Asia-Pacific Journal of Science and Technology: Volume: 25. Issue: 03. Article ID.: APST-25-03-08. Research Article

APST

Asia-Pacific Journal of Science and Technology

https://www.tci-thaijo.org/index.php/APST/index

Published by the Research and Graduate Studies,
Khon Kaen University, Thailand

# The association between road traffic noise and annoyance levels in residential and sensitive areas of Ayutthaya, Thailand

Minta Thareejit[1,2], Tanasri Sihabut[1,2] and Withida Patthanaissaranukool[1,2,*]

[1]Department of Environmental Health Sciences, Faculty of Public Health, Mahidol University, Bangkok, Thailand
[2]Center of Excellence on Environmental Health and Toxicology (EHT), Bangkok, Thailand
[*]Corresponding author: withida.pat@mahidol.ac.th

Received 7 February 2020
Revised 30 May 2020
Accepted 8 June 2020

**Abstract**

In urban areas of Thailand, noise emission from road traffic has been found to be a serious concern among the general public. Therefore, socio-acoustic surveys of community response to road traffic noise were conducted to investigate annoyance level of people residing in sensitive and residential areas of Ayutthaya Municipality with a sample size of 265 respondents. Noise-sensitive receptors in this study included hospital, schools and temples. In addition, the relationship between the percentage of "highly annoyed" persons (%HA) and day-night noise levels ($L_{dn}$) were described using a dose-response curve. The results showed that road traffic noise levels in sensitive areas were greater than those in residential areas. Most measurement sites exceeded the national ambient noise standard, resulting in the number of individuals annoyed by road traffic noise totaling 75.1% of total respondents. However, highly annoyed persons were computed to be 23.1-37.5 and 30.0-40.0% of total respondents in residential and sensitively areas, respectively. When $L_{dn}$ was greater than 70 dB(A), the %HA due to road traffic noise in sensitive areas was significantly higher than that in residential areas with the same $L_{dn}$. These indicated that people of Ayutthaya in sensitive areas were more sensitive to road traffic noise than those residing in residential areas. Therefore, mitigation measures to reduce road traffic noise should be implemented in these areas to prevent noise problems in urban communities.

**Keywords:** Road traffic noise, Annoyance, Exposure-response relationship, Public health, Ayutthaya

## 1. Introduction

Environmental noise is a public health problem greatly impacting on both individual and community health issues [1]. Several studies have shown that noise pollution, mainly caused by road traffic, is a major public health threat in developing countries [2-3]. Road traffic noise was reported as a possible risk factor for arterial hypertension among adults in Serbia [4]. Exposure to road traffic noise increased blood pressure levels among Belgrade preschool children and school children [5] Some studies supported a positive correlation between children's blood pressure and road traffic noise [6]. Moreover, adverse mental health outcomes due to traffic noise can be explained by its unwanted and annoying character [7]. The World Health Organization (WHO) has estimated 487,000 Disability-Adjusted Life Years (DALYs) lost every year in Europe due to road traffic noise annoyance [1]. Accordingly, several researchers interested in studying the relationship of traffic noise and annoyance level of people in community areas [3,8]. The results of those studies have indicated that traffic noise is a major source of annoyance. Moreover, one study aimed at developing a dynamic noise mapping system to detect and represent in real time the acoustic impact of road infrastructure in Rome and Milan Italy [9].

In Thailand, noise-related complaints comprised 14% of all complaints. In 2017, the average of traffic noise was reported to be 74.7 dB(A), of which 88.2% of measurement sites were higher than the ambient noise standard [10]. However, few studies have been conducted concerning the annoyance levels from road traffic noise in a community of Thailand. Some studies found that the average annoyance scores (see Section 2.4 for definition) of traffic noise in Muang Phuket, Thalang and Kathu were 1.78, 2.52, and 2.75, respectively. However, the results also found that people in Muang Phuket were more sensitive to road traffic noise than those in Talang and Kathu District of Phuket Province [11].

Ayutthaya is one of the important provinces in Thailand as one part of Ayutthaya Historical Park is located in the Ayutthaya Municipality, declared as a UNESCO World Heritage Site in 1991. Therefore, it constitutes one of the major tourist attractions in Thailand and is easily accessible due to its close proximity to Bangkok. According to statistical data from the Department of Tourism, the number of tourists in Ayutthaya was recorded to comprise 7,216,514 and 7,631,557 people in 2016 and 2017, respectively [12]. In addition, it indicated that the number of tourists has been gradually increasing because Ayutthaya is considered one of the top world attractions. Accordingly, the traffic volume of Ayutthaya has also increased. As we know, residential area is land used in which housing predominates. However, sensitive areas mean low density residential areas, schools, hospitals, nursing homes, places of worship, religious buildings and law courts [13]. In addition, many sensitive receptor areas located in Ayutthaya Municipality include hospitals, schools and temples. Consequently, the increase of traffic volume and traffic noise affects people residing along thoroughfares, especially sensitive receptors.

Therefore, this study aimed to investigate environmental noise and noise annoyance levels among sensitive and residential receptors in Ayutthaya Municipality, Thailand. The results of this study could be used as guidelines for noise-related annoyance assessment in urban areas of Thailand.

## 2. Methods

This study was designed as an analytical survey research to determine the annoyance levels from road traffic noise between sensitive and residential areas in Ayutthaya Municipality, covering an area of 14.84 square km. The study was divided in two parts including traffic noise measurement and annoyance survey.

### *2.1 Study areas*

Ayutthaya Municipality was selected as the study area, given that most of the historical parks is located in this area. According to statistical data from the Department of Tourism, the number of tourists in Ayutthaya increased from 7.216 to 7.631 million from 2016 to 2017 [12]. However, traffic volume in Ayutthaya has also increased. Consequently, increasing traffic volume and traffic noise might affect people residing along thoroughfares, especially sensitive receptors. Thus, sensitive areas (hospital, schools, and temples) and residential areas (households) located near main roads in Ayutthaya Municipality were selected for traffic noise measurement and social survey in this study.

### *2.2 Noise exposure measures*

To quantify road traffic noise levels, noise measurements were undertaken along the roadside in front of 15 selected points of sensitive and residential areas using a Sound Level Meter -NL-21 (Class 2). The measurement points of traffic noise in residential areas were selected for residential housing along main arterial routes and high-density housing. In addition, hospital, schools, and temples located along the main road were selected for traffic noise measurement points in sensitive areas as shown in Figure 1.

The 24-h trend of noise levels of each measurement point was obtained for three days including two weekdays and weekends during the dry season from February to April 2017. The sound level meter was set on a tripod at a height of 1.2 m above ground level at a distance of 1 to 5 m from the roadside. Meanwhile, the parameters of road traffic including traffic flow and speed of vehicles were recorded. The $L_{dn}$ (day-night level) was used to depict the noise exposure for road traffic. It constituted a weighted equivalent sound level for a 24-hperiod with 10 dB(A) compensation for nighttime noise level (10.00 pm.-07.00 am.) to take into account increasing noise annoyance of overnight sleep h. $L_{dn}$ was defined as shown in Equation (1).

$$L_{dn} = 10log\left[\left(\frac{15}{24}\right)\times 10^{(L_{day}/10)} + \left(\frac{9}{24}\right)\times 10^{((L_{night}+10)/10)}\right] \quad (1)$$

Where, $L_{day}$ and $L_{night}$ represent the average day (07:00 to 22:00) and night-time (22:00 to 7:00) sound levels.

### *2.3 Social survey*

The socio-acoustic surveys of community response to road traffic noise were conducted to investigate annoyance level of people residing in sensitive and residential areas of Ayutthaya Municipality from March to May 2017. Sample size of respondent residing along the main road around measurement points of traffic noise in

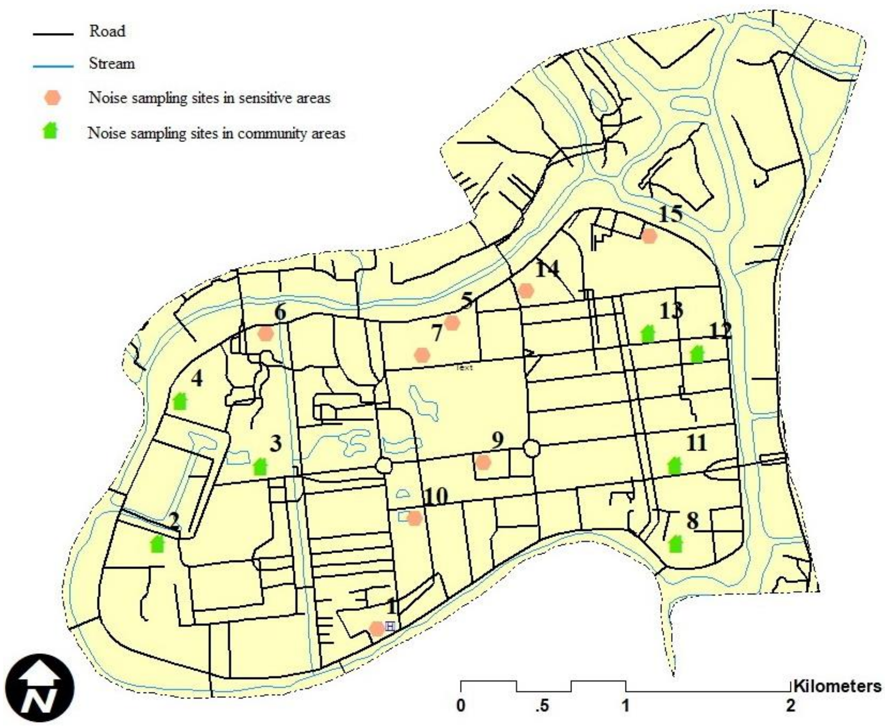
Ayutthaya Municipality were calculated using Cochran's formula as shown in Equation (2). This study considered the expected prevalence of annoyance using data from a preliminary survey.

$$n = \frac{Z^2 \times p \times q}{e^2} \rightarrow n = \frac{1.96^2 \times 0.83 \times 0.17}{0.05^2} \rightarrow n = 217 \quad (2)$$

Where; n is the sample size; Z is 1.96 (percentile of normal distribution); p is the estimated proportion of people who feel annoyed to the total number of people from the preliminary survey data (25/30); q is 1-p and e is the maximum permissible error in absolute value.

Using Equation (2), the sample size for the annoyance survey totaled at least 217 respondents. However, a safety margin of 20% was added to the final sample size. Therefore, respondents of this study totaled 265 people. To compare the annoyance level between two groups of receptors, the sample size was divided in 145 and 125 respondents in sensitive and residential areas, respectively. In addition, the number of respondents required in each area was estimated using a proportional ratio between the total number of people residing along the main road around measurement points and the final sample size.

In some studies, data on annoyance level were obtained using residential telephones and email interviews according to the addresses listed within the targeted areas [14]. In this study, the sample population for face-to-face interviews was conveniently selected from the communities because annoyance had been identified as the most significant psychological impact of traffic noise. Accordingly, respondents were asked questions such as, "Thinking over the last three months, how much did noise from traffic noise source trouble, disturb or annoy you: not at all, slightly, moderately, very much or extremely annoyed?".




**Remark:**

**Sensitive areas**

**No. 1** is Hospital A
**No. 5** is Temple A
**No. 6** is School A
**No. 7** is School B
**No. 9** is School C
**No. 10** is School D
**No. 14** is Temple B
**No. 15** is School E

**Community areas**

**No. 2**.is Household-1
**No. 3**.is Household-2
**No. 4** is Household-3
**No. 8** is Household-4
**No. 11** is Household-5
**No. 12** is Household-6
**No. 13** is Household-7

**Figure 1** Noise measurement points in Ayutthaya Municipality (orange dots represent sensitive areas; green dots represent residential areas.

*2.4 Annoyance*

Annoyance is a commonly used indicator to assess noise impact on exposed populations. The term "annoyance" was developed as a key concept in the field of environmental pollution and has been considered a comprehensive description of the overall community response to noise [15]. Moreover, the WHO has recommended the percentage of respondents who felt highly annoyed (%HA) constituted an environmental health indicator to explain the effect of environmental noise on health [16].

The questionnaire developed for the annoyance survey in this study was divided in three sections including personal characteristics (sex, age, education and career), residential or office characteristics, and annoyance level. Annoyance levels caused by traffic noise were measured using international standardized scales, following the ICBEN method [17]; a five-point scale (extremely annoyed = 5, very annoyed = 4, moderately annoyed = 3, slightly annoyed = 2, and not at all annoyed = 1).

*2.4.1 Annoyance level*

The average annoyance score was calculated using Equation (3).

$$A = \frac{(5\times N5)+(4\times N4)+(3\times N3)+(2\times N2)+(1\times N1)}{N1+N2+N3+N4+N5} \times 100 \qquad (3)$$

Where, A represents the average annoyance score; 5 is extremely annoyed; N5 is the number of respondents feeling extremely annoyed; 4 is very annoyed; N4 is the number of respondents feeling very annoyed; 3 is moderately annoyed; N3 is the number of respondents feeling moderately annoyed; 2 is slightly annoyed; N2 is the number of respondents feeling slightly annoyed; 1 is not at all annoyed and N1 is the number of respondents feeling not at all annoyed.

*2.4.2 Exposure-response relationship for noise annoyance*

Schultz was the first researcher to establish a single curve for the relationship between community reaction and noise exposure [18]. As shown in several studies, %HA was selected as an effect measure to establish exposure-response relationships [19]. It indicates the relationship between the %HA and $L_{dn}$. However, the %HA was combined between extremely and very annoyed from the ICBEN scale as calculated by Equation (4).

$$\%\,HA = \frac{N4+N5}{n} \times 100 \qquad (4)$$

Where, %HA is the percentage of those highly annoyed; N4 is the number of respondents feeling very annoyed; N5 is the number of respondents feeling extremely annoyed and n represents the total number of respondents.

Moreover, other indicators introduced to correlate traffic noise level and annoyance included the intermittency ratio (IR), which expresses the proportion of the acoustical energy contribution in the total energetic dose that is created by individual noise events above a certain threshold [20]. Some researchers used the harmonica index employing a scale of 0 to 10 of sound environment and can be assessed as quiet, noisy or very noisy for people's perception of environmental noise [21].

**3. Results and discussion**

*3.1 Characteristics of respondents*

Characteristics of respondents in residential and sensitive areas are presented in Figure 2. The percentage of respondents of residential areas comprised males and females at 40.8 and 59.2%, respectively. Moreover, the respondents of sensitive areas totaled 55 and 45% males and females, respectively. The majority of the respondents (48.8%) in residential areas were aged from 31 to 50 years and the remainder was at ages ranging below 20 years (4.8%), 20 to 30 years (21.6%), 51 to 60 years (21.6%) and more than 60 years (3.2%), respectively. However, the majority of the respondents in sensitive areas were aged below 20 years (52.9%). The remainder was at ages ranging from 31 to 40 years (18.57%), 20 to 30 years (9.29%), 41 to 50 years (9.29%), 51 to 60 years (8.57%) and more than 60 years (1.43%). In terms of education, one half of the respondents in residential areas attained senior high school, vocational certificate and diploma level education (60%). In the sensitive areas, the majority of the respondent (28.57%) obtained bachelor level education. The rest were vocational certificate, senior high school, junior high school, higher bachelor degree, diploma and primary school education level, contributing to 17.86, 17.14, 13.57, 10.71, 10 and 2.14%, respectively. In addition, most respondents in residential areas were business owners, laborers and homemakers, contributing to 26.4, 23.2 and 17.6%, respectively. In sensitive areas, most respondents comprised students, government officers and monks, corresponding to 60.7, 22.1 and 7.14%, respectively.

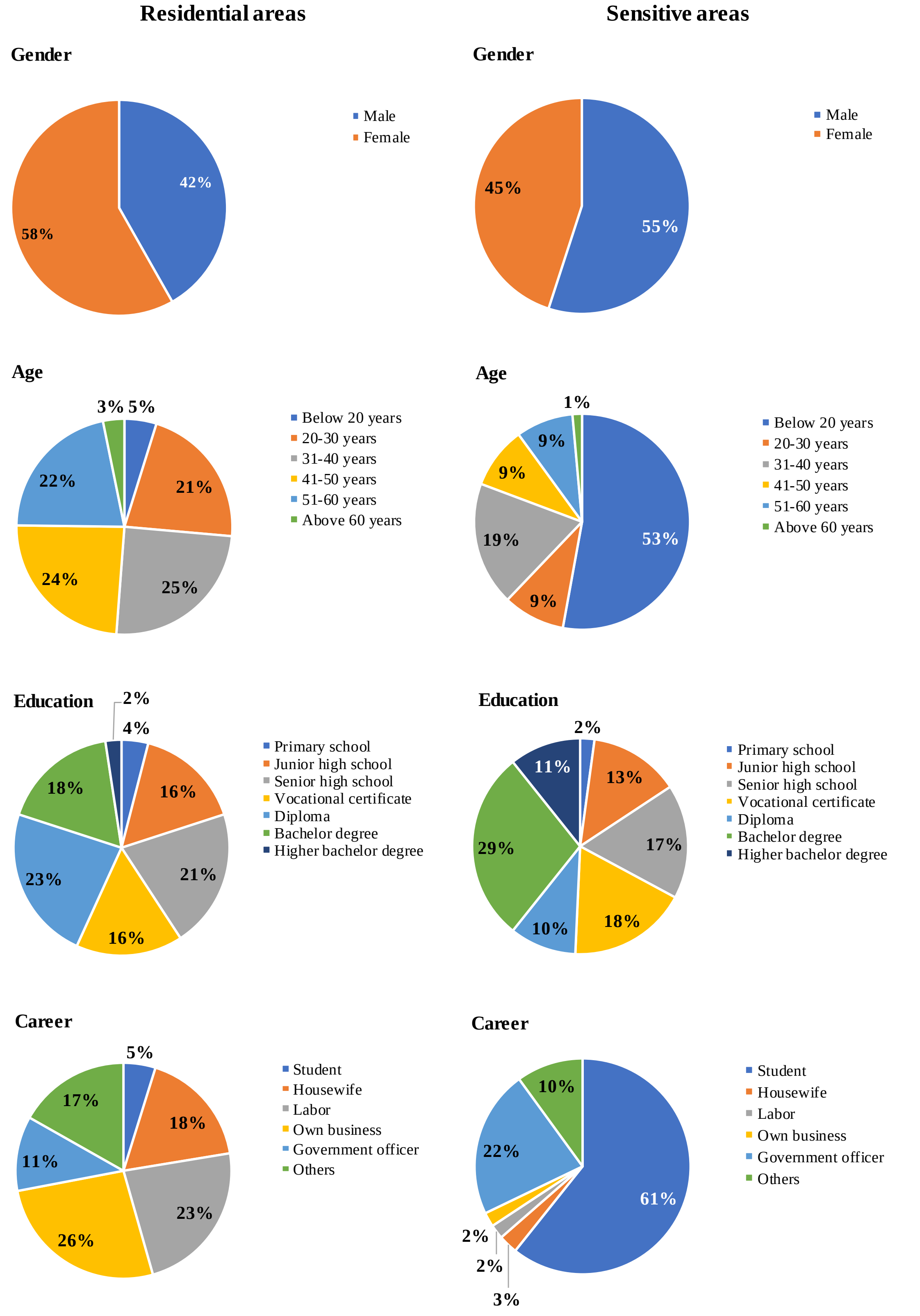



**Figure 2** Characteristics of respondents in residential and sensitive areas.

*3.1.1 Residential characteristics of respondents in residential areas*

Type of dwelling in the residential areas included row house, single house and apartment, contributing to 46.4, 31.2, and 13.6%, respectively. However, the majority of respondents in residential areas resided in dwellings located along two-lane roads (53.6%). In addition, house structures in these areas were composed of wooden structures mixed with brick, cement and wood, corresponding to 56.0, 32.0 and 40.0% of the total respectively. One half of the dwellings of respondents in residential areas had installed air conditioning in some room or every room comprising 86.4% of the total. The range in length of residence among residential respondents was found at less than 1 year (4.8%), 1 to 5 years (16.0%), 6 to 10 years (31.2%), 11 to 20 years (25.6%), 21 to 30 years (17.6%) and more than 30 years (4.8%). Respondents in residential areas spent time in their house at durations less than 8 h, 8 to 10 h, 10 to 15 h and more than 15 h, corresponding to 46.4, 24.0, 20.8 and 8.8%, respectively.

*3.1.2 Office characteristics of respondents in sensitive areas*

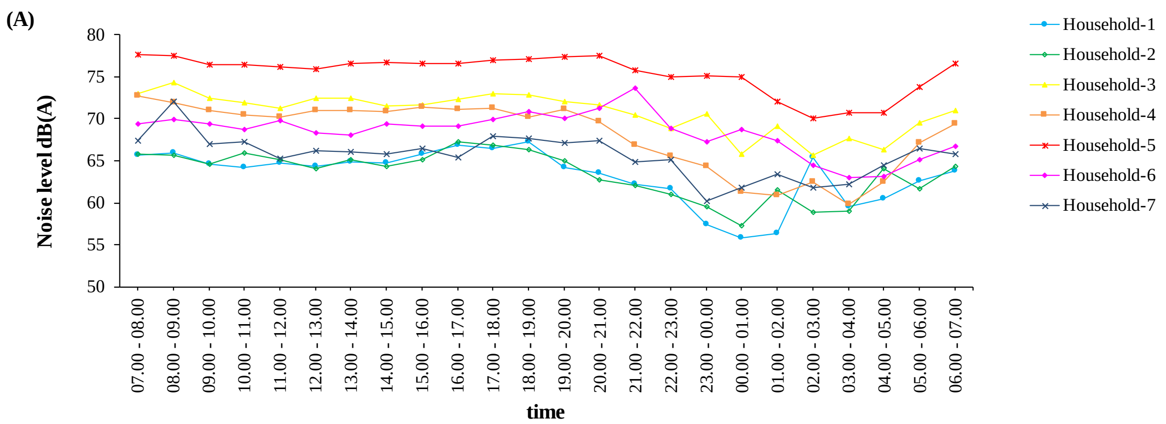
Ayutthaya Hospital is classified as a large hospital with a capacity of 500 beds located on U-Thong Road (3 lanes). The hospital was selected to measure noise in Ayutthaya Municipality. Materials used for building included brick and cement. The distance point from traffic noise measurement to roadside totaled 1.4 m. Of the two temples in Ayutthaya Municipality, i.e., Temple A (No.5) and Temple B (No.14), Temple A was located on U-Thong Road (2 lanes) in Ayutthaya Municipality as presented in Figure 1. These temples were also built from brick and cement. Five schools, i.e., School A (No. 6), School B (No. 7), School C (No. 9), School D (No. 10) and School E (No.15) were selected to measure road traffic noise in sensitive areas. Most materials used in building these schools were wood and bricks totaling 97.14%. However, most respondents spent about 5 to 10 h daily in school comprising 73.1% of total respondents.

*3.2 Traffic noise and related factors*

The results of this study showed that road traffic noise levels (Leq 24 h) were 63.3 to 75.4 and 64.1 to 72.6 dB(A) in residential and sensitive areas, respectively. Moreover, the average traffic noise levels (Leq 24 h) were 67.9±4.3 and 69.6±2.5 dB(A) in residential and sensitive areas, respectively (Table 1). This suggested that road traffic noise levels in sensitive areas were greater than those in residential areas. In addition, the average equivalent noise level in some investigated areas exceeded the National Ambient Noise Standard of Thailand, established at 70 dB(A). Studies conducted in residential areas in Brazil and Saudi Arabia reported similar findings, in which noise levels exceeded the limits recommended by the country' environmental noise regulations [22-23]. From the hourly traffic noise level in Figure 3, the maximum noise level in residential areas ranged from 66.0 to 78.0 dB(A) from 07.00 to 09.00 AM. The minimum noise levels observed in residential areas ranged from 56.0 to 70.0 dB(A) from 11.00 PM to 01.00 AM. In sensitive areas the maximum noise levels ranged from 68.0 to 76.0 dB(A) from 07.00 to 09.00 AM. The minimum noise levels observed in sensitive areas ranged from 54.0 to 70.0 dB(A) from 11.00 PM to 01.00 AM. The results indicated that the highest noise level in both residential and sensitive areas was observed from 07.00 to 09.00 AM during rush hours. Moreover, traffic activities were lowest from 11.00 PM to 01.00 AM in both residential and sensitive areas.

**Table 1** Road traffic noise levels (Leq 24 h) in residential and sensitive areas.

| Areas | ID location | Location | Leq 24 h (dB(A)) (average ±SD) | Lmin dB(A) (average ±SD) | Lmax dB(A) (average ±SD) |
|---|---|---|---|---|---|
| Sensitive areas | 1 | Hospital A | 70.4±0.2 | 62.9±0.3 | 78.4±3.7 |
| | 5 | Temple A | 70.6±1.1 | 66.2±1.6 | 75.7±2.7 |
| | 6 | School A | 70.1±0.6 | 65.4±0.5 | 74.3±1.1 |
| | 7 | School B | 64.1±1.1 | 51.2±3.6 | 71.1±0.3 |
| | 9 | School C | 68.6±0.2 | 60.3±0.6 | 74.0±0.8 |
| | 10 | School D | 70.2±0.3 | 63.1±1.6 | 74.6±1.1 |
| | 14 | Temple B | 72.6±0.2 | 67.9±0.2 | 76.7±1.3 |
| | 15 | School E | 70.4±0.5 | 64.2±0.5 | 74.6±1.4 |
| | | Average | 69.6±2.5 | 62.7±5.2 | 74.9±2.1 |
| Residential areas | 2 | Household-1 | 63.3±0.4 | 54.4±1.5 | 68.8±1.5 |
| | 3 | Household-2 | 63.5±0.6 | 57.1±0.8 | 68.9±3.5 |
| | 4 | Household-3 | 70.7±0.5 | 64.4±0.4 | 74.3±1.2 |
| | 8 | Household-4 | 68.1±0.5 | 58.9±1.2 | 72.8±1.4 |
| | 11 | Household-5 | 75.4±0.1 | 70.0±0.5 | 78.2±0.6 |
| | 12 | Household-6 | 68.4±0.4 | 62.7±0.4 | 73.6±0.4 |
| | 13 | Household-7 | 65.6±0.1 | 60.0±0.7 | 72.7±0.9 |
| | | Average | 67.9±4.3 | 61.1±5.2 | 72.8±3.2 |



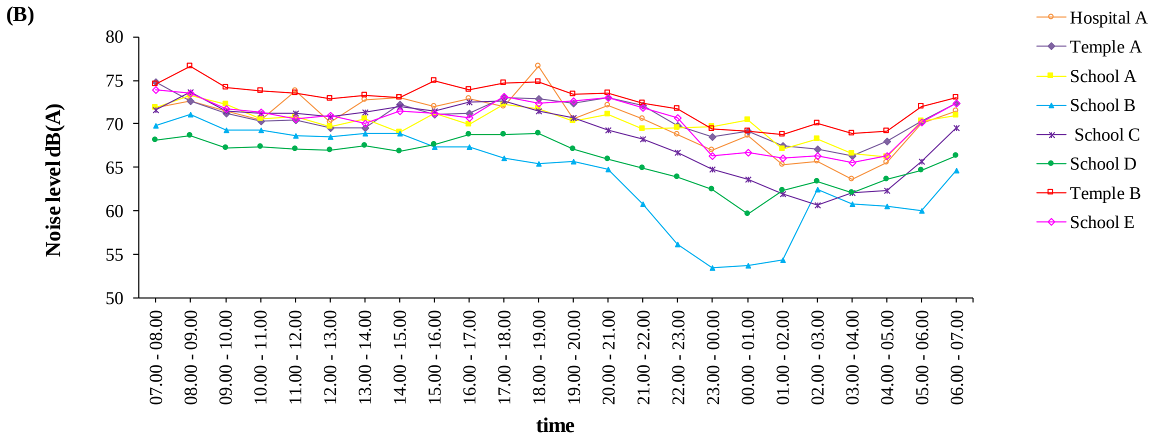




**Figure 3** Hourly noise levels in (A) residential areas and (B) sensitive areas of Ayutthaya Municipality.

The highest noise level was found in Household-5 and Temple B in residential and sensitive areas, respectively. This was because the main road passes this area and the speed of the vehicles is quite high compared with other areas. The speed of vehicles in Ayutthaya Municipality ranged from 40.5 to 73.2 km/h. The speed of vehicles in sensitive and residential areas ranged from 49.8 to 70.8 and 40.5 to 73.2 km/h, corresponding to an average of 64.1 and 54.7 km/h, respectively. These results indicated that speed of vehicles in sensitive areas was higher than that in residential areas. The maximum speed of vehicles in sensitive and residential areas was observed at Temple B and Household-5, corresponding to the maximum noise levels of 73.1 and 75.5 dB(A), respectively. Using Pearson's correlation, traffic noise level in Ayutthaya Municipality positively correlated to the speed of vehicles with a correlation coefficient of 0.937 at 95% confidence level (p-value <0.05). These results revealed that speed of vehicles was positively associated with traffic noise levels. This result was relatively similar to the study of Zambon et al, 2017 who reported that speed is the most relevant characteristic to discriminate between different vehicle noise spectrums [24-25]. Therefore, the speed of vehicles should be restricted in residential and sensitive areas to help reduce road traffic noise and annoyance levels. From the Land Transport Act of Thailand, speed of light vehicles and heavy vehicle in a municipality should be limited at 80 and 60 km/h, respectively [26].

Traffic volume in sensitive and residential areas was found to range from 1726 to 2382 and 749 to 3246 vehicles/h, respectively. Using Pearson's correlation, traffic noise level in Ayutthaya Municipality positively correlated with traffic volume with a correlation coefficient of 0.770 at 95% confidence level (p-value <0.05), respectively. These results revealed that traffic volume was positively associated with traffic noise levels. Moreover, the ratios of heavy and light vehicles in sensitive areas were greater than those in residential areas. Major types of vehicles in Ayutthaya Municipality included personal car and motorcycle, contributing to 52.21, and 37.75% of total vehicles, respectively. Comparing with other studies, motorcycles were found to constitute the major type of vehicle in Hanoi and Ho Chi Minh City, corresponding to 91.0 and 94.0% of total vehicles, respectively [8]. Similarly, the major type of vehicle in Muang Phuket and Kathu were motorcycles found to be 59.4 and 58.7% of the total number of vehicles, respectively [27].

Comparing traffic noise levels in Ayutthaya Municipality with Hanoi, Hue City and Ho Chi Minh City, the Leq, 24 h were 71 to 77 dB(A), 58 to 69 dB(A) and 73 to 79 dB(A), respectively [8]. This indicated traffic noise levels in Hanoi and Ho Chi Minh City of Vietnam were higher than that in Ayutthaya Municipality. In addition, traffic noise level in Ayutthaya was lower than that in Bangkok and Phuket Province. Traffic noise levels in Muang Phuket, Thalang and Kathu Districts were reported to range from 70.0 to 70.9, 72.7 to 74.7 and 74.6 to 74.8 dB(A), respectively [11,27].

*3.3 Annoyance levels*

The respondents of this study comprised 265 individuals residing in Ayutthaya Municipality. The respondents were divided in 140 and 125 in sensitive and residential areas, respectively. The results of the social survey found that more than 75.1% of total respondents residing in Ayutthaya Municipality were annoyed by road traffic noise. Noise annoyance was determined using a five-point annoyance scale. As shown in Table 2, the result revealed that the average annoyance score was 2.8 and 2.7 in sensitive and residential areas, respectively. This resulted because traffic noise levels in sensitive areas were higher than those in residential areas. Similarly, the average speed of vehicles and percentage of heavy and light vehicles in sensitive areas were also higher than those in residential areas. These results indicated that road traffic noise and related noise factors were associated with annoyance level.

In sensitive areas, the highest annoyance score of 3.1 was found in School E (No.15). Among residential areas, the highest annoyance score of 3.2 was found in Household-5. Accordingly, respondents in sensitive areas reported feeling not at all, slightly, moderately, very much and extremely annoyed from road traffic noise at 26.4, 15.7, 21.4, 22.1 and 14.3% of total respondents, respectively. In residential areas, the percentage of respondents reported feeling not at all, slightly, moderately, very much and extremely annoyed at 27.2, 15.2, 28.8, 14.4 and 14.4% of total respondents, respectively. Moreover, the results indicated that the majority of annoyance scores of sensitive and residential receptors ranged from moderately to extremely annoyed, contributing to 57.9 and 57.6%, of total respondents, respectively. The annoyance distribution of Ayutthaya's respondents in sensitive and residential areas is presented in Figure 4.

**Table 2** Noise related factors, Ldn, and annoyance score in sensitive and community areas.

| Areas | ID location | Location | Speed (km/h) | Percentage of HV (%) | $L_{dn}$ (dB(A)) | Annoyance score |
|---|---|---|---|---|---|---|
| Sensitive areas | 1 | Hospital A | 67.7 | 8.72 | 75.6 | 2.5 |
| | 5 | Temple A | 63.7 | 2.77 | 76.2 | 2.8 |
| | 6 | School A | 62.3 | 3.48 | 76.1 | 2.9 |
| | 7 | School B | 49.8 | 3.36 | 69.9 | 2.5 |
| | 9 | School C | 64.2 | 1.81 | 73.3 | 2.9 |
| | 10 | School D | 65.5 | 2.87 | 75.1 | 2.9 |
| | 14 | Temple B | 70.8 | 3.05 | 77.8 | 2.6 |
| | 15 | School E | 68.6 | 4.44 | 75.9 | 3.1 |
| | | Average | 64.1±6.4 | 3.8±2.1 | 75.0 | 2.8 |
| Residential areas | 2 | Household-1 | 40.5 | 0.67 | 69.3 | 2.5 |
| | 3 | Household-2 | 44.3 | 0.53 | 69.4 | 2.3 |
| | 4 | Household-3 | 65.4 | 0.76 | 75.9 | 2.8 |
| | 8 | Household-4 | 51.5 | 3.09 | 72.9 | 3.0 |
| | 11 | Household-5 | 73.2 | 4.13 | 80.7 | 3.2 |
| | 12 | Household-6 | 53.5 | 6.70 | 73.8 | 2.8 |
| | 13 | Household-7 | 54.7 | 1.83 | 71.2 | 2.3 |
| | | Average | 54.7±11.4 | 2.5±2.2 | 73.3 | 2.7 |

**Remark:** HV = heavy vehicle

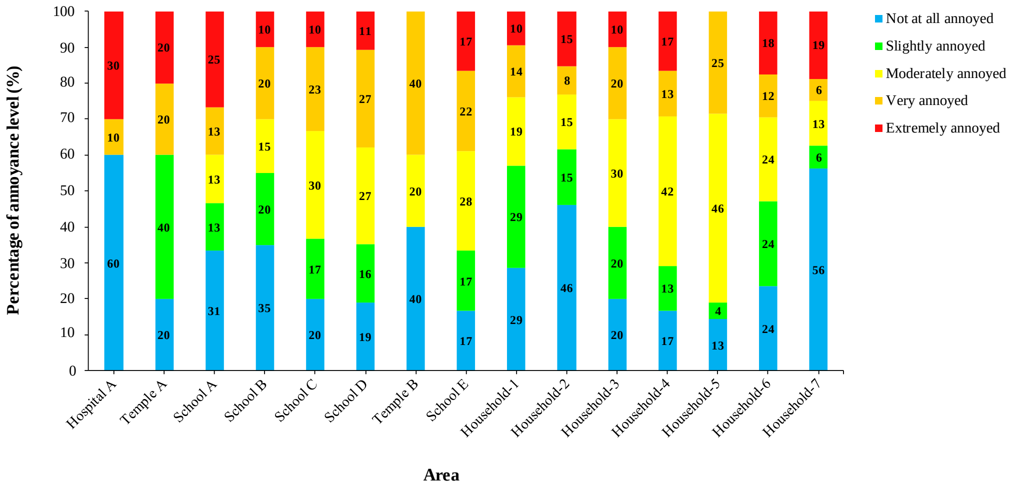



**Figure 4** Annoyance levels of Ayutthaya's respondents in residential and sensitive areas.

Comparing annoyance scores in Phuket Province, the annoyance score was 2.24 dB(A), respectively [11]. This indicated the annoyance scores in Ayutthaya Municipality were higher than those in Phuket Province. In addition, some studies presented that 81.7% of respondents were annoyed by road traffic noise. The types of vehicles producing the most noise annoyance were identified as buses and heavy trucks. Moreover, 53.5% of respondents reported feeling highly annoyed from road traffic noise [28]. Moreover, noise-related annoyance in Brazil was reported at 48.4% of the total respondents with the average Leg of 73.1±0.6 dB(A) [22]. Additionally, noise annoyance with the Lden level between 65 and 80 dB(A) in Ghent, Belgium reported by 105 respondents indicated that 53.0% were not annoyed, 47.0% were slightly annoyed, 19.0% were moderately annoyed and 8.0% were highly annoyed [29]. Therefore, annoyance levels of respondents in Ayutthaya Municipality were higher than those reported in Ghent, Belgium.

Noise annoyance is influenced by sound-related factors: type of noise, noise level and person-related factors: physiological, and social factors [30]. Therefore, correlation analysis between noise annoyance and person-related variables and housing conditions is summarized in Table 3. Noise annoyance significantly and positively correlated with sex, age, education, type of dwelling, location of places, structure of places, installed air conditioning, daily working hours, length of residence and source of annoyance at 95% confidence level (p-value <0.05). Accordingly, age and daily working hours were strongly associated with noise annoyance. The dwelling conditions found where respondents spent most of their time (in air conditioned rooms, in window-opened rooms and outdoors) negatively correlated with noise annoyance. The correlation of some socio-economic factors, such as education, type of work, type of dwelling and working hours were statistically significant. The result of this study was similar to the findings of Jakovljevic et al. [30], reporting results regarding social factors related to noise annoyance in a Serbian urban population. They found that noise annoyance significantly and positively correlated with age of respondents, length of residence, years of employment and duration of stay in the apartment during daytime. In addition, they also found that education, type of work, apartment size and working hours positively correlated with noise annoyance. However, the type of floor showed a negative and statistically significant correlation with noise annoyance.

**Table 3** Correlation coefficients (Pearson's) between traffic noise annoyance and related factors.

| Related factors | Correlation coefficients | *P*-Value |
|---|---|---|
| Sex | 0.729 | 0.000* |
| Age | 0.816 | 0.000* |
| Education | 0.755 | 0.000* |
| Career | 0.759 | 0.000* |
| Type of dwelling | 0.716 | 0.000* |
| Locations | 0.650 | 0.000* |
| Structure of places | 0.613 | 0.000* |
| Installed air conditioning | 0.657 | 0.000* |
| Daily working kiloms | 0.875 | 0.000* |
| Length of residence | 0.657 | 0.000* |
| Source of annoyance | 0.678 | 0.000* |
| Period of week when extremely annoyed by noise | 0.034 | 0.749 |
| Period of day when extremely annoyed by noise | 0.074 | 0.489 |
| Dwelling condition where spending most of the time | - 0.109 | 0.304 |

Remark: * significant at P-value <0.05

*3.4 Dose-response relationship between traffic noise and annoyance level in sensitive and residential areas*

Dose response curves between the established percentage of highly annoyed and the $L_{dn}$ in sensitive and residential areas in Ayutthaya Municipality are presented in Figure 5. These results indicated that the number of extremely and very annoyed levels in sensitive and residential areas were the highest, 51 and 36 people contributing to 36.4 and 28.8% of total respondents, respectively. In addition, the percentage of highly annoyed people in sensitive and residential areas was found to range from 30.0 to 40.0 and 23.1 to 37.5 %, respectively. $L_{dn}$ in sensitive and residential areas were found to range from 69.9 to 75-2 and 69.3 to 80.7 dB(A) as shown in Table 4. The highest $L_{dn}$ levels were found to be 77.8 and 80.7 dB(A) in sensitive and residential areas, respectively. The results confirmed that road traffic noise annoyance in sensitive areas was higher than that of residential areas in Ayutthaya Municipality. Therefore, respondents in sensitive areas were more sensitive than those in residential areas. At 30% HA from the dose-response curves in sensitive and residential areas, $L_{dn}$ levels were 69.9 and 74.3 dB(A), respectively. Overall, $L_{dn}$ levels in Ayutthaya Municipality was found to be 70.3 dB(A) at 30% HA.

Compared with other studies, road traffic noise annoyance levels of Ayutthaya Municipality were higher than those in Hue and Da Nang City. Therefore, people in Ayutthaya Municipality were less tolerant of road traffic noise than those Vietnamese in Hue and Da Nang City [8]. In addition, road traffic noise annoyance levels of Ayutthaya Municipality were also higher than those in Phuket Province [11].

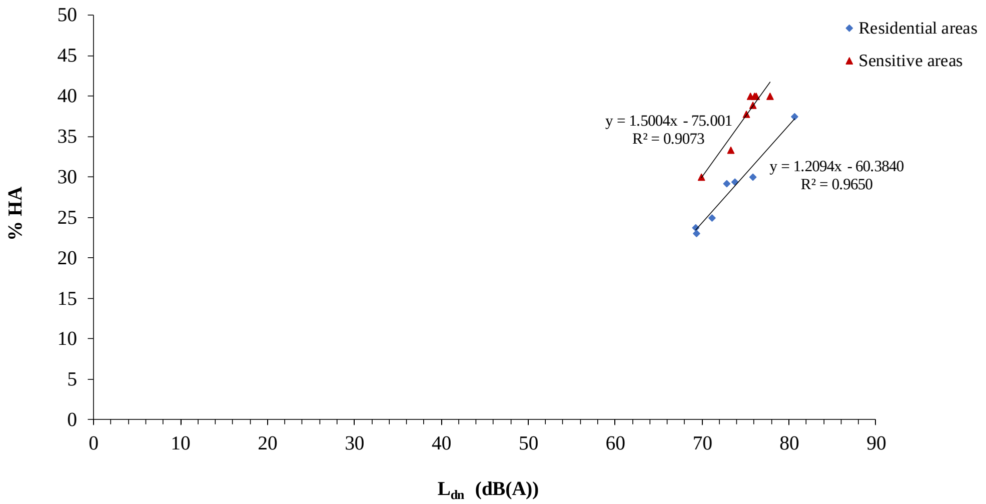



**Figure 5** Dose-response curve between %HA and $L_{dn}$ in residential and sensitive areas.

However, possible reasons for different perceptions of noise level among sensitive areas were type of places and noise level of each areas. As shown in Table 4, people at hospital, schools, and temples in location no. 1, 5, 6, 10, 14 and 15 showed a highly annoyed percentage (38-40%). Here, we have the presence of sensitive receptors, i.e., patients who are in their recovery period, students and monks who need quiet areas for resting, studying and working, respectively. However, noise levels in two other schools in location no. 7 and 9 were lower than those of no.10, resulting in the percentage of highly annoyed between 30 and 33. Additionally, the results of spatial mapping using Geographic Information Systems (GIS) in Ayutthaya Municipality (Figure 6) confirmed that traffic noise levels were positively correlated with %HA. Here, more than 68% of measurement sites in the map showed results positively correlated between traffic noise levels and %HA.

**Table 4** $L_{dn}$ and percentage of highly annoyed people in sensitive and residential areas.

| Areas | ID location | Location | $L_{dn}$ (dB(A)) | % Highly annoyed |
|---|---|---|---|---|
| Sensitive areas | 1 | Hospital A | 75.6 | 40.0 |
| | 5 | Temple A | 76.2 | 40.0 |
| | 6 | School A | 76.1 | 40.0 |
| | 7 | School B | 69.9 | 30.0 |
| | 9 | School C | 73.3 | 33.3 |
| | 10 | School D | 75.1 | 37.8 |
| | 14 | Temple B | 77.8 | 40.0 |
| | 15 | School E | 75.9 | 38.9 |
| | | Range | 69.9-75.2 | 30.0-40.0 |

| Areas | ID location | Location | $L_{dn}$ (dB(A)) | % Highly annoyed |
|---|---|---|---|---|
| Residential areas | 2 | Household-1 | 69.3 | 23.8 |
| | 3 | Household-2 | 69.4 | 23.1 |
| | 4 | Household-3 | 75.9 | 30.0 |
| | 8 | Household-4 | 72.9 | 29.2 |
| | 11 | Household-5 | 80.7 | 37.5 |
| | 12 | Household-6 | 73.8 | 29.4 |
| | 13 | Household-7 | 71.2 | 25.0 |
| | | Range | 69.3-80.7 | 23.1-37.5 |

**Remark:** Total respondents in sensitive and residential areas were 140 and 125 people, respectively.

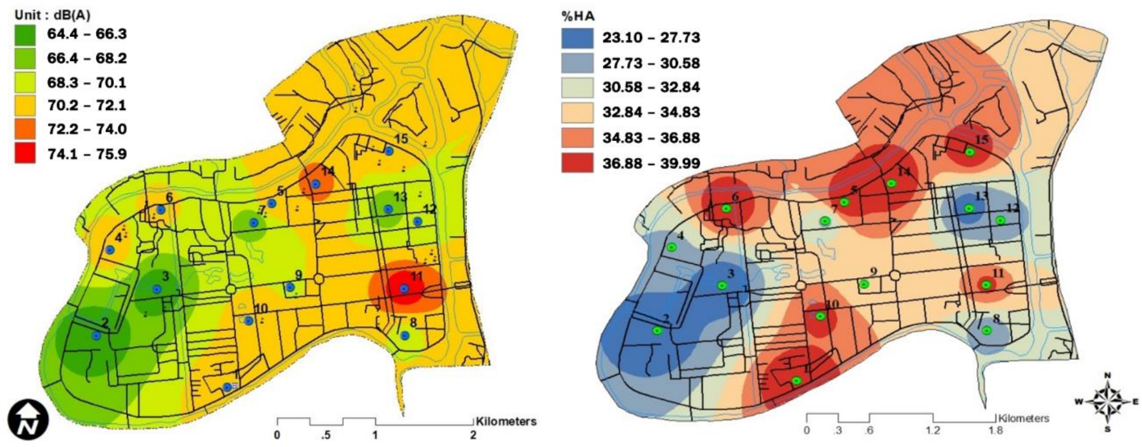



**Figure 6** Spatial data of road traffic noise and % highly annoyed in Ayutthaya Municipality.

## 4. Conclusion

Road traffic noise levels in sensitive areas were greater than those in residential areas in Ayutthaya Municipality. More than 60% of all investigated areas exceeded the Ambient Noise Standard of Thailand, established at 70 dB(A). In addition, the results of the social survey found that more than 75.1% of total respondents were annoyed by road traffic noise. The average annoyance score of road traffic noise in residential and sensitive areas were 2.7 and 2.8, respectively. Most annoyance levels of respondents were ranged from “moderately” to “extremely” annoyed at 38 to 84% and 38 to 67% in residential and sensitive areas, respectively. Overall, average annoyance score of Ayutthaya Municipality was 2.7. In addition, the percentage of highly annoyed respondents in residential and sensitive areas was estimated to range from 23.1 to 37.5% and 30.0 to 40.0%, respectively. At 30% HA from the dose-response curve, $L_{dn}$ was revealed as 74.3 and 69.9 dB(A) in residential and sensitive areas, respectively. Moreover, the dose-response relationship between $L_{dn}$ and the percentage of highly annoyed respondents indicated the Ayutthaya residents in sensitive areas were more sensitive to road traffic noise than those residing in residential areas. Therefore, the speed of vehicles should be restricted in residential and sensitive areas to help reduce road traffic noise and annoyance levels. The findings of this study would help government for city and tourism planning to protect human health from environmental noise and ensure the health and quality of life of people in Ayutthaya Municipality.

## 5. Acknowledgments

This study was partially supported for publication by the Faculty of Public Health, Mahidol University, Bangkok, Thailand. The authors are thankful to the Department of Environmental Health Sciences, Faculty of Public Health, Mahidol University for providing noise measuring equipment. Also, the authors would like to thank Mr. Thomas McManamon of Mahidol University Faculty of Public Health for editing the English in this paper.

## 6. Ethics approval

This study was reviewed and approved according to the Declaration of Helsinki by the Ethics Review Committee for Human Research, Faculty of Public Health, Mahidol University (COA No. MUPH 2017-062, Protocol No. 14/2560).

## 7. References


[1] WHO. Burden of disease from environmental noise: quantification of healthy life years lost in Europe 2011 [Internet]. 2019 [cited 2019 Apr 5] Available from http://www.euro.who.int/__data/assets/pdf_file/0008 /136466/e94888.pdf.

[2] Camusso C, Pronello C. A study of relationships between traffic noise and annoyance for different urban site typologies. Transp Res D Transp Environ. 2016;44:122-133.

[3] Dzhambova A, Tilov B, Markevych I, Dimitrova D. Residential road traffic noise and general mental health in youth: the role of noise annoyance, neighborhood restorative quality, physical activity, and social cohesion as potential mediators. Environ Int. 2017;109:1-9.

[4] Belojeviæ GA, Jakovljeviæ BD, Stojanov VJ, Slepceviæ VZ, Paunoviæ KZ. Nighttime road-traffic noise and arterial hypertension in an urban population. Hypertens Res. 2008;31:775-781.

[5] Belojevic G, Jakovljevic B, Stojanov V, Paunovic K, Ilic J. Urban road-traffic noise and blood pressure and heart rate in preschool children. Environ Int. 2008;34:226-231.

[6] Babisch W, Neuhauser H, Thamm M, Seiwert M. Blood pressure of 8-14-year-old children in relation to traffic noise at home-results of the German environmental survey for children (GerES IV). Sci Total Environ. 2009;407:5839-5843.

[7] Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, et al. Auditory and non-auditory effects of noise on health. Lancet. 2014;383(9925):1325-1332.

[8] Ky NM. Community response to road traffic noise in Hue City, Vietnam. Environ Nat Resource J. 2014; 12:24-28.

[9] DYNAMAP. DYNAMAP project [Internet]. 2020 [cited 2020 May 30]. Available from http://www.life-dynamap.eu/project/.

[10] PCD. Air quality and noise [Internet]. 2020 [cited 2019 Apr 7]. Available from http://noisemonitor.net /web/download.php.

[11] Bunnakrid K, Sihabut T, Patthanaissaranukool W. The relationship between road traffic noise and annoyance level in Phuket Province, Thailand. Asia Pac J Sci Technol. 2017;22(4):1-8.

[12] National Statistical Office. Ayutthaya Province: 2016-2018 [internet]. 2019 [cited 2019 Jun 19]. Available from http://ayuttaya.nso.go.th/index.php?option=com_content&view=category&id=120&Itemid=507.

[13] DOE. Environmental Noise Limits and Control [Internet]. 2020 [cited 2020 May 30]. Available from http://www.life-dynamap.eu/project/.

[14] Lam KC, Chan PK, Chan TC, Au WH, Hui WC. Annoyance response to mixed transportation noise in Hong Kong. Appl Acoust. 2009;70:1-10.

[15] Guski R, Felscher-Suhr U, Schuemer R. The concept of noise annoyance: how international experts see it. J Sound Vib. 1999;223(4):513-527.

[16] WHO. Environmental health indicators: development of a methodology for WHO European Region. World Health Organization. Copenhagen: Denmark; 2000.

[17] Yano T, Sato T, Bjorkman M, Rylander R. Comparison of community response to road traffic noise in Japan and Sweden. J Sound Vib. 2004;250:169-174.

[18] Schultz TJ. Synthesis of social surveys on noise annoyance. J Acoust Soc Am. 1978;64,377-405.

[19] Brink M, Schäffer B, Vienneau D, Foraster M, Pieren R, Eze IC, et al. A survey on exposure-response relationships for road, rail, and aircraft noise annoyance: differences between continuous and intermittent noise. Environ Int. 2019;125:277-290.

[20] Wunderli JM, Pieren R, Habermacher M, Vienneau D, Cajochen C, Probst-Hensch N, et al. Intermittency ratio: a metric reflecting short-term temporal variations of transportation noise exposure. J Expo Sci Environ Epidemiol. 2016;26(6):575-585.

[21] Praščević M, Mihajlov D, Cvetkovic D, Gajicki A. Long-term noise measurements and harmonica index as a way of raising public awareness about traffic noise in the city of NIŠ. Facta Univ Ser Work Living Environ Prot. 2017;14(1):41-51.

[22] Paiva KM, Cardoso MRA, Zannin PHT. Exposure to road traffic noise: annoyance, perception and associated factors among Brazil's adult population. Sci Total Environ. 2018;650:978-986.

[23] Zytoon AM. Opportunities for environmental noise mapping in Saudi Arabia: a case of traffic noise annoyance in an urban area in Jeddah City. Int J Environ Res Public Health. 2016;13(496):1-19.

[24] Zambon G, Roman HE, Benocci R. Vehicle speed recognition from noise spectral patterns. Int J Environ Res Public Health. 2017;11(4):449-459.

[25] Zambon G, Roman HE, Benocci R. Scaling model for a speed-dependent vehicle noise spectrum. J Traffic Transp Eng. 2017;4(3):230-239.

[26] TRSO. Speed of vehicle [Internet]. 2019 [cited 2019 Jul 15]. Available from http://trso.thairoads.org/statistic /risk/detail/5066.

[27] Patthanaissaranukool W, Bunnakrid K, Sihabut T. Applying mathematical modeling to predict road traffic noise in Phuket Province, Thailand. Int J GEOMATE. 2019;62:133-139.
[28] Ali SA, Tamura A. Road traffic noise levels, restrictions and annoyance in Greater Cairo, Egypt. Appl Acoust. 2003;64:815-23.
[29] Renterghem TV, Botteldooren D. View on outdoor vegetation reduces noise annoyance for dwellers near busy roads. Landscape Urban Plan. 2016;148:203-215.
[30] Jakovljevic B, Paunovic K, Belojevic G. Road-traffic noise and factors influencing noise annoyance in an urban population. Environ Int. 2009;35:552-556.