Science of the Total Environment 508 (2015) 136–144

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Spatial vulnerability of fine particulate matter relative to the prevalence of diabetes in the United States

Lung-Chang Chien [a,b,*], Hasanat Alamgir [c], Hwa-Lung Yu [d]

[a] University of Texas School of Public Health at San Antonio Regional Campus, Department of Biostatistics, San Antonio, TX, USA
[b] University of Texas Health Science Center at San Antonio, Research to Advance Community Health Center, San Antonio, TX, USA
[c] University of Texas School of Public Health at San Antonio Regional Campus, Department of Epidemiology, Human, Genetics & Environmental Sciences, San Antonio, TX, USA
[d] National Taiwan University, Department of Bioenvironmental Systems Engineering, Taipei, Taiwan

HIGHLIGHTS

- Diabetes prevalence was investigated in $PM_{2.5}$ and the locations of counties.
- Diabetes prevalence was geographically associated with $PM_{2.5}$ in the U.S.
- Over 40% of counties displayed significantly diabetes vulnerability.
- Most vulnerable counties were located in the Southwest, Central, and South Regions.
- Counties in Michigan are more vulnerable to diabetes at median-high $PM_{2.5}$ level.

ARTICLE INFO

Article history:
Received 27 August 2014
Received in revised form 7 November 2014
Accepted 26 November 2014
Available online xxxx

Editor: P. Kassomenos

Keywords:
Diabetes prevalence
$PM_{2.5}$
Spatiotemporal model
Spatial vulnerability

ABSTRACT

Recent research supports a link between diabetes and fine particulate matter (≤2.5 μg in diameter; $PM_{2.5}$) in both laboratory and epidemiology studies. However, research investigating the potential relationship of the spatial vulnerability of diabetes to concomitant $PM_{2.5}$ levels is still sparse, and the level of diabetes geographic disparities attributed to $PM_{2.5}$ levels has yet to be evaluated. We conducted a Bayesian structured additive regression modeling approach to determine whether long-term exposure to $PM_{2.5}$ is spatially associated with diabetes prevalence after adjusting for the socioeconomic status of county residents. This study utilizes the following data sources from 2004 to 2010: the Behavioral Risk Factor Surveillance System, the American Community Survey, and the Environmental Protection Agency. We also conducted spatial comparisons with low, median-low, median-high, and high levels of $PM_{2.5}$ concentrations. When $PM_{2.5}$ concentrations increased 1 μg/m^3, the increase in the relative risk percentage for diabetes ranged from −5.47% (95% credible interval = −6.14, −4.77) to 2.34% (95% CI = 2.01, 2.70), where 1323 of 3109 counties (42.55%) displayed diabetes vulnerability with significantly positive relative risk percentages. These vulnerable counties are more likely located in the Southeast, Central, and South Regions of the U.S. A similar spatial vulnerability pattern for concentrations of low $PM_{2.5}$ levels was also present in these same three regions. A clear cluster of vulnerable counties at median-high $PM_{2.5}$ level was found in Michigan. This study identifies the spatial vulnerability of diabetes prevalence associated with $PM_{2.5}$, and thereby provides the evidence needed to prompt and establish enhanced surveillance that can monitor diabetes vulnerability in areas with low $PM_{2.5}$ pollution.

1. Introduction

Diabetes is one of the most prevalent chronic diseases and an increasing health concern in the United States (U.S.). Since 1990, the prevalence of diagnosed diabetes in the U.S. has risen sharply among all age groups and all racial/ethnic groups regardless of sex (Centers for Disease Control and Prevention, 2012). From 1995 to 2010, the age-adjusted prevalence of diagnosed diabetes among U.S. adults increased in all geographic areas, with the median prevalence for all states increasing from 4.5% to 8.2% (Centers for Disease Control and Prevention, 2012). Recent research supports a link between diabetes and fine particulate matter (≤2.5 μg in diameter; $PM_{2.5}$) in both laboratory and epidemiology studies. For example, the investigation of inhalational exposure to concentrated $PM_{2.5}$ revealed an increased inflammation in insulin responsive organs, and resulted in a significant association between $PM_{2.5}$ and type II diabetes mellitus genetically (Liu et al., 2014). A case-crossover study investigating short term exposure to $PM_{2.5}$ documented significant increases in hospitalization risks for diabetes

* Corresponding author at: UT School of Public Health at San Antonio Regional Campus, 7411 John Smith Drive, Suite 1050, Room 505, San Antonio 78229, TX, USA.
E-mail address: Lung-Chang.Chien@uth.tmc.edu (L.-C. Chien).

http://dx.doi.org/10.1016/j.scitotenv.2014.11.090
0048-9697/

(Zanobetti et al., 2014). Survival research also suggests an increased incidence rate ratio for type II diabetes in conjunction with increases in $PM_{2.5}$ concentrations (Coogan et al., 2012). However, the national trend for $PM_{2.5}$ concentrations revealed a 33% decrease since 2000 (U.S. Environmental Protection Agency, 2013). This inverse trend, the rising prevalence of diabetes and the decreasing levels of $PM_{2.5}$, concentrations, imply that there might be additional underlying risk factors or alternate mechanisms that may explain any association between $PM_{2.5}$ levels and diabetes prevalence.

Among the possible underlying risk factors, a geographic impact has been associated with both diabetes and $PM_{2.5}$, but this has not been thoroughly investigated. For example, between 1995 and 2010, the relative increase in the age-adjusted prevalence of diabetes broadly ranged from 8.5% in Puerto Rico to 226.7% in Oklahoma, with an overall median increase of 82.2% (Centers for Disease Control and Prevention, 2012). For $PM_{2.5}$, during 2012, the annual average concentration was as high as 10.44 $\mu g/m^3$ in the Central U.S. while only 7.69 $\mu g/m^3$ in the Southwest U.S. (U.S. Environmental Protection Agency, 2013). These numbers reveal the possibility of geographic disparities that might lead to the varied prevalence of diabetes and varied levels of $PM_{2.5}$ in different areas. However, scant research exists regarding whether or not any diabetes geographic disparities could be attributed to $PM_{2.5}$ concentrations.

Over the last decade, $PM_{2.5}$ research related to geoscience has been frequently investigated in the fields of Environmental Engineering and Epidemiology. Within U.S. urban areas, the data from the U.S. Environmental Protection Agency (EPA) shows that there is a considerable degree of heterogeneity in $PM_{2.5}$ concentrations (Pinto et al., 2004). Studies conducted in large U.S. cities including Pittsburgh, Atlanta, and Philadelphia also indicate the existence of spatial variation in $PM_{2.5}$ concentrations (Burton et al., 1996; Tang et al., 2004). Moreover, the spread of $PM_{2.5}$ affects broad areas and is not limited locally. Reports indicate that high $PM_{2.5}$ concentrations appear in southern California, with especially higher values in Rubidoux which is located in Riverside County (Kim et al., 2000; Motallebi et al., 2003). In addition, adverse health impacts due to $PM_{2.5}$ have also been noted in other geographic areas. For instance, the incidences of $PM_{2.5}$-attributed asthma emergency room visits have been documented in New York City (Kheirbek et al., 2013), the incidences of $PM_{2.5}$-attributed respiratory and cardiovascular diseases have been documented in New England (Kloog et al., 2012), the incidences of $PM_{2.5}$-attributed ischemic heart disease and lung cancer have been documented in Los Angeles, CA (Jerrett et al., 2005), and the incidences of $PM_{2.5}$-attributed pediatric asthma cases have been documented in Washington, DC (Greene and Morris, 2006). Furthermore, multi-city projects in different countries have produced further scientific evidence on the association of $PM_{2.5}$ and the impairment of human health (Boldo et al., 2006; Franklin et al., 2006; O'Connor et al., 2008; Viana et al., 2007).

Even though people with diabetes are sensitive to pollution-triggered heart diseases, a relationship between air pollution and diabetes risk has not been well described. Preliminary evidence reveals that areas in the U.S. that have higher $PM_{2.5}$ concentrations also have a higher prevalence of diabetes (Pearson et al., 2010). However, to date, research has not specifically identified these areas and no attempts have been made to determine any association between the two. Thus, this study attempts to statistically define these areas. An advanced analytical technique is applied to generate further evidence of the spatiotemporal impact of $PM_{2.5}$ on diabetes prevalence in the U.S. at the county level from 2004 to 2010. The purpose of this study is to investigate the spatial variations and geographic disparities of diabetes prevalence and how these factors relate to county-level $PM_{2.5}$ concentrations in the U.S. Specifically, three research questions are addressed: (1) whether $PM_{2.5}$ concentration levels are spatially associated with diabetes prevalence, (2) whether the geographic disparities of diabetes prevalence can be quantified and vary with increased levels of $PM_{2.5}$, and (3) whether counties with higher $PM_{2.5}$ concentrations have a higher vulnerability to diabetes than counties with lower $PM_{2.5}$ concentrations. It is hoped that our findings will help diabetes researchers, health care providers, and health advocates to focus more prevention and care efforts on diabetes patients in the identified high risk areas.

2. Material and methods

2.1. Data source

County-level age-adjusted diabetes prevalence was calculated from the database of the Behavioral Risk Factor Surveillance System (BRFSS) which is conducted by individual state health departments under the direction of the U.S. Centers for Disease Control and Prevention (CDC). Since 1984, BRFSS has conducted on-going annual telephone surveys that track risk behaviors and health characteristics across the U.S. Two diabetes-related risk factors, obesity and physical inactivity, were also documented by county in the BRFSS database.

Socioeconomic status (SES) factors were collected from the American Community Survey (ACS), the largest decennial survey administrated by the U.S. Census Bureau since 2005. The ACS database gathers data every year to provide the most updated information about the social and economic needs in communities. We used the 5-year estimate for SES factors because it contains data on all counties. In addition, we used health insurance data from the Small Area Health Insurance Estimates from the U.S. Census.

Air pollutant concentrations were collected by the Environmental Protection Agency's Air Quality System monitoring stations that are located throughout the U.S., and obtain the air quality monitoring data by state and local agencies. Because atmospherically driven pollutants are not expected to have a simple and stationary form of spatial covariance (Fuentes et al., 2007), the EPA collaborates with the CDC on a CDC initiative to establish a National Environmental Public Health Tracking network that facilitates the collection, generation, and dissemination of environmental hazard monitoring data. The EPA, the CDC, and some local public health departments work together to link monitoring measurements and air quality estimates for the daily maximum 24-hour average ambient $PM_{2.5}$ concentrations, and the daily maximum 8-hour average ambient ozone (O_3) concentrations during a 24 h period at the county-level. These measurements were utilized in order to perform sensitivity analysis in this study.

2.2. Study area

This study included 3109 counties in the 48 contiguous states. County boundary data downloaded from the U.S. Census Bureau were used for mapping, and helped determine a two-dimensional weighted neighborhood matrix for spatial function estimation. Neighbors are defined as counties that share a common boundary. The U.S. climate regions, defined by the National Climatic Data Center and used by the EPA for publishing regional trends of $PM_{2.5}$ concentrations, were also utilized in order to more effectively explain the spatial pattern changes noted in this study (Fig. 1).

2.3. Variable definitions

Respondents were classified as having diabetes if they answered “yes” to the following question: “Has a doctor ever told you that you have diabetes?” Females who had diabetes during pregnancy were not included in this analysis. Each respondent's weight (in kilogram) and height (in meter) were used to calculate their body mass index (BMI). Obesity was defined as a BMI $\geq$ 30. The respondents were classified as being physical inactive if they answered “no” to the following question: “During the past month, other than your regular job, did you participate in any physical activities or exercises such as running, calisthenics, gardening, or walking for exercise?”

The daily county-level air pollutant data that is in the original EPA database has only been gathered in less than 700 counties with air