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INVESTIGATION OF TREE CHARACTERISTICS FOR TRAFFIC NOISE ABATEMENT

There is a connection between noise reduction and roadside tree plantation. Understanding how properties of trees (density, height, leaf type, crown spread, etc.) impact noise attenuation is crucial. The current study measured and compared the roadside traffic noise at various locations (with/without trees/plantations) in selected Multan areas. Eight locations (Bahawalpur Road, Expressway, Vehari Road, Bosan Road, Eidgah Road, Masoom Shah Road, Piran-Gaib Road, and Khanewal Road) throughout Multan City. A digital sound level meter (MS-6701) was used to measure the noise levels during months of winter and summer seasons. During field visits, the tree type, leaf type, average height, density, canopy crown spread, and presence of any vegetation in each designated area were noted. The sound pressure data was compared with the noise level standards as recommended by Punjab Environment Quality Standards. A clear reduction in sound levels can be observed with trees. The tree plantings reduced the noise only on the Expressway (65 dbA) and Piran Gaib Road (64 dbA) in May 2022. In June 2022, the trees were only beneficial in reducing noise near Piran Gaib Road (64 dbA). Due to tree plantation, the maximum reduction of 11 dbA) was reported in June 2022 at Eig Gah Road, followed by a 10.1 dbA) reduction in December 2021 at Khanewal Road. Maximum noise reduction was observed at the Expressway and Piran Gaib Roads, where Pongamia pinata and Melia azedarach are planted along with some grass. The comparison clearly showed a reduction in noise due to roadside plantations. Tree plantation helps improve the area's overall look and enhances aesthetic sense and scenic beauty.

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1. INTRODUCTION

A sound level above 55 dB creates hearing pain, while noise beyond 65 dB can induce hearing loss if the individual is in contact for an extended period [1–3]. High traffic volumes, poor road conditions, and a dearth of vegetation/trees contribute to noise pollution. Humans are impacted by noise, which can disrupt sleep, cause anxiety, ruin attention, and impair learning ability. Roadside noise has become more prevalent, with vehicles, public transportation, bicycles, and rickshaws (local autos) contributing the most. Yofianti and Usman [4] ascertained that different plants absorb roadway noise. Data on plant types and noise pollution on urban highways are gathered from studies carried out along various urban road segments. It has been demonstrated that some plant species can help to reduce the amount of noise pollution along metropolitan highways. The comfort of road users while driving can be improved by lowering the noise pollution caused by absorption by specific plant kinds. Additionally, a well-engineered green roadside infrastructure can improve the environment and atmosphere. Therefore, while designing urban roadways, the road environment's condition may be considered. To implement effective noise abatement measures, noise levels should be regularly assessed. Urban noise control strategies include pathway control, recipient control, and design control. A commonly used noise abatement strategy includes making a noise obstruction along the roads/streets. Noise barriers made of various materials are designed to obstruct the line of sight between houses (constructed along streets) and running vehicles on highways to reduce noise levels [4]. Federal Highway Authority (FHWA) advised that the noise in the residential areas should not be more than 67 dB [5]. If roadside traffic noise exceeds these limits, appropriate noise-control measures should be implemented.

There is a connection between noise reduction and roadside tree plantation. Understanding how vegetation impacts noise attenuation is therefore crucial. Vegetation may naturally lower noise and temperature. Planting plants beside the road with a shrub arrangement will minimize noise and heat pollution [6]. Noise reduction can be attained by increasing the space between the source and receiver, but this is not always very effective. Tree plantation is the most suitable strategy for reducing noise pollution [7, 8]. Various research on tree belts concluded that tree length, size, density, and width all have an important influence on noise absorption. The width of tree belts was critical in decreasing noise, as breadth increased, considerable absorption and reduction were seen [7, 9]. Plant species, plant height, density, and tree crown spread, as well as various climatic variables such as wind speed, humidity, temperature, and sound types, all have a role in noise suppression. The various plant parts especially leaves, branches, bushes, and twigs of trees absorb sound waves. Plants with thick leaves and branches can greatly absorb sounds. Large trees' branches, twigs, and branches cause sound to be refracted and deflected. Figure 1 shows the abatement effect of trees on noise and trees as a noise barrier. The width, height, and density of the vegetative barrier affect sound intensity absorption.

There is a complex relationship between noise attenuation and vegetation, and therefore understanding how vegetation impacts noise attenuation is also crucial.

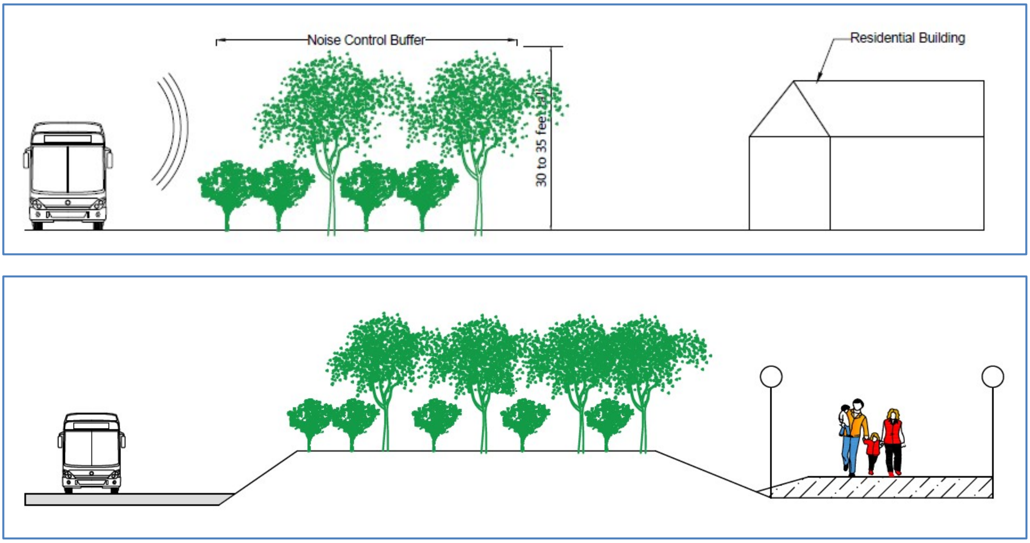

Fig. 1. Abatement effect of trees on noise (a), and trees working as a noise barrier (b)

The most common health problem of noise pollution is noise-induced hearing loss (NIHL). Natives who are exposed to loud noise can suffer from high blood pressure, heart disease, sleep disorders, stress, aggravation, and decreased productivity. Roadside traffic noise is restricted by laws and administrative directives, and hence, when planning a road or highway project, the installation of noise barriers should also be considered to protect the populace from the harmful impacts of noise pollution. Out of the different noise barriers in the world, trees are the most sustainable, aesthetically pleasing, and environmentally friendly. Denser tree rows give acoustic noise buffering and abating benefits in addition to being more visually pleasing and economically more inexpensive than choices such as precast concrete and iron barriers. Tyagi et al. [10] concluded that vegetation belts of sufficient density would cause the desirable abatement of roadside traffic noise. Vegetation belts are efficient in reducing roadside traffic noise and provide aesthetic aspects that have a very positive effect on human nature and psychology, which is also very crucial for the reduction of annoyance caused by noise.

Multan is a relatively less-developed region of South Punjab, therefore it is rapidly growing and developing. The amount of traffic in Multan is increasing continuously. The current study measured and compared the roadside traffic noise at various locations (with/without trees/plantations) in selected Multan areas. By contrasting the noise levels with and without trees, the influence of vegetation on noise reduction was investigated. It also investigated how traffic noise changed with the seasons (winter and summer).

We also assessed which tree characteristics – tree species, height, density, canopy spread, and leaf size – significantly reduce noise. This study looked at how different kinds of trees can affect the amount of traffic noise on city streets. Due to the increased noise pollution spurred on by the increased traffic, people are becoming more and more irritated and restless. Residents of Multan suffer a lot from the traffic noise from motorcycles, rickshaws, cars, buses, and trucks. Therefore, a traffic noise survey was conducted to evaluate the residents' responses to impacts from noise pollution. The noise data was collected from the locations selected on the eight different roads of Multan. Out of these eight locations, four locations have trees, bushes, and shrubs, while the other four are without trees.

2. MATERIALS AND METHODS

Study locations. Eight locations (Bahawalpur Road, Expressway, Vehari Road, Bosan Road, Eidgah Road, Masoom Shah Road, Piran-Gaib Road, and Khanewal Road) throughout Multan City were selected based on their different and unique demographic features. Out of these eight locations, four are with trees, and four are without trees. The information is given in Table 1. The distances between the noise source(s) and receiver instrument are also mentioned in the table.

Table 1

Location of sites under study

Road	Land use type	*D* [m]	Type of road	Vegetation	Coordinates
Bosan Road	residential	3.8	major arterial	no	71.475672°, 30.221235°
Bahawalpur Road		3.5		no	71.492484°, 30.158936°
Eid Gah Road		3.9		yes	71.477083°, 30.209584°
Expressway	commercial	3.3	connector	yes	71.509171°, 30.175783°
Piran-Gaib Road		3.0		yes	71.551452°, 30.200346°
Masoom Shah Road		3.2		no	71.500920°, 30.204964°
Khanewal Road		3.0	highway	yes	71.586115°, 30.246231°
Vehari Road		3.0	district road	no	71.523651°, 30.165029°

D – distance between the n mmbn mmmmmmmmnoise source and receiver instrument.

Bahawalpur Road. This road surrounds (Figs. 2 and 3) a residential area predominantly. There are different housing societies with shops and plazas around them. Most of the traffic on this road consists of bikes, rickshaws, cars, tractor trollies, loading vehicles, buses, and wagons. Mainly, buses, bikes, and cars contribute significantly to roadside traffic noise. During rush hour, a large number of people, especially university and college students, utilize this road to commute. This road is also utilized by people heading to Lodhran and Bahawalpur to avoid city traffic.

Fig. 2. A view of the Bahawalpur Road with traffic flowing

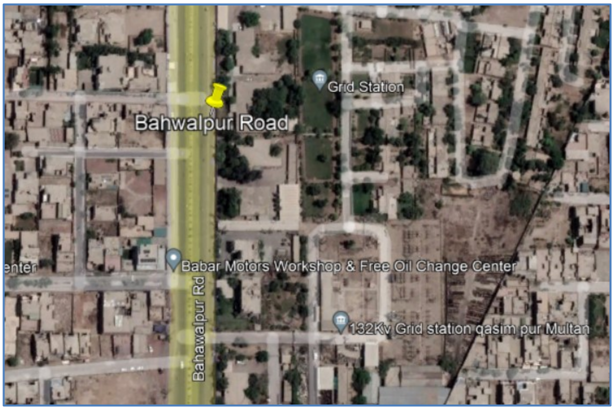

Fig. 3. A Google Earth image of Bahawalpur Road

Expressway near Faisal Movers Bus Terminal. This place is near Faisal Movers Bus terminal and General Bus Stand Multan (Figs. 4–6). The Expressway goes all the way from Vehari Chowk (road junction) to Chowk Kumharan Wala. This area is predominantly commercial, along with some hotels and educational institutes. Due to its proximity to bus terminals, a sizable portion of the traffic is made up of buses, wagons, rickshaws, motorcycles, and vehicles. It is one of the noisier parts of the city because of the significant vehicle traffic and their obvious use of pressure horns. Essentially, it acts as the city's entry and departure point, since the majority of commercial vehicle traffic utilizes this route to enter and exit Multan. There are several large transportation companies with amenities here.

Fig. 4. A view of the Expressway without trees on the roadside

Fig. 5. A view of the Expressway with a thick belt of trees

Fig. 6. A Google Earth image of the Expressway road

Bosan Road. This is an important route that serves as a connection in Multan's transport system, connecting several different areas of the city. It links the residential, business, and industrial sectors as well as the city's outskirts and urban areas. It is a multilane one-way road with a plantation median at its center and a service road on both sides to facilitate the road users. It starts from 9 number Chungi (impost) and goes all the way to Baha Uddin Zakariya University Multan (Figs. 7, 8). It is also one of the busiest roads in the city. Moreover, this area consists of some renowned public and private sector schools, colleges, and shopping plazas. All of these locations contribute to the increasing number of journeys in this area, which increases the quantity of noise on the road. Bikes, rickshaws, schools, college and university buses, and vehicles make up the majority of the traffic in this area.

Fig. 7. A view of Bosan Road

Fig. 8. A Google Earth image of Bosan Road

Masoom Shah Road. This road is one of the main connector roads that connects Daulat Gate to Chowk Kumharan (Figs. 9, 10). This area is densely populated and predominantly commercial having a huge market of marble, granite, and tuff tiles. The area also has private colleges and Islamic learning institutions. The traffic on this road mainly consists of bikes, carts, speedo buses, donkey carts, and other loading vehicles.

Fig. 9. Traffic flowing on Masoom Shah Road

Fig. 10. A Google Earth image of Masoom Shah Road

Piran Ghaib Road. Piran Ghaib Road is a significant artery in Multan, serving many residential, commercial, and industrial zones. It serves as an important link for business activities, freight transportation, and commuting. Because of its important location, it is often packed with traffic, especially during peak hours. It is the primary route for locals traveling to work, school, or business enterprises. This is also a connector road (Figs. 11, 12). This route is frequently used by motorists traveling from the Canal route to the Samejabad neighborhood in New Multan.

Khanewal Road. Khanewal Road is a significant thoroughfare that connects the city with the regional transit system. It is a multilane one-way road with a plantation median in some areas and a plain concrete New Jersey barrier in others, as well as a service road in certain locations to help road users. This district road connects Multan and Khanewal City along several small towns and villages (Figs. 13, 14). To determine the impact of trees on noise, two places along this route were chosen: one with trees and vegetation and the other without. The traffic on this road consists of buses, trucks, cars, and other load-carrying vehicles.

Fig. 11. Piran Ghaib Road

Fig. 12. A Google Earth image of Piran Gaib Road

Eid Gah Road. In Multan, Eid Gah Road is ideally situated to link several significant neighborhoods. It offers access to Eid Gah, one of the city's most well-known religious and cultural hubs. Furthermore, it connects to numerous other important roads, notably Vehari Road and Sher Shah Road, making it an important component of the metropolitan transportation system. It is a multilane one-way road with a plantation border in some areas, back-connecting curb stones in others, and a service road in certain places to help road users. The area around this road is predominantly residential and commercial, with houses, shops, and restaurants (Figs. 15, 16). This route experiences heavy traffic throughout the day, especially in the morning and evening rush hours.

Fig. 13. Thick trees on Khanewal Road

Fig. 14. A Google Earth image of Khanewal Road

Fig. 15. Thick rows of trees on Eid Gah Road

Fig. 16. A Google Earth image of Eid Gah Road

Vehari Road. One of the major roads in Multan, Vehari Road is an important part of the city's transport system. It runs through a variety of residential and business locations as it advances from downtown to the outskirts. This road connects Multan to Mailsi, Vehari, Burewala, and other cities. It is also a district road with a high volume of traffic flowing each day on it (Figs. 17, 18). The data was collected in residential and commercial locations with few schools and colleges. Traffic on this road is mainly bikes, cars, buses, and rickshaws.

Fig. 17. A view of traffic on Vehari Road

Fig. 18. A Google Earth image of Vehari Road

Sound pressure measurements and threshold. A digital sound level meter (model MS-6701) was used to measure the noise levels. Before and after readings, the sound meter was calibrated and tested. The measurements were done using a fast-sampling rate. The sound level meter can measure sound pressure levels ranging from 30 to 130 dB with a precision of 0.1 dB and an accuracy of up to 1.5 dB. The sound pressure data obtained was compared with the noise level standards (in dbAL_{eq}] as recommended in Punjab Environment Quality Standards (PEQS) by the Environmental Protection Department (EPD), Punjab. Where dbAL_{eq} is the weighted average of the level of sound in decibels on scale A which is relatable to human hearing.

Punjab Environment Quality Standards (PEQS-2016) provided the following limits of noise levels during day and night times in different types of zones as follows: residential day time: 55 dbA, residential night time: 45 dbA, commercial day time: 65 dbA, commercial night time: 55 dbA, industrial day time: 75 dbA, industrial night time 65 dbA, and silence zone day time: 50 dbA, silence zone night time: 45 dbA. These regulations establish the legal noise limits for several zones, including residential, commercial, and industrial ones. Therefore accordingly, we considered the daytime noise restriction in residential zones as 55 dbA, and 65 dbA in commercial areas. During the day, construction sites are permitted to be as loud as 75 dbA. The allowable noise level in silence zones close to hospitals and schools is 50 dB at all times [11].

Data collection and sampling. A random sampling technique was used to collect data for each location. The data was taken in 10-minute periods four times during the winter (December 2021 and January 2022) and summer (May 2023 and June 2022) seasons, from 8:00 AM to 8:40 AM and 6:00 PM to 6:40 PM at 8 different locations in the city of Multan. These time durations were included in day-time measurements, because as per PEQS guidelines, daytime hours include from 6.00 AM to 10.00 PM and nighttime from 10.00 PM to 6.00 AM. The total number of readings taken in a single season at a single site was 2400 [11]. Sound pressures at the locations were calculated through a sound meter mentioned above. Sound pressure levels were recorded in the following residential areas: Bosan Road, and Bahawalpur Road. There are no trees or plants on Bosan and Bahawalpur Roads. Sound pressure levels were only compared with/without trees at the following selected commercial locations: Piran Gaib Road, Expressway, and Khanewal Road. Sound pressure levels were recorded with and without trees in one residential area, Eid Gah Road. Sound pressure levels were also measured at the following commercial areas: Vehari Road and Masoon Shah Road. There are no tree plantations along these commercial areas. The instrument was kept at a height of 1.524 m (adopted from standards) from the ground level and a distance of 4.572 m from the nearest edge (outer edge of pavement to where the instrument was placed, i.e., the outer edge is the edge where the pavement ends) [12]. Data output was received on MS Excel.

Calculation of tree type, density, height, and crown spread. During field visits, the tree type and presence of any vegetation in each designated area were also noted. The number of trees per 100 m of street length is referred to as street tree density, while the number of trees per 100 m across hierarchical street classes is referred to as street tree distribution [13]. The tree density was calculated by counting the number of trees per 3.048 running meters [14]. The tree height was measured from the ground level to the highest point. The stick method mentioned by The University of British Columbia (UBC) was followed to calculate the tree height [15]. This approach requires a stick and a measuring tape. The stick was the same length as the arm, or it was grasped at the point where the length above the hand matched the arm's length. The stick was held 90° to the straight outstretched arm. We took our time walking backward till the top of the tree aligned with the top of our stick and from where we grasped the stick should coincide with the bottom of the tree. We took note of the location of our feet. The distance between our feet and the tree should be nearly equal to the tree's height. The height of the tree was measured in meters. The diagram elaborating the process is given in Fig. 19.

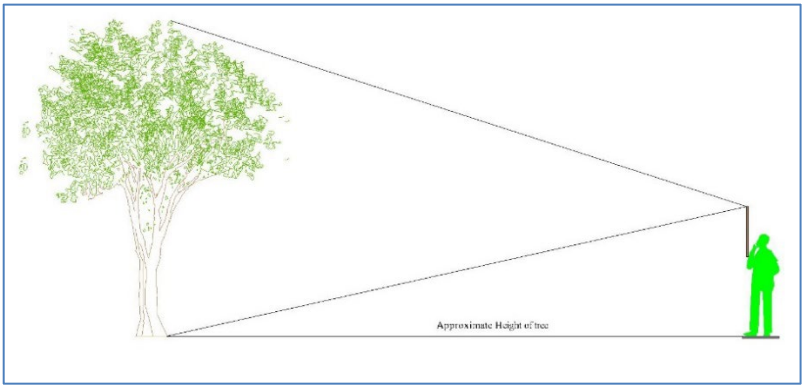

Fig. 19. Measuring the approximate height of a tree

Trees have a crown that is uneven in form. The crown spread was measured from branch tip to branch tip in two distinct directions and averaged to account for this. The initial measurement was obtained at the broadest point of the crown. The second was taken at 90° to the first, again at the broadest point of the crown [15]. The average crown spread was calculated by adding the two distances (A, B) and dividing them by two. The diagram elaborating the principle is given in Fig. 20.

$$\text{Crown spread} = \frac{A+B}{2} \tag{1}$$

$L_{EX,8\ h}$ calculation. The International Organization for Standardization (ISO) recommendations were used to calculate A – weighted noise exposure values adjusted to

an 8-hour working day. This is also termed as daily exposure level. It is very useful in assessing the harmful effects of noise on humans [16]

$$L_{\mathrm{EX,8\,h}} = L_{A\,\mathrm{eq},T_e} + 10\log\frac{T_e}{T_0} \tag{2}$$

where $L_{A\,\mathrm{eq},T_e}$ is the A-weighted equivalent continuous sound pressure level for T_e, db, T_e is the effective duration of the working day, h, T_0 is the reference duration (T_0 = 8 h).

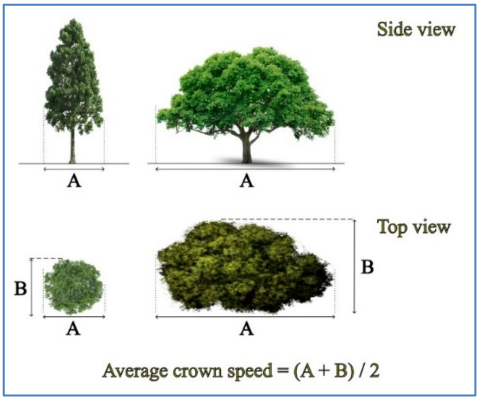

Fig. 20. Method of measuring crown spread

Survey on noise pollution. A survey was conducted to find out about public/resident reactions to the negative effects of roadside traffic noise. Google Forms was used to obtain feedback on roadside traffic noise from residents of the designated communities. The questions were asked on the effects of noise on their ability to focus at work, insomnia, watching TV, depression/anxiety, blood pressure, and headaches.

3. RESULTS

Overall, the noise data comparison clearly showed a reduction in noise due to roadside vegetation, i.e., trees, shrubs, and grass.

3.1. NOISE LEVEL COMPARISONS FROM PEQ STANDARDS (WITHOUT TREE AREAS)

The locations where there are no trees or vegetation, i.e., Bosan Road (residential), Bahawalpur Road (residential), Vehari Road (commercial), and Masoom Shah Road (commercial). At these locations, the noise levels exceeded the PEQ standards both in the summer and winter months (see Tables 2–5 for details). Tables 2–5 represent the comparisons from PEQ standards with noise levels in dbA for different locations during

December 2021, January 2022, May 2022, and June 2022. Maximum sound pressure (78.661 dbA) was detected on the Vehari Road in the summer (May 2022).

3.2. NOISE LEVEL COMPARISONS AS PER PEQS (WITH/WITHOUT TREES)

For daytime, as per PEQS standard, the residential limit for noise is 55 dbA, and 65 dbA for commercial. With/without tree comparisons for noise levels were done at Eid Gah Road (residential), Expressway (commercial), Piran Gaib Road (commercial), and Khanewal Road (commercial) in both seasons. A clear reduction in sound levels can be observed with trees at these locations. Tables 2–5 represent the comparisons from PEQ standards with noise levels (dbA) with/without tree plantation for different locations during December 2021, January 2022, May 2022, and June 2022. The tables also mention the difference in noise levels (L_{Aeq} in dbA) between the presence/absence of trees at the specified locations.

Table 2

Noise levels [dbA] for different locations in winter (December 2021)

No.	Trees	Min	Max	Mean	*SD*	L_{Aeq}[c]	PEQS[d]	Location	Difference (L_{Aeq})
1	no	61.5	94.2	70.6	2.9	72.361	55	Bosan Road[b]	
2	no	59.8	85.5	70.9	4.1	72.661	55	Bahawalpur Road[b]	
3	no	59.7	83.2	68.9	3.9	70.661	55	Eid Gah Road[b]	9.4
	yes	52.3	75.7	59.5	3.0	61.261	55	Eid Gah Road[b]	
T test results: $t = 93.59$, 95% CI 9.203–9.597, p-value < 0.0001 < 0.050 (statistically significant)									
4	no	55.3	81.1	64.3	3.4	66.061	65	Expressway[a]	6.9
	yes	52.1	73.0	57.4	2.3	59.161	65	Expressway[a]	
T test results: $t = 82.34$, 95% CI 6.735–7.065, p-value < 0.0001 < 0.050 (statistically significant)									
5	yes	59.4	74.7	67.0	4.4	68.761	65	Piran Gaib Road[a]	6.9
	yes	55.4	70.4	60.1	2.2	61.861	65	Piran Gaib Road[a]	
T test results: $t = 68.71$, 95% CI 6.703–7.097, p-value < 0.0001 < 0.050 (statistically significant)									
6	no	58.5	88.0	71.2	2.9	72.961	65	Vehari Road[a]	
7	no	57.2	91.8	72.5	4.8	74.261	65	Masoom Shah Road[a]	
8	no	60.5	83.8	72.2	6.7	73.961	65	Khanewal Road[a]	0.1
	yes	52.6	78.0	62.1	3.0	63.861	65	Khanewal Road[a]	
T test results: $t = 64.40$, 95% CI 9.806–10.394, p-value < 0.0001 < 0.050 (statistically significant)									

[a]Commercial areas: Expressway, Vehari Road, Khanewal Road, Piran Gaib Road, and Masoom Shah Road.

[b]Residential areas: Bosan Road, Bahawalpur Road, and Eid Gah Road. PEQS standards are used subsequently following these criteria.

[c]$L_{EX,8h}$ is the equivalent sound exposure level (L_{eq}) of noise averaged over 8 hours measured in dbA as defined by ISO 1999, 1990 point 3.6.

[d]PEQS (Punjab Environmental Quality Standards): residential (daytime: 55 dbA), rommercial (daytime 65 dbA).

With tree plantations, the noise level was within the PEQ standard at Expressway (commercial area: 59 dbA, Piran Gaib Road (commercial area: 61 dbA, and Khanewal Road (commercial area: 63 dbA in December 2021 (Table 2). Similarly, with tree plantations, the noise level was within the PEQ standard at Expressway (commercial area: 61 dbA, Piran Gaib Road (commercial area: 60 dbA, and Khanewal Road (commercial area: 65 dbA in January 2022 (Table 3).

Table 3

Noise levels [dbA] for different locations in winter (January 2022)

No.	Trees	Min	Max	Mean	*SD*	L_{Aeq}[c]	PEQS[d]	Location	Difference (L_{Aeq})
1	no	61.5	87.4	70.2	3.3	71.961	55	Bosan Road[b]	
2	no	63.3	88.1	72.3	3.4	74.061	55	Bahawalpur Road[b]	
3	no	63.7	84.8	70.7	2.8	72.461	55	Eid Gah Road[b]	8.5
	yes	56.4	80.9	62.2	3.1	63.961	55	Eid Gah Road[b]	
T test results: $t = 99.68$, 95% CI 8.332–8.668, p-value < 0.0001 < 0.050 (statistically significant)									
4	no	56.0	82.0	61.2	3.0	62.961	65	Expressway[a]	1
	yes	54.9	78.2	60.2	2.9	61.961	65	Expressway[a]	
T test results: $t = 11.74$, 95% CI 0.833–1.167, p-value < 0.0001 < 0.050 (statistically significant)									
5	no	56.2	82.8	65.9	3.5	67.661	65	Piran Gaib Road[a]	7.4
	yes	53.5	71.7	58.5	2.3	60.261	65	Piran Gaib Road[a]	
T test results: $t = 86.56$, 95% CI 7.232–7.568, p-value < 0.0001 < 0.050 (statistically significant)									
6	no	63.1	96.7	67.9	3.1	69.661	65	Vehari Road[a]	
7	no	61.0	80.7	68.2	4.3	69.961	65	Masoom Shah Road[a]	
8	no	58.6	88.9	71.9	3.0	73.661	65	Khanewal Road[a]	7.8
	yes	54.3	80.5	64.1	3.0	65.861	65	Khanewal Road[a]	
T test results: $t = 90.066$, 95% CI 7.630–7.970, p-value < 0.0001 < 0.050 (statistically significant)									

[a]Commercial areas: Expressway, Vehari Road, Khanewal Road, Piran Gaib Road, and Masoom Shah Road.

[b]Residential areas: Bosan Road, Bahawalpur Road, and Eid Gah Road. PEQS standards are used subsequently following these criteria.

[c]$L_{EX,8h}$ is the equivalent sound exposure level (L_{eq}) of noise averaged over 8 hours measured in dbA) as defined by ISO 1999, 1990 point 3.6.

[d]PEQS (Punjab Environmental Quality Standards): residential (daytime 55 dbA), commercial (daytime 65 dbA).

The tree plantings reduced the noise only on the Expressway (commercial area 65 dbA) and Piran Gaib Road (commercial area 64 dbA) in May 2022 (Table 4). Furthermore, in the summer month of June 2022 (Table 5), the trees were only beneficial in reducing noise near Piran Gaib Road (commercial area 64 dbA).

Due to tree plantation, the maximum reduction of 11 dbA was reported in June 2022 at Eig Gah Road (residential area), followed by a 10.1 dbA reduction in December 2021 at Khanewal Road (commercial area). Further, up to 9 dbA reduction was observed at Eig Gah Road in December 2021 and May 2022. Also, a 9 dbA reduction was observed on Khanewal Road in June 2022.

Table 4

Noise levels [dbA] for different locations in summer (May 2022)

No.	Trees	Min	Max	Mean	*SD*	L_{Aeq}[c]	PEQS[d]	Location	Difference (L_{Aeq})
1	no	66.1	101.3	75.9	3.1	77.661	55	Bosan Road[b]	
2	no	64.1	91.6	76.0	4.4	77.761	55	Bahawalpur Road[b]	
3	no	64.5	89.9	74.4	4.2	76.161	55	Eid Gah Road[b]	9
	yes	57.5	83.2	65.4	3.3	67.161	55	Eid Gah Road[b]	
T test results: $t = 82.54$, 95% CI 8.786–9.214, p-value < 0.0001 < 0.050 (statistically significant)									
4	no	60.1	88.1	69.9	3.7	71.661	65	Expressway[a]	6.1
	yes	57.9	81.1	63.8	2.5	65.561	65	Expressway[a]	
T test results: $t = 66.922$, 95% CI 5.921–6.279, p-value < 0.0001 < 0.050 (statistically significant)									
5	no	61.3	88.1	70.9	3.5	72.661	65	Piran Gaib Road[a]	8.3
	yes	57.7	73.3	62.6	2.3	64.361	65	Piran Gaib Road[a]	
T test results: $t = 97.088$, 95% CI 8.132–8.468, p-value < 0.0001 < 0.050 (statistically significant)									
6	no	69.7	94.6	76.9	3.0	78.661	65	Vehari Road[a]	
7	no	59	94.6	74.7	4.9	76.461	65	Masoom Shah Road[a]	
8	no	64.5	89.9	74.4	4.2	76.161	65	Khanewal Road[a]	7.6
	yes	56.6	83.9	66.8	3.2	68.561	65	Khanewal Road[a]	
T test results: $t = 70.51$, 95% CI 7.388–7.812, p-value < 0.0001 < 0.050 (statistically significant)									

[a]Commercial areas: Expressway, Vehari Road, Khanewal Road, Piran Gaib Road, and Masoom Shah Road.

[b]Residential areas: Bosan Road, Bahawalpur Road, and Eid Gah Road. PEQS standards are used subsequently following these criteria.

[c]$L_{EX,8h}$ is the equivalent sound exposure level (L_{eq}) of noise averaged over 8 hours measured in dbA as defined by ISO 1999, 1990 point 3.6.

[d]PEQS (Punjab Environmental Quality Standards): Residential (daytime 55 dbA), vommercial (daytime 65 dbA).

Table 5

Noise levels [dbA] for different locations in summer (June 2022)

No.	Trees	Min	Max	Mean	*SD*	L_{Aeq}[c]	PEQS[d]	Location	Difference (L_{Aeq})
1	no	65.4	93	74.7	3.5	76.461	55	Bosan Road[b]	
2	no	65.3	90.8	74.6	3.6	76.361	55	Bahawalpur Road[b]	
3	no	67.1	89.3	74.5	2.9	76.261	55	Eid Gah Road[b]	11.1
	yes	57.5	82.6	63.4	3.1	65.161	55	Eid Gah Road[b]	
T test results: $t = 97.088$, 95% CI 8.132–8.468, p-value < 0.0001 < 0.050 (statistically significant)									
4	no	60.2	88.2	65.9	4.2	67.661	65	Expressway[a]	0.6
	yes	59	84.1	65.3	2.4	67.061	65	Expressway[a]	
T test results: $t = 128.100$, 95% CI 10.93–11.27, p-value < 0.0001 < 0.050 (statistically significant)									
5	no	58.9	87.2	70.1	3.7	71.861	65	Piran Gaib Road[a]	7.2
	yes	57.5	77.1	62.9	2.5	64.661	65	Piran Gaib Road[a]	
T test results: $t = 78.99$, 95% CI 7.021–7.379, p-value < 0.0001 < 0.050 (statistically significant)									
6	no	64.1	95.8	72.3	4.9	74.061	65	Vehari Road[a]	

Table 5

Noise levels [dbA] for different locations in summer (June 2022)

No.	Trees	Min	Max	Mean	*SD*	L_{Aeq}[c]	PEQS[d]	Location	Difference (L_{Aeq})
7	no	63.0	90.7	70.0	5.9	71.761	65	Masoom Shah Road[a]	
8	no	62.3	94.6	76.5	3.2	78.261	65	Khanewal Road[a]	9.2
	yes	56.6	89.5	67.3	3.1	69.061	65	Khanewal Road[a]	
T test results: $t = 101.16$, 95% CI 9.021–9.379, p-value < 0.0001 < 0.050 (statistically significant)									

[a]Commercial areas: Expressway, Vehari Road, Khanewal Road, Piran Gaib Road, and Masoom Shah Road.

[b]Residential areas: Bosan Road, Bahawalpur Road, and Eid Gah Road. PEQS standards mentioned in the tables are used subsequently following these criteria.

[c]$L_{EX,8\,h}$ is the equivalent sound exposure level (L_{eq}) of noise averaged over 8 hours measured in dbA as defined by ISO 1999, 1990 point 3.6.

[d]PEQS (Punjab Environmental Quality Standards): residential (daytime: 55 dbA), commercial (daytime 65 dbA).

3.3. STATISTICAL COMPARISONS

An unpaired t-test was used to compare the mean values of sound pressure levels for areas with and without trees. The t-test results are given in the last rows of Tables 2–5. There existed a significant difference (p-value < 0.0001) between with/without sound pressure measurements for all data collection months.

3.4. VEGETATION AND TREE TYPES AT SELECTED LOCATIONS

The type of planted trees and vegetation in the locations along with their physical characteristics with leaf types, average tree height (meter), and average canopy spread are mentioned in Tables 6, 7.

Table 6

Tree characteristics of the selected locations

Location	Tree type	Density of trees [trees/10 m]	Any other vegetatiom
Expressway	sukh chyn, bakain	dense 6.56–9.84	grass
Eid Gah Road	arjun, sufeda, bakain, neem	dense 6.56–9.84	dabh, khabbal
Khanewal Road	mango, shisham, neem	dense 6.56–9.84	daabh
Piran Gaib Road	sukh chyn	moderate 3.28–4.92	grass

Table 7

Detailed information regarding trees

Common /local	English name	Species	Family	Average		Leaf type
				Height [m]	Canopy range [m]	
Sukh Chyn	Indian Beech Tree	Pongamia pinnata	Fabaceae	5.49	9.14–10.06	Short-stalked, and rounded
Shisham	North Indian rosewood	Dalbergia sissoo	Fabaceae	9.14	13.716–15.24	2.5–6 cm long, oval, tough and pointed
Neem	Indian Lilac	Azadirachta indica	Meliaceae	6.71	9.14–9.60	compound, leaflets 2–7.5 cm long, edges toothed
Daabh	*Halfa Grass*	*Desmostachya bipinnata*	Poaceae	0.46	NA	shrubby
Khabbal	*Bermuda Grass*	*Cynodon dactylon*	Poaceae	0.46	NA	shrubby
Babul	*Gum Arabic tree*	*Acacia nilotica*	Fabaceae	8.53	7.62–8.84	small, 2.5–7.5 cm long, with yellow flowers
Sufeda	Tree Eucalyptus	Eucalyptus globulus	Myrtaceae	10.67	3.05–4.57	Simple 3–5 lobed, 5–10 cm long, broad
Bakain	China berry tree	Melia azedarach	Meliaceae	7.01	10.67–12.19	Compound up to 60 cm long
Arjun	Arjun Tree	Terminalia arjuna	Combretaceae	11.58	18.29–21.34	10–15 cm long
Mango	Mango tree	Mangifera indica	Anacardiaceae	16.76	15.24–17.68	Dark green leathery, shiny, 18 cm long, 4–8 cm wide

Table 8 comprises combined data on mean sound pressure levels and L_{Aeq}, as well as the type of plantations and tree densities in the summer and winter seasons. Maximum noise reduction was observed at the Expressway and Piran Gaib Roads, where Sukh Chyn (Pongamia pinata) and Bakain (Melia azedarach) are planted along with some grass. Sukh Chyn (Pongamia pinata) and Bakain (Melia azedarach) are found in thick stands of 2–3 trees per foot on the Expressway. On Piran Gaib Road, Sukh Chyn (Pongamia pinata) is found in moderate density, with 3.28–4.93 trees per 10 m. Sukh Chyn had an average height of 5.49 m and a canopy of 9.14 m, whereas Bakain had an average height of 7.01 m and a canopy of 10.67 m.

Table 8

Noise levels with plantation/trees

Location	Mean±*SD* [dbA]	L_{Aeq} [dbA]	Tree plantations	Tree density
December 2021				
Eid Gah Road	59.5±3.0	61.261	Arjun, Sufeda, Bakain, Neem, Daabh and Khabbal	dense
Expressway	57.4±2.3	59.161	Sukh Chyn, Bakain and grass up to 1 ft	dense
Khanewal Road	62.1±3.0	63..861	Mango, Shisham, Neem and Daabh	dense
Piran Gaib Road	60.1±2.2	61.861	Sukh Chyn and grass up to 1 ft	moderate
January 2022				
Eid Gah Road	62.2±3.1	63.961	Arjun, Sufeda, Bakain, Neem, Daabh and Khabbal	dense
Multan Expressway	60.2±2.9	61.961	Sukh Chyn, Bakain and grass upto 1 ft	dense
Khanewal Road	64.1±3.0	65.861	Mango, Shisham, Neem and Daabh	dense
Piran Gaib Road	58.5±2.3	60.261	Sukh Chyn and Grass up to 1 ft	moderate
May 2022				
Eid Gah Road	65.4±3.3	67.161	Arjun, Sufeda, Bakain, Neem, Daabh and Khabbal	dense
Multan Expressway	63.8±2.5	65.561	Sukh Chyn, Bakain and Grass upto 1 ft	dense
Khanewal Road	66.8±3.2	68.561	Mango, Shisham, Neem and Daabh	dense
Piran Gaib Road	62.6±2.3	64.361	Sukh Chyn and grass up to 1 ft	moderate
June 2022				
Eid Gah Road	63.4±3.1	65.161	Arjun, Sufeda, Bakain, Neem, Daabh, and Khabbal	dense
Multan Expressway	65.3±2.4	67.061	Sukh Chyn, Bakain and grass up to 1 ft	dense
Khanewal Road	67.3±3.1	69.061	Mango, Shisham, Neem and Daabh	dense
Piran Gaib Road	62.9±2.5	64.661	Sukh Chyn and Grass up to 1 ft	moderate

3.5. NOISE POLLUTION SURVEY

There were 46 (9.1%) respondents from Eig Gah Road, 56 (11%) from Bosan Road, 101 (20%) from Bahawalpur Road, 35 (7%) from Multan Expressway (near local bus

Table 9

Residents' responses on impacts from noise pollution (*n* = 507)

Question	Yes	No	Percent of yes	Percent of no
Noise makes it harder to hear sounds	486	21	95.85	4.15
Noise reduces focus on work	481	26	94.87	5.13
Sleeplessness is caused by noise	405	102	79.88	20.12
The incapacity to study is caused by noise	469	38	92.50	7.50
The noise makes it difficult to watch television	348	159	68.63	31.37
Noise contributes to depression and anxiety	396	111	78.10	21.90
Noise raises blood pressure	449	58	88.56	11.44
Headaches are caused by noise	470	37	92.70	7.30

stand), 107 (21.1%) from Vehari Road, 64 (12.6%) from Khanewal Road, 48 (9.5%) from Masoom Shah Road and 50 (10%) from Piran Gaib Road. 92–96% of respondents found it difficult to focus on work/study and to hear other sounds. 93% reported headaches, 80% lack of sleep, 78% anxiety, and 88% raised blood pressure (Table 9).

4. DISCUSSION

The population is increasing daily around the globe, and so is the case with Pakistan. More roads are being built, and as traffic grows, so do the difficulties connected with traffic and roads, the most prominent of which are noise and vehicle pollution. The current study monitored and contrasted roadside traffic noise in several Multan regions (with and without trees/plantations). Following vegetation characteristics including the type, height, density of trees, and crown spread are mentioned. According to this study, the presence of flora helps to reduce noise. Additionally, increasing the vegetation along the roadside reduces roadside traffic noise. Furthermore, the tree plantation promotes the aesthetic sense and visual attractiveness of the region. Overall, the noise data comparison demonstrated that roadside vegetation, such as trees, bushes, and grass, reduced noise. In the summer of 2022, the Vehari Road recorded the highest sound pressure (78.661 dbA. In both seasons, noise levels were compared with and without trees on Eid Gah Road (residential), Expressway (commercial), Piran Gaib Road (commercial), and Khanewal Road (commercial). The presence of trees in these places reduces sound levels. In December 2021, the noise level at the Expressway, Piran Gaib Road, and Khanewal Road was within the PEQ requirement due to tree plantings. Similarly, with tree plantings, the noise level was within the PEQ limit in January 2022 at the Expressway, Piran Gaib Road, and Khanewal Road. In May 2022, the tree plantings decreased noise on the Expressway and Piran Gaib Road. Furthermore, the trees were only useful in lowering noise near Piran Gaib Road during the summer month of June 2022. The greatest noise reduction was recorded along the Expressway and Piran Gaib Roads, where Sukh Chyn (Pongamia pinata) and Bakain (Melia azedarach) were planted beside grass. On the Expressway, Sukh Chyn (Pongamia pinata) and Bakain (Melia azedarach) grow in dense stands of 2–3 trees per foot. The biggest drop of 11 dbA was observed in June 2022 at Eig Gah Road (residential area), followed by a 10.1 dbA reduction in December 2021 at Khanewal Road (business area) due to tree plantation.

Natural vegetation can also be used as a noise barrier to reduce noise pollution in urban areas – plants along the roadside act as green barriers. Natural plants, if excessively enough, tall, and dense, can cause a reduction in roadside traffic noise. Vegetation plants act as environment-friendly noise barriers due to their herbal look are pleasant to see, and give satisfactory visual inspection. The screening effectiveness relies upon the thicknesses of tree belts and leaves density alongside the roadways. Effective plantation can lessen noise pollution by 10 to 15 decibels [17]. Through absorption, scattering, and reflection, trees can reduce noise levels. Different plant elements, such as leaves, bushes, and trunks, reflect and scatter sound, which lowers the noise level. The surface area of the leaves, trunks, and needles determines the amount of noise suppression. The level of noise reduction increases with the surface area. Greater noise attenuation will result from a wider tree belt [7, 18, 19]. Tree foliage also contributes significantly to sound dispersing, and it has been observed that larger leaves have a greater impact on sound level reduction than smaller leaves. In comparison to trees with narrow or needle-like leaves, such as conifers trees, broadleaved trees tend to attenuate noise more [20]. Broadleaved and evergreen trees are proved more effective in noise reduction, e.g., eucalyptus, holly, and evergreen oak. According to studies, conifers give more noise reduction per year. Shrubs and hedges also improve the noise reduction capabilities of trees that are nearest to the source. Additionally, tree bark has proven to be effective at reducing noise [21].

It was also determined that certain types of transportation contribute to noise pollution. According to a site assessment, cars made less noise than bikes, rikshaws (local autos), buses, and trucks. Therefore, the primary noise sources are buses and trucks, followed by rickshaws and motorbikes. As per the survey of this study, it is difficult for the majority of responders to focus on work/study when hearing other sounds. Headaches were reported by 93%, difficulty of sleep by 80%, anxiety by 78%, and high blood pressure by 88%. According to the World Health Organization (WHO), traffic noise is linked to sleep issues, fatigue, headaches, high blood pressure, anxiety, stress, and a higher risk of heart disease. Noise from traffic was not linked to ischemic heart disease morbidity or death. Noise sensitivity and irritation did not influence the effects of road traffic noise on ischemic heart disease morbidity. When exposed to road traffic noise, noise sensitivity may raise the risk of psychological illness. The impact of road traffic noise on psychological ill-health may be mediated through noise discomfort [22]. During the urban development of the residential schemes in the cities, a buffer zone should be kept between the housing schemes and roads. As a result, the nearby residents will not be adversely affected by the high roadside traffic noise.

The largest decrease of 11 dbA was observed in June 2022 at Eig Gah Road (residential area), followed by a 10.1 dbA reduction in December 2021 at Khanewal Road (business area) due to tree plantation. Furthermore, in December 2021 and May 2022, the Eig Gah Road saw a 9 dbA drop. In addition, a 9 dbA drop was reported on Khanewal Road in June 2022. Samara and Tsitsoni [14] and Tyagi et al. [10] indicated that flora not only reduces roadside traffic noise but also improves the aesthetics and visual attractiveness of the region. Samara and Tsitsoni [14] investigated road noise reduction by vegetation along the ring road of Thessaloniki. This noise reduction is considered satisfactory due to the tree belts extending on both sides of the ring road. The levels of noise along the ring road of Thessaloniki are over the limits. This is due to the high speed of passing vehicles, the tremendous activity, and the rate of heavy vehicles with more than two axles. The noise data were collected at two places: through the belt of vegetation and the simple grass-covered ground without trees. Higher reductions in noise were observed through the belt of trees than in the grass-covered ground. The results showed that the Pinus brutia belt of trees reduced about 6 dB of noise 60 m away from the road. It is imperative to underline that Pinus brutia is an evergreen species, so its tree needles retain acoustic energy throughout the entire year.

Karbalaei et al. [23] highlighted the potential significance of greenbelts along the roadside for noise attenuation by utilizing several tree species of three widths. Greenbelts are astonishingly effective strategies for reducing traffic-induced noise pollution (25, 50, and 100 m). According to their findings, greenbelts significantly and positively correlated with the reduction of noise pollution. The most significant noise level decrease was 44 dbA, 42.84 dbA, and 40.34 dbA, respectively, for trees and shrubs with a width of 100 m, a mixture of conifers and broadleaves with a width of 100 m, and 50 m. Pathak et al. [24] investigated noise level monitoring and reduction with varying width and height of vegetation belts in Varanasi. Noise level measurement in Varanasi found that areas without greenery were substantially polluted in comparison to areas with vegetation that had less variability in traffic load. At various frequencies, four plant species were examined for noise reduction: Putranjeva roxburghi (up to 17 dB), Cestrum nocturnum, Hibiscus rosasinensis (up to 24 dB), and Murraya peniculata (up to 22 dB). Pudjowati et al. [6] studied the Waru Sidoarjo highway, where there is no vegetation component, only the tree and shrub components. The noise reduction and temperature decrease rates of each existing vegetation component along the roadway are compared in this study. The composition of vegetation, which included trees, bushes, and shrubs, was shown to be more successful in lowering noise (up to 12.25%).

Ow and Ghosh [25] observed that on average, vegetation could decrease by 9–11 dB. They conducted a study to assess the effect of roadside vegetation on reducing road traffic noise under varying planting intensities. The roadside vegetation included minimal planting and moderate, dense plantations. The study results showed a 50% reduction in roadside traffic noise levels when the plantations were improved from minimal to moderate, and no significant improvement was seen in going to dense plantations. It was found that a vegetation depth of 5 m is satisfactory for noise reduction. It was found that the observed noise levels were 78 dB without the vegetative barrier. The trunk measurement is closely connected to traffic clamor reduction. Furthermore, tree belts were deemed superior in terms of noise reduction qualities and mind comfort when compared to constructed noise barriers. Kalansuriya et al. [17] reported an approximate noise attenuation of 4 dB. The quantity of sound absorption is related to the width of the vegetative barrier. Tashakor and Chamani [26] showed that there is an average attenuation of 1.8 dB due to parks' vegetation. It was also observed that the noise is reduced by 1–2 dB by a standard deciduous hedge with a width of 180 cm and a breadth of 160 m. Planting trees and plants in 7–8-meter wide belts reduces noise by 10–13 dB. Even narrower rows, despite their lower noise reduction, absorb and disperse some of the acoustic energy, which lessens severe surges and declines in noise levels. According to the results of Maleki and Hosseini [27] a mixed stand of trees experienced the biggest noise reduction, which was approximately 19.07 dbA, and the pure stand of Robinia pseudoacasia experienced the smallest decrease, which was around 14.7 dbA. The pure stand of Robinia pseudoacasia and the mixed stand showed distinct noise pollution abatement values of 5.01 and 6.05 dbA in the spring and fall, respectively. Fang and Ling [7] compiled the results of their research into three groups based on the noise attenuation caused by the type of vegetation and its characteristics. Group 1 was the region of effective noise attenuation with more than 6 dbA reduction. This group had large shrubs with a visibility of less than 5 m. Group 2 was a sub-reduction region and provided a reduction of 3–5.9 dbA. This group included the shrubs and trees with visibility ranging from 6–19 m. Group 3 was designated as a low-reduction zone because the noise attenuation was less than 2.9 dbA. This group also included sparsely spaced tiny plants and trees.

Onder [28] carried out a study regarding the relationship between noise reduction and green belts of bushes. The study was conducted in two stages. In the first stage, specific plant species (Juniperus horizontalis L., Spirea vanhouetti Briot., Cotoneaster dammerii C.K., Berberis thunbergii D.C., Pyracantha coccinea M., etc.) were chosen for the city of Konya. Trials were run on the Konya motorway. The largest noise reduction values were 6.3 dbA, 4.9 dbA, and 6.2 dbA. Lacasta et al. [29] discussed using green streets to lessen city noise. Standard remedies, like towering noise barriers or expansive areas of dense vegetation, are frequently impractical in urban settings, necessitating the consideration of other approaches. Due to their potential placement close to both the noise source and the receiver, hedges, and medium-height plant barriers might be intriguing design components. The integration of plants into walls, building facades, and roofs as well as the presence of trees along the streets all help to absorb sound, lowering the volume of noise and the resulting irritation. Renterghem et al. [30] investigated the influence of tree planting approaches in vegetation belts with limited depth on road traffic noise reduction using a 3D Finite-Difference Time-Domain (FDTD) numerical model. Measuring the acoustical influence of a tree/vegetation belt is a typical study topic that has been studied. Acoustic waves interact with vegetation, causing reflection, scattering, and diffraction at plant elements such as trunks, branches, twigs, and leaves. This may result in enhanced downward scattering at low source and receiver heights near trees. Tyagi et al. [10] gathered noise data at eleven locations in India's Tarai area to analyze the influence of tree belts on lowering roadside traffic noise. Their research was based on field trials to determine the effectiveness of plant belts in lowering roadside traffic noise at eleven distinct locations in Pant Nagar, Haridwar, and Dehradun. For each site, attenuation per doubling of distance was calculated, and excess attenuation at various 1/3 octave frequencies was predicted. The average excess attenuation over low frequencies (from 200 to 500 Hz) was determined to be roughly 15 dB. The findings suggest that extensive plant belts along roadsides can act as effective noise barriers, with considerable attenuation obtained over the middle frequencies.

As per the findings of Renterghem et al. [19], traffic noise insertion loss is projected to increase with rising tree stem diameter and decreasing distance for each planting design evaluated (simple cubic, rectangular, triangular, and face-centered cubic). The presence of tree stems, bushes, and tree crowns is expected to have an additive impact. The estimates implied that plant belts with a height of 1.0–1.5 m (in a non-refracting environment) can compete with the noise-reducing performance of a traditional thin noise barrier (on grassland). Li et al. [31] stated that the scattering of sound waves by the trunks of trees leading to noise level reduction is a primary factor. Nevertheless, the detailed information on the abatement of noise through the bark of a tree is minimal. They conducted experiments using an impedance tube to measure the bark's noise abatement properties, including the characterization of the bark's thickness, roughness, age of the tree, and moss coverage. Measurements show that assimilation (at typical rates) is generally less than 0.1 for the species considered and may be independent of frequencies below 1 kHz. There is an essential contrast in the average absorption between species. Roughness is the most important visual indicator of the noise-absorbing properties of the bark. The barks with moss grown on them efficiently increase the absorbing capability for the frequency range up to 800 Hz. Particularly in the denser belts of vegetation, the noise-absorbing powers of barks could impact the final noise abatement performance.

Dispersion and ground attenuation are the main contributors to vegetation noise attenuation. Both factors attenuate a relatively small amount of sound as the distance from the sound source increases. The roadside noise through diverse plants, e.g., corn, hemlock, pine, hardwood, and overdeveloped soil. It has been noted that the corn crop had an excess abatement of 19.69 dB per 100 m for each multiplying frequency between 500 and 4000 Hz. On the other hand, the stems of the hemlock, pine, and brush decreased roadside noise by 16.4 dB per 100 m at 4000 Hz. Uncovered grounds reduced frequencies of 200–1000 Hz, and the most significant noise reduction frequency depends on the soil penetrability to air [32]. It was also observed that when sound was transmitted through grassy surfaces and other porous terrains at frequencies over 2 kHz, the tree belt had much greater attenuation values than the grassy ground [33]. The significance of the flora belt in noise reduction demonstrated that a larger tree belt gives more surface area and, therefore, more possibilities for diffusion and absorption, resulting in a more substantial decrease. The breadth of the flora belt is an important noise-cancelling component. When the receiver and noise source heights are lower than the flora belt height, a more substantial decrease occurs because when a noise encounters a barrier, a shadow zone emerges behind the barrier. The noise reduction is significant within the shadow zone but decreases outside of it. Based on the association between flora belt and flora height and relative noise attenuation at different frequencies, it is possible to deduce that a suitable flora belt with the proper width and height may be used for noise reduction [17] investigated the influence of roadside vegetation on the decrease of road traffic noise levels under various traffic circumstances. This study focused on roadside vegetation that can act as noise barriers. The noise from traffic on the route was measured. Combined with the vegetation-controlling parameters. The quantity of sound absorption is related to the width of the vegetative barrier. This study observed approximately a 4 dB reduction in noise pollution.

The results' generalizability was restricted by the following factors: the data was not gathered in all seasons, and it was not collected day and night (24 hours). Depending on local climatic circumstances, tree species, and urban architecture, the efficiency of various tree attributes in noise attenuation may vary. This variety, however, highlights the necessity of personalized solutions in urban planning and the importance of considering local conditions in tree planting projects.

A comprehensive study of the effect of the vegetative noise barrier in all seasons should be conducted so that seasonal change may be detected in all country's major cities. We must identify peak noise hours and provide mitigating measures. More research should be done on the health effects of noise pollution. A thorough investigation of the impact of adopting other sustainable and environment-friendly materials, low-noise pavements, and other proper roadway geometric patterns should be conducted.

5. CONCLUSIONS

Overall, the noise data comparison demonstrated that roadside vegetation, such as trees, bushes, and grass, reduced noise. Due to tree plantation, the maximum reduction of 11 dbA was reported at Eig Gah Road (residential area). Maximum noise reduction was observed at the Expressway and Piran Gaib Roads, where Pongamia pinata and Bakain Melia azedarach are planted. Tree and shrub vegetation contribute significantly toward noise reduction. Therefore, for aesthetic attractiveness, comfortable travel, and a lack of noise pollution, we should implement a green solution based on civil engineering design that incorporates nature. Nature's solutions combined with engineered barriers can result in effective sound reduction. The government should take concrete measures for the plantation of trees and shrubs on the roadsides that would abate the roadside traffic noise and increase the area's monetary worth and aesthetics. Old vehicles with no proper and regular maintenance routines should be banned from being on the road, a significant source of noise and air pollution. Concerned authorities should consider the vegetative barriers while planning the new roads. Environment regulation enforcement authorities should have proper check and balance that the citizens are correctly following noise limit criteria in different zones of the area. The public transport system should be improved, and its use should be encouraged through proper campaigning, seminars, and lectures arranged by environmental agencies, NGOs, and individual activists. Concerned authorities must cooperate with planning authorities to situate noise-sensitive land uses, such as residences and schools, far from major roads. This will need compatible zoning interfaces and appropriate urban and site design. Use

ITS (Intelligent Transportation System) technologies to improve smooth traffic flow and reduce noise from frequent braking and starting.

REFERENCES

[1] GIL-LOPEZ T., MEDINA-MOLINA M., VERDU-VAZQUEZ A., MARTEL-RODRIGUEZ B., *Acoustic and economic analysis of the use of palm tree pruning waste in noise barriers to mitigate the environmental impact of motorways*, Sci. Total Environ., 2017, 584, 1066–1076. DOI: 10.1016/j.scitotenv.2017.01.162.

[2] APARICIO-RAMON D.V., MORALES SUAREZ-VARELA M.M., RUANO L., SANCHEZ A.M., *Subjective annoyance caused by environmental noise*, J. Environ. Pathol. Toxicol. Oncol., 1993, 12 (4), 237–243.

[3] WEBER N., HAASE D., FRANCK U., *Assessing modelled outdoor traffic-induced noise and air pollution around urban structures using the concept of landscape metrics*, Land. Urban Plan., 2014, 125, 105–116. DOI: 10.1016/j.landurbplan.2014.02.018.

[4] YOFIANTI D., USMAN K., *Relationship of plant types to noise pollution absorption level to improve the quality of the road environment*, IOP Conference Series: Earth Environ. Sci., 2021, 926 (1), 012074. DOI: 10.1088/1755-1315/926/1/012074.

[5] Federal Highway Administration (FHWA), *Highway traffic analysis and abatement policy and guidance*, 2017, available from: https://www.fhwa.dot.gov/environment/noise/regulations_and_guidance/polguide/polguide04.cfm [accessed: 19th September 2023].

[6] PUDJOWATI U.R., YANUWIADI B., SULISTIONO R., SUYADI S., *Effect of vegetation composition on noise and temperature in Waru-Sidoarjo Highway, East Java, Indonesia*, Int. J. Conserv. Sci., 2013, 4 (4).

[7] FANG C.F., LING D.L., *Guidance for noise reduction provided by tree belts*, Land. Urban Plan., 2005 71 (1), 29–34. DOI: 10.1016/j.landurbplan.2004.01.005.

[8] MOHAMMADI GALANGASH M., NIKKHAH P., NIKOOY M., *The effect of tree covers on reducing noise pollution load in Saravan Forest Park, Guilan Province, Iran*, Caspian J. Environ. Sci., 2020, 18 (1), 73–80. DOI: 10.22124/cjes.2020.3980.

[9] ISLAM M.N., RAHMAN K.S., BAHAR M.M., HABIB M.A., ANDO K., HATTORI N., *Pollution attenuation by roadside greenbelt in and around urban areas*, Urban For. Urban Green., 2012, 11 (4), 460–464. DOI: 10.1016/j.ufug.2012.06.004.

[10] TYAGI V., KUMAR K., JAIN V.K., *Road traffic noise attenuation by vegetation belts at some sites in the Tarai Region of India*, Ar. Acoust., 2013, 389–395. DOI: 10.2478/aoa-2013-0046.

[11] Government of Punjab, Environment Protection Department (EPD), *Punjab Environment Quality, Standards for Noise*, The Punjab Gazette (Extraordinary) August 15, 2016, available from: https://epd.punjab.gov.pk/system/files/Punjab%20Environmental%20Quality%20Standards%20for%20Noise.pdf (accessed: September 19, 2023].

[12] Mastech, (2023) MS6701*, Sound Meter*. Available from: https://mastech-group.com/na/en/MS6701

[13] SMART N., EISENMAN T.S., KARVONEN A., *Street tree density and distribution: An international analysis of five capital cities*, Front. Ecol. Evol., 2020, 8, 1–12. Article: 562646. DOI: 10.3389/fevo.2020.562646.

[14] SAMARA T., TSITSONI T., *The effects of vegetation on reducing traffic noise from a city ring road*, Noise Cont. Eng. J., 2011, 59 (1), 68–74. DOI: 10.3397/1.3528970.

[15] Faculty of Forestry, the University of British Columbia, *Tree Measurements: Height and Crown Spread*, 2016, available from: https://bigtrees.forestry.ubc.ca/measuring-trees/ (accessed: November 16, 2023).

[16] ISO (1999:2013(en) (2013), *Standard for acoustics. Estimation of noise-induced hearing loss*, available from: https://www.iso.org/obp/ui/#iso:std:iso:1999:ed-3:v1:en

[17] KALANSURIYA C.M., PANNILA A.S., SONNADARA D.U., *Effect of roadside vegetation on the reduction of traffic noise levels*, Institute of Physics, Sri Lanka, Proc. Technical Sessions, 2009, 25.

[18] VAN RENTERGHEM T., DE COENSEL B., BOTTELDOOREN D., *Loudness evaluation of road traffic noise abatement by tree belts*, 42nd International Congress and Exposition on Noise Control Engineering (Inter-Noise 2013), Innsbruck 2013.

[19] VAN RENTERGHEM T., BOTTELDOOREN D., VERHEYEN K., *Road traffic noise shielding by vegetation belts of limited depth*, J. Sound Vibr., 2012, 331 (10), 2404–2425. DOI: 10.1016/j.jsv.2012.01.006.

[20] MARTENS M.J., MICHELSEN A., *Absorption of acoustic energy by plant leaves*, J. Acoust. Soc. Am., 1981, 69 (1), 303–306. DOI: 10.1121/1.385313.

[21] WANG H., GUO J., ZHANG Y., WEI H., FENG L., *Study on noise attenuation impact of roadside tree belts and related influence factors*, J. Ecol. Environ. Sci., 2010, 19, 1403–1408.

[22] STANSFELD S., CLARK C., SMUK M., GALLACHER J., BABISCH W., *Road traffic noise, noise sensitivity, noise annoyance, psychological and physical health and mortality*, Environ. Health, 2021, 20 (1), 1–5. DOI: 10.1186/s12940-021-00720-3.

[23] KARBALAEI S.S., KARIMI E., NAJI H.R., GHASEMPOORI S.M., HOSSEINI S.M., ABDOLLAHI M., *Investigation of the traffic noise attenuation provided by roadside green belts*, Fluct. Noise Lett., 2015, 14 (4), 1550036. DOI: 10.1142/S0219477515500364.

[24] PATHAK V., TRIPATHI B.D., MISHRA V.K., *Dynamics of traffic noise in a tropical city Varanasi and its abatement through vegetation*, Environ. Monitor. Asses., 2008, 146, 67–75. DOI: 10.1007/s10661-007-0060-1.

[25] OW L.F., GHOSH S., *Urban cities and road traffic noise. Reduction through vegetation*, Appl. Acoust., 2017, 120, 15–20. DOI: 10.1016/j.apacoust.2017.01.007.

[26] TASHAKOR S., CHAMANI A., *Temporal variability of noise pollution attenuation by vegetation in urban parks*, Environ. Sci. Poll. Res., 2021, 28, 23143–23151. DOI: 10.1007/s11356-021-12355-5.

[27] MALEKI K., HOSSEINI S.M., *Investigation of the effects of leaves, branches and canopies of trees on noise pollution reductio*n, Ann. Environ. Sci., 2011, 5, 13–21.

[28] ONDER S., KOCBEKER Z., *Importance of the green belts to reduce noise pollution and determination of roadside noise reduction effectiveness of bushes in Konya, Turkey*, Int. J. Agri. Biosys. Eng., 2012, 6 (6), 373–376. DOI: 10.5281/zenodo.1071085.

[29] LACASTA A.M., PEÑARANDA A., CANTALAPIEDRA I.R., *Green streets for noise reduction*, Nat. Based Strat. Urban Build. Sust., 2018, 1, 181–190. DOI: 10.1016/B978-0-12-812150-4.00017-3.

[30] VAN RENTERGHEM T., BOTTELDOOREN D., VERHEYEN K., *3D numerical assessment of road traffic noise reduction by ordered planting schemes*, Forum Acous., European Acoustics Association (EAA), 2011, 2011, 857–861.

[31] LI M., VAN RENTERGHEM T., KANG J., VERHEYEN K., BOTTELDOOREN D., *Sound absorption by tree bark*, App. Acoust., 2020, 165, 1–17, Article 107328. DOI: 10.1016/j.apacoust.2020.107328.

[32] AYLOR D., *Noise reduction by vegetation and ground*, J. Acous. Soc. Am., 1972, 51 (1B), 197–205. DOI: 10.1121/1.1912830.

[33] KRAGH J., *Road traffic noise attenuation by belts of trees*, J. Sound Vibr., 1981, 74 (2), 235–241. DOI: 10.1016/0022-460X(81)90506-X.

[34] COOK D.I., VAN HAVERBEKE D.F., *Tree-covered land-forms for noise control*, Forest Service, US Department of Agriculture, 1974.

[35] HERRINGTON L.P., *Effect of vegetation on the propagation of noise in the out-of-doors*, USDA Forest Service General Technical Report, US Rocky Mountain Forest Range Experimental Station, 1976, 25, 229–233.

[36] WIENER F.M., KEAST D.N., *Experimental study of the propagation of sound over ground*, J. Acoust. Soc. Am., 1959, 31 (6), 724–733. DOI: 10.1121/1.1907778.