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Assessing environmental inequalities in the city of Santiago (Chile) with a hierarchical multiscale approach

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ABSTRACT

Environmental inequalities are a common characteristic of urban areas. Environmental inequality is the unequal spatial distribution of environmental risks and goods among social groups. As environmental inequalities are inherently a spatial matter the choice of scale is essential for correctly understanding inequality issues and for designing proper and effective mitigation policies. However, the potential effects of scale of analysis on inequalities results have largely been underestimated in the assessment of environmental inequalities, leading to contradictory results from different studies. In this study we assess the patterns of environmental inequalities and associated scale issues in the city of Santiago (Chile) using a hierarchical multiscale approach. Our approach focuses on the analysis of spatial relationships between three environmental (i.e., surface temperature, air pollution, vegetation cover) and two socio-demographic variables (i.e., household wealth, population density) on multiple grain sizes and extents. We used census data, remote sensing data, and air pollution monitoring stations to generate raster layers at five grain sizes and five nested extents. We tested for inequalities through Pearson correlation analysis resulting in a total of 1530 assessed relationships. Our results show that environmental inequalities are a prevalent phenomenon in the city of Santiago, but the details of these inequalities are highly scale dependent. Changing the grain size and extent of analysis do not only affect the strength of relationships between socio-demographic and environmental variables, but also the spatial distribution of environmental inequalities across the urban landscape. Therefore, due to the scale-dependence of assessment results, researchers and decision-makers should be extremely careful when interpreting their findings and translating them into policy making. If the scale dependency of environmental inequalities is not taken into account, policy interventions may be largely ineffective because the scale at which interventions are designed may not match the scale at which inequalities are generated.

1. Introduction

Urban areas are home to more than 50% of the world population, and this number is expected to go beyond 65% by the middle of this century, with most of this growth taking place in the developing world (UNDESA, 2014). Urban areas are hubs for human development, but also places of increasing environmental problems and socioeconomic inequalities (Wu, He, Huang, & Yu, 2013). Furthermore, as cities are the result of complex socio-ecological interactions operating at different spatial scales, environmental quality, ecosystem services, and social groups are seldom homogenous across the landscape, often leading to environmental inequalities (e.g., Bowen, Salling, Haynes, & Cyran, 1995; Daniels and Friedman 1999; Heynen, Perkins, & Roy, 2006; Mitchell and Chakraborty 2014; Pope & Wu, 2014).

Environmental inequality is “the unequal social distribution of environmental risks and hazards and access to environmental goods and services” (Sustainable Development Research Network, 2007). Thus, environmental inequality relates to the statistical spatial relationship between social and environmental variables and should not be confounded with the normative concept of environmental inequity or distributive environmental justice (Kaswan, 2003). Whereas the inequality concept does not entail a normative judgment about the resource distribution, the inequity

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concept implies that the resource distribution is judged as socially unfair (Kawachi, Subramanian, & Almeida-Filho, 2002).

Although environmental inequalities may have long characterized urban settlements, they only started to gain attention from researchers and policy-makers in the 1980's, when studies in U.S.A found that disadvantaged people tended to be exposed to higher levels of environmental hazards (Szasz & Meuser, 1997). This inequitable distribution of environmental hazards triggered the environmental justice movement, as well as the environmental justice studies as an interdisciplinary body of research (Mohai, Pellow, & Roberts, 2009). Since the pioneering studies in the 1980's, environmental justice research has increased substantially in the developed world, but it was not until the 2000's that these topics started to gain attention from academics and decision-makers in developing countries (Mohai et al., 2009; Walker, 2009). This has limited the generation of locally-based knowledge on environmental inequalities/inequities in developing countries, whose underlying causes, key drivers, scales, and patterns may differ greatly from those in the developed world (Carruthers, 2008).

Numerous studies have shown that statistical analyses based on spatial data are often affected by the scale of observation/analysis (e.g., Buyantuyev, Wu, & Gries, 2010; Jelinski & Wu, 1996; Turner, O'Neill, Gardner, & Milne, 1989; Wu, Gao, & Tueller, 1997). In particular, different scales of observation/analysis may lead to different or sometimes conflicting results, and the same phenomenon may manifest itself variably across scales (Wu, 2007). As environmental inequalities are inherently a spatial matter, therefore, the choice of scale is essential for correctly detecting and quantifying inequity issues and for designing proper and effective policies to deal with them (Baden, Noonan, & Turaga, 2007; Cutter, Holm, & Clark, 1996; Noonan, 2008; Pope & Wu, 2014; Pope, Wu, & Boone, 2016). Nevertheless, potential scale effects have rarely been examined explicitly in assessing environmental inequalities, leading to contradictory results from different studies (Anderton, Anderson, Oakes, & Fraser, 1994; Baden et al., 2007).

Two scale-related issues are particularly important for assessing and interpreting environmental inequalities: The modifiable areal unit problem (MAUP) and the ecological fallacy (Wu, 2007). MAUP arises from the fact that units of analysis are modifiable in the sense that they can be aggregated into different sizes or spatial arrangements for statistical analysis (Fotheringham & Wong, 1991; Openshaw, 1989). MAUP has two related but different components: the scale effect and the zoning problem (Jelinski & Wu, 1996). The scale effect is the variation in statistical results in response to aggregation of data into fewer and larger areal units, whereas the zoning effect is the variation in results due to different delineation of areal units at a given scale (Jelinski & Wu, 1996; Wu, 2007).

An ecological fallacy may occur when the inferences made at the aggregated-level data are directly extrapolated to the individual level, or in other words to assume that the relationships observed for aggregated units necessarily hold for individual units (Freedman, 2001). In some cases, correlations at the aggregate and individual levels may have opposite signs (Buyantuyev et al., 2010; Jargowsky, 2005; Wu et al., 1997). Also, an "individualistic fallacy" or "atomistic fallacy" – the reverse problem of ecological fallacy – may also occur as a result of improperly inferring aggregate-level relationships from individual-level results (Diez Roux, 2002). Thus, cross-level or cross-scale inferences using spatial data must be done with caution (Wu, 2007).

The MAUP and inference fallacies need to be considered explicitly in designing research projects and interpreting analysis results in environmental inequality assessments. Otherwise, policies and management actions will not be effective or justified when they are based on erroneous inferences. To overcome these scale-related problems, the assessment of environmental inequalities should take a hierarchical multiple scale approach that evaluates the occurrences of inequities, as well as their spatial patterns and drivers, on a range of scales (Buyantuyev et al., 2010; Wu, 2007; Wu et al., 1997).

The main objective of this study was to assess the patterns of environmental inequalities and associated scale issues in the city of Santiago (Chile) using a hierarchical multiscale approach. Our approach focused on the analysis of spatial relationships between three environmental and two socio-demographic variables on multiple nested scales. The three environmental variables were: vegetation coverage, summer surface temperatures, and winter air pollution. We selected these environmental variables because the scarcity of green infrastructure, summer heat risk and winter air pollution are among the most important factors currently affecting the health and quality of life of Santiago's residents (De La Barrera, Reyes-Paecke, & Banzhaf, 2016; Krellenberg, Müller, Schwarz, Höfer, & Welz, 2013; Toro, Morales, Canales, Gonzalez-Rojas, & Leiva, 2014). The two socio-demographic variables were: household wealth and population density. Household wealth was selected as the main socioeconomic indicator to evaluate environmental inequalities and inequities in Santiago. Population density was used as a supporting variable to analyze if wealth-environmental relation patterns could be associated to other underlying factors, but also as an additional socio-demographic variable to evaluate the scale effect on spatial relationship assessment.

The following specific questions were addressed: Does the spatial relationship between environmental and socio-demographic variables suggests the occurrence of environmental inequalities in Santiago? How does the scale of analysis affect the degree and spatial pattern of environmental inequalities? What may be the potential drivers for these inequalities at different scales? What are some policy-relevant implications?

2. Methods

2.1. The study area

Santiago de Chile (33°26′15″S; 70°39′01″W) is located in the Maipo river basin, bounded on the east by the Andes Mountain Range, and on the west by the Coastal Mountain Range. The city covers a surface of about 617 km^2 (Romero et al., 2012), with elevation ranging from 450 to 1000 m above the sea level. The climate is Mediterranean, characterized by cold and rainy winters months and warm and dry summers (Cruz & Calderón, 2008). With a projected population of 6.4 million by the year 2015, Santiago has almost doubled the number of residents in the last 30 years, and currently harbors about 37% of Chile's total population (Instituto Nacional de Estadísticas, 2015).

The population growth has been coupled with urban expansion that has doubled the spatial extent of the city since 1975, mostly replacing agricultural land and surrounding natural habitats (Romero et al., 2012). The transformation of agriculture and natural areas to urban infrastructure has negatively impacted the environmental quality of the city, including decreases in vegetation cover and increases in temperatures and air pollution (Krellenberg et al., 2013; Romero & Vásquez, 2005; Romero, Ihl, Rivera, Zalazar, & Azocar, 1999). In addition, the lack of appropriate urban planning and a highly liberalized real-estate market have led to high levels of spatial segregation between social classes (Borsdorf & Hidalgo, 2008). These factors are possibly key ingredients for high levels of environmental inequities. Previous studies have reported that lower socioeconomic groups tend to live in areas of lower environmental quality (De La Barrera et al., 2016; Escobedo et al., 2006; Reyes-Packe & Figueroa, 2010) and higher environmental risks