Science of the Total Environment 595 (2017) 413–424

Contents lists available at ScienceDirect

Science of the Total Environment

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

A new approach to spatial identification of potential health hazards associated with childhood asthma

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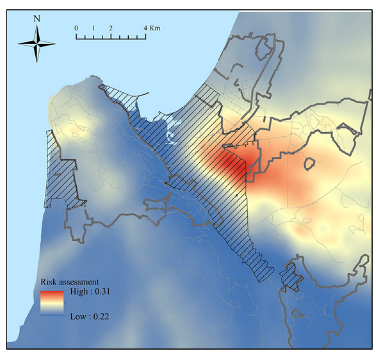
HIGHLIGHTS

- A novel approach to the identification of environmental health hazards is proposed.
- The approach is based on the extended distance gradient method (DGM).
- The proposed approach was tested in Greater Haifa Metropolitan Area in Israel.
- The analysis identified a spot in the local industrial zone as the main risk source.
- The proposed approach can be used as a preliminary risk source identification tool.

GRAPHICAL ABSTRACT

Risk source assessment of childhood asthma incidence.



ARTICLE INFO

Article history:
Received 10 December 2016
Received in revised form 23 March 2017
Accepted 24 March 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Childhood asthma
Incidence
Air pollution
Health hazards
Distance gradient method (DGM)
Distance decay function (DDF)
Major metropolitan area

ABSTRACT

Research background: Childhood asthma is a chronic disease, known to be linked to prolonged exposure to air pollution. However, the identification of specific health hazards, associated with childhood asthma is not always straightforward, due to the presence of multiple sources of air pollution in urban areas. In this study, we test a novel approach to the spatial identification of environmental hazards that have the highest probability of association with the observed asthma morbidity patterns.

Methods: The effect of a particular health hazard on population morbidity is expected to weaken with distance. To account for this effect, we rank potential health hazards based on the strength of association between the observed morbidity patterns and wind-direction weighted proximities to these locations. We validate this approach by applying it to a study of spatial patterns of childhood asthma in the Greater Haifa Metropolitan Area (GHMA) in Israel, characterised by multiple health hazards.

Results: We identified a spot in the local industrial zone as the primary risk source for the observed asthma morbidity patterns. Multivariate regressions, controlling for socio-economic and geographic variables, revealed that the observed incidence rates of asthma tend to decline as a function of distance from the identified industrial location.

Conclusion: The proposed identification approach uses disease patterns as its main input, and can be used by researches as a preliminary risk assessment tool, in cases in which specific sources of locally elevated morbidity are unclear or cannot be identified by traditional methods.

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http://dx.doi.org/10.1016/j.scitotenv.2017.03.222

1. Introduction

According to the World Health Organization, about 334 million people worldwide are currently diagnosed with asthma, and 14% of children and 8.6% of young adults experience asthma symptoms (WHO, 2014).

Childhood asthma incidence is frequent in densely populated urban areas (Koren, 1995; Sagai et al., 1996; Goldsmith and Kobzik, 1999; Gasana et al., 2012; Guarnieri and Balms, 2014; Fireman et al., 2015), where exposure to air pollution often result in the development and exacerbations of asthma symptoms in children and young adults (Peden, 2005; Trasande and Thurston, 2005; Subbarao et al., 2009; Pénard-Morand et al., 2010; Portnov et al., 2012; Yungling and Dong, 2012; Clark et al., 2010; Deng et al., 2015; Greenberg et al., 2016). However, the identification of specific environmental hazards associated with the observed asthma morbidity patterns is not always straightforward, mainly due to a large number of potential health hazards and air pollution sources in urban areas (Trasande and Thurston, 2005; Sly, 2009; Akinbami et al., 2016; Qijin, 2016).

Assessments methods used in empirical studies for spatial identification of potential health hazards can be classified into two groups: *direct and indirect* approaches. The former group of methods is based on measurements of air pollutants performed at the receptor sites, followed by a comparison of the results of such measurements with the chemical composition of particles emitted from different emission sources (Cooper and Watson, 1980; Stohl, 1996; Hopke, 2003; Salvador et al., 2004; Begum et al., 2004; Kim and Hopke, 2004; Xie and Berkowitz, 2006; Cesari et al., 2014; Banerjee et al., 2015; Zhang et al., 2015).

By contrast, the second group of methods uses aerial proximities to *pre-identified* health hazards as proxies for unknown (or unmeasured) concentrations of air pollutants. In recent empirical studies, this approach, also known as the *distance gradient method* or DGM, was used for the investigation of health effects associated with various sources of exposure, including thoroughfare roads, power stations, and various industrial facilities (Gatrell et al., 1996; Neidell, 2004; McConnell et al., 2006; Gordian et al., 2006; Wichmann and Fernando, 2009; Marco de et al., 2010; Brender et al., 2011; Rava et al., 2012; Marchetti et al., 2014; Paz et al., 2009; Zusman et al., 2012; Rosser et al., 2014; Moshe et al., 2015; Ramis et al., 2015; Eldeirawi et al., 2016).

Thus, in a recent study, conducted by Wichmann and Fernando (2009) in La Plata, Argentina, the health status of 6–12-year-old children living close to the petrochemical plants (n = 282), was compared to that of those living in a region with exposure to heavy traffic (n = 270) and to the health status of children living in less polluted areas (n = 639). As the study revealed, children living in the area exposed to petrochemical pollutants, exhibited substantially higher prevalence of asthma (P < 0.001), more asthma exacerbations (P < 0.001), and more respiratory symptoms (P < 0.001) than children residing elsewhere.

In another study, conducted in the Viadana district in Northern Italy, Marco de et al. (2010) revealed that upon controlling for sex, age, nationality, residential area, proximity to traffic thoroughfares, parental education, passive/parental smoking, health risks associated with industrial proximities were found to be elevated for respiratory symptoms (OR = 1.33, 95%CI: 1.11, 1.60), cough/phlegm (OR = 1.43, 95%CI: 1.08, 1.88), nose/throat/mouth symptoms (OR = 1.47, 95%CI: 1.23, 1.75), eye symptoms (OR = 1.24, 95%CI: 1.04, 1.48), school-days loss (OR = 1.24, 95%CI: 1.04, 1.48), emergency room admissions (OR = 2.14, 95%CI: 1.47, 3.11) and hospital admissions (OR = 2.21, 95%CI: 1.17, 4.18).

Although DGM is a common tool for assessing the adverse effects of different health hazards on human morbidity, this method has been mostly applied to *pre-identified* health risk sources, that is, health hazards found at *known* locations, such as e.g., roads, industrial sites, etc. In the following sections, we apply this method to the spatial identification of a priori *unidentified* hazards, assuming that several potential sources of exposure may exist simultaneously, differing by the strength of association with the observed morbidity patterns.

2. Materials and methods

The main objective of the present study is to extend DGM to the *spatial identification of* a priori *unidentified environmental hazards associated with childhood asthma in urban areas*. To achieve this goal, we estimate distance gradients of asthma incidence for several potential "source" locations and then rank these locations based on the strength of association between the observed morbidity patterns and wind-direction weighted proximities to these locations, as detailed in Subsection 2.1. We test this approach by applying it to a study of the spatial patterns of childhood asthma in the Greater Haifa Metropolitan Area (GHMA) in Israel, which is characterised by multiple health hazards (see Subsections 2.2–2.7).

2.1. DGM-based risk source identification approach

Following the methodological approach described in Svechkina et al. (2017), the *incidence rate* of a disease, observed in the i^{th} point of space (I_i), can be expressed by a linear function, reflecting a monotonic decline in I_i as a function of $dist_{ji}$, affected by wind frequency between j and i, and confounded by other factors (e.g., geographic location, socio-economic status of the neighbourhood, exposure to additional sources of air pollution, etc.):

$$I_i = b_0 + b_1 \cdot \widetilde{dist}_{ji} + b_2 \cdot \mathbf{SEC} + b_3 \cdot \boldsymbol{POL} + b_4 \cdot \boldsymbol{GEO} + \varepsilon_i \tag{1}$$

where $b_0 \ldots b_4$ are coefficients, $dist_{ji}\sim$ = distance between from j to i adjusted for wind direction and frequency (W_{ji}) (see Appendix 1), $\boldsymbol{SEC}$ = vector of socio-economic characteristics, including residential conditions, education and income; $\boldsymbol{POL}$ = vector of ambient air pollution levels measured at i; $\boldsymbol{GEO}$ = vector of geographic attributes of i, including local topography, building patterns, etc. ε_i = random error term.

As long as the locations of specific sources of exposure (e.g., roads, industrial facilities, etc.) are known, the calculation of the strength of association between I_i and $dist\sim_{ji}$ is technically simple. However, if actual sources of exposure for I_i are unknown, each alternative location j, can be assessed, in sequence, as a potential exposure source. The probability of j being the source of exposure (P_{ji}) for I_i can then be graded based on the values of the coefficient of determination, R^2_{ji},estimating the proportion of the I_i variance explained by $dist\sim_{ji}$ in addition to other potential confounders:

$$P_{ji} \rightarrow R^2_{ji}(I_i, dist_{ji}\sim, \boldsymbol{SEC}, \boldsymbol{POL}, \boldsymbol{GEO}), \forall b_1 < 0. \tag{2}$$

The interpretation of P_{ji} is relatively simple: values of R^2_{ji} close to 1 (when b_1 is negative) indicate a high probability that exposure originating from point j is associated, ceteris paribus, with morbidity observed in i, whereas values of R^2_{ji} close to *zero* will point out at the absence of any significant association between I_i and $dist\sim_{ji}$.

2.2. Study area

The Greater Haifa Metropolitan Area (GHMA), which forms our study region, consists of the city of Haifa and its suburbs (see Fig. 1) and hosts about 600,000 residents (as of 2014; ICBS, 2015). GHMA is the main industrial centre of Israel, which hosts several pharmaceutical and chemical processing plants, oil refineries and a major power plant; a sea port and a local airport are also located in the city proper. As recent study by Portnov et al. (2012) revealed, childhood asthma in the in the GHMA appears to be significantly associated with PM_{10} air pollution. However, other studies of respiratory morbidity in the GHMA had