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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 1. 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)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 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

Use **Body Text** style.

### 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.

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 (H. Anderson et al., 2013; Khreis, Kelly, 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 (S. Holgate et al., 2007; S. T. Holgate et al., 2000; Mauad et al., 2007; Tgavalekos et al., 2007; Wenzel et al., 2009). 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 (S. T. Holgate, 2007; Martin et al., 2008; Nadeem et al., 2008; Ober et al., 2011). 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 H. Anderson et al. (2013) 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, Kelly, 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., 2013; Perez et al., 2009; Perez et al., 2012). 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 1.

The model illustrated in Figure 1 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 1 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 1); but also for asthma symptoms triggered by other causes in children who developed asthma *because* of their air pollution exposure (BoxD in Figure 1). 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 1), 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 (H. R. Anderson et al., 2013; Bechle et al., 2015). 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 & 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].

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.

# Problem

Use **Body Text** style.

# Approach

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# Methodology

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### Study area and time period

We analyzed census, air pollution and asthma incidence rates data for the contiguous U.S. (48 states and the District of Columbia) for the years 2000 and 2010. The analysis was done using the finest geographical level in the hierarchy of census geographic entities within U.S. when available [Figure]. The census block is the bases and building block for each of the hierarchies and is the finest geographical unit for census data. Data available at the census block level included population counts, urban or rural living location and air pollution data. The median household income data was only available at the census group level (one level higher than the census block). Childhood asthma incidence rates were only available at the state level. 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.

### Census data

#### Geographical hierarchy of the US census

The U.S. Census Bureau recognizes multiple geographical hierarchies to address the needs of different users [Figure of census hierarchy]. 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 unlike other geographic entities, for example zip codes may cross county lines but census blocks do not cross neither the boundaries of zip codes nor the boundaries of counties. The hierarchy used by the census bureau to conduct population counts includes regions, divisions, states, counties, census tracts, block groups and census blocks. For our analysis we used the latter hierarchy for our main analysis and “Places” when summarizing our data at the city level.

#### Identify a census block unique code

Each census block is identified with a Federal Information Processing System (FIPS) code. A FIPS code is a sequence of numbers that uniquely identify each level of geographical entity depending on the geographical hierarchy used. For example, the Texas A&M Transportation Institute building at the Rellis campus lies within the following FIPS code [48-041-000202-3-001] where:

* State code [48] is for Texas
* County code [041] is for Brazos County
* Tract code [000202]
* Block group code [3]
* Block code [001]

#### 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 complete population counts of children <18 years of age and was classified into urban or rural. Urban classified census blocks were either urban clusters or urbanized areas based on multiple criteria by the census bureau. Urban clusters generally have a population threshold of ≥2,500 and <50,000, while urbanized areas have a threshold of ≥50,000 people. Annual median household income 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. 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

Air pollution exposure was based on the annual average pollutant concentration at the centroid of each census block for the years 2000 and 2010. 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 [cite]. Air pollution concentrations were available at populated census blocks. The following sections present adscription of the modeling method used and each pollutant.

#### NO2 model and concentrations

In this project, exposure to NO2 was used as the main analysis in our study since it is a good predictor for traffic related air pollution sources, and studies have associated NO2 pollution with multiple adverse health outcomes including asthma and asthma exacerbations (Anderson et al., 2011; H. R. Anderson et al., 2013; Khreis, Kelly, et al., 2017). To measure NO2 exposure we adopt the US-wide LUR model developed by Bechle et al. (2015) to estimate the annual 2000 and 2010, NO2 concentrations 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, a scaling factors derived using monthly NO2 mean concentrations for 11 consecutive years from EPA air quality monitors were added 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%.

Add NO2 concentration results in this section

NO2 concentrations dropped between the years 2000 and 2010 in the whole of the US and across all the 48 states and D.C. with a national mean and median difference of - 37% (Figures 2-5). District of Columbia had the highest NO2 levels compared to other states: in 2000 the mean NO2 concentration was 20.58 ppb which dropped to 14.12 ppb in 2010 with an absolute difference of 6.47 ppb and a 31.4% reduction. North Dakota was the state with the lowest mean NO2 concentration in 2000 of 3.13 ppb which dropped to 2.42 ppb in 2010. The state with the highest absolute mean NO2 concentration difference between 2000 and 2010 was New Jersey with a difference equal to 7.09 ppb (17.86 to 10.76 ppb) while the state with the highest percent mean change of NO2 concentrations between 2000 and 2010 was Florida with a 47.2% reduction in mean NO2 concentrations (9.86 to 5.21 ppb)

* National
* Mean concentration
* Absolute and relative difference
* Concentration by living location
* Concentration by median income
* Concentration by living location stratified into median income
* State specific comparison
* Highest vs lowest for two years
* Largest absolute diff
* Largest relative diff
* State specific 2010
* Concentration by living location
* Concentration by median income

#### PM2.5 concentrations and exposure

Annual average air pollution concentrations for PM2.5 were estimated using 17 years of data (1999-2015) from regulatory 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 hold-out cross validation with a satisfactory performance of 10-fold CV-R2 reaching 0.86 and 0.85 in 2000 and 2010, respectively.

Add PM2.5 concentration results in this section

#### 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. The validation had a 10-fold CV-R2 reaching 0.60 and 0.57 in 2000 and 2010, respectively.

Add PM10 concentration results in this section

### Asthma incidence rate data

Text here ….

#### National asthma incidence rate

Text here ….

#### State-specific asthma incidence rate

Text here ….

### Concentration response function

Text here ….

### Burden of disease methodology

Text here ….

### Counterfactual scenarios

Text here ….

### Sensitivity analysis

Text here ….

### Running the analysis

Text here ….

#### Software used

Text here ….

#### Spatial maps production

Text here ….

#### 500 cities lookup table

Text here ….

# Results

### Census description

[Table of demographic summary] summarizes the demographic and geographic characteristics of the census data. The total population of children were at 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 (encompassing both urban clusters and urbanized areas) in 2000 and 2010. The table provides the population distribution by median household income group for each year.

### 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. We then repeated our analysis for the year 2010 using state-specific asthma incidence rates for the years 2006-2010 following Winer et al. (2012) proposed method. For the period 2006-2010, childhood asthma incidence rates were available for 32 states from a total sample of 16,153. States with missing childhood asthma incidence rates (16 states) were assigned an average asthma incidence rate of 12.1 per 1,000 at-risk children. The incidence rate was the average across all available states for the period 2006-2010. The District of Columbia had the highest childhood asthma incidence rate of 17.1 per 1,000 while Montana had the lowest incidence rate of 4.3 per 1,000 for the period 2006-2010. [Table of asthma incidence rate] provides a detailed summary of the asthma incidence rates across all available states. The following section provides a detailed description of the ACBS and BRFSS surveys used to estimate the state-specific asthma incidence rates.

### ACBS and BRSS survey

Text here ….

# 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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