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Traffic-induced noise levels in residential urban structures using landscape metrics as indicators

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ABSTRACT

Traffic noise is one of the most prominent environmental stressors in cities. It often results in cardio-respiratory diseases among urban dwellers and thus counteracts important urban health targets. Using the city of Leipzig in Germany as a case study, we show that the noise level depends on the properties of the urban structure type, determined by landscape metrics. Landscape metrics, as a type of indicator, describe potential noise in residential areas in cases in which no measured data are available, e.g., for future planning purposes. Potential noise conflict areas can be efficiently, easily and reliably detected. For each considered residential urban structure type, we computed nine different models to evaluate the noise level and the number of exposed persons in addition to 14 landscape metrics for all patches of the urban structure type. The results offer significant correlations between noise level and landscape metrics. In addition, construction height and total built area was found to reduce the noise level in neighbourhoods. These results can be adopted for other cities in Europe facing considerable structural changes in residential areas.

1. Introduction

The health status of European urban dwellers has been improving continuously over the last several decades (OECD, 2010). Nevertheless, urban traffic remains an important source of noise exposure in residential urban areas. The negative effects of long-term exposure to road traffic noise levels are quantified in the 'Burden of disease by environmental noise' report (WHO, 2013). Noise-induced stress can influence the human immune system and increase respiratory indisposition. In addition to general annoyance and sleep disturbance (Kim et al., 2012; Tiesler et al., 2013), studies indicate effects on stress hormone level (Sørensen et al., 2013), arterial blood pressure (Belojevic and Evans, 2012) and cardiovascular diseases (Eriksson et al., 2012b; Xie and Kang, 2009) as well as concentration, memory and learning capacity (Van Kempen et al., 2012).

Strategic noise mapping in European urban agglomerations with more than 250,000 inhabitants indicated that approximately 56 million people are exposed to L_{DEN} levels above 55 dB (A) and 40 million to L_{Night} (Renterghem and Botteldooren, 2012). In densely populated areas in particular, noise pollution has major health effects. Multiple reflections between façades create a strong amplification of the noise levels in city streets (Renterghem and Botteldooren, 2012). Noise maps based on the Environmental Noise Directive (END) are useful for assessing residential traffic noise exposure (Eriksson et al., 2012a).

Previous studies on noise exposure have rarely offered any link to urban (land-use) structures. Nijland et al. (2007), for example, highlight the connection between traffic-induced noise and the coherent choice of location of a residence but does not report any significant statistical correlation between the noise level and the perception of noise in single and semi-detached housing or other urban structure types. Gidlöf-Gunnarsson and Öhrström (2010) uncover the influence of the physical environmental qualities of quiet courtyards on residents' noise responses. Their findings show that general annoyance is significantly related to noise exposure and courtyard quality and that the form of building blocks also has a substantial effect on the noise level at the quiet façade of a building. Noise levels at quiet facades were found to be lower in closed building blocks than open blocks (Salomons and Pont, 2012). In addition, urban residents are exposed to higher noise

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levels at the noise-exposed façade. Ranjbar et al. (2012) explore the impact of traffic noise on high-rise buildings and the surrounding areas in Tehran, Iran. The highest noise level arises at the lowest front corner of the side panels closest to the motorway, and the lowest noise level occurs at the back edge of the roof. A 7-m-tall barrier at a distance of 2 m from the edge of the road reduced the noise level dramatically. Lam et al. (2013) report a strong correlation between noise characteristics and morphological indicators at the dwelling scale. The results suggest an influence of urban forms on noise level in urban environments. Another study by Lam and Ma (2012) explored the traffic noise exposure for old and recently built residential buildings in Hong Kong, finding lower noise exposure for recently built residential complexes.

Landscape metrics are algorithms that quantify specific spatial characteristics of elements (patches, classes of patches or entire landscape/land-cover/land-use mosaics) using categorical maps (Turner and Gardner, 1991). They can be straightforwardly and quickly computed when a land-use map is available. In addition, they have already been successfully applied to urban form analysis (Schwarz, 2010). Many land-use and landscape studies have utilised landscape metrics to assess the impacts of the form, pattern and the configuration of built and non-built land covers on ecological processes, the bio-physical properties of the earth's surface, biodiversity (Höbinger et al., 2012; Schindler et al., 2013; Uuemaa et al., 2009), the quality of habitats (Cushman et al., 2012; Santos-Filho et al., 2012), land-use change (Hassett et al., 2012; Kong et al., 2012; Wang et al., 2012) and fragmentation (Cushman et al., 2012).

The suitability of using landscape metrics for the estimation and prediction of acoustic noise based on urban land-use/cover structures—represented in our study by urban structure types according to a classification scheme proposed by Haase and Nuissl (2007; Table 1)—has not been tested. Based on a study on traffic-induced noise and air pollution in urban structures (Weber et al., in press), we simulated different noise scenarios for a full range of landscape metrics in different urban structure types.

Our study investigates the following hypotheses:

1. Urban land-use/structure type has a significant influence on exposure traffic noise, especially the height of construction and the percentage of built area.
2. Building/house density has a significant influence on traffic noise level.
3. Identical changes in height construction and built area (models) cause the same noise level changes in each structure type.
4. Landscape metrics are able to predict the level of traffic noise in urban structure types and thus allow the prediction and ranking of noise levels in different urban structure types.

2. Materials and methods

2.1. Study area

As a consequence of the German reunification in 1990, a structural change in urban land-use and built-up structures occurred in most cities in eastern Germany. The city of Leipzig is highly suitable for this study because it is a typical compact Central European city undergoing post-socialist structural changes in its characteristic and comparatively homogenous built structures, such as "Wilhelminian-period" block estates, prefabricated (large) housing estates, single and detached homes and twin houses, all in primary residential areas. Additionally, a broad urban restructuring process has been underway since 2000, characterised by land-use fragmentation followed by reurbanisation (Kabisch et al., 2010), including the erection of inner-city townhouses (narrow row houses with 3 or 4 floors). Due to the closing of numerous industrial and commercial facilities and the reduction in coal-fuelled domestic heating in the course of the German reunification and economic transformation, pollutant loads, mainly produced by the coal and chemical industries, have decreased dramatically (Couch et al., 2005; McGarigal and Marks, 1995).

This study relies on municipal monitoring instruments in the form of noise maps and noise models in combination with spatial vector and raster data on urban land use and built structures (including building densities, heights, vacancies and alterations) in the city. Due to the use of the common urban land-use classification system proposed by Haase and Nuissl (2007), the findings of this study can be transferred and compared to other German or European cities with structures and degrees of compactness comparable to those of Leipzig. Seven urban land-use structure types were considered: multi-storey tenement blocks, prefabricated housing estates, residential cores, residential parks, single and semi-detached houses, terraced houses and villa areas (see more details in Table 1).

2.2. Noise exposure

Traffic noise monitoring for the city of Leipzig was established in 2005–2007 by the Environmental Agency (Environmental

Table 1
Land use classification system used in this study.

Land use class	Definition	Patch density (number/100 ha)	Area (km^2)	Mean height (m) and number of buildings	LDEN Average noise level (dB (A))
MSTB (multi-storey housing, tenement blocks)	19th-Century built-up area (1870–1910); arrangement of buildings around a shared leafy court	554.07	14.41	12.28 (28,728)	62.89
PHE (prefabricated housing estates)	Multi-storey dwellings	365.10	5.03	14.48 (2089)	59.23
RC (residential inner city core)	City centre	661.58	7.08	8.32 (13,036)	63.91
RP (residential park)	Modern high-density single house estates built after 1990	397.64	1.43	9.78 (1049)	58.96
SSDH (single and semi-detached houses)	Low-density single-house built-up area	454.74	27.71	6.46 (44,211)	58.45
TH (terraced houses)	Low-density single-house built-up area (alignment with noise prevention)	586.66	5.89	11.85 (7180)	61.82
V (villa area)	High-quality detached houses supplemented by private gardens	546.05	2.06	9.18 (3099)	62.59

Modified from Haase and Nuissl (2007).