Front. Earth Sci. 2020, 14(3): 512–521
https://doi.org/10.1007/s11707-020-0816-2

RESEARCH ARTICLE

Acoustics in urban parks: Does the structure of narrow urban parks matter in designing a calmer urban landscape?

Shahla TASHAKKOR, Atefeh CHAMANI (✉), Mozhgan Ahmadi NADOUSHAN, Minoo MOSHTAGHIE

Environmental Sciences Department, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan 81595-158, Iran

Abstract Urban parks can function as a proper sink of noise pollution. However, lack of universally-agreed upon methodologies and differing urban conditions have fueled controversy surrounding the effectuation of this urban park function around the world. Hence, to address this controversy in narrow urban parks (with a mean width of ~109 m) in Isfahan City, Central Iran, noise levels (L_{q30}) were measured along two longitudinal transects placed along the interior northern river-and adjacent to the southern edge of the parks bordered by a heavily-conjected road. We used statistical tests and models to determine the association of noise levels measured along the northern transect with the distance to, and the intensity of noise emitted from, the road, vegetation biomass, and vegetation height within two 50 and 100 m buffer rings drawn around northern sites and the richness of bird species. The average L_{q30} values differed significantly between the southern (~73.21 dB) and northern (~66.43 dB) transects and correlated negatively with species richness ($r(98) = -0.324$, $p < 0.01$). Three variables including mean NDVIwithin the 100 m buffer ring, distance from the road and mean L_{q30} values of the nearest three southern sites were included to build the best predictive multiple-linear regression model through the step-wise procedure with r^2 of 0.52. These findings suggest that further attempts aiming to alleviate the parks' interior noise level should be attentive to distance to road, traffic at the nearest road part, and the interior vegetation characteristics.

Keywords noise pollution, multiple-linear regression, NDVI, vegetation height, Isfahan

1 Introduction

Preserving natural environments has long been recognized as indispensable and strategic for ensuring sustainable development (Larson et al., 2016). Natural environments upon which human life depends not only consist of bio-diverse, vast, and relatively pristine ecosystems but also involve the type of nature near where humans live like urban green spaces, or more specifically, urban parks (Chiesura, 2004; Low et al., 2009). Urban parks are defined as green and wilderness spaces within the urban canopy which are mainly covered by vegetation (and water) and are reserved for public use and recreation (Konijnendijk et al., 2013). The idea of introducing urban parks and green spaces into urban areas, as defined above, dates back to the 19th century in the US and Europe (Loughran, 2018). At first, they were aimed at compensating for population crowding and nature loss, thereafter mediating social and cultural problems (Schuyler, 1986; Greenberg and Lewis, 2000). Currently, inspired by raising awareness of the benefits of urban parks, they are considered as a major sink for many urban problems such as urban heat islands (Asgarian et al., 2015) and air and noise pollution (Bloemsma et al., 2019).

Ecosystem services and goods of urban parks are manifold, such as air and noise pollution abatement, heat island alleviation, wildlife habitat provisioning as well as cultural, social, and mental well-being to name just a few (Millennium Ecosystem Assessment, 2005; Mexia et al., 2018). The role of urban parks in noise pollution attenuation has been frequently acknowledged in the literature (Van Renterghem et al., 2012; Sakieh et al., 2017; Margaritis, 2018), due to the continuous technological advances of industrialization (Szeremeta and Zannin, 2009) and our better understanding of the effects of noise pollution (Polak et al., 2013). Despite the proliferation of studies on the relationship between urban soundscape and urban parks, no general method has yet been proposed to address this issue (Arana et al., 2010, Gozalo et al., 2016). Moreover, significant variations in urban characteristics among different urban centers, such as the type of vegetation, climate, and urban morphology have resulted

Received September 10, 2019; accepted February 14, 2020

E-mail: a.chamani@khuisf.ac.ir

in studies with differing perspectives and scales of analyses (Horoshenkov et al., 2013). Broadly, however, these studies can be categorized into two main groups of research. One group of studies mainly looks into urban parks as homogenous surfaces, considering that the way in which urban parks are distributed and geometrically configured within the urban environment contributes significantly to noise pollution attenuation. These studies, for example Weber et al. (2014) and Sakieh et al. (2017), attempt regression and correlation analyses to capture a meaningful association between noise levels and the spatial pattern of green covers measured via landscape metrics or using factors related to road and building characteristics.

Regardless of the spatial pattern of urban parks as a homogenous surface, studies of the other group, although very limited in number (Margaritis et al., 2018), investigate the contribution of urban park's in situ green structures in filtering noise propagation which range from plants' leaves and branches (Attenborough, 2002) to different vegetation communities (van Renterghem et al., 2012). For instance, (van Renterghem et al., 2014) assessed the efficacy of hedgerows in lowering traffic noise levels. They found that denser hedgerows are more effective in absorbing or scattering noise pollution emitted from light vehicles. Margaritis et al. (2018) attempted to predict noise levels in urban parks based on a set of predictive vegetation-related (e.g., park size and tree coverage) and morphological variables (e.g., distance to road and traffic volume). They found the lowest noise levels around dense vegetation covers in the center of urban parks that are dominated by trees. In a study by González-Oreja et al. (2010), the size of urban parks, tree density, and tree canopy were identified as the foremost independent noise-reducing variables while park location and tree species composition were not associated with noise levels. Jang et al. (2015) investigated the relationship of noise levels with trees, shrubs, vegetated facades, and green roofs installed in street canyons and courtyards, concluding that the maximum noise reduction occurs where an integrated vegetation treatment is installed. In a multi-side study, Lam et al. (2005) found that noise levels in urban parks become as noisy as built-up areas when located in close proximity to roads. In terms of the relationship with urban birds, González-Oreja et al. (2012) found that species richness in urban parks decreased according to background noise levels, when comparing the edges and interiors of urban parks. Fernandez-Juricic (2001) revealed that the number of species, density of guilds, and density of individual species decreasing toward the interior are more a function of traffic noise than the habitat physical characteristics. Patón et al. (2012) related changes in bird richness in urban parks across a rural-urban core spectrum to background noise, suggesting a threshold of 50 dB to bring back some rare bird species in urban parks.

All these studies suggest that leveraging the maximum potential of urban parks in confronting noise pollution rests on developing an effective network of green spaces both in terms of spatial patterns (configuration and composition) and structure of vegetation while not limiting the proper arrangement of urban blocks (Van Renterghem et al., 2012; Margaritis and Kang, 2017). To add to the current body of literature on traffic noise shielding by urban parks, we adopted a typical case study in the crowded city of Isfahan, central Iran with an innovative sampling design and predictive variables to investigate the performance of five river-adjacent urban parks in providing their visitors with calm and green environments. Specifically, this study attempted the following hypotheses (H1): there is a significant difference between noise levels in two parallel sides of a set of narrow urban parks: i.e. the park edge along a heavily trafficked road and the interior side along the Zayandeh-Rood River that seemed to be calmer due to its remoteness from noise sources (especially the above-mentioned bordering road as the nearest source); Vegetation cover and height play a noticeable noise attenuation role in narrow urban parks; Bird richness varies significantly with changes in noise levels over small distances in urban parks.

2 Material and methods

2.1 Study area

Isfahan City, with an area of 340 km^2, is the third most populous city of Iran, behind the capital Tehran and Mashhad. After the Islamic revolution in Iran in 1979, the population of this city started to grow dramatically and has increased from 1.4 million in that year to over 2.2 million people in 2018 (Iranian Bureau of Statistics, 2015). The residents of Isfahan City, similar to other Iranians, primarily use personal vehicles for transportation in the city. In 2014, more than 1.88 million personal vehicles including cars and motorbikes were registered in the city, equating to over 0.8 vehicles per person. Besides, Isfahan was planned to be a Museum City due to being endowed with a treasure of tourist attractions (mostly bridges) built during Safavieh dynasty in the early 17th century. In pursuit of this goal, many core parts of the city (including our study region) retained their historical form which is characterized by very narrow streets and pavements. According to this and along with the increasing number of personal vehicles, Isfahan is now one of the most road-congested cities of Iran with around 0.11 vehicles per m^2 asphalted road (Isfahan Ziba, 2015). Despite its arid climate, Isfahan has been successful in designing an effective network of urban parks and green spaces (Mazaheri, 2018). Currently, about 10% of the city's area is devoted to 59 distinct urban parks and public green spaces.

This study was carried out in a network of five narrow urban parks connected to each other (in the west-to-east direction) along the south of Zayandeh-Rood River in one of the most crowded and heavily road-congested parts of Isfahan (Fig. 1). Collectively, the case study parks have an area of 55.84 ha. As shown in Fig. 1, these parks are bordered to the north by the Zayandeh-Rood River which is surrounded by green urban parks to the north while a wide mostly congested two-way road (Mellat Boulevard) borders the south of these parks. By considering the Mellat Boulevard as the nearest source of noise pollution affecting these parks, noise levels are expected to be higher in the south while lower in the north.

2.2 Methods

2.2.1 Field sampling

We established two linear transects, each with a total length of ~4.5 km, along the length of the study parks (Fig. 2); one in the immediate vicinity of Mellat Boulevard in the south and the other one almost in parallel to the northern margin of the parks close to the river. Fifty noise measurement sites, with an average 50 m spacing between sites, were first selected along the southern transect based on the distribution and type of vegetation cover. Another 50 sampling sites were also placed along the northern transect, almost perpendicular to the southern sampling sites. This procedure allowed us to measure how green structures contribute to lowering noise propagation from its major source, i.e. Mellat Boulevard, into the parks. A sound level meter device (Kasella model-490/450-CEL) was situated about 1.5 m above the ground and at least 2 m from shrubs and trees as possible noise-reflective surfaces to measure noise (in unit of dB) once at each site for a continuous duration of 30 min. The number of common bird species (i.e., species richness) flying or walking near each measurement site (within a radius of 20 m) was also counted for 30 min while recording noise levels at each site by an ecologist to identify whether the recorded noise levels are associated with birds populations. Noise measurements were conducted in spring 2019 between 7 to 8 am when urban birds are more readily identifiable and the road traffic is relatively heavy as people leave for work. The weather conditions, especially the wind speed (<8 m/h), temperature (<25°C) and relative humidity ($<10\%$), were controlled before the onset of noise measurement to provide less biased results. Having noise levels measured for each site, the 30 m Equivalent Sound Level (L_{q30} – in dB) was measured to provide a single noise value representative of the noise gathered during the measurement period. In other words, L_q refers to a continuous and steady level of noise over a certain length of time which is equivalent to that measured during the same period. L_{q30} is computed using Eq. (1) in which t_1 and t_2 indicate the start and end time of a recorded trace, P_o and P_a are the reference (20 μPa) and A-weighted pressure level, respectively (Sakieh et al., 2017).

$$L_q = 10\log\left[\left(\frac{1}{t_2 - t_1}\right)\int_{t_1}^{t_2}(P_a^2/P_o^2)\mathrm{d}t\right]. \tag{1}$$

2.2.2 Measuring noise-reducing variables

Based on the opinions of experts, availability of data and previous works carried out in this field (van Renterghem et al., 2012; Jang et al., 2015; Margaritis et al., 2018), we selected and measured a large array of variables that seem to effectively attenuate noise propagation in urban parks. Some factors such as the density of vegetation surrounding the noise emitting source (i.e., southern sites) were found as important noise attenuation variables in previous research (e.g., van Renterghem et al. (2014)) but were

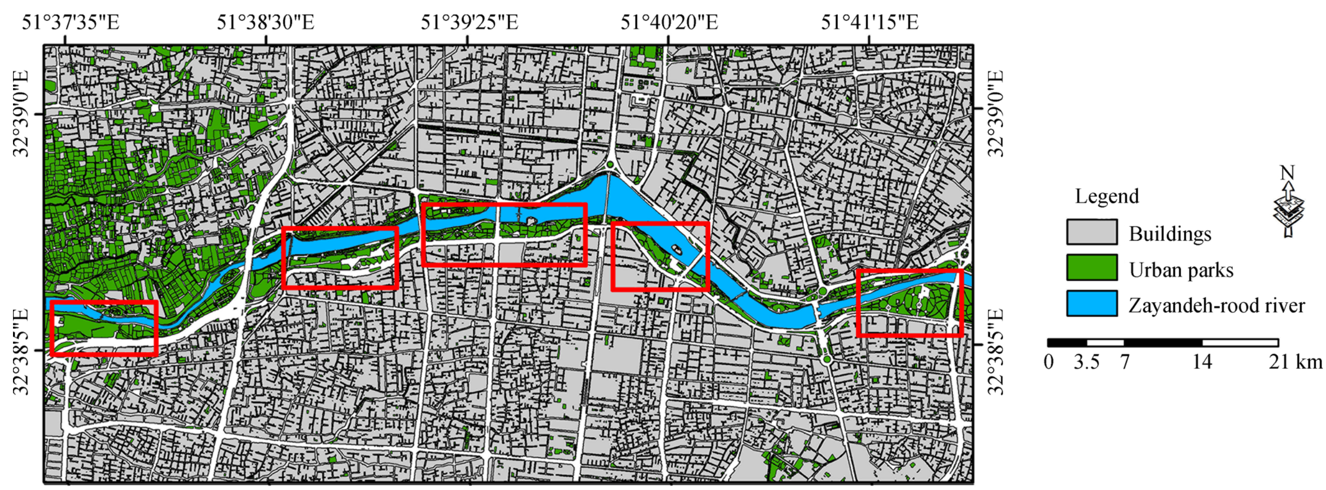

Fig. 1 Geographical location of Isfahan Province and case study parks.

discarded from this research due to their insignificant relationship with noise levels in the parks' interior. The variables that showed a significant relationship (see Table 1 in the results section) consisted of: the Euclidean distance from each northern site to the road, the average height of vegetation and above-ground vegetation biomass within 50 and 100 m radius rings drawn around each northern site, the level of noise at the nearest southern site, and the average level of noise at the three nearest southern sites. The height of vegetation was measured from a 2 m LIDAR DSM (Digital Surface Model) map obtained from the municipality of Isfahan. This map shows the height of objects from sea surface not from the ground. To address this issue, we first recorded 10 evenly distributed benchmarks in each park as bare land spots, totaling 50 points. The points were interpolated using Inverse Distance Weighting (IDW) Interpolation to delineate the altitude of the ground from the sea surface, known as the land-bare map. Finally, by subtracting the interpolated surface map from the DSM map, the height of vegetation was delineated. To evaluate the validity of this method, we compared the actual height of 50 trees, 10 trees in each park, ranging from 3 to 5 m with the estimated values. A 10 m normalized difference vegetation index (NDVI) map was delineated from Sentinel-2 satellite images as a proxy for vegetation biomass. Most studies in this field (Mazaheri, 2018) and in many other areas of urban research (Tian et al., 2019; Wong et al., 2019) have relied on remote sensing NDVI maps to identify different aspects of urban green areas. NDVI, as the most common vegetation index (Lillesand et al., 2015), is calculated by measuring the normalized difference between the spectral reflectance red and near-infrared spectrum with values ranging from -1 to $+1$ in which values increasing from 0 to $+1$ reflect denser vegetation covers and higher biomasses (Gandhi et al., 2015). To provide the best representative NDVI map for this research, the whole Sentinel-2 images taken during spring from April 1 to July 1, 2019, were called within the open-source platform of Google Earth Engine platform and applied for a median

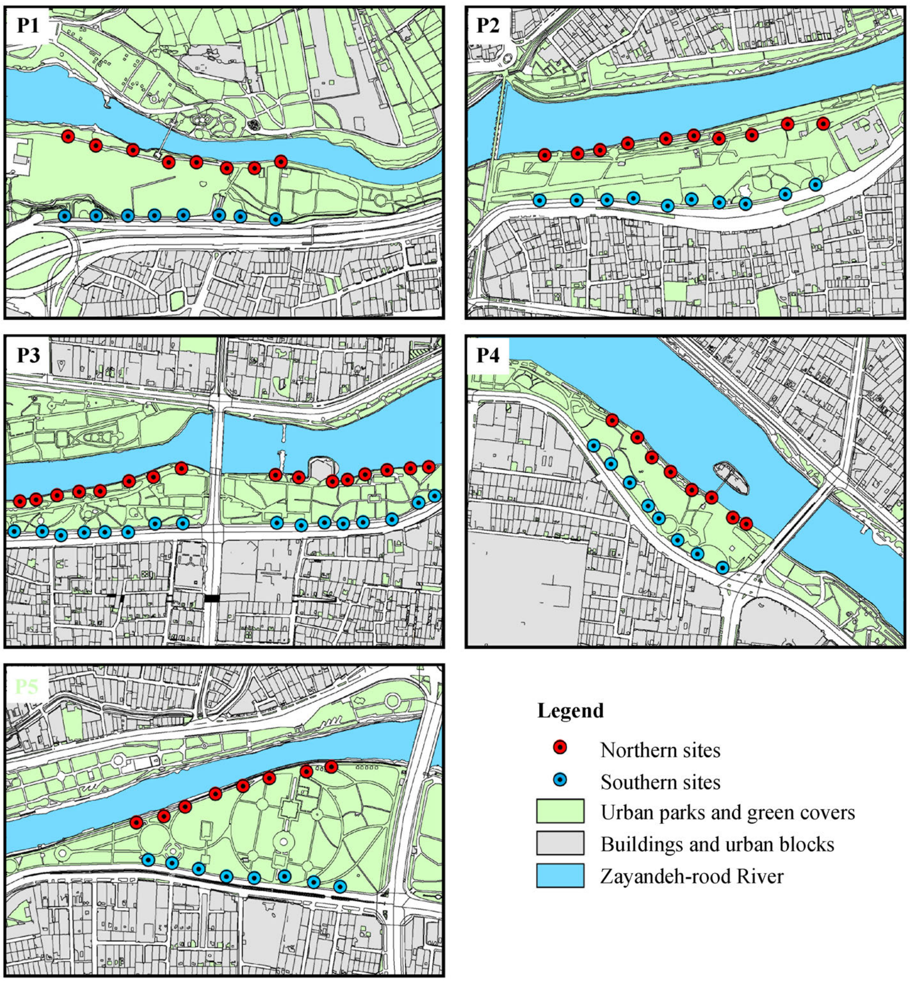

Fig. 2 Distribution of noise measurement sites.

Table 1 Descriptive statistics of dependent and independent variables and results of normality test

Variables	Descriptive statistics					Correlation with Ni-L_{eq30}	Normality (2-tailed)	
	No.	Min	Max	Mean	Std.		Test	Sig.
N-L_{eq30}	50	62.4	69.7	66.43	1.73		0.098	0.19 [1]
S-L_{eq30}	50	70.19	77.09	73.21	1.60	0.39 [1]	0.070	0.20 [1]
3S-L_{eq30}	50	71.59	76.20	73.37	1.18	0.45 [1]	0.102	0.20 [1]
Distance	50	65.96	169.09	109.24	22.83	−0.42 [1]	0.123	0.55 [1]
H-50	50	0.10	7.09	3.43	0.74	−0.25 [1]	0.123	0.56 [1]
H-100	50	0.40	7.29	3.52	0.71	−0.43 [1]	0.106	0.20 [1]
NDVI-50	50	0.13	0.42	0.26	0.06	−0.31 [1]	0.104	0.19 [1]
NDVI-100	50	0.14	0.39	0.29	0.51	−0.54 [1]	0.103	0.20 [1]

Note: 1 indicates significant at 0.05; N: northern sites; S: the nearest southern site to site N; 3S: the three nearest southern sites to site N; *H*: vegetation height; *r*: ring followed by its radius in m.

filter to derive a single cloud-free NDVI map. Detailed information about the characteristics of Sentinel 2 and the Google Earth Engine can be found in Gorelick et al. (2017) and Carrasco et al. (2019). The distance between northern sites and the noise source (i.e., Mellat Boulevard) as well as the buffer rings were measured using spatial analyst in Quantum GIS. Other factors such as the area of surrounding vegetation cover (the number of green pixels and the biomass and height of vegetation in larger buffer rings were not statistically related to noise levels nor followed the normal distribution (even after performing a series of data transformations) for inclusion into statistical analyses described in the following.

2.2.3 Statistical analyses

To identify how the soundscape of urban parks works, we modeled the relationship of noise levels with a number of noise-reducing variables. We also investigated the response of birds' populations to different noise levels. The normality of data was first tested using the Kolmogorov–Smirnov test ($p < 0.01$) (Evans et al., 2017) to decide between parametric and nonparametric methods. We performed a mean comparison analysis to assess whether there is a significant difference in noise levels and also in bird populations between the northern and southern transects. Moreover, the Pearson's correlation test (Hall, 2015) was employed to investigate the association between noise and bird populations across all 60 sites. Ultimately, we used the stepwise multiple linear regression (MLR) model (Khademi and Behfarnia, 2016) to determine to which and what degree the selected noise-reducing variable(s) explain variability in noise mitigation in urban parks. The best performing MLR model was selected according to level of significance (p-value) and determination coefficient (r^2). We ultimately checked the model's coefficients to be statistically significant and the model's residuals to follow a normal distribution.

3 Results

All data analyzed in this research followed the normal distribution according to the Kolmogorov–Smirnov test at a significance level of 5% (Table 2). The average L_{eq30} value along the southern transect (~73.21 dB) was significantly higher than that of along the northern transect (66.43 dB) (Table 1). The largest noise value was recorded along the southern transect near the most crowded part of Mellat Boulevard. The results of one-way ANOVA showed a significant difference in noise levels between northern and southern sites (F (1, 98) = 303.02, p = 0.00). In total, 44 different bird species (Table 1) were identified during noise measurement with house sparrow and carrion crow as the most prevalent species which were observed in almost all sites. The minimum and maximum number of unique species observed across the sites were 4 and 7, with an average of 5.47 species per site. As shown in Table 2, rare species in Isfahan city such as *Sylvia nisoria*, *C. coccothraustes*, *Motacilla flava*, *and Remiz pendulinus* (Hemami et al., 2009) were more observed at northern sites. In terms of more common species, the presence and frequency birds were relatively higher along the northern sites than the southern transect. The correlation analysis between noise levels and species richness was significantly negative ($r(98) = -0.324$, $p < 0.01$).

The maximum and minimum distance between the two transects were 170 and 70 m, respectively, with a mean of 109 m, based on which we considered two buffer rings with radiuses of 50 and 100 m to evaluate the effect of vegetation height and biomass on noise mitigation. The validity of vegetation height measurement was found to be below 1 m (the resulting map of vegetation height is shown in Fig. 3). As was observed during the field survey and according to our findings, vegetation height and biomass varied significantly across the parks (see Fig. 3). The minimum amount of NDVI (0.13) and vegetation height (0.1 m) were observed in areas mostly covered with lawn

Table 2 Name of species observed, number of sites in which the species was observed (richness column) and the total number of individuals (observation column)

Species name	Southern transect		Northern transect		Species name	Southern transect		Northern transect	
	# of sites the species was seen	Total # of individuals	# of sites the species was seen	Total # of individuals		# of sites the species was seen	Total # of individuals	# of sites the species was seen	Total # of individuals
Corvus corone	44	235	44	218	*Sylvia communis*	0	0	1	1
Corvus frugilegus	19	52	14	31	*Sylvia atricapilla*	0	0	1	1
Passer domesticus	46	475	50	558	*Sylvia nisoria*	0	0	1	1
Motacilla alba	13	20	17	20	*C. coccothraustes*	0	0	1	1
Pica pica	24	73	27	63	*Caruelis chloris*	0	0	1	1
Spilopelia senegalensis	24	48	17	30	*Luscinia megarhynchos*	0	0	2	3
Hyppolais languida	0	0	2	2	*Pycnonotus leucotis*	0	0	2	2
Phlloscopus collybita	10	15	5	8	*Phoenicurus phoenicurus*	0	0	2	2
A. arundinaceus	1	1	0	0	*Turdus philomelos*	0	0	1	1
Acridotheres tristis	2	4	3	4	*Turdus ruficollis*	0	0	1	2
Sturnus rulgaris	18	39	27	58	*Streptopelia dacaocto*	1	2	1	2
Fringilla coelbs	0	0	3	8	*Motacilla flava*	0	0	1	1
Dendrocopos syricus	5	6	8	8	*Accipiter nisus*	1	1	0	0
Parus major	3	4	3	6	*Lanius collurio*	0	0	1	1
Columba livia	7	17	3	5	*Upupa epops*	1	1	5	8
Motacilla cinerea	0	0	1	1	*Oriolus oriolus*	1	1	3	3
columba palumbus	4	5	11	22	*Psittacula krameri*	0	0	2	4
lanius isabellinus	0	0	1	1	*Falco tinnunculus*	0	0	1	1
Passer montanus	0	0	1	2	*Remiz pendulinus*	0	0	1	0
Muscicapa striata	0	0	1	1	*Erithacus rubecula*	0	0	1	1
Apus apus	23	86	36	167	*Troglodytes troglodytes*	0	0	1	1
Hippolais pallida	7	13	6	11	*Merops apiaster*	0	0	1	1

while areas adorned with trees, especially plane trees (Platanus) had denser and taller vegetation cover. In total, the mean NDVI and height of vegetation cover were found to be 0.27 and 3.46 m, respectively.

The results of the best fitted MLR model with r^2 of 0.52 is presented in Table 3. The multi-collinearity between independent variables measured by calculating Variance Inflation Factor (VIF) was near the acceptable threshold of 1.0 in all cases. Using t-test, the independent variable coefficients were all significant at $p < 0.05$. The validity of the model was assessed by testing the model residuals for their normality of distribution using the Shapiro-Wilk test. According to the Shapiro-Wilk test (presented in the two rightmost columns of Table 3), the model residuals were not auto-correlated. NDVI values with the 100 m buffer ring, distance from the road, and mean L_{q30} values of the nearest three southern sites were included in the model while the height of vegetation within both 50 and 100 m buffer rings were omitted from the model.

4 Discussion

Designing a well-distributed network of urban parks with ideal geometric and structural formations is a daunting task as they are expected to address many urban problems. This task is more complicated in arid desert regions like Isfahan where severe scarcity of water resources impedes proper expansion of dense urban parks. Moreover, many urban planning reports and studies have pointed out that Isfahan should adopt a very centralized growth pattern to avoid urban sprawl and further conversion of surrounding arable agricultural lands into impervious surfaces (Asgarian et al., 2018; Moein et al., 2018). Hence, Isfahan urban planners have always wrestled with the question of how to create an effective network of urban parks. In dealing with this question, Asgarian et al. (2015) found that arranging large urban parks with minimum distance from each other, minimum perimeter-to-area ratio, and maximum core area contribute more significantly to urban heat island

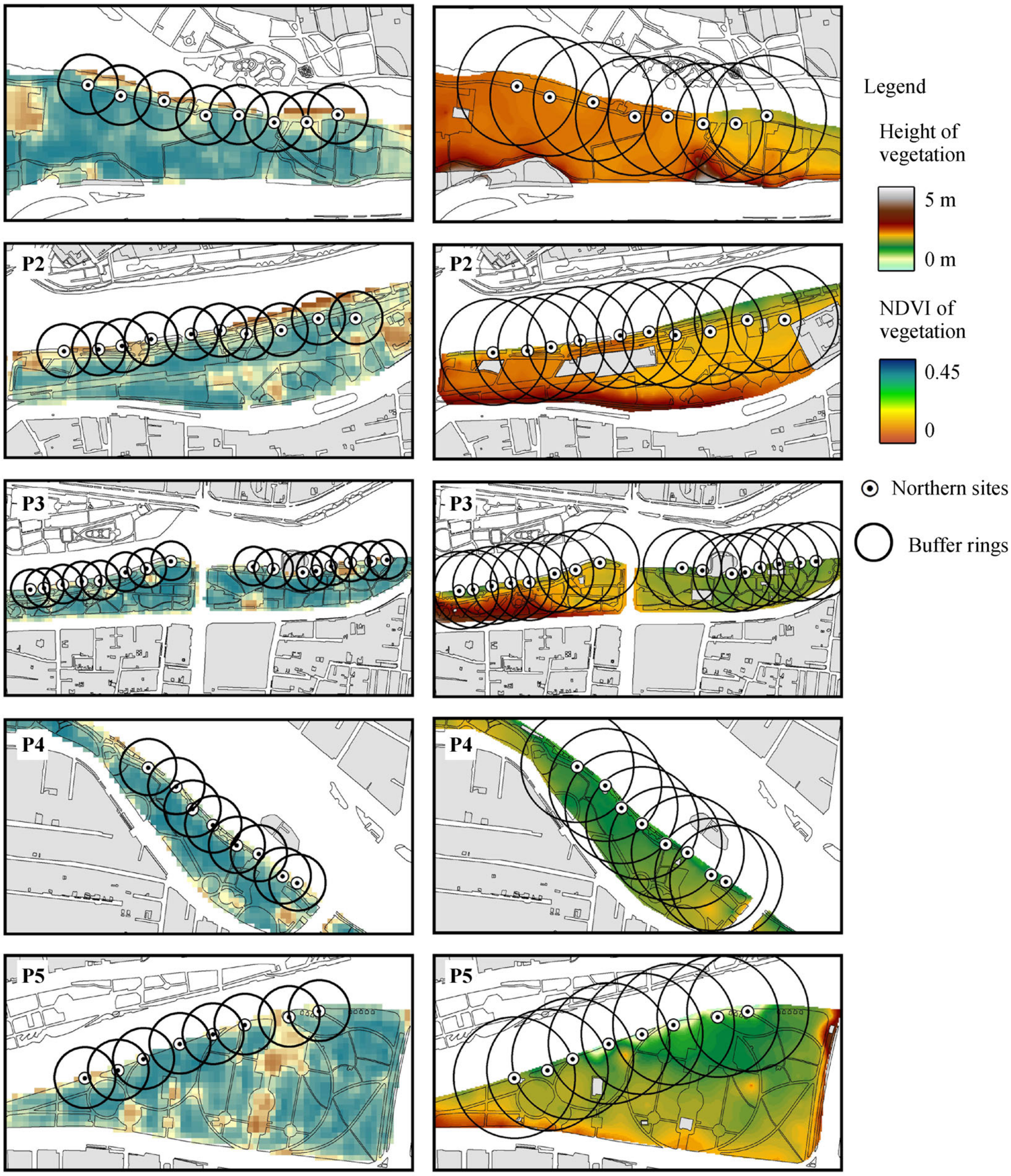

Fig. 3 Distribution of vegetation height (left) and NDVI (right) as well as 50 and 100-m buffer rings placed around northern sites; note that 50-m buffer rings were only shown in the NDVI layouts and 100-m buffer rings were shown in the vegetation height layouts for better representation of objects.

Table 3 Parameters of the best performing stepwise MLR model (For abbreviations see the legend of Table 1)

Variable		Coeff.	Statistics							Shapiro-Wilk	
Dependent	Independent		S.E.	R^2	F	Sig.	t	Sig.	VIF	Stat.	Sig.
N-L_{eq30}	Constant	67.80	16.5	0.52	16.3	0.00	4.73	0.00		0.40	0.09
	NDVI-100	−182.7	44.3				−4.10	0.00	1.09		
	3S-L_{eq30}	0.60	0.16				3.67	0.01	1.02		
	Distance	−0.18	0.08				−2.31	0.02	1.01		

Excluded variables: S-L_{eq30}; *H*-50; *H*-100; NDVI-50 mitigation over adjacent buildings. By focusing on noise pollution, Mazaheri (2018) concluded that increasing geometric complexity and interspersion of urban parks, i.e. constructing a more compact and connected pattern of parks, along with increasing density and decreasing clumpiness of residential blocks would effectively reduce noise pollution in Isfahan. Unfortunately, all these studies have considered urban parks as homogenous surfaces and outlined planning recommendations and implementation strategies related exclusively to the configuration and distribution of urban parks while our knowledge of how physical structure of urban parks (in particular vegetation characteristics) can effectively reduce noise pollution is still premature.

The specific morphological characteristics of Isfahan as a Museum City and the intense interest of its residents in using personal vehicles (see Section 2.1) have exacerbated noise pollution in Isfahan. In this study, noise levels measured along the Mellat Boulevard were all above 70 dB. Similar to our findings, Jafari et al. (2015) and Mazaheri (2018) found that the maximum noise level in the central historical part of Isfahan exceeds even 80 dB during the busiest time of day. This is while, according to the environmental principles ratified by the Cabinet on Iran in 1999, ambient noise levels in Iranian urban environments should be regularly monitored and kept under 60 dB to ensure the health of urban residents. In urban parks, specifically, there is no universally agreed noise level to compare the results with Eq.(1). Considering the WHO recommendation of a 55 dB noise level for outdoor playgrounds (Lam et al., 2005), however, the study parks can be classified as noisy environments due to its narrowness and close proximity to a heavily trafficked road. In line with our results, Lam et al. (2005) and Zannin et al. (2006) also found that noisy urban parks are those that are small in area and located very close to roads. They therefore suggested that urban parks should be situated as far away as roads of intense traffic of vehicles to have calmer parks.

As a part of the present study, the association between noise levels and birds' population (species richness) was found to be significant and negative. A similar association was also yielded by González-Oreja et al. (2012), demonstrating that bird richness increases according to background noise levels. In Isfahan city, Rashidi et al. (2019) found that the abundance and diversity of bird species decreased with increasing noise levels and decreasing vegetation cover and density under similar environmental (wind and temperature) attributes. By comparing a wide spectrum of urban parks with differing noise levels ranging between 40 and 70 dB, Patón et al. (2012) found a noise threshold of 50 dB for urban parks below which most bird species can be attracted to urban parks. Likewise, most species were observed once at the study sites, particularly at the northern sites, accounting for over 65% of sighted species which could be therefore increased in number in Isfahan urban parks by providing their essential habitat requirements such as nesting sites (González-Oreja et al., 2012) and quiet environments (Zannin et al., 2006). In terms of habitat requirements, Fernandez-Juricic (2001) found that human disturbance, especially car and pedestrian traffic noises, are more important than other habitat characteristics that cause the edge of urban parks poorer in terms of the number of both foraging and nesting birds than the interiors. Drawing from these studies and keeping in mind the importance of other habitat characteristics such as provisioning of nesting sites, it seems that road traffic noise stands out as one of the most important factors limiting the presence of a large suite of birds in the urban parks.

Due to the attenuation behavior of sound over distance, noise levels are expected to decrease toward the interior of urban parks which are sufficiently away from noise emitting sources (González-Oreja et al., 2010; Margaritis et al., 2018). In the present study, however, our case study parks were very narrow in width (~110 m in average) and faced with high levels of noise emanating from a heavy, noisy traffic. Under such a condition, noise levels may be as strong across the entire parks and any success in filtering noise levels rests on proper selection and arrangement of vegetation covers. Keeping in mind the effect of distance and the level of noise emitted by the traffic, we attempted to find the dependency of noise measured in the core of narrow urban parks to two main physical characteristics of vegetation: above-ground biomass and height. In agreement with other similar studies in this field (Sakieh et al., 2017; Margaritis et al., 2018), our results showed that, irrespective of the type of plants, the biomass of vegetation (NDVI) surrounding the noise measurement sites is one of the most important factors in scattering and absorbing noise levels. For instance, Margaritis et al. (2018) concluded that dense trees outweighed grass areas in noise reduction. Chronopoulos et al. (2002) measured this difference to range from 2 to 4 dB between dense vegetation of trees and areas with lawn and bedding plants.

We identified three types of vegetation in the parks including low-growing lawn grasses forming a dense turf, hedgerows, and tall deciduous plane trees. Despite significant variation in the height of plants and its high correlation with noise levels, the mean value of this variable within both 50 and 100 m radius rings were excluded from the model due to collinearity with NDVI which indicates that taller plants like trees have denser biomass. Similar to our findings, Jang et al. (2015) proved that the height of vegetation which is also indicative of other vegetation characteristics matters significantly in designing calmer urban landscapes. Drawing from the literature review and based on our findings, it can be concluded that adopting a more geometrically complex and evenly distributed network of urban parks at the urban scale, with dense vegetation covers dominated by biomass-rich trees at the park scale are more effective in designing a calmer and greener ambient in the noisy city of Isfahan.

5 Conclusions and implications for urban design

Noise pollution has recently emerged out as a major and growing challenge to the main Iranian urban landscapes. By considering green spaces as a key sink for noise pollution, urban planners and designers need to be informed about where (overall distribution) and how (vegetation structure) to establish urban parks. Our results show that the level of noise radiation inside the core of urban parks is dependent upon a variety of factors. First, we found that the level of noise propagated inside urban parks is a function of the intensity of noise emitted from traffic. Besides, denser vegetation covers (like tall trees) were identified as a major contributing factor to noise pollution attenuation. If the goal is to design a calm zone within urban parks, our results indicate that it should be located as far away as the noise pollution sources by keeping in mind that the intensity of noise emitted from the nearest road section needs to be kept as low as possible. In addition, these areas should be kept populated with dense peripheral vegetation to provide calm and green zones inside narrow parks. Future studies in this field should put more emphasis on the acoustic properties of different types of plants species, especially trees, in lowering noise radiation inside urban parks and adopt more sophisticated modeling perspectives such as spatial regression models.

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