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The impact of outdoor environment on residential noise level satisfaction: GIS-based Analysis

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ABSTRACT: Urban residents in crowded complexes are making increasing civil complaints about noise and demanding pleasant and comfortable residential environments. Because noise is one of the most important factors related to urban residents' dissatisfaction with their living environments, the present study investigates the direct and indirect effects of noise-related outdoor environmental factors on residential level satisfaction, using noise level data from 29 noise-measuring stations in Seoul. From 62 multi-family apartment complexes near these stations, the authors collected GIS-based environmental attribute data, as well as survey data including the residents' personal characteristics and indicators designed to measure latent psychological characteristics: noise sensitivity and residential noise level satisfaction. This study then utilized structural equation models to analyze the direct variables influencing the latent variables of noise sensitivity and residential noise level satisfaction, as well as the complex relationships among all variables. The result showed that residents who are exposed to less noise, possibly due to living in apartments facing relatively quiet roads, protected by soundproof walls, or surrounded by densely planted trees, tend to be less noise sensitive, which makes them more satisfied with the ambient noise level. Therefore, critical outdoor environmental variables can be used to reduce noise sensitivity and improve residential noise level satisfaction.

KEYWORDS: GIS, Noise Monitoring, Residential Noise Level Satisfaction, Structural Equation Model

1. Introduction

Noise, defined as "unwanted sound," is increasingly perceived as a pollutant that negatively affects public health and comfort (Stansfeld, Haines, & Brown, 2000). Environmental noise is linked to tinnitus, cardiovascular disease, child cognitive disabilities, sleep disorders, and noise annoyance (Stansfeld & Matheson, 2003; WHO, 2011). Also, noise pollution hinders the execution of complex work and has been identified as a source of environmental stress and discomfort. In metropolitan cities, comparatively more sources of noise exist, and thus, there is a greater need for comfortable and peaceful residential environments to mitigate the risks of environmental noise.

In Seoul, there were more than 40,000 civil complaints in 2015; the proportion of those related to noise pollution was 38.8%, which was the highest in the nation. Moreover, the level of environmental noise pollution averages 68 dB in the day and 65 dB at night in Seoul; these levels are poor, given that the criteria for noise pollution during the day and night are 65dB and 55dB, respectively (Ministry of Environment, 2014). In an online survey (Seoul Survey, 2014), 21.2% of citizens residing in Seoul perceived noise pollution to be "very serious" and 66.6% as "rather serious." Moreover, some 32% of total households in Seoul were dissatisfied with their residential environments according to a residential environment satisfaction study on noise pollution, indicating that excessive noise pollution is a factor in declining residential satisfaction (Seoul Survey, 2014).

Presently, the Seoul Metropolitan Government is engaged

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in creating guidelines for noise-producing establishments, designating traffic noise management sites and noise regulation areas. Moreover, it also mandates the installation of soundproof walls or tunnels in regions with high traffic noise and provides legal oversight over construction noise, which is the main source of noise within the city.

Other countries are implementing initiatives to limit noise. For example, the European Union (2002) mandated the creation of noise maps for cities with populations of more than 250,000 to study noise-exposed cities and the population and economics of its member states. The EU also has set a limit on noise pollution from construction machinery, banned the distribution of machinery with specific noise levels, and provided financial support to soundproof windows in residential areas (Senate Department for the Environment, 2014).

Accordingly, researchers have investigated the association between noise and residential satisfaction. Early studies on factors that determine residential satisfaction focused on objective characteristics of residents. Variables such as residential ownership type, income, education, race, gender, children, and length of residency showed statistically significant relationships with residential satisfaction (Amérigo & Aragonés, 1990).

Kroesen et al. (2010) asserted the role of objective characteristics and subjective evaluations, as well as physical, environmental, social, and physical factors, in determining residential satisfaction. Analyzing the influence of aircraft noise, their study assumed that both objective and subjective variables had a direct and indirect influence on residential satisfaction. The results indicated that objective and physical characteristics (level of exposure to aircraft noise) had a larger influence on residential satisfaction than subjective factors (noise annoyance). Moreover, residential satisfaction rose when facilities were established to block out noise, including aircraft noise, thus lowering noise annoyance.

Urban and Máca (2013) noted that only a limited number of studies had investigated the influence of traffic noise on overall life satisfaction. They concluded that traffic noise had a negative influence on residential satisfaction but did not have a direct or indirect influence on life satisfaction.

According to Kroesen et al. (2010), the most important factors determining residential satisfaction are age, road and traffic noise, and noise annoyance caused by neighbors. Noise annoyance is defined as "a feeling of displeasure caused by noise" (Lindvall & Radford, 1973) and is a sensitive indicator of adverse noise effects. Such negative emotional and attitudinal responses to noise imply that noise affects people's quality of life (Miedema & Vos, 2007). Therefore, noise annoyance has a close relationship with noise level and individual characteristics, as well as certain housing conditions; it is often influenced by night-time traffic noise, individual noise sensitivity, and the direction of living room and bedroom windows in relation to the noise source (Jakovljevic et al., 2009).

Noise sensitivity is the most consistent predictor of noise annoyance. It is a subjective factor denoted according to the emotional characteristics of the individual (Jakovljevic et al., 2009), and higher sensitivity toward noise is associated with noise annoyance. Nijland et al. (2007) reported that individuals with higher noise sensitivity had lower residential satisfaction. While there is no clear correlation between noise level and noise sensitivity, some studies have asserted that longer duration of noise exposure can lead to higher noise sensitivity (Sung et al., 2017; van Kamp et al., 2004; Hatfield et al. 2002).

Factors influencing noise level include traffic volume, speed, distance from the noise source, height of soundproofing facilities, thickness of soundproofing material, and receiving distance. When the distance is twice as far from the noise source, the actual noise level declines by 2.5~4dB (Kim, Joo, & Joo, 2005). To improve soundproofing effects, it is important to consider the height of the soundproofing facility, as well as the width and density of the material (Jeon & Park, 2000).

While a review of previous studies suggests a complex association among noise level, environmental characteristics, objective personal characteristics, and psychological factors such as residential satisfaction, noise annoyance, and noise sensitivity, few studies have comprehensively and empirically investigated this relationship. Therefore, the purpose of this study was to identify how noise pollution, outdoor environmental factors, and landscape elements of multi-family apartment complexes directly and indirectly affect the noise sensitivity of residents and residential noise level satisfaction by combining noise–level data of objective outdoor environmental variables and survey data showing psychological factors.

We hypothesized that noise levels and outdoor environmental characteristics, as well as the personal characteristics of residents directly affect noise sensitivity and residential noise level satisfaction and indirectly influence residential noise level satisfaction via noise sensitivity (Figure 1). This study collected survey data from apartment residents and utilized structural equation models to analyze the objective factors influencing the noise sensitivity and residential noise level satisfaction of the residents.

This study differs from previous studies that have considered noise level as a variable of residential satisfaction by incorporating data on residents' experiences, soundproofing facilities, and other external environmental factors of multi–family apartment complexes and quantitatively analyzing the relationship between these factors and residential noise level satisfaction. We anticipate the results of the present study will shed light on urban landscape factors that can alleviate noise annoyance and improve residential noise level satisfaction.

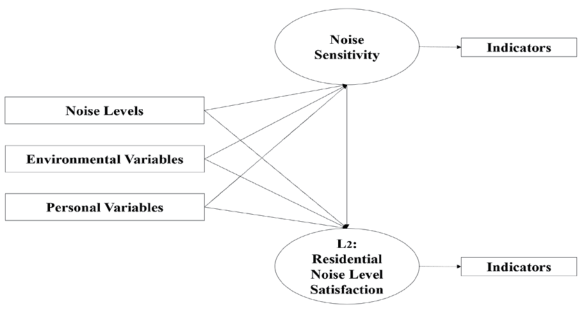

Figure 1. Conceptual framework

2. Methods

2.1 Site

Seoul has total 143 noise–measuring stations. The preset study focused on 29 of these stations near apartment complexes in order to clarify the effect of outdoor environmental factors on residential noise satisfaction in multi–family apartment complexes (Figure 2). These stations are located within 14 administrative districts of Seoul. We identified 62 multi–family apartment complexes within 100 meters of the 29 noise measurement stations as study sites.

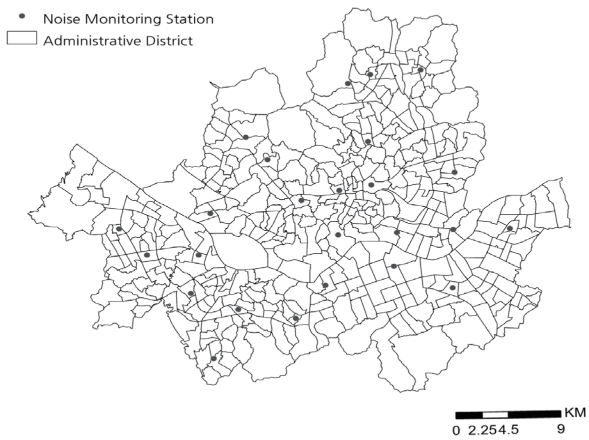

Figure 2. Research area

2.2 Data and Variables

Table 1 shows key variables and descriptive statistics. Noise data was extracted from the National Noise Information System for the year 2016 (Ministry of Environment, 2016). We geocoded the location of noise monitoring stations to collect environmental variables around the stations. The physical environments such as the type of street, distance from noise station to dwellings, the existence of barrier between the noise station and dwellings are examined based on GIS.

We also conducted a survey in August 2017 to collect the personal characteristics, such as gender, age, home ownership, length of residence, education, of residents living in the selected apartment complexes, as well as indicators to measure latent psychological characteristics including noise sensitivity and residential noise level satisfaction. The survey instrument also included housing unit characteristics such as floor and the existence of soundproofing windows. Trained surveyors distributed survey instruments door–to–door to 2,000 units randomly selected from the 62 apartment complexes and gathered the completed surveys after several days.

A total of 590 questionnaires were collected, yielding a 29.5% response rate. Some of the collected responses were incomplete or included unanswered questions. These were excluded from the sample, resulting in a total of 425 surveys used for statistical analysis. The surveyors also collected data on outdoor landscape and environmental elements including the presence of noise barriers, tree heights and types, types of plants, plant density, the type of road facing the residence, and the distance from a noise station to the apartment.

Table 1. Key Variables and descriptive statistics

Variables	Definition	N	Mean	SD
Outdoor environmental variables				
Noise level	Noise measurement value (dB(A))	62	55.94	6.63
Local Street	Road facing the apartment (1. Local; 0. Collecting or arterial highway)	62	50.35	21.54
Soundproof wall	1. Installed; 0. Not present	62	0.42	-
Tree height	Height of trees (1. High; 0. Low)	62	0.15	-
Tree density	Distance between trees (1. Less than width of crown; 0. Greater than width of crown)	62	0.65	-
Tree type	Shape of leaves (1. Hardwood; 0. Conifer)	62	0.94	-
Distance	Distance to noise measurement position (m)	62	0.34	-
Personal characteristics variables				
Male	1. Male; 0. Female	453	0.44	-
Age	Age	425	46.40	14.47
Married	1. Married; 0. Single	424	0.83	-
Children	1. Yes; 0. No	380	0.81	-
Duration of residence	1. Less than 1 year; 0. More than 1 year	453	0.12	-
Household size	1. Greater than 2; 0. Less than 2	453	0.81	-
Education	1. Graduated from university or graduate school; 0. High school or less	453	0.72	-
Soundproof window	1. Installed; 0. Not present	453	0.20	-
Floor	Which floor in building	453	6.12	5.12

In this study, residential noise level satisfaction and noise sensitivity are latent variables, which are not directly observable (Table 2). The indicators for residential noise satisfaction are overall residential satisfaction, traffic and roadside noise satisfaction, and satisfaction when sleeping and relaxing. The other latent variable, noise sensitivity, was measured using the indicators of self-reported noise sensitivity, noise importance, and noise stress.

2.3. Structural Equation Model

To test the relationships described in Figure 1, we used structural equation model (SEM), which is used to extract latent variables, such as residential noise level satisfaction and noise sensitivity. Also, SEM tests direct and indirect effects among exogenous and endogenous variables while consistently incorporating latent variables extracted from indicators. Thus, the total effect between two types of variables (exogenous and endogenous/latent and observed) can be calculated by adding the direct and indirect effects, which is the product of direct effects among the two variables and an intervening variable (Golob, 2003). In the present study, SEM estimated the complex correlation among the latent variables (residential noise level satisfaction and noise sensitivity) and observed variables (environmental factors and objective personal characteristics).

Table 2. Measures of latent variables

Latent variables	Operational definition	Indicators	Mean	SD
Residential noise level satisfaction	When you consider everything (noise, safety, green space, etc.), how satisfied are you with the environment of the residence you are living in? (5. Very satisfied; 0. Very unsatisfied)	Residential satisfaction	3.60	1.15
	How uncomfortable have you been in the last 12 months due to the following noise around your residence? (5. Not at all uncomfortable; 0. Very uncomfortable)	Satisfaction with traffic noise	3.05	1.41
		Satisfaction with airplane noise	4.49	1.00
		Satisfaction with roadside noise	3.23	1.39
	Have you experienced any discomfort due to the various noises around your residence during the last 12 months? (5. No discomfort; 0. Very uncomfortable)	Satisfaction during sleeping	3.44	1.37
		Satisfaction during learning	3.91	1.25
		Satisfaction during relaxing	3.29	1.37
Noise sensitivity	How sensitive do you think you usually feel to noise? (5. Very annoyed; 0. Not annoyed at all)	Noise annoyance	2.88	1.36
	How important do you think noise is to the quality of your residential environment? (5. Very important; 0. Not important at all)	Noise importance	3.96	1.07
	How much stress do you think you usually feel getting from noise? (5. A lot of stress; 0. No stress at all)	Noise stress	2.10	1.27

3. Results

Figure 3 summarizes the SEM results, and Table 3 shows the full results. The measurement model showed that the indicators were successful in extracting the two latent variables, residential noise level satisfaction and noise sensitivity, because their coefficients were significant. The fit indices, including the root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), comparative fit index (CFI), and Tucker-Lewis index (TLI), assessed model fit. In general,

Table 3. Structural equation model results (N = 425)

Variables		Coef.	Robust S.E.	P>|z|
Measurement Model				
Latent Variable (L1): Residential Noise Level Satisfaction	I1: Noise Satisfaction during sleeping	1.000	(constrained)	
	I2: Noise Satisfaction during relaxing	0.999*	0.048	0.000
	I3: Noise Satisfaction with traffic noise	0.991*	0.071	0.000
	I4: Noise Satisfaction with roadside noise	0.971*	0.070	0.000
	I5: Noise Satisfaction during learning	0.776*	0.056	0.000
	I6: Residential satisfaction	0.551*	0.060	0.000
Latent Variables (L2): Noise Sensitivity	I7: Noise stress	1.000	(constrained)	
	I8: Noise annoyance	0.684*	0.083	0.000
	I9: Noise importance	0.327*	0.051	0.000
Structural Model				
Exogenous Variable (L1): Residential Noise Level Satisfaction	Noise sensitivity	-0.789*	0.081	0.000
	Noise level	-0.007	0.008	0.407
	Distance	0.004	0.002	0.070
	Local street	-0.066	0.109	0.543
	Soundproof wall	-0.200	0.169	0.238
	Tree height	-0.150	0.125	0.232
	Tree type	-0.156	0.169	0.357
	Tree density	-0.221	0.125	0.076
	Soundproof window	-0.044	0.116	0.703
	Floor	0.001	0.011	0.961
	Male	-0.052	0.084	0.534
	Age	0.034	0.019	0.082
	Age2	0.000	0.000	0.121
Exogenous Variable (L2): Noise Sensitivity	Noise level	0.057*	0.012	0.000
	Distance	-0.001	0.004	0.752
	Local street	-0.516*	0.137	0.000
	Soundproof wall	-0.773*	0.175	0.000
	Tree height	-0.084	0.133	0.527
	Tree type	-0.283	0.211	0.181
	Tree density	-0.344*	0.146	0.019
	Soundproof window	0.114	0.150	0.445
	Floor	0.019	0.013	0.157
	Male	-0.347*	0.120	0.004
	Age	0.045	0.024	0.058
	Age2	0.000	0.000	0.084
	Chi-square	198.43(107)		0.000
	RMSEA	0.045		
	SRMR	0.032		
	CFI	0.949		
	TLI	0.932		

Note: *: P < .05

RMSEA and SRMR values less than 0.05 and CFI and TLI values greater than 0.95 indicate good model fit (Hu and Bentler,1999). The RMSEA and SRMR values of our model satisfied this guideline. The CFI and TLI values were less than 0.95, yet still greater than 0.90, which indicated acceptable model fit.

The results partially supported the hypothesis that noise levels, outdoor environmental characteristics, and the objective personal characteristics of residents directly and indirectly affect residential noise level satisfaction. The SEM identified no statistically significant association of the environmental and personal variables with residential noise level satisfaction. However, there were direct effects of noise level, local roads, the presence of soundproofing, tree density, and gender on noise sensitivity. This indicated that residents tend to be more sensitive to noise if they have relatively high noise levels around their apartments. Noise sensitivity tends to be lower when an apartment faces

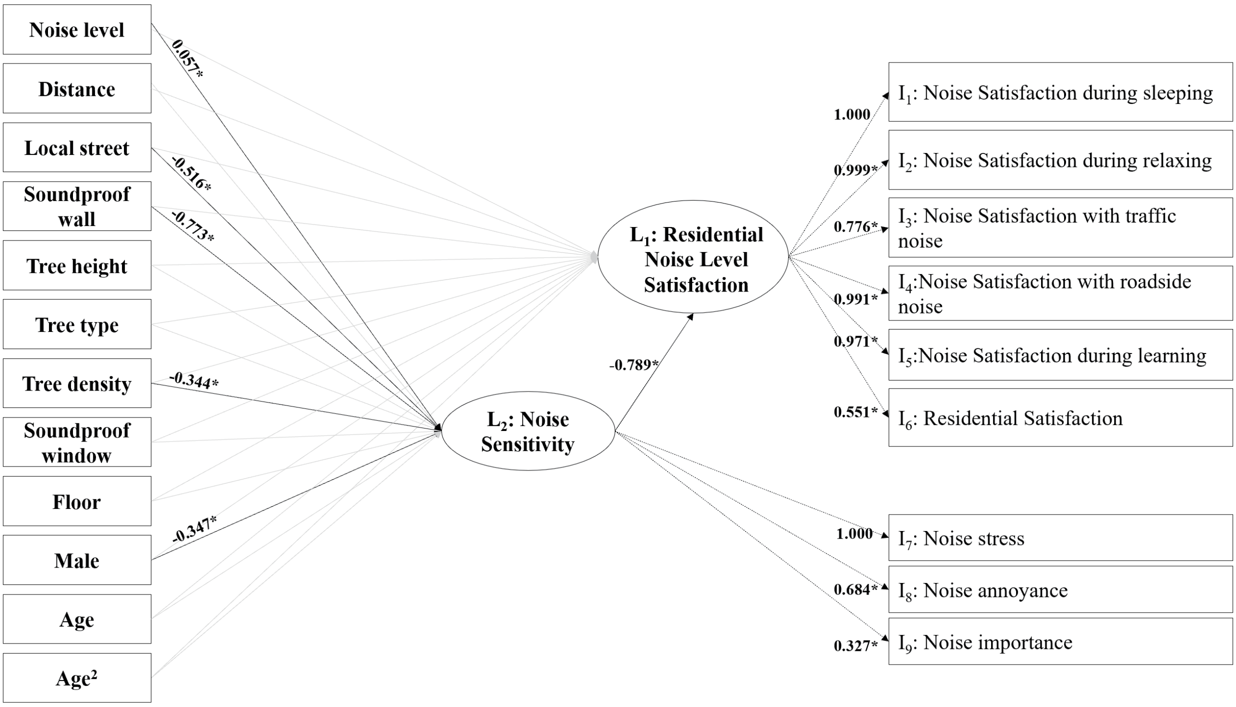

Figure 3. Path diagram and SEM results. (Note: results from models in Table 3; * p 〈 0.05)

local roads compared to arterial or collector roads. The presence of a soundproof wall around the residential area and trees planted denser than the width of the tree crown are associated with lower noise sensitivity. Lastly, men tend to be less sensitive to noise than women. The model also revealed a negative association between noise sensitivity and residential noise level satisfaction, implying that residents who are more sensitive to noise are likely to be less satisfied with the noise levels of their living environments.

The model detected indirect effects of noise level, local roads, the presence of a soundproof wall, tree density, and gender on residential noise level satisfaction via noise sensitivity. Table 4 shows the direct, indirect, and total effect of these variables on residential noise level satisfaction. The total effect of each variable is the sum of its direct effect and indirect effect, which is the product of each variable's effect on noise sensitivity and effect of noise sensitivity on residential noise satisfaction. Thus, the total effects indicated that the higher the noise level the lower residential satisfaction level. Residents living in apartments that face local roads rather than arterial roads, and are surrounded by soundproof walls and dense trees, are likely to be more satisfied with the noise levels of their living environments. Also, women are less satisfied with noise levels than men.

4. Discussion and conclusions

Although noise is increasing in cities and is associated with many health problems, noise pollution is a serious problem that remains insufficiently addressed (Goines & Hagler, 2007). Thus, the present study aimed to understand residents' psychological reactions to noise and to gain insight into the outdoor environmental and landscape factors that could alleviate the negative influence of noise pollution. A structural equation model was used to identify the direct and indirect influence of noise-related outdoor environmental factors on residential noise level satisfaction near multi-family apartment complexes in Seoul. The research findings can be summarized as follows. First, noise sensitivity was the only variable that directly influenced residential noise level satisfaction. Second, a total of five exogenous variables, noise level, road type, the existence of a soundproof wall, tree density, and gender, were found to have statistically significant relationships with noise sensitivity, which indirectly influenced residential noise level satisfaction.

These results imply that there are complex relationships among factors that affect residential noise level satisfaction. The study showed that the noise level or other environmental factors on a resident's noise level satisfaction influence that individual's subjective noise sensitivity. In other words, residents who are less exposed to noise, possibly due to living in apartments facing relatively quiet local roads, protected by soundproof walls, or surrounded by densely planted trees, tend to be less noise sensitive, which makes them more satisfied with the noise level. Therefore, the use of critical outdoor environmental variables can be recommended to reduce noise sensitivity in order to improve residential noise level satisfaction.

The results of this study also recognize noise as an important variable in improving satisfaction with the residential environment in Seoul and can be used to derive solutions to improve the outdoor environments of residential areas. Moreover, these solutions may include regional efforts to mitigate noise and alter the characteristics of residential environments through housing policy or urban planning. The results can also be used to improve the living environments of Seoul's residents by raising residential noise level satisfaction and reducing the number of noise-related complaints.

From a planning perspective, this study proposes denser tree planting and the installation of soundproof walls that are oriented toward local roads in residential areas rather than roads with higher traffic volume, such as arterial roads and collector roads, thus reducing noise sensitivity. Such considerations in planning the outdoor environments of multi-family apartment complexes would also improve residential noise level satisfaction. Moreover, this study confirmed the potential of reducing noise levels in the planning stage of road and building construction for reducing noise sensitivity and raising residential noise level satisfaction.

Also, the present study identified the influence of personal characteristics, such as gender and sensitivity to noise. Thus, planning approaches that mediate noise sensitivity of residents may be an effective way to improve their quality of life.

However, this study has the following limitations. We did not collect data about household-specific soundproofing facilities other than windows, as well as the habits of closing and opening windows. Also, this study was not able to perfectly isolate the influence of inside noise. In the case of multi-family apartment complexes, inside noise, such as inter-floor noises, can be as loud as those from outside. Therefore, advanced GIS approaches that analyze multiple noise sensors that measure noise from various sources may further contribute to design and policy approaches toward building comfortable urban residential environments.

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