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Estimation of the quality of an urban acoustic environment based on traffic noise evaluation models

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ABSTRACT

Traffic noise pollution is a widespread public health problem in both developing and developed countries. Quickly and effectively evaluating the quality of an urban acoustic environment is an important challenge for urban planning and management. To solve this problem, this study first classified the urban function area of the study area according to the functional characteristics and environmental quality requirements of the region, and then, the traffic noise propagation model was applied to predict instantaneous sound levels (L_A) based on noise attenuation. Finally, a traffic noise evaluation model was proposed to evaluate the quality of the urban acoustic environment. Taking Changchun city as our study area, eighty field samples of equivalent noise levels (L_{eq}) were measured every ten minutes at four types of roads, classified as trunk roads, secondary roads, expressways and rural roads, in different urban function areas. An urban noise map was drawn to reflect the degree of traffic noise pollution. By comparing the measured and predicted values of noise levels, the results show that the traffic noise propagation model can be used to predict instantaneous sound levels. The traffic noise evaluation results show that the quality of the acoustic environment in our study area was at a medium level, which means that long-term exposure to it can affect the normal work and life of people. The traffic noise propagation model and proposed evaluation model are feasible methods for evaluating the quality of the acoustic environment and can provide a reference for the management of noise pollution control of urban traffic.

1. Introduction

Transportation systems are an important component of society, as they provide an infrastructure which satisfies the mobility and accessibility needs of society. However, the rapid development of the transportation industry in the last few decades has led to many environmental problems. One of these major problems is noise pollution resulting from road traffic [1]. With the development of industrialization and urbanization, noise pollution has seriously increased in recent years [2,3], and complaints about noise pollution account for a large proportion of the environmental issues that concern urban residents [4]. Furthermore, as one of the main sources of environmental pollution, urban traffic noise has the potential risk of causing human diseases, such as high blood pressure, diabetes and atrial fibrillation [5–10]. Therefore, measuring the intensity of traffic noise and evaluating the extent of populations exposed to traffic noise in urban areas are essential for sound environment management and could provide the basic data for the management of traffic noise.

Noise pollution levels are usually expressed as noise indexes. There are several noise index types, e.g., noise index [11], noise impact index [12], and noise pollution index [13], which were all developed to measure the intensity and impacts of noise. With the increasing adverse impacts of noise on human health, exposed populations have become an important indicator of noise evaluation systems in recent years [14,15]. Furthermore, the sound requirements of residents have gradually developed more importance. Several studies have conducted detailed research about noise evaluation with the help of population distribution and sound requirements [16,17], and the results revealed that the combination of exposed populations and sound requirements greatly contributes to not only inferring functional properties but also evaluating and protecting the environment [18]. The degree of noise pollution can be expressed by developing a noise map, which can be used to evaluate the environmental impacts caused by noise pollution and to provide information for local and global action plans [19,20]. There are

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two main models of noise maps. One is the empirical model, such as the multiple regression and logistic curve models, which are usually built around relationships among traffic flow factors (e.g., number of cars, buses, trucks and motorcycles), traffic speed factors (e.g., mean speed of cars, buses, trucks and motorcycles) and road dimensions factors (e.g., width, length and gradient of roads and height of buildings around the roads). The other model is the physical propagation model. These models consider the propagation and reduction of noise in air. To date, these two kinds of models have been widely used in software packages such as CadnaA, SoundPLAN, and LimA to make noise maps [21].

Noise maps are usually combined with noise monitoring of limited sampling points to represent noise pollution levels. For noise map production, the most important factor is the description of the sources of road traffic noise, which are usually made in terms of known parameters, such as speed and number of vehicles. To calculate noise propagation, it is necessary to create a model with points, lines and areas of noise sources. However, because of the limited number of noise monitoring points, it is difficult to reflect the overall level of noise propagation in large areas, so noise prediction is necessary for the noise evaluation of large areas. The traffic noise prediction model is a common technology for predicting traffic noise levels and evaluating traffic noise. To date, several traffic noise prediction models (e.g., FHWA model, NMPB, ASJRTN and CNOSSOS-EU model) were proposed to analyse the urban noise caused by road traffic under different conditions (traffic flow, vehicle speed, ground absorption, etc.) [22–25]. As a kind of energy, noise attenuates during the transmission process caused by different influence factors (such as distance, obstacle, and air absorption). Recent research about traffic noise attenuation has considered the effects of urban buildings and afforested belts [26–28], and the noise attenuation levels were calculated through models or algorithms. The application of the noise propagation model based on noise attenuation can effectively be used to predict noise levels and evaluate the quality of the urban acoustic environment.

Existing research has promoted the development of evaluation systems for regional noise pollution, but there has been less research about noise evaluation using noise maps combined with the acoustic environment functional areas and exposed populations. In this study, a traffic noise propagation model based on noise attenuation was applied to predict the noise levels of road traffic in an urban area. A comparative analysis was conducted between the measured and predicted noise levels obtained by a traffic noise propagation model. The present traffic noise evaluation indexes and methods have not taken both the population density and acoustic environment functional areas into consideration. Therefore, a traffic noise evaluation model is proposed by considering these factors. The quality of the urban acoustic environment was evaluated according to the traffic noise evaluation model combined with an urban traffic noise map. The application of the traffic noise propagation model and the establishment of a traffic noise evaluation model can provide technical support for the management of urban noise pollution and the improvement of the quality of the urban acoustic environment.

2. Materials and methods

2.1. Study area

As a notable downtown area in Northeast China, Nanguan District is located in the middle of Changchun city (Fig. 1) and possesses 12 streets, 1 provincial development zone, 57 communities and 7 administrative villages. Nanguan District has a population of 0.7 million and 0.213 million registered vehicles. The total length of the district's road network is 753.6 km. Nanguan District has heavy traffic due to its unique geographical location, so people are exposed to an environment seriously polluted by traffic noise. The traffic noise pollution in Nanguan District is due to its unmatched urban public facilities and abundance of parked vehicles, and noise pollution is aggravated by the over-saturation of traffic flow. Therefore, measures should be taken to solve the problem of urban road traffic noise pollution in Nanguan District.

2.2. Traffic noise propagation model

As a kind of energy, noise is affected by air absorption, obstacle reflex and ground absorption during its transmission process, which causes noise attenuation. In this study, a traffic noise propagation model was applied to predict the instantaneous sound level (L_A) considering noise attenuation. The model is described as follows:

$$L_{A(r)} = L_{A(r0)}(A_{geo} + A_{bar} + A_{air} + A_{gro}) \tag{1}$$

where $L_{A(r)}$ is the instantaneous sound level at the measured point with distance r from the sound source; $L_{A(r0)}$ is the instantaneous sound level at the reference point with distance r_0 from sound source; A_{geo} is the geometric attenuation of noise as calculated by Eq. (2); A_{bar} is the barrier obstructing the attenuation of noise as calculated by Eq. (3); A_{air} is the air absorption attenuation of noise as calculated by Eq. (4); and A_{gro} is the ground absorption attenuation of noise as calculated by Eq. (5).

$$A_{geo} = 20lg(r/r_0) \tag{2}$$

$$A_{bar} = L_{p1} - L_{p2} \tag{3}$$

where L_{p1} is the instantaneous sound level without barrier obstruction and L_{p2} is the instantaneous sound level with barrier obstruction. The location sketch is shown in Fig. 2.

$$A_{air} = \frac{a(r-r_0)}{100} \tag{4}$$

where a is the air absorption coefficient measured every 100 m, which is affected by temperature and humidity.

$$A_{gro} = 5lg(r/r_0) \tag{5}$$

2.3. Traffic noise evaluation model

Noise pollution can cause harmful effects to the people exposed to it in different acoustic environment functional areas. According to the noise evaluation model (NEM) [29], traffic noise evaluation should not only consider the intensity of noise sources and propagation attenuation but also synthesize the effects of acoustic environment functional areas, population density and other factors. Therefore, in this study, a traffic noise evaluation model (TNEM) was proposed. The traffic noise evaluation model mainly selected the total amount of noise pollution and the per-capita noise pollution index as evaluation indicators. Based on the general noise evaluation model, the traffic noise evaluation model added a method to calculate the extent of exposed populations, shown as Eq. (7). The flowchart of TNEM in this study is shown in Fig. 3.

According to the spatial distribution of the population density and the functional areas of the urban acoustic environment, the study area was divided into 10 patches according to the quality requirements of acoustic environments. Combining the specified noise limit of the acoustic environment functional area, the exceeding standard noise level (ΔL_{Ai}) was selected as an indicator for calculating the accumulated effect that noise causes on people. Based on the total amount of noise pollution (T_{TNEM}), the per-capita noise pollution index (A_{TNEM}) was used to reflect the overall pollution level in the urban area and per-capita noise pollution level. The computational method of the traffic noise evaluation model (TNEM) is expressed as follows:

$$T_{TNEM} = \sum_{i=1}^{m} (n_i \Delta L_{Ai}) \tag{6}$$