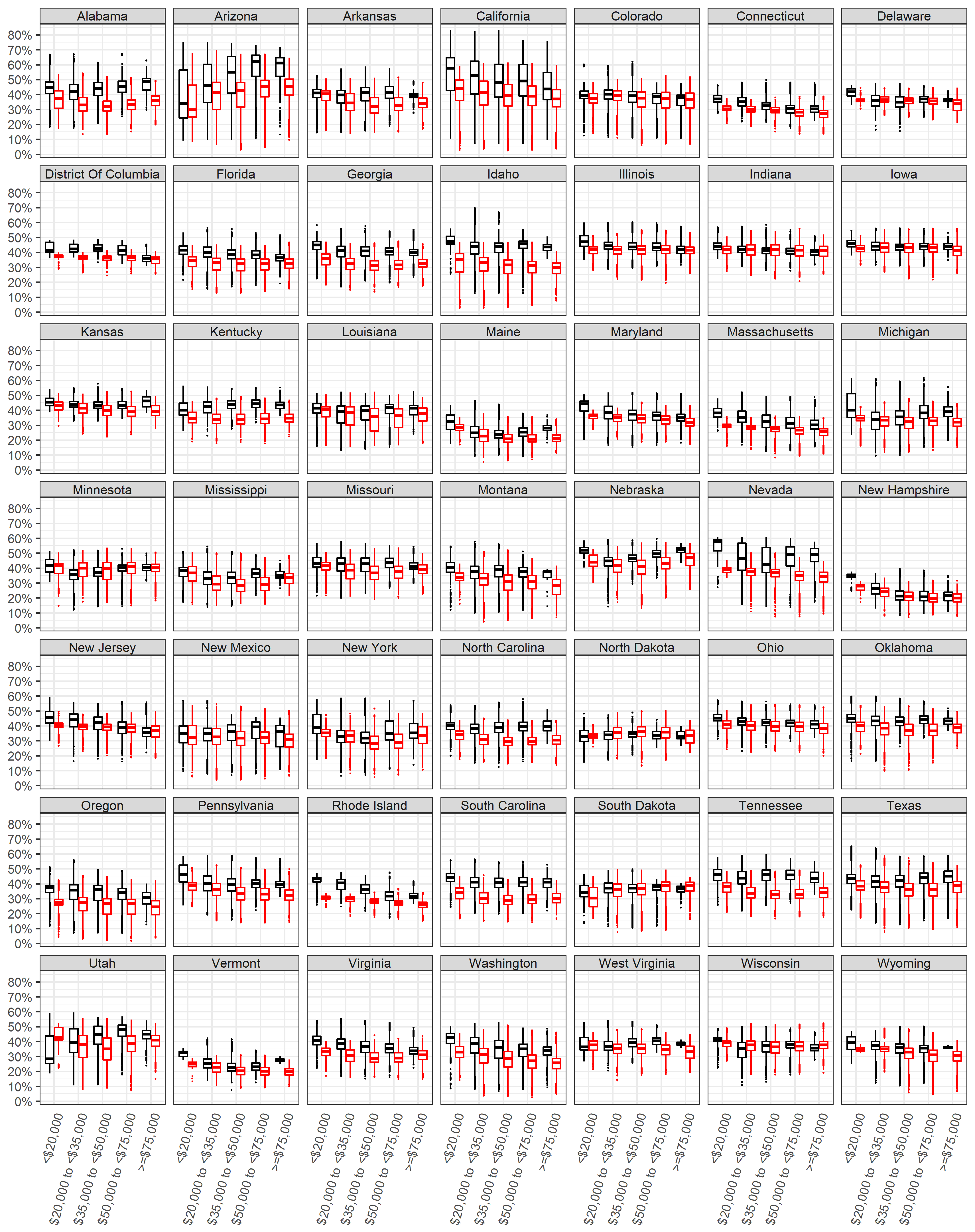
*\*Black box represent year 2000, and red boxes year 2010*

Figure S. Attributable fraction due to PM2.5 by median household income

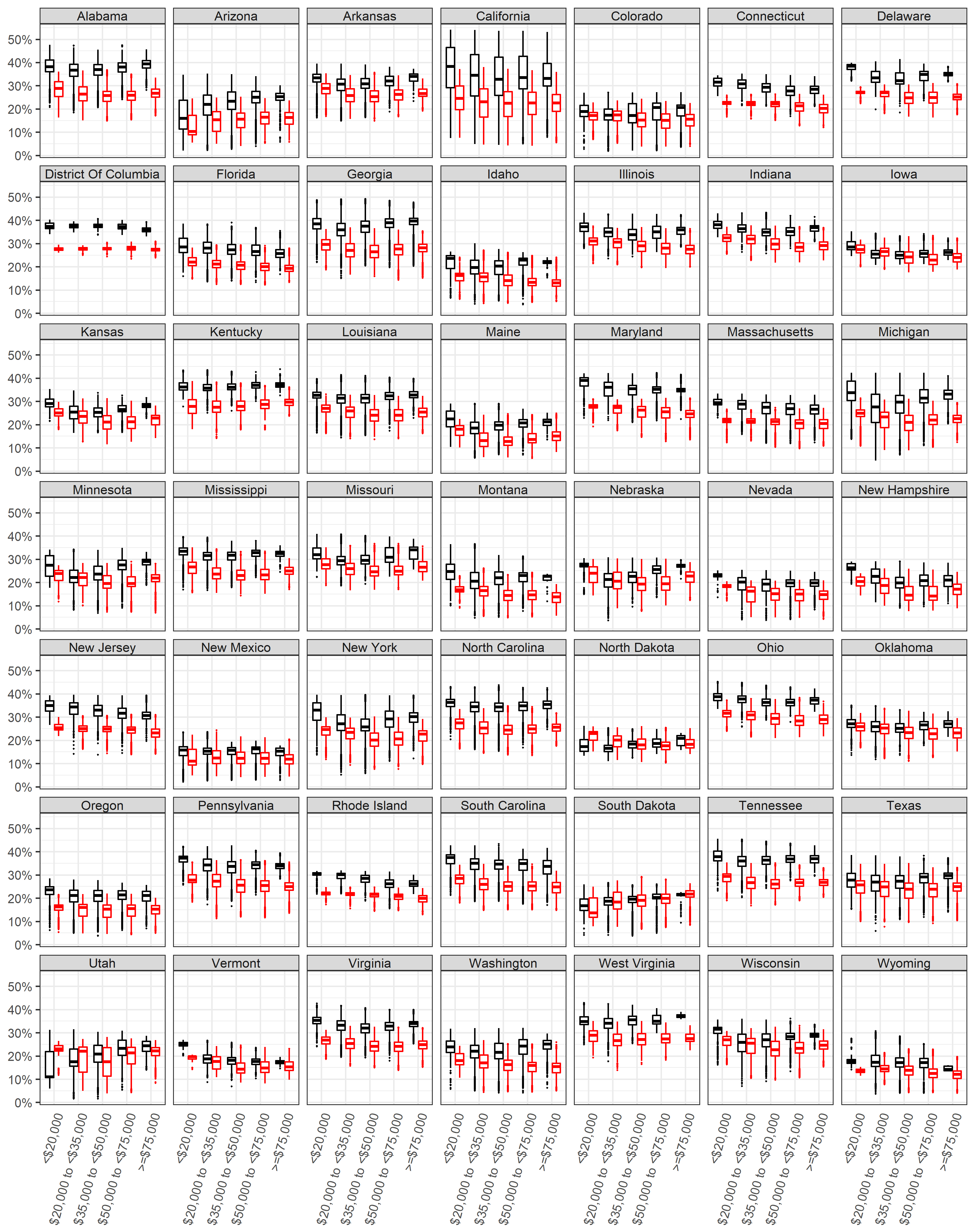
*\*Black box represent year 2000, and red boxes year 2010*

Table S. Geographical and demographical characteristics by state

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Populated Census Blocks** | | | **Total Population** | | | **Total Children** | | |
| **State** | **2000** | **2010** | **Change** | **2000** | **2010** | **Change** | **2000** | **2010** | **Change** |
| Alabama | 114,211 | 135,439 | 18.6% | 4,447,100 | 4,779,736 | 7.5% | 1,123,422 | 1,132,459 | 0.8% |
| Arizona | 80,553 | 114,742 | 42.4% | 5,130,632 | 6,392,017 | 24.6% | 1,366,947 | 1,629,014 | 19.2% |
| Arkansas | 84,150 | 96,096 | 14.2% | 2,673,400 | 2,915,918 | 9.1% | 680,369 | 711,475 | 4.6% |
| California | 344,356 | 403,398 | 17.1% | 33,871,648 | 37,253,956 | 10.0% | 9,249,829 | 9,295,040 | 0.5% |
| Colorado | 83,672 | 105,025 | 25.5% | 4,301,261 | 5,029,196 | 16.9% | 1,100,795 | 1,225,609 | 11.3% |
| Connecticut | 42,575 | 47,412 | 11.4% | 3,405,565 | 3,574,097 | 5.0% | 841,688 | 817,015 | -2.9% |
| Delaware | 13,184 | 15,933 | 20.9% | 783,600 | 897,934 | 14.6% | 194,587 | 205,765 | 5.7% |
| D.C. | 4,324 | 4,440 | 2.7% | 572,059 | 601,723 | 5.2% | 114,992 | 100,815 | -12.3% |
| Florida | 254,409 | 300,524 | 18.1% | 15,982,378 | 18,801,310 | 17.6% | 3,646,340 | 4,002,091 | 9.8% |
| Georgia | 144,008 | 167,353 | 16.2% | 8,186,453 | 9,687,653 | 18.3% | 2,169,234 | 2,491,552 | 14.9% |
| Idaho | 37,740 | 54,223 | 43.7% | 1,293,953 | 1,567,582 | 21.1% | 369,030 | 429,072 | 16.3% |
| Illinois | 254,521 | 300,384 | 18.0% | 12,419,293 | 12,830,632 | 3.3% | 3,245,451 | 3,129,179 | -3.6% |
| Indiana | 153,168 | 181,534 | 18.5% | 6,080,485 | 6,483,802 | 6.6% | 1,574,396 | 1,608,298 | 2.2% |
| Iowa | 122,243 | 137,429 | 12.4% | 2,926,324 | 3,046,355 | 4.1% | 733,638 | 727,993 | -0.8% |
| Kansas | 105,939 | 124,563 | 17.6% | 2,688,418 | 2,853,118 | 6.1% | 712,993 | 726,939 | 2.0% |
| Kentucky | 81,447 | 91,035 | 11.8% | 4,041,769 | 4,339,367 | 7.4% | 994,818 | 1,023,371 | 2.9% |
| Louisiana | 87,812 | 100,666 | 14.6% | 4,468,976 | 4,533,372 | 1.4% | 1,219,799 | 1,118,015 | -8.3% |
| Maine | 33,013 | 34,604 | 4.8% | 1,274,923 | 1,328,361 | 4.2% | 301,238 | 274,533 | -8.9% |
| Maryland | 60,164 | 80,944 | 34.5% | 5,296,486 | 5,773,552 | 9.0% | 1,356,172 | 1,352,964 | -0.2% |
| Massachusetts | 88,315 | 96,334 | 9.1% | 6,349,097 | 6,547,629 | 3.1% | 1,500,064 | 1,418,923 | -5.4% |
| Michigan | 190,827 | 207,522 | 8.8% | 9,938,444 | 9,883,640 | -0.6% | 2,595,767 | 2,344,068 | -9.7% |
| Minnesota | 133,531 | 151,983 | 13.8% | 4,919,479 | 5,303,925 | 7.8% | 1,286,894 | 1,284,063 | -0.2% |
| Mississippi | 82,279 | 84,750 | 3.0% | 2,844,658 | 2,967,297 | 4.3% | 775,187 | 755,555 | -2.5% |
| Missouri | 156,435 | 184,400 | 17.9% | 5,595,211 | 5,988,927 | 7.0% | 1,427,692 | 1,425,436 | -0.2% |
| Montana | 38,505 | 47,433 | 23.2% | 902,195 | 989,415 | 9.7% | 230,062 | 223,563 | -2.8% |
| Nebraska | 79,867 | 97,030 | 21.5% | 1,711,263 | 1,826,341 | 6.7% | 450,242 | 459,221 | 2.0% |
| Nevada | 26,209 | 35,617 | 35.9% | 1,998,257 | 2,700,551 | 35.1% | 511,799 | 665,008 | 29.9% |
| New Hampshire | 24,797 | 28,880 | 16.5% | 1,235,786 | 1,316,470 | 6.5% | 309,562 | 287,234 | -7.2% |
| New Jersey | 112,186 | 118,654 | 5.8% | 8,414,350 | 8,791,894 | 4.5% | 2,087,558 | 2,065,214 | -1.1% |
| New Mexico | 48,883 | 60,810 | 24.4% | 1,819,046 | 2,059,179 | 13.2% | 508,574 | 518,672 | 2.0% |
| New York | 225,167 | 242,807 | 7.8% | 18,976,457 | 19,378,102 | 2.1% | 4,690,107 | 4,324,929 | -7.8% |
| North Carolina | 157,641 | 185,219 | 17.5% | 8,049,313 | 9,535,483 | 18.5% | 1,964,047 | 2,281,635 | 16.2% |
| North Dakota | 39,145 | 47,559 | 21.5% | 642,200 | 672,591 | 4.7% | 160,849 | 149,871 | -6.8% |
| Ohio | 211,111 | 243,021 | 15.1% | 11,353,140 | 11,536,504 | 1.6% | 2,888,339 | 2,730,751 | -5.5% |
| Oklahoma | 111,022 | 135,561 | 22.1% | 3,450,654 | 3,751,351 | 8.7% | 892,360 | 929,666 | 4.2% |
| Oregon | 72,756 | 85,922 | 18.1% | 3,421,399 | 3,831,074 | 12.0% | 846,526 | 866,453 | 2.4% |
| Pennsylvania | 251,525 | 292,143 | 16.1% | 12,281,054 | 12,702,379 | 3.4% | 2,922,221 | 2,792,155 | -4.5% |
| Rhode Island | 17,196 | 17,644 | 2.6% | 1,048,319 | 1,052,567 | 0.4% | 247,822 | 223,956 | -9.6% |
| South Carolina | 95,667 | 108,669 | 13.6% | 4,012,012 | 4,625,364 | 15.3% | 1,009,641 | 1,080,474 | 7.0% |
| South Dakota | 42,094 | 45,168 | 7.3% | 754,844 | 814,180 | 7.9% | 202,649 | 202,797 | 0.1% |
| Tennessee | 122,059 | 143,319 | 17.4% | 5,689,283 | 6,346,105 | 11.5% | 1,398,521 | 1,496,001 | 7.0% |
| Texas | 388,643 | 454,658 | 17.0% | 20,851,820 | 25,145,561 | 20.6% | 5,886,759 | 6,865,824 | 16.6% |
| Utah | 36,375 | 45,558 | 25.2% | 2,233,169 | 2,763,885 | 23.8% | 718,698 | 871,027 | 21.2% |
| Vermont | 16,105 | 17,541 | 8.9% | 608,827 | 625,741 | 2.8% | 147,523 | 129,233 | -12.4% |
| Virginia | 101,285 | 145,045 | 43.2% | 7,078,515 | 8,001,024 | 13.0% | 1,738,262 | 1,853,677 | 6.6% |
| Washington | 100,263 | 118,774 | 18.5% | 5,894,121 | 6,724,540 | 14.1% | 1,513,843 | 1,581,354 | 4.5% |
| West Virginia | 49,101 | 66,728 | 35.9% | 1,808,344 | 1,852,994 | 2.5% | 402,393 | 387,418 | -3.7% |
| Wisconsin | 139,546 | 152,756 | 9.5% | 5,363,675 | 5,686,986 | 6.0% | 1,368,756 | 1,339,492 | -2.1% |
| Wyoming | 20,190 | 25,633 | 27.0% | 493,782 | 563,626 | 14.1% | 128,873 | 135,402 | 5.1% |

Table S. State-specific Childhood asthma incidence rate and prevalence rate

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **State** | **2006\*** | **2007\*** | **2008\*** | **2009\*** | **2010\*** | **Aggregate**  **IR\*** | **Aggregate PR\*\*** |
| Alabama |  |  |  |  |  | 11.6 | 14.4 |
| Arizona | 23.7 | 6.8 |  |  |  | 15.2 | 13.1 |
| Arkansas |  |  |  |  |  | 11.6 | 13.1 |
| California | 12.1 | 6.5 |  |  |  | 9.3 | 12.2 |
| Colorado |  |  |  |  |  | 11.6 | 13.1 |
| Connecticut |  | 9.9 | 14.1 | 10.8 | 13.5 | 12 | 16 |
| Delaware |  |  |  |  |  | 11.6 | 18.2 |
| District of Columbia | 5.3 | 28.8 |  |  |  | 17.7 | 19.9 |
| Florida |  |  |  |  |  | 11.6 | 13.1 |
| Georgia | 6.4 | 5.8 | 9.1 | 16.6 | 6.9 | 9.1 | 15.1 |
| Idaho |  |  |  |  |  | 11.6 | 9 |
| Illinois |  | 4.2 |  | 9.2 |  | 6.7 | 12.4 |
| Indiana | 25.4 | 9.3 | 13.4 | 9.9 | 17.6 | 15.2 | 12.8 |
| Iowa | 5 | 4 | 9.9 |  |  | 6.3 | 8.4 |
| Kansas | 7.8 | 9.9 | 9.9 | 8.3 | 9 | 9 | 11.6 |
| Kentucky |  |  |  |  |  | 11.6 | 14 |
| Louisiana |  |  |  | 5.8 |  | 5.8 | 13 |
| Maine | 13 | 8.7 | 5.8 |  |  | 9.2 | 13.2 |
| Maryland | 16.2 | 8.6 | 11 | 17.3 | 2.3 | 11.2 | 14.8 |
| Massachusetts |  |  |  |  |  | 11.6 | 13.1 |
| Michigan | 5.3 | 7.7 | 5.2 | 13.4 | 29.3 | 12 | 13.6 |
| Minnesota |  |  |  |  |  | 11.6 | 9.5 |
| Mississippi |  | 10.8 |  |  | 17.2 | 14 | 14.2 |
| Missouri | 21.2 | 10.3 | 7.2 |  |  | 12.9 | 13.9 |
| Montana | 2.8 | 2 |  | 3.7 | 8.5 | 4.3 | 9.7 |
| Nebraska | 11.9 | 8.3 | 8.9 | 3.3 | 12.9 | 9.1 | 9.3 |
| Nevada |  |  |  |  |  | 11.6 | 10.9 |
| New Hampshire | 11.5 | 13.8 | 10.4 |  |  | 12 | 12.1 |
| New Jersey |  |  | 6.3 | 12.5 | 10.5 | 9.8 | 14.3 |
| New Mexico |  | 3.2 | 9.5 |  | 7.2 | 6.7 | 12 |
| New York | 12.9 | 6.1 | 28.4 | 11.2 |  | 14.7 | 15.8 |
| North Carolina |  |  |  |  |  | 11.6 | 13.1 |
| North Dakota |  |  |  |  |  | 11.6 | 8.9 |
| Ohio |  | 13.1 | 17 |  |  | 15.1 | 12.3 |
| Oklahoma |  | 9.2 | 10.1 |  | 12.9 | 10.8 | 14 |
| Oregon |  | 11.1 |  |  |  | 11.1 | 11.1 |
| Pennsylvania |  | 21.8 |  |  | 4.3 | 13.2 | 13.9 |
| Rhode Island |  |  | 15.3 | 13.2 |  | 14.3 | 16.1 |
| South Carolina |  |  |  |  |  | 11.6 | 13.1 |
| South Dakota |  |  |  |  |  | 11.6 | 13.1 |
| Tennessee |  |  |  |  |  | 11.6 | 13.1 |
| Texas | 14.4 |  | 18.2 | 12.5 | 21 | 16.6 | 13.1 |
| Utah |  | 15.4 | 11.9 | 5.6 | 9.3 | 10.4 | 10.2 |
| Vermont | 13.5 | 4.4 | 8.5 | 21.2 | 10.4 | 11.5 | 13.8 |
| Virginia |  |  |  |  |  | 11.6 | 13.6 |
| Washington |  |  |  | 7.9 | 5.6 | 6.8 | 10.8 |
| West Virginia |  | 11.8 |  |  |  | 11.8 | 12.7 |
| Wisconsin | 12.3 |  |  |  |  | 12.3 | 10.6 |
| Wyoming |  |  |  |  |  | 11.6 | 9.5 |

*\*Incidence rate per 1,000 at-risk children*

*\*\* Prevalence rate per 100 children*

*[Note: The grey highlight represents no available data]*

Table S. Air pollution concentrations by state

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **NO2** | | | **PM10** | | | **PM2.5** | | |
| **State** | **2000** | **2010** | **Change (%)** | **2000** | **2010** | **Change (%)** | **2000** | **2010** | **Change (%)** |
| Alabama | 16.2 | 10.3 | -36% | 23.4 | 17 | -27% | 15.6 | 10.3 | -34% |
| Arizona | 27.8 | 17 | -39% | 31.5 | 22.6 | -28% | 8.8 | 5.7 | -35% |
| Arkansas | 13.2 | 9.3 | -30% | 20.5 | 17.3 | -16% | 12.4 | 10.2 | -18% |
| California | 35.9 | 21.1 | -41% | 28.6 | 20.2 | -29% | 14.5 | 8.6 | -41% |
| Colorado | 26.5 | 18.1 | -32% | 19.4 | 18.6 | -4% | 6.8 | 5.6 | -18% |
| Connecticut | 26.3 | 15.6 | -41% | 15.6 | 13.4 | -14% | 11.4 | 7.9 | -31% |
| Delaware | 20.4 | 13.2 | -35% | 18.2 | 17.9 | -2% | 13.8 | 9.7 | -30% |
| District of Columbia | 38.2 | 26.3 | -31% | 21.8 | 18.1 | -17% | 15.7 | 11 | -30% |
| Florida | 19.7 | 10.7 | -46% | 20.5 | 15.9 | -22% | 11 | 7.8 | -29% |
| Georgia | 16.6 | 10.8 | -35% | 21.6 | 15.9 | -26% | 15.7 | 10.8 | -31% |
| Idaho | 15.3 | 9.8 | -36% | 22.8 | 14.9 | -35% | 7.5 | 5.3 | -29% |
| Illinois | 25.6 | 19 | -26% | 24.2 | 22.1 | -9% | 14.4 | 11.3 | -22% |
| Indiana | 24.8 | 15.4 | -38% | 22 | 22 | 0% | 14.9 | 12 | -19% |
| Iowa | 11.9 | 9.1 | -24% | 23.7 | 23 | -3% | 9.9 | 9.4 | -5% |
| Kansas | 13.4 | 9.7 | -28% | 23.8 | 21 | -12% | 10 | 8.2 | -18% |
| Kentucky | 19.7 | 12.4 | -37% | 22.9 | 17.4 | -24% | 15.3 | 11.3 | -26% |
| Louisiana | 15.8 | 9.6 | -39% | 19.9 | 18.2 | -9% | 12.7 | 9.6 | -24% |
| Maine | 10.8 | 6.3 | -42% | 12 | 10.1 | -16% | 7.3 | 5 | -32% |
| Maryland | 24.1 | 16.1 | -33% | 18.8 | 16.5 | -12% | 14.6 | 9.8 | -33% |
| Massachusetts | 23.9 | 14.1 | -41% | 16.2 | 12.4 | -23% | 10.6 | 7.7 | -27% |
| Michigan | 19.8 | 12.9 | -35% | 18.9 | 15.9 | -16% | 12 | 8.3 | -31% |
| Minnesota | 14.1 | 9.9 | -30% | 19.3 | 20.5 | 6% | 9.7 | 7.7 | -21% |
| Mississippi | 12.4 | 8.3 | -33% | 17.1 | 15.2 | -11% | 12.8 | 9.3 | -27% |
| Missouri | 13.1 | 9.3 | -29% | 22.8 | 19.5 | -14% | 12.2 | 10.1 | -17% |
| Montana | 9.6 | 6.2 | -35% | 19 | 15.1 | -21% | 8.2 | 5.5 | -33% |
| Nebraska | 12.3 | 8.6 | -30% | 25.3 | 22.4 | -11% | 8.5 | 7.6 | -11% |
| Nevada | 22.5 | 15.9 | -29% | 26 | 17.8 | -32% | 7.3 | 5.4 | -26% |
| New Hampshire | 16.4 | 9.1 | -45% | 10.4 | 9.4 | -10% | 7.9 | 6 | -24% |
| New Jersey | 34.4 | 21 | -39% | 20.6 | 19.3 | -6% | 13 | 9.2 | -29% |
| New Mexico | 16 | 12.1 | -24% | 17.5 | 15.9 | -9% | 5.5 | 4.5 | -18% |
| New York | 28.8 | 16.6 | -42% | 18 | 15.5 | -14% | 11.2 | 8.1 | -28% |
| North Carolina | 17.1 | 11 | -36% | 20.2 | 14.9 | -26% | 14.2 | 9.8 | -31% |
| North Dakota | 6.8 | 5.4 | -21% | 17 | 18.2 | 7% | 6.5 | 6.9 | 6% |
| Ohio | 23.6 | 14.3 | -39% | 22.8 | 20.8 | -9% | 15.6 | 11.8 | -24% |
| Oklahoma | 14.8 | 10.4 | -30% | 23.7 | 19.6 | -17% | 10.1 | 9.2 | -9% |
| Oregon | 18.1 | 11.1 | -39% | 16.9 | 11.9 | -30% | 7.8 | 5.4 | -31% |
| Pennsylvania | 27.6 | 16.6 | -40% | 21.2 | 17 | -20% | 14 | 10.1 | -28% |
| Rhode Island | 23.6 | 13.8 | -42% | 18.1 | 13.1 | -28% | 11 | 7.8 | -29% |
| South Carolina | 14.2 | 9.4 | -34% | 21.5 | 14.7 | -32% | 14.3 | 9.9 | -31% |
| South Dakota | 7.6 | 5.2 | -32% | 18.9 | 18.7 | -1% | 7.1 | 7.2 | 1% |
| Tennessee | 19.4 | 12.7 | -35% | 24.6 | 16.9 | -31% | 15.3 | 10.5 | -31% |
| Texas | 16.2 | 11.5 | -29% | 22.4 | 18.8 | -16% | 10.7 | 9.2 | -14% |
| Utah | 25.5 | 17 | -33% | 23.8 | 19.8 | -17% | 8.2 | 7.4 | -10% |
| Vermont | 14 | 8.3 | -41% | 11.3 | 9.4 | -17% | 6.8 | 5.7 | -16% |
| Virginia | 21 | 13.5 | -36% | 19 | 14.7 | -23% | 13.4 | 9.5 | -29% |
| Washington | 20.9 | 14.9 | -29% | 17.9 | 13.2 | -26% | 8.7 | 5.8 | -33% |
| West Virginia | 19.9 | 12.7 | -36% | 19.7 | 17.8 | -10% | 14.4 | 10.8 | -25% |
| Wisconsin | 15.9 | 10.6 | -33% | 18.5 | 18.8 | 2% | 10.6 | 9.1 | -14% |
| Wyoming | 12.3 | 7.6 | -38% | 18.3 | 15.4 | -16% | 6.6 | 4.8 | -27% |

Table S. Incident cases by state

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Incident Cases** | | |
| **STATE** | **2000** | **2010** | **Change (%)** |
| Alabama | 12,300 | 12,200 | -1% |
| Arizona | 15,000 | 17,600 | 17% |
| Arkansas | 7,500 | 7,700 | 3% |
| California | 101,300 | 100,300 | -1% |
| Colorado | 12,100 | 13,200 | 9% |
| Connecticut | 9,200 | 8,800 | -4% |
| Delaware | 2,100 | 2,200 | 5% |
| District of Columbia | 1,300 | 1,100 | -15% |
| Florida | 39,900 | 43,200 | 8% |
| Georgia | 23,800 | 26,900 | 13% |
| Idaho | 4,000 | 4,600 | 15% |
| Illinois | 35,500 | 33,800 | -5% |
| Indiana | 17,200 | 17,300 | 1% |
| Iowa | 8,000 | 7,900 | -1% |
| Kansas | 7,800 | 7,800 | 0% |
| Kentucky | 10,900 | 11,000 | 1% |
| Louisiana | 13,400 | 12,100 | -10% |
| Maine | 3,300 | 3,000 | -9% |
| Maryland | 14,900 | 14,600 | -2% |
| Massachusetts | 16,400 | 15,300 | -7% |
| Michigan | 28,400 | 25,300 | -11% |
| Minnesota | 14,100 | 13,900 | -1% |
| Mississippi | 8,500 | 8,200 | -4% |
| Missouri | 15,600 | 15,400 | -1% |
| Montana | 2,500 | 2,400 | -4% |
| Nebraska | 4,900 | 5,000 | 2% |
| Nevada | 5,600 | 7,200 | 29% |
| New Hampshire | 3,400 | 3,100 | -9% |
| New Jersey | 22,900 | 22,300 | -3% |
| New Mexico | 5,600 | 5,600 | 0% |
| New York | 51,400 | 46,700 | -9% |
| North Carolina | 21,500 | 24,600 | 14% |
| North Dakota | 1,800 | 1,600 | -11% |
| Ohio | 31,600 | 29,500 | -7% |
| Oklahoma | 9,800 | 10,000 | 2% |
| Oregon | 9,300 | 9,300 | 0% |
| Pennsylvania | 32,000 | 30,100 | -6% |
| Rhode Island | 2,700 | 2,400 | -11% |
| South Carolina | 11,100 | 11,700 | 5% |
| South Dakota | 2,200 | 2,200 | 0% |
| Tennessee | 15,300 | 16,100 | 5% |
| Texas | 64,500 | 74,100 | 15% |
| Utah | 7,900 | 9,400 | 19% |
| Vermont | 1,600 | 1,400 | -13% |
| Virginia | 19,000 | 20,000 | 5% |
| Washington | 16,600 | 17,100 | 3% |
| West Virginia | 4,400 | 4,200 | -5% |
| Wisconsin | 15,000 | 14,400 | -4% |
| Wyoming | 1,400 | 1,500 | 7% |

Table S. Burden estimates due to NO2 by state

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **NO2** | **Attributable Cases** | | | **Attributable Fraction** | | |
| **STATE** | **2000** | **2010** | **Change (%)** | **2000** | **2010** | **Change (%)** |
| Alabama | 2,300 | 1,400 | -39% | 19% | 11% | -42% |
| Arizona | 4,900 | 3,800 | -22% | 33% | 22% | -33% |
| Arkansas | 1,200 | 900 | -25% | 16% | 12% | -25% |
| California | 39,300 | 25,400 | -35% | 39% | 25% | -36% |
| Colorado | 3,800 | 3,100 | -18% | 31% | 23% | -26% |
| Connecticut | 2,600 | 1,600 | -38% | 28% | 18% | -36% |
| Delaware | 500 | 400 | -20% | 24% | 18% | -25% |
| District Of Columbia | 500 | 300 | -40% | 38% | 27% | -29% |
| Florida | 8,700 | 5,500 | -37% | 22% | 13% | -41% |
| Georgia | 5,000 | 3,900 | -22% | 21% | 14% | -33% |
| Idaho | 700 | 600 | -14% | 18% | 13% | -28% |
| Illinois | 12,000 | 8,300 | -31% | 34% | 25% | -26% |
| Indiana | 4,800 | 3,100 | -35% | 28% | 18% | -36% |
| Iowa | 1,300 | 1,000 | -23% | 16% | 13% | -19% |
| Kansas | 1,400 | 1,100 | -21% | 18% | 14% | -22% |
| Kentucky | 2,500 | 1,600 | -36% | 23% | 15% | -35% |
| Louisiana | 2,500 | 1,400 | -44% | 19% | 12% | -37% |
| Maine | 400 | 200 | -50% | 12% | 7% | -42% |
| Maryland | 4,000 | 2,800 | -30% | 27% | 19% | -30% |
| Massachusetts | 4,300 | 2,500 | -42% | 26% | 16% | -38% |
| Michigan | 7,000 | 4,200 | -40% | 25% | 17% | -32% |
| Minnesota | 2,900 | 2,100 | -28% | 21% | 15% | -29% |
| Mississippi | 1,300 | 800 | -38% | 15% | 10% | -33% |
| Missouri | 2,700 | 1,800 | -33% | 17% | 12% | -29% |
| Montana | 300 | 200 | -33% | 12% | 8% | -33% |
| Nebraska | 900 | 600 | -33% | 18% | 12% | -33% |
| Nevada | 1,500 | 1,400 | -7% | 27% | 19% | -30% |
| New Hampshire | 600 | 300 | -50% | 18% | 10% | -44% |
| New Jersey | 8,200 | 5,400 | -34% | 36% | 24% | -33% |
| New Mexico | 1,100 | 900 | -18% | 20% | 16% | -20% |
| New York | 19,400 | 11,800 | -39% | 38% | 25% | -34% |
| North Carolina | 4,100 | 3,200 | -22% | 19% | 13% | -32% |
| North Dakota | 200 | 100 | -50% | 11% | 6% | -45% |
| Ohio | 8,400 | 5,000 | -40% | 27% | 17% | -37% |
| Oklahoma | 1,800 | 1,300 | -28% | 18% | 13% | -28% |
| Oregon | 2,000 | 1,300 | -35% | 22% | 14% | -36% |
| Pennsylvania | 9,600 | 6,000 | -38% | 30% | 20% | -33% |
| Rhode Island | 700 | 400 | -43% | 26% | 17% | -35% |
| South Carolina | 1,800 | 1,300 | -28% | 16% | 11% | -31% |
| South Dakota | 200 | 200 | 0% | 9% | 9% | 0% |
| Tennessee | 3,400 | 2,500 | -26% | 22% | 16% | -27% |
| Texas | 12,900 | 10,700 | -17% | 20% | 14% | -30% |
| Utah | 2,300 | 1,900 | -17% | 29% | 20% | -31% |
| Vermont | 300 | 100 | -67% | 19% | 7% | -63% |
| Virginia | 4,600 | 3,400 | -26% | 24% | 17% | -29% |
| Washington | 3,900 | 3,000 | -23% | 23% | 18% | -22% |
| West Virginia | 900 | 600 | -33% | 20% | 14% | -30% |
| Wisconsin | 3,100 | 2,100 | -32% | 21% | 15% | -29% |
| Wyoming | 200 | 100 | -50% | 14% | 7% | -50% |

Table S. Burden estimates due to PM10 by state

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **PM10** | **Attributable Cases** | | | **Attributable Fraction** | | |
| **STATE** | **2000** | **2010** | **Change (%)** | **2000** | **2010** | **Change (%)** |
| Alabama | 5,300 | 4,200 | -21% | 43% | 34% | -21% |
| Arizona | 8,500 | 8,100 | -5% | 57% | 46% | -19% |
| Arkansas | 3,000 | 2,700 | -10% | 40% | 35% | -13% |
| California | 53,100 | 41,300 | -22% | 52% | 41% | -21% |
| Colorado | 4,600 | 5,000 | 9% | 38% | 38% | 0% |
| Connecticut | 3,000 | 2,500 | -17% | 33% | 28% | -15% |
| Delaware | 800 | 800 | 0% | 38% | 36% | -5% |
| District of Columbia | 500 | 400 | -20% | 38% | 36% | -5% |
| Florida | 15,500 | 14,000 | -10% | 39% | 32% | -18% |
| Georgia | 9,700 | 8,900 | -8% | 41% | 33% | -20% |
| Idaho | 1,700 | 1,500 | -12% | 42% | 33% | -21% |
| Illinois | 16,300 | 14,000 | -14% | 46% | 41% | -11% |
| Indiana | 7,100 | 7,100 | 0% | 41% | 41% | 0% |
| Iowa | 3,500 | 3,300 | -6% | 44% | 42% | -5% |
| Kansas | 3,400 | 3,200 | -6% | 44% | 41% | -7% |
| Kentucky | 4,700 | 3,800 | -19% | 43% | 35% | -19% |
| Louisiana | 5,200 | 4,300 | -17% | 39% | 36% | -8% |
| Maine | 800 | 600 | -25% | 24% | 20% | -17% |
| Maryland | 5,500 | 4,800 | -13% | 37% | 33% | -11% |
| Massachusetts | 5,400 | 4,000 | -26% | 33% | 26% | -21% |
| Michigan | 11,000 | 8,200 | -25% | 39% | 32% | -18% |
| Minnesota | 5,500 | 5,500 | 0% | 39% | 40% | 3% |
| Mississippi | 2,900 | 2,500 | -14% | 34% | 30% | -12% |
| Missouri | 6,700 | 5,900 | -12% | 43% | 38% | -12% |
| Montana | 900 | 700 | -22% | 36% | 29% | -19% |
| Nebraska | 2,400 | 2,200 | -8% | 49% | 44% | -10% |
| Nevada | 2,800 | 2,600 | -7% | 50% | 36% | -28% |
| New Hampshire | 800 | 600 | -25% | 24% | 19% | -21% |
| New Jersey | 9,200 | 8,400 | -9% | 40% | 38% | -5% |
| New Mexico | 2,000 | 1,900 | -5% | 36% | 34% | -6% |
| New York | 21,000 | 16,200 | -23% | 41% | 35% | -15% |
| North Carolina | 8,400 | 7,500 | -11% | 39% | 30% | -23% |
| North Dakota | 600 | 600 | 0% | 33% | 38% | 15% |
| Ohio | 13,400 | 11,500 | -14% | 42% | 39% | -7% |
| Oklahoma | 4,300 | 3,900 | -9% | 44% | 39% | -11% |
| Oregon | 3,200 | 2,500 | -22% | 34% | 27% | -21% |
| Pennsylvania | 13,200 | 10,200 | -23% | 41% | 34% | -17% |
| Rhode Island | 1,000 | 700 | -30% | 37% | 29% | -22% |
| South Carolina | 4,500 | 3,500 | -22% | 41% | 30% | -27% |
| South Dakota | 800 | 800 | 0% | 36% | 36% | 0% |
| Tennessee | 6,800 | 5,500 | -19% | 44% | 34% | -23% |
| Texas | 28,000 | 28,000 | 0% | 43% | 38% | -12% |
| Utah | 3,600 | 3,800 | 6% | 46% | 40% | -13% |
| Vermont | 400 | 300 | -25% | 25% | 21% | -16% |
| Virginia | 6,900 | 6,300 | -9% | 36% | 32% | -11% |
| Washington | 5,800 | 4,600 | -21% | 35% | 27% | -23% |
| West Virginia | 1,700 | 1,400 | -18% | 39% | 33% | -15% |
| Wisconsin | 5,600 | 5,500 | -2% | 37% | 38% | 3% |
| Wyoming | 500 | 500 | 0% | 36% | 33% | -8% |

Table S. Burden estimates due to PM2.5 by state

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **PM2.5** | **Attributable Cases** | | | **Attributable Fraction** | | |
| **STATE** | **2000** | **2010** | **Change (%)** | **2000** | **2010** | **Change (%)** |
| Alabama | 4,500 | 3,200 | -29% | 37% | 26% | -30% |
| Arizona | 3,600 | 3,000 | -17% | 24% | 17% | -29% |
| Arkansas | 2,300 | 2,100 | -9% | 31% | 27% | -13% |
| California | 37,700 | 24,400 | -35% | 37% | 24% | -35% |
| Colorado | 2,300 | 2,200 | -4% | 19% | 17% | -11% |
| Connecticut | 2,700 | 1,900 | -30% | 29% | 22% | -24% |
| Delaware | 700 | 600 | -14% | 33% | 27% | -18% |
| District Of Columbia | 500 | 300 | -40% | 38% | 27% | -29% |
| Florida | 11,000 | 8,700 | -21% | 28% | 20% | -29% |
| Georgia | 9,000 | 7,600 | -16% | 38% | 28% | -26% |
| Idaho | 800 | 700 | -13% | 20% | 15% | -25% |
| Illinois | 12,800 | 9,700 | -24% | 36% | 29% | -19% |
| Indiana | 6,200 | 5,200 | -16% | 36% | 30% | -17% |
| Iowa | 2,100 | 2,000 | -5% | 26% | 25% | -4% |
| Kansas | 2,100 | 1,800 | -14% | 27% | 23% | -15% |
| Kentucky | 4,000 | 3,200 | -20% | 37% | 29% | -22% |
| Louisiana | 4,200 | 3,000 | -29% | 31% | 25% | -19% |
| Maine | 700 | 400 | -43% | 21% | 13% | -38% |
| Maryland | 5,200 | 3,700 | -29% | 35% | 25% | -29% |
| Massachusetts | 4,500 | 3,200 | -29% | 27% | 21% | -22% |
| Michigan | 9,000 | 5,700 | -37% | 32% | 23% | -28% |
| Minnesota | 3,800 | 3,000 | -21% | 27% | 22% | -19% |
| Mississippi | 2,700 | 2,000 | -26% | 32% | 24% | -25% |
| Missouri | 4,900 | 4,100 | -16% | 31% | 27% | -13% |
| Montana | 600 | 400 | -33% | 24% | 17% | -29% |
| Nebraska | 1,200 | 1,100 | -8% | 24% | 22% | -8% |
| Nevada | 1,100 | 1,100 | 0% | 20% | 15% | -25% |
| New Hampshire | 700 | 500 | -29% | 21% | 16% | -24% |
| New Jersey | 7,400 | 5,300 | -28% | 32% | 24% | -25% |
| New Mexico | 800 | 700 | -13% | 14% | 12% | -14% |
| New York | 16,200 | 10,900 | -33% | 32% | 23% | -28% |
| North Carolina | 7,400 | 6,200 | -16% | 34% | 25% | -26% |
| North Dakota | 300 | 300 | 0% | 17% | 19% | 12% |
| Ohio | 11,700 | 8,800 | -25% | 37% | 30% | -19% |
| Oklahoma | 2,600 | 2,400 | -8% | 27% | 24% | -11% |
| Oregon | 2,000 | 1,500 | -25% | 22% | 16% | -27% |
| Pennsylvania | 11,000 | 7,800 | -29% | 34% | 26% | -24% |
| Rhode Island | 800 | 500 | -38% | 30% | 21% | -30% |
| South Carolina | 3,800 | 3,000 | -21% | 34% | 26% | -24% |
| South Dakota | 400 | 400 | 0% | 18% | 18% | 0% |
| Tennessee | 5,600 | 4,400 | -21% | 37% | 27% | -27% |
| Texas | 18,100 | 18,300 | 1% | 28% | 25% | -11% |
| Utah | 1,800 | 2,000 | 11% | 23% | 21% | -9% |
| Vermont | 300 | 200 | -33% | 19% | 14% | -26% |
| Virginia | 6,300 | 5,000 | -21% | 33% | 25% | -24% |
| Washington | 3,900 | 2,700 | -31% | 23% | 16% | -30% |
| West Virginia | 1,500 | 1,100 | -27% | 34% | 26% | -24% |
| Wisconsin | 4,200 | 3,600 | -14% | 28% | 25% | -11% |
| Wyoming | 200 | 200 | 0% | 14% | 13% | -7% |

Table S. Sensitivity analysis: percentage change in attributable cases due to trap

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sensitivity Analysis of Attributable Number of Cases (% Change)** | | | | | | | | | |
|  | Concentration response function | | | | | | |  | |
|  | Year 2000 | | |  | Year 2010 | | |
|  | LL | M | UL |  | LL | M | UL |
| NO2 | -62% | -16% | 9% |  | -63% | -16% | 11% | LL | Incidence rate |
| -55% | **0%\*** | 29% |  | -56% | **0%\*** | 33% | M |
| -48% | 15% | 49% |  | -50% | 15% | 53% | UL |
|  |  |  |  |  |  |  |  |  |
| PM2.5 | -68% | -16% | 23% |  | -69% | -16% | 27% | LL |
| -62% | **0%\*** | 46% |  | -63% | **0%\*** | 51% | M |
| -56% | 15% | 69% |  | -57% | 15% | 74% | UL |
|  |  |  |  |  |  |  |  |  |
| PM10 | -60% | -16% | 14% |  | -61% | -16% | 17% | LL |
| -52% | **0%\*** | 36% |  | -54% | **0%\*** | 40% | M |
| -45% | 15% | 56% |  | -47% | 15% | 61% | UL |

Table S. Comparison of results using state-specific IR

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Flat national-level IR** | | | **State-specific IR** | | | **Difference** | | | **Difference (%)** | | |
| State | **Incident cases** | **AC** | **AF** | **Incident cases** | **AC** | **AF** | **Incident cases** | **AC** | **AF** | **Incident cases** | **AC** | **AF** |
| Alabama | 12,200 | 1,400 | 11.5% | 11,300 | 1,300 | 11.5% | -900 | -100 | 0.0% | -7.4% | -7.1% | 0.3% |
| Arizona | 17,600 | 3,800 | 21.6% | 21,500 | 4,600 | 21.4% | 3,900 | 800 | -0.2% | 22.2% | 21.1% | -0.9% |
| Arkansas | 7,700 | 900 | 11.7% | 7,200 | 800 | 11.1% | -500 | -100 | -0.6% | -6.5% | -11.1% | -4.9% |
| California | 100,300 | 25,400 | 25.3% | 75,800 | 19,200 | 25.3% | -24,500 | -6,200 | 0.0% | -24.4% | -24.4% | 0.0% |
| Colorado | 13,200 | 3,100 | 23.5% | 12,400 | 2,900 | 23.4% | -800 | -200 | -0.1% | -6.1% | -6.5% | -0.4% |
| Connecticut | 8,800 | 1,600 | 18.2% | 8,300 | 1,500 | 18.1% | -500 | -100 | -0.1% | -5.7% | -6.3% | -0.6% |
| Delaware | 2,200 | 400 | 18.2% | 2,000 | 300 | 15.0% | -200 | -100 | -3.2% | -9.1% | -25.0% | -17.5% |
| D.C. | 1,100 | 300 | 27.3% | 1,400 | 400 | 28.6% | 300 | 100 | 1.3% | 27.3% | 33.3% | 4.8% |
| Florida | 43,200 | 5,500 | 12.7% | 40,500 | 5,200 | 12.8% | -2,700 | -300 | 0.1% | -6.3% | -5.5% | 0.8% |
| Georgia | 26,900 | 3,900 | 14.5% | 19,200 | 2,800 | 14.6% | -7,700 | -1,100 | 0.1% | -28.6% | -28.2% | 0.6% |
| Idaho | 4,600 | 600 | 13.0% | 4,500 | 600 | 13.3% | -100 | 0 | 0.3% | -2.2% | 0.0% | 2.2% |
| Illinois | 33,800 | 8,300 | 24.6% | 18,300 | 4,500 | 24.6% | -15,500 | -3,800 | 0.0% | -45.9% | -45.8% | 0.1% |
| Indiana | 17,300 | 3,100 | 17.9% | 21,300 | 3,900 | 18.3% | 4,000 | 800 | 0.4% | 23.1% | 25.8% | 2.2% |
| Iowa | 7,900 | 1,000 | 12.7% | 4,200 | 500 | 11.9% | -3,700 | -500 | -0.8% | -46.8% | -50.0% | -6.0% |
| Kansas | 7,800 | 1,100 | 14.1% | 5,800 | 800 | 13.8% | -2,000 | -300 | -0.3% | -25.6% | -27.3% | -2.2% |
| Kentucky | 11,000 | 1,600 | 14.5% | 10,300 | 1,500 | 14.6% | -700 | -100 | 0.0% | -6.4% | -6.3% | 0.1% |
| Louisiana | 12,100 | 1,400 | 11.6% | 5,600 | 700 | 12.5% | -6,500 | -700 | 0.9% | -53.7% | -50.0% | 8.0% |
| Maine | 3,000 | 200 | 6.7% | 2,200 | 200 | 9.1% | -800 | 0 | 2.4% | -26.7% | 0.0% | 36.4% |
| Maryland | 14,600 | 2,800 | 19.2% | 12,800 | 2,500 | 19.5% | -1,800 | -300 | 0.4% | -12.3% | -10.7% | 1.8% |
| Massachusetts | 15,300 | 2,500 | 16.3% | 14,400 | 2,400 | 16.7% | -900 | -100 | 0.3% | -5.9% | -4.0% | 2.0% |
| Michigan | 25,300 | 4,200 | 16.6% | 24,400 | 4,100 | 16.8% | -900 | -100 | 0.2% | -3.6% | -2.4% | 1.2% |
| Minnesota | 13,900 | 2,100 | 15.1% | 13,500 | 2,100 | 15.6% | -400 | 0 | 0.4% | -2.9% | 0.0% | 3.0% |
| Mississippi | 8,200 | 800 | 9.8% | 9,100 | 900 | 9.9% | 900 | 100 | 0.1% | 11.0% | 12.5% | 1.4% |
| Missouri | 15,400 | 1,800 | 11.7% | 15,800 | 1,900 | 12.0% | 400 | 100 | 0.3% | 2.6% | 5.6% | 2.9% |
| Montana | 2,400 | 200 | 8.3% | 900 | 100 | 11.1% | -1,500 | -100 | 2.8% | -62.5% | -50.0% | 33.3% |
| Nebraska | 5,000 | 600 | 12.0% | 3,800 | 500 | 13.2% | -1,200 | -100 | 1.2% | -24.0% | -16.7% | 9.6% |
| Nevada | 7,200 | 1,400 | 19.4% | 6,900 | 1,400 | 20.3% | -300 | 0 | 0.8% | -4.2% | 0.0% | 4.3% |
| New Hampshire | 3,100 | 300 | 9.7% | 3,000 | 300 | 10.0% | -100 | 0 | 0.3% | -3.2% | 0.0% | 3.3% |
| New Jersey | 22,300 | 5,400 | 24.2% | 17,300 | 4,200 | 24.3% | -5,000 | -1,200 | 0.1% | -22.4% | -22.2% | 0.3% |
| New Mexico | 5,600 | 900 | 16.1% | 3,000 | 500 | 16.7% | -2,600 | -400 | 0.6% | -46.4% | -44.4% | 3.7% |
| New York | 46,700 | 11,800 | 25.3% | 53,600 | 13,500 | 25.2% | 6,900 | 1,700 | -0.1% | 14.8% | 14.4% | -0.3% |
| North Carolina | 24,600 | 3,200 | 13.0% | 23,100 | 3,000 | 13.0% | -1,500 | -200 | 0.0% | -6.1% | -6.3% | -0.2% |
| North Dakota | 1,600 | 100 | 6.3% | 1,600 | 100 | 6.3% | 0 | 0 | 0.0% | 0.0% | 0.0% | 0.0% |
| Ohio | 29,500 | 5,000 | 16.9% | 36,100 | 6,200 | 17.2% | 6,600 | 1,200 | 0.2% | 22.4% | 24.0% | 1.3% |
| Oklahoma | 10,000 | 1,300 | 13.0% | 8,600 | 1,200 | 14.0% | -1,400 | -100 | 1.0% | -14.0% | -7.7% | 7.3% |
| Oregon | 9,300 | 1,300 | 14.0% | 8,500 | 1,200 | 14.1% | -800 | -100 | 0.1% | -8.6% | -7.7% | 1.0% |
| Pennsylvania | 30,100 | 6,000 | 19.9% | 31,600 | 6,300 | 19.9% | 1,500 | 300 | 0.0% | 5.0% | 5.0% | 0.0% |
| Rhode Island | 2,400 | 400 | 16.7% | 2,700 | 400 | 14.8% | 300 | 0 | -1.9% | 12.5% | 0.0% | -11.1% |
| South Carolina | 11,700 | 1,300 | 11.1% | 10,900 | 1,200 | 11.0% | -800 | -100 | -0.1% | -6.8% | -7.7% | -0.9% |
| South Dakota | 2,200 | 200 | 9.1% | 2,100 | 200 | 9.5% | -100 | 0 | 0.4% | -4.5% | 0.0% | 4.8% |
| Tennessee | 16,100 | 2,500 | 15.5% | 15,100 | 2,400 | 15.9% | -1,000 | -100 | 0.4% | -6.2% | -4.0% | 2.4% |
| Texas | 74,100 | 10,700 | 14.4% | 99,100 | 14,300 | 14.4% | 25,000 | 3,600 | 0.0% | 33.7% | 33.6% | -0.1% |
| Utah | 9,400 | 1,900 | 20.2% | 8,100 | 1,700 | 21.0% | -1,300 | -200 | 0.8% | -13.8% | -10.5% | 3.8% |
| Vermont | 1,400 | 100 | 7.1% | 1,300 | 100 | 7.7% | -100 | 0 | 0.5% | -7.1% | 0.0% | 7.7% |
| Virginia | 20,000 | 3,400 | 17.0% | 18,700 | 3,200 | 17.1% | -1,300 | -200 | 0.1% | -6.5% | -5.9% | 0.7% |
| Washington | 17,100 | 3,000 | 17.5% | 9,600 | 1,700 | 17.7% | -7,500 | -1,300 | 0.2% | -43.9% | -43.3% | 0.9% |
| West Virginia | 4,200 | 600 | 14.3% | 4,000 | 600 | 15.0% | -200 | 0 | 0.7% | -4.8% | 0.0% | 5.0% |
| Wisconsin | 14,400 | 2,100 | 14.6% | 14,700 | 2,200 | 15.0% | 300 | 100 | 0.4% | 2.1% | 4.8% | 2.6% |
| Wyoming | 1,500 | 100 | 6.7% | 1,400 | 100 | 7.1% | -100 | 0 | 0.5% | -6.7% | 0.0% | 7.1% |

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