Exploring the impact of environmental factors on soundscape perception for sustainable and resilient urban environments

Nor Hamizah Abdul Hamid[1*], *Muhamad Ezran* Zainal Abdullah[2], *Syahidah Amni* Mohamed[1], *Nurul Izzati* Othmani[3], *Lee Bak* Yeo[1], *Wan Saiful Nizam* Wan Mohamad[3], *Noorliyana* Ramlee, and *Siti Nurul Diana* Sukri[2]

[1]Sustainability and Urban Design Research Group, Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia
[2]ISM Research Group, Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia
[3]Habitat – Ekistics Research Group, Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia

Abstract. The impacts of global climate change are becoming increasingly alarming, highlighting the need for sustainable urbanism practices. The soundscape has been identified as crucial for achieving sustainable development goals. Using an ergo-aesthetic framework, this research aims to investigate the impact of weather conditions and sound levels on soundscape perception in urban shopping streets. Data was collected through a soundscape survey (n = 411) in Kuala Lumpur, Malaysia, based on the ISO12913-2 technical specification standards. The result from multivariate analysis of variance revealed that weather and sound level significantly influenced soundscape perception. Based on analysis of variance, a significant difference in perception was found between low and high levels of loudness, with high levels of loudness having a significantly higher perception. It is observed that users tend to have a stronger preference for an "appropriateness" soundscape in urban shopping streets during cloudy weather conditions based on multiple comparison analysis. The participants generally reported feeling acoustically comfortable with lower temperatures in cloudy weather, possibly due to the increased cloud coverage acting as a form of background noise absorber, thereby enhancing the perceived appropriateness of the soundscape. These findings contribute to understanding soundscapes in creating sustainable and resilient urban environments.

1 Introduction

Climate change is a global phenomenon that significantly impacts various aspects of the natural environment. Moreover, climate change exerts extensive repercussions on urban areas, particularly concerning the urban soundscape. In pursuing sustainable design,

* Corresponding author: norhamizah@umk.edu.my

designers have increasingly turned to nature as inspiration. Biomimicry, a discipline that emulates biological strategies and forms, has increasingly addressed complex design challenges[1]. Similar to biomimicry, the soundscape approach seeks to identify noise pollution issues and develop appropriate solutions. The International Standard ISO 12913 provides a comprehensive definition of the soundscape as the acoustic environment as perceived or experienced and/or understood by a person or people, in context[2]. Recent research in Malaysia has predominantly focused on the significant impact of expected physical elements (β=.536, β=.356, and β=.202) on soundscape perception with other predictors by comparing the standardised coefficients[3]. Users reported more positive perceptions of the soundscape when the visual surroundings were aesthetically pleasing, well-maintained and visually harmonious[4].

Research has demonstrated a positive correlation between relatively high and intermediate loudness levels and the soundscape's perceived pleasantness[5]. However, no significant difference was observed when explicitly examining intermediate loudness levels[5]. These findings underscore the nuanced interplay between sound characteristics and subjective perception, emphasising the need to understand the factors that shape the urban soundscape comprehensively. However, a significant research gap still needs to be addressed regarding the impact of weather conditions and sound levels on soundscape perception in these urban environments. As the world faces the challenges posed by global climate change, it becomes increasingly crucial to understand and address the effects of environmental factors on the urban soundscape. The ergo-aesthetic framework entails the integration of ergonomic principles to minimise unwanted noise and promote acoustic comfort, while also incorporating aesthetic elements in enhancing user experiences within the urban soundscape[6]. Therefore, this research aims to address this gap by examining the effects of weather conditions and sound levels, which have received comparatively less attention in the literature. This research seeks to contribute to developing sustainable and resilient urban environments by exploring the relationship between environmental factors and soundscape perception.

2 Methods

2.1 Study area

Kuala Lumpur, Malaysia's capital, has become a bustling metropolis where most of the population resides in urban areas. The urbanisation rate in Malaysia reached 75.1% in 2020 and is projected to rise further to 88.0% by 2050[7]. This research concentrates on the main shopping street in Kuala Lumpur, which are Jalan Bukit Bintang (JBB), Jalan Tuanku Abdul Rahman (JTAR), and Jalan Masjid India (JMI) which shares the same characteristics based on previous studies[3]. The sample streets in this study were chosen to represent the most common urban streets based on the scale factor. The standard width of the urban streets should be between 8 m and 25 m for a comfort and security in a street canyon[8,9]. The widths of the selected sample sites range from 5 m to 30 m, while the lengths of the surveyed streets range from 150 m to more than 1 km.

2.2 Respondent selection

Data was collected through a soundscape survey (n = 411) based on the ISO12913-2 technical specification standards[10]. Respondents who reported any form of hearing impairments or auditory disorders were excluded from the research to maintain the homogeneity of the sample[3]. This criterion aimed to minimise confounding factors influencing respondents' perception and evaluation of the soundscape.

Table 1. Sample size for surveys.

Sample site	Respondents (n)
Jalan Bukit Bintang (JBB)	148
Jalan Tuanku Abdul Rahman (JTAR)	131
Jalan Masjid India (JMI)	132
Total	411

2.3 Statistical procedures for data analysis

The data was analysed using IBM SPSS Statistics version 25.0 software. Multivariate analysis of variance (MANOVA), analysis of variance (ANOVA), and multiple comparison analysis were employed to determine the differences in mean preferences among the weather and sound level sub-categories. First, a MANOVA test was conducted with all dependent variables (eventfulness, appropriateness, and calmness) and independent variables (weather and sound level). This analysis aimed to assess if there were significant differences in the mean preferences between the sub-categories based on weather and sound level. Subsequently, ANOVA tests were performed to examine if the mean preferences within each dependent variable differed across the nominal independent variable sub-groups, given that the MANOVA results were statistically significant. The ANOVA analysis focused on exploring specific differences within each dependent variable, considering the various sub-categories of the independent variables. Upon identifying significant differences through ANOVA, a multiple comparison analysis was conducted to determine which specific groups exhibited significant variations. The Bonferroni Post Hoc analysis was selected for this multiple comparison analysis due to its suitability for examining a moderate number of groups and controlling type I errors. By adopting a significance level of 95%, the statistical analyses allow for a more nuanced interpretation of the data, considering potential variations in mean preferences among the weather and sound level sub-categories.

3 Results

3.1 The environmental factors affecting the soundscape

The results of the MANOVA analysis, as presented in Table 2, revealed significant relationships between weather ($F = 2.377$, $P = .005$) and sound level ($F = 2.383$, $P = .016$) with regard to the soundscape perception dimensions.

Table 2. Multiple analysis of variance.

Environmental factors	**Subgroups**				**MANOVA**	
					F	**P<.05**
Weather	Rainy	Cloudy	Sunny	Hot	2.377	.005
Sound Level	Low level of loudness	Intermediate level of loudness	High level of loudness		2.383	.016

3.2 The relationship between weather categories and soundscape perception dimensions

The relationship between weather categories and soundscape perceptions dimensions highlighted in ANOVA indicates that significant perception of differences exists among user perception for the 'appropriateness' component (Table 3).

Table 3. Analysis of variance for the weather.

Acoustic/Physical	**Subgroups**				**Univariate**	
Weather	**Rainy**	**Cloudy**	**Sunny**	**Hot**	**F**	**P<.05**
Appropriateness	4.18	4.92	4.40	3.86	5.244	.001
Calmness	4.08	4.51	4.30	4.02	Not sig.	
Eventfulness	4.88	4.97	4.60	4.63	Not sig.	

The results indicate that the user perception of the cloudy weather group (M = 4.92) is significantly higher than the user perception of the sunny weather group (M = 4.40), rainy weather group (M = 4.18), and hot weather group (M = 3.86) ($p < 0.05$). Specifically, users reported a more positive perception of the urban environment during cloudy weather conditions than other weather conditions.

Table 4. Multiple comparisons analysis for the weather.

Dependent Variables	Weather	Mean Diff. (I-J)	P < .05
Appropriateness	Rainy VS Cloudy	-.742	Not sig.
	Rainy VS Sunny	-.215	Not sig.
	Rainy VS Hot	.325	Not sig.
	Cloudy VS Sunny	.527	.003
	Cloudy VS Hot	1.067	Not sig.
	Sunny VS Hot	.540	Not sig.

Furthermore, the multiple comparisons analysis reveals a significant positive correlation between users' experience in cloudy weather and their preference for soundscape appropriateness in urban shopping streets. This result suggests that as the cloud coverage of the sky increases, the sound environment in the park becomes more even or less diverse. Conversely, a positive correlation suggests that as the cloud coverage decreases (i.e., in sunny weather conditions), the sound environment becomes more varied or diverse.

3.3 The relationship between sound level categories and soundscape perception dimensions

The univariate analysis evaluated the relationship between sound level categories and soundscape perception dimensions. Each category reveals significant perception differences between the low, intermediate, and high loudness groups in the 'calmness' component (F = 14.4034, P =.000).

Table 5. Analysis of variance for the sound level.

Acoustic/Physical	Groups' Means			Univariate	
Sound level	Rainy	Cloudy	Sunny	F	P<.05
Appropriateness	4.58	4.40	4.58	Not sig.	
Calmness	3.86	4.44	4.76	14.403	.000
Eventfulness	4.59	4.64	4.89	Not sig.	

The results of the multiple comparison analyses using the Bonferroni Post Hoc method indicate a significant difference in soundscape perception between low and high loudness levels, as presented in Table 6. Participants reported a significantly higher in 'calmness' components in soundscape perception, characterised by high levels of loudness (M = 4.76) compared to those with low levels of loudness (M = 3.86).

Table 6. Multiple comparisons analysis for the sound level.

Dependent Variables	Sound level	Mean Diff. (I-J)	P < .05
Calmness	Low level of loudness VS Intermediate level of loudness	-.577	.002
	Low level of loudness VS High level of loudness	-.906	.000
	Intermediate level of loudness VS High level of loudness	-.329	Not sig.

4 Discussion

4.1 Effects on sound level on soundscape perception for sustainable and resilient urban environments

The significant difference between low and high loudness levels highlights the importance of considering acoustic factors when designing sustainable and resilient urban environments. Urban shopping streets are known for their vibrancy. Therefore, the high levels of loudness are primarily due to human activities. These active sounds, originating from anthrophonic sources, are crucial in creating a comfortable and contextually appropriate soundscape experience within these urban environments. The dynamic nature of these sounds aligns with the bustling atmosphere of urban shopping streets, enhancing the overall ambience and sense of liveliness.

The higher perception of calmness in environments with high loudness levels can be attributed to the psychological adaptation to the urban soundscape. The phenomenon of habituation to urban noise may have implications for public health and well-being, as individuals may become less aware of the harmful effects of noise and consequently reduce people's demand for noise reduction measures. These findings highlight the importance of raising awareness and implementing interventions to address habituation and promote sustainable and resilient urban environments that prioritise the well-being of residents.

This research also emphasises the significance of controlling unwanted sounds and incorporating preferred sound sources in soundscape design through the concept of masking, where high levels of loudness, and the dominance of specific sound sources, effectively masks other sources, resulting in perceived acoustic comfort. This approach allows for preserving the vibrant atmosphere of urban shopping streets while minimising the harmful effects of excessive noise. In addition to masking, implementing noise reduction measures is crucial in creating more tranquil urban spaces. Strategies such as installing sound barriers or vegetative buffers can effectively attenuate noise and enhance the well-being of residents. These measures reduce exposure to excessive noise and provide a sense of calmness and tranquillity in urban environments.

4.2 Effects of weather on soundscape perception for sustainable and resilient urban environments

The results indicate that users perceive a more positive soundscape than sunny weather due to the acoustic characteristics of the environment during cloudy weather. Cloudy conditions often involve higher humidity levels, affecting sound propagation and absorption. The presence of clouds may act as natural diffusers, scattering sound waves and creating a more balanced auditory experience. These findings can create a more pleasant and immersive soundscape for individuals in urban shopping streets. Additionally, the greater cloud coverage may serve as a background noise absorber, reducing the perception of unwanted noise and enhancing the appropriateness of the soundscape[11].

Furthermore, cloudy weather may also influence the visual environment, indirectly affecting soundscape perception. Cloud cover creates a more subdued visual setting, reducing visual distractions and allowing individuals to focus more on the soundscape. These weather conditions can enhance the perception of pleasant sounds while minimising the impact of ambient noise sources. In contrast, sunny weather conditions may introduce various factors that negatively impact the soundscape quality in urban shopping streets. Increased outdoor activity, traffic noise, and other ambient noise sources can contribute to a less desirable auditory experience. The contrast between the user perception during sunny and cloudy weather highlights the importance of considering environmental factors when designing urban spaces to promote positive auditory experiences.

Urban planners and architects can use these findings to inform their decisions in creating environments that prioritise positive soundscape experiences. Incorporating natural features such as urban greenery and water elements into urban shopping streets can play a crucial role in reducing unwanted sound and enhancing the acoustic qualities of the built environment. The 'urban green sponge' concept can be a valuable design interpretation for this purpose[12,13]. By maximising greenery in urban areas, the noise absorption capacity can be increased while addressing other environmental issues, such as the urban heat island effect and carbon dioxide emissions. This approach should be a primary goal in soundscape design, particularly during the initial planning and development stages.

5 Conclusion

This research has discovered that the weather and sound level factors are significant in the user's soundscape perceptions. The findings demonstrate that cloudy weather is associated with significantly higher user perception than other weather conditions. The findings also highlight the significant difference between low and high loudness levels in the soundscape perception of the calmness dimension. The implications of these results extend to the development of sustainable and resilient cities, emphasising the need to prioritise the soundscape approach to enhance the overall urban experience. This research would contribute to a better understanding of soundscapes and assist urban planners, architects, and landscape architects in designing conducive acoustic environments for urban shopping streets. The designers need to take the initiative by adding value to their design using the significant factor that influences the soundscape perception. Indeed, designers should look closely at the users' needs by seeking insights into variations or changes that look appealing to potential users.

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