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Research on soundscape identification – A case study in Shenzhen, China

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ABSTRACT

Subjective evaluation of soundscape is much related with the sound sources. Due to ambiguous understanding of annoy perception of a noise, a large number of soundscapes were recorded. The study samples were obtained via intensive field works covering spatial and temporal variations of Shenzhen, China. Using Co-kriging method, information content of sound source to all soundscape samples was thoroughly analyzed. Forty-four typical sounds representing various sound sources in Shenzhen were gained. Experimental research was conducted to depict how various sounds influencing subjective evaluations, in which more than two hundred participants were involved. Five soundscape categories were got based on cluster analysis on subjective annoyance evaluations to forty-four typical sounds. It is found that soundscapes with more natural sounds were perceived less annoy whereas the ones having more mechanical sounds perceived more annoy; however, to some soundscapes containing more urban living sounds or hybrid sounds, subjective evaluations were not definite. A reason might be related with an individual's social and cultural background linking with former experiences from once happened incidents linking with social activities/functions.

Keywords: Identification, Soundscape, Shenzhen

1. INTRODUCTION

Shenzhen is a coastal city located in the southern China near Hong Kong. Since having became the China's first special economic zone in 1979, it has transformed from an unknown area with many fishing villages to one of the four China's mega-cities nowadays. During such a transformation, the city's population has increase from less than 100,000 in 1979 to more than 20 million in 2017, accompanied with huge traffic network built with a consequent of tremendous soundscape changes. Although the city is quite modern currently, it remains some ecological characters in its development. The city is reputed as 'garden city' in China with fruitful soundscapes, which need to be identified due to increasing physiological and mental health problem brought by noise pollution resulting in rapid industrialization and urbanization (1).

In EU, the Environmental Noise Directive (END) was promoted to assess and manage sound environment for creating quiet environments and reducing sound negative influence on community (2). The noise map was given to identify noise exposure based on sound level calculations. Despite benefits of noise maps in controlling a high sound level area, a good sound environment does far not reach as sound sources have taken a part in deciding noise annoyance effects. Noise maps focus on negative sound sources such as traffics and industrials, but do not give positive information for pleasant/preferred sounds such as water flowing, bird singing, or tree rustling sound (3). Although being a metropolis, Shenzhen still has much mountainous and coast topography with ecological components owning a garden city reputation. It is quite important to take sound sources into account when managing urban sound environment, in which soundscape is more important.

A soundscape is defined as a perceived acoustic environment (4), psychological effects of a soundscape to people are emphasized. In order to create a healthy city with a good sound environment, appropriate descriptor for a soundscape is crucial. Study pointed that affective quality of a soundscape

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perception towards a 2-dimensional soundscape model is useful (5). Among the many soundscape descriptors, noise annoyance is acknowledged as a main indicator to evaluate noise and usually lead immediate reactions of acoustic environment (6). Implementing soundscape approach to assess noise annoyance has been broadly investigated. Former study suggested that except sound level, sound source containing certain information is important to determine subjective noise perception (7). For creating healthy environment with a regard of sound aspect, identifying a soundscape specially on its annoyance attribute is necessary. Based on the soundscape concept, the study explored various soundscapes in Shenzhen and provided feasible tool to identify a soundscape according to annoyance descriptor from either sound level or sound sources.

2. METHEDOLOGY

For identifying a soundscape in Shenzhen, various acoustic environment samples have been collected through intensive field works covering different urban forms of Shenzhen. As the samples were gained according to the spatial disparity of the mega-city, they are assumed to present different kinds of soundscape in Shenzhen. As sound level influence on a soundscape is definite and can be easy measured, sound source (as another essential factor to soundscape) has been focused. In the study, 44 typical sound sources were abstracted from 702 samples employing Co-kriging analysis. The sound sources were used in lab experiments for giving annoyance evaluations. Following this, ANN models were developed to present annoyance evaluation of sound sources based on acoustic and psychoacoustic factors. Using such models, annoyance evaluation from certain sounds could be measured. Combining annoyance evaluation of sound source with sound level, a soundscape can be identified with respect of annoyance descriptor by exclusively using acoustic and psychoacoustic factors, which can be obtained through calculations.

2.1 Collecting study samples

Shenzhen is a dense city with a high population within a long east-west narrow strip area. It is then developed along the east-west axis and formed various administration urban groups namely Da Peng, Long Gang, Bao An, Fu Tian, Nan Shan, and Luo Hu. Each one has its unique urban morphology that configures its own soundscape features. The selected study sites for collecting soundscape samples are selected to capture a wide range of urban configurations in terms of each administration urban group possibly expressing topological and morphological status of Shenzhen. Through a serial of intensive field studies in Shenzhen, 702 soundscape samples are obtained by route measurements meanwhile more than 60000 samples are collected by fixed measurements (8). The samples from route measurements reflect a diversity of Shenzhen soundscape according to spatial variations as 116 different study sites concluded, while the samples from fixed measurements represent a diversity of soundscapes due to temporal variations as measurements were made covering variabilities of season, week, and day. In general, more than 60000 study samples reflecting various soundscapes in Shenzhen are obtained. Geographically, soundscapes from the purely nature areas, low density built areas with some natural components, and artificial areas barely with natural component are got. Temporally, various time's soundscapes from different season, week, day, and time are also obtained.

2.2 Lab experiments

As sound source is the key determinant to a soundscape as containing information to affect peoples' perception, lab experiments are designed to elicit subjective evaluations of different sounds. After analyzing sound sources differentia to all collected samples based on spatial and temporal characteristics, 44 soundscape samples are selected from all the samples as assumed to stand for all soundscapes of Shenzhen. The selection work is through firstly comparing soundscapes obtained in the fixed measurements and the route measurements according to sound level variations and then analyzing amplitude domain, frequency domain, and time domain acoustic and psychoacoustic factors of the collected samples (9). In order to get effective responses in the lab experiment, 44 samples from field studies were cut into 25 seconds recording. For excluding sound level influence on subjective evaluation to sound source as sound meaning is emphasis, 44 recordings were adjusted to the same sound level as 65 dB in the lab. The 44 sound samples and questionnaire surveys were combined using MATLAB software and replayed randomly to the subjects. In total, 161 participants involved in the lab experiments with various social/demographic background.

3. RESULTS

As sound levels and sources are key factors to decide a person's perception of a soundscape, identifying a soundscape should take these two factors into account simultaneously. It is simple to get a value of sound level in measurement, however to get sound meanings only by measurement is rather difficult. In the study, subjective evaluations of 44 recordings from the lab experiments used to know affection information of sound sources. As noise annoyance is a key factor acknowledged as evaluative aspects related to 'noise' (6), the study used noise annoyance indicator to categorize sound sources based on data obtained from lab experiments. Then, employing ANN models to predict sound sources according to the sound categories.

In order to use noise annoyance to categorize sound sources, hierarchical clustering analysis is applied to quantitatively analyze relationship of sound sources to the noise annoyance evaluation. A 5-category from the least annoyance to the most annoyance is found to the 44 sound sources as shown in the Figure 1.

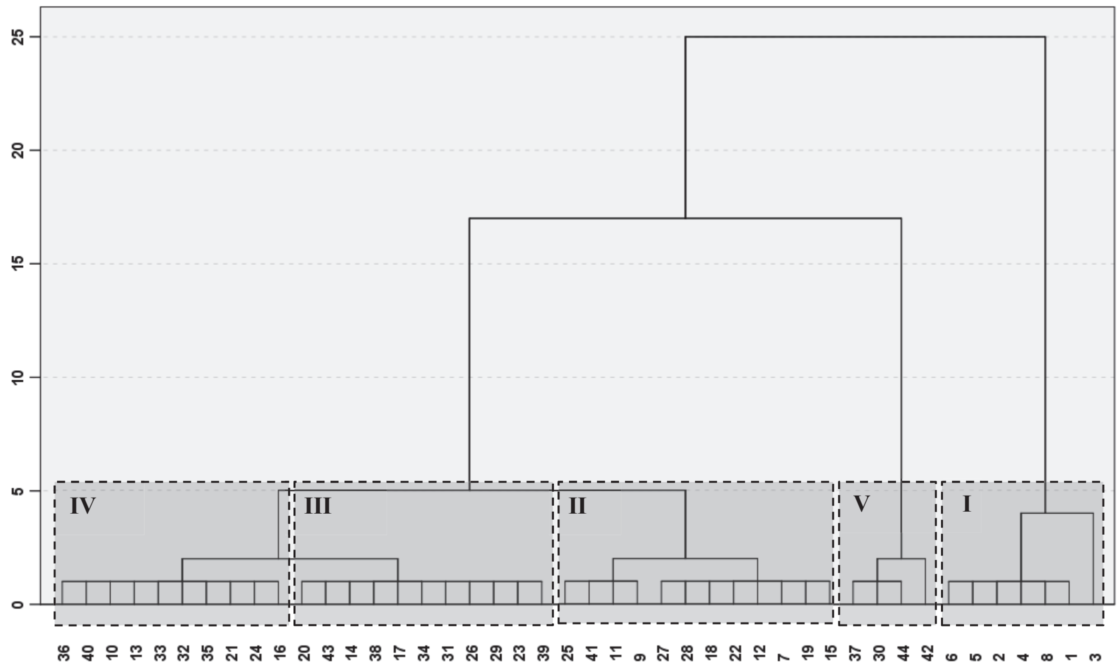

Figure 1 – Hierarchical clustering analysis on 44 sound sources

To each sound source category, the exact involved sounds are shown in the Table 1, which can be seen that the Category I includes almost natural sounds such as sea waves, bird twittering, sounds of streams, the Category II includes natural and also meaningful urban living sounds, the Category III includes most urban living sounds but barely mechanical sounds, the Category IV includes some natural sounds, some urban living sounds and some mechanical sounds, however the Category V includes most mechanical sounds.

Table1 – Sounds and sound category according to the hierarchical clustering analysis

Sound category	Sounds	Avg. of Annoy Eva.
I	Wave, wind, running water, rain, birdsong, insect	5.51
II	Birdsong, insect, human living, aircraft, music, rain, wind, road traffic, yacht, running water, frog	4.38
III	Music, activity (playing ball), amplified broadcast, birdsong, insect, road traffic, activity, human living, rain, machinery noises, aircraft, wind	3.83
IV	Birdsong, insect, human living, yacht, construction machine, human living (commercial noise), wave, music, road traffic, machinery noises	3.35
V	Running water, yacht, birdsong, insect, construction machine, human living, machinery noises	2.39

According to the Table 1, it can be concluded that sound sources referring to annoy perception could be quantitatively categorized and measured based on sound types included. The more natural sounds the soundscape would be perceived less annoy, the more mechanical sounds the soundscape would be perceived more annoy. To the urban living sounds, their affection on annoyance are mostly decided by how meaningful of it in a whole soundscape, when more natural sounds mixed with the urban living sounds, they turn to present active affection on mitigating annoy perception; but when more mechanical sounds mixed, they turn to show more negative affection. So it is acknowledged that natural sounds contribute good quality to a soundscape whereas mechanical sounds offer bad one while urban living sounds are neutral.

Therefore, the following sections discuss how to identify a soundscape in Shenzhen according to sound levels and sources it contains. For calculating sound source contribution on a soundscape, a descriptor of occupation percentage of one kind of sound sources (natural, urban living, mechanical) named PctN, PctU, and PctM, is used and obtained by listening the studied soundscape samples.

3.1 Soundscapes inside the ecological line

Shenzhen has a unique morphology according to an ecological line, which is appointed by the Shenzhen Urban Planning and Natural Resources Bureau. The ecological line is defined according to the hilly terrain and coastline topography that remains very natural areas inside the line whereas very urbanization areas away from the line and hybrid areas mixed natural and artificial components around the line. This provides interesting base to form a very different soundscape in this city.

To identify a soundscape inside the ecological line, study samples from 36 case study sites are used including either route or fixed measurements. A variation sound level of soundscapes in these areas is from 35 dB(A) to 70 dB(A), and average sound level to all the time according to the fixed measurements is 54.1 dB(A). However, the highest average sound level occurs in the afternoon (14:00pm – 17:59pm) and the lowest one occurs in the morning (8:00am – 10:59am). This variation might be related with creatures' activity time. Maybe with the same reason, the sound level in summer is higher than that in winter although the difference is not obvious, but the variation in summer is rather bigger than that in winter, indicating winter is the rather quiet season in the Shenzhen ecological area.

Although there is very limit development inside the ecological line, there are still road constructions and artificial green spaces and fish villages exist creating various fabric configurations in the ecological areas60Table 2 shows the correlations of urban development indices with a soundscape referring sound level and source parameters. It can be seen that only ratio of road areas and ratio of green land areas have been involved which is because other indices are barely used as not much that kinds of development made. From the Table 2, it can be seen that sound level and sound source parameters are significantly correlated with ratio of road and green land; however, the correlation is positive to positive to the road and negative to the green land referring sound level indicating more green lands lower sound level and more road areas higher sound level. According to sound source, a significant positive correlation is found to green land with PctN and road areas to PctM, whereas a significant negative is found road areas to PctN and green land to PctM. The results show that more road areas would create more mechanical sounds (most traffic noise) and less natural sounds but more green land would create more natural sounds both significantly.

Table2 – Relationships of Sound level and source with development indices inside ecological line

	Ratio of road area	Ratio of green land area
Sound Level	.225*	-.255*
PctN	-.557**	.808**
PctM	.528**	-.780**

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

3.2 Soundscapes outside the ecological line

For soundscapes outside the ecological line, 80 case study sites can be used while 20 of them from the complete urbanization areas and 60 from the areas mixed natural and artificial components. To the complete urbanization areas, sound level is varied from 48 dB(A) to 83 dB(A) and average is 64.7 dB(A). There is not much difference of sound level in different times of a day and also different seasons of a year, which is unlike the areas inside the ecological line. To the hybrid areas surround the ecological line, it is also found that barely difference of sound level in different times of a day and also not much difference in different season.

Although sound level changes in the areas outside the ecological line are limited, further study of various urban development indices on a soundscape refereeing sound level and sources in the urbanization and hybrid areas has been made, results are shown in the Table 3 & 4. The Table 3 shows that the sound level and PctN and PctM correlations with the development parameters in the complete urbanization area. It can be seen that sound level is significantly correlated with FAR, building coverage density, ratio of road area, ratio of green land area. Except green land, all other correlations are positive indicating with a denser development, a sound level is getting higher. However, the situation is opposite to PctN although similar to PctM. All development indices have a negative significant correlation with PctN except ratio of green land areas indicating a denser development eliminating more natural sounds. To PctM, the number of building floors is not significantly correlated with. Likely sound level, PctM has positive correlation with all the development indices except ratio of green land area, indicating a denser development creating more mechanical sounds.

Table3 – Relationships of Sound level and source with development indices in the complete urbanization areas

	Land use	FAR	Building coverage density	Building floors	Ratio of road area	Ratio of green land area
Sound Level	0.091	.328**	.327**	-0.03	.333**	-.281**
PctN	-.300**	-.364**	-.439**	-.239**	-.173**	.483**
PctM	.212**	.137*	.160**	0.091	.257**	-.306**

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

Table4 – Relationships of Sound level and source with development indices in the hybrid areas

	Land use	FAR	Building coverage density	Building floors	Ratio of road area	Ratio of green land area
Sound Level	.343**	.396**	.434**	.190**	.476**	-.508**
PctN	-.604**	-.484**	-.546**	-.332**	-.472**	.659**
PctM	.510**	.334**	.358**	.304**	.475**	-.525**

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

3.3 Identifying a soundscape by using ANN

From above analyses it is found that identifying a soundscape needs to get knowledge of sound sources, which are obtained through calculating hearing times of natural sounds, mechanical sounds, and urban living sounds to a soundscape recording in a certain time. However, such a way is not efficient for measure a soundscape in reality. Through lab experiments, 5 sound categories reflecting subjects responding of annoyance evaluation can be got using the hierarchical clustering analysis. The sound categories express information of sound sources as natural, mechanical, urban living meanings. This can be seen from the Table 1 of sound category and its including sounds. It is thus prospective that sound sources of a soundscape could be measured if they could be predicted by measurement parameters such as acoustic and psychoacoustic parameters. In the study, using artificial neural network (ANN) model to predict and judge sound source is developed to give a method to measure type of sound sources containing in a soundscape.

For training ANN models to predict sound source for identify a soundscape, acoustic and psychoacoustic parameters from amplitude domain, frequency domain, and time domain have been considered as input, the output is the 5-category sound. As PctN, PctU and PctM are parameters to describe sound sources closely related to the 5-category sounds, their relations with the acoustic and psychoacoustic parameters are broadly analyzed as important in accuracy of ANN model prediction. Table 5 shows correlations of the acoustic and psychoacoustic parameters with PctN, PctU and PctM to the 5-category sounds.

Using the parameters significant to the sound source, two kinds of ANN models are developed: one is the general model for all the 5 category sounds; the other is the sub models, one for the 3 of 5 category sounds and the one for the 2 of 5 category sounds as they are found having different significant influence factors. The result shows that the sub model has better prediction with an average accurate prediction of 0.83 to one and 0.73 to another whereas the general model did much worse with an average accurate prediction of 0.53. This shows again that closer relationships between inputs and output are key determinant in which a general model is usually ineffective (10). To identify a soundscape according to sound level and sound source variations, the sound level should be firstly considered critical factor in determining subjective annoy perceptions (10), however, when the sound level is up to a certain value (say 55 dB) and below to a certain value (say 65 dB), the meaning of sound source might play more roles. And this can be measured by using ANN models.

Table5 – Relationships of sound sources with acoustic and psychoacoustic parameters

Sound source		L_{eq}	L_{10}	L_{50}	L_{90}	Loudness	Roughness	Sharpness	Fluctuation strength	Tonality
Ⅰ	PctN	-.322**	-.309**	-.325**	-.330**	-.287**	-.094	-.156	.194	-.157
	PctU	.149	.15	.149	.135	.11	.029	-.023	-.023	.139
Ⅱ	PctN	-.412**	-.356**	-.486**	-.527**	-.469**	-.102	.316**	.062	.119
	PctM	.331**	.292**	.415**	.459**	.453**	.242**	-.197**	-.170*	-.182**
	PctU	.174*	.143*	.175*	.180**	.106	-.149*	-.200**	.117	.053
Ⅲ	PctN	-.442**	-.412**	-.559**	-.616**	-.465**	-.016	.453**	-.212**	.215**
	PctM	.174*	.143	.269**	.331**	.203*	-.121	-.375**	.045	-.288**
	PctU	.457**	.449**	.517**	.527**	.455**	.169*	-.231**	.267**	.027
Ⅳ	PctN	-.395**	-.389**	-.449**	-.488**	-.375**	-.140*	-.016	-.268**	.148*
	PctM	.189**	.211**	.173*	.087	.119	.326**	-.072	-.222**	-.067
	PctU	.187**	.163*	.249**	.359**	.231**	-.158*	.077	.431**	-.073
Ⅴ	PctM	.533**	.530**	.481**	.445*	.554**	.444*	.203	.451*	.073
	PctU	.041	.015	.106	.223	-.059	.068	.015	-.295	.452*

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

4. CONCLUSIONS

Using the soundscape samples from a wide range field studies in Shenzhen, the study explores soundscapes in different areas of Shenzhen due to its ecological particularity. It is found that the sound level is usually low to the areas inside the Ecological Line with more natural sounds and less mechanical sounds whereas the sound level is usually higher to the complete urbanization areas with more mechanical sounds. To identify a soundscape, sound level and source should be emphasized. The more developed areas usually have high sound level and less natural sounds and more mechanical sounds, but the less developed areas are opposite. Although a soundscape could be roughly identified according to the urban morphological indices, specific identification based on quantitative descriptors is still necessary in which measurement is required. It is easy to measure sound levels of a soundscape but difficult to measure sound source. In the study, sound sources have been categorized into 5 based on evaluation surveys in a lad condition. A good prediction model to sound sources is sub models. To identify a soundscape affection on annoyance perception, sound level should be taken firstly and then sound source when the level falls in certain value.

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