Research Article

Bhagwat Singh Chauhan*, Naveen Garg, and Shashikant Tiwari

Predictive noise annoyance and noise-induced health effects models for road traffic noise in NCT of Delhi, India

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Abstract: The present study analyzed the effect of noise annoyance due to road traffic based on a comprehensive socio-acoustics survey at a large number of sites in the NCT of Delhi. This study presents the development of exposure–effect relationships and noise annoyance models using the Structural Equation Modeling (SEM) approach. The study assesses the traffic noise annoyance caused by road traffic at various sites in NCT of Delhi, India. Exposure–effect relationships correlate the noise annoyance and traffic noise levels. The Structural Equation Model depicts the relationship between noise annoyance and various psychological factors. The effect of noise annoyance and awareness level was determined using a socio-acoustic questionnaire survey among the community of NCT of Delhi. The various parameters undertaken were demographic, honking, health impacts, and psychological perception. The developed PLS (Partial Least Square)–SEM model predicted that noise sensitivity and road traffic noise remarkably affected the noise-induced annoyance.

Keywords: noise perception, noise annoyance, structural equation modeling, logistic regression, road traffic noise

Acronyms

NCT	National Capital Territory
PLS-SEM	Partial Least Square-Structural Equation Modeling
%HA	Percentage Highly Annoyed
%*A*	Percentage Annoyed
END	European Noise Directive
WHO	World Health Organization
$L_{\mathrm{Aeq,1h}}$	A-weighted hourly equivalent noise levels
ANN	Artificial Neural Network
HTMT	Heterotrait-Monotrait
CR	Composite reliability
AVE	Average variance extracted

*** Corresponding author: Bhagwat Singh Chauhan,** CSIR-National Physical Laboratory, New Delhi, 110012, India; Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, 201002, India, e-mail: bhagwatchauhan100@gmail.com
Naveen Garg: CSIR-National Physical Laboratory, New Delhi, 110012, India; Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, 201002, India
Shashikant Tiwari: Balaji Institute of Modern Management, Sri Balaji University, Pune, 411033, India

1 Introduction

Traffic noise emission contributes a major role in total urban noise [1]. The urban inhabitants are continuously exposed to air and noise pollution [2]. The acoustic environment of urban agglomerations is severely affected by the noisy environment of road traffic [3]. In the past few decades, urbanization has caused a drastic increment in vehicular activities that is leading to the degradation of the acoustical environment in urban areas [4]. Noise and well-being are significantly mediated by annoyance [5]. The major source of noise pollution is road traffic noise followed by railroad and airport noise, according to the "European Environmental Agency (2021)." Furthermore, around 81 million persons (European Union countries) are mostly exposed to traffic noise that exceeds 55 dB(A) [6]. The impact of road traffic noise in big metropolitan cities is a noteworthy fact because of not only vehicular increment but also the increment in the level of annoyance produced by the road traffic on Indian roads which is causing a decrease in quality of human life [7]. As a developing country, India encounters tremendous growth in vehicular activities. A total of 9.9% growth in vehicle population has been recorded in the decade of 2001–2011 (Ministry of Road Transport and Highways 2011) [8]. This alarming growth in vehicles needs to be complemented by requisite infrastructure but it is quite difficult to do so due to limited resources in a developing country. As a result of this, an additional burden is imposed on the present road infrastructure [9]. Such inconsistency in the completion of the requisition causes a rise in noise levels, which could have more serious negative effects on health owing to road noise. Basner *et al.* (2011) elucidated that road traffic is more likely to create annoyance in comparison to air and rail traffic [10]. Many studies predicted the various factors of annoyance due to traffic noise by giving different results [11]. Kroesen *et al.* (2008) reported noise annoyance and noise disturbance as influencing factors to have deleterious health effects [12]. According to a review by the Environmental Noise Directive (2002), road noise causes around 10,000 early deaths in Europe each year [13]. The documented effects of noise pollution include annoyance, disturbed sleep, headache, hypertension, hair loss, irritability, cardiovascular disease, stress, and dementia [14,15]. Transportation noise causes noise-induced annoyance, which is a problem for the environment, especially in urban regions [16]. In the past, numerous surveys were carried out to assess community's annoyance level with various noise sources, including railroad noise, aircraft noise, and traffic noise [17–20]. The source of the noise, noise levels, the duration of exposure, and the recipient's internal and psychological processes all significantly contribute to annoyance [21]. Additionally, long-term noise exposure causes an increment in the level of annoyance [22]. Numerous studies have been carried out in the past utilizing different statistical approaches to ascertain the relationship between socio-demographic characteristics and relative health impacts on annoyance [23–25]. A strong relationship was observed between equivalent noise levels and noise annoyance along with maximum noise levels in a study conducted by Sato *et al.* (1999) [26]. The A-weighted sound level, L_{Aeq}, and L_{10} have been proposed as effective predictors of community reaction to traffic noise annoyance [27,28]. Apart from this, the socioeconomic factors and noise annoyance correlation were also evaluated in some research studies, and the possibility of minor impacts between them was carried out [29,30]. In a survey-based case study of Tehran, 495 responses were collected from employees working in non-manufacturing industries. It was reported that traffic noise annoyance is significantly exposed to personal characteristics (age, marital status, residential period, and wealth) as well as subjective parameters (noise sensitivity, requirement of noise control, and ambient noise assessment [31]. There are several ways to assess of human response to noise. The most common method is conducting a population survey based on the community's personal and subjective information. It is noteworthy that conducting surveys by questionnaire has the benefits of being quick, economical, and easy to perform tasks. There are extensively used subjective questionnaires to evaluate annoyance and sleeping disorders [32,33]. However, due to a number of variables, subjective judgments are frequently vulnerable to variation, making it challenging to establish causality [34]. Many researchers have used the SEM-ANN technique to construct prediction models in a variety of domains, including management, computer applications, noise, and industries [35,36]. Numerous research has demonstrated the connection between traffic noise and various physiological, psychological, and physical effects. Traffic noise has been shown to annoy people by interfering with their daily lives [37], hearing damage [38], sleep disorders [39], learning impairment [40], heart diseases [41], and metabolic diseases like diabetes [42]. Additionally, the most negative effects of traffic noise on the environment are disturbed sleep and annoyance [36]. Many developing and developed countries, including the USA and many European nations, are concerned about environmental noise [43,44]. The European Noise Directive (END) has recommended designing and implementing noise action plans to reduce urban noise exposure so that they can be helpful in mitigating annoyance and sleep disturbance [45]. However, in India, environmental noise is not to be considered a big issue as compared to water and air. Various socio-demographic factors, health factors, and equivalent noise levels (L_{eq}) were taken into account for developing the annoyance model in the present study. These socioeconomic and health factors are primarily included because they have remarkable effects on annoyance. The results of the annoyance surveys depend on the subjective assessments of the respondents because the annoyance responses to road traffic noise may vary in a complex manner. These variations in responses suggest the necessity of substantial research for both psychological annoyance and road traffic noise, particularly in metropolitan cities of India.

The present study has the following objectives:

- To conduct a socio-acoustic survey amongst the community of the National Capital Territory (NCT) of Delhi, India, covering a large number of sites including all zones like Silence, Residential, Commercial, and Industrial, for analyzing the effect of road traffic noise and honking noise on annoyance experienced by the community.
- To develop an exposure–effect relationship on noise-induced annoyance in terms of linear, polynomial regression, and logistic regression.
- To develop a Structure Equation Model (SEM) for noise annoyance and noise-induced health effects.
- To analyze the effect of various factors such as demographic characteristics, noise sensitivity, honking noise, perceived noisiness, *etc.*, on noise-induced annoyance.

The present research work is the first comprehensive study carried out in the NCT of Delhi covering 42 sites and all zones with an objective of analyzing the community response to higher noise levels exposure. The study shall be instrumental in devising suitable noise control strategies, conducting noise impact assessment, increasing public participation, inculcating awareness, and implementing new policy interventions for mitigation and control of noise pollution.

2 Material and methods

2.1 Study area

The present study is an exposure-effect study of the community exposed to road traffic noise in the NCT of Delhi. The duration of the study was from October 2021 to January 2023. Figure 1 illustrates the site map of the study area region developed using the *ArcGIS v10.8 software*. Delhi is known as the capital of India and NCT stands for the National Capital Territory of India. It has an area of 1,483 km^2 and a population of around 16.8 million people in 2011 of which 53.53% were male and 46.47% were female [46]. Delhi has the highest road density of 11865.37 km/1,000 km^2 among all cities in India [47]. New Delhi is located at 28.38 N and 77.12 E in the northern part of India [48].

2.2 Experimental data acquisition and analysis

Two calibrated sound level analyzers, *B&K 2250 and Norsonic Nor145*, both traceable to the national sound standards

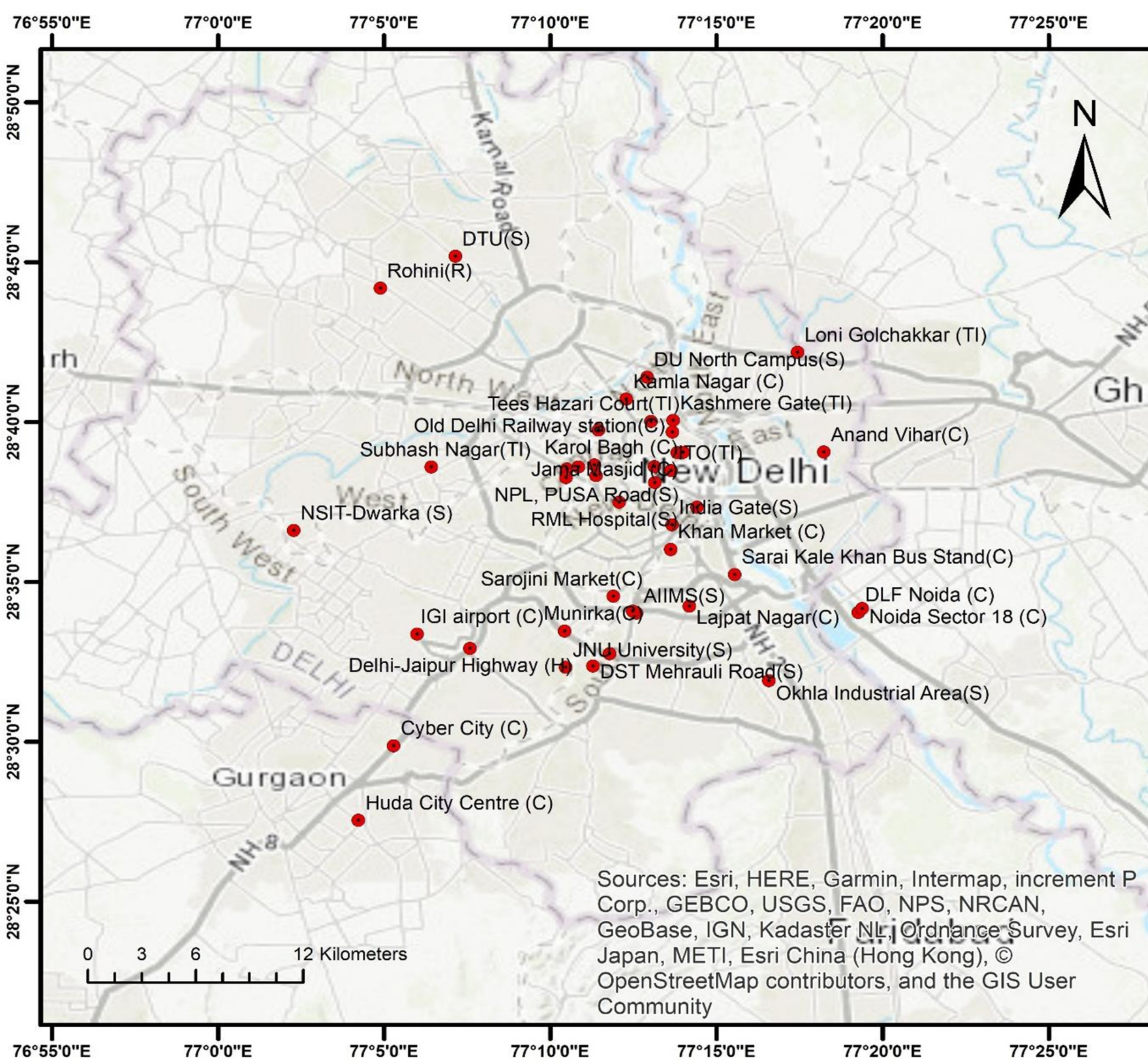

Figure 1: Site map of 42 noise monitoring locations in the NCT of Delhi.

maintained at CSIR-National Physical Laboratory, India, were used to assess the day-time hourly traffic noise levels at 42 sites in NCT of Delhi for road traffic [49]. The short-term hourly equivalent traffic noise level measurements ($L_{\mathrm{Aeq,1h}}$) were undertaken at peak hours in the daytime from 10.00 am to 4.00 pm in the duration from October 2021 to January 2023. The duration of the A-weighted equivalent traffic noise level ($L_{\mathrm{Aeq,1h}}$) measurements ranged from 30 min to 1 h. The sound-level analyzers were installed on a tripod stand with a fixed height of 1.5 m above the ground level and 3 to 3.5 m away from walls to avoid reflections, if presented at any location, in accordance with the general recommendations stated in ISO 9613-1 [50]. However, the personal noise exposure data were not measured due to infrastructural and administrative complications. Exposed noise levels were measured in terms of $L_{\mathrm{Aeq,1h}}$ at various sites in conjunction with socio-acoustic survey from the nearby residents. The temperature was observed as 23 ± 8°C, and relative humidity was observed as 50 ± 20% during the measurements.

2.3 Socio-acoustic survey

The present study was conducted in the NCT of Delhi covering all types of zones like Silence, Residential, Commercial, Industrial, Highways, Crowded Markets, Intersections, Educational Institutions, Hospitals, Airports, Railway and Metro Stations, Bus Stands, Presidential Estates, Monumental areas, Judiciary academy *etc.* The study was conducted among 1,390 people (male and female) in the NCT of Delhi from various professions and educational statuses at the same sites where hourly equivalent noise levels were measured to develop linear and logistic exposure–effect relationships. The shopkeepers, taxi drivers, rickshaw drivers, laborers, security guards, vendors, school students, private professionals, government employees, policemen, social workers, doctors, teachers, judiciary experts, college and doctoral students, scientists, technical community, professors and the common public have exclusively participated in this socio-acoustic survey. The self-employed community participated with the highest number of participants (31.4%) in the survey followed by students (30.2%), government-employed (27.0%), and industrial community (11.4%). The collected data were used for the exposure–effect relationships and noise annoyance model development. Along with this, traffic noise levels were also measured for the same sites in the study area to investigate the effect of noise annoyance due to these levels [51]. The survey was aimed to obtain the response from the traffic noise exposed people with numerous psychological impacts. The most interesting part of the survey was that it included the feedback of the well-educated class: University faculty, teachers, doctors, policemen present at traffic junctions, scientists, and policy-makers having a thorough knowledge of the ill effects of noise pollution.

2.3.1 Questionnaire details and methodology

A random sampling strategy was utilized for data collection. A questionnaire survey was conducted at 42 locations in the NCT of Delhi where the hourly traffic noise levels were also measured. The survey was conducted in the immediate vicinity of the respondents near the noise level measurement sites for obtaining reliable responses from the respondents affected due to road traffic noise. The objective of conducting the survey was to obtain the subjective perception of traffic noise along with psychological and health effects caused by the noise annoyance. The survey was distributed to the participants while performing noise monitoring at various sites in the big metropolitan city. The respondent's involvement was entirely deliberate and no inducements were provided. The various demographic parameters were measured along with psychological and health factors in the questionnaire survey. The demographic parameters were age, gender, education, and social status while the various psychological parameters such as noise annoyance, noise sensitivity, perceived noisiness, and annoyance due to noise levels were taken into account for the perception survey. Along with these, the discrete health factors have been taken as stress, headache, sleeping disorder, hearing disorder, heart attack, and blood pressure in the questionnaire. The survey obtains the responses on a verbal Likert scale from 1 (not at all) to 5 (very much). Respondents who replied on the scale as slightly and moderately (rated their annoyance levels 2 and 3) were considered to be annoyed (A). While respondents who replied on the verbal scale much or very much (rated their annoyance levels 4 and 5) were considered to be highly annoyed (HA). The classification cut-offs were considered from the studies reported by Li *et al.* and Gong *et al.* [52,53]. The various key questions asked for the questionnaire are listed in Appendix A.

3 Socio-acoustics data analysis and interpretation

The questionnaire responses are acquired based on their possible relative outcomes. A two-point nominal scale was used to determine gender. Educational and Social status data were acquired using a four-point ordinal scale. Noise sensitivity, honking, noise annoyance, and noise level exposure were observed on a five-point ordinal scale. A five-point Likert scale was used to assess the annoyance induced by road traffic. Based on acquired data from the socio-acoustic survey, exposure–effect relationships and structural equation models were developed for noise annoyance prediction.

3.1 Exposure–effect relationships

The relationship between noise exposure and its effects on individuals can vary based on factors such as the intensity and duration of the noise, the individual's sensitivity, and their overall health. Noise exposure can have various physiological, psychological, and behavioral effects. In order to determine the significance of traffic noise levels as predictors of noise annoyance, the relationships between traffic noise levels and noise annoyance were examined by using acquired data from the socio-acoustic survey. There are three kinds of exposure–effect relationships were developed for the present study are briefly explained below:

3.1.1 Linear regression relationship

The linear regression relationship describes the correlation between traffic noise levels and induced noise annoyance. In the present study, the exposure–effect relationships were developed between the hourly equivalent noise levels, $L_{\mathrm{Aeq,1h}}$, and the percentage of highly annoyed respondents, %HA, as well as the percentage of annoyed respondents, %A, for 42 sites in the study area using the linear regression method. The minimum threshold limit for $L_{\mathrm{Aeq,1h}}$ was presumed as 60 dB(A) in the Indian scenario similar to that of 42 dB(A) in European countries [37,54]. The minimum limit stands for the minimum noise level from where the annoyance is being started. Therefore, considering the degree of annoyance is zero for levels around or below 60 dB(A), the study elaborates simpler $L_{\mathrm{Aeq,1h}}$–annoyance linear relationships [37]. The noise levels were measured in terms of $L_{\mathrm{Aeq,1h}}$ in the present study for short-term noise assessment similar to L_{den} parameter used in European countries for day–evening–night noise levels. The general equations for the linear regression exposure–effect relationship are expressed as follows:

$$\%\mathrm{HA} = A(L_{A\mathrm{eq,1h}} - 60) + B, \tag{1}$$

$$\%A = A(L_{A\mathrm{eq,1h}} - 60) + B, \tag{2}$$

where A and B are regression constants.

3.1.2 Polynomial regression relationship

The Polynomial regression fits a nonlinear relationship between the traffic noise levels and induced noise annoyance. In a typical linear regression, the relationship between the variables is assumed to be a straight line, but in polynomial regression, the polynomial function of more than one order is to be considered to model the relationship. Polynomial regression models a nonlinear association of data as a statistical linear estimation problem. Polynomial regression is therefore seen as a specific instance of multiple linear regression. In the present study, the polynomial regression method is also used to develop exposure–effect relationships between $L_{\mathrm{Aeq,1h}}$ levels, and percentage of highly annoyed respondents, %HA, as well as the percentage of annoyed respondents, %A, at the same sites in NCT of Delhi. The threshold limit for $L_{\mathrm{Aeq,1h}}$ was presumed as 60 dB(A) after analyzing the community response as same as the linear regression relationships [54]. The general equations for the polynomial regression exposure–effect relationship are expressed as,

$$\begin{aligned}\%\mathrm{HA} = {} & A(L_{A\mathrm{eq,1h}} - 60)^3 + B(L_{A\mathrm{eq,1h}} - 60)^2 \\ & + C(L_{A\mathrm{eq,1h}} - 60) + D,\end{aligned} \tag{3}$$

$$\begin{aligned}\%A = {} & A(L_{A\mathrm{eq,1h}} - 60)^3 + B(L_{A\mathrm{eq,1h}} - 60)^2 \\ & + C(L_{A\mathrm{eq,1h}} - 60) + D.\end{aligned} \tag{4}$$

where A, B, C, and D are regression constants.

3.1.3 Logistic regression relationship

Logistic regression, also known as a dose–response curve, is a graphical representation of the relationship between the dose (amount) of a substance and its corresponding effect on a system. It is commonly used in various scientific fields to study how the intensity or magnitude of a response changes as the dose of a substance is increased or decreased. Based on the socio-acoustic survey and the observed noise levels in participant's areas, the dose-effect curves were plotted using the logistic regression method in *Origin 2023b software* at the same sites in NCT of Delhi. The dose used was the A-weighted hourly equivalent noise levels, $L_{\mathrm{Aeq,1h}}$, while the responses were the percentage of highly annoyed respondents, %HA, as well as the percentage of annoyed respondents, %A, at the given levels of noise [55]. The purpose of using logistic regression over the linear regression method is it overcomes the drawback of the non-linearity of the data and represents a better correlation between input and output variables. The general equations for the logistic regression exposure–effect relationship are expressed as,

$$\%\mathrm{HA} = \mathrm{A1} + \left\{\frac{A_2 - A_1}{1 + 10^{(\mathrm{LOG}X_0 - L_{A\mathrm{eq,1h}})\times p))}}\right\}, \tag{5}$$

$$\%A = A_1 + \left\{\frac{A_2 - A_1}{1 + 10^{(\mathrm{LOG}X_0 - L_{A\mathrm{eq,1h}})\times p))}}\right\}, \tag{6}$$

where A_1 and A_2 are lower and upper bound constants, respectively, and; X_0 and p are the parametric constants to be estimated.

3.2 PLS-SEM model

Although linear and logistic regression relationships are enough to predict the noise annoyance caused by traffic noise levels, they are not sufficient to elucidate the multivariable correlations and indirect effects of non-acoustical factors on noise annoyance. Therefore, in order to investigate the desired multivariate factor analysis, the Partial Least Square Structure Equation Modeling (PLS-SEM) is used to develop a noise annoyance model in the present study. *SmartPLS 4.0 version software* is applied to implement the PLS-SEM. This model establishes the significance of the weights of each attribute taken as a single one. Additionally, it offers details on the methodology for empirical assessment, which supports decision-making and defines people according to their preferences. PLS-SEM is very beneficiary in computing binary decision models [56]. SEM is commonly used to evaluate hypothetical relationships. SEM oversimplifies the limitation of the complexity of datasets of linear models. This technique uses the measured and latent variables. A variable that is measurable and capable of direct observation is called a “measured” variable. Observed variables, indicators, and manifest variables are other names for measured variables. On the other hand, a latent variable is one that has to be inferred from measured variables as it cannot be directly observed. The SEM technique combines multiple regression and factor analysis. In this, Path analysis is a process that examines a set of relationships between one or more independent and dependent variables. This process can be continuous or discrete depending on the variables. The path analysis is also known as a subset of Structural Equation Modeling which considers only measured variables. Path models and SEM are generally more effective than multiple regression analysis [57]. The structural model can be described as a path model, which allows for the assessment of both direct and indirect effects. The study was carried out using *SmartPLS 4.0 software* with bootstrapping of 5,000 random subsamples with default individual and combined factors to figure out the direct and indirect effect of indicators on noise annoyance. The path analysis was used to investigate the hypothetical relationship between annoyance and sociodemographic characteristics as well as health impacts. Along with this, Heterotrait–Monotrait Ratio (HTMT), Fornell–Larcker test, and Cronbach’s alpha tests were performed in the software to assess the reliability and discriminant validity of the model [58–61].

4 Results and discussion

4.1 Hourly noise monitoring data collection

Table 1 presents the A-weighted hourly equivalent traffic noise levels measured at 42 sites in NCT of Delhi for the assessment of exposure–effect of noise and annoyance. The table summarizes the noise levels measured, locations names with zone characteristics, and their geographical coordinates. The measured traffic noise levels varied in the range from 67.3 to 85.5 dB(A). The noise monitoring sites were categorized into six zone sites as “S” indicates silence zone sites, “R” indicates residential zone sites, “C” indicates commercial zones sites, “I” indicates industrial zone sites, “H” indicates highway sites, and “TI” indicates traffic intersection sites [51]. The measured noise levels, $L_{\mathrm{Aeq,1h}}$, were utilized as input parameters for exposure–effect relationships and noise annoyance models.

4.2 Socio-demographic data analysis

Table 2 represents the socio-demographic information of a total of 1,390 survey participants. There are four demographic parameters have been undertaken for the present study described below.

4.2.1 Gender

The participated respondents’ male and female ratios in the socio-acoustic survey were 64.6 and 35.4%, respectively.

4.2.2 Age

The respondents were divided into five age groups (below 15 years, 15–25 years, 26–40 years, 41–60 years, and above 60 years) represented 10.7, 24.3, 28.8, 24.7, and 11.4%,

Table 1: Summary of measured hourly equivalent noise data at 42 sites in NCT of Delhi

S. no.	Location	Geographical coordinates		Hourly noise levels, $L_{Aeq,1h}$
		Latitude	Longitude	
1	Karol Bagh (C)	28°38′39.43″N	77°11′19.82″E	77.7
2	RML Hospital (S)	28°37′29.21″N	77°12′4.69″E	72.8
3	Connaught Place (TI)	28°38′6.12″N	77°13′8.62″E	72.9
4	Lajpat Nagar (C)	28°34′14.92″N	77°14′11.05″E	76.3
5	AIIMS (S)	28°34′1.33″N	77°12′35.69″E	76.1
6	Safdarjung Hospital (S)	28°34′5.12″N	77°12′28.85″E	78.1
7	Rajendra Place Roundabout (TI)	28°38′32.07″N	77°10′30.39″E	77.5
8	NPL, PUSA Road (S)	28°38′15.53″N	77°10′28.33″E	74.6
9	DTU (S)	28°45′11.02″N	77°7′8.53″E	77.8
10	ITO (TI)	28°38′28.92″N	77°13′38.24″E	79.9
11	Anand Vihar (C)	28°39′3.35″N	77°18′13.99″E	77.4
12	Kashmere Gate (TI)	28°40′2.89″N	77°13′41.59″E	80.0
13	IIT Delhi Main Gate (S)	28°32′45.23″N	77°11′47.28″E	80.0
14	BLK MAX Hospital (S)	28°38′35.82″N	77°10′50.87″E	74.8
15	Sir Ganga Ram Hospital (S)	28°38′19.28″N	77°11′22.83″E	74.7
16	India Gate (S)	28°36′46.92″N	77°13′39.82″E	75.2
17	Supreme Court (S)	28°37′19.84″N	77°14′25.18″E	67.3
18	DU North Campus (S)	28°41′24.35″N	77°12′54.83″E	71.7
19	JNU University (S)	28°32′19.79″N	77°10′27.87″E	74.0
20	Okhla Industrial Area (S)	28°31′55.17″N	77°16′34.64″E	80.5
21	Sarai Kale Khan Bus Stand (C)	28°35′14.12″N	77°15′32.94″E	76.3
22	Tees Hazari Court (TI)	28°40′1.1″N	77°13′1.88″E	82.4
23	Chandni Chowk (C)	28°39′2.5″N	77°13′49.57″E	74.1
24	New Delhi Railway Station (C)	28°38′36.21″N	77°13′8.38″E	68.2
25	DST Mehrauli Road (S)	28°32′22.69″N	77°11′16.83″E	74.0
26	Munirka (C)	28°33′28.21″N	77°10′25.65″E	76.5
27	Sarojini Market (C)	28°34′33.2″N	77°11′54.08″E	75.1
28	Old Delhi Railway station (C)	28°39′40.82″N	77°13′40.3″E	78.9
29	Sarai Rohilla Railway Station (C)	28°39′44.54″N	77°11′27.04″E	72.1
30	Rohini (R)	28°44′11.02″N	77°4′53.15″E	71.1
31	Subhash Nagar (TI)	28°38′35.45″N	77°6′25.09″E	76.5
32	Cyber City (C)	28°29′52.76″N	77°5′16.81″E	73.2
33	Delhi-Jaipur Highway (H)	28°32′55.68″N	77°7′35.21″E	79.7
34	DLF Noida (C)	28°34′2.91″N	77°19′16.03″E	74.3
35	Huda City Centre (C)	28°27′32.85″N	77°4′13.43″E	77.8
36	IGI airport (C)	28°33′22.36″N	77°5′59.78″E	73.9
37	Jama Masjid (C)	28°39′3.16″N	77°13′59.88″E	75.8
38	Kamla Nagar (C)	28°40′43″N	77°12′16.82″E	77.4
39	Khan Market (C)	28°36′0.82″N	77°13′37.54″E	78.6
40	Loni Roundabout (TI)	28°42′10.82″N	77°17′26.55″E	85.5
41	Noida Sector 18 (C)	28°34′10.59″N	77°19′23.02″E	79.2
42	NSIT-Dwarka (S)	28°36′36.26″N	77°2′16.54″E	74.9

respectively, of the active participation in the survey. The age group 26–40 years participated with the highest number of respondents.

4.2.3 Educational status

The participants were divided into four educational status groups: high school, graduate, post-graduate, and doctorate. The post-graduate individuals have participated with 36.5% of the total sample which is the highest among all educational groups.

4.2.4 Social status

The participants were divided into four social status groups: higher class, upper middle class, middle class, and lower class.

Table 2: Profile of the participated respondents (*N* = 1,390)

Category	Sub-category		Frequency	Percentage (%)
Demographic characteristics	Gender	Male	898	64.6
		Female	492	35.4
	Age (years)	Below 15	149	10.7
		15–25	338	24.3
		26–40	401	28.8
		41–60	344	24.7
		Above 60	158	11.4
	Education (up to)	High school	379	27.3
		Graduate	388	27.9
		Post graduate	507	36.5
		Doctorate	116	8.3
	Social status	Higher class	144	10.4
		Upper middle class	422	30.4
		Middle class	636	45.8
		Lower class	188	13.5
Psychological factors	Noise sensitivity	Not at all	187	13.5
		Slightly	219	15.8
		Moderate	292	21.0
		Much	328	23.6
		Very much	364	26.2
	Noise annoyance	Not at all	93	6.7
		Slightly	203	14.6
		Moderately	295	21.2
		Annoyed	439	31.6
		Highly annoyed	360	25.9
	Perceived noisiness	Not at all	135	9.7
		Slightly	243	17.5
		Moderate	318	22.9
		Much	433	31.2
		Very much	261	18.8
	Honking	Not at all	90	6.5
		Slightly	103	7.4
		Moderate	333	24.0
		Much	379	27.3
		Very much	485	34.9

The middle-class category has participated with 45.8% of the total sample which is the highest among all social status groups.

4.3 Source-apportionment analysis

A source apportionment analysis of various sources of noise pollution was also done by using the noise perception data depicted in Figure 2. The community was asked about the vicinity of the source causing the noise annoyance. It was observed that the community felt “road traffic noise along with honking” as the most dominant source (76%) causing annoyance among all the other sources as shown in Figure 2. This study strengthens the dominance of road traffic noise among various sources of noise as reported by Chauhan *et al.* [51]. Figure 3 depicts the distribution of annoyance due to various noise sources. It was observed that traffic noise and honking noise were the major sources of noise-induced annoyance.

4.4 Psychological data analysis

There are four psychological parameters have been undertaken for the present study to observe their effect on noise annoyance towards road traffic in the survey as described below.

4.4.1 Noise annoyance

The community was asked about the annoyance caused by the road traffic noise. In a subjective response, it was

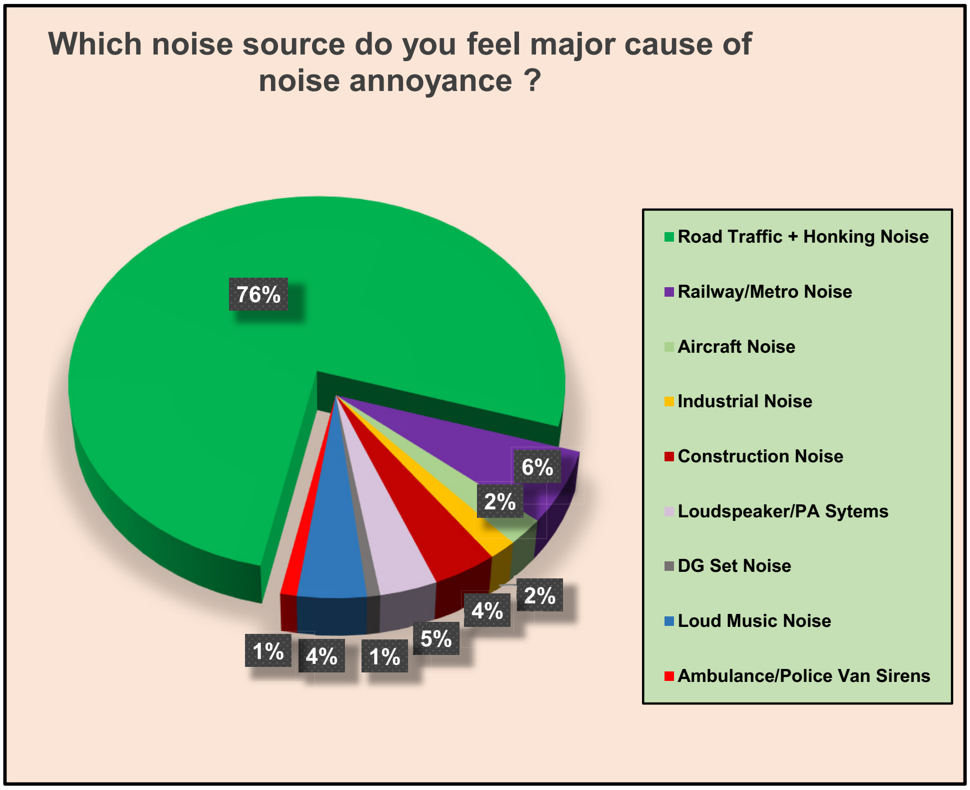

Figure 2: Source-apportionment analysis obtained from socio acoustic survey amongst community (N = 1,390) of NCT of Delhi.

observed that 25.9% of respondents felt very much annoyed due to road traffic noise annoyance.

4.4.2 Noise sensitivity

The community was asked about how they are sensitive to traffic noise. It was observed that 26.2% of respondents felt themselves very much sensitive towards road traffic noise.

4.4.3 Perceived noisiness

The community was asked about the noisiness of road traffic they can feel at their residences. It was observed that 18.8% of respondents felt very much perceived noisiness.

4.4.4 Honking noise

The community was asked about the severity of the honking noise causing annoyance. It was observed that 34.9% of

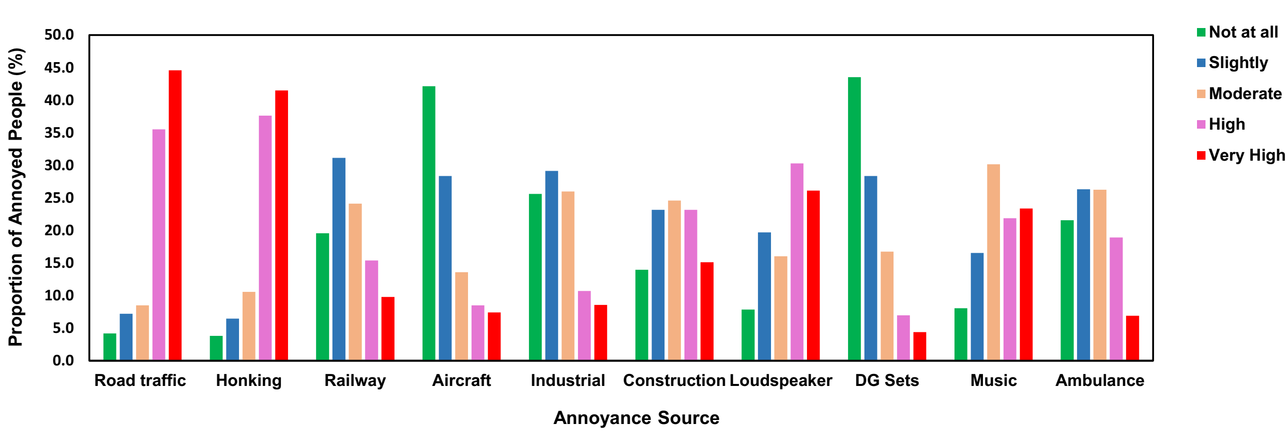

Figure 3: Proportion of level of annoyance due to different noise sources.

respondents felt very much annoyed due to the honking in their surroundings and traveling.

4.5 Self-reported health effects analysis

Table 3 represents the self-reported health effects data of a total of 1,390 survey participants. The community was asked about the following six health effects felt due to the traffic noise in the questionnaire listed as follows:
1. headache,
2. blood pressure,
3. stress,
4. hearing disorder,
5. heart attack, and
6. sleeping disorder.

It was observed that 18.7% of the community was extremely exposed to headache, 12.4% of the community was extremely exposed to blood pressure, 30.0% of the community was extremely exposed to stress, 28.8% of the community was extremely exposed to hearing disorder, 6.6% of the community extremely exposed to heart attack, and 31.2% of the community extremely exposed to sleeping disorder. Figure 4 shows the proportion of the exposed community relative to various self-reported health effects.

Table 3: Self-reported health effects data of participated respondents (N = 1,390)

Category		Frequency	Percentage (%)
Hearing disorder	Not at all	74	5.3
	Slightly	152	10.9
	Moderate	307	22.1
	Much	457	32.9
	Very much	400	28.8
Blood pressure	Not at all	247	17.8
	Slightly	310	22.3
	Moderate	359	25.8
	Much	301	21.7
	Very much	173	12.4
Stressed	Not at all	131	9.4
	Slightly	176	12.7
	Moderate	267	19.2
	Much	399	28.7
	Very much	417	30.0
Headache	Not at all	287	20.6
	Slightly	292	21.0
	Moderate	389	28.0
	Much	162	11.7
	Very much	260	18.7
Heart attack	Not at all	301	21.7
	Slightly	241	17.3
	Moderate	404	29.1
	Much	352	25.3
	Very much	92	6.6
Sleeping disorder	Not at all	80	5.8
	Slightly	194	14.0
	Moderate	269	19.4
	Much	414	29.8
	Very much	433	31.2

4.6 Exposure–effect relationships

In order to determine the prediction of noise annoyance due to traffic noise levels, the exposure–effect relationships between traffic noise levels and noise annoyance were examined by using acquired data from the socio-acoustic survey conducted at 42 sites in the study area. Three kinds of exposure–effect relationships that were developed for the present study are briefly explained below:

4.6.1 Linear regression relationship

Two linear regression relationships were developed between the hourly equivalent traffic noise levels, $L_{\mathrm{Aeq,1h}}$, and the percentage of highly annoyed respondents, %HA, as well as the percentage of annoyed respondents, %A, for traffic noise in the NCT of Delhi. The developed relationships are depicted in Table 4. Moderate correlations were observed for the developed linear exposure–effect relationships for traffic noise. These results corroborate the earlier research done by Agarwal and Swami (2009) on traffic noise annoyance [62]. The results also match with the studies performed by Sato *et al.* (1999) [26] and Ohrstrom *et al.* (2006) [63].

4.6.2 Polynomial regression relationship

Two polynomial relationships were developed in *SPSS software version v20* between the $L_{\mathrm{Aeq,1h}}$ levels and the percentage of highly annoyed respondents, %HA, as well as the percentage of annoyed respondents, %A, for traffic noise in the NCT of Delhi. The developed relationships are depicted in Table 4. Moderate correlations were observed for the developed polynomial exposure–effect relationships which were improved in comparison to developed linear relationships. These results match the earlier noise annoyance studies performed by Miedema and Oudshoorn (2001) [37], WHO (2018) [64], and Guski *et al.* (2017) [65]. Thus,

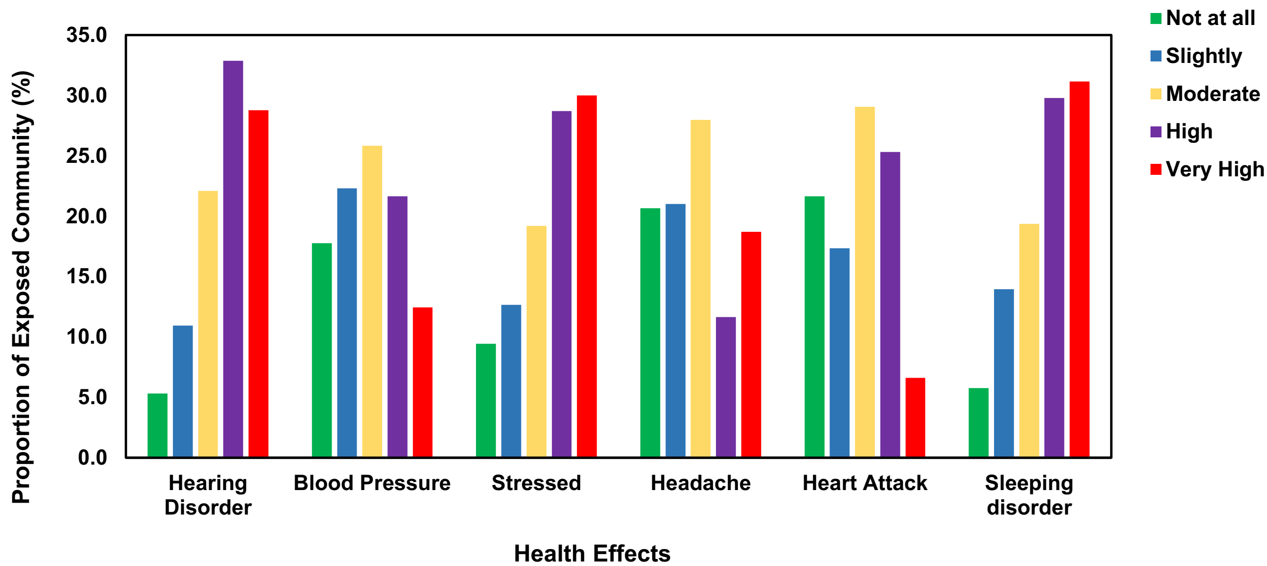

Figure 4: Proportion of exposed community (N = 1,390) relative to various self-reported health effects.

the study reaffirmed the utility of polynomial regression in developing noise exposure–effect relationships [66].

4.6.3 Logistic regression relationship (dose–effect curve)

Two logistic regression relationships were developed using *OriginPro 2023b* software between the $L_{\mathrm{Aeq,1h}}$ levels and the percentage of highly annoyed respondents, %HA as well as the percentage of annoyed respondents. In these logistic regressions, the dose (input variable) used was the A-weighted hourly equivalent noise levels, $L_{\mathrm{Aeq,1h}}$ while responses (output variable) were the percentage of highly annoyed (%HA) and the percentage of annoyed (%A) respondents, respectively, at the given traffic noise levels. In the total measured data, 80% of data were utilized for developing the dose–effect curves while remaining 20% of data were utilized for validating the models. The fitted curves are represented by Equations (7) and (8) and also shown in Table 4.

$$\%\mathrm{HA} = 16.55 + \left\{\frac{35.62}{1 + 10^{(6.06 - 0.07\times L_{\mathrm{Aeq,1h}})}}\right\}, \tag{7}$$

$$\%A = 13.78 + \left\{\frac{27.92}{1 + 10^{(6.11 - 0.08\times L_{\mathrm{Aeq,1h}})}}\right\}. \tag{8}$$

Figures 5 and 6 show the dose–response curves of the developed logistic regression equations for the percentage highly annoyed (%HA) and percentage annoyed (%A) respectively. Tables 5 and 6 represent the parameter estimation of dose–effect relationships. It was observed from the validity test that the results obtained were within a range of (−6.5 to

Table 4: Exposure–effect relationships developed for 42 noise monitoring sites in the NCT of Delhi

S. no.	Regression	Equation	Coefficient of determination (R^2)
1.	Linear	$\%\mathrm{HA} = 1.32(L_{\mathrm{Aeq,1h}} - 60) + 12.39$	0.52
		$\%A = 0.78(L_{\mathrm{Aeq,1h}} - 60) + 22.07$	0.47
2.	Polynomial	$\%\mathrm{HA} = 7.13\times10^{-4}(L_{\mathrm{Aeq,1h}} - 60)^3 - 2.15\times10^{-2}(L_{\mathrm{Aeq,1h}} - 60)^2 + 1.43(L_{\mathrm{Aeq,1h}} - 60) + 13.95$	0.57
		$\%A = 1.54\times10^{-3}(L_{\mathrm{Aeq,1h}} - 60)^3 - 6.88\times10^{-2}(L_{\mathrm{Aeq,1h}} - 60)^2 + 1.69(L_{\mathrm{Aeq,1h}} - 60) + 20.72$	0.53
3.	Logistic	$\%\mathrm{HA} = 16.55 + \left\{\frac{35.62}{1+10^{(6.06-0.07\times L_{\mathrm{Aeq,1h}})}}\right\}$	0.65
		$\%A = 13.78 + \left\{\frac{27.92}{1+10^{(6.11-0.08\times L_{\mathrm{Aeq,1h}})}}\right\}$	0.56

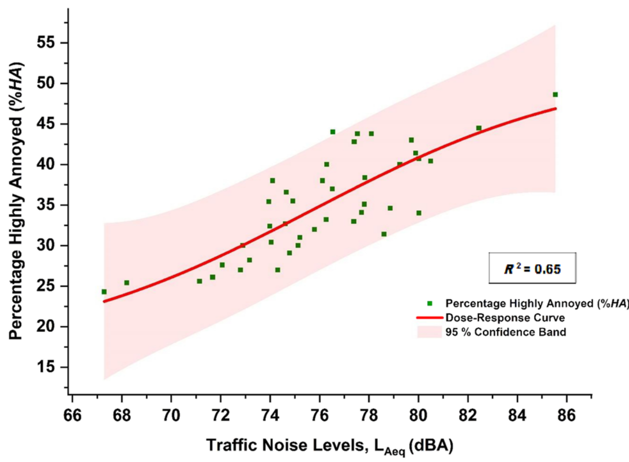

Figure 5: Dose–effect curve of logistic regression for the percentage highly annoyed (%HA) respondents along with 95% confidence band.

9.0)% and (−7.7 to 8.1)% from the actual values of %HA and %*A*, respectively [66]. The first dose-response curve provides a fair relationship between the observed noise levels, $L_{Aeq,1h}$, and the percentage of highly annoyed (%HA) respondents with the coefficient of determination (R^2) of 0.66 which is the highest in all the developed exposure–effect relationships. Additionally, the second dose-response curve provides a moderate correlation between the observed noise levels, $L_{Aeq,1h}$, and the percentage of annoyed (%*A*) respondents with the coefficient of determination (R^2) of 0.56. These results corroborated the earlier research on logistic regression between noise annoyance and traffic noise levels by Gilani and Mir [55] and Bouzid *et al.* [67]. Thus, the study reaffirmed the utility of logistic regression over linear and polynomial regressions in developing the exposure–effect relationships

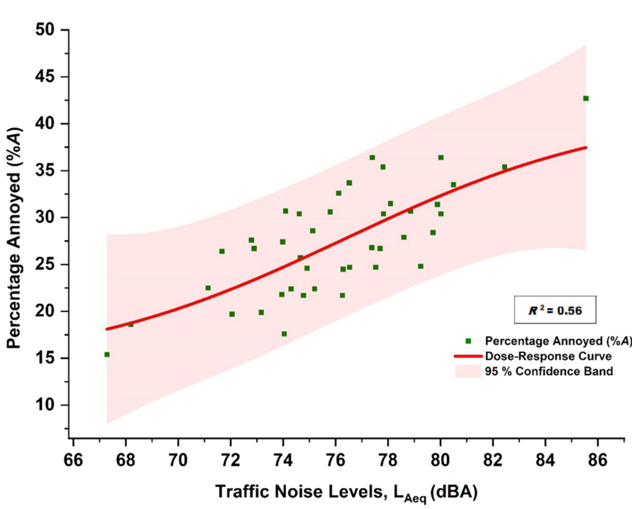

Figure 6: Dose–effect curve of logistic regression for the percentage annoyed (%*A*) respondents along with 95% confidence band.

Table 5: Parameter estimation of logistic regression relationship for percentage highly annoyed (%HA)

Model	Dose–effect (response)
Equation	$y = A_1 + (A_2 - A_1)/(1 + 10\hat{}((\mathrm{Log}X_0 - X) \times p))$
Plot	Percentage highly annoyed (%HA)
A_1	16.550 ± 16.068
A_2	52.172 ± 14.721
Log X_0	75.698 ± 3.429
p	0.077 ± 0.075
Reduced Chi-Sqr	14.56
R^2 (COD)	0.65
Adj. R^2	0.62

for predicting traffic noise annoyance as recommended by Finegold *et al.* [68].

4.7 Structural equation modeling (PLS-SEM)

The exposure–effect relationships and annoyance modeling enable a better understanding of the various psychological and physiological effects on human beings. This incorporates better tools for enhancing the management of the urban acoustic environment.

The conventional regression techniques only assess the direct impact of noise exposure on both noise annoyance and health effects while ignoring any indirect effect. A statistical method called Partial Least Squares-Structural Equation Modeling is employed to maximize the explained variance in dependent variables. PLS-SEM, similar to other structural equation modeling (SEM) methods like LISREL or linear structural relation, allows researchers to simultaneously examine the factors in the measurement model and path coefficients in the structural model. Unlike covariance-based SEM methods, PLS-SEM does not rely on assumptions of multivariate normality and large sample

Table 6: Parameter estimation of logistic regression relationship for percentage annoyed (%*A*)

Model	Dose–effect (response)
Equation	$y = A_1 + (A_2 - A_1)/(1 + 10\hat{}((\mathrm{Log}X_0 - X) \times p))$
Plot	Percentage annoyed (%*A*)
A_1	13.783 ± 13.502
A_2	41.699 ± 14.714
Log X_0	76.362 ± 4.029
p	0.081 ± 0.093
Reduced Chi-Sqr	16.19
R^2 (COD)	0.56
Adj. R^2	0.51

Table 7: Reliability and validity test for PLS-SEM model

S. no.	Parameters	Cronbach's alpha	Composite reliability ('rho'_a)	Composite reliability ('rho'_c)	Average variance extracted (AVE)
1.	Noise annoyance	1.000	1.000	1.000	1.000
2.	Demographic characteristics	0.893	0.896	0.926	0.757
3.	Honking	1.000	1.000	1.000	1.000
4.	Perceived noisiness	1.000	1.000	1.000	1.000
5.	Noise sensitivity	1.000	1.000	1.000	1.000
6.	L_{Aeq}	1.000	1.000	1.000	1.000

sizes. To examine the multivariable correlations among various predictors of noise annoyance, a structure equation model is developed through the PLS-SEM method in *SmartPLS 4.0 software*. PLS-SEM is an adequate method to examine the hypothetical testing of linear relationships. This software is most commonly used in the validation of the research model hypothesis for such kinds of problems [69].

4.7.1 Measurement model

The predictability of the model was evaluated by conducting tests for reliability and validity. This assessment included the use of parameters like Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). Table 7 represents the reliability and validity of the developed model by confirming the fact that the "Cronbach's alpha" values for all factors are greater than 0.70 and CR, and AVE must be greater than 0.60, and 0.50, respectively [58–61]. Tables 8 and 9 represent the results of Fornell–Larcker criterion and "Heterotrait-Monotrait" (HTMT) criterion to assess the discriminant validity of models [58–61].

4.7.2 Structural equation model for noise annoyance prediction

The outcomes of the developed SEM model are depicted in Figure 7. It represents the structure of the developed

Table 8: Fornell-Larcker criterion

	Annoyance	DC	Honking	L_{Aeq}	Perceived noisiness	Sensitivity
Annoyance	**1**					
DC*	0.908	**0.871**				
Honking	0.934	0.848	**1**			
L_{Aeq}	0.906	0.828	0.845	**1**		
Perceived noisiness	0.756	0.683	0.723	0.679	**1**	
Sensitivity	0.947	0.847	0.896	0.849	0.727	**1**

Annoyance is the main parameter corresponding to which all the other parameter's Fornell-Larcker criterion is calculated. Hence, its values are given in bold font. *DC = Demographic Characteristics.

Table 9: Heterotrait–Monotrait ratio (HTMT)

	Annoyance	DC	Honking	L_{Aeq}	Perceived noisiness	Sensitivity
Annoyance						
DC*	0.896					
Honking	0.893	0.842				
L_{Aeq}	0.881	0.801	0.786			
Perceived noisiness	0.756	0.721	0.709	0.589		
Sensitivity	0.898	0.856	0.726	0.679	0.624	

Bold values show the significance of respective parameters. *DC = Demographic Characteristics.

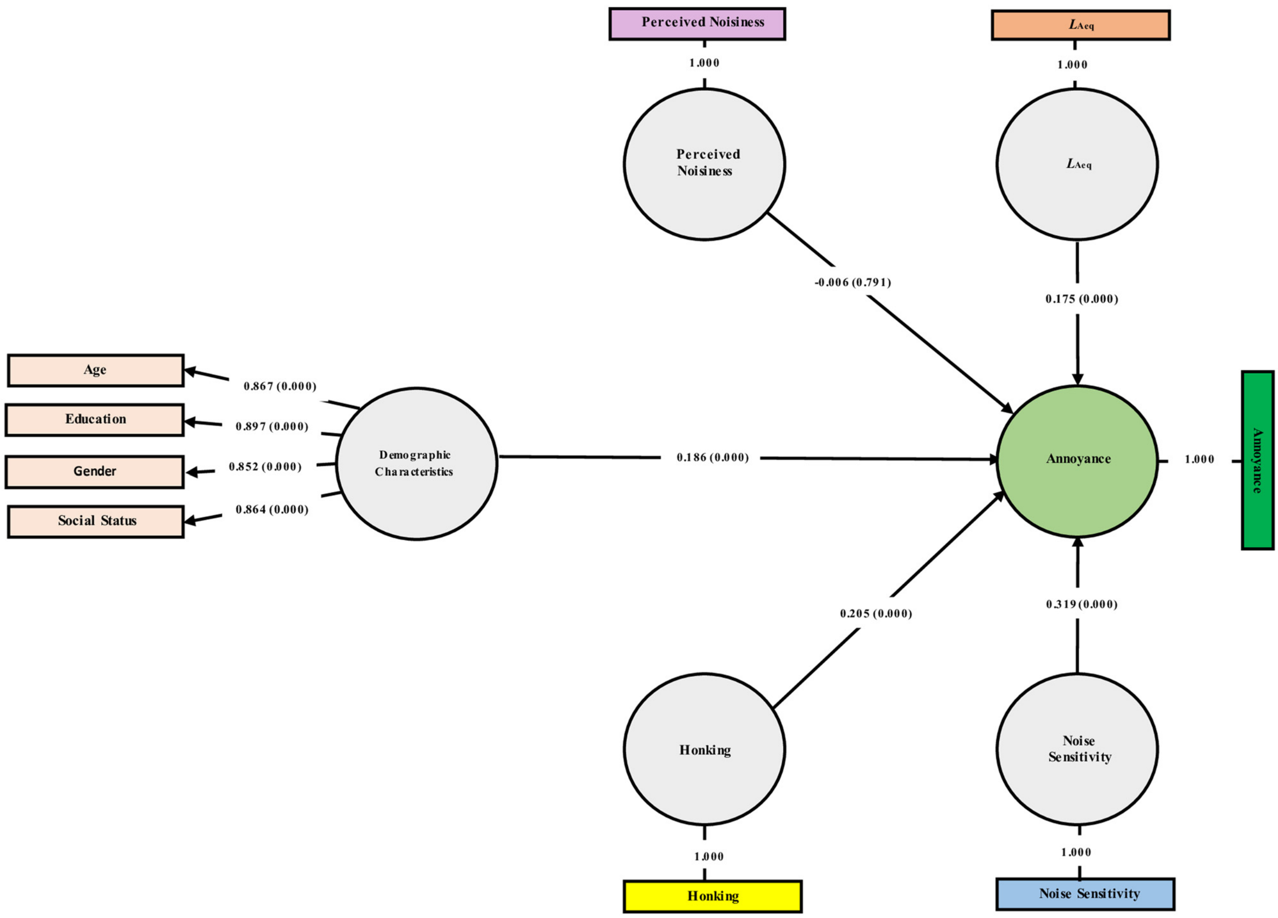

Figure 7: Structured PLS-SEM model for multivariable-noise annoyance.

PLS-SEM model for examining the prediction of noise annoyance due to various demographic and psychological factors. According to the structured models (Figure 7) and path analysis results (Table 10), four (Noise Sensitivity, Honking, Demographic Characteristics, and L_{Aeq}) out of the five paths are found to be significant with a *p*-value less than 0.001. The *p*-values, *T*-statistics, and 95% confidence interval level are used to determine the significance of relationships among various paths. Perceived noisiness is found to be an insignificant predictor of noise annoyance.

4.7.3 Structural equation model for self-reported health effects prediction

Figure 8 represents the structure of the developed PLS-SEM model to examine the prediction of various health effects due the traffic noise annoyance. these health effects include headache, blood pressure, stress, hearing disorder, heart attack, and sleeping disorder. It can be observed from Figure 8 that annoyance has a significant effect on headache, stress, hearing disorder, and sleeping disorder with

Table 10: Path analysis of multivariable-annoyance model

	Original sample	Sample mean	Standard deviation	*T*-statistics	*p*-Values	Significance
DC* → Annoyance	0.186	0.183	0.028	6.618	0.000	**Yes**
Honking → Annoyance	0.205	0.206	0.043	4.795	0.000	**Yes**
L_{Aeq} → Annoyance	0.175	0.179	0.047	3.704	0.000	**Yes**
Perceived noisiness → Annoyance	−0.006	−0.006	0.022	0.265	0.791	No
Sensitivity → Annoyance	0.319	0.309	0.048	6.513	0.000	**Yes**

Bold values show the significance of respective parameters. *DC = Demographic Characteristics.

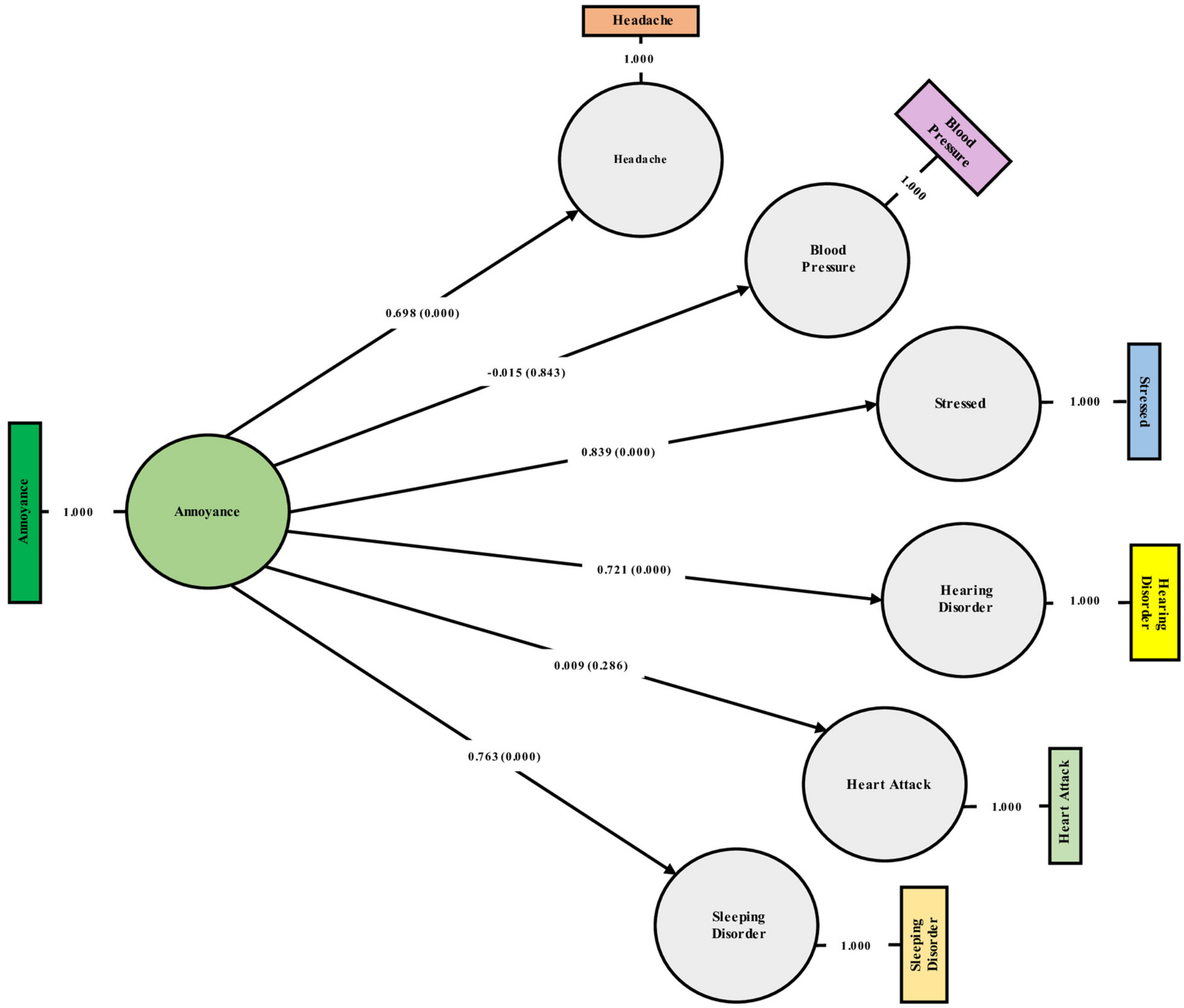

Figure 8: Structured PLS-SEM model for noise annoyance-self-reported health effects.

a *p*-value less than 0.001, whereas noise annoyance is found to be an insignificant factor in blood pressure and heart attack. It was observed that stress was a prominent health issue among the people as compared to other health effects.

The following major observations were drawn from the partial least square-structural equation models:

- **Noise sensitivity** is observed as the highest significant predictor of annoyance with a path coefficient of 0.319. The highest correlation was observed between noise sensitivity and annoyance towards traffic noise rather than other factors due to the fact that more sensitive people experience a higher level of annoyance. These findings are also reported in studies presented by Das *et al.* [36] and Tiwari *et al.* [70] for the traffic noise annoyance prediction. A similar observation was found for the annoyance and sensitivity relationship by Moghadam *et al.* (2020) and Baudin *et al.* (2021) [21,29].
- **Honking** has emerged as the second most significant predictor of noise annoyance as honking plays an important role in increasing noise levels. The standardized regression coefficient between the honking noise and noise annoyance is 0.205. A similar observation was observed in a study reported by Tiwari *et al.* (2023) [71] for Dhanbad city where honking noise is an important predictor of noise annoyance with a sensitivity percentage of 18.6.
- **Demographic characteristics** are observed to be a significant factor in noise annoyance with a path coefficient of 0.186. There are four demographic parameters have been undertaken for the present study namely, Age, Education, Gender, and Social status. Education is observed as the most significant parameter in correlation with annoyance among all four demographic characteristics. People with higher education levels were more likely to be affected towards

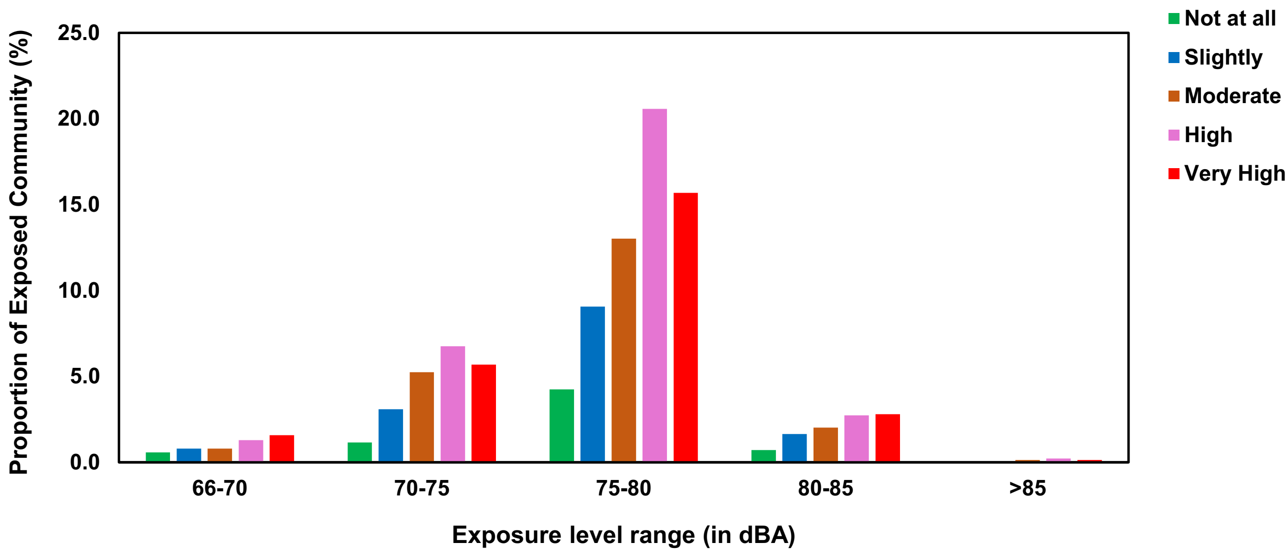

Figure 9: Proportion of exposed community (N = 1,390) relative to the traffic noise levels (L_{Aeq}).

noise annoyance due to road traffic noise in comparison to lower educated people [30]. This result supported the earlier investigation on the relationship between education level and noise annoyance reported by Monazzam *et al.* (2019) [72]. Age was found to be the second most significant socio-demographic predictor of noise annoyance. Many of the studies concluded that age is a remarkable factor in the prediction of noise annoyance [30,73,74]. The age group of 41–60 years was most affected due to annoyance with 70.06% followed by the age group of above 60 years with 64.5%. This result reaffirmed the fact that people with older age are highly prone to noise annoyance in comparison to younger ones [30,73,74]. Social status is found to be the third most significant socio-demographic predictor of noise annoyance due to road traffic followed by Gender. Gender was observed as the least significant predictor of annoyance in the present study. It was revealed that females were more affected by annoyance due to road traffic noise in comparison to males. This result corroborated the earlier findings in which the high proneness of females was reported towards noise annoyance in comparison to males [41,75,76]. Apart from these socio-demographic characteristics, various psychological factors were also assessed for the prediction of noise annoyance.

- The study revealed ***equivalent sound level*** **(L_{Aeq})** was obviously a significant predictor of noise annoyance with a path coefficient of 0.175, as around 90% of the sites had L_{Aeq} levels of traffic noise between 70 and 85 dB(A), which is very high from the minimum annoyance level. Figure 9 represents the proportion of exposed community relative to the traffic noise levels, $L_{\text{Aeq,1h}}$. A noise level up to 55 dB(A) causes light stress led to noise-induced annoyance and 65 dB(A) or above noise levels can cause deep stress leading to high noise-induced annoyance in the human body as reported by Moura-de-Sousa and Cardoso (2002) [77].
- **Perceived noisiness** was observed to be an insignificant predictor of traffic noise annoyance in the present research. This may be attributed to the tolerance to noise of the Asian community when compared to others [78].
- In order to examine the relationships between various subjective health complaints and traffic noise annoyance,

Table 11: Path analysis of annoyance-self-reported health effects model

	Original sample	Sample mean	Standard deviation	*T*-statistics	*p*-values	Significance
Annoyance → Hearing disorder	0.721	0.721	0.035	20.875	0.000	**Yes**
Annoyance → Blood pressure	−0.015	−0.015	0.016	0.689	0.843	No
Annoyance → Sleeping disorder	0.763	0.762	0.026	28.824	0.000	**Yes**
Annoyance → Headache	0.698	0.699	0.027	25.943	0.000	**Yes**
Annoyance → Stressed	0.839	0.839	0.018	45.832	0.000	**Yes**
Annoyance → Heart attack	0.009	0.008	0.010	0.321	0.286	No

Bold values shows the significance of respective parameters.

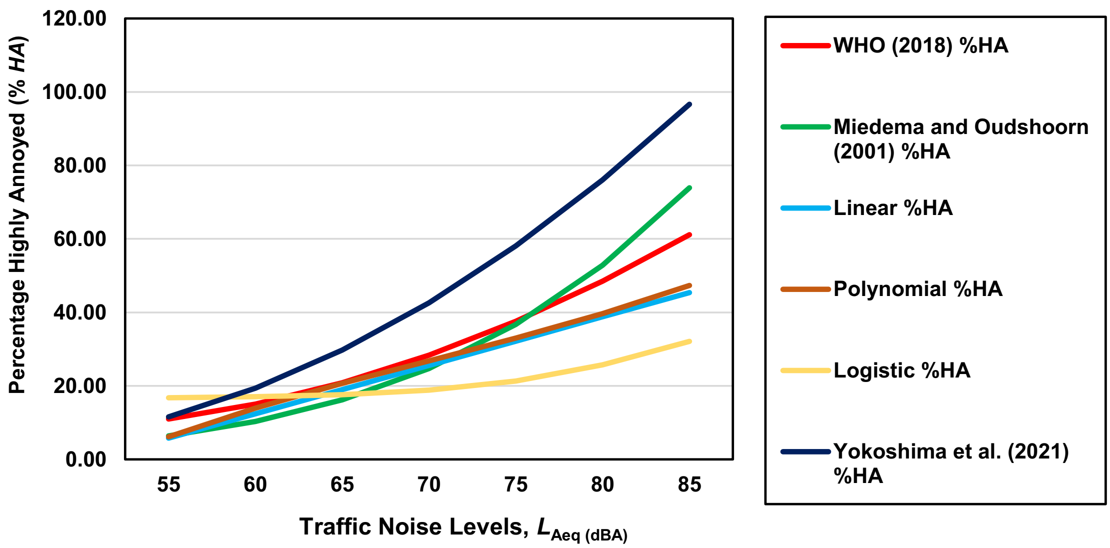

Figure 10: Comparison of developed linear, polynomial and logistic regression exposure–effect relationships with WHO (2018), Miedema and Oudshoorn (2001) and Yokoshima *et al.* (2021) models in terms of percentage highly annoyed (%HA).

a Structured Equation Model is also developed between traffic noise annoyance and health effects [24]. The highest correlation was observed between noise annoyance and stress followed by sleeping disorder. Fyhri and Aasvang (2010) examined annoyance as a moderating factor between a general assessment of the quality of sleep and a specific noise-induced sleep disturbance [24,36]. Table 11 demonstrates the path analysis results of the structured model which indicates that annoyance has a significant relationship with four out of six health effects caused by traffic noise annoyance. Apart from stress and sleeping disorder, hearing disorder and headache were also observed to have significant relationships with noise-induced annoyance, while blood pressure and heart attack showed insignificance with annoyance.

5 Comparison of exposure–effect relationships

In order to examine the validity, the developed exposure–effect relationships in the present study are compared to various exposure–effect relationships developed across the

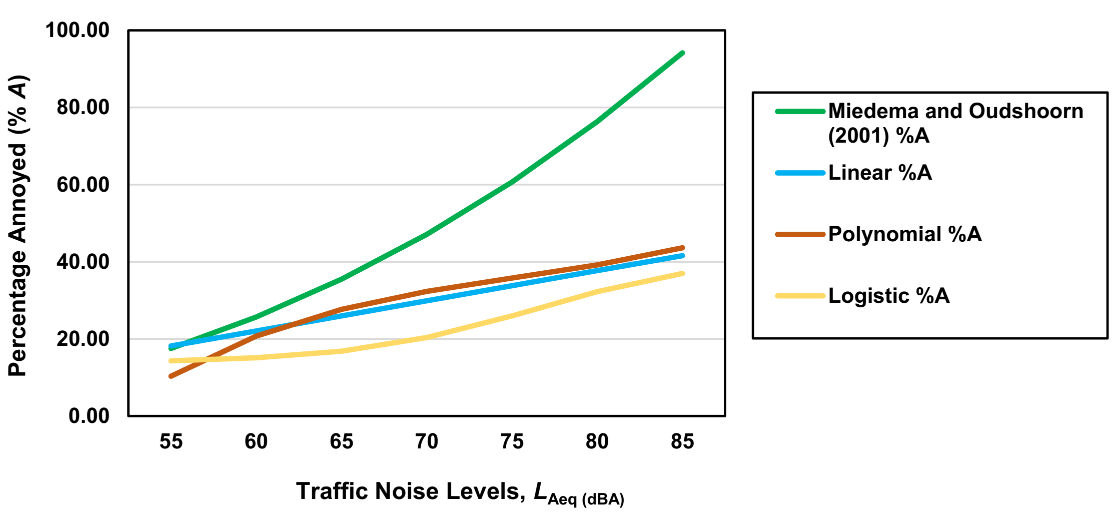

Figure 11: Comparison of developed linear, polynomial, and logistic regression exposure–effect relationships with Miedema and Oudshoorn (2001) model in terms of percentage annoyed (%*A*).

world. Three developed exposure–effect relationships namely, linear regression, polynomial regression, and logistic regression relationships are compared to the WHO model (2018), Miedema and Oudshoorn model, and Yokoshima *et al.* model for the percentage highly annoyed (%HA) and percentage annoyed (%A) [37,64,65,79]. The comparison curves are depicted in Figures 10 and 11, respectively. Here, it can be observed that the values predicted from the linear regression, polynomial regression, and logistic regression models match with the European studies for corresponding 10 dB(A) higher noise exposure levels. However, it was observed that the logistic regression model predicts the values nearer to the WHO (2018) model for corresponding 10 dB(A) higher equivalent exposure levels. Gjestland *et al.*'s study in Vietnam revealed that Asian people are more tolerant in comparison with the European population for the same noise exposure level. The present study reaffirmed the fact that the noise exposure levels can be increased up to 10 dB(A) in order to have a similar response to the curve recommended in the WHO (2018) report [64,78]. However, the results of the present study do not match with the model recommended by Yokoshima *et al.* [79] as a significant difference in the %HA values is observed for noise exposure levels higher than 70 dB (A). In the second case of the developed models for predicting percentage annoyed (%A), it was observed that the polynomial model fits better with the Miedema and Oudshoorn model for corresponding 10 dB(A) higher noise exposure levels.

The corresponding change in %HA with the change in $L_{\text{Aeq,1h}}$ is thus evaluated as:

$$\begin{aligned}\%\text{HA} = {} & 7.13 \times 10^{-4}(L_{A\text{eq,1h}} - 60)^3 - 2.15 \\ & \times 10^{-2}(L_{A\text{eq,1h}} - 60)^2 + 1.43(L_{A\text{eq,1h}} - 60) \\ & + 13.95,\end{aligned} \tag{9}$$

$$\begin{aligned}\frac{d(\%\text{HA})}{d(L_{\text{Aeq,1h}})} = {} & 21.39 \times 10^{-4}(L_{\text{Aeq,1h}} - 60)^2 - 4.30 \\ & \times 10^{-2}(L_{\text{Aeq,1h}} - 60) + 1.43,\end{aligned} \tag{10}$$

$$\begin{aligned}d(\%\text{HA}) = {} & d(L_{A\text{eq,1h}}) \\ & \times (21.39 \times 10^{-4}(L_{A\text{eq,1h}} - 60)^2 - 4.30 \\ & \times 10^{-2}(L_{A\text{eq,1h}} - 60) + 1.43).\end{aligned} \tag{11}$$

Thus, for a corresponding change of $\Delta L_{\text{Aeq,1h}}$ by 3 dB(A) for a location having 80 dB(A) $L_{\text{Aeq,1h}}$, the Δ %HA changes by 4.2%. While a change of $\Delta L_{\text{Aeq,1h}}$ by 3 dB(A) for a location having 70 dB(A) $L_{\text{Aeq,1h}}$, the Δ %HA changes by 3.6%.

Similarly, in the case of the percentage annoyed (%A) model, for a corresponding change of $\Delta L_{\text{Aeq,1h}}$ by 3 dB(A) for a location having 80 dB(A) $L_{\text{Aeq,1h}}$, the Δ %A changes by 2.4%. While a change of $\Delta L_{\text{Aeq,1h}}$ by 3 dB(A) for a location having 70 dB(A) $L_{\text{Aeq,1h}}$, the Δ %A changes by 2.3% [54].

6 Conclusions

This article presents a rarely reported comprehensive study in the NCT of Delhi, India with an objective of collecting and analyzing the subjective noise perception of community towards annoyance due to road traffic noise at 42 sites in the NCT of Delhi. The article presents extensive research to evaluate the significant relationships between traffic noise annoyance and traffic noise levels as well as demographic, psychological, and health factors. The study also describes the applicability of the Logistic regression and Structure Equation Modeling (SEM) for evaluating the annoyance effect due to various factors for traffic noise. The linear regression relationships, polynomial regression relationships, logistic regression relationships, and SEM model presented in this article can be utilized for conducting noise impact assessment studies and devising suitable noise action plans and policy interventions for noise abatement and control. Some major findings from the study are drawn as,

- Source-apportionment analysis of various sources of noise pollution in the NCT of Delhi based on community response revealed that road traffic noise along with honking noise was observed as the most dominant source causing noise annoyance among all other sources.
- A comprehensive socio-acoustic survey covering 42 sites and all zones in the NCT of Delhi was utilized for developing exposure–effect relationships and noise annoyance models.
- Generalized exposure–effect relationships were developed using the linear and polynomial regression methods to evaluate the correlation between traffic noise levels and noise annoyance. These equations represent the correlation between noise exposure and annoyance by using the results of the socio-acoustic survey.
- Logistic regression dose–effect relationships are derived using A-weighted hourly equivalent noise levels, $L_{\text{Aeq,1h}}$ as dose input, and the percentage of highly annoyed respondents (%HA) as well as the percentage of annoyed respondents (%A) as response outputs. These equations can be extensively used for the prediction of traffic noise annoyance. This analysis revealed a high risk for communities residing in noisy areas having greater noise levels as compared to those residing in quiet areas having less noise levels.
- The article presents the development of Structural Equation Models (SEM) for evaluating the factor analysis and assessing the prediction of traffic noise annoyance due to various psychological factors. The study also presents an SEM model for assessing the various health effects caused by road traffic noise annoyance. The developed models provide

the advantage of multivariable intercorrelations analysis among various factors causing noise annoyance.
- The study concluded that noise sensitivity was observed to be the highest significant predictor for annoyance towards road traffic noise. Additionally, honking has emerged as the second most significant parameter for the prediction of noise annoyance.
- The study revealed that stress was found to be the most significant health impact caused by annoyance followed by sleeping disorder.
- Comparison of developed linear regression, polynomial regression, and logistic regression models with the other models and WHO (2018) report shows that the results match with the European studies for corresponding 10 dB(A) higher noise exposure levels. It was observed that the logistic regression model predicts the values nearer to the WHO (2018) model for corresponding 10 dB(A) higher equivalent levels.
- The developed relationships and models can facilitate the feasible predictions of noise annoyance and environmental noise impact assessment. Also, these may be very useful in planning strategic noise action plans and abatement. The present work may be very useful in the risk management of various health effects caused by noise annoyance. The study shall also be useful in planning and developing smart cities in the future.

The work thus illustrated the possible predictors of noise annoyance and its severe health impacts on human beings. The study provides three generalized methods for assessing the correlations among various psychological factors, traffic noise levels, and noise annoyance. It can be extended to a large number of sites in the NCT of Delhi as well by considering the particular age groups and educational status for classified assessment of noise annoyance.

7 Limitations and scope for future work

The present study has some limitations that will be carried out in future:
- The study relies on self-reported annoyance levels, which can be subjective and influenced by various factors. Future research might consider objective measures of annoyance, such as physiological responses.
- The study does not consider contextual factors. The future study may investigate the role of contextual factors, such as the built environment, green spaces, and transportation modes, in influencing noise annoyance. This could lead to more comprehensive models.
- The random strategy is undertaken for the respondent's participation at many sites in the NCT of Delhi in the present study. Future work might focus on the classified assessment of noise annoyance based on particular age groups and socio-economic status.
- The study in general deals with traffic-induced noise annoyance. The future study will focus on analyzing the combined effect of road traffic, railway noise, and aircraft noise. Also, future studies shall focus on developing linear, polynomial, and logistic regression relationships with long-term noise levels like L_{day}, L_{night}, $L_{\mathrm{Aeq,\,24h}}$, and L_{den}.
- A strategic noise map should be developed for NCT of Delhi in future work to better understand the noise environment in the study.

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Appendix A

List of key questions asked in the questionnaire and the scales used

Name: ____________________

Age (In years): ☐Below 15/ ☐15–25 / ☐26–40 / ☐41–60 / ☐Above 60 years

Gender: ☐Male**/** ☐Female

Occupation: ☐Student/ ☐Self-Employed/ ☐Govt.-Employed/ ☐Industry

Education (up to): ☐High School/ ☐Graduate/ ☐Post Graduate/ ☐Doctorate

Social Status: ☐Higher Class/ ☐Upper Middle Class/ ☐Middle Class/ ☐Lower Class

1. How do you rate yourself as being **Noise Sensitive**?

Not at all				**Very Much**
☐1	☐2	☐3	☐4	☐5

2. How seriously are following **noise sources** affecting your daily life **(Major Noise Source)**?

	Not at all				**Very Much**
•Road Traffic Noise	☐1	☐2	☐3	☐4	☐5
•Honking Noise	☐1	☐2	☐3	☐4	☐5
•Railway/Metro Noise	☐1	☐2	☐3	☐4	☐5
•Aircraft Noise	☐1	☐2	☐3	☐4	☐5
•Industrial Noise	☐1	☐2	☐3	☐4	☐5
•Construction Noise	☐1	☐2	☐3	☐4	☐5
•Loudspeaker/Public Address Systems	☐1	☐2	☐3	☐4	☐5
•DG Set Noise	☐1	☐2	☐3	☐4	☐5
•Loud Music	☐1	☐2	☐3	☐4	☐5
•Ambulance/Police Van Sirens	☐1	☐2	☐3	☐4	☐5

3. How annoying is **Road traffic noise** in your surroundings (**Annoyance**)?

Not at all				**Very Much**
☐1	☐2	☐3	☐4	☐5

4. How noisy **Road transportation noise** you can hear at home (**Perceived noisiness**)?

Not at all				**Very Much**
☐1	☐2	☐3	☐4	☐5

5. How annoying is **Honking noise** in your surroundings and traveling (**Honking noise**)?

Not at all				**Very Much**
☐1	☐2	☐3	☐4	☐5

6. Do you experience any health effects due to noise exposure (**Health Effects**)?

Not at all				**Very Much**
☐1	☐2	☐3	☐4	☐5

7. Which health effect do you experience when exposed to noise levels and noise pollution?

Not at all					**Very Much**
•Headache	☐1	☐2	☐3	☐4	☐5
•Blood Pressure	☐1	☐2	☐3	☐4	☐5
•Stressed	☐1	☐2	☐3	☐4	☐5
•Hearing disorder	☐1	☐2	☐3	☐4	☐5
•Heart Attack	☐1	☐2	☐3	☐4	☐5
•Sleeping disorder	☐1	☐2	☐3	☐4	☐5