I S A V

Journal of Theoretical and Applied Vibration and Acoustics

journal homepage: http://tava.isav.ir

Assessment of the acoustical condition of metro stations by emphasizing auditory satisfaction (Case Studies: Saat and Khayyam Metro Stations)[1]

Paria Meshkabadi[a], Abbas Ghaffari[b*], Elham Nazemi[c], Narges Dehghan[c]

[a]*Ph.D. Candidate, Department of Architecture, Advancement in Architecture and Urban Planning Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran*

[b]*Associate professor, Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*

[c]*Assistant Professor, Department of Urban Planning ,Advancement in Architecture and Urban Planning Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran*

ARTICLE INFO

Article history:
Received 14 March 2021

Received in revised form
5 April 2021

Accepted 23 June 2021

Available online 11 July 2021

Keywords:
Acoustical conditions

Sound pressure level

Reverberation time

Metro stations

Auditory satisfaction

ABSTRACT

Metro stations as public places are very important in terms of speech clarity, safety, and security. However, due to the size and physical-special characteristics of these places, the use of non-acoustic materials, and providing acoustical comfort is practically not possible, and in emergencies, hearing voice messages is not possible for people with different mental and physical conditions and workers are prone to hearing damage. The purpose of the study is to assess the acoustic conditions of metro stations to provide auditory satisfaction. Two crucial and distinct stations of Tabriz city were measured using B&K2260 sound level meter. SPL and RT are two of the most significant parameters in users' auditory satisfaction, which are used in the assessment of sound level and speech perception by humans. The measurements and evaluations show that (Lt) in Saat and Khayyam Stations are 106.4 and 104.2 dB, and the minimum is 85.6 and 82.4 dB, respectively. The measured maximum reverberation time (RT) is 7.21 and 5.17 seconds, respectively, at frequencies of 500 and 630 Hz with Gain=-20. According to the values of international standards, both parameters are in the unacceptable range, and in addition to causing irreparable damage to human hearing, in the long run, it covers all sounds, and people are not able to hear the sounds with lower levels than the level of the environmental noise. Therefore, by increasing the surfaces and reducing the volume via architectural elements, it is possible to help improve the acoustical conditions in metro stations.

[*] Corresponding author:
*E-mail addres:*ghaffari@tabriziau.ac.ir (A. ghaffari)

http://dx.doi.org/10.22064/tava.2023.128055.1169

1. Introduction

With the rapid development of the transportation industry, the metro has gradually become the most important way to solve public transportation problems in some large and medium-sized cities. Metro with features such as capacity, speed, and convenience plays an important role in improving the road traffic of cities. But the use of the subway also has the problem of noise pollution[1]. Metro systems improve urban environments by reducing pressure from urban transportation, reducing noise, and improving air quality, but the interiors of their metro stations are acoustically problematic[2]. The World Health Organization (WHO) has proposed restrictions on weighted sound pressure levels concerning noise pollution in professional activities. This limit is a maximum value of 75 (dB (A)), which puts too much exposure in these environments and may increase the risk of hearing loss. It is accepted that even after 40 years of daily exposure to a sound with a sound pressure level of 75 (dB (A)) for 8 hours, there is a risk of permanent hearing loss. The recommended value for a normal working day of 8 hours and 40 hours per week is 90 (dB (A)), which an employee can be exposed to before facing the risk of permanent deafness. If this lasts for more than 20 years, it will cause permanent deafness. Such a risk does not apply to travelers whose journey is short, but what is important here in terms of audio communication (talking, listening to messages from public information systems, television, etc.). Does that cause people anxiety and trouble? [3] Satisfaction is one of the main criteria for measuring the quality of the environment, and theorists have defined the quality of the environment as follows: High-quality environment transfers its population the feeling of well-being and satisfaction due to characteristics that may be physical, social, or symbolic[4]. In general, there are two categories of factors in the study of noise-induced annoyance: 1. Sound-related factors like Physical quantities of sound (noise type, noise level, duration of noise exposure, frequency spectrum), time of day or week, Month, year means when exposure to noise occurs and previous experience with the source of the noise and 2. Person-related factors including physiological, psychological, and social factors that affect the perception of noise and impair activities (communication, concentration, sleep, recreation, or rest) [5]. There are three characteristics in measuring auditory satisfaction in metro stations which include functional, psychological, and physical characteristics. Speech intelligibility, the ability to understand speech, is the main factor of readability in these places, which is reduced due to being masked by noise. From an acoustical point of view, people who use the subway are satisfied if it is not only responsive in terms of the functionality of the environment, but also in terms of psychoacoustic science, bringing peace and acoustical comfort and ensuring physical health. Table (1) shows the positive and negative indications of satisfaction and dissatisfaction in each of the related factors. In this study, due to the importance of functionality, safety, and security in metro stations, auditory satisfaction emphasizing speech intelligibility and influencing factors in creating dissatisfaction will be discussed.

In a metro station, where a large number of passengers and staff are usually concentrated, during the time a train passes near or passes the station by, the impact and friction of wheels and rails, as well as noises from braking and movement increase noise levels in the waiting and working environments, which is involved in both physical and mental health of individuals [6]. Sound sources that affect noise generation in metro stations are complex and include; the ventilation system, information system, television, passengers, railway auxiliary equipment, propulsion system, and aerodynamics of trains [3]. It is important to use hybrid solutions to reduce noise levels. In this regard, noise intensity can be reduced by creating noise barriers and sound insulation walls [7]. Another significant issue in metro stations is acoustic design and voice control in terms of speech clarity [2]. Speech intelligibility is the ability to understand the message conveyed, which is also essential in communicating, and understanding instructions and safety warnings. Background noise and reverberation reduce speech intelligibility [8]. What makes it difficult to control noise and speech intelligibility is: the high use of low-absorption materials and reflective surfaces, which are chosen more for damage control, fire, hygiene, and maintenance rather than acoustical quality. The use of appropriate materials with the high absorption of different sounds and scattering characteristics plays a significant role in targeted performance [2]. Despite the importance of speech intelligibility in metro stations, however, minimum audio standards are rarely applied to metro station [9].

Table 1. Factors involved in auditory satisfaction, their positive and negative aspects (Source authors)

Domains	**Aspect**	
Functional	Satisfaction	Routing- orientation- access, easy movement- clarity and transparency- legibility - speech intelligibility- quality of the space
	dissatisfaction	Lack of Routing- straying- waste of time- reduced demand
Psych acoustical	Satisfaction	Social and personal interactions- mental comfort- sense of place- concentration
	dissatisfaction	Disturbance, mental disorder, violence, bad behavior, tension
Physiological	Satisfaction	Safety and security, physical health
	dissatisfaction	Hearing impairment- stress-related diseases such as high blood pressure, heart attack, the dysfunction of the digestive system, respiratory organs, blood circulation, and so on

Each space has a unique sound environment; Soundscape, sound sources, and acoustic requirements are different in each space. Of course, the requirements for sound quality standardization in relation to interiors are more diverse and complex, and auditory perception varies due to factors such as building geometry, joinery materials, activities, and echoes [10]. Sound fields in underground stations are considered to be highly reflective due to the successive reflections of sound in a closed and long environment. The sound beams are reflected on the walls, ceiling, and floor of the station with a reflective pattern according to the shape of the station. Inside the tunnels, the reflection increases with decreasing volume relative to the station, even if the cross-section is round or right-angled [11]. Two significant and influential physical parameters in the acoustics of metro stations are related to sound pressure level and reverberation time. Noise is any unwanted sound and background noise refers to the noise in the space. Its source can be external, such as the noise of transport vehicles, or internal, such as the sound of facilities or the noise of people [12]. Noise in any acoustic environment interferes with human hearing. Reverberation amplifies the background noise and makes it difficult to understand the sound. By decreasing the background noise, speech can be heard well in reverberant areas. Therefore, noise has a significant effect on speech intelligibility, which should be removed as much as possible from the main sound sources [13]. Subway station waiting platforms are enclosed spaces in which the hearing conditions must be appropriate and the background noise must be somewhat constant. Since these sounds may be constant in the long run, 55 dB(A) is considered according to international standards [11]. The maximum sound pressure level on platforms is when the train enters the station. The noise level generated by underground stations in high-speed transit systems is in the range of 80 to 115 dB(A) at high frequencies [14]. Since trains operate at speeds above 130 km/h and despite maximum acceleration and speed, they can enter or leave at about 80 km/h depending on the length of the waiting platform, the sound level according to the principles of optimal acoustic design should be limited to Maximum 80 dB (A) [15]. In the case of high-speed trains, the sound level is limited to 85 dB (A) [16]. According to APTA, metro stations should not produce noise levels of more than 85 dB when trains enter and leave. Of course, 5 dB should be less than that. However, according to the national authorities of the tunnels, the noise level at any point of the station platform should not exceed 82 dB at the time of arrival and departure of the train (closed doors). The noise source level is usually 1.5 m above the platform and approximately between the edge of the platform to the back wall or 1.5 m from the edge of the platform, whichever is closer to the rail. Noise levels apply to total noise levels, including noise from wheel/rail sources, traction motor equipment, wagon ventilation, air conditioning equipment, and braking systems [11]. When the train is standing at the station, 4.5 meters from the train, the noise of the stationary train should be limited to 65 dB. Therefore, the noise level of the station at any point of the waiting platform should be limited to a maximum of 67 dB(A). According to the National Tunnel Authority, railway noise levels for a standing train should not exceed 65 dB(A) at any point on the station platform while the doors are open [11].

Table 2. The maximum level of sound at underground metro station platforms [15, 16]

The maximum level of noise at underground train station platforms	
Entering and leaving trains	80dB(A)
	82dB(A)
Passing through trains	85dB(A)
Stationary trains (doors open)	67dB(A)
	65dB(A)
Only station ventilation systems operating	55dB(A)
Maximum time of reverberation at the platform	1.6- 2 seconds
The optimum time of reverberation at the platform	1- 1.4 seconds

Reverberation time is the basic parameter that should be calculated in the assessment of room acoustics. This parameter indicates the efficiency of a room in fulfilling the acoustical requirements, depending upon the activity or function that takes place [2]. Reverberation time is a measure of the rate of decay of sound. It is defined as the time in seconds required for sound intensity in a room to drop 60 dB from its original level [17].

Among the methods described for calculating the reverberation time are the following four formulas [17] in which the Sabin equation is more consistent and is of great importance.

Sabin:
$$T_{60.s} = \frac{0.161\,V}{S\bar{\alpha}} \tag{1}$$

Eyring:
$$T_{60.E} = \frac{0.161\,V}{-SIn(1-\bar{\alpha}) + 4mV} \tag{2}$$

Fitzroy:
$$T_{60.F} = \frac{0.161\,V}{S\alpha F + 4mV} \tag{3}$$

EN 12354-6:
$$T_{60} = \frac{16\,V\,(1-\Psi)}{A} \tag{4}$$

In metro stations, the maximum reverberation time on the waiting platforms to reduce speech interference should be limited to a maximum of 1.6 to 2 seconds at mid-frequencies [16]. Even for better performance at certain stations, the reverberation time range is reduced to 1 to 1.4 seconds in the mid-frequency ranges. In general, low reverberation times are desirable but also depend on the size of the station and the acoustical behaviors. This contributes to the intelligibility of people's information and voice communication systems [18]. As mentioned, metro stations are functional places that are architecturally closed and long. Since the proportions of space are important in the acoustics and reflections, if not taken into account in the designing stage, noise exposure will lead to irreparable damages because of the invisibility of noise and revealing its effects on humans in the long run. Speech intelligibility is crucial in such stations and high-level sounds can mask voice messages and prolong reverberation time, which can impair speech intelligibility. Speech intelligibility is one of the significant acoustic components in such large spaces due to unwanted echoes caused by the form and geometry of the space which are not particularly desirable and affect the auditory satisfaction of users. Many studies have been conducted worldwide, which unfortunately are very limited in Iran and the stations have not been studied.

Therefore, the main question of the research is what is the condition of the metro stations of Tabriz in terms of acoustical quality and whether the international standards for providing auditory satisfaction are quantitatively observed in them or not? are the sound pressure level and reverberation time, the two main factors in determining the audience's auditory satisfaction in terms of noise and the ability to understand speech? In this study, an attempt has been made to measure the variables related to sound quality in metro stations. Sound pressure level and reverberation time are the two main parameters in the assessment of acoustical conditions that will be compared with international standards after field measurements.

1-1. literature Review

Research in the field of acoustics is very extensive and Table (3) presents various methods to achieve the desired goals that compare and evaluate physical characteristics with standards. The most common method for measuring acoustic quality is field survey and measurement by audio devices that measure acoustic parameters by frequency domain. Simulation is another method that is useful for improving conditions with physical changes. In this study, following previous studies and to initially evaluate the acoustic quality, the measurement of two significant and effective indicators in creating auditory satisfaction has been used.

Table 3-1. An overview of acoustic measurement methods, indicators, and criteria

Authors	**Title**	**Method**	**Index**	**Assessment methods**
P.A.A. Kootwijk 1996 [19]	The Speech Intelligibility of the Public Address Systems at 14 Dutch Railway Stations	Computer measurement and By Ray modeling Tracing method	STI, SPL	ISO
Mohanan, V, et al 1989 [3]	A Noise and Vibration Survey Railway in an Underground System	Field measurement by B&K equipment	BN, SPL, RT	WHO ISO ANSI[†]
Shield, Yang 2001 [20]	The prediction of speech intelligibility in underground stations of rectangular cross section	Computer measurement and modeling By Ray Tracing method	،D50 ،EDT ،RT STI،C50	ANSI

Table 3-2. An overview of acoustic measurement methods, indicators, and criteria

Kang, Orlowski 2001 [21]	Guidelines for Predicting Acoustic Characteristics in Subway Stations	Theoretical-computer model by TNS method (quasi-experimental)	AI, STI, RASTI	-
Su, Caliskan 2007 [2]	Acoustical Design and Noise Control in Metro Stations: Case Studies of the Ankara Metro System	Computer modeling with ODEON software	STI ،RT, T_{20}, T_{30} SPL, materials	TNCA[‡]
Mohamed Hassan Hussein 2010 [11]	Effect of Architectural Treatments on Acoustic Environment (Case Study: Underground Stations)	Computer modeling with ODEON software	RT و SPL Material	BS EN ISO 3095:2005

[†] . American National Standards Institute
[‡] . Turkish Noise Control Act

Ghotbi, et, 2011 [22]	Noise pollution survey of a two-story intersection station in Tehran metropolitan subway system	digital SLM and statistical analysis with SPSS 16.0 software	$L_{eq(10)min}$	NIOSH[§] OSHA[**] EPA/WHO
Kim, Soeta 2013 [23]	Architectural treatments for improving sound fields for public address announcements in underground station platforms	Computer modeling with ODEON software by Ray Tracing method	SPL, STI, EDT, T_{20}, T_{30}, D_{50}, C_{50}, I-IACC	IEC 60268-16 ISO 3382-1
Tang, Wang, Guo 2013 [6]	Sound Field Simulation and Optimization at an Underground Subway Station	Computer modeling with ACTRAN software with finite element method (FEM)	SPL And energy distribution	GB50157-2003
Ghaffari, Mofidi 2014 [24]	Comparing Reverberation Time in West Churches and Mosques of Ghajar Era in Tabriz	Computer modeling with EASE software	RT Volume of space	Similar cases
Berardi, et al 2015 [9]	Acoustic Characteristics of Four Subway Stations in Naples, Italy	Computer modeling with ODEON and DIRAK software	،D_{50} ،C_{80} ،T_{30} STI, RT	ISO 3382-1

Table 3-3. An overview of acoustic measurement methods, indicators, and criteria

Yilmazer et al. 2017 [10]	Understanding the indoor soundscape in public transport spaces: A case study in Akkopru metro station	Objective measurement with B&K 2230 and subjective measurement with SPSS 13	SPL L_{Aeq}	ISO 12913-1:2014
Sygulska et al. 2018 [25]	Experimental Investigations and Computer Simulations to Solve Acoustic Problems in the Modern Church	Sound level meter B&K Computer modeling with ODEON software 11	RASTI, STI, RT, T_{30}, EDT, T_s, C_{50}, C_{80}, D_{50}	Comparison of measurements with simulations
Su Gul et al. 2020 [26]	Comparative Evaluation of Ray Tracing and Diffusion Equation Modeling in Room Acoustics Design of Subway Stations	Computer modeling with DIRAK	RT, SPL	ISO 3382-1.35

§ . National Institute for Occupational Safety and Health
** . Occupational Safety and Health Administration

Wu et al. 2020 [27]	Acoustic Comfort in Large Railway Stations	sound level meter, Questionnaire	SPL, RT	ISO3382
Liu. Ch. et al. 2020 [28]	Effect of sound on visual attention in large railway stations: A case study of St. Pancras railway station in London	Combination through questionnaire, field measurement, and laboratory experiments	BN, SPL	Adoptive comparison of the indicators of each variable
Indrayani et al. 2021 [29]	Analysis of train noise level at bandar khalipah station, deli serdang using sound level meter 130 dB	Experimental Sound Level Meter	SPL. Intensity	Minister of Health of the Republic of Indonesia: KEP-48 / MENLH / 11/1996

1-2. Research method

This research is a case study and uses a quantitative method to achieve the objectives, but requires knowledge and scrutiny of the literature, the study of the variables, measurement, and evaluation of samples. The data relating to research literature was collected through library studies (books, articles, authoritative publications) and sound field measurements were conducted in the desired stations. The B&K2260 sound level meter equipped with an amplifier and an Omni- Directional speaker, as well as an acoustic camera[††] were used for measurement, which can be seen in Figure 1.

[††] . Acoustic Camera (AC (100)) Sinus Messtechnik Gmbh

Fig. (1) Right-to-left B&K 2260 sound level meter, Omni-directional speaker, and acoustic camera

The studied samples are from two metro stations in Tabriz and it has been tried to select two types of stations that are different in terms of dimensions, form-geometry and architectural plan to study their acoustic behavior. Measurements were conducted at two levels of the waiting platform and the ticket control hall and at the three starting, middle, and end points of the desired stations. In the waiting platform, the device is 1.5 meters away from the edge of the platform and is placed at a height of 1.6 meters, equal to the human ear. The sound pressure level was considered in two modes: empty hall (without train) to measure background noise and full hall (with train) to measure the maximum sound pressure level. The reverberation time (T20) and (T30) were also performed in two empty and full states with 3 intensities G = 0, -10, -20, and the results presented in the article are the outcome of measured points.

Table 4: Physical-Formal characteristics of the Saat Station (Source: Authors)

Physical specifications (dimensions and area)

Waiting platform			Rail			Ticket control hall			Total area	
length (m)	Width (m)	Height (m)	length (m)	Width (m)	Height (m)	length (m)	Width (m)	Height (m)	Area (m^2)	Volume (m^3)
100	10.5	3	100	10.70	5.40	60	45	4.05	5115	20965

Used Materials

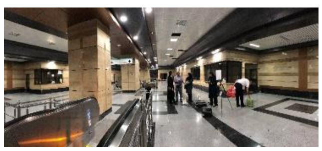
Waiting platform			Rail			Side spaces			Ticket control hall			
floor	wall	ceiling	floor	wall	ceiling	tunnel	stairs	elevator	floor	wall	ceiling	window
Granite	stone	Porous Aluminum damper	concrete	concrete	concrete	concrete	stone	steel	Granite	stone	Aluminum damper	glass

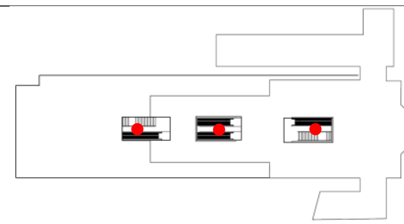
2. Case studies

Saat station is an intersection station with an island-shaped platform and an H-shaped cross-section that is located in the center of the city with high depth (3 basement floors). Khayyam station with two floors, which is shallower compared to the previous station, is a middle station with a side platform and a +shape cross-section on Elgoli Boulevard. Tables 4 and 5 show the physical characteristics of each station and the materials used at different levels, and the images and maps of the measured classes:

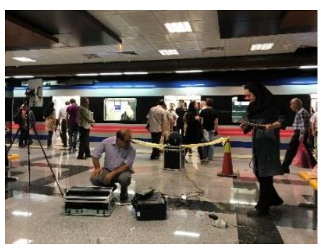
Image and plan

Ticket control hall





Waiting platform



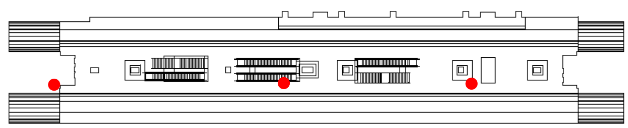


Table 5-1: Physical characteristics of Khayyam Station

Physical specifications (dimensions and area)												
Waiting platform					Rail			Ticket control hall			Total area	
Length (m)	Minimum width (m)	Maximum width (m)	Minimum height (m)	Maximum height (m)	Length (m)	width (m)	height (m)	length (m)	width (m)	height (m)	area (m^2)	Volume (m^3)
100	8.6	16.6	4.76	5.33	100	6.29	8.1	60	35.5	4.05	3600	20800

2-1. Sound Pressure level

According to the measurements made from both stations and the studies that were done in Figures 2 to 5, the highest sound pressure level is measured to be at the frequency of 1000 Hz. The maximum sound pressure in the central frequency range on the station ticket control floor is 101.1 dB and the minimum is 70.2 dB on the waiting platform of Khayyam Station when the train is not at the station. (The diagrams show the ticket control floor with T and the waiting platform with P, and the numbers 0 for when the train is not at the station and 1 for when the train is at the station).

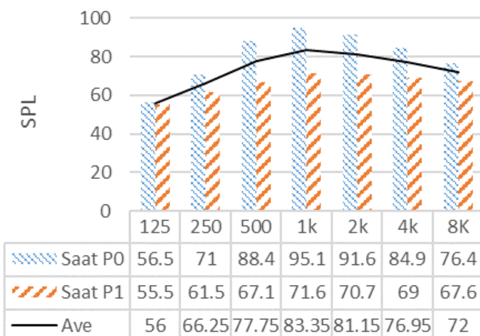
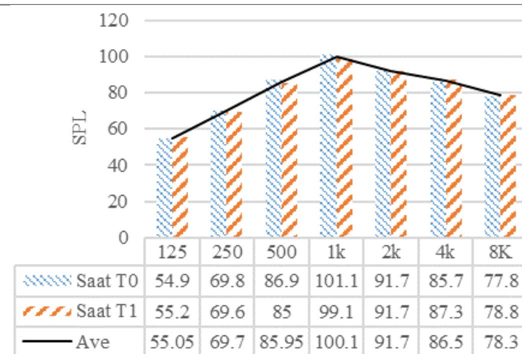
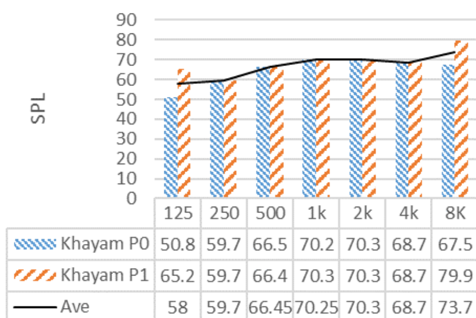
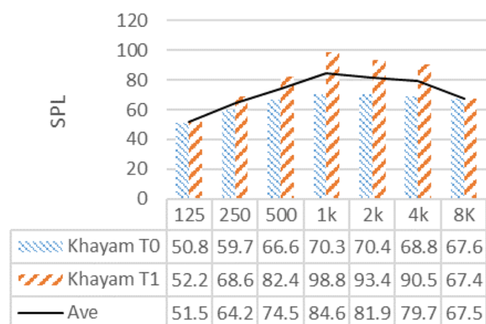
Station	Ticket control hall	Waiting platform
Saat		
Khayyam		

Fig. (2) to (5): Sound pressure level in two levels and two times and the average of both modes (Source: Authors)

Table 5-2: Physical characteristics of Khayyam Station

Used Materials												
Waiting platform			Rail			Side spaces			Ticket control hall			
floor	wall	ceiling	floor	wall	ceiling	tunnel	stairs	elevator	floor	wall	ceiling	window
Granite	stone	Aluminum damper	concrete	concrete	concrete	concrete	stone	metal	Granite	stone	Porous Aluminum damper	glass

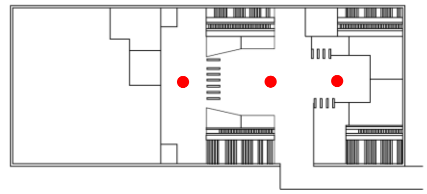
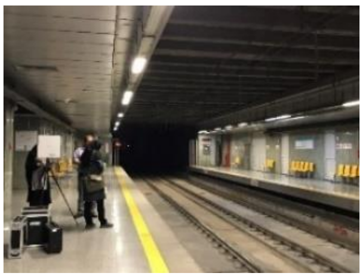
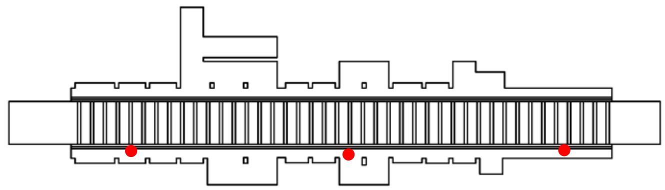
	Image and plan	
Ticket control hall		
Waiting platform		

Figure 6 shows the sound pressure level in all modes at two metro stations with a frequency range of 25 to 10,000 Hz. It can be seen that in most cases at frequencies between 250 Hz to 10,000 Hz, the sound pressure level is higher than 60 dB. Therefore, even when the train is not at the station, the background noise is high. The sound pressure level in the three Saat Station diagrams in the frequency range of 500 to 2500 Hz is higher than 80 dB, and in the fourth diagram (full platform of the Saat Station), it can be seen that the ascending trend is more slowly than the previous ones. Despite the simultaneous trains at Khayyam Station, only on the full waiting platform, the chart rises to a maximum of about 100 dB. Despite the presence of the train, on the ticket control floor of Saat Station, no data was available for the sound pressure level at some frequencies.

Figure 7 also shows the minimum, maximum, and midpoint of the sound level at all frequencies measured in all cases. At mid frequencies of 500 to 2000 Hz in the diagram, the maximum values obtained were above 85 dB. The highest intermediate limit is for frequencies above 1000 Hz and more than 80 dB. The highest value of the minimum limit in this range is at the frequency of 1000 Hz and has about 70 decibels of sound pressure. At a frequency of 800 Hz, it suddenly reaches 60 decibels and then goes through a downward trend.

The total sound pressure level (Lt) and frequency weighting (At) in each station according to its position are shown in Figure 8. The linear graphs of both variables are consistent with each other and do not differ much. At Saat Station, both parameters are above 100 except for the full waiting platform. This is while in Khayyam Station in the same situation, the amount is increasing and is higher than 100. It can be seen that the stations under study are opposite.

Figure 9 tries to examine the minimum, average, and maximum sound pressure levels separately in each station and their different classes. The highest sound level range at Saat Station is approximately 19 to 102 decibels, with a difference of 83 decibels. The smallest range is about 30 to 72 decibels with a difference of 42 dB. At Khayyam Station, the highest sound pressure level range is approximately 24 to 98 decibels, with a difference of 74 decibels, and the lowest sound level range is 18 to 70 decibels, with a difference of 52 decibels. It can be seen that the line that specifies the maximum pressure level is exactly different in the two stations and similar situations. Saat Station has the highest value and Khayyam Station has the lowest value, and vice versa. The type of design, dimensions, the height of the space, and even the materials used can cause these differences. The average line is closer to the maximum line and varies in the range of 60 to 80 dB. The minimum line is smoother and differs by about 10 dB, which indicates that the minimum sound level at the two stations is almost the same.

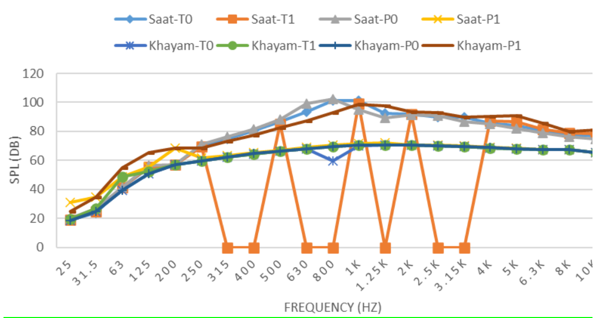


Fig. (6): Sound pressure level at different frequencies of both stations

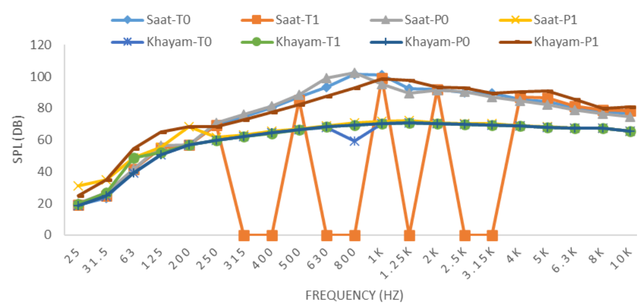


Fig. (7): Minimum, medium, and maximum sound pressure levels in all modes of both stations

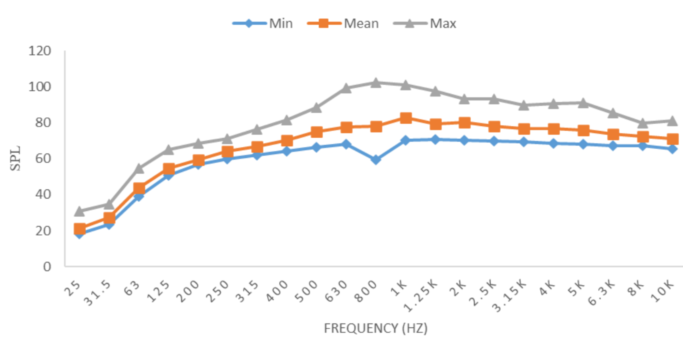


Fig. (8): (Lt) and (At) in two stations in different situations

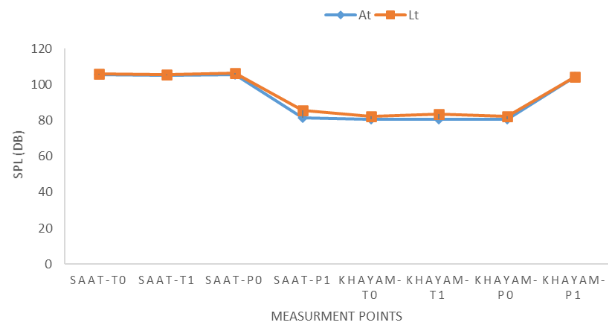


Fig. (9): Minimum, medium, and maximum ~~of~~ sound pressure in two stations of Saat and Khayyam

2-2. Reverberation Time (RT)

The Reverberation time in the two stations was measured using a 2260 B&K device together with speakers and amplifiers with the gains of G =0, -10, and -20. On the ticket control floor, the devices were tested once in the center of the space without train (T) with train (T0) and again at a distance of about 40 meters from the speaker located in the center (T1). On the waiting platform floor, the device is placed in the center of the platform without train (P0) with train (P1), and the speaker, once near the train door and again between the columns (P2).

Figures 10, 11, and 12 show the RT at mid frequencies from 125 to 8000 Hz at different positions with three intensities (G = 0, -10, -20) at the stations. The RT with G = 0 is in a range of 0 to approximately 3 seconds and the minimum RT at 8000 Hz in all situations is in the range of 0.5 to 1 second. The RT in each position is different from other situations, but all of them have had a downward trend with increasing frequencies.

The RT with G = -10 at both stations was investigated in different positions, and Figure 11 shows that the RT was lower than 4 seconds at all frequencies. The RT with G =-10 at both stations was investigated in different positions, and Figure 11 shows that the RT was lower than 4 seconds at all frequencies. The maximum RT in the waiting platform of Saat Station at a frequency of 1000 Hz was about 3.7 seconds. The shortest RT is related to the full platform of Saat Station. Also, no data was obtained on the full platform of Khayyam Station. The shortest RT is related to the full platform of Saat Station. Also, no data was obtained on the full platform of Khayyam Station.

The RT with G =-10 at both stations was investigated in different positions, and Figure 11 shows that the RT was lower than 4 seconds at all frequencies. The maximum RT in the waiting platform of Saat Station at a frequency of 1000 Hz was about 3.7 seconds. The shortest RT is related to the full platform of Saat Station. Also, no data was obtained on the full platform of Khayyam Station

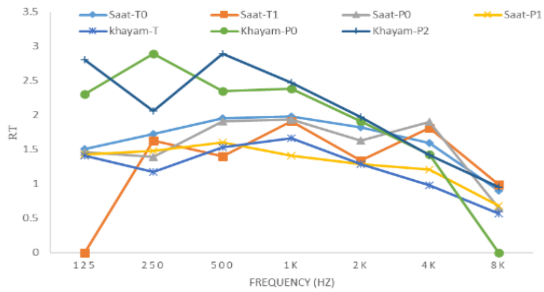


Fig. (10): RT at two stations with G = 0

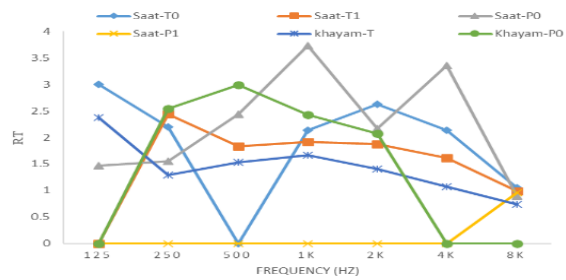


Fig (11): RT at two stations with G = -10

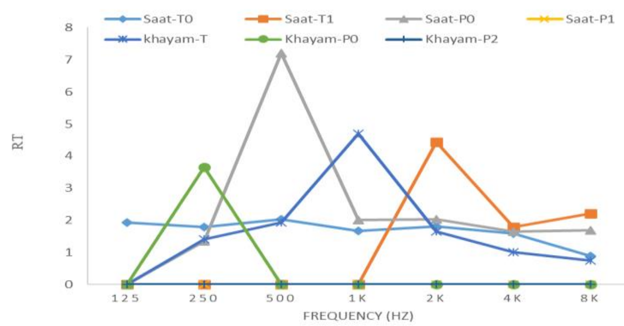


Fig (12): RT at two stations with G = -20

Figure 13 shows the aggregation of the minimum, mean and maximum RT, and it can be seen that the accumulation of the most minimums is in the range of 0 to 2 seconds, and the aggregation of the means is in the range of 1 to 3 seconds, and the maximum is in the range of 3 to 7 seconds. The total RT aggregation is higher in the interval between 0 and 5 seconds. The minimum and average values of RT up to 3 seconds and the maximum value in the range of 4 to 5 seconds are more frequent.

The average RT according to the frequencies in the two stations in Figure 14 shows that in the Khayyam Station, with increasing frequencies, the RT has a decreasing trend, and its peak point is at the frequency of 1000 Hz and is about 2.5 seconds. At Saat Station, the chart has an ascending trend, and with the increase of the frequency, the RT also increases, and its peak point is at the frequency of 500 Hz and is approximately 2.5 seconds. For both stations, the RT peaks are at 2.5 seconds at the central frequencies. The maximum averages at both stations are approximately equal, differing only in frequency.

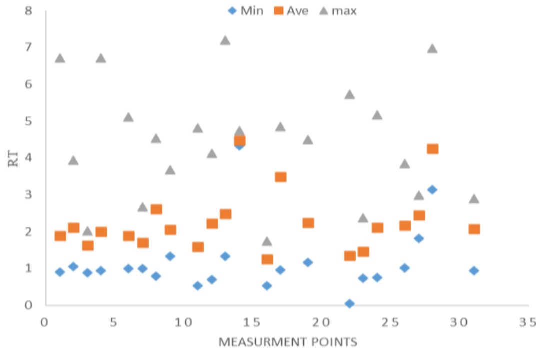


Fig (13): Aggregation of minimum, mean, and maximum RT

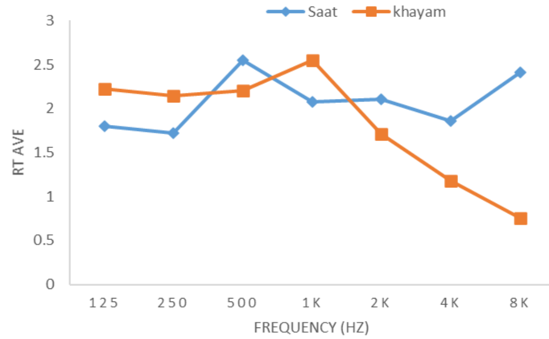


Fig (14): Mean RT at mid frequencies

2-3. Comparison and summary

In the previous section, the measurements were plotted in the two domains of sound pressure level and RT, which show how sound is distributed at frequencies at different points with the same conditions. The following is a review of the data together:

1. Table 6 shows the highest sound pressure level ranges in the mid frequencies (125 Hz to 4 kHz) of two stations. As can be seen in Table 6, the maximum sound pressure level at the frequencies of 1000 to 8000 Hz and the SPL at the frequency of 500 Hz are on the unauthorized threshold. The minimum range is at Khayyam station, and the maximum range except 250, 500, and 1000 Hz is at Khayyam Station. The maximum SPL in Saat station is also on the platform and the ticket floor.

Table 6. The highest sound pressure level intervals at each frequency by the position of stations (Source: Authors)

Frequency	Position	SPL Intervals (dB)
125 (HZ)	(KH P0-KH T0) - (KH P1)	**50.8-65.2**
250 (HZ)	(KH T0-KH P0-KH P1) – (S P0)	**59.7-71**
500 (HZ)	(KH P1) – (S P0)	**66.4-88.4**
1 (KHZ)	(KH P0) – (S T0)	**70.2-101.1**
2 (KHZ)	(KH P0- KH p1-KH T0) – (KH T1)	**70.3-93.4**
4 (KHZ)	(KH P0- KH P1)- (KH T1)	**68.7-90.5**
8 (KHZ)	(KH T1) – (KH P1)	**67.4-79.9**

2. The average of the minimum, mid, and maximum of all measurements in the total frequencies in each station is calculated separately and the results are given in Table (7). Saat station has the highest sound pressure level and the lowest SPL is at Khayyam station.

Table 7. Average minimum, middle, and maximum sound pressure level in two stations (Source: Authors)

Station	Average total minimum sound pressure level	Total average of sound pressure level	The average of the total maximum sound pressure level
Saat	22.2	68.27	93.72
Khayyam	20.35	62.73	**77.7**5

3. The average minimum, middle, and maximum RT were obtained based on the intensity of sound emitted in both stations. As can be seen in Table (8), the total RT in Khayyam station was higher than that of Saat station.

Table 8. Average Minimum, Middle, and Maximum Rt according to Gain (Source: Authors)

Station	G	Overall average of minimum RT	Overall Average of RT	Overall average of maximum RT
Saat	G=0	0.73	1.65	4.59
	G=-10	0.92	2.38	3.90
	G=-20	1	2.24	4.59
Khayyam	G=0	0.67	1.89	4.15
	G=-10	1.28	1.95	**2.68**
	G=-20	1.94	3.18	**6.07**

4. According to the existing standards, the maximum sound pressure level in an empty station with a ventilation system should not exceed 55 decibels, while in Saat Station at a frequency of 1000 Hz, there were 101.1 decibels of sound. At Saat station with the train standing and the door open, the maximum permissible sound pressure level is 67 decibels, while at Khayyam Station, despite the simultaneous train at the station, this level has reached 98.8 decibels. Also, when the train is passing, the maximum sound pressure level at the station should be limited to 85 decibels, while according to several measurements made at Saat station, this number reaches 99.1 decibels at the frequency of 1000 Hz.

5. The images obtained from the acoustic camera are related to Saat station (Figures 15, 16) at a frequency of 10,000 Hz and the Khayyam Station (Figures 17, 18) at a frequency of 25,000 Hz. These sound maps, which show the source and intensity of sound in the color range of 20 to 120 decibels, indicate that even at higher frequencies, there is noise. Given the fact that at metro stations, sound pressure levels at higher frequencies are more dangerous than at lower frequencies, acoustical conditions should be taken into account.

15. 

16. 

17. 

18. 

Fig. (15) to (18): Color maps of the sound pressure level at a frequency of 25,000 Hz at both stations (Source: Authors)

3. Discussion

The results show that the maximum values of sound pressure level are related to Saat station in the empty waiting platform (102.3 dB) at a frequency of 800 Hz. Also, the minimum level at Saat station on the empty ticket control floor is 18.1 dB at a frequency of 25 Hz. Studies show that the minimum sound pressure level in both stations is almost the same and slightly different, while the maximum sound pressure level in both stations is different and variable, which can be due to the physical conditions of the space (plan, height, and materials), the number of trains and people, existing barriers, etc. On the other hand, it can be concluded that the background noise in the stations, whether in the empty station or the station with the train, or the existence of simultaneous trains, has an excess sound pressure level according to the rules and standards, but in Khayyam Station, in most cases there was a normal state, but from the time the train approaches the station until the moment the other train arrives and stops, the sound pressure level suddenly reaches its peak. At the empty Saat Station, the sound pressure level is at ~~a~~ maximum, and the decrease in level occurs only when the doors of the standing train are open. The opening of train doors and the reduction of sound level indicate that in such environments where the SPL level is higher, cavities should be used or fibers and screens should be used to absorb other frequencies. Practically, it is observed in these stations that no surfaces have an acoustic and purposeful design.

Also, the maximum RT at Saat Station on the full waiting platform and G = -20 was 7.21 seconds at 500 Hz, and the minimum value of RT was 0.04 seconds at 6300 Hz on the empty ticket control floor at Khayyam station. The average and minimum are more frequent in the range of 1 to 3 seconds, but the maximum accumulation of RT is higher in the interval of 4 to 5 seconds. At Saat Station, with increasing frequency, the RT has an upward trend, but Khayyam Station has a downward trend. According to the stated standards, to reduce speech interference, RT should be between 1 to 1.4 seconds and a maximum of 1.6 to 2 seconds. In the studied stations, only the minimum RT stand in this range.

Local observations and the position of the stations themselves to the wall and ceiling surfaces show that no acoustic design and fibrous sound absorbers or cavities or surfaces have been used and it is quite obvious that these smooth and especially smooth stone and polished surfaces can increase RT. Increasing the RT in frequency octaves will naturally cause the RT to rise and increase the sound pressure level (SPL) at different frequencies. Increasing the RT by the surfaces and the frequency response of the surfaces can increase the SPL when the station is populated and the train arrives at the station. Most stations that are acoustically designed worldwide have used more absorbing surfaces to absorb sound at different frequencies. While most of the surfaces seen in these studied stations are smooth, polished, stone, or composite surfaces. Strong reflectors, such as surfaces used in the studied stations, eventually increase the RT and SPL simultaneously which can have an adverse effect on STI, AL_{Cons}, and Clarity, which in turn imposes more background noise pressure on the environment. Increasing the SPL will increase the physical annoyance and deafness and insecurity mentioned in the article.

The issue has not been seen from an architectural point of view and the main part of the acoustic problems are related to the design and surfaces and dimensions of the space. In this regard, to increase the sound quality of the space, it is better to make an acoustic simulation during the design phase and the design should be checked in terms of speech intelligibility and acoustic comfort. According to the results of the present study, it is suggested to increase the surfaces and decrease the volume by using architectural elements. Paying attention to the form and geometry of the space, observing the proportions based on the bolt diagram, using materials with high absorption coefficients, and embedding cavities and porous surfaces for reducing and absorbing additional sounds~~, which~~ will greatly increase the quality and auditory satisfaction of the audiences.

4. Conclusion

In this research, the acoustic conditions of two metro stations in Tabriz were evaluated. Saat Station has an island platform with an H-shaped cross-section, and Khayyam Station has a side platform with a + cross-section. Saat Station is crucial due to its location in the city center and is a busy station in terms of the number of passengers. Khayyam Station is also of great importance because trains from both routes arrive at the station at the same time.

Given that the discussion of auditory satisfaction seeks to provide acoustic comfort and speech intelligibility, two important acoustic indicators (SPL and RT) were proposed in this regard and were measured in a field study with the mentioned devices. These two indicators were studied in both full and empty stations on the two floors of the waiting platform and ticket control hall.

In general, it can be concluded that with increasing frequency, the sound pressure level increases and the RT decreases, and as the SPL propagated in the environment increases, the RT decreases.

Island-shaped stations increase the amount of noise compared to side stations due to the removal of barriers and noise-canceling valves, as well as, the placement of communication accesses in the center of the platforms. Since measuring the time of speech is used to determine speech intelligibility, its excess from standard ranges, in addition to reducing safety and security, has caused physical and psychological harm to people, resulting in hearing dissatisfaction among the audiences.

References:

[1] S. Peters, The prediction of railway noise profiles, Journal of sound vibration, 32 (1974) 87-99.
[2] Z. Sü, M. Çalışkan, Acoustical design and noise control in metro stations: case studies of the Ankara metro system, Building Acoustics, 14 (2007) 203-221.
[3] V. Mohanan, O. Sharma, S. Singal, A noise and vibration survey in an underground railway system, Applied acoustics, 28 (1989) 263-275.
[4] J.B. Lansing, R.W. Marans, Evaluation of neighborhood quality, Journal of the American Institute of Planners, 35 (1969) 195-199.
[5] B. Jakovljevic, K. Paunovic, G. Belojevic, Road-traffic noise and factors influencing noise annoyance in an urban population, Environment international, 35 (2009) 552-556.
[6] C. Tang, Y. Wang, H. Guo, Sound Field Simulation and Optimization at an Underground Subway Station, Building Acoustics, 20 (2013) 243-253.
[7] Y. Sarikavak, A. Boxall, The impacts of pollution for new high-speed railways: the case of noise in turkey, Acoustics Australia, 47 (2019) 141-151.
[8] D. Havelock, S. Kuwano, M. Vorländer, Handbook of signal processing in acoustics, Springer, 2008.
[9] U. Berardi, G. Iannace, G. Giordano, Acoustic characteristics of four subway stations in Naples, Italy, in: Proceedings of the INTER-NOISE, 2015.
[10] S. Yilmazer, Z. Bora, Understanding the indoor soundscape in public transport spaces: A case study in Akköprü metro station, Ankara, Building Acoustics, 24 (2017) 325-339.
[11] m.h. manar, Effect of Architectural Treatments on Acoustic Environment (Case Study: Underground Stations). Master Thesis., (2010).
[12] Issue 18 of National Building Regulations , Tehran: Iran Development Publishing (in Persian). (2009).
[13] Long, Marshal, Architectural Acoustic, London: Elsevier, pp 88-89, (2006).
[14] N.P. Cheremisinoff, Noise control in industry: A practical guide, Elsevier, 1996.
[15] Knight, K.G. Guidelines and Principles for Design of Rapid Transit Facilities, ed. W.H. Paterson. Washington: Institute for Rapid Transit., (1973).
[16] J.T. Nelson, Wheel/rail noise control manual, (1997).
[17] M.N. Barros, A. Raeder, M. Borin, A comparison study between prediction models and in situ measurements of acoustic clouds in open plan offices, in, Euronoise, 2018.
[18] M. Hersen, R.T. Ammerman, Advanced abnormal child psychology, Routledge, 2000.
[19] P. Kootwijk, The speech intelligibility of the public address systems at 14 Dutch railway stations, Journal of sound and vibration, 193 (1996) 433-434.
[20] L. Yang, B.M. Shield, Modeling of acoustic parameters and speech intelligibility in long enclosures, The Journal of the Acoustical Society of America, 103 (1998) 2999-2999.
[21] E. Nowicka, Assessing the acoustical climate of underground stations, International Journal of Occupational Safety and Ergonomics, 13 (2007) 427-431.
[22] M.R. Ghotbi, M.R. Monazzam, M.R. Baneshi, M. Asadi, S.M.B. Fard, Noise pollution survey of a two-storey intersection station in Tehran metropolitan subway system, Environmental monitoring and assessment, 184 (2012) 1097-1106.
[23] Y.H. Kim, Y. Soeta, Architectural treatments for improving sound fields for public address announcements in underground station platforms, Applied acoustics, 74 (2013) 1205-1220.

[24] A. Ghaffari, S.M. Mofidi, Comparing Reverberation Time in West Churches and Mosques of Qajar Era in Tabriz, معماری و شهرسازی آرمان شهر, ۷ (۲۰۱٤) ۲۹-۱۳.
[25] A. Sygulska, T. Czerniak, A. Czarny-Kropiwnicki, Experimental investigations and computer simulations to solve acoustic problems in the modern church, Engineering Structures and Technologies, 10 (2018) 34-45.
[26] Z. Sü Gül, E. Odabaş, M. Çalışkan, Comparative evaluation of ray tracing and diffusion equation modeling in room acoustics design of subway stations, Acoustics Australia, 48 (2020) 93-105.
[27] Y. Wu, J. Kang, W. Zheng, Y. Wu, Acoustic comfort in large railway stations, Applied Acoustics, 160 (2020) 107137.
[28] C. Liu, J. Kang, H. Xie, Effect of sound on visual attention in large railway stations: a case study of St. Pancras railway station in London, Building and Environment, 185 (2020) 107177.
[29] M. Yani, A. Amiruddin, Analysis of train noise level at bandar khalipah station, deli serdang using sound level meter 130 dB, in: Journal of Physics: Conference Series, IOP Publishing, 2021, pp. 012017.