Factors Affecting Traffic Noise and Annoyance from Different Types of Roads: A Case Study in Nakorn Pathom Province, Thailand

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ABSTRACT

This study investigated factors associated with road traffic noise and residents' annoyance from three distinct types of roads (major arterial, minor arterial, and collector roads). Nine sampling locations in Thailand's Nakorn Pathom Province were chosen for the measurement of noise levels and three contributing characteristics: traffic volume, vehicle speed, and the proportion of heavy to total vehicles. Along with a housing survey, face to face interviews with a total of 387 roadside dwellers recorded their sociodemographic data, activity-based locations, and noise impacts experienced. A statistical analysis based on Spearman correlation revealed a positive relationship between traffic volume and traffic noise level on major arterial (r=0.607) and collector roads (r=0.885). Residents around collector roads were more sensitive than those along the main arterial road, in spite of having lower noise levels and less intense traffic patterns. Longer housing setbacks appeared to be a key factor in reducing noise annoyance from all road types, according to an exact logistic regression analysis (OR=0.11, 95% CI: 0.003, 0.73 for the major arterial road; OR=0.29, 95% CI: 0.10, 0.78 for the minor arterial road; and OR=0.32, 95% CI: 0.12, 0.84 for collector roads). However, performing activities in closed areas (OR=0.05, 95% CI: 0.01, 0.17 for the minor arterial road; OR=0.22, 95% CI: 0.54, 0.90 for collector roads) and living in soundproof structures (OR=0.05, 95% CI: 0.001, 0.31 for collector roads) played additional roles to reduce the annoyance of residents along the roads with shorter setback lines.

1. INTRODUCTION

Concerns about the health impacts of exposure to ambient noise have emerged as a result of the rapid global development of urbanization and transportation networks. Over 100 million people in Europe alone were subjected to excessive environmental noise, which had physical and psychological effects, particularly severe annoyance (22 million cases) and sleep disturbance (6.5 million) (EEA, 2020). Since up to 113 million people have been exposed to hazardous levels of road traffic noise, it can be determined that road traffic noise is a pollution source that poses a serious threat to environmental health (EEA, 2020). To begin alleviating the problem, we must first explore the road traffic noise characteristics and understand the annoyance of residents residing along the roads. While information on the former is useful for local authorities to implement appropriate control measures, findings on the latter imply the acceptable safety noise level of each culture which can be used for urban planning without stunting economic growth. As a result, investigations into the speed and volume of vehicles that contribute to road traffic noise have been conducted (Tripura and Sarkar, 2011; Miškinytė and Dėdelė, 2014; Halim et al., 2019), and studies into the annoyance in large and popular tourist cities around the world, including H. Matamoros and Tamaulipas in northeast Mexico, Sfax in Tunisia, Seoul and Ulsan in South Korea, Copenhagen, Aarhus, Odense and other cities in Denmark, and Phuket and

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Ayutthaya in Thailand, have been reported (Sung et al., 2016; DRD, 2016; Bunnakrid et al., 2017, Thareejit et al., 2020; Bouzid et al., 2020; Zamorano-González et al., 2021). No less significant than in these places, people in frontier areas have also complained about traffic noise brought on by town expansion and various types of nearby transit linkages going to large cities.

Although Nakorn Pathom is a small province with an area of 2,168.3 km^2 and a population of 920,729 individuals, it is currently ranked in the top 10 highest gross provincial product (GPP) in Thailand (NESDC, 2022). With seven adjacent provinces, including the capital Bangkok, and its proximity to the Myanmar border, Nakorn Pathom serves as a significant agricultural and industrial production hub as well as a gateway to other parts of Thailand. While Route 4 or Petchkasem Rd (the longest major arterial road in Thailand) serves as the only major highway to the south, and Route 321 or Malaiman Rd (an important minor arterial road for cargo transportation) serves as a shortcut to the west, many crowded collector roads serve as links between Nakorn Pathom communities and these arterial roads. Thus, to better understand how motor traffic affects the nearby inhabitants along each road, factors contributing to traffic noise and residents' annoyance were examined.

2. METHODOLOGY

2.1 Data collection

Road traffic noise levels, traffic characteristics, and information on residents along the roadsides were collected from January to April 2020. To avoid atypical traffic characteristics, we temporarily stopped collecting data a week before and after any town special event and public holiday.

2.1.1 Measurement of road traffic noise and its contributing factors

According to the community settlement, Route 4 from km 50 to km 61 (+100), Route 321 from km 0 to km 5 (+200) and three collector roads, Ying Pao, Thahan Bok, and Ratchamanka Rd, constituted the study territory. To measure noise levels, three sampling sites along each type of road were determined (Figure 1) and a calibrated class I SVAN971 sound level meter was installed 1.5 meters above the ground at a distance of approximately five meters, three meters, and two meters away from the roadsides of major arterial, minor arterial, and collector roads, respectively. At each site, hourly equivalent sound levels (L_{eq}) over 24 hours were measured for three days on both weekdays and weekends and the day-evening-night average sound level (L_{den}) was calculated using Equation 1.

$$L_{den} = 10\log\left[\frac{1}{24}\left(12 \times 10^{\frac{L_{day}}{10}} + 4 \times 10^{\frac{L_{evening}+5}{10}} + 8 \times 10^{\frac{L_{night}+10}{10}}\right)\right] \quad (1)$$

Where; L_{day}= the average sound level from 07.00 to 19.00; $L_{evening}$=the average sound level from 19.00 to 23.00; L_{night}=the average sound level from 23.00 to 07.00.

A video camera that covered a 100-meter radius around two reference stations, where the sound level meter was situated in the middle, also recorded traffic volumes and vehicle types in addition to the measurements. During the morning and evening rush hours, the number of motorcycles, motor tricycles, cars/vans, and buses/trucks were counted. The ratio of buses/trucks to all vehicles was then calculated. To determine the vehicle speed, the distance traveled between those two fixed points was divided by the time taken to complete the trip.

2.1.2 Social survey

Personal and housing factors were collected through a pre-tested survey form and questionnaire with the acceptable item-objective congruence index rated by three experts (0.9). Based on Cochran's formula (Cochran, 1977), a total of 387 households were chosen to participate. Forty-three residents of homes in the first row of buildings closest to the road verge made up 129 representative samples for each type of road surrounding each noise monitoring site. Along with the observation on their housing types, structures, and setbacks — residents aged between 18 and 65 years that have been residing in the area for more than one year and spending more than eight hours in their residence while having no hearing impairment were asked about their socioeconomic status (sex, age, education attainment, health status), activity-based locations (open/closed spaces), and noise impacts. Perceived annoyance was verbally rated according to the five-point International Commission on Biological Effects of Noise (ICBEN) scale: (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) mostly annoyed, and (5) extremely annoyed (Fields et al., 2001). The ratio of the sum of respondents' rating scores to the total number of respondents was used to determine the average annoyance. The percentage of highly annoyed (%HA) participants included the number of residents who felt mostly and extremely annoyed (Brink et al., 2021).

2.1.3 Ethical approval

The Ethics Review Committee for Human Research at Mahidol University granted ethics approval for this study (COA No. MUPH 2019-147 on November 28, 2019).

2.2 Data analysis

Statistical analysis was performed by R (R Core Team, 2019). The relationship between the traffic noise level measured during rush hours and three contributing factors, traffic volume, vehicle speed, and the proportion of bus/truck to total vehicles, was analyzed using Spearman correlation. Comparative community sensitivities were derived from the trends between the percentage of highly annoyed (%HA) and the day-evening-night average sound level (L_{den}). The exact logistic regression, which is better suited to a small sample size (Zamar et al., 2007), was used to quantify the relationships between personal and housing factors and residents' annoyance because the traditional logistic regression used the unconditional maximum likelihood estimation with asymptotic assumption.

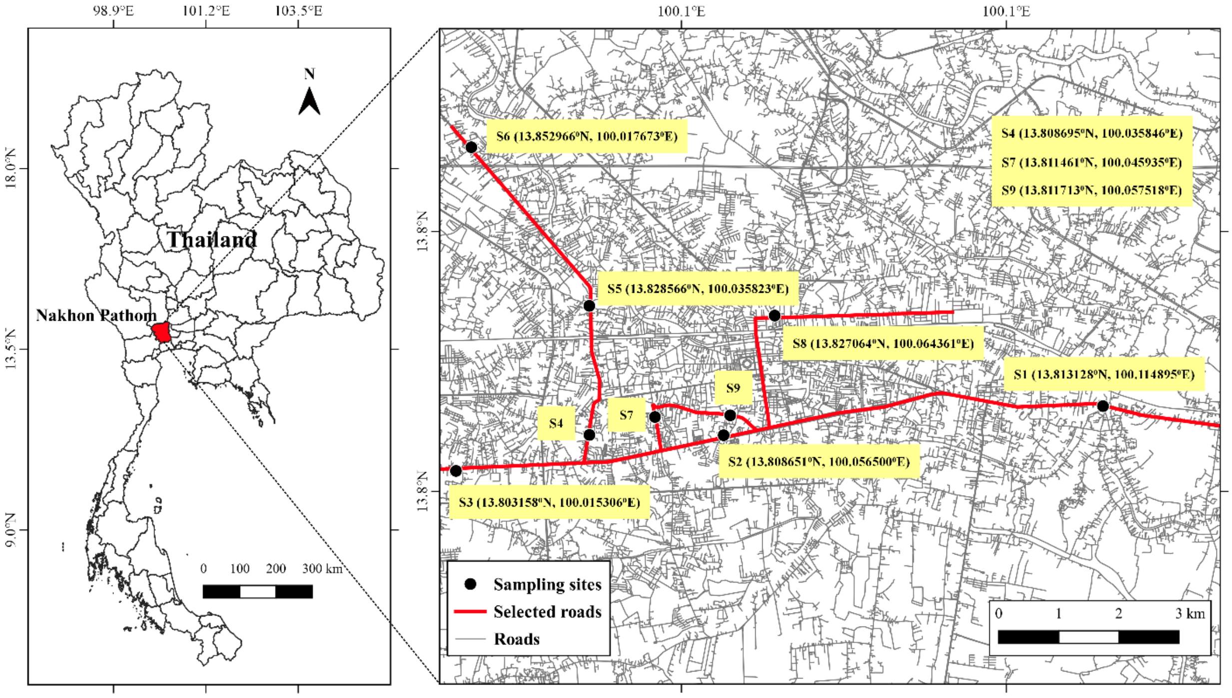

Figure 1. Sampling sites in Nakorn Pathom: Route 1 (S1, S2, S3), Route 321 (S4, S5, S6), and three collector roads, i.e., Ying Pao, Thahan Bok and Ratchamanka (S7, S8, S9)

3. RESULTS AND DISCUSSION

3.1 Road traffic characteristics, noise levels, and their contributing factors among different types of roads

In general, the major arterial road had the highest vehicle volumes, followed by minor arterial and collector roads, respectively (Table 1). According to the Thailand Road Traffic Act (Ministry of Interior, 1979; Ministry of Interior, 1981), heavy vehicles and cars/vans at several sites, especially on the minor arterial road, accelerated at speeds over the limit (inside city municipality: car/van ≤80 km/h, bus/truck ≤60 km/h; outside city municipality: car/van ≤90 km/h, bus/truck ≤80 km/h). As a result of engine noises combined with tire noises at higher speeds (Grubeša and Suhanek, 2021; Lechner et al., 2020), noise levels measured at these arterial roads were greater than those at collector roads (Table 2). Additionally, this pattern was seen in Delhi, India, and Phuket, Thailand (Ahmad and Sarkar; 2014, Bunnakrid et al., 2017).

Similar to many roads in large cities such as Doha in Qatar (Abdur-Rouf and Shaaban, 2022) and Sao Paulo in Brazil (Paiva et al., 2019), $L_{eq,\ 24h}$ at all sampling points on major and minor arterial roads in Nakorn Pathom exceeded the limit (70 dB(A)) determined by the Thailand Pollution Control Department, US Environmental Protection Agency, and World Health Organization (Ministry of Natural Resources and Environment, 1997; CDC, 2019). Although L_{den} and L_{night} in our study were determined from traffic noise levels measured over a typical week, residents along the roads in Nakorn Pathom were exposed to a much higher noise threshold than that recommended by the Guideline Development Group (GDG) used in the European region — which accounted for added noises from special events throughout the year (WHO, 2018).

Table 1. Average of vehicle speeds, volumes and proportions of heavy to total vehicles in major arterial, minor arterial and collector roads in Nakorn Pathom Province

Road type	ID	Vehicle type								
		Motorcycle		Tricycle		Car/van		Bus/truck		Heavy to total vehicles*
		Speed (km/h)	Volume (veh/h)	Speed (km/h)	Volume (veh/h)	Speed (km/h)	Volume (veh/h)	Speed (km/h)	Volume (veh/h)	
Major arterial Rd	S1[O]	57.6	913.3	39.0	8.2	85.9	10,332.3	61.0	515.2	0.051
	S2[I]	60.1	747.2	41.4	9.0	85.5**	7,181.2	59.2	428.5	0.052
	S3[O]	51.3	579.8	33.0	4.7	82.7	5,802.7	55.7	468.2	0.068
	Mean	56.3	746.8	37.8	7.3	84.7	7,772.1	58.6	470.6	0.057
	(SD)	(4.5)	(166.8)	(4.3)	(2.3)	(1.7)	(2,321.9)	(2.7)	(43.4)	(0.010)
Minor arterial Rd	S4[I]	49.4	620.2	34.2	4.0	68.7	4,084.5	44.2	501.0	0.100
	S5[I]	58.3	501.3	41.3	7.0	83.3**	2,754.7	62.4**	429.8	0.119
	S6[O]	56.7	314.5	41.0	2.0	90.5**	2,361.3	71.2	389.8	0.127
	Mean	54.8	478.7	38.8	4.3	80.8	3,066.8	59.3	440.2	0.115
	(SD)	(4.7)	(154.1)	(4.0)	(2.5)	(11.1)	(903.0)	(13.8)	(56.3)	(0.014)
Collector Rd	S7[I]	46.7	944.3	32.9	9.7	48.9	1,277.8	43.6	19.2	0.008
	S8[I]	50.7	981.5	34.3	17.3	50.3	647.0	40.2	15.0	0.009
	S9[I]	53.0	749.2	40.5	4.0	56.1	868.5	50.0	12.7	0.008
	Mean	50.1	891.7	35.9	10.3	51.8	931.1	44.4	15.6	0.008
	(SD)	(3.2)	(124.8)	(4.0)	(6.7)	(3.8)	(320.0)	(5.0)	(3.3)	(0.001)

I: located inside city municipality; O: located outside city municipality; *: the ratio of buses/trucks to all vehicles; **: over the speed limit as determined by the Thailand Road Traffic Act B.E.2522 (Ministry of Interior, 1979; Ministry of Interior, 1981)

Table 2. Average noise and annoyance levels and the percentage of highly annoyed (%HA) from road traffic noise in Nakorn Pathom Province

Road type	ID	Noise level (dB(A))					Annoyance level	%HA
		L_{day}	$L_{evening}$	L_{night}	L_{den}	$L_{eq, 24h}$		
Major arterial Rd	S1	79.4	77.2	76.1	83.2	78.4	2.8	53.5
	S2	77.4	75.3	72.8	80.3	76.0	2.2	34.9
	S3	76.2	74.9	72.5	79.8	75.1	1.8	25.6
Minor arterial Rd	S4	76.0	76.4	72.9	80.3	75.4	2.4	44.2
	S5	76.4	73.9	70.8	78.7	74.9	2.5	48.9
	S6	78.8	72.1	69.8	78.9	76.5	2.2	41.9
Collector Rd	S7	70.7	69.4	69.5	76.1	70.3	2.3	46.5
	S8	70.4	70.1	67.5	74.7	69.7	2.5	48.8
	S9	69.3	67.6	65.5	72.8	68.2	1.7	21.0

When the relationships between traffic noise level and its contributing factors were explored (Table 3), traffic volumes showed a significant correlation in regards to traffic noise, corresponding to several other studies (Halim et al., 2019; Peeters and Blokland, 2007; Miškinytė and Dėdelė, 2014). In contrast to normal circumstances, it was noted that traffic volume on the minor arterial road and vehicle speed on collector roads negatively correlated with noise level ($p=0.049$ and $p=0.002$, respectively).

The negative relation between traffic volume and noise level might be explained by road surface condition and vehicle type. As shown in Table 1, the proportions of heavy to total vehicles on this minor arterial road were high since it served as a shortcut for cargo transport when traveling west of Thailand. Once the traffic volume was low, many truck drivers tended to accelerate their vehicle speeds. This resulted in higher noise levels from propulsion and tire rolling-contact surface (Peeters and Blokland, 2007; Grubeša and Suhanek, 2021) and rattling bodies from turbulence caused by the deteriorating pavements, which were commonly observed on arterial roads with a high number of trucks. Consequently, the noise level rose when the traffic volume was low, corresponding to a study of Anachkova et al. (2022).

For the latter case, a negative correlation could be elucidated by a traffic violation. Because collector roads had only two to four lanes with many vehicles parking along the roadsides, the drivers had to reduce their vehicle speeds which made vehicle volumes accumulate on the road. Thus, inverted relation was explored, possibly due to the influence of another factor. A similar condition was also observed in a congested area in Agartala City in India (Tripura and Sarkar, 2011).

Table 3. Spearman correlation coefficients between noise level ($L_{eq,1h}$) and its contributing factors

Road type		Traffic volume	Vehicle speed	Proportion of heavy to total vehicles
Major arterial	coefficient	0.607	0.269	-0.414
	p value	0.008	0.281	0.087
Minor arterial	coefficient	-0.469	0.444	-0.081
	p value	0.049	0.065	0.751
Collector	coefficient	0.885	-0.673	0.065
	p value	<0.001	0.002	0.797

3.2 Resident characteristics, noise impacts, and community sensitivities among different types of roads

As shown in Table 4, approximately one-half of the respondents were female. Most were middle-aged and their educational attainments were below college graduate levels. The majority performed their daily activities in open spaces and verbally described their physical status as healthy. Considering their housing characteristics, terraced houses along minor arterial and collector roads were common but relatively equal amounts of terraced and detached houses were observed along the major arterial road. The vast majority of housing was set back along the major arterial road further than 13 meters but only 0 to 6 and 0 to 5 meters away from the road verges for minor arterial and collector roads, respectively. Approximately 75% of the houses were made of cement, which was classified as effective soundproof structures, and the rest were either cement-wood-mixed or wood structures — which were classified as partially soundproof structures.

According to the interviews, adverse noise impacts involved annoyance (93.0-96.1%), conversation disturbance (42.6-86.8%), interference with hearing TV/Radio (38.8-60.0%), sleep disturbance (25.6-40.0%) and interference with working/reading (5.4-23.2%) (Figure 2). The average annoyance scores ranged from 1.7 to 2.8, and 21.0-53.5% of them felt highly annoyed (Table 2). Residents along arterial roads perceived trucks as the most annoying vehicle type while on collector roads were motorcycles. In this case, noise and vibration from a large number of trucks as previously discussed, as well as driving patterns, might be a cause. Since high proportions of heavy to total vehicles on arterial roads, especially on the minor arterial road, were observed — most truck drivers often touched the brake pads and used their unusually modified horns to avoid car accidents. The same reason can be used to account for residents' annoyance from collector roads. As a consequence of similar behaviors of riders, such as weird and distortedly loud accelerating, fast and aggressive riding, and group riding, this extreme annoyance response to motorcycles was also perceived by residents in Phuket, Thailand — as well as the Alpine valleys (Bunnakrid et al., 2017; Lechner et al., 2020).

Considering dose-response relationship, residents along collector roads with lower noise levels were more sensitive than the ones along the major arterial road (Figure 3). Although the significant correlations between road categories and noise-related impacts were indirectly described by noise levels in a previous study (González et al., 2023), the aforementioned noise characteristics together with shorter setback distance on collector roads might be an explanation for our case. As confirmed by several studies, noise characteristics, in addition to noise levels, significantly increased traffic annoyance (Sung et al., 2016; Jeon et al., 2010; Erkan, 2017; Phan et al., 2009). Compared to other studies in Thailand (Bunnakrid et al., 2017; Thareejit et al., 2020), it was obvious that the traffic noise sensitivity among Thais who lived close to the same type of roads was alike. However, as a result of cultural differences, various sensitivities from many countries were observed (Bouzid et al., 2020; Sieber et al., 2018).

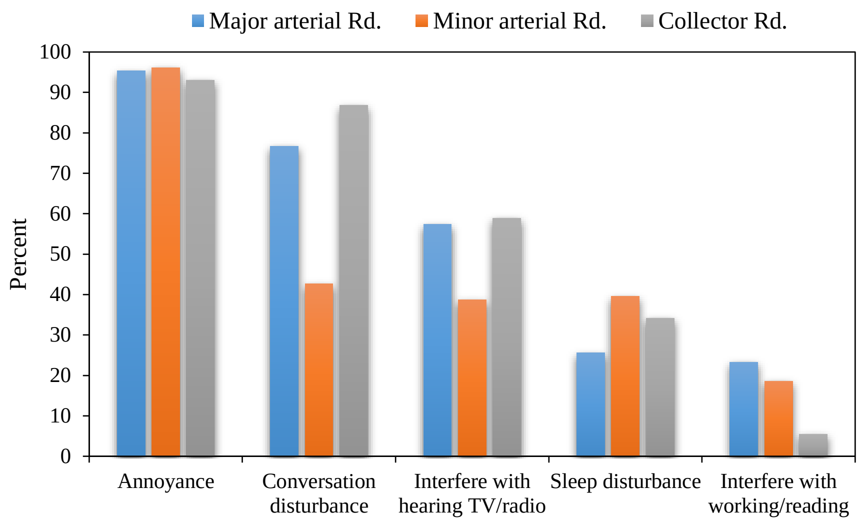

Figure 2. Noise impacts from major, minor and collector roads (n=129 individuals for each road)

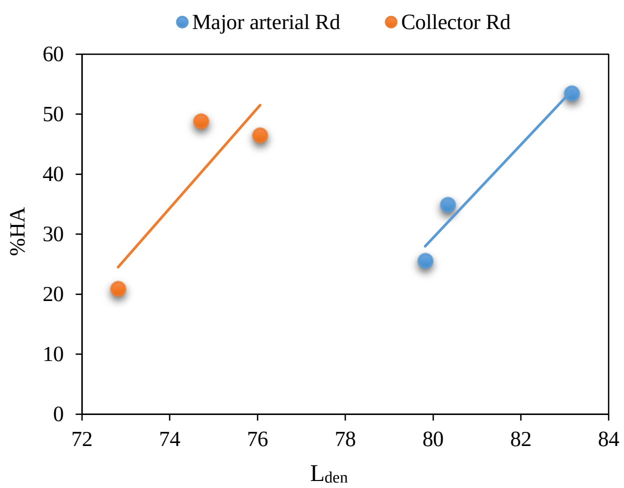

Figure 3. Noise sensitivities of residents living along different road types

3.3 Factors associated with residents' annoyance from different types of roads

As shown in Table 4, when the relations among variables were explored, two factors (sex and housing setback), three factors (age, housing setback, and activity-based location), and four factors (sex, housing setback, activity-based location, and housing structure) were significantly associated with residents' annoyance from the major arterial, minor arterial, and collector roads, respectively. From these findings, it consistently indicated that the further the housing setback distance, the lower the probability of being annoyed by traffic noise in every road type (OR=0.11, 95% CI: 0.003, 0.73 for the major arterial road; OR=0.29, 95% CI: 0.10, 0.78 for the minor arterial road and OR=0.32, 95% CI: 0.12, 0.84 for collector roads) (Table 4). As inverse relations between distance and noise levels have been confirmed in many studies (Miškinytė and Dėdelė, 2014; Azodo et al., 2019; Moshtaghie et al., 2012; Singhal et al., 2018), these may explain why activity-based locations and housing-related factors were insignificantly associated with residents' annoyance from the major arterial road. In contrast, these two factors played an important role in relieving noise disturbance to residents who lived in dwellings with the shorter setback distance. For instance, residents performing their daily activities in closed spaces along minor arterial (OR=0.05, 95% CI: 0.01, 0.17) and collector roads (OR=0.22, 95% CI: 0.54, 0.90) were less likely to be annoyed than those in open spaces. Another example was housing structure. The annoyance probability of residents living in houses with soundproof structures along collector roads was lower than among those in partially soundproof structures (OR=0.05, 95% CI: 0.001, 0.31). Although this relationship could not be explored from the minor

Table 4. Factors associated with annoyance of residents along different types of roads

Variable	Major arterial road					Minor arterial road					Collector roads				
	Total		Annoyance		p value OR (95% CI)	Total		Annoyance		p value OR (95% CI)	Total		Annoyance		p value OR (95% CI)
	n	%	n	%		n	%	n	%		n	%	n	%	
Total	129	100	103	79.8		129	100	104	80.6		129	100	93	72.1	
Sex					0.027					0.403					0.047
Female	67	51.9	59	88.1	1	69	53.5	58	84.1	1	77	59.7	61	79.2	1
Male	62	48.1	44	71.0	0.33 (0.11, 0.90)	60	46.5	46	76.7	0.63 (0.23, 1.64)	52	40.3	32	61.5	0.42 (0.18, 0.99)
Age					0.142					0.003					0.214
18-40	24	18.6	16	66.7	1	25	19.4	14	56.0	1	25	19.4	15	60.0	1
41-60	105	81.4	87	82.9	2.40 (0.77, 7.10)	104	80.6	90	86.5	4.97 (1.69, 14.73)	104	80.6	78	75.0	1.99 (0.71, 5.43)
Education					0.747					0.608					1.000
≥College	109	84.5	88	80.7	1	105	81.4	86	81.9	1	103	79.8	74	71.8	1
<College	20	15.5	15	75.0	0.72 (0.22, 2.81)	24	18.6	18	75.0	0.67 (0.21, 2.32)	26	20.2	19	73.1	1.06 (0.38, 3.32)
Health status					0.751					0.186					0.479
Unhealthy	10	7.8	9	90.0	1	18	14.0	17	94.4	1	21	16.3	17	81.0	1
Healthy	119	92.2	94	79.0	0.43 (0.01, 3.39)	111	86.0	87	78.4	0.22 (0.005, 1.52)	108	83.7	76	70.4	0.56 (0.13, 1.91)
Setback*					0.012					0.011					0.020
Inside cutoff	29	22.5	28	96.6	1	73	56.6	65	89.0	1	102	79.1	79	77.5	1
Outer	100	77.5	75	75.0	0.11 (0.003, 0.73)	56	43.4	39	69.6	0.29 (0.10, 0.78)	27	20.9	14	51.9	0.32 (0.12, 0.84)
Housing type					0.540					0.248					0.056
Detached	64	49.6	53	82.8	1	23	17.8	21	91.3	1	10	7.8	4	40.0	1
Terraced	65	50.4	50	76.9	0.69 (0.26, 1.79)	106	82.2	83	78.3	0.35 (0.04, 1.59)	119	92.2	89	74.8	4.39 (0.97, 22.64)
Soundproofing					0.148					0.248					<0.001
Partial	31	24.0	28	90.3	1	15	11.6	15	100.0	1	36	27.9	35	97.2	1
Effective	98	76.0	75	76.5	0.35 (0.06, 1.31)	114	88.4	89	78.1	0.24 (0.005, 1.71)	93	72.1	58	62.4	0.05 (0.001, 0.31)
Working space					0.250					<0.0001					0.001
Open	98	76.0	81	82.7	1	107	82.9	97	90.7	1	86	66.7	71	82.6	1
Closed	31	24.0	22	70.9	0.52 (0.19, 1.50)	22	17.1	7	31.8	0.05 (0.01, 0.17)	43	33.3	22	51.2	0.22 (0.54, 0.90)

* Due to different types of roadside characteristics, cutoff points for the major arterial, minor arterial and collector roads were 13, 6, and 5 meters, respectively.

arterial road, a high possibility of noise impact existed for the residents residing in houses with partly efficient soundproof structures, noticed by their consistent annoyance confirmation (Table 4).

For demographic factors, females residing along major arterial and collector roads and the older age group residing along the minor arterial road generally were more likely to be annoyed by road traffic noise. These resulted from higher environmental perceptions and awareness of females (Dratva et al., 2010) and loud noise acclimatization of younger respondents (Zamorano-González et al., 2021), respectively. However, as a result of individual factors, the relations could not be explored from some types of roads. The ground for these reasons should be explored further in-depth.

4. CONCLUSION

Road traffic noise levels at almost all sampling points in Nakorn Pathom Province exceeded the established limits. As a result, more than 90% of the respondents perceived slight to extreme annoyance. On collector roads, both the vehicle volume and the speed were significantly correlated with noise levels, while on major and minor arterial roads, vehicle volume was correlated with noise levels exclusively. According to the root causes, various legal measures, e.g., traffic flow and speed control should be implemented to alleviate the annoyance problem. For self-prevention, exact logistic regression analysis showed that housing setback potentially reduced noise annoyance from every road type. However, for minor arterial and collector roads, housing structure and activity-based location significantly played an additional role. Therefore, constructing houses with effective soundproof structures and performing activities in closed spaces were recommended.

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