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Mapping alternatives for public policy decision making related to human exposures from air pollution sources in the Federal District, Brazil

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ABSTRACT

Several studies have assessed air pollution risks to guide environmental and public health policies. However, most studies have proposed risk management actions that address a specific situation. To our knowledge, no studies have investigated the spatial distribution of risks to evaluate alternatives for environmental public policies. Therefore, this study had two specific aims. The first was to map human exposures to emissions from air pollution sources in the Federal District, Brazil. The second was to create and map the alternatives for public policies related to human exposures. For this study, we used the following approaches: techniques in Geographic Information System (GIS); multicriteria model – Analytic Hierarchy Process (AHP); and, Fuzzy logic. Our findings suggest that vehicle traffic control and public transportation development are the most effective alternatives with weights equal to 0.318 and 0.332, respectively. The estimated weights for land use management and new green areas are equal to 0.179 and 0.171, respectively. Vehicle traffic, population density, illegal urban settlements, economic activities and daily flux of people (origin and destination) were the main factors determining the spatial distribution of each alternative. This proposed analytical framework may be of interest to policy makers seeking to minimize costs for designing and evaluating effective public policies.

1. Introduction

Air pollution is a serious public health problem worldwide. In 2010, it was responsible for 3.3 million premature deaths globally (Lelieveld et al., 2015). Specifically exposure to Particulate Matter ($PM_{2.5}$) contributes to approximately 2 million premature deaths per year, ranking it as the 13th leading cause of worldwide mortality (Lozano et al., 2012).

Several studies have assessed air pollution related risks to guide environmental and public health policies (Bind et al., 2015; Lee et al., 2012; Lin et al., 2013; Pereira et al., 2014; Réquia Júnior et al., 2015a; Valdés et al., 2012). Risk-based decision-making can generate more efficient and consistent public policies (Tran et al., 2002; Vlachokostas et al., 2009; Yerramilli et al., 2011). However, studies have only suggested types of risk management actions necessary to address a given exposure problem situation. To our knowledge, there are no studies that have shown the spatial distribution of the specific alternatives for public policy decision making related to risk assessment.

According to Berry (1993) and Mitchell (1999), geographical mapping of proposed element (e.g., alternatives for public policy) is a potential tool to identify priority areas, to monitor conditions on the ground, to calculate temporal changes and to compare populations. The conceptual mapping of alternatives for public policy makes it much easier to communicate to potentially affected people and governmental agencies (Bateman et al., 2013).

Our study had two aims. The first was to map human exposure from air pollution sources in the Federal District. The second was to create and map alternatives for public policy decision making related to human exposures.

This study arose from the exchange of ideas with the Environmental Agency in the Federal District. The Environmental Agency is developing the Ecological-economic zoning (EEZ) based on several

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pieces of information, one of them are the findings from previous researches (Réquia Júnior et al., 2015a,b,c). However, the Environmental Agency in the Federal District does not has a guide for public policy decision making related to spatial variation of the human exposure.

2. Materials and methods

2.1. Study area

The study area was the state of Federal District (FD), Brazil, which has 2.8 million inhabitants in 5802 km^2. The FD is located in the center west of Brazil, between the parallels of 15° 30′ and 16° 03′ South Latitude and the meridians of 47° 25′ and 48° 12′ West Longitude. The area of FD is divided into 31 administrative regions of which one of them is Brasilia, Brazil's capital (IBGE, 2013). Fig. 1 presents the FD and its 31 administrative regions.

The FD faces several challenges. Two of them are urban growth and air pollution. Effective public policy addressing these challenges would improve quality of life among the FD population and reduce economic cost to government. Several studies have shown the relationship between urban growth and air quality (Cervero 2013; Réquia Júnior et al., 2015b,c; Torres et al., 2007), and the economic value of deaths and diseases due to air pollution (Davis, 2012; Shah et al., 2013). In short, the economic values corresponds to the amount societies are willing to pay to avoid these deaths and diseases with necessary interventions.

The FD is the fourth most populous state in Brazil. Over the last 15 years, the FD urban area became30% bigger. By 2030, FD population is expected to surpass 3.7 million inhabitants (IBGE, 2013). The FD has approximately 1.6 million vehicles, a rate of 0.6 vehicles per inhabitant, ranking it as the 5th Brazilian state with the higher rate (IBGE, 2013). Over the last 5 years, 15,000 people died due to cardiorespiratory diseases in the FD (Datasus, 2015). Studies have shown that in the FD air pollution is associated with an increase in cardiorespiratory diseases (Réquia Júnior and Abreu, 2011; Réquia Júnioret al., 2015b) and vehicle traffic is a significant source of air pollution (Réquia Júnior et al., 2015a,c).

2.2. Study design and data

This study was performed in nine stages. Stages 1 through 4 refer to the first aim (to map human exposure from air pollution sources) and stages 5 through 9 refer to the second aim (to create and map alternatives for public policy decision-making related air pollutant emissions). These stages were as follows: i) define the hierarchical network; ii) develop a spatial multicriteria model to generate weights for risk maps; iii) perform sensitivity analysis for the estimated weights; iv) apply GIS techniques for risk maps consolidation; v) definition of the alternatives; vi) include the alternatives in the hierarchical network, which was established on the stage 1; vii) use a spatial multicriteria model to generate the weights only for the alternatives; viii) perform sensitivity analysis for the weights, considering the alternatives, and; ix) apply GIS techniques for public policy maps consolidation (Fig. 2).

We used one input data to represent human exposures (Fig. 2). This data results from previous study in the Federal District (Requia et al., 2016).

The human exposure data refer to 9 risk maps of cardiorespiratory disease prevalence in the FD. Each map represents one predictor variable, which was identified by Requia et al. (2016) as significantly associated with an increase in cardiorespiratory disease. The variables were: highways, streets/avenues, wildfires, light vehicles, motorcycles, heavy vehicles, commercial areas, industry areas and exposed soil. Appendix B presents the description of all 9 variables and Appendix C presents the risk maps.

2.3. Hierarchical network (Stage 1)

The hierarchical network characterizes the conceptual model, which is needed for most multi-criteria models. The goal of our conceptual model was to create a map that depicts air pollutant exposures in the FD. We established the hierarchical network using nine-predictor variables, which were associated with an increase in cardiorespiratory morbidity (as shown in Appendix C).

We defined two primary criteria: transport; land use and other sources. Fig. 3 shows the complete hierarchical network.

2.4. Spatial multi-criteria model (Stage 2)

We used a multi-criteria decision-making (MCDM) approach to generate weights for risk maps. According to Gwo-Hshiung and Huang (2011), a MCDM is represented by various methods such as Elimination et Choix Traduisant la Réalité (ELECTRE), Preference Ranking Organization Method for Enrichment Evaluations (PROMETEE), Simple Additive Weighting, and Analytic Hierarchy Process (AHP). Among these possibilities, we choose the AHP.

The AHP method was developed by Saaty (1980) and has been frequently used in environmental studies (Fontana et al., 2013; Greening and Bernow, 2004; Tran et al., 2002). It is considered one of the best approaches of MCDM, because it is flexible because and it enables us to make decisions by combining judgment and personal values in a pairwise comparison. In addition, it can be used to decompose a complex decision-making problem into numerous simple sub problems (hierarchy network). It is a process for identifying, understanding, and assessing the interactions of a system as a whole. In summary, the advantages of AHP are as follows: it is a flexible model for a wide range of unstructured problems; it does not rely on consensus but synthesizes a representative outcome from different judgments, and; it provides a scale for measuring intangibles and a method for establishing priorities (Saaty, 1980).

Therefore, after defining the hierarchy network in Stage 1, we used AHP to assign the weights in a stratified fashion by obeying each level of the hierarchy that was established. The agents of FD Environmental Agency established the weights. One of the agents was the Assistant Administrator of the Agency. This local agency is one of the main stakeholders in the decision-making to reduce air pollution risks.

According to Saaty (1980) the weight scale varies from 1 to 9, with 1 = equal importance; 3 = weak importance; 5 = strong importance; 7 = very strong importance; 9 = maximal importance; and 2, 4, 6 and 8 representing intermediate importance. After assignment, we modeled the importance values using matrix (A) shown in Eq. (1).

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

Where $a_{ij} = \alpha$; $a_{ji} = \frac{1}{\alpha}$; a is a joint comparison; and α is the assigned importance value. We calculated the matrix (A) by the auto valueV_i, as shown in Eq. (2).

$$V_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{1/n} \quad (2)$$