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Article

Predicting the urban sound environment pleasantness with the soundscape approach by fuzzy SMRGT method: A case study in Diyarbakır Suriçi

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ABSTRACT

In the soundscape approach, environmental sounds are not considered noise, but as a source and as a component of the spatial planning and design process. It is necessary to evaluate the soundscape in urban spaces in a multifaceted and holistic manner, together with many factors such as physical, social, cultural, psychological, architectural, and so on. In this study, it is aimed to develop an estimation model that will allow the stages that take a long time to progress faster and more systematically in the multifaceted evaluation of the sound environment pleasantness levels of the users in urban spaces with the soundscape approach. For the model's quantitative data, sound quality metrics (loudness, sharpness, roughness) obtained from binaural sound recordings were used. The fuzzy logic estimation model is constructed by using Simple Membership Functions and the Fuzzy Rules Generation Technique (SMRGT) method, considering the characteristics of users and the survey area. In the model, it was possible to convey user experiences, and a simple approach that could be expressed numerically and understood was obtained with the fiction created with verbal concepts. Flexibility is allowed to diversify quantitative and qualitative metrics. The model has been tested with the case study performed with the users. As a result of the study, a close relationship was determined between the model outputs and the subjective data of the users. The efficiency ratios of other variables (age, gender, reasons for coming to the region, frequency of visit, duration of stay) belonging to users not included in the model were also determined. In this study, it has been revealed that the level of pleasantness of the sound environment in urban spaces should be evaluated not only in terms of quantitative data but also on the characteristics of the spaces and users.

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INTRODUCTION

One of the most important conditions for ensuring the acoustic comfort of the users in indoor or outdoor spaces is that they are free of disturbing and unwanted sounds (noise). In many studies (Alves et al., 2015; Asdrubali, 2014; Andringa et al., 2013; Maffei, 2008), it has been emphasized that the noise reduction intended for noise control, which focuses on environmental noise policies (Commission to The European Parliament and The Council, 2002; WHO,

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1999), is not sufficient to improve the quality of life in urban areas and to ensure acoustic comfort. In research, it has been shown that how noise affects people is not consistent with expectations. Therefore, the soundscape approach has emerged in urban acoustic comfort. The term soundscape was first used by urban planner Southworth in 1969 to indicate the acoustic characteristics of cities (Pijanowski et al., 2011), and Schafer (1977) formalized the term "soundscape" as the "auditory properties of landscapes." In ISO 12913-1 (International Organization for Standardization, 2014), soundscape is defined as "acoustic environment as perceived or experienced and/or understood by a person or people, in context." In the beginning, the first soundscape concept was encountered in music and acoustic ecology studies, and it became widespread in other disciplines. In the auditory landscaping studies that started in the late 1960s, the first articles began to be seen in 1999 (Davies, 2013), and in the last 15 years, there has been a significant increase, and many important projects and works have been carried out worldwide (Kang et al., 2016). Extensive data have been obtained in different cultures, from small areas to large cities, from closed, semi-closed to urban open areas.

This soundscape research represents a paradigm shift from noise control policies towards a new multidisciplinary approach. Environmental sounds are not considered as noise but as a resource and as a component of the spatial planning and design process. In studies beginning with questioning the meaning of the soundscape, the context involves not only physical measurements but also the cooperation of humanities and social sciences to account for the diversity of soundscapes across countries and cultures, with more focus on how people actually experience the acoustic environments. In urban spaces, it is necessary to evaluate the soundscape with many factors such as physical, social, cultural, psychological, architectural, and many other factors. Studies should be conducted taking into account both positive and negative sound sources; thus, a different perspective can be developed by combining the methods obtained from various disciplines on human perception of the soundscape. There have been researches on this subject which were developed by a wide range of academic disciplines, and many different methods were applied to them over time.

In the studies related to the soundscape, many methods are used in the objective evaluation of the sound environment or in determining the user perception. In these methods, it is seen that artificial intelligence techniques have been used in acoustics and especially in soundscape as in many scientific fields in recent years. Yu, Kang, & Harrison (2007) developed prediction models using artificial neural networks (ANN) and ordinal logistic regression (OLR) techniques for soundscape evaluations in urban areas. Yu & Kang (2009) have statistically analyzed the data obtained in urban open spaces with physical, social, behavioral, demographic, and psychological characteristics for soundscape evaluations. Artificial Neural Network (ANN) was used for modeling, and it was stated that models based on individual field studies were functioning better and special models suitable for various regions and functions could be reliable. In the study conducted by Yu & Kang in 2010, different kinds of sounds such as nature, human, mechanical, and industrial sounds were taken into consideration and included in the evaluation as factors affecting sound preferences. The results of the study are intended to provide data for soundscape prediction modeling using the artificial neural network technique. Yu (2009) stated that, based on the ANN model, soundscape maps could be produced, and Torija et al. (2014) tried to create the soundscape classification model with Support Vector Machines (SVM). Maristany et al, (2016) used fuzzy logic to analyze the soundscape quality of urban areas.

Scientific and practical guidance on soundscape needs to be provided rapidly and systematically. For this reason, different methods have been developed and diversified in recent years; especially computer simulation and artificial intelligence techniques have been used in studies. In the literature, soundscape studies with artificial intelligence applications are quite limited. The application techniques of artificial intelligence used in many fields of science and also in the field of soundscape should be increased.

The purpose of this study, which is based on the point mentioned above, is to develop an estimation model that will enable the users to progress in a faster and more systematic way to determine the level of pleasantness of the users in the urban areas by using the soundscape approach. This work aims to:

- increase the diversity of research on soundscape,
- contribute to the assessment of the urban spaces soundscape,
- provide a systematic conduct of long-time processes of soundscape by using the fuzzy logic technique of artificial intelligence.

METHODS

This study, which aims to estimate the sound environment pleasantness levels of users in urban spaces with fuzzy logic, was carried out in the Diyarbakır Suriçi region. The study was carried out in two phases. In the first phase, using the quantitative data and subjective evaluations, the predictive model of the users' sound environment pleasantness level in urban spaces was formed by Simple Membership Functions and the Fuzzy Rules Generation Technique (SMRGT) (Toprak, 2009). In the second phase, the model was applied and its accuracy tested. For the quantitative data to be used in the model, loudness, sharpness, and roughness were used as the sound quality metrics that are effective in the perception of the sound environment of the users (Çakır Aydın & Yılmaz, 2016).

Quantitative data of the sound quality metrics are needed for the prediction model. In the field study, binaural sound recordings were made with reference to the ISO 12913-2 (International Organization for Standardization, 2018) in order to obtain quantitative data of the sound quality metrics. In order to determine the area where sound recordings should be made in the study, sound walks were held in many places in the city center of Diyarbakır. The Suriçi region of Diyarbakır has been identified as the region to be studied with the impressions obtained from these walks. Due to the availability of this area at an accessible location, living with cultural, social, commercial, and recreational activities, having the original architecture on a large scale, not only traffic or human sounds, but also various sound sources including soundmarks belonging to the region, this field has been chosen as the study area.

Sound sources in the region are identified through interviews with users and sound walks held on weekdays and weekends, and the points and routes where sound recordings will be made are determined (Figure 1).

Binaural sound recordings were performed on weekdays (5 days) and on weekends (Saturdays) so that the sound recordings can give detailed information about the general sound environment of the region. Recordings were made between 07:30-09:00 in the morning, 12:00-13:30 at noon, and 17:00-18:30 in the evening when the users frequently use the area. Binaural sound recordings were made using the Brüel & Kjær 2270-A-D00 and the Brüel & Kjær 4101. The calibration of the microphone set was done with the B & K 4231 before each sound recording. Then, binaural sound recordings were made at the specified routes and points. The calibration of the microphone set was repeated when each sound recording was completed. The duration of the sound recordings varied from 5 minutes to 10 minutes, which can reflect the sound environment of the area.

Model

The flow chart in Figure 2 was followed for the prediction model. The operations of the dependent and independent variables were performed, membership functions were created, fuzzy inference was made with rules, and then the system was established by obtaining the output with the defuzzification.

Input: Includes dependent/independent variables of the model and all data about them. The dependent variable was determined, and independent variables affecting dependent variables were determined. The independent variables are inputs, whereas the dependent variable is the output of the fuzzy system. The independent variables of the study consist of the sound quality metrics of loudness, sharpness, and roughness. The pleasantness level of the users' perception of urban sound environments was indicated as the dependent variable of the study.

Figure 1. The points and the routes where sound recordings were made.

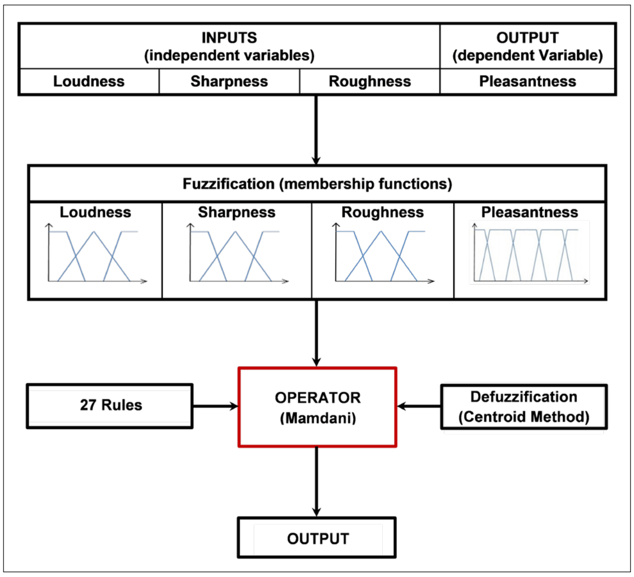

Figure 2. Flow chart for fuzzy SMRGT.

Fuzzification: This step is the phase in which the input information from the fuzzy system and the data from the database are converted into linguistic qualifier values. The linguistic qualifiers to be used for the sound quality metrics in the model were defined as low, medium, and high membership functions. The pleasantness of the users' perception of the urban sound environments was determined as the membership functions of 1, 2, 3, 4, 5 on the Likert scale.

Rules: Depending on the variables in the input parameters, it contains all of the rules that can be typed if-then. In this study, 27 rules were established.

Fuzzy inference: It is an expression obtained by applying fuzzy logic to fuzzy rules (Zadeh, 1996). In this study, the prediction model was constructed using the "Mamdani" fuzzy inference method.

Defuzzification: It is the process of transforming blurred information into a numerical value (Elmas, 2011). In the model, the centroid method was used for defuzzification.

Output: In the last stage of the fuzzy logic system, the dependent variable obtained as a result of the interaction with the information and fuzzy rule bases through the fuzzy inference is determined (Uygunoğlu & Yurtcu, 2006). In this study, the model is prepared by using the Fuzzy Logic tool in MATLAB software. Independent variables, dependent variables, and fuzzy clusters, membership forms, and membership functions were determined, and output data was obtained by creating rules.

For input data, the number and form of membership functions, and the lowest and highest quantitative data of loudness, sharpness, and roughness were determined for the independent variables. The quantitative values of the binaural sound recordings made in the study area have been calculated using PULSE Reflex for the values of loudness, sharpness, and roughness. In the model, for each of the loudness, sharpness, and roughness metrics, fuzzification was performed, and metrics were transformed into low, medium, and high linguistic qualifiers, resulting in three membership functions. In this study, trapezium shapes were chosen for low and high values of membership functions and triangular shapes for medium values. The trapezium was used because when the quantitative values of the metrics go below the lowest value or when the highest value goes up further, there is no change in input. For the intermediate values, triangles were chosen for the medium values of the membership functions since the output could change.

The unit width (*UW*), core value (*Ci*), and key values (*Ki*) of the fuzzy clusters for each sound quality metric created for the prediction model were determined (Toprak, 2009) (Figure 3).

The number of fuzzy clusters of the level of pleasantness that constitutes the output of the estimation model (dependent variable) is composed of 5 clusters. Therefore, the lowest value of the fuzzy clusters is 1 and the highest value is 5. The calculation method used to obtain quantitative data of the independent variables was also used for the fuzzy clusters of the dependent variable. In the forms of the membership functions, the trapezoidal shape is used to reduce fuzziness and to draw the result to an integer (Figure 4).

It is necessary to determine the number of rules of the model to be created with fuzzy logic in order to estimate the users' pleasantness levels in the urban environment.

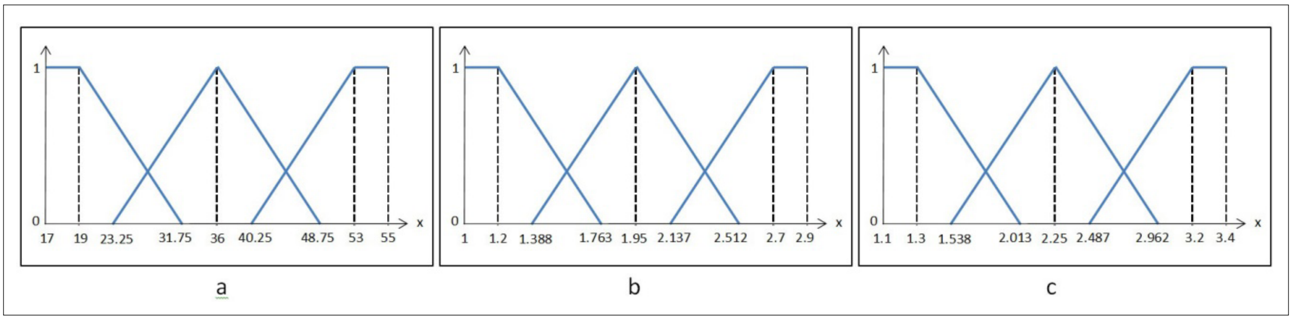

Figure 3. Quantitative values of membership functions a) Loudness, b) Sharpness, c) Roughness

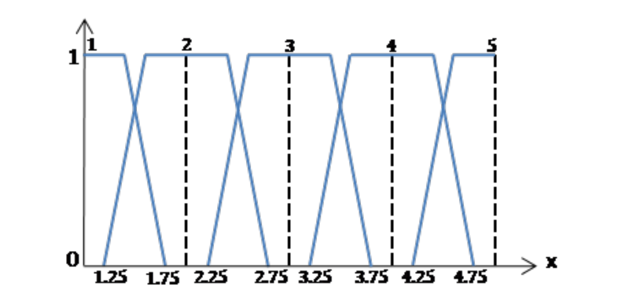

Figure 4. Values calculated for the membership functions of the output.

The number of independent variables and the number of fuzzy clusters per independent variable determine the number of rules. When the fuzzy clusters of low, medium, and high quantitative values of the independent variables formed by the loudness, sharpness, and roughness metrics are considered, 27 different possibilities occur. Therefore, 27 different rules have been established for the model. Many sources can be used in fuzzy logic when creating rules. The rules are formed by data obtained from literature information, experiences, and deterministic methods.

In this study, the independent variables consist of sound quality metrics: loudness, sharpness, and roughness. As the quantitative values of sound quality metrics increase, it is known that users' sound environment pleasantness levels decrease (Zwicker & Fastl, 1999). It is necessary to know the correlation between the three metrics and the level of pleasantness in order to determine the ratios at which these metrics affect the level of pleasantness of the users. At this stage, the results of the previous study were used (Çakır Aydın & Yılmaz, 2016). In the model, it is not enough to create rules according to the correlations between the sound environment pleasantness levels of the users and the sound quality metrics. Although the comparisons made

Table 1. Fuzzy logic rules

Rule 1	If	loudness	low	and	sharpness	low	and	roughness	then	pleasantness	5
Rule 2	If	loudness	low	and	sharpness	low	and	roughness	then	pleasantness	5
Rule 3	If	loudness	low	and	sharpness	low	and	roughness	then	pleasantness	4
Rule 4	If	loudness	low	and	sharpness	medium	and	roughness	then	pleasantness	4
Rule 5	If	loudness	low	and	sharpness	medium	and	roughness	then	pleasantness	4
Rule 6	If	loudness	low	and	sharpness	medium	and	roughness	then	pleasantness	3
Rule 7	If	loudness	low	and	sharpness	high	and	roughness	then	pleasantness	3
Rule 8	If	loudness	low	and	sharpness	high	and	roughness	then	pleasantness	3
Rule 9	If	loudness	low	and	sharpness	high	and	roughness	then	pleasantness	3
Rule 10	If	loudness	medium	and	sharpness	low	and	roughness	then	pleasantness	4
Rule 11	If	loudness	medium	and	sharpness	low	and	roughness	then	pleasantness	4
Rule 12	If	loudness	medium	and	sharpness	low	and	roughness	then	pleasantness	3
Rule 13	If	loudness	medium	and	sharpness	medium	and	roughness	then	pleasantness	3
Rule 14	If	loudness	medium	and	sharpness	medium	and	roughness	then	pleasantness	3
Rule 15	If	loudness	medium	and	sharpness	medium	and	roughness	then	pleasantness	3
Rule 16	If	loudness	medium	and	sharpness	high	and	roughness	then	pleasantness	2
Rule 17	If	loudness	medium	and	sharpness	high	and	roughness	then	pleasantness	2
Rule 18	If	loudness	medium	and	sharpness	high	and	roughness	then	pleasantness	2
Rule 19	If	loudness	high	and	sharpness	low	and	roughness	then	pleasantness	3
Rule 20	If	loudness	high	and	sharpness	low	and	roughness	then	pleasantness	3
Rule 21	If	loudness	high	and	sharpness	low	and	roughness	then	pleasantness	3
Rule 22	If	loudness	high	and	sharpness	medium	and	roughness	then	pleasantness	3
Rule 23	If	loudness	high	and	sharpness	medium	and	roughness	then	pleasantness	2
Rule 24	If	loudness	high	and	sharpness	medium	and	roughness	then	pleasantness	2
Rule 25	If	loudness	high	and	sharpness	high	and	roughness	then	pleasantness	2
Rule 26	If	loudness	high	and	sharpness	high	and	roughness	then	pleasantness	1
Rule 27	If	loudness	high	and	sharpness	high	and	roughness	then	pleasantness	1

in this way have meaning, they do not show the success of the model alone. Together with the correlation coefficient, more criteria should be considered. In this study, in addition to the effect of each metric on the level of pleasantness perceived by the users, the studies in the literature related to the sound environment have also been utilized. The views and experiences of the people who have done similar studies have been utilized. In addition, considering the historical, architectural, and socio-cultural structure of the region, 27 rules were written for the model prepared with fuzzy logic (Table 1). The weight of each input in the model was 1 when creating the rules.

The output data of the model can be obtained after the input created by the dependent and independent variables and the rules that create the interaction between them. In the model, the quantitative values of the loudness, sharpness, and roughness sound quality metrics of a sound recording can be written as input data, and the sound environment pleasantness levels of the users for urban spaces can be estimated. Figure 5 shows the output value of the system in response to the quantitative values of the sound quality metrics loudness, sharpness, and roughness.

The effect of sharpness and loudness metrics on the level of pleasantness is distributed evenly (Figure 6). The level of pleasantness decreases as the quantitative values of both metrics increase; pleasantness level increases with the decrease of quantitative values.

The effect of roughness on the level of pleasantness is lower than that of loudness (Figure 7). There is no significant decrease in pleasantness level, even if roughness is high, in cases where loudness is low.

Sharpness is more effective on the level of pleasantness in the changes that occur in the quantitative data of sharpness and roughness (Figure 8). Even if the quantitative value of roughness is low, the level of pleasantness is low if the quantitative value of sharpness is high. If sharpness is low and roughness is high, the decrease in the level of pleasantness is not significant.

Model Implementation and Test

For the application of the model, quantitative data of the loudness, sharpness, and roughness metrics were obtained from the binaural sound recordings performed in the study area. These data were transferred to the model prepared to estimate the users' sound environment pleasantness levels. Output data were obtained by processing the quantitative values of loudness, sharpness, and roughness metrics in the input data in the model. Thus, the sound environment pleasantness levels of the users in the study area can be estimated. Unlike the study of Maristany et al. (2016), in this paper, the model was tested in order to compare the data with the actual data after the implementation of the model.

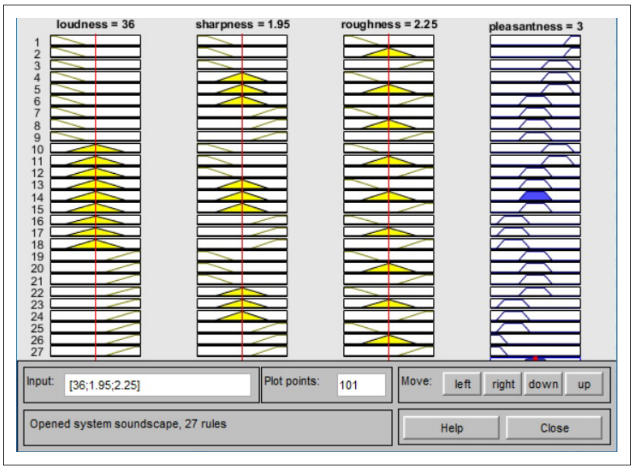

Figure 5. Graphical view of output value generated by rules.

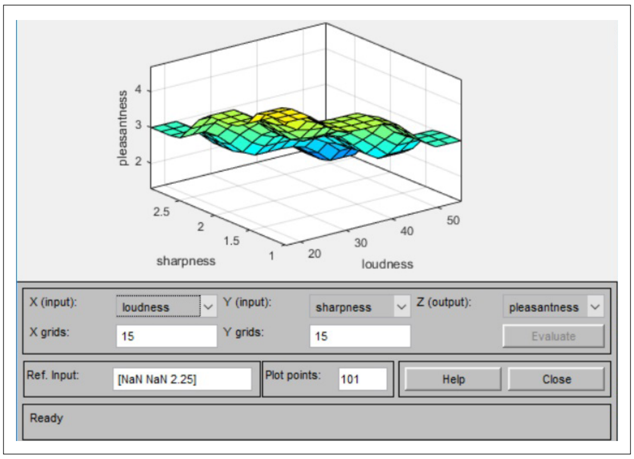

Figure 6. Surface viewer of pleasantness-sharpness-loudness viewer.

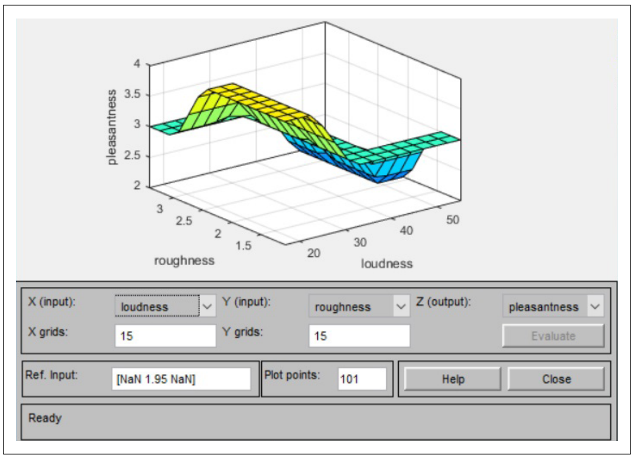

Figure 7. Surface viewer of pleasantness-roughness-loudness.

In the model test, simultaneous surveys were performed while making binaural sound recordings in the study area. The survey was conducted with 390 participants. In many studies in the literature, it was observed that factors such

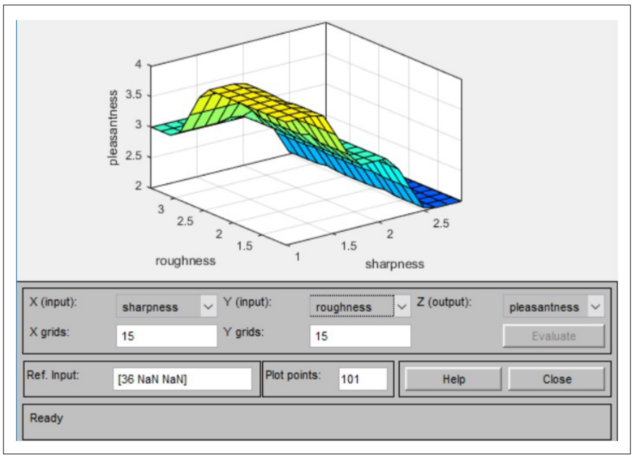

Figure 8. Surface viewer of pleasantness-roughness-sharpness.

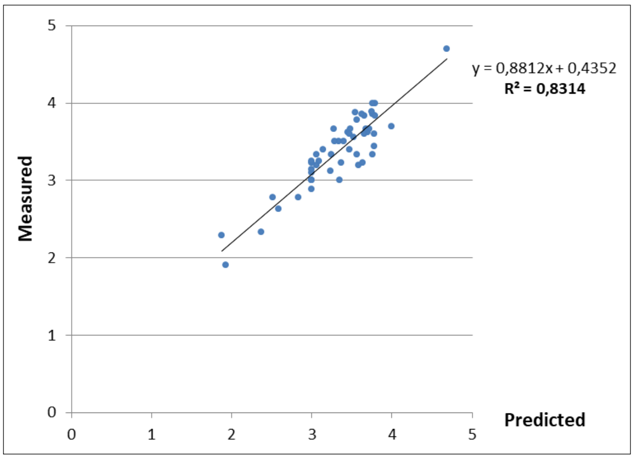

Figure 9. Relationship between the predicted and measured pleasantness level (1-not pleasant at all, 5-very pleasant).

as gender, demographic characteristics, education levels, physiological, sociological, and psychological factors, usage area, and duration of the users were effective in changing their perceptions about the sound environment (Yu & Kang, 2010; Yu & Kang, 2014; Tse et al., 2012; Kang, 2010). Therefore, in the questionnaire applied for the model, participants were asked about their gender, age, education levels, reasons for coming to the field, frequency of arrivals, and time in the area.

Participants were offered options to choose from 1 to 5 for the sound environment pleasantness levels (1: not pleasant at all, 5: very pleasant). Some factors are listed considering the characteristics of the region, as many factors other than sound sources in the perception of the sound environment of urban spaces can affect the choice of pleasant level. In this part of the questionnaire, participants were asked to rank seven factors (sound sources, historical texture, architectural structure, landscape, social structure, commercial structure, touristic value) between 1 and 7, which could affect their pleasant levels.

RESULTS

At the testing stage of the study, Pearson correlation coefficients between the measured (survey study) data and predicted data (SMRGT) were calculated. The regression line was formed between the two data groups and the coefficient of determination was calculated. The Pearson correlation coefficient was 0.91 among the data obtained from the survey conducted in the field with the pleasantness levels of the users about the sound environment predicted by SMRGT. As shown in Figure 9, $R^2 = 0.8314$ was obtained in reliability level. According to Rubin (2013) and Jackson (2014), a correlation of 0.90 and above is statistically significant (Rubin, 2013; Jackson, 2014).

In the model generated by SMRGT, the coefficient of determination (R^2) is 0.8314. This coefficient shows that about 83% of the total changes in the dependent variable are explained by the independent variables. The $1\text{-}R^2$ value (about 17%) refers to the part described by other independent variables not included in the model generated by SMRGT. In order to determine the parameters affecting approximately 17% of the study, the results of the survey conducted simultaneously with the sound recordings were used in the study area (Table 2).

As a result of the questionnaire applied to the participants, the effect of their gender on the change in pleasantness level is 17%. This study showed that the effect of participants' ages on pleasantness level changes was approximately 24%. It is understood that as the age of the participants increases, the pleasantness levels of the sound environment increase. It was determined that the effect of the level of education on the change in pleasantness level was approximately 34%. It was observed that the reasons for the participants' arrival in the field were about 43% effective in changing the pleasantness level. Employees in the region were negatively affected by the sound environment, and the majority of the participants (31.8%) preferred '1' level of pleasantness. The participants (35.7%) who visited the area to visit and the participants (40%) who relaxed in the area considered the sound environment '4'. When the effect of the arrival frequency of the participants on the change in

Table 2. Effect rates of other independent variables not included in the model

	Chi-Square	p	phi
Gender	11,596	0,021	0,172
Age	22,348	0,004	0,239
Education	44,460	0,000	0,338
Reason for coming	72,704	0,000	0,432
Frequency of arrival	68,352	0,000	0,419
Duration of stay	47,708	0,000	0,350

the pleasantness level was examined, it was determined that there was an effect of about 42%. Thirty-five percent of those who come to the field every day have chosen '1' as the sound environment pleasantness level. Considering the participants who visited the study area several times a year, several times a month, and several times a week, it was observed that the majority of all three groups preferred the sound environment pleasantness level '4'. As a result of the analyses, it was found that the duration of stay of the participants was 35% effective in the change in pleasantness levels. The majority (26.9%) of those who spent 6 hours or more in the field preferred the '1' option as the level of pleasantness.

CONCLUSION AND FUTURE WORK

In this study, a model has been developed in urban areas to predict the sound environment pleasantness levels of users. For this model proposal, artificial intelligence techniques, which are frequently used in prediction models, have been examined in recent years, and a fuzzy logic prediction model has been formed by the SMRGT method. With the testing of the model, it has been demonstrated that the sound environment pleasantness level in urban spaces should be evaluated not only with quantitative data, but also with the historical, architectural, social, and cultural characteristics of the spaces as well as the demographic structure of the users, and the reasons, duration, and frequencies of using spaces. This study shows that the results can be improved by reflecting the spatial and user characteristics together with the quantitative data.

The perception of the countries, regions, societies, and cultures of the soundscape is different from each other. Therefore, the adaptation of studies for a region to other regions may not give accurate results. In this study with fuzzy logic, the characteristics of different societies, regions, and cultures can be reflected in the model. The model to be created can be used for places with different characteristics. In addition, the model has the ability to be developed by recycling.

This study aims to expand the concept of the soundscape and to develop it using new models. To achieve this, a prediction model has been created as an alternative to traditional statistical calculation methods. This model allows for the transmission of both quantitative data and experiential information. Conclusions can be drawn using a straightforward approach that incorporates verbal concepts, which can subsequently be expressed numerically. As a result, this study enhances the flexibility and diversification of both quantitative and qualitative metrics in soundscape research, thereby increasing the diversity of research on soundscape.

It is a time-consuming and laborious process to measure the perception of the soundscape of urban spaces. This model suggestion will allow the long-term stages to evaluate the acoustic comfort of urban spaces in a faster and more systematic way.

In the prediction model studies to determine the sound environment pleasantness levels of the users in the soundscape, the results will be more successful with the development of the models which include the data of the cities and the users with the characteristics of the users with the diversification of the quantitative data. In such studies, analysis of experimental sound data should be developed and interdisciplinary studies should be given importance.

Moreover, this study has provided a valuable contribution to the assessment of the urban sound environment by employing the soundscape approach to evaluate the Diyarbakır Suriçi region. Additionally, sound sources within this area were meticulously recorded and archived, enriching the available data for further analysis and research in the field of urban soundscape.

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