



Temporal variability of noise pollution attenuation by vegetation in urban parks

Shahla Tashakor¹ · Atefeh Chamani¹

Received: 21 April 2020 / Accepted: 2 January 2021 / Published online: 13 January 2021
© The Author(s), under exclusive licence to Springer-Verlag GmbH, DE part of Springer Nature 2021

Abstract

The present study proposed a novel approach to investigate variability in the acoustic behavior of a number of deciduous tree-dominated narrow and long urban parks in Isfahan city, central Iran, between winter leaf fall and summer foliage. Noise levels (L_{q30} in dB) were measured along two adjacent sides of the parks: along the road-adjacent side (Ro transect) and the relatively calmer river-adjacent side of the parks (Ri transect) during 4–17 January 2018 and 7–14 August 2019. Using Sentinel-2 images, two NDVI maps were also produced for these two periods to determine how changes in green biomass were associated with changes in noise levels. Using ANOVA, a significant difference was found in Ri- L_{q30} and NDVI maps between winter and summer ($p = 0.0$), while the difference was insignificant for Ri- L_{q30} ($p = 0.1$). We also developed two multiple linear regressions, one for each season, to assess the dependency of Ri- L_{q30} to the intensity of vegetation and Ro- L_{q30} and compare the two seasons by performing a t test analysis on the intercept and slope of the models, with results suggesting there is a significant difference in the association of green biomass and noise levels measured inside the parks between leaf fall and foliage time ($p = 0.04$). Our results indicated the temporal variability of park characteristics in providing calmer urban landscapes throughout the year.

Keywords Acoustic behavior · Isfahan · NDVI · Noise pollution · Urban greenery · Urban park designation

Introduction

Urban areas are highly dynamic and complex systems, the functioning of which is dependent upon a wide range of interlocking factors (Peng et al. 2017). Some factors such as the extensive use of (mostly fossil fuel) vehicles can undermine the well-functioning of the system, mainly due to their potential for emitting air and noise pollution and augmenting health risk concerns (Apparicio et al. 2018; Rojas-Rueda et al. 2017). Contrarily, urban green structures (urban parks in particular) serve as a sink to many of these undermining sources (Buchel and Frantzeskaki 2015; Langemeyer et al. 2015). They are beneficial from many points of view ranging from

heat island alleviation (Asgarian et al. 2015) to air purification (Vieira et al. 2018) and noise attenuation (Lopez and Souza 2018) to meet some basic human needs, especially comfort and relaxation (Ayeghi and Ujang 2017). Urban parks were first developed following the industrial revolution (in the nineteenth century) in Europe and North America to bring back nature to cities and address the problems associated with population crowding (Loughran 2018). Currently, however, with the increasing rate of urbanization and the unprecedented physical expansion of urban areas, appropriate designation of green parks has emerged as an indispensable component of urban environments to lead urban growth towards sustainability from a variety of perspectives. In terms of noise pollution, Pathak et al. (2011) describe urban parks as efficient (noise) pollutant trapping devices. Drawing from a literature review, Cohen et al. (2014) found that noise level attenuation by urban parks ranged between 6 and 27 dB depending on the characteristics of urban parks and the surrounding built-up environment. Sakieh et al. (2017) also discuss that the relationship between urban morphological features and the acoustic ambient is a complex function related to urban architecture design which aims to compromise between the area allocated to built-up and vegetation land uses.

Responsible Editor: Philippe Garrigues

✉ Atefeh Chamani
a.chamani@khuisf.ac.ir
Shahla Tashakor
tashakor95@gmail.com

¹ Environmental Science Department, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

Noise is characterized as an important but relatively neglected form of pollution (Demian et al. 2009). Since being recognized as a type of pollution by the World Health Organization (WHO) of the United Nations in 1972 (WHO 1972), investigating the acoustic behavior of urban landscapes has increasingly become a very active area of research (Lu et al. 2019; Purser and Radford 2011). Studies in this field have specifically looked into noise measurement and mapping and attempted finding the possible association between noise levels and the characteristics of emitting sources/receiving surfaces, aiming to provide practical solutions for noise attenuation in the urban ambient. Studies focusing on noise-emitting sources have all implicated road traffic as the main—and in some cases as the sole—source of noise in urban areas which is present everywhere in the city from home to street and at every time of the day (Margaritis et al. 2018; Ware et al. 2015). Mindful of the importance of road traffic, some other studies have investigated how urban (environmental) design contributes to reducing harmful noise levels, with more emphasis being put on green structures and urban parks. At the city scale, e.g., Weber et al. (2014), Sakieh et al. (2017), and Margaritis and Kang (2017) showed that the way in which urban parks are distributed within the city and their geometric shape (regardless of their vegetation composition) is of high importance in attenuating noise pollution. At the park scale, however, studies have been more attentive to assessing the effect of different types, densities, and combinations of vegetation on noise levels using a variety of approaches and tools, with focus ranging from leaves, branches, and trees (Horoshenkov et al. 2013) to different combinations and patterns of vegetation forms (Van Renterghem et al. 2012). Methodologically, several approaches have been also developed to help determine the association between noise attenuation and green structures such as the TRAP tool (Pheasant et al. 2010), QUIETE index (Brambilla and Gallo 2016), and regression modeling as the most prevalent technique (Ragettli et al. 2016).

Despite the proliferation of studies assessing the spatial correspondence between noise levels and vegetation covers (especially in the vicinity and within urban parks), little is yet known about how this association may vary over temporal scales. By monitoring noise levels in three different locations of an urban environment, street canyon, urban square, and urban park, Cohen et al. (2014) found that noise levels are independent of changing environmental conditions occurring between foliage evergreenness and deciduousness. To better capture this trend, it was focused on the acoustic characteristics of a coupled road park system where the majority of green structures are deciduous, thus serving as a good candidate in revealing temporal changes in traffic noise attenuation by vegetation between winter and summer. In other words, it was assessed whether there is a significant difference in noise exposure reduction by deciduous vegetation forms between their

foliage times in summer and when they enter a period of inactivity, known as dormant during winter season. Taking a number of narrow and long river-adjacent parks in Isfahan, central Iran, an array of statistical tests and models supported by noise measurements and remote sensing-derived vegetation maps was utilized to investigate temporal variability of noise attenuation by deciduous vegetation between summer and winter to assist urban designer in providing a calmer urban ambient, particularly in winter season.

Material and methods

Study area

Isfahan city in central Iran (340 km² in area between 32° 32' 38" to 32° 40' 49" N longitude and 52° 26' 27" to 51° 49' 58" E latitude) (Iranian Bureau of Statistics 2015) has a good network of 59 urban parks and green spaces, accounting for 10% of the city's area (Fig. 1). The majority of the parks are located on the western side of Isfahan where Zayandeh-rood River enters the city. Although Isfahan is situated in an arid region close to the central desert of Iran with a mean annual precipitation of below 130 mm, the river plays a leading role in the development of urban parks and building a green city (Mazaheri 2018). Our study parks are collectively 55.84 ha in area and rank as the oldest parks of the city (shown in Fig. 1). They are very narrow in width ranging from 50 to 150 m and, due to sufficient water availability from the river, are designed with dense plane trees. To the south, these parks are bordered by one of the most congested roads of Isfahan (Mellat Boulevard) while Zayandeh-rood River borders them from the north, forming a condition in which the northern parts of the parks experience calmer conditions. Currently, Isfahan is the third most populated city of Iran with a total population of 2.2 million people whose average personal fossil fuel vehicles including cars and motorbikes are estimated to be more than 0.8 per individual with around 11-m² asphalted road per vehicle (Isfahan Ziba 2015).

Methods

Noise measurement

Noise levels were measured along two (almost) parallel transects (Fig. 1); one transect was located in the southern edge of the parks along the Mellat Boulevard (hereafter the Ro transect) which is likely the sole source of noise affecting the parks and the other one was located along the (relatively calm) northern edge of the parks (along the Zayandeh-rood River) having the longest distance to the noise-emitting source (hereafter the Ri transect). A total of 100 noise measurement sites were placed along the transects, 50 sites on each transect with a distance of

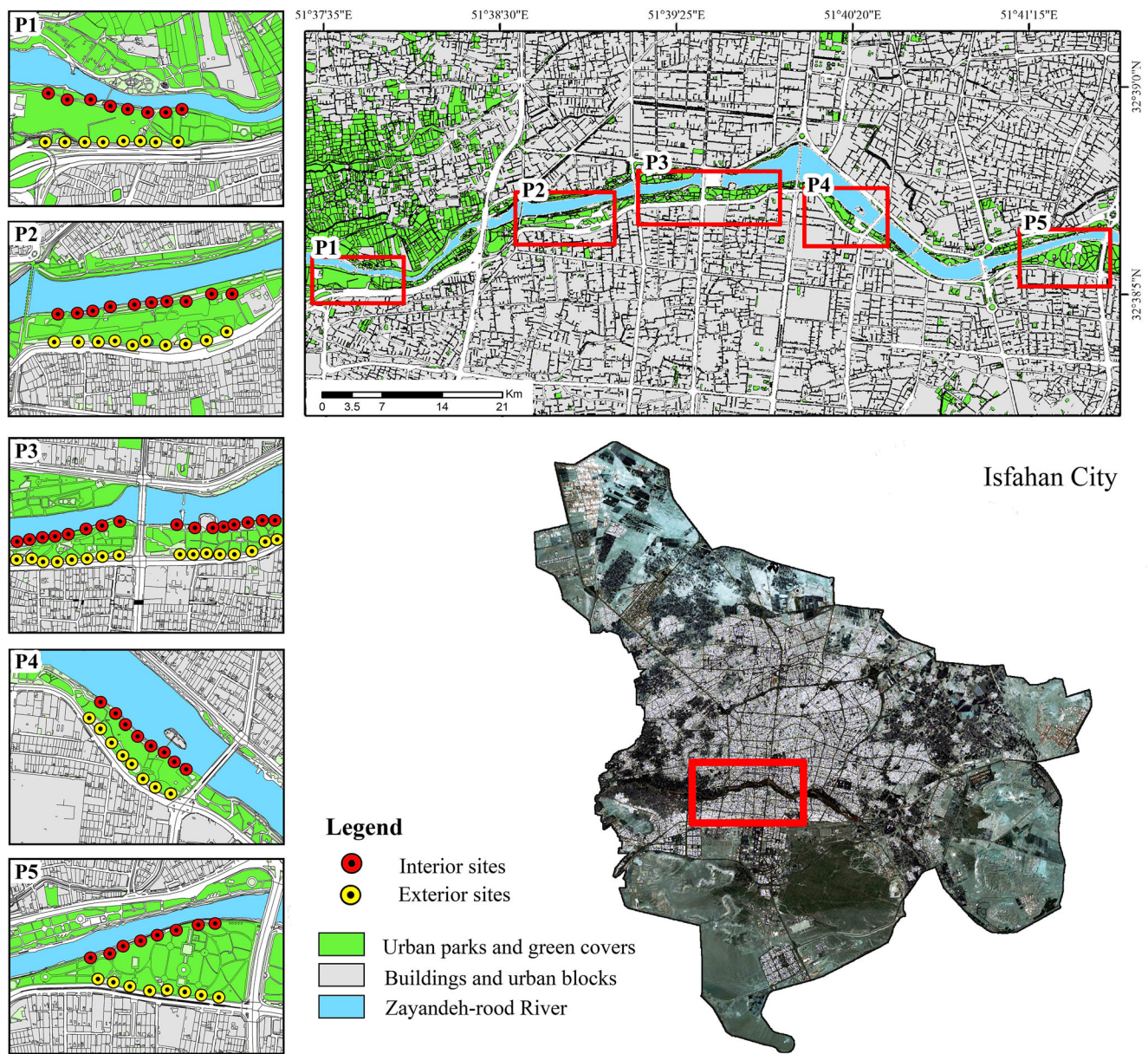


Fig. 1 Study parks and distribution of noise measurement sites

approximately 50 m in between. Noise levels (in dB) was recorded with three replications using a sound recording device for a duration of 30 min at the noisiest and busiest time of the day when traffic peaks, between 7 and 9 A.M. during 4–17 January 2018 (in peak leaf fall in winter) and 7–14 August, 2019 (in peak green foliage in summer), except for weekends. During measurements, the number of cars passing the road was counted. Using the ANOVA test, the difference in noise source between the seasons was measured. It was hypothesized that the noise source is stable with time if the ANOVA test indicated an insignificant difference. Moreover, the study road only provides access for personal cars with a certain speed limit which further indicates the stability of noise sources. Noise recording was performed under constant and stable environmental conditions with low

wind speed and relative humidity. The 30-m Equivalent Sound Level (L_{q30} – in dB) was then measured to integrate both the intensity and duration of noise recorded at each site into an interpretable value. In other words, L_q refers to a single decibel value indicating a constant level of noise which is the most representative of noise measured with varying intensities during the same period of time (Han et al. 2018), 30 min in our case. The equation for measuring L_q is given below (Eq. 1) with t_1 and t_2 as the start and end time of a recording and P_o and P_a as the reference (20 μ Pa) and A-weighted pressure level, respectively (Sakieh et al. 2017).

$$L_q = 10 \log \left[\left(\frac{1}{t_2 - t_1} \right) \int_{t_1}^{t_2} (P_a^2 / P_o^2) dt \right] \quad (1)$$

Measuring temporal variability in vegetation

Studies investigating noise attenuation by green structures have unanimously agreed that denser vegetation covers are more successful in lowering noise levels (Margaritis and Kang 2017). More specifically, they documented that plant leaves are highly efficient in absorbing acoustic energy by converting the kinetic energy of the vibrating air to the vibration pattern of the leaves (Samara and Tsitsoni 2011). In practice, however, a diversity of methods have been employed to measure green foliage the terms of canopy volume (Underwood et al. 2016), leaf area index (Olsoy et al. 2016) and aboveground biomass (Inoue et al. 2015). Foremost among the available methods is probably the application of remote sensing techniques that have proven to capture accurate estimates of vegetation occurrence, condition, and pattern (Lillesand et al. 2015). The first generation of Earth observation satellites was initially shipped to investigate vegetation cover by capturing surface reflectance from the red and near-infrared electromagnetic spectrum. Data received from these channels, together, have proven the potential to reveal vegetation type, amount, density, structure, and vigor given the unique role of leaves' chlorophyll in absorbing red light while reflecting near-infrared waveband (Lillesand et al. 2015).

In this specific field, the most common approach to yield vegetation (green biomass) data from remote sensing is the use of vegetation indices, among which the normalized difference vegetation index (NDVI) has been widely recognized as a robust and powerful tool for investigation of vegetation. NDVI is calculated using Eq. 2 which subtracts the surface reflectance of red band (ρ_{red}) from the near-infrared (ρ_{NIR}) ones and divides the result by their sum. NDVI obtains values ranging from -1 to $+1$ where values close to $+1$ are associated with larger amounts of vegetation—biomass (reference). In this research, the new fine-to-medium Sentinel-2 images were used to provide NDVI maps for our analysis. From the USGS EarthExplorer website, two cloud-free image tiles acquired at the nearest time to noise measurement (1 October 2018 for summer and 8 November 2019 for winter) were freely downloaded, corrected atmospherically using sen2cor tool available at SNAP software (see Badia et al. (2017) for a detailed description of atmospheric correction by SNAP), and applied for computing NDVI maps. To have NDVI maps only over green spaces, they were overlaid with a fine land use/land cover map with a scale of 1:200 to extract NDVI values of the parks.

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \quad (2)$$

Statistical analysis

The Kolmogorov-Smirnov test ($p < 0.05$) was used to assess the normal distribution of data. The difference in each data set

(NDVI maps and noise measured along each transect) was analyzed using the Analysis of Variance (ANOVA) test. The possible association of noise levels measured along the river-adjacent transect (Ri- L_q) was then tested with those of the road-adjacent transect (Ro- L_q) and the mean NDVI value of their surroundings. To find a meaningful association between noise levels and NDVI, multiple rings with varying radii ranging from 10 m (which included only 4 pixels) to over 100 m were placed, among which the best results were achieved by considering the 100-m buffer ring (NDVI₁₀₀). In terms of the relationship between Ri- L_q and Ro- L_q , the most significant correlation was found between Ri- L_q and the mean of their nearest three Ro- L_q (Ro- ML_q). Using Ri- L_q as the independent variable and Ro- ML_q and NDVI₁₀₀ as dependent variables, two multiple regression models were constructed for winter and summer. Ultimately, in order to assess the significant impact of vegetation on noise levels (by considering the results of ANOVA analysis), the t test was used to investigate the statistical difference between the slope and intercept of the models built for peak foliage and leaf fall time.

Results

Descriptive statistics of noise measurements and NDVI are presented in Table 1. The mean noise level along the Ri transect (Ri- L_q) was lower than that of the Ro transect (Ro- L_q) both in winter (66.0 dB compared to 72.5 dB) and summer (67.8 dB compared to 72.9 dB). The maximum noise level of 76.3 dB was measured along the Ro transect, while the lowest level of about 63 dB was found along the Ri transect, both in winter and summer. The number of cars passing the road during the noise measurements had a normal distribution and were statistically similar ($F(1, 297) = 5.854, p = 0.016$). The NDVI-based vegetation biomass was higher in summer than winter. Mean NDVI in summer was about 0.33 with a

Table 1 Descriptive statistics of noise levels and NDVI values and results of normality test using Kolmogorov-Smirnov

Season	Type	Statistics				Normality (K-S test)	
		Min	Max	Mean	SD	Stat.	P
Winter	Ri- L_q	64.9	69.9	67.8	1.3	0.46	0.11*
	Ro- L_q	69.9	76.3	72.5	1.8	0.16	0.20*
	NDVI	0.15	0.47	0.26	0.1	0.95	0.20*
Summer	Ri- L_q	63.1	67.8	66.0	1.4	0.16	0.08*
	Ro- L_q	70.1	75.8	72.9	1.5	0.05	0.20*
	NDVI	0.18	0.67	0.33	0.1	0.09	0.20*

Ri- L_q and Ro- L_q indicate noise levels measured along the interior and exterior transects, respectively

*shows the normality of distribution

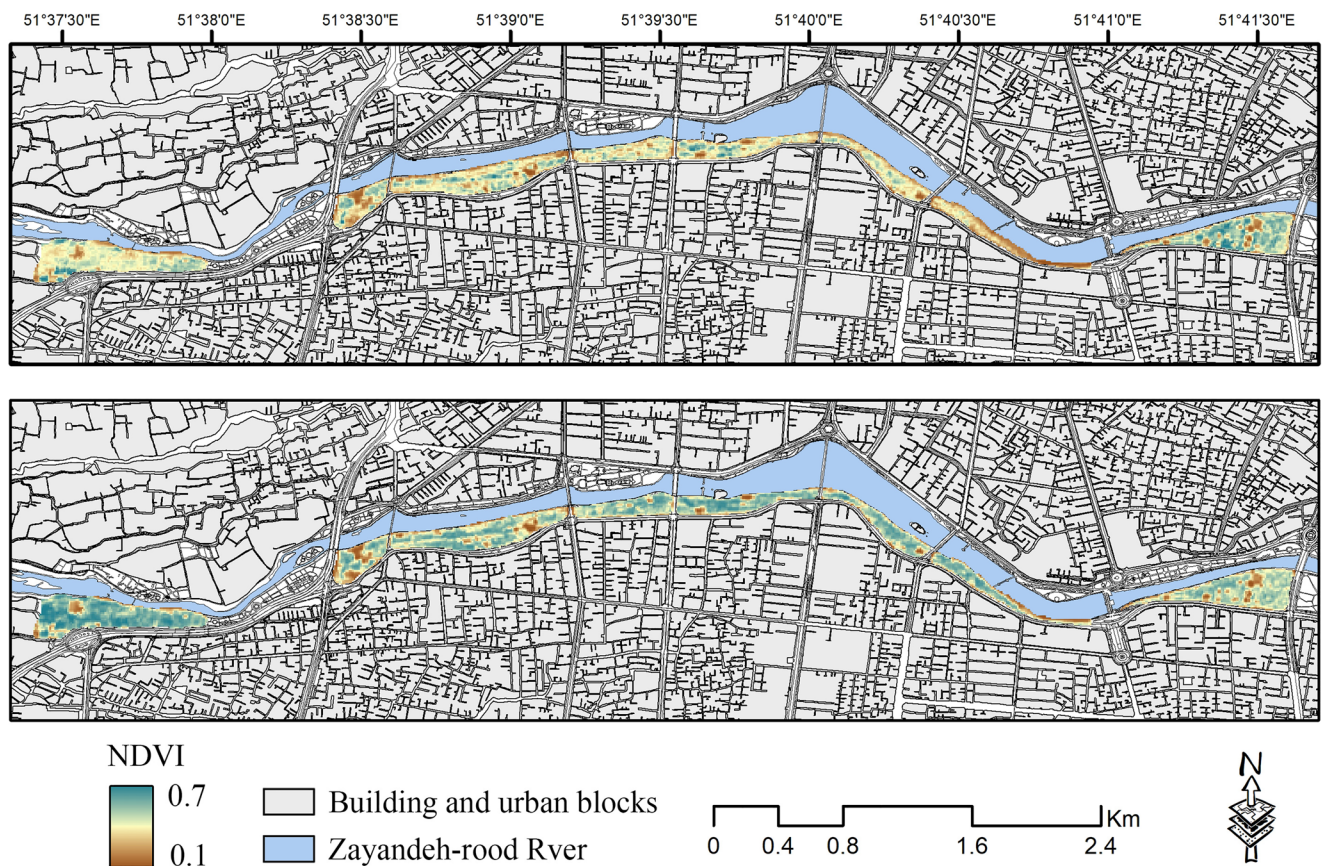


Fig. 2 NDVI maps of urban parks in winter (upper layout) and summer (lower layout)

maximum value of 0.67. In winter, however, mean NDVI was as low as 0.26 (maximum of 0.47). Using the Kolmogorov-Smirnov test ($p < 0.05$), our data sets were of normal distribution (Table 1). NDVI maps are illustrated in Fig. 2 (with a total number of 7746 pixels) in which the lighter color indicates areas with a relatively low vegetation cover while greener areas show regions with denser vegetation. As shown in this figure, there was a noticeable difference in the amount of vegetation cover (green biomass) between summer and winter, especially in the easternmost park where the majority of its area is covered by deciduous (mostly *Platanus*) trees. Using the one-way ANOVA test (Table 2), these maps were also found to be statistically different ($F(1, 15,489) = 459.4, p = 0.00$) which indicates the substantial loss of plant leaves during winter season.

Table 2 Results of ANOVA comparison between NDVI values of summer and winter

	Sum of squares	df	Mean square	F	P
Between groups	6.82	1	6.82	459.4	0.000
Within groups	230.20	15,489	0.015		
Total	237.03	15,490			

The mean comparison between winter and summer noise levels along each transect is shown in Table 3. Due to persistent heavy traffic load in Mellat Boulevard, the noise levels along the Ro transect were not statistically different ($F = 1.452, p = 0.10$) between the two seasons, while along the Ri transect, the difference in seasonal noise levels was highly significant ($F = 3.34, p = 0.00$), indicating the presence of physical barriers in attenuating road traffic noise during summer and their absence during winter.

Surprisingly, our analysis showed that $Ri-L_q$ is significantly correlated with two variables in both seasons: including the mean of its three nearest $Ro-L_q$ and the mean NDVI within a 100-m circular ring placed around each $Ri-L_q$. These findings are shown in the graphs of Fig. 3. Using these two variables, the stepwise multiple linear regression was used to produce two regression models with identical variables for summer and winters, thus enabling their comparison using t test. The best-fitted model for winter was found ($F = 17.2, p < 0.05$) with an r^2 of 0.40. The summer model was also yielded a significant r^2 of 0.46 ($F = 20.1, p < 0.05$). The results of t test showed the significant inclusion of both variables in the two models (Table 4). The models' residuals were not autocorrelated and the VIF factors measured for each variable were within the acceptable threshold of around 1. Having two fitted regression models, the significance

Table 3 Results of ANOVA comparison between noise levels measured in winter and summer for each transect

		Sum of squares	df	Mean square	F	P
Ro transect	Between groups	15.614	53	0.295	1.452	0.101
	Within groups	9.133	45	0.203		
	Total	24.747	98			
Ri transect	Between groups	19.214	50	0.384	3.334	0.000
	Within groups	5.533	48	0.115		
	Total	24.747	98			

of difference between the slope and intercept of the models using t test (see Table 4, the last row) was assessed, with results indicating the significant difference between the two regression models ($p = 0.04$).

Discussion

General comments

This study investigated seasonal changes in the acoustic behavior of deciduous tree-dominated urban parks between foliage evergreens and deciduousness. Noise sampling sites were distributed along two adjacent sides of the parks to determine whether there is a difference between noise levels arising from the source (by measuring noise levels along the road) and those received along the far side of the parks from the road. It was assumed that the difference in noise levels between the two sides of such narrow urban parks represents the efficacy of vegetation cover in lowering noise propagation. According to Cohen et al. (2014), noise attenuation depends on the volume of noise emanating from the source, distance, and the characteristics of vegetation cover. Specifically, our study was designed to test and model noise attenuation in relation to vegetation characteristics and partly due to at-source noise levels while keeping distance constant.

Our results showed a noticeable difference in noise levels measured along the riverside and roadside transects. Except for one site, noise levels measured along the road were above

70 dB in both seasons. Such a noise range is considered very high (according to the principles ratified by the Iran Cabinet) and is most observed in the immediate vicinity of main roads in Isfahan (Jafari et al. 2015; Mazaheri 2018) and also in other large cities (e.g., see noise maps produced by Margaritis and Kang (2017)). Along the riverside transect, however, noise levels decreased to below 67.8 dB in winter and 66.0 in summer. Results of ANOVA test showed that the noise levels measured along the river differ significantly between seasons while such a difference was insignificant along Ro transect. This finding suggests that noise attenuating factors, probably vegetation cover, were performed differently between seasons. This finding is in line with those of Tashakor et al. (2020) who found that vegetation cover is among the most important factors that alleviate the noise penetration into the interior parts of the parks. To further corroborate the effect of vegetation, two Sentinel-2-derived NDVI maps were also measured and compared, as a surrogate for vegetation green biomass that includes tree species like *Ulmus Ulmaceae*, *Salix alba*, *Fraxinus excelsior*, and *Morus alba*. As expected, NDVI maps also differed highly significantly between winter and summer, suggesting that green biomass is a significant factor in lowering noise levels, in a condition under which the effect of distance is counteracted and the noise level emitted from the source is statistically the same through the seasons. Contrary to studies adopting a spatial framework (e.g., see Sakieh et al. (2017)), we developed a temporal perspective to better highlight the capability of vegetation cover in noise pollution alleviation by taking advantage of the

Fig. 3 Graphs showing the association of $Ri-L_q$ with $Rp-ML_q$ and $NDVI_{100}$ in summer (left) and winter (right)

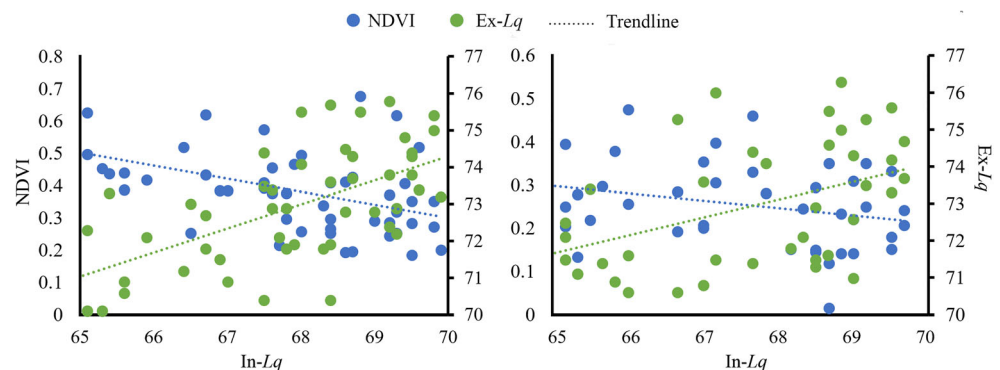


Table 4 Multiple linear regression models describing the association of noise levels along the Ri transect with the mean of the three nearest Ro-Lq and mean of NDVI within the surrounding 100-m ring

	Variable		b	Statistics						
	Dependent	Independent		S.E.	R ²	F	P	t	P	VIF
Winter model	In L _{q30}	Constant	36.78	6.46	0.40	17.2	0.00	6.46	0.00	1.09
		Ex ML _{q30}	0.415	0.087				0.087	0.00	
		NDVI _m	-3.51	1.543				1.54	0.04	
Summer model	In L _{q30}	Constant	33.78	7.76	0.46	20.1	0.00	4.34	0.000	1.01
		Ex ML _{q30}	0.487	0.104				4.66	0.000	
		NDVI _m	-3.14	1.27				-2.80	0.007	
Results of <i>t</i> test for model comparison								-2.07	0.04	

Ex- ML_{q30} is the mean of the three nearest Ex L_{q30} and NDVI_m is the mean MDVI within the 100-m buffer rings

prevalence of deciduous vegetation forms (mostly plane trees) which show a remarkable seasonal pattern of leaf growth and loss.

In addition to the utilization of variance analysis, two multiple linear regression models was also developed, one for each season, to represent the dependency of noise levels to the intensity of vegetation and at-source noise level and provide an novel procedure for the comparison of winter and summer conditions by performing a *t* test analysis on the intercept and slope of the models. By keeping in mind that at-source noise levels do not differ significantly between winter and summer, we assumed that the significant difference between the two regression lines is strongly indicative of remarkable temporal changes in the characteristics and, especially, performance of vegetation forms in alleviating noise levels. To the best of our knowledge, only one study by Price et al. (1988) assessed the efficacy of green biomass in noise attenuation over temporal timescales and at the park scale. Similar to our findings, they found that the performance of deciduous stands in noise reduction differed significantly between winter and spring, mainly due to leaf loss and significant differences in environmental (climatic) conditions. According to Arana et al. (2010), lack of a universal methodology and significant variability in urban local conditions has led to diverse perspectives and scale of analyses in this research field. Among such methodological diversity, our approach seems to be best suited in deciduous vegetation-dominated green spaces and urban parks to investigate how such greenery is useful in providing a calmer urban landscape through all seasons of the year.

Conclusion and implications for urban park designation

In the present study, a number of narrow and long, mostly deciduous tree-covered urban parks in Isfahan City, central Iran, were used to investigate the contribution and efficacy

of such a vegetation form in noise filtering and absorption through different seasons, thereby helping city planners to better cope with urban noise pollution. As Weber et al. (2014) and Sakieh et al. (2017) discuss, the first step towards developing a noise efficient urban landscape is to have urban parks and green spaces evenly distributed and more connected and compacted within the urban blocks. At local scales (park level), however, it is more related to the parks’ physical (vegetation) structures. Using a modeling perspective, Tashakor et al. (2020) also showed that green biomass has a meaningful contribution in the park noise attenuation in the studied parks. Several other studies at this level have unanimously shown that vegetation covers contribute significantly to noise attenuation (Attenborough 2002; Van Renterghem et al. 2012), but differently depending on the physicochemical and structural properties of their green biomass (i.e., leaf). Hence, identification of appropriate species for greening with the aim of noise pollution attenuation is a careful process and has been the subject of many studies in this field (Horoshenkov et al. 2013). Following a different objective, but in line with our conclusion, Pathak et al. (2011) found that species with a dense canopy of evergreen foliage is more applicable in coping with noise pollution. These findings emphasize on the complex relationship between noise attenuation and green cover that change over time. If it is decided to populate urban parks and green belts with deciduous trees, it would be then important to understand how they operate during winter season, not only in terms of noise attenuation but also in terms of esthetic properties such as beauty. In our case, specifically, our results showed that the performance of such a vegetation form in noise attenuation is averagely about 1.8 dB. It is then incumbent upon city planners to decide whether such a significant difference is of advantage to change the parks’ vegetation structure. In other words, selection of proper vegetation, aiming to reduce noise levels in the parks interior areas, as measured through summer season, would be the next step towards creating calm urban parks.

This decision would also be supported by investigating the increasing annoyance that such an increase in noise level produces and the perceived benefits that the park visitors receive.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Shahla Tashakor. The first draft of the manuscript was written by Atefeh Chamani and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This research was funded by Islamic Azad University, Isfahan (Khorasgan) Branch, Isfahan, Iran.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

References

- Apparicio P, Gelb J, Carrier M, Mathieu M-È, Kingham S (2018) Exposure to noise and air pollution by mode of transportation during rush hours in Montreal. *J Transp Geogr* 70:182–192
- Arana M, San Martín R, San Martín M, Aramendia E (2010) Strategic noise map of a major road carried out with two environmental prediction software packages. *Environ Monit Assess* 163:503–513
- Asgarian A, Amiri BJ, Sakieh Y (2015) Assessing the effect of green cover spatial patterns on urban land surface temperature using landscape metrics approach. *Urban Ecosyst* 18:209–222
- Attenborough K (2002) Sound propagation close to the ground. *Annu Rev Fluid Mech* 34:51–82
- Ayeghi A, Ujang N (2017) The impact of physical features on user attachment to Kuala Lumpur City Centre (KLCC) Park, Malaysia. *Geografia: Malaysian Journal of Society and Space* 10
- Badia N, Amó J, Martínez-Casasnovas JA (2017) Using Sentinel-2 images to implement precision agriculture techniques in large arable fields: First results of a case study. *Adv Anim Biosci* 8:377–382
- Brambilla G, Gallo V (2016) QUIETE: a scheme for a new index of the environmental quality of green areas. *Noise Mapping* 3
- Buchel S, Frantzeskaki N (2015) Citizens' voice: a case study about perceived ecosystem services by urban park users in Rotterdam, the Netherlands. *Ecosystem Services* 12:169–177
- Cohen P, Potchter O, Schnell I (2014) The impact of an urban park on air pollution and noise levels in the Mediterranean city of Tel-Aviv, Israel. *Environ Pollut* 195:73–83
- Demian G, Demian M, Grecu L (2009) Grecu V Studies about noise pollution in urban areas. In: *Proceedings of the 10th WSEAS international conference on Acoustics & music: theory & applications*, pp 87–91
- Han X, Huang X, Liang H, Ma S, Gong J (2018) Analysis of the relationships between environmental noise and urban morphology. *Environ Pollut* 233:755–763
- Horoshenkov KV, Khan A, Benkreira H (2013) Acoustic properties of low growing plants. *The Journal of the Acoustical Society of America* 133:2554–2565
- Inoue T, Nagai S, Kobayashi H, Koizumi H (2015) Utilization of ground-based digital photography for the evaluation of seasonal changes in the aboveground green biomass and foliage phenology in a grassland ecosystem. *Ecological Informatics* 25:1–9
- Iranian Bureau of Statistics (2015) *Statistical yearbook of Isfahan Province*
- Isfahan Ziba (2015) *The worrying statistics of Isfahan City*
- Jafari N, Abdollahnejad A, Ebrahimi A, Bina B, Mortezaie S (2015) Geographic information system based noise study in crowded areas of Isfahan city in 2010–2011 *International Journal of Environmental Health. Engineering* 4(24)
- Langemeyer J, Baró F, Roebeling P, Gómez-Baggethun E (2015) Contrasting values of cultural ecosystem services in urban areas: the case of park Montjuïc in Barcelona. *Ecosystem Services* 12: 178–186
- Lillesand T, Kiefer RW, Chipman J (2015) *Remote sensing and image interpretation*. John Wiley & Sons
- Lopez GAP, Souza LCLD (2018) Urban green spaces and the influence on vehicular traffic noise control. *Ambiente Construído* 18:161–175
- Loughran K (2018) Urban parks and urban problems: an historical perspective on green space development as a cultural fix. *Urban Stud*: 0042098018763555
- Lu C, Gao L, Pan Q, Li X, Zheng J (2019) A multi-objective cellular grey wolf optimizer for hybrid flowshop scheduling problem considering noise pollution. *Appl Soft Comput* 75:728–749
- Margaritis E, Kang J (2017) Relationship between green space-related morphology and noise pollution. *Ecol Indic* 72:921–933
- Margaritis E, Kang J, Filipan K, Botteldooren D (2018) The influence of vegetation and surrounding traffic noise parameters on the sound environment of urban parks. *Appl Geogr* 94:199–212
- Mazaheri R (2018) Noise pollution in Isfahan City, central Iran: finding the association between noise levels and surrounding urban landscape characteristics. *Gorgan University of Agriculture and Natural resources*
- Olsoy PJ, Mitchell JJ, Levia DF, Clark PE, Glenn NF (2016) Estimation of big sagebrush leaf area index with terrestrial laser scanning. *Ecol Indic* 61:815–821
- Pathak V, Tripathi B, Mishra V (2011) Evaluation of anticipated performance index of some tree species for green belt development to mitigate traffic generated noise. *Urban For Urban Green* 10:61–66
- Peng J, Zhao M, Guo X, Pan Y, Liu Y (2017) Spatial-temporal dynamics and associated driving forces of urban ecological land: a case study in Shenzhen City, China. *Habitat Int* 60:81–90
- Pheasant RJ, Horoshenkov KV, Watts GR (2010) Tranquillity rating prediction tool (TRAPT). *Acoustics Bulletin* 35:18–24
- Price MA, Attenborough K, Heap NW (1988) Sound attenuation through trees: Measurements and models. *The Journal of the Acoustical Society of America* 84:1836–1844
- Purser J, Radford AN (2011) Acoustic noise induces attention shifts and reduces foraging performance in three-spined sticklebacks (*Gasterosteus aculeatus*). *PLoS One* 6:e17478
- Ragetti MS, Goudreau S, Plante C, Fournier M, Hatzopoulou M, Perron S, Smargiassi A (2016) Statistical modeling of the spatial variability of environmental noise levels in Montreal, Canada, using noise measurements and land use characteristics. *Journal of exposure science and environmental epidemiology* 26:597
- Rojas-Rueda D, Nieuwenhuijsen M, Khreis H (2017) Autonomous Vehicles and Public Health: Literature Review. *J Transp Health* 5: S13
- Sakieh Y, Jaafari S, Ahmadi M, Danekar A (2017) Green and calm: Modeling the relationships between noise pollution propagation and spatial patterns of urban structures and green covers. *Urban For Urban Green* 24:195–211
- Samara T, Tsitsoni T (2011) The effects of vegetation on reducing traffic noise from a city ring road. *Noise Control Eng J* 59:68–74
- Tashakor S, Chamani A, Ahmadi M, Moshtaghi M (2020) Acoustics in urban parks: does the structure of narrow urban parks matter in designing a calmer urban landscape? *Front Earth Sci* 163:503–513
- Underwood JP, Hung C, Whelan B, Sukkarieh S (2016) Mapping almond orchard canopy volume, flowers, fruit and yield using LiDAR and vision sensors. *Comput Electron Agric* 130:83–96

- Van Renterghem T, Botteldooren D, Verheyen K (2012) Road traffic noise shielding by vegetation belts of limited depth. *J Sound Vib* 331:2404–2425
- Vieira J et al (2018) Green spaces are not all the same for the provision of air purification and climate regulation services: the case of urban parks. *Environ Res* 160:306–313
- Ware HE, McClure CJ, Carlisle JD, Barber JR (2015) A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. *Proc Natl Acad Sci* 112:12105–12109
- Weber N, Haase D, Franck U (2014) Assessing modelled outdoor traffic-induced noise and air pollution around urban structures using the concept of landscape metrics. *Landsc Urban Plan* 125:105–116
- WHO (1972) Health hazards of the human environment

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.