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Analysis of the relationships between environmental noise and urban morphology☆

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ABSTRACT

Understanding the effects of urban morphology on urban environmental noise (UEN) at a regional scale is crucial for creating a pleasant urban acoustic environment. This study seeks to investigate how the urban morphology influences the UEN in the Shenzhen metropolitan region of China, by employing remote sensing and geographic information data. The UEN in this study consists of not only regional environmental noise (RN), but also traffic noise (TN). The experimental results reveal the following findings: 1) RN is positively correlated with the nighttime light intensity (NTL) and land surface temperature (LST) ($p < 0.05$). More interestingly, landscape composition and configuration can also significantly affect RN. For instance, urban vegetation can mitigate the RN ($r = -0.411$, $p < 0.01$). There is a reduced RN effect when fewer buildings exist in an urban landscape, in terms of the positive relationship between building density and RN ($r = 0.188$, $p < 0.01$). Given the same percentage of building area, buildings are more effective at reducing noise when they are distributed across the urban scenes, rather than being spatially concentrated ($r = -0.205$, $p < 0.01$). 2) TN positively relates to large ($r = 0.520$, $p < 0.01$) and small–medium ($r = 0.508$, $p < 0.01$) vehicle flow. In addition, vegetation along or near roads can alleviate the TN effect ($r = -0.342$, $p < 0.01$). TN can also become more severe in urban landscapes where there is higher road density ($r = 0.307$, $p < 0.01$). 3) Concerning the urban functional zones, traffic land is the greatest contributor to urban RN, followed by mixed residential and commercial land. The findings revealed by this research will indicate how to mitigate UEN.

1. Introduction

Urbanization, which has been taking place at a dramatic rate over the past few decades, is having an increasingly strong impact on the Earth's environment, including biodiversity, energy flows, and biogeochemical cycles, as well as environmental noise and human health (Chi et al., 2012; Han et al., 2014; Peters and Bratton, 2016). Among these effects, urban environmental noise (UEN) has recently drawn much attention (Tenailleau et al., 2016; Wang et al., 2016; Halonen et al., 2017). In general, the acoustic environment is made up of both natural sounds, referring to animal vocalizations and, for instance, the sounds arising from the geophysical environment (wind, thunder, etc.); and environmental sounds created by humans, generated from the various human activities. Nonetheless, accompanied by the accelerated urbanization process, environmental or anthropogenic sounds have come to dominate the urban acoustic environment (Pijanowski et al., 2011).

Noise pollution produced by anthropogenic sounds profoundly influences biodiversity and ecosystem functions. It has been proven that UEN degrades the habitat for many wildlife species, and thereby affects biodiversity and ecosystem functions (Ware et al., 2015). At the same time, increasingly annoying noise interferes in our daily activities such as study, work, leisure, and rest (Freedman et al., 2001; Tassi et al., 2010; Engel and Zannin, 2014), and affects our health (Miedema and Oudshoorn, 2001; Chang and Merzenich, 2003; Min and Min, 2017). Therefore, the study of urban noise is essential for ecology in an urban context (Pijanowski et al., 2011; Schnell et al., 2016).

To date, many acoustic studies have focused on noise model prediction (Doygun and Gurun, 2008; Paz and Zannin, 2010; Morley

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and Gulliver, 2016; Lu et al., 2017) or related factor analysis, such as the urban fabrics of different types of building blocks (Salomons and Pont, 2012), construction density, open spaces, and the position of buildings (Guedes et al., 2011; Wang and Kang, 2011) and outdoor vegetation (Van Renterghem and Botteldooren, 2016). These related factors have significant roles when considering noise propagation. However, to the best of our knowledge, these studies have only investigated one or several city blocks or neighborhoods. Recently, Ryu et al. (2017) presented a statistical model for predicting the noise level of road traffic over residential areas in Cheongju (153.44 km^2) of South Korea. The data used in this study was noise map predicted by the RLS90 model that is embedded in SoundPLAN® (Diniz and Zannin, 2004; SoundPLAN, 2010). However, the in-situ measurement data including RN and TN, and comprehensive and in-depth analysis of environmental noise are relatively lacking in the current literature, especially over a relatively large area (e.g., an entire city).

On the other hand, the collection of sounds emanates from and interacts with urban landscapes, the characteristics of which have a great effect on the acoustic environment. Therefore, the study of the acoustic environment cannot be isolated from the underlying urban morphology. In particular, urban morphology is considered as the study of urban fabrics, which comprise coherent neighborhood morphology (e.g., open spaces, buildings), as well as functions which result from human activity, as a means of discerning the environmental level closely correlated with urban planning. Urban morphology represents not only the physical form or spatial structure, but also social forms which are expressed in the physical layout of a metropolitan area or city. To better characterize the urban morphology, many studies have relied on remote sensing data, due to its wall-to-wall coverage of entire urban areas, which can explicitly reveal the spatial pattern of ground features in a recurrent and consistent way (Li et al., 2011). However, as far as urban noise is concerned, there have, as yet, been few attempts to comprehensively relate urban morphology to environmental noise, especially over an entire city area.

In this study, based on the above considerations, we took Shenzhen (1997 km^2), one of the mega cities in China, as an example, and statistically analyzed the measured noise data. The data were acquired from 248 RN and 101 TN monitoring stations of the Human Settlements and Environment Commission of Shenzhen Municipality. RN and TN are separately measured and recorded with significantly different monitoring purposes and layout of monitoring stations. Specifically, in order to evaluate noise intensity and urban acoustic environment of the whole city, urban built-up areas are divided into a set of non-overlapped square grids, and RN monitoring stations are placed at or near the center of each grid. The noise sources of RN vary among industry, construction sites, traffic, and social activities (such as entertainment, shopping, etc.). TN focuses on evaluating intensity of traffic noise, and monitoring stations are set at locations along the main roads of the city. Moreover, we aimed to investigate how different underlying urban morphology affects environmental noise in the following aspects.

Firstly, from the socioeconomic aspects, we tested the potential associations between urban noise and socioeconomic factors, e.g., nighttime light intensity (NTL), land surface temperature (LST), gross domestic product (GDP), and demographic data. In many studies, NTL intensity (Zhang and Seto, 2011), LST (Li et al., 2011), GDP (Wu et al., 2013), and demographic data (Pham et al., 2017) have been widely used to depict the urban social forms, and can therefore be used to portray human activities.

We then explored if landscape structure affects urban noise, including RN and TN. Considering that urban scenes are characterized by different land–cover types having their own surface characteristics, and forming patch mosaics, we assumed that landscape composition and configuration can affect sound generation and propagation, and thus the characteristics of the acoustic environment. To represent the spatial pattern or structure of urban scenes, landscape metrics based on land cover data have been developed and widely used to quantify landscape composition and configuration (Frohn and Hao, 2006).

Finally, we conducted an investigation into the noise characteristics of different urban morphology types in terms of urban functional zones, and their effects on urban noise. The acoustic environment mainly comprises sounds generated by anthropogenic activities with different intensities among different urban functional zones. These urban functional areas, in terms of land-use forms in large areas, are generally made up of residential, commercial, industrial, education land, etc., with different kinds of human activities, along with different noise intensity. As such, the change in urban functional areas affects local and regional biodiversity, and is therefore one of the major components of urban environmental changes (Grimm et al., 2008). Understanding the characteristics of urban noise and its relationship with urban morphology in Shenzhen has important implications for many other cities that suffer from urban noise.

2. Materials and methods

2.1. Study area

The city of Shenzhen (113°46′–114°37′E, 22°27′–22°52′N), located in Guangdong province, was chosen as the study area, considering its fast economic development and rapid urbanization in both scope and intensity during the past (Fig. 1). Since Shenzhen became China's first special economic zone (SEZ) in 1979, it has transformed from an unknown fishing village to one of the most prosperous cities in China. During this period, Shenzhen's population has increased from less than 100,000 in 1979 to over 10 million in 2015, accompanied by huge migration from all over the country. Consequently, Shenzhen belongs to a young immigrant city. Compared to other coastal cities, the Shenzhen SEZ has unique location advantages due to its geographical proximity to Hong Kong. By means of tax relief and favorable land, Shenzhen has attracted massive domestic and foreign investments, resulting in its rapid urbanization. Under this circumstance, GDP reached $253.6 billion in 2015. With the development, Shenzhen has been a “window” for economic, scientific, and technological exchanges.

Shenzhen is a “linear city” with a moderately hilly terrain, extending 49 km along the east-west axis and 7 km along the north-south axis. The topography of the city is undulating, particularly in the southeastern part, which shields it from typhoons in summer. Shenzhen has a subtropical monsoon climate with a mean annual temperature of 22.4 °C, and a mean annual precipitation of 1933.3 mm. The rainy season runs from May to September. Native vegetation is mainly composed of tropical evergreen monsoon forest and south subtropical evergreen broad-leaved forest.

Along with the rapid urbanization, Shenzhen has experienced environmental problems, particularly noise pollution. In 2015, according to the bulletins on environmental situations from the Human Settlements and Environment Commission of Shenzhen Municipality, there were 24,663 complaints about noise from residents, accounting for approximately 60% of all the environmental complaints. In addition, the Shenzhen local government has laid noise-reduction pavement, and optimized transportation management at the transport nodes with excessive complaints. Thus, research into environmental noise in Shenzhen is urgently required for urban planning and land-use management, to give some suggestions about possible UEN mitigation strategies.