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Sulfur dioxide exposure and environmental justice: a multi–scale and source–specific perspective

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ABSTRACT

Recent studies examining racial and ethnic inequities in exposure to urban air pollution have led to advances in understanding the nature and extent of overall concentration exposures by pollutant, demarcated by disadvantaged groups. However, the stability of inequities at various spatial units and the exposure by air pollution sources are often neglected. In this case study from the Dallas–Fort Worth (Texas, USA) area, we used Geographic Information Systems (GIS) and an air dispersion model to estimate environmental justice impacts at different spatial scales (i.e., zip code, census tract, block group) and by source (i.e., industrial pollution sources, vehicle pollution sources, industry and vehicle pollution sources combined). Using whites as a reference, blacks and other races were more likely to be exposed to higher sulfur dioxide (SO_2) concentrations although the Odds Ratio (OR) varied substantially by pollution source type [e.g., industrial pollution source based: (OR=1.80; 95% CI (Confidence Interval): 1.79–1.80) vs. vehicle pollution source based: (OR=2.70; 95% CI: 2.68–2.71)] and varied less between spatial scales [for vehicle pollution sources, (OR=2.70; 95% CI: 2.68–2.71) at the census tract level but was (OR=2.54; 95% CI: 2.53–2.55) at the block group scale]. Similar to the pattern of racial inequities, people with less education (i.e., less than 12 years of education) and low income (i.e., per capital income below $20 000) were more likely to be exposed to higher SO_2 concentrations, and those ORs also varied greatly with the pollution sources and slightly with spatial scales. It is concluded that the type of pollution source plays an important role in SO_2 pollution exposure inequity assessment, while spatial scale variations have limited influence. Future studies should incorporate source–specific exposure assessments when conducting studies on environmental justice.

Keywords: *Air pollution exposure, inequity, AERMOD, spatial scale, GIS*

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1. Introduction

Air pollution is recognized as a priority global health issue, affecting millions in both the developed and developing world (Brauer et al., 2012). Early studies have found that socioeconomic disparities in air pollution exposure and related health effects are prevalent (Zanobetti and Schwartz, 2000; O'Neill et al., 2003). Identification of susceptible and disadvantaged socioeconomic status (SES) groups at the greatest risk of air pollution exposure is critical for accurately estimating the adverse outcomes of air pollution and may provide additional explanations for inconsistency in results between studies.

For the purpose of fair treatment and meaningful involvement of all people regardless of age, race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies, the field of environmental justice has been increasingly regarded as a critical component in environmental policy debates (O'Neill et al., 2003; U.S. EPA, 2009).

In the field of air pollution exposure justice, since Asch and Seneca (1978) first found that exposure to air pollution in the United States (based on micro data) was related to socioeconomic characteristics, increasing interest has been paid to the assessment of air pollution exposure inequities. The past 34 years have seen the study areas of environmental justice expand from the United States to other developed countries (e.g., Canada, New Zealand, Britain, France) and as well as developing countries (e.g., China, India). Methods used to measure the level of exposure to air pollution mainly include proximity models (Stretesky and Lynch, 1999), air dispersion models (Fisher et al., 2006); Geographic Information Systems (GIS) spatial interpolation models (Su et al., 2011), and land use regression models (Crouse et al., 2009). The final results of environmental justice assessment are generally presented using statistical indicators, such as OR (odds ratio), ER (excess ratio), RD (risk difference), and RR (relative risk) with the baseline reference group being whites in racial comparisons.

To date, studies on air pollution exposure justice have consistently shown that certain subgroups of the general population are likely to suffer higher levels of air pollution exposure, depending on socio–demographic characteristics such as race/ethnicity, educational attainment, age, and SES (Foos et al., 2008). For example, Marshall (2008) found that mean exposure to benzene, butadiene, chromium particles, and diesel particles was higher than average for people who are nonwhite in California's South Coast Air Basin. Kingham et al. (2007) found that the vehicle pollution (i.e., PM_{10}) inversely related to the percentage of Europeans in a census area unit in Christchurch, New Zealand. Llop et al. (2011) found that younger women, immigrants from Latin American counties, and those belonging to the lower social strata were exposed to higher NO_2 levels in Spain. Ma (2010) highlighted the fact that an increase in income level was positively associated with the higher levels of industrial pollution exposure in Henan province, China.

In summary, there have been a large number of quantitative studies examining social inequities based upon a calculated or measured geographic distribution of air pollution, usually across an urban area. Although researchers have made strides towards understanding the nature and extent of air pollution exposure inequities, at least three aspects have often been overlooked. First, most studies have shown air pollution exposure inequities at the census tract scale due to the lack of individual level data (Kingham et al., 2007). These studies generally neglected to account for potential variations in air pollution and SES across different classes of spatial units (e.g., U.S. "zip code" vs. "census tract" vs. "block group"). Results of air pollution exposure equity assessment may be sensitive to analysis at these various levels. Second, most previous studies only considered a single type of pollution source (e.g., industrial pollution sources or vehicle pollution sources) or an aggregated exposure measurement (e.g., PM_{10} from all sources) instead of multiple types of pollution sources which represent a closer approximation to actual air pollution exposure. Understanding the source components of exposure would allow for a more accurate assessment of health effects from dose–response relationships and would also allow for more targeted policy measures limiting exposure. Last, when researchers focused on differences or similarities of air pollution exposure inequity in different areas (e.g., between developed countries and developing countries), they usually ignored the exposure level difference that might exist inside the study area due to the variation of dividing lines (Zou et al., 2013).

As a toxic gas and a precursor to particulates in the atmosphere, sulfur oxide (SO_2) is mainly released during various industrial processes (e.g., smelters, coal–fired power plants) and contributed by trucks and cars with low–grade diesel fuel (Zhang and Iwasaka, 2001). Since SO_2 emissions have consistently decreased in most countries over the past decades (Smith et al., 2001), it is generally recognized as a low–risk pollutant by environmental scientists and epidemiologists. However, recent studies found that low concentrations of SO_2 are still possibly associated with adverse health effects (Bell et al., 2007). Furthermore, GIS have empowered researchers with a tool for conducting spatial analysis by coupling air pollution and socioeconomic data at a variety of spatial scales (Viel et al., 2011). Methods of air dispersion modeling also provide a novel way to estimate source–specific air pollution concentrations (Zou et al., 2010) which could help detect and understand source–specific exposure inequities.

Therefore, this study aims to use GIS and air dispersion modeling methods to examine whether disadvantaged groups (e.g., blacks, individuals with low income or less education) are more likely to be exposed to higher levels of SO_2. This study differs from previous studies in that we: (1) ascertained the impact and sensitivity of the adjustment of spatial scale on the results of SO_2 pollution exposure inequity; and (2) differentiated the results of exposure inequity by the type of SO_2 pollution source. Our results show utility on several fronts. First, results of this study can aid in determining an appropriate spatial scale and geographical extent for accurately ascertaining exposure inequity while estimating the size of the effects of arbitrary selection of scale in a particular case study. Second, our results can help decision–makers to understand the SO_2 pollution sources that are most responsible for exposure inequity.

2. Materials and Methods

2.1. Study area

The Dallas–Fort Worth (DFW) metropolitan statistical area (MSA) in Texas, United States was selected as the study site (Figure 1). The DFW MSA includes six counties (Dallas, Tarrant, Johnson, Ellis, Denton, Collin), and covers an area of 13 728 km^2, contains 983 census tracts, and had a total population of 4 827 940 in 2000, making it the 4th largest MSA in the United States (U.S. Census Bureau, 2008). As shown in Figure 1, while vehicle–based SO_2 pollution sources (i.e., roads) are distributed relatively evenly over the entire DFW MSA (which is especially obvious in Dallas County), the industrial based SO_2 pollution sources exhibit a more clustered pattern across the entire DFW area. For this reason, we hypothesize that the intensity of SO_2 pollution exposure across the study area differs between vehicle pollution sources and industrial pollution sources. This variability makes DFW an ideal study area to ascertain the influence of source contribution on SO_2 pollution exposure inequities.

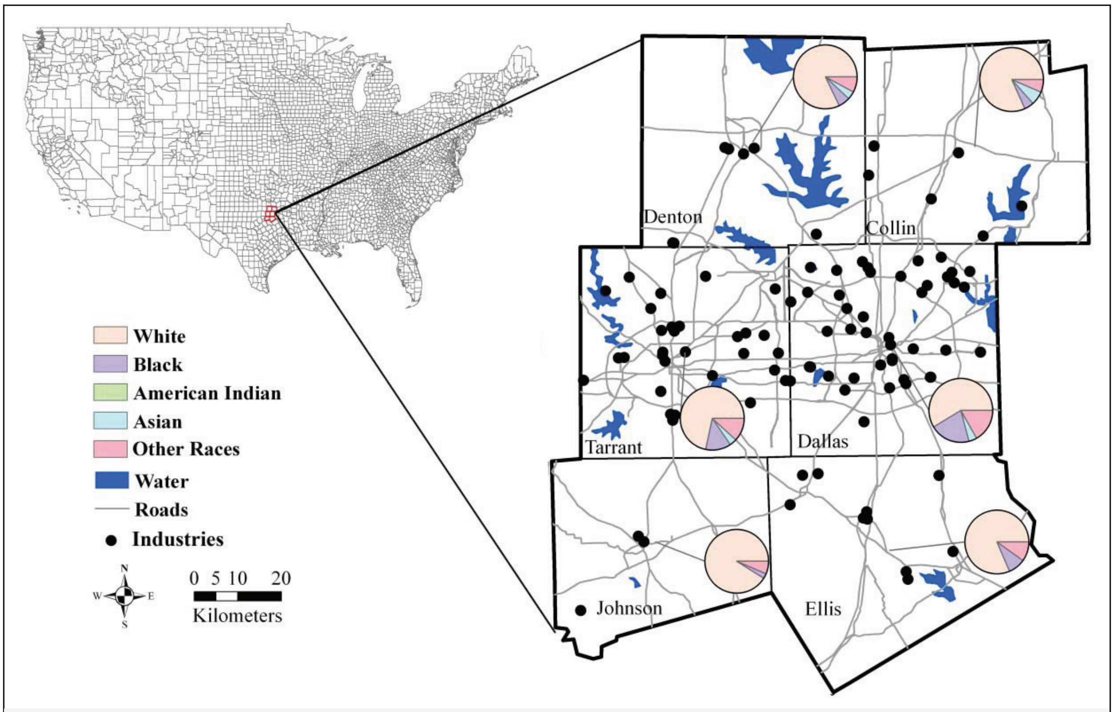

Figure 1. *Study area: DFW area in Texas, USA.*