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Species-Related Difference to Noise Reduction Between Trees in Urban Forest: The Abidar Forest Park (Case Study)

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Abstract: Sound pollution is one of the most important urban problems which endangers mental and physical health of the residents. This study was aimed to assess the influence of different tree species, including *Fraxinus rotundifolia*, *Robinia pseudoacacia*, *Platanus orientalis*, *Platycladus orientalis*, and *Pinus eldarica*, in reducing noise pollution in the Abidar Forest Park. A further objective was to identify the contaminated areas of Sanandaj city and to propose suitable noise absorbent tree species in consistent conditions. For each tree stands the noise measurements were performed during intervals at frequencies of 250, 500 and 1000 Hz, besides an open area with the same topography. With regards to the second purpose, a total of 50 stations with residential, commercial, residential-commercial, and green space applications were selected across the city. Equivalent Continuous Sound Pressure Level (Leq) was determined in five replicates for 30 min. The measurements were performed under stable weather conditions and low wind velocity at 17:00 (traffic peak) in summer and fall. All of the Leq values were above the threshold noise level. The highest noise reduction was recorded in summer (i.e., green season); *Platanus* and *Platycladus* species demonstrated the highest and lowest noise absorption (31.43 dB and 22.28 dB, respectively). Furthermore, a meaningful difference was observed between Leq values of commercial, residential, commercial-residential, and green space urban applications, and the central parts of the city showed noticeable noise pollution. Taken together, due to being exposed to higher than the acceptable threshold noise level, the residents of Sanandaj will be endangered to health problems in the near future; thus consideration should be given to the noise pollution sources.

Keywords: Urban green space; noise attenuation; Abidar Forest Park

1 Introduction

Nowadays, over half of the world's population resides in urban areas, and it is expected to increase about 70 percent in the next three decades. The rapid urbanization is accompanied by exposure to anthropogenic noise pollution around the world [1, 2]. Given being a conceptual linkage between tranquility and environmental quality, the increased magnitude and distribution of anthropogenic noise has raised concerns about the potential noise problems to human health and wildlife. For example, noise pollution leads to distraction, stress, cognitive behavior, as well as directly alters physiology, survival, and reproduction of humans and animals [1, 3-8].

Traffic noise is the main noise pollution source in urban settings and an inevitable problem faced by development of technologies in the contemporary society. As such, over 44% of the population in the European Union is exposed to over-threshold anthropogenic noise levels (>55 dB) which could pose adverse effects to health [8]. To mitigate the potential impacts of noise in the urban scale, scientists have put emphasis on generic characteristics of urban morphology, such as building element and road infrastructure noise barriers [9, 10], traffic settlement form [11-14], and urban green spaces primarily covered by vegetation, including parks, forests, public squares, recreational grounds and private front or backyard garden land [15-18].

Previous researches assessed the effectiveness of parks and greenbelts on traffic noise reduction. Islam [19] assessed the potential role of greenbelt for the reduction of noise levels in a megacity of Bangladesh and reported a great reduction in noise level (up to 17 dB) when compared to an open area. Another study investigated the effect of roadside vegetation on the reduction of road traffic noise under varying planting intensities and showed that the traffic noise was reduced by 50% when vegetation was enhanced from a minimal to moderate planting intensity [20]. Furthermore, it has been showed that the wooden parts of plants such as stem, branches, and twigs have a capacity to absorb noise in the mid frequency range of 0.5-2 kHz, while the leaves mostly absorb the frequency range of above 1 kHz [21]. However, far too little attention has been paid to the influence of tree diversity as well as leaf-off and leaf-on seasons on traffic noise pollution. In the present study, therefore, we selected Sanandaj Abidar Forest Park to compare the influence of each tree species on the intensity of traffic noise pollution, to identify suitable areas in Sanandaj city for planting plants compatible with noise pollution, and also to compare noise pollution in various urban applications. In addition, the effect of different distances and species were investigated to find the most suitable species as a biological noise barrier. The target for second experiment is to identify the contaminated areas of Sanandaj city and to compare the noise pollution in various urban applications.

2 Materials and Methods

Sanandaj with about half a million permanent inhabitants is the twenty-third largest city in Iran, and the population increased by 1.4% from 2017 to 2018.

2.1 Study Area Description

The study was conducted in the Abidar Forest Park with an area of 1555 ha. The park is located in the south-western of Sanandaj city, Iran, between the geographic longitudes 46°55′24″ to 46°59′12″E and longitudes 35°15′52″ to 46°19′24″N (Fig. 1). Its elevation scope is from 1600 (Abidar ring road) to 2546 m (Abidar peak) above sea level. The park is predominantly covered with five tree species including *Fraxinus rotundifolia, Robinia pseudoacacia, Platanus orientalis, Platycladus orientalis*, and *Pinus eldarica*. These tree species were selected to follow the above mentioned objectives.

2.2 Noise Measurement

To assess the effect of trees on noise pollution reduction, the noise measurement was conducted at six points of the park at seven distances from the noise source behind tree stands. An open area with the same topography was selected as the control stand [22]. Each stand was transected into 5 segments with a distance of 10 m from each other. A noise meter (Model 9019 DELTAOHM HD) was calibrated with calibrator 910HD on 94 dB and at frequency of 250, 500, and 1000 Hz. The source and the sound level were set at a height of 1.5 m above ground level at specified stations [23, 24].

To compare the acoustic filtration influence of leaves and branches, measurement of sound pressure levels was carried out in summer and fall (leaves-on and leaves-off seasons, respectively) under stable weather

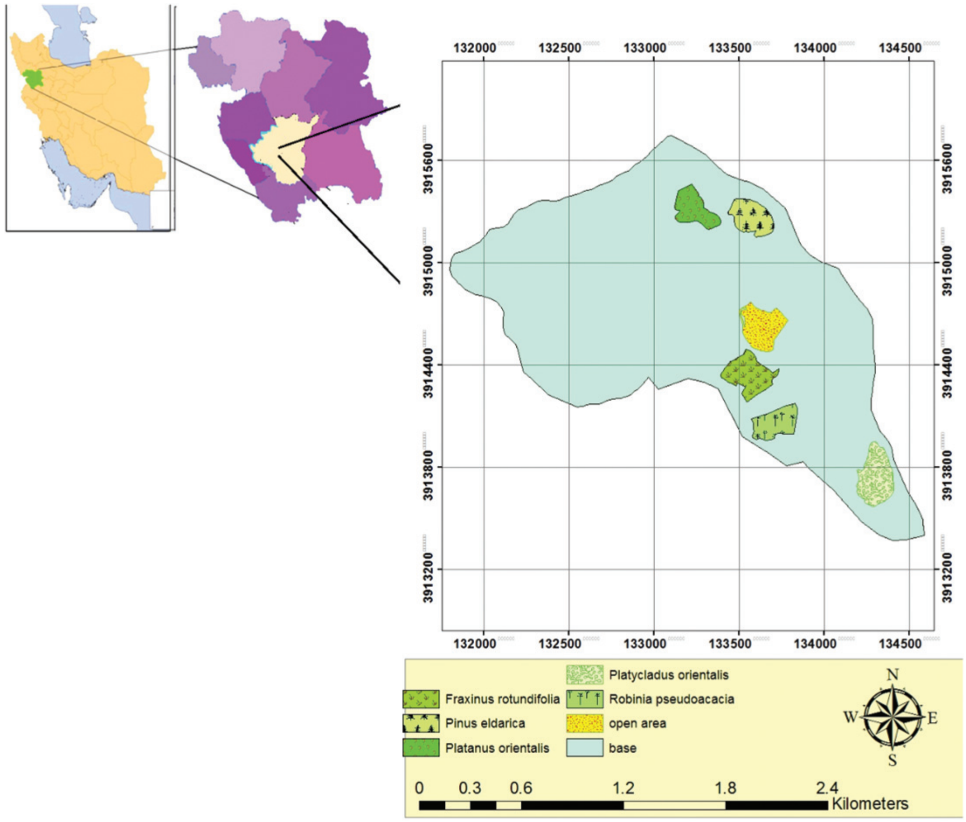

Figure 1: The geographical location of each species in Abidar Forest Park

conditions and low wind velocity at 17:00 (traffic peak). All measurements were done in five replicates for 30 min and the mean values were used in the analysis [20, 25]. Due to varying sound sources over the period of sound measurements, Equivalent Continuous Sound Level (Leq) was taken into account [20].

Diameter at Breast Height (DBH), canopy volume, and height of the trees were determined at every stand in three 10-square-meter plots using a selective statistical method. To determine canopy volume, two diameters of canopy for each tree were measured and then their volumes were calculated.

2.3 Planting Site Selection for Sound Barrier

To propose planting site in Sanandaj city, vegetation and vegetation-free areas with the lowest and the highest peak traffic were selected using a completely systematic approach. Briefly, a total of 50 stations in the areas with different urban applications including residential, residential-commercial, commercial, and green spaces were chosen. The sound meter was fixed on a 1.5 m-height tripod and placed 3.5 meters away from buildings and concrete walls to avoid sound reflection. A sponge was used to insert the sound meter on the microphone in order to prevent the occurrence of any error caused by the vibration of air molecules. The sound meter was set to A-weighted frequency measurement, the most commonly used frequency response by the human ear. The noise levels commonly people are exposed in different areas of the city were determined based on the time-weighted F and the Leq values [26]. The noise polluted areas were identified through recording the coordinates of the points by a GPS device and then these coordinates and the Leq values were entered into ARC GIS 10.4 software. Finally, an inverse distance weighting (IDW) map was developed using the best IDW interpolation method to recognize the noisiest areas and to propose cultivation of tree species for reducing the noise pollution [27, 28].

2.4 Statistical Analysis

Data analysis was performed using SPSS software (version 22). Kolmogorov–Smirnov test was applied to assess the normality and homogeneity of the measured noise levels. Levene's test was used to assess the homogeneity of variances. Tukey HSD test was applied to compare the noise reduction between the open area and the three stands. All results are presented as the mean ± standard deviation (S.D.). Moreover, the general linear model (GLM) was also performed to evaluate the interactive effects of different stands and distances on sound reduction.

3 Results

3.1 Noise Pollution

The background noise in the forest park was 40-41 dB. Noise was measured when no noise pollution was being produced by the amplifier at all of the stands and in the control area. The noise value in the selected area (101.5 dB) was significantly higher than 9 dB (The difference between the two levels: the study area without sound pollution and while causing noise pollution). The intensity level of field noise was ignored [29, 30].

The studied region is a residential-industrial one and its noise level is about 101 dB (A), significantly higher than the national noise standards of Iran (Tab. 1).

Table 1: Iranian national noise standard

The type of regions	7AM-10PM Leq(30') dB(A)	10AM-7AM Leq(30') dB(A)
Residential	50	30
Residential-Commercial	60	50
Commercial	65	55
Residential-Industrial	70	60
Industrial	75	65

The measurements demonstrated that sound reduction in the open area and other obstacles occurred in gradual and sharp attenuations, respectively. The tree species, especially *P. orientalis*, exhibited noticeable effect in reducing sound density when compared to the area with no vegetation (Fig. 2). The tree species reduced the noise values about 23-30 dB.

The reduction of noise pollution at different frequencies and a distance of 100, 75, 50 and 10 meters are described in Tab. 2.

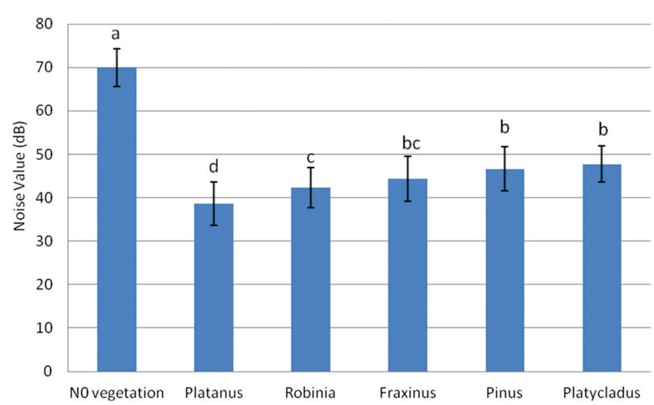

Figure 2: The comparison between effects of different stands on noise pollution reduction. Different letters show significant statistical difference ($p < 0.5$)

Table 2: The average of noise pollution attenuation in different tree types at 100, 75, 50 and 10 m away from the noise source (mean ± SD)

Frequencies (Hz)		250				500				1000			
Tree species	Distance (m)	100	75	50	10	100 m	75	50	10	100 m	75	50	10
(open area)		$(94.1 \pm 0)^{a}$	$(95.6 \pm 5)^{a}$	$(101.6 \pm 2)^{a}$	$(114.6 \pm 2.1)^{a}$	$(80 \pm 0.6)^{a}$	$(91.3 \pm 1)^{a}$	$(97.3 \pm 1.8)^{a}$	$(110.3 \pm 1)^{a}$	$(70 \pm 0.9)^{a}$	$(79.1 \pm 3.1)^{a}$	$(85.1 \pm 2)^{a}$	$(98.1 \pm 2.2)^{a}$
Platanus	Summer	$(67.1 \pm 3)^{d}$	$(68.1 \pm 3)^{d}$	$(76.5 \pm 2.1)^{d}$	$(99 \pm 2.2)^{d}$	$(51 \pm 1.8)^{d}$	$(61.8 \pm 2)^{d}$	$(72.2 \pm 2)^{d}$	$(94.7 \pm 1)^{d}$	$(38.6 \pm 1)^{d}$	$(49.6 \pm 4.2)^{d}$	$(60 \pm 4.2)^{d}$	$(82.5 \pm 3.1)^{d}$
	Fall	$(76.5 \pm 2)^{b}$	$(75.9 \pm 3)^{b}$	$(86.3 \pm 3.1)^{b}$	$(104.6 \pm 2.1)^{b}$	$(60.4 \pm 3)^{b}$	$(71.6 \pm 2)^{b}$	$(82 \pm 2.4)^{b}$	$(100.3 \pm 1)^{b}$	$(49.9 \pm 2)^{b}$	$(59.4 \pm 1)^{b}$	$(69.8 \pm 1)^{b}$	$(88.1 \pm 2.1)^{b}$
Robinia	Summer	$(70.8 \pm 1)^{c}$	$(70.7 \pm 2)^{cd}$	$(81 \pm 2.5)^{c}$	$(102.3 \pm 2.5)^{c}$	$(54.7 \pm 2)^{cd}$	$(66.4 \pm 3)^{c}$	$(76.7 \pm 1.1)^{c}$	$(98.2 \pm 1)^{c}$	$(42.2 \pm 2)^{c}$	$(54.2 \pm 3.3)^{c}$	$(64.5 \pm 2.3)^{c}$	$(85.8 \pm 0.9)^{c}$
	Fall	$(77.3 \pm 2)^{b}$	$(76.6 \pm 1)^{b}$	$(86.8 \pm 1)^{b}$	$(105.6 \pm 1.9)^{b}$	$(61.3 \pm 3)^{b}$	$(72.3 \pm 5)^{b}$	$(82.5 \pm 3.9)^{b}$	$(101.3 \pm 2)^{b}$	$(53.8 \pm 2)^{b}$	$(60.1 \pm 4.1)^{b}$	$(70 \pm 3.8)^{b}$	$(89.1 \pm 2.2)^{b}$
Fraxinus	Summer	$(71.8 \pm 1)^{c}$	$(71.9 \pm 4)^{cd}$	$(82.2 \pm 2.1)^{c}$	$(103.6 \pm 2.4)^{c}$	$(55 \pm 1.4)^{cd}$	$(67.6 \pm 4)^{c}$	$(77.9 \pm 3.5)^{c}$	$(99.3 \pm 3)^{c}$	$(43.3 \pm 1)^{c}$	$(55.4 \pm 3.3)^{c}$	$(65.7 \pm 4.4)^{c}$	$(87.1 \pm 1.2)^{c}$
	Fall	$(77.1 \pm 1)^{b}$	$(76.8 \pm 5)^{b}$	$(86.8 \pm 4.4)^{b}$	$(105.9 \pm 1.3)^{b}$	$(62.1 \pm 2.1)^{b}$	$(72.5 \pm 1)^{b}$	$(82.5 \pm 1.4)^{b}$	$(101.6 \pm 1)^{b}$	$(51.6 \pm 1)^{b}$	$(60.3 \pm 4.4)^{b}$	$(70.3 \pm 3.3)^{b}$	$(89.4 \pm 2.2)^{b}$
Pinus		$(75.1 \pm 3)^{bc}$	$(73.2 \pm 3)^{c}$	$(83.6 \pm 1.8)^{bc}$	$(103.6 \pm 2)^{bc}$	$(59.1 \pm 4)^{c}$	$(68.9 \pm 3)^{bc}$	$(79.3 \pm 0.9)^{bc}$	$(99.3 \pm 3)^{bc}$	$(46.6 \pm 1)^{bc}$	$(56.7 \pm 3)^{bc}$	$(67.1 \pm 2)^{bc}$	$(87.1 \pm 2)^{bc}$
Platycladus		$(76.2 \pm 1)^{bc}$	$(75.3 \pm 1)^{c}$	$(85.6 \pm 1.7)^{bc}$	$(103.8 \pm 1)^{bc}$	$(60.2 \pm 2)^{c}$	$(71 \pm 2)^{bc}$	$(81.3 \pm 2.1)^{bc}$	$(99.5 \pm 3)^{bc}$	$(45.7 \pm 2)^{bc}$	$(58.8 \pm 2.8)^{bc}$	$(69.1 \pm 2)^{bc}$	$(87.3 \pm 2)^{bc}$

Note: Different letters in column indicate significant differences of means at 5% level.

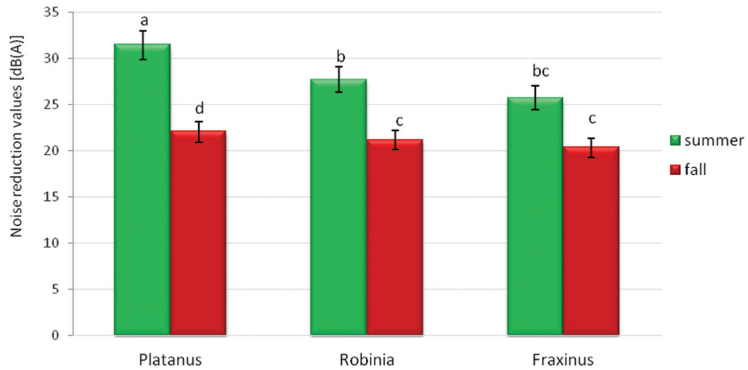

Figure 3: Noise attenuation in summer and fall in a different tree stands at 100 meters away from the noise source

Figure 3 compares the noise reduction by three tree species at a frequency of 1000 Hz in summer and fall. The trees exhibited significantly higher capability to attenuate the noise level in summer when compared to fall, with being about 9.37, 6.55, and 5.33 dB by *Fraxinus rotundifolia, Robinia pseudoacacia* and *Platanus orientalis*, respectively.

The relationship between increasing distance and noise level in the stands of the six tree species is presented in Fig. 4. In all of the stands, besides the open area, the noise levels displayed a distance- and stand- dependent attenuation, with the highest reduction rate (slope) up to the first 50 m from the noise sources.

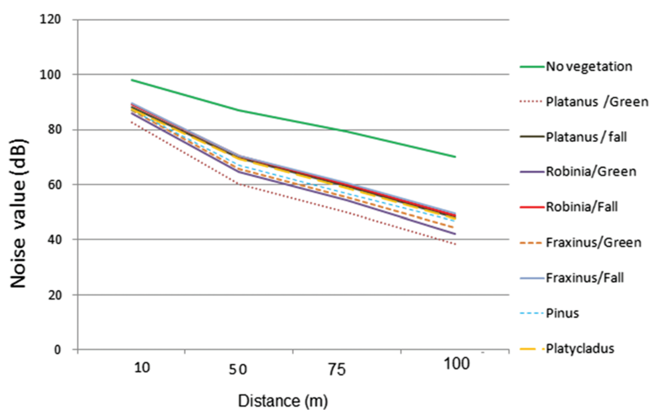

Figure 4: The relationship between increasing distance and noise level in the stands of *Fraxinus rotundifolia*, *Robinia pseudoacacia*, *Platanus orientalis*, *Platycladus orientalis*, and *Pinus eldarica*

The influence of distance and distribution of the tree species on noise level showed a significant difference between different distances for Leq ($p < 0.05$). Leq intensity was significantly affected by different species and distances, and also the tree species and distance exhibited a strong interaction in reducing the Leq values ($p < 0.05$; Tab. 3).

In the needle-leaf strands (*Platycladus orientalis* and *Pinus eldarica*), sound level was noticeably reduced from 10 to 50 m distance of the sound sources, but not from 75 to 100 m (Tab. 4). In the other strands, however, the noise values were significantly reduced at all points from the center of the sound source.

3.2 Effect of Tree Quantitative Factors on Noise Level

Canopy volume, DBH and height of the tree stands are presented in Tab. 5. The highest (1698 m3 per ha,) and lowest (1039 m3 per ha) canopy volume were recorded for *Platanus orientalis* and *Platycladus*

Table 3: Analysis of variance of the reducing Leq

Source	Sum of Squares	Df	Average of Squares	F	*p*-value
Species	800.556	4	200.139	117.893	0.000
Distance	1102.939	1	1102.939	649.691	0.002
Species × Distance	54.215	4	13.554	7.984	0.002
Error	108.649	4	1.698		
Total	108.649	60			

Table 4: The effect of distance from noise source of frequency (1000 Hz).on noise attenuation caused by different tree species

Distance (m)		10	50	75	100
(open area)		98.13^{a}	85.14^{b}	79.13^{c}	70^{d}
Platanus	Summer	82.5^{a}	60.03^{b}	49.69^{c}	38.57^{d}
	Fall	88.12^{a}	69.8^{b}	59.46^{c}	47.94^{d}
Robinia	Summer	85.8^{a}	64.55^{b}	54.21^{c}	42.29^{d}
	Fall	89.12^{a}	70.3^{b}	60.12^{c}	48.84^{d}
Fraxinus	Summer	87.12^{a}	65.76^{b}	55.42^{c}	44.3^{d}
	Fall	89.43^{a}	70.37^{b}	60.39^{c}	49.67^{d}
Pinus		87.13^{a}	67.12^{b}	56.78^{c}	46.66^{c}
Platycladus		87.33^{a}	69.18^{b}	58.84^{c}	47.72^{c}

Note: Different letters in row indicate significant differences of means at 5% level

Table 5: Canopy volume, DBH, and height of five tree stands (*Fraxinus rotundifolia, Robinia, Platanus orientalis, Platycladus orientalis*, and *Pinus eldarica*) in Sanandaj Abidar Forest Park

Tree species	Diameter at breast height (m)	Height (m)	Canopy Volume (m^3)/ha
Platanus	29.9	8.1	1698
Fraxinus	22.9	7.1	1335
Robinia	20.1	7.3	1508
Pinus	19.6	9.3	1243
Platycladus	16.2	6.1	1039

orientalis, respectively. However, DBH showed the highest value (29.9 cm) for *Platanus orientalis* and the lowest one (16.2 cm) for *Platycladus orientalis*.

3.3 Noise Polluted Areas in Sanandaj City

The Leq values for all of the evaluated 50 points are presented in Tab. 6. The maximum (91.1 dB) and minimum (55.3 dB) levels of Leq were recorded at a station with commercial application, called Azadi Square station, and at Abidar Forest Park station, respectively.

Table 6: Leq values at 50 stations across Sanandaj city in 2017

Row	Application type	Point-x	Point-y	Leq	Row	Application type	Point-x	Point-y	Leq
1	Residential	681025.3	3909122	71	26	Commercial	681359.1	3911151.4	74.3
2	Commercial	683118.2	3909776	71.4	27	Commercial	683595	3907834.9	75.3
3	Residential	682268.1	3905445	51.1	28	Residential	680902.1	3906282.9	77.3
4	Residential	681177.3	3909752	76.3	29	Green space	681984.7	3909638.4	62.3
5	Commercial	681336.9	3908966	75.3	30	Residential	680687.1	3908981.2	78.3
6	Commercial	681643.1	3909228	69.1	31	Commercial	683773.9	3910425.1	72.300
7	Green space	683553.4	3907472	55.3	32	Commercial Residential	681360	3908889.2	70.100
8	Commercial	680248.7	3910003	70	33	Commercial Residential	681361.6	3909572	75.600
9	Commercial	682568.2	3910107	75.3	34	Commercial Residential	681008.6	3909431.1	77.300
10	Commercial	681286.8	3907412	80.1	35	Commercial Residential	680605.2	3905863.9	71.200
11	Commercial	683309.4	3906271	79.8	36	Commercial Residential	681283.5	3907091.9	70.300
12	Commercial	682457.3	3905219	65.8	37	Commercial Residential	682615.8	3908040.2	68.300
13	Commercial	681625.5	3909011	82.1	38	Commercial Residential	681834	3910054.9	68.900
14	Commercial	683819.5	3909755	73.1	39	Commercial Residential	682847.6	3908548.4	75.100
15	Commercial Residential	681200.6	3910240	72.9	40	Green space	682033.7	3909543.9	68.200
16	Commercial	681671.6	3911079	70.8	41	Commercial	682196.8	3910468.4	69.000
17	Green space	681853.4	3910431	73.5	42	Residential	682181.3	3909772.2	69.100
18	Residential	683500.4	3909402	72.	43	Green space	680823.4	3904868.2	71.300
19	Commercial	680948.6	3907763	82.6	44	Residential	679515.6	3909310.9	67.300
20	Commercial	683302.1	3907169	91.1	45	Residential	682880.7	3907936.7	68.230
21	Commercial	683383.3	3907439	73.3	46	Commercial Residential	682018.5	3908304.2	68.880
22	Residential	684215.7	3909333	75.1	47	Commercial	681489.6	3907342.8	62.300
23	Residential	681022	3904760	68.2	48	Residential	680378.4	3909892.3	59.800
24	Residential	682381.5	3908580	72.9	49	Commercial Residential	680461.4	3907243.8	74.300
25	Residential	681726.5	3909526	76.8	50	Commercial	681928.7	3909551.8	61.120

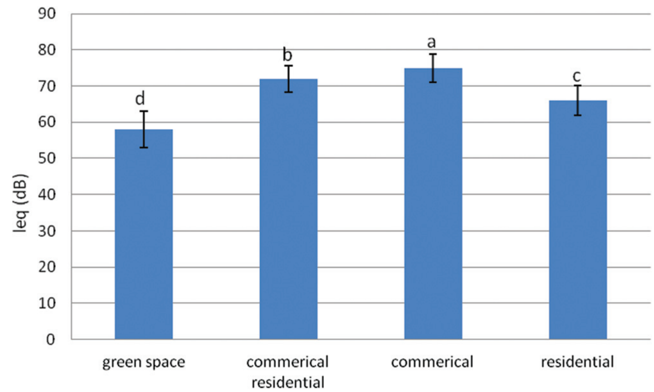

Figure 5: Sound pollution in use Sound pollution zoning in Sanandaj

3.4 Noise Pollution and Urban Application

A significant difference was observed in Leq values between urban applications ($p < 0.05$; Fig. 7). Leq values in high traffic points (commercial and commercial-residential) were above 70 dB.

The sound pollution zonation of Sanandaj city was prepared using the acquired Leq values (Fig. 6). The Leq data was introduced to the ArcGIS 10.4 environment and a map was produced via the IDW technique.

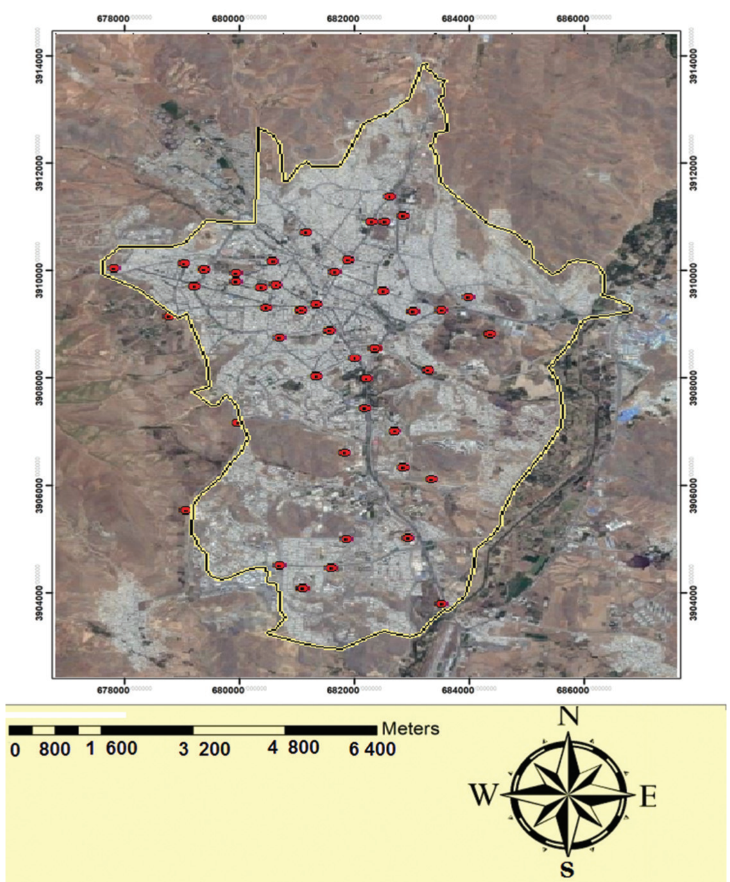

Figure 6: Position of metering stations on the image of Google Earth in Sanandaj, Iran

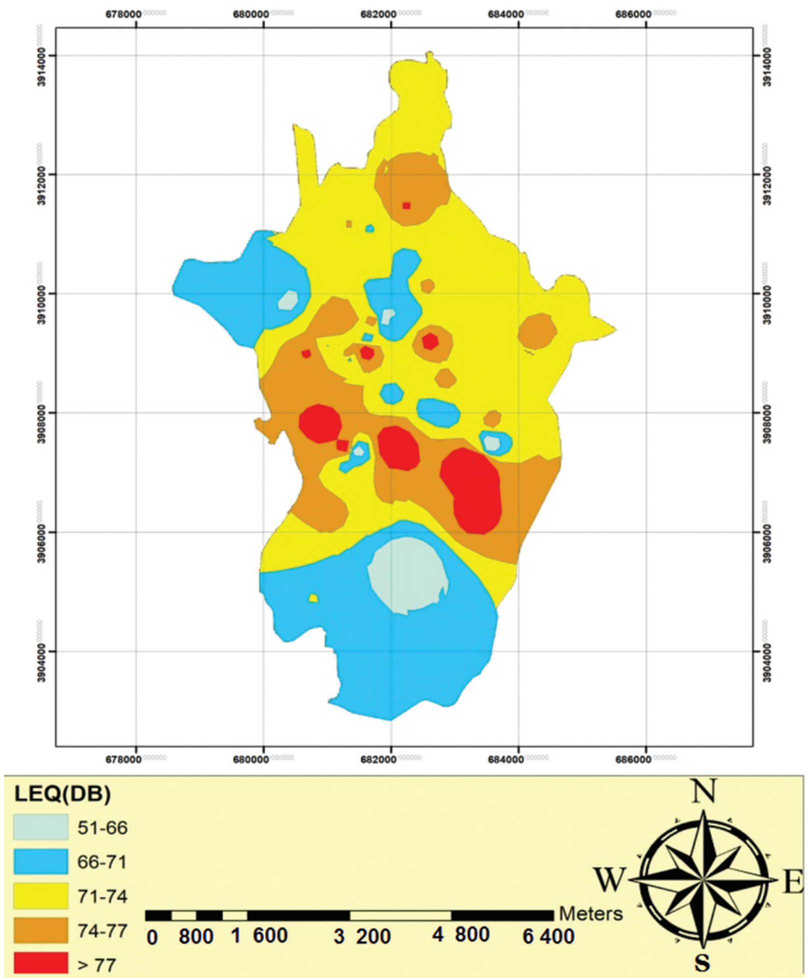

Figure 7: Sound zonation of Sanandaj city, Iran

The findings revealed that about 21 percent of the area was in exposure to sound with >70 dB density. This sound pressure level is much higher than the permissible level (60 dB) in commercial-residential areas. Moreover, the central areas of the studied region with commercial and residential-commercial applications demonstrated significantly higher sound pollution levels than did the other areas.

4 Discussions

Noise which has been defined as the unwanted noise being made up of sound waves which are not sinusoid, particularly affect and disturb people depending on the intensity, spectrum frequency and the period. Noise is a problem that affects everybody. Noise is likely to continue as a major issue well into the next century. There are two types of barriers which prevent noise pollution in place: Synthetic barriers (concrete, stone and wood) and living elements (the plant belts which are formed by trees and bushes). Because of their known other benefits (aesthetic, functional, climate improvement, providing moisture, prevention of erosion and etc.), vegetation should be preferred to mitigate traffic noise, if appropriate areas and adequate maintenance facilities exists. Green space establishment techniques should be in accordance with scientific methods and the diversity of plant species appropriate to the local ecology should be increased in terms of both quality and quantity [31].

Through pollution removal and other tree functions, urban forest parks can help to improve the environmental quality and consequently improve human health. The present study focused on the importance and necessity of trees, urban forest parks, for noise pollution reduction. The results were consistent with those reported by previous studies which demonstrated significant noise reduction in the areas covered with wider greenbelt (i.e., tree belt width) [19, 32-34]; in general, the more greenbelt width it is, the more noise attenuation it will be expected. Moreover, the scattered frequency areas become more extensive with increasing distance from noise source and, in turn, the noise intensity is reduced [35]. On the other hand, the experimental studies presented conflicting evidence: Kuttruff and Heinrich [36] concluded that vegetation did effectively reduce perception of noise. They suggested that the presence of vegetation can generally reduce the negative perception of noise. They showed that the effect on noise attenuation, of trees and or forests, is more psychological than physical. So in our study this further enforces the fact that although aesthetics are important, they are not incremental in the judgment of a barrier's ability to attenuate noise.

In the present study, the planted tree species reduced noise intensity about 23-30 dB. The finding was fairly higher than those reported by previous studies [37, 38]. That assessed the influence of greenbelt or urban park on traffic noise levels or other sources of sound pollution.

Researchers suggested that forest stands and tree belts with at least 12 m width could be efficiently used as noise barriers in urban areas [22, 39]. When compared to our results, their suggestion may be useful for planting certain tree species; that is, the effectiveness of tree stands or green belt in reducing sound pollution depends on tree species and its characteristics [40]. A tree-dependent noise reduction was observed; the broad-leaf species (*Platanus orientalis, Robinia* and *Fraxinus rotundifolia*) showed more effectiveness in Leq reduction than the needle leaf ones; similar results have reported previously [41]. The density and width of trees disperse the sound waves and direction [18], and the leaf size and tree branching type are of high importance in sound absorption level [15].

In the present research, the more leaf area and crown there was observed, the greater reduction it occurred in the sound level. Support for this data has come from the study conducted by Fang and Ling [42] who revealed that more canopy volumes and subsequently more leaves and branches could play an important role in reducing sound.

Margaritis and Kang [1] studied the role of trees in controlling noise pollution and stated that the extent of sound reduction varies and depends on some morphological and physical characteristics, including type, density, height, texture, leaf location on the branch, as well as the position of trees and weather condition. The density of trees (i.e., number) is of paramount importance to be considered in constructing a green sound barrier. A confirmative finding was found in the needle-leaf stands in which the sound density was significantly reduced up to 50 m distance of the sound sources but not from 75 to 100 m, suggesting more effectiveness of the broad-leaf species in less density in noise reduction. In addition, the finding implied that the capability of the trunk of needle-leaf trees for reducing sound intensity is higher than that of broad-leaf ones, particularly in winter, as approved previously [43]. The noise zonation revealed the highest Leq values for high traffic streets with commercial (73.70 dB) and residential-commercial (71.32 dB) applications. These values are close to those reported for high traffic streets in Messina (75 dB) [44].

Given that the noise exposure limit for residential areas is 55 dB, most of the residential and commercial areas of Sanandaj are suffering traffic sounds with impermissible Leq. Moreover, due to the increasing modernization and population growth and, in turn, the increasing urban traffic in Sanandaj, the noise level would be expected to exceed the standard level all day.

5 Conclusions

The present study was designed to determine the effect of an urban forest park on sound reduction in summer and fall seasons. This study found that generally *Platanus orientalis* species has the highest efficacy in noise absorption when compared with the other planted species. Therefore, planting these species could be suggested for the central regions of the city with similar topographic and physiological conditions to reduce the complications of noise pollution. Moreover, due to being exposed to higher than acceptable threshold noise level, the residents of Sanandaj will be endangered to health problems in the near future; thus consideration should be given to the noise pollution sources. More broadly, research is also needed to determine to assess the suitability of trees to grow in urban surroundings. This suitability can be described as high tolerance to urban soil properties, ability to survive and grow without consistent watering, longevity and sustainability, as well as aesthetic value and limited volatile organic compound emissions.

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