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Social indicators are predictors of airborne outdoor exposures in Berlin

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ABSTRACT

Exposure by airborne pollutants adversely affects human health and well-being. Particulate matter (PM10, PM2.5) and nitrogen oxides (NO_X, NO_2) are two of the most important airborne pollutants in Germany. Epidemiological studies found that these pollutants significantly increase morbidity and mortality by cardiovascular, respiratory and other diseases. Inner-urban differences of human exposure are often higher than mean differences between cities. Therefore it is necessary to investigate the inner-urban spatial distributions of human exposures. Additionally the question arises if the social situation of population is also related to airborne outdoor exposures.

On the example of Berlin the spatial distribution of airborne exposures of PM2.5 and NO_2 was determined for the 447 Berlin planning areas (PLAs), each characterized by about 7500 inhabitants, rather unique structure of buildings, big roads, and certain social structure. In this study we also investigated the combined exposure by PM2.5 and NO_2. Because both types of air pollutants are traffic related, traffic parameters were included into the assessment.

In order to investigate the socio-spatial distribution of PM2.5 and NO_2 at the planning area level the air pollution was statistically and spatially correlated with the development index of the Berlin Social Urban Development Monitoring and other social indices. Generally, but also in Berlin, there exists a strong tendency that decreasing social indicators are related to increasing human exposures. About 10% of Berlin's population live in PLAs with a very low or low development index and with very high or high air pollution levels and thus are discriminated twice. The lower the development index in a PLA, the higher is the share of population exposed to high air pollution and vice versa.

1. Introduction

An emerging topic in the field of urban ecology is the concept of ecosystem services and disservices (Burgin et al., 2013; Lyytimäki and Sipilä, 2009). On the one hand cities benefit from ecosystem functions in form of ecosystem services, on the other hand they produce disservices (Gómez-Baggethun and Barton, 2013). In the literature different definitions of ecosystem services can be found (Boyd and Banzhaf, 2007; Constanza et al., 1997; Daily, 1997). According to the Millennium Ecosystem Assessment (W.H.O., 2005) ecosystem services are the benefits people obtain from ecosystems. They include provisioning, regulating, cultural and supporting services. Fisher et al. defined ecosystem services as 'the aspects of ecosystems utilized (actively or passively) to produce human well-being' (Fisher et al., 2009, p.645). In TEEB ecosystem services were defined as the benefits that humans derive from nature (Mader et al., 2011). In contrast Lyytimäki and Sipilä defined ecosystem disservices as 'functions of ecosystems that are perceived as negative for human well-being' (Lyytimäki and Sipilä, 2009, p.311).

Ecosystem disservices can strongly harm human health (Andersen, 2011). Especially in urban agglomerations the interrelations between ecosystem services and disservices and their consequences for urban population are considerable. A very important regulating ecosystem service is the provision of clean air to breathe (Bolund and Hunhammar, 1999; Gómez-Baggethun and Barton, 2013). The emission of air pollutants is a disservice which

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Table 1
Target/limit values for NO_2 and PM2.5 according to (i) air quality Directive 2008/50/EC for PM10, PM2.5 and NO_2 (2008) and (ii) WHO Air Quality Guidelines for Particulate Matter and Nitrogen Oxides (2006).

Pollutant	Yearly average [μg/m^3]	Type of value [entered into force]	According to
PM2.5	25	Target value [1-1-2010] Limit value [1-1-2015]	(i)
	10	Guidline [2006]	(ii)
NO_2	40	Limit value [1-1-2010]	(i)
	40	Guidline [2006]	(ii)

endangers public health. Urban outdoor air pollution influences the whole urban population. In contrast to waterborne and soil pollutions, there is no effective strategy to avoid the intake of airborne pollutants. Indoor air contains outdoor pollutants, too (Abt et al., 2000; Cyrys et al., 2004; Franck et al., 2003). Epidemiological studies have consistently demonstrated that numerous health problems can be caused or worsened by exposure to outdoor air pollutants such as nitrogen oxides and particulate matter. These pollutants play a dominant role in most urban agglomerations and are associated to traffic emissions (Lewne et al., 2004; Penard-Morand et al., 2006; Rijnders et al., 2001; Tramuto et al., 2011). Many epidemiological studies indicated that both morbidity and mortality are influenced by these airborne exposures (Ackermann-Liebrich, 2011; Adar and Kaufman, 2007; Beelen et al., 2008; Boldo et al., 2006; Brunekreef et al., 2009; Kappos et al., 2004; Mills et al., 2008; Peters, 2005). Medina et al. investigated the health impact of PM10 in 19 European cities with nearly 32 million of inhabitants in total and mean PM10 concentrations in the range between 14 and 73 μg/m^3 (Medina et al., 2004). They concluded that a reduction of average concentrations of PM10 (mass concentrations of airborne particles with aerodynamic diameters < 10 μm) by 5 μg/m^3 would be able to prevent between 3300 and 7700 premature death in these cities annually. Particles in this size range are able to penetrate the respiratory tract deeply, reaching the alveoli. Exposure to fine particles can cause short-term health effects such as eye, nose, throat, and lung irritation. It can also affect lung function and exacerbate common medical conditions such as asthma and cardiovascular diseases, but also allergic diseases, atherosclerosis, diabetes, premature birth outcomes, headache and even mental depression (Brauer et al., 2008; Chiusolo et al., 2011; Dijkema et al., 2011; Kramer et al., 2000; Oftedal et al., 2007; Sun et al., 2005; Szyszkowicz et al., 2009). Studies also suggested that long term exposure to fine particulate matter or NO_2 may be associated with increased rates of chronic bronchitis, reduced lung function and increased mortality from cancer and cardiovascular diseases (Beelen et al., 2008; Boldo et al., 2006; Brunekreef et al., 2009). People with preexisting cardiorespiratory conditions, children and the elderly may be particularly sensitive to exposure (Barnett et al., 2006; Dijkema et al., 2011).

Such results are expressed in preventive measures of outdoor air pollution standards and/or regulations. In the European Union, the concern has been on PM10. In other countries, e.g. the U.S, so-called fine particles <2.5 mm (PM2.5) are in the focus of prevention. In the EU, there has been a target value for PM2.5 since 2010 and will become a limit value in 2015 (Table 1).

Yearly mean concentrations of airborne pollutants are not equal in urban agglomerations but show often remarkable spatial differences (Boogaard et al., 2011; Medina et al., 2004; Penard-Morand et al., 2006; Rijnders et al., 2001). On the other hand, socio-spatial differentiation is a phenomenon which results in the spatial segregation of groups of different socio-economic levels within urban areas (Haase et al., 2010; Hornberg and Pauli, 2007; Romero et al., 2012). Hence, this study aimed on the assessment of relationships between ecosystem disservices and their socio-spatial distribution in Berlin. We hypothesized that so-called planning areas (PLAs) are associated to both, a particular level of urban exposure and a specific social level. For verifying this hypothesis we tested various indicators describing the social status of population and its development and visualized the socio-spatial distribution of NO_2 and PM2.5 exposures in Berlin.

2. Materials and methods

2.1. Study area and spatial structure of data base

Berlin is located in eastern Germany, in an area of low-lying marshy woodlands with a mainly flat topography of an ice age glacial valley, 34–115 m above sea level. Berlin has a humid continental climate (Köppen climate classification). It covers an area of 892 km^2. With a population of 3.43 million people, Berlin is Germany's largest city and is the second in the European Union (Meng, 2012). The population density is 3842 inhabitants per km^2. In 2006, 1.416 million motor vehicles were registered in the city (Statistisches Bundesamt, 2006).

Administratively, Berlin is structured into 12 urban districts, 60 so-called prognosis areas, and 138 district regions. According to a 2006 Senate decree, an additional new spatial basis was introduced for monitoring and planning of different urban development processes including demographic and social developments in Berlin (Welsch et al., 2011). This classification offered new and unique opportunities for the assessment and evaluation of social-economic, environmental, infrastructural, and further characteristics and developments including the interrelations between the social situation of population, environmental quality and health. The classification aimed on homogeneously structured living areas as smallest analytical units. These planning area units were therefore defined by uniform urban structure types and local environment, large roads and traffic arteries, as well as natural barriers (e.g. water bodies). These premises resulted in 447 PLAs in the average with 7538 persons and a mean area of around 2.0 km^2. Exposure parameters and social indices were available or determined for each PLA. The definition based on homogeneity and sufficient number of PLAs facilitated their comparability within statistical assessments and the interpretation of results, but also allowed informative spatially resolved mapping in geographical information systems.

2.2. Social indicators

The social indicators include information about unemployment (percentages of unemployed, unemployed in the age between 15 and 24, people unemployed longer than one year, beneficiaries of welfare aid/unemployment pay (so-called Hartz IV compensation). The dynamic indicator also includes changes of parameters and migration balances of different groups. (A detailed description of this index is given in Häußermann et al. (2009).)

For this study, data within two index systems were available for 2008 from the Social Urban Development Monitoring 2009 in Berlin (Häußermann et al., 2009).

1. The status-dynamic index has two dimensions describing the present social status of the PLA and its developmental potential. The status dimension classifies the two deciles of PLAs with the highest status as "high". The deciles with the lowest status and with the second-lowest status are classified as "very low" and "low", respectively. The six deciles between the top two and bottom deciles are marked "medium". The dynamic dimension has three classes covering the first and second, third to seventh, as well as the ninth and tenth decile.