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Atmospheric metal pollutants and environmental injustice: A methodological approach to environmental risk analysis using fuzzy logic and tree bark

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ABSTRACT

Air pollution is the single largest environmental risk today and is increasing in developing countries. In addition, exposure to air pollution is correlated to poor socioeconomic conditions owing to political processes and cultural and historic occupation of land. Ports have several structures that are potential emitters of pollutants such as large ship engines, diesel trucks, and trains. Owing to the considerable costs of implementing direct monitoring networks, alternatives like biomonitoring are an interesting approach to evaluate the environmental status of a particular area using living organisms or their parts such as bark, even though the use of bark as a biomonitor has several problems such as difficulties in determining the exposure period and its correlation with human exposure. Therefore, the use of a complementary mathematical logic is necessary. This study describes a methodological approach to evaluate the environmental risk from air pollution integrating data on environmental pollutants from tree bark using Fuzzy logic, based in the port city of Paranaguá in the state of Paraná in Brazil, and validated using income indicators. The results indicate that the risk distribution patterns have an inverse relationship with the income indicator, i.e., higher risk levels indicate lower income levels and vice versa. It was concluded that the system was able to identify the distribution of risk and that there is a context of environmental injustice in the region, where the environmental risk related to air pollution is inversely proportional to income levels. This type of information provides a decision making tool for environmental risk analysis from air pollution and can be used in the definition of public policies.

1. Introduction

In Latin America, approximately 35,000 people die annually because of air pollution, which is related to rapid development and urbanization processes based on the use of fossil fuels and industrialization (Bell et al., 2011; Romieu et al., 2011). It is estimated that air pollution-related diseases killed seven million people in 2012 worldwide, and it is known to be the single largest environmental risk today (WHO, 2014).

The atmospheric pollution trend is outstanding in developing countries but tends to stabilize in developed countries because air pollution sources result from economic, population, and transport growth, urbanization, energy consumption (Chen and Kan, 2008), and industrialization. In general, the government tends to ignore air pollution problems owing to lack of scientific knowledge and public policies, the idea that environmental policies can be "anti-economic," and the fact that the few industries and companies who may be impacted by such policies have strong political influence (Mcgranahan and Murray, 2012).

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The environmental crisis is a result of development models that consider the environment as a subsystem of the economy, using nature as a source of raw materials and a sewer for production workflow in processes that do not correspond to the thermodynamical laws of ecological systems (Cavalcanti, 2012). There is a relationship between development, environment, and health (Galvão et al., 2011). Therefore, environmental risk is a way to understand how production processes and development models contribute to degrading the health of communities.

Pearce et al. (2006) found that the groups responsible for the majority of the emissions are not the same groups that are exposed to them. Atmospheric pollution, even in countries with advanced economies, has a strict relationship with lower socioeconomic conditions due to political, historic, and cultural processes (Jerrett, 2009; Makri and Stilianakis, 2008; O'Neill et al., 2003). In Strasbourg, France, a relationship between the economic privation rate and levels of nitrogen dioxide (NO_2) was found (Havard et al., 2009). Living next to highways, areas that are usually inhabited by low-income families, is another risk factor (Brauer et al., 2002; Gauderman et al., 2004; Lin et al., 2002).

Environmental injustice is the disproportional exposure of certain groups of people, to pollution, environmental risks, or environmental policies (Maantay, 2002). This idea was consolidated in the 1980s, in the United States, in the context of the fight for racial equality. A landmark case for this concept occurred in 1982, when Afro-American residents in North Carolina opposed the installation of a toxic waste landfill in their vicinity (Laurent, 2011). In Brazil, studies concerning this topic have been consolidated via the structuring of the Brazilian Network for Environmental Justice (Porto, 2005).

For air pollution, port installations have several pieces of equipment that are potential emission sources, such as ships, trucks, and train engines (Bailey and Solomon, 2004). Diesel is widely used in port activities and is directly related to asthma, rhinitis, and the development of cancer (Dawson and Alexeeff, 2001; Pandya et al., 2002; Silverman, 1998). A recent study has estimated the annual environmental costs of the Port of Kaohsiung in Taiwan at approximately 123 million dollars (Berechman and Tseng, 2012).

Air monitoring networks have a high cost of implementation and operation and are generally not a priority for public investment, especially in developing countries. Therefore, the establishment of alternative monitoring techniques, such as biomonitoring, is important to visualize the air conditions. A biomonitor is an organism that accumulates pollutants in its tissues, acting as a sampler of those elements, and after being exposed to the environment, it can be used to determine the contamination level in a laboratory analysis (Marć et al., 2015). Tree bark has been used as a way to identify the distribution of metals in the air due to its capacity to absorb pollutants and its wide distribution in cities (Carneiro et al., 2011; Guéguen et al., 2011; Lahd Geagea et al., 2008a,b; Moreira et al., 2016; Senhou et al., 2002). In Brazil, recent studies have validated the use of tree bark as a biomonitor, notably in environments with heavy traffic (Carneiro et al., 2011; Moreira et al., 2016) and descriptions of industrial activities (Ferreira et al., 2012).

While reliable, the use of tree bark has several difficulties, e.g., the problems of identifying the exposed period and of providing comparisons with human exposure to the pollutant (Marć et al., 2015). Therefore, the use of an associated statistical method can be useful. Fuzzy logic is an important tool when working with environmental risk because it can use membership levels, as opposed to binary logic, to deal with the haziness and uncertainty of data in a realistic manner (Coutinho et al., 2015). In addition, Fuzzy models are easy to understand and have a low processing cost (Nascimento and Ortega, 2002), which contributes to their wide use in public health environmental studies, environmental health indicators, and expert-based models in multiple fields (Canavese et al., 2014; Canavese and Ortega, 2013; Chaves, 2013; Coutinho et al., 2015; Nascimento et al., 2009; Phillis and Andriantiatsaholiniaina, 2001).

This study developed a methodological approach to evaluate the environmental risks of air pollution using accessible indicators to provide strategic information to public health professionals and public administrations and to help in the decision making process, using the port city of Paranaguá as a model. This methodological approach was validated using relationships with income indicators.

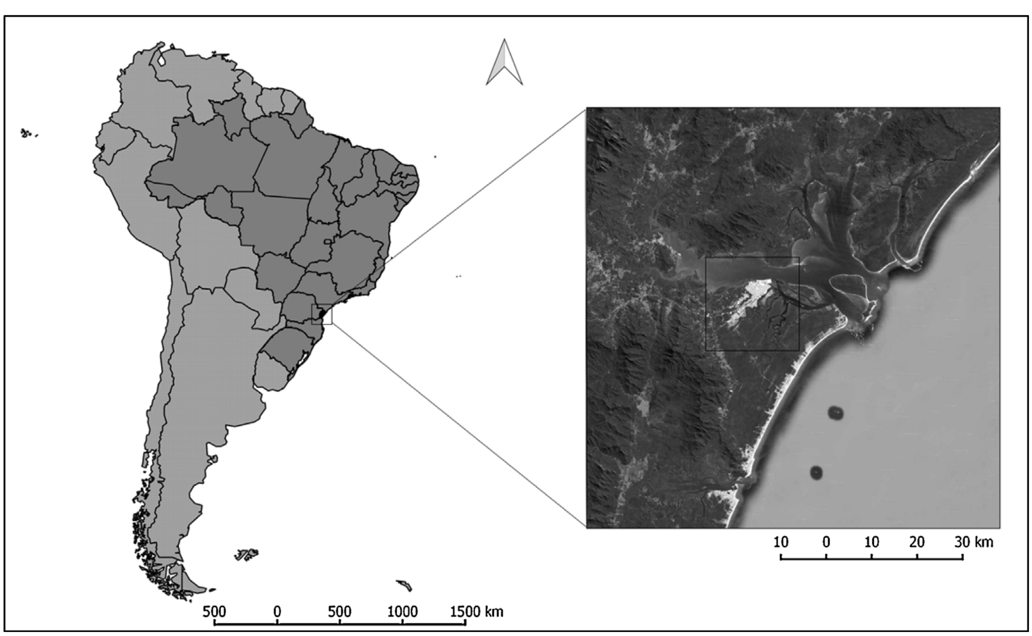

Fig. 1. Maps showing the location of the city of Paranaguá in Paraná State, Brazil. The white area in the satellite image represents the urban area of the city. Note its isolation and distance from any other urban-industrial locations.