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Geospatial analysis of naturally occurring boundaries in road-transport emissions and children's respiratory health across a demographically diverse cityscape

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ABSTRACT

The motor-vehicle is accountable for emitting a substantial concoction of air quality objective pollutants and carcinogenic hydrocarbons within close proximity to urbanised residential districts. The spatial extent of health impacts associated with road-transport pollutants have traditionally been explored through the examination of artificially created buffers, defined by subjective distances from specified major road links. Within this paper an alternative approach is presented using boundary statistics, which describe naturally occurring shifts of magnitude in socio-environmental and health outcomes across the wider urban area. In contrast, previous distance-threshold investigations have used arbitrarily sized buffers placed upon predetermined locations in response to environmental attributes, without considering the combined influence of additional social burdens. The demographically diverse City of Leicester, situated within the heart of the United Kingdom's major road-transport network, was selected to showcase such methods.

Descriptive multilevel modelling strategies accommodating for generalised spatial structures across Leicester, globally associated issues of deprivation, road-transport emissions and ethnic minorities with increased respiratory risks. Getis-Ord Gi* spatial pattern recognition statistics identified the existence of localised variations, with inner city neighbourhoods tending to house children of ethnic minority groups whom experience disproportionately large environmental and respiratory health burdens. Crisp polygon wombling boundary detection across Leicester appeared to broadly complement the Gi* statistics, identifying naturally occurring boundaries in road-transport emissions to result in elevated children's respiratory admissions within a distance of 283 m ($P < 0.05$). The designated threshold was identified to reduce in relation to certain ethnic groups, thus suggesting environmental injustices likely prevail within the model British multicultural City of Leicester. The study's findings have applications within healthcare management and urban planning for locating vulnerable populaces and for minimising health risks in future road network designs.

Introduction

Childhood is a critical period for the development and maturation of the delicate spongy organs of the cardiorespiratory system, which are particular susceptible to the absorption of external environmental agents experienced within the urban arena. Compared to adults, a child's lung surface area is also considerably larger in relation to their body mass, with children potentially breathing up to 50% more air per kilogram of body weight (Schwartz, 2004). Another major factor that influences the relative impact of air pollution on children versus adults is exposure, with children in the UK tending to spend prolonged periods outdoors especially in the evening and over summer months, conducting activities that increase ventilation rates (Cooper et al., 2010; Steele et al., 2010).

Such increased levels of organ receptiveness combined with high metabolic rates and comparatively large consumption levels of air pollutants, thus offer favourable conditions for either damaging and/or stunting the development of vital organs of the cardiorespiratory system, potentially creating problems which prevail throughout adulthood (Schwartz, 2004). This is of critical importance when considering that personal exposure to air pollutants is currently estimated to reduce the life expectancy of every person within the UK by an average of 7–8 months, with costs to the National Health Service (NHS) of up to £20 billion per annum (DEFRA, 2007).

Across the urban environment, road-transport constitutes as the predominant source of outdoor air pollution, emitting a concoction of air quality objective pollutants and carcinogenic hydrocarbons within close proximity to residential districts. Simplistic

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approaches towards distinguishing unique community exposures to traffic pollutants, commonly involve the utilisation of surrogate measures such as residential proximity to major road links, with questionnaires or spirometry tests measuring diminishing respiratory functions in relation to distance (Brunekreef et al., 1997; Oosterlee, Drijver, Lebret, & Brunekreef, 1996). A recent proximity based study inspecting 8-years of lung development within Californian children, identified residents $\leq$500 m from freeways to experience a decline in Forced Vital Capacity (FVC) of -63 ml, diminishing to -19 ml at distances of 1000–1500 m (Gauderman et al., 2007). Maantay (2007) investigated the occurrence of asthma hospitalisations in relation to air pollution across the Bronx, NY, through applying established environmental agency proximity standards to construct environmental hazard buffers for Toxic Release Inventory (TRI) facilities (800 m), stationary point sources (400 m) and major truck routes (150 m). Approximately 66% of the Bronx's land mass fell within the buffers, which were predominantly occupied by ethnic minorities (88%), and contained a substantial amount of persons living below the federal poverty level (33%). Maantay's study also showed that across the 5-year study period of 1995–1999, children aged 0–15 years residing within pollutant buffers were observed to experience a greater risk of hospitalisation, as defined by Odds Ratio's (OR) of 1.11–1.17. Within a European context, the Health Survey for England datasets nationally identified respiratory outcomes across 6015 children aged 7–15 years to become exacerbated across extremely localised distance bands from main roads after adjustment for sex and deprivation (Pujades-Rodriguez, Lewis, Mckeever, Britton, & Venn, 2009). Adjusted Odds Ratios (AOR) using the 120–150 m band as a benchmark, identified wheeze, asthma and allergic rhinitis symptoms to progressively increase with proximity, reaching respective AOR's of 1.62, 1.35, and 1.14 for children residing $<$30 m from major roads (Pujades-Rodriguez et al., 2009).

Thus, it is well documented that exposure to elevated levels of air pollution causes acute respiratory distress, with such effects tending to exacerbate within artificially created buffers that are of closest proximity to specified major roadways. However, it remains unclear whether exposure in the every-day environment to naturally occurring zones of rapid change in pollutants, is sufficient to considerably attribute towards the spatial existence of marked boundaries in respiratory health (Jacquez, 1995). This research intends to address such issues through the application of geographic boundary analysis techniques, which define the natural occurrence and magnitude of objects across spatial fields.

Studies involving the detection and overlap of naturally occurring geographic boundaries have been widely applied within the fields of genetics and ecology (Barbujani, Oden, & Sokal, 1989; Fortin & Drapeau, 1995; Hall, 2008), for the evaluation of locations portraying an amalgamation of biological, physical and social processes at work. However, few studies have explored their applications within the wider fields of epidemiology and public health, with applicable studies tending to solely focus on issues concerning the late-stage diagnosis and mortality rates of cancer patients (Jacquez & Greiling, 2003).

An ecological boundary analysis approach was favoured over conventional population targeted proximity enquiries, primarily due to its elimination of selection bias, and secondly because such techniques determine the exact critical distance threshold between substantial gradient shifts in air pollutants and health outcomes, without testing across multiple arbitrary distances. Furthermore, traditional proximity studies of pollutants on health outcomes have often treated supplementary social circumstances purely as confounding measurements, for which populaces may require necessary adjustments. In contrast, boundary analysis methods can be used to define zones of rapid change across multiple socio-environmental variables of interest, which may then be compared to health boundaries. This is of particular importance when considering that specific communities tend to experience a 'triple jeopardy' of social, health and environmental inequalities (Pearce, Richardson, Mitchell, & Shortt, 2010). Finally, such techniques should be viewed as a more appropriate form of analysis across urban environments, which contain vast road networks and experience complex transport flows. In some cases, congestion on minor roads close to residential areas perhaps poses a higher respiratory health risk than what would be experienced along fast-flowing major roads. Therefore it would be of greater interest to explore naturally occurring urban pollutant gradients rather than focussing on a specific major roadway. However it is not the authors' intention to discount traditional individual subject-level proximity based enquiries, but rather emphasise that future research should appreciate the application of ecological approaches to rationally locate and determine appropriate thresholds for use within a population specific analysis.

The following article explores whether residential exposure to geographically elevated levels of road-transport emissions recorded as PM_{10} (TPM_{10}), affects severe respiratory responses across sensitive individuals within the City of Leicester. To address this question, naturally occurring boundaries defined from spatially detailed datasets of social and environmental variables, were compared with children's respiratory hospital admissions; in order to assess whether such factors provoked boundaries to occur across surfaces of respiratory health. The study's spatial datasets were collected across Leicester Unitary Authority's (UA) 187 Lower Level Super Output Areas (LSOA's), each of which contains approximately 1500 residents occupying an area of roughly 0.39 km^2.

Data collection

Study setting

The City of Leicester contains some 280,000 inhabitants spread across an area of 73.32 km^2, and is regarded as providing a unique model of a harmonious multicultural city (Vidal-Hall, 2003). Population demographics from the 2001 UK Census reveal a relatively young population to inhabit Leicester, with 22.29% of residents being under the age of 16 years (ONS, 2003). Furthermore 47.09% of children aged 0–15 years are from ethnic minority groups, of which 63.71% are identified to be of Indian ethnicity (ONS, 2003). The cities other clearly defined ethnic minority groups are representative of contemporary UK migration trends, including children of Afro-Caribbean (5.69%), White Non-British (3.17%), and Other South Asian (12.49%) ethnicities. In general Leicester is considered a relatively poor city, ranked as the 31st poorest out of 354 Local Authorities in England under the 2007 Indices of Multiple Deprivation (ONS, 2008a).

Hospital admission database

A geocoded respiratory subset of NHS hospital admissions (ICD-10: J00-99) for persons aged 0–15 years residing within the Leicester Unitary Authority's (UA) 187 Lower Level Super Output Areas (LSOA's) from 2000 to 2009, was obtained through the Leicester City Primary Care Trust (PCT). The geocoded dataset was based on residential address, and contains details of admissions for patients regardless of whether they were admitted to a hospital within or outside of the Leicester UA catchment area. From this dataset a 1-year standardised hospital admission rate for 'All diseases of the respiratory system' was calculated.

Routine UK hospital statistics classifying patients on discharge are generally thought to be of a high standard, which is maintained through a considerable expenditure of NHS resources on quality assurance activities. A systematic review of 12 studies comparing