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Green and calm: Modeling the relationships between noise pollution propagation and spatial patterns of urban structures and green covers

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ABSTRACT

The mechanism of noise pollution propagation is considerably affected by 1) the type and configuration of its receiving environment and 2) the distance that sound waves pass to reach that environment. This study adopts a spatio-statistical approach to quantify and model associations between noise pollution levels and landscape metrics of land categories (built-up structures and urban green covers). Accordingly, noise levels were measured employing a sound pressure meter to quantify equivalent levels (*Leq* in dB *A*), in addition to their corresponding percentiles (L_{10} and L_{90}). A collection of 30 sampling points were selected to measure noise data within the fall season and between 4 p.m. and 8 p.m. hours of the day. A hierarchical distance-sampling framework based on buffer areas with different radius (300 m, 600 m and 1 km) around each sampling point was compiled to measure composition and configuration metrics of land categories within each buffer area. The results derived from Pearson correlation analysis and multiple-linear regression models indicated that there is a distance-dependent relationship between the metrics of green areas and noise levels. We didn't find remarkable distance-dependency between built-up structures and noise levels. Based on our new spatio-statistical approach, we conclude that more connected and compacted pattern of green areas closer to pollution centers can significantly alleviate the effects of noise propagation mechanism and appropriate pattern of built-up areas follows a low density distribution with coming green areas in between. Findings of this study highlight the potential of landscape ecology approach as an effective planning paradigm for designing greener and calmer cities.

1. Introduction

Exposure of city dwellers to noise pollution levels is one of the most important environmental stressors in urban environments. According to the report by World Health Organization (WHO), noise has been identified as a pollutant since 1972 and later also acknowledged being an important issue affecting life quality of urban residents (WHO, 2013). Noise-related stress can psychologically and physiologically influence the exposed people. The most adverse consequences are referred to as annoyance and sleep disturbance (Murphy et al., 2009). Annoyance is a psychological feedback to noise and it can result in severe feelings such as anger, disappointment, anxiety and depression (Moudon 2009). Traffic-induced noise pollution at night can greatly influence sleep patterns, causing fatigue, decreased attention performance and alter social behavior (Gidlöf-Gunnarsson and Öhrström 2007; Moudon, 2009). Gidlöf-Gunnarsson and Öhrström (2007) argues that noise pollution can lead to non-auditory stress effects such as changes in the physiological systems (e.g., increased blood pressure), different cognitive problems (e.g., poor sustained attention, concentration deficits) and modification of social behavior. Taking the adverse effects of noise pollution on human communities into account, there has been a growing body of studies in the literature on methods and models for noise assessment. In this regard, each country tends to implement its own methodology. According to Arana et al. (2010), there is no universal consensus on these methodologies; however, the majority of studies have considered noise propagation as function of its surrounding characteristics (Weber et al., 2014a,b). In other words, interior urban environments are responsible for both producing noise exposure levels and also they can exacerbate or alleviate the situation based on the type and spatial configuration of the receiving surfaces that are reached by sound waves.

According to the study by Pinto and Mardones (2009), there are several factors responsible for acoustic ambience in cities, which can be categorized into four groups: sources, surroundings, environment and

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demographic properties. Main sources of noise pollution in urban environments are road network, rail and air traffic, industrial and entertaining centers. Transportation system is widely acknowledged as the major source of noise pollution, however, urban morphological features are also considered to have a significant influence on propagation mechanism of sound waves (Souza and Giunta, 2011; Liu et al., 2013,b; Weber et al., 2014a,b; Fuller et al., 2015). Propagation of sound waves follows an elastic medium; therefore reflection, absorption and transition of sound waves are dependent on the characteristics of the surface they reach. In other words, spatial physiognomy of road surfaces, building structures, streets and façade materials can influence the reflectivity, absorptivity and transitivity of noise levels. Therefore, elements of an urban environment can effectively interact with sound waves and influence the soundscape (Weber et al., 2014aSouza and Giunta, 2011,b; Weber et al., 2014a,b). Impervious surfaces with higher densities, more connectivity and compactness, more complex shapes and less distance from their neighbors of the same type can lead to multiple sound reflections, which trap and amplify noise levels and increase reverberation time (Souza and Giunta, 2011).

Mehdi et al. (2011) investigated spatiotemporal patterns of road traffic noise pollution in Karachi, Pakistan. They concluded the average value of noise levels to be over 66 dB, which could cause serious disturbances according to the WHO outdoor noise standards and the maximum peak noise was over 101 dB that can lead to possible hearing impairment. Souza and Giunta (2011) analyzed noise levels of an urban area by treating them as function of features such as block shapes and urban indices in a residential neighborhood of a medium sized Brazilian city. The effect of urban indices on the acoustic ambience of streets is modelled with artificial neural network in which Floor Space Index (FSI), block shape and building area/lot area ratio had higher levels of relative importance, respectively. Using the concept of landscape metrics, Weber et al. (2014a, 2014b) modelled outdoor traffic-induced noise and air pollution around urban structures in Leipzing, Germany. According to their results, a significant statistical relationship was identified such that air pollution concentration and acoustic noise level differ according to urban structure type, as determined by landscape metrics. Landscape metrics have also been implemented as practical tools for noise pollution mapping (Iglesias Merchan and Diaz-Balteiro, 2013). In a study conducted by Liu et al. (2013), a framework for examining the variation in urban soundscape composition changes over multiple scales was outlined. The results depicted that anthropogenic sounds dominated urban acoustic ambience both spatially and temporally, however, certain biological and geophysical sounds, especially bird song had a considerable role. They also highlighted spatial variation of urban soundscape patterns could be explained by underlying landscape characteristics, while temporal variation was mainly affected by urban activities.

Weber et al. (2014a) and Fuller et al. (2015) report that noise and air pollution are among the most important environmental issues in cities as they often yield in cardiorespiratory diseases among urban citizens. They highlighted that landscape metrics can statistically model the relationships between urban structure types and concentration of acoustic noise levels. Green areas in urban contexts can alleviate the adverse consequences brought about by such environmental issues. Gidlöf-Gunnarsson and Öhrström (2007) examined whether the perceived availability to nearby urban green areas influences different aspects of humans well-fare in both noise-free and noisy neighborhoods. The results indicated that availability to nearby green areas is an important parameter for the well-fare of the residents and would affect their daily behavior patterns by decreasing long-term noise disturbances and increasing the use of outdoor spaces. Having access to local parks, green areas and noise-free locations provide opportunities for relaxation, audio-visual attractions, ventilation of noise contaminated environment and effortless attention. Therefore, there is a crucial need for city planners to adopt informed strategies that ensure a healthy and relaxing environment for urban dwellers. This issue is more problematic when tacking the ongoing expansion rate of urban areas into account. Therefore, it is time incumbent upon to take prohibitive and restorative measure in terms of currently applied planning strategies.

Tacking the abovementioned studies into account, the main focus of such researches was to statistically analyze the relationships between morphological features of urban elements and the acoustic ambience. Besides, majority of these studies only considered built-up structures for statistical modeling. However, synoptic consideration of built-up areas and green covers in a spatio-statistical manner can provide deeper and more practical implications for designing calmer cities. On this basis, this paper not only measures the associations between landscape metrics (quantifiers of composition and configuration attributes of built-up areas and green covers) and noise exposure levels, but it explicitly discusses how this spatio-statistical approach can contribute to urban architecture design. Therefore, this study seeks to answer the following questions: 1) is there any relationship between composition and configuration attributes of built-up areas and green covers with noise propagation mechanism in an urban ambient? If yes, 2) which category exacerbates and which one alleviates the effects of noise propagation in an urban context? 3) what number of the landscape metrics can adequately explain the variation in noise exposure values? and 4) how the results derived from statistical analyses between landscape metrics and noise pollution levels can inform spatial planning plans for designing calmer cities?

To answer such questions the rest of the paper is organized to first describe how noise data were measured and compiled. Then, based on a digital categorical map of the study area, a series of landscape metrics within several buffer zones around noise sampling centers were computed. In the next step, a Pearson correlation matrix is developed to measure the bivariate associations between landscape metrics and noise exposure values. Subsequently, separate multiple-linear regression (MLR) models for each category are developed to evaluate and compare the explanatory power of composition and configuration metrics for predicting noise pollution levels. Finally, based on the results derived from statistical analyses, a spatial panning strategy for designing a calmer city is discussed.

2. Materials and methods

2.1. Study area

Karaj with population size of 1.7 million is the fourth populated city in Iran located in the southern Alborz mountains chain. The city spans between latitudes 35° 67′–36° 14′N and longitudes 50° 56′–51° 42′E and covers a total area of 141 km^2 (Fig. 1). The study site is characterized with ascending elevation from south to north and average elevation is 1320 m above the sea level. The targeted area is located in a semi-arid environment, where annual rainfall is 246.3 mm and annual average temperature varies between 15 and 16 °C. Köppen-Geiger climate classification system characterizes the city's climate as cold semi-arid.

The city has a role of being an urban railway organization regulated on 21 December 2001. It is also served by the Karaj Metro Station, which was established on 7 March 1999, and is located in the southern Karaj, near Tehran-Qazvin freeway. Karaj is connected by railways and highways to Tehran 40 km east and Qazvin 100 km northwest, and by commuter rail to the subway system of Iran. The highway system of Karaj includes Tehran-Karaj Highway, Karaj Special Road, and old road of Karaj. Bākeri expressway is one of the major north-to-south routes in the Western Tehran, which is connected to the Tehran-Karaj Highway. Tehran-Karaj Highway is one of the busiest sections in Iran with annual average daily traffic (AADT) of 217084. Karaj-Qazvin has an AADT of 79606 (URL 1, 2016). Fig. 2 demonstrates the complex transportation network of the study area.

Because of its economic and social attractions such as proximity to country's capital (i.e. Tehran), surrounding environment, transportation and affordable general facilities and educational benefits, Karaj