Traffic-related Noise at Roadside Schools: Assessment and Prediction in Urban Setting

Tingkat Kebisingan Lalu Lintas di Sekolah Tepi Jalan: Penilaian dan Prediksi di Lingkungan Perkotaan

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ABSTRAK

Kebisingan lalu lintas adalah salah satu ancaman bagi kesehatan masyarakat perkotaan. Paparan bising memberikan efek kesehatan jangka pendek dan panjang, dan efeknya berpotensi lebih buruk pada anak-anak yang belajar di sekolah pinggir jalan. Penelitian ini bertujuan untuk mengkarakterisasi kebisingan lalu lintas jalan di sekolah-sekolah yang terletak di jalan-jalan utama di Bandung, Indonesia serta memberikan rekomendasi mitigasi dan adaptasi untuk pengendalian kebisingan. Kebisingan lalu lintas diperoleh di dua sekolah pinggir jalan terletak di dua jalan utama (Jalan Suci dan Djuanda), beserta data volume dan komposisi lalu lintas, serta kecepatan kendaraan. Pengukuran dilakukan antara jam sekolah selama satu hari yang mewakili lokasi trotoar jalan, depan sekolah, dan halaman sekolah. Parameter tingkat kebisingan yang penting (Leq, L10, L50, L90) diukur, dan dilakukan analisis korelasi antara masing-masing parameter kebisingan. Model CoRTN digunakan untuk memprediksi kebisingan lalu lintas pada jarak tertentu dari jalan raya. Sepeda motor merupakan jenis kendaraan dominan secara berturut 79,1% dan 67,1% dari total volume kendaraan di ruas jalan Suci dan Djuanda. Kendaraan berat menyumbang <1%. Mayoritas kebisingan lalu lintas yang diukur sebagai Leq, L10, L50, L90 melebihi batas maksimum untuk pinggir jalan dan zona sekolah menurut standar internasional dan nasional <55 dBA). Model tersebut berkinerja lebih baik di ruas jalan Djuanda daripada Suci. Jumlah lokasi dan waktu pengukuran yang lebih banyak dapat memberikan penilaian paparan tingkat kebisingan lalu lintas yang lebih baik dengan menggunakan model CoRTN. Hasil penelitian ini diharapkan dapat menjadi masukan kebijakan berbasis pengetahuan bagi pemerintah kota dan lembaga untuk mengurangi dampak bising bagi anak didik.

Kata kunci: kebisingan lalu lintas jalan, tingkat kebisingan, Model CoRTN

ABSTRACT

Road traffic noise is one of the most ubiquitous threats to public health in an urban setting. Its exposures have proven short-and long-term health effects and potentially worse for children studying at roadside schools. This study aimed to characterize the traffic noise at schools located on primary roads in Bandung, Indonesia, and propose recommendations for future mitigations and adaptation measures. Traffic noise was obtained from two roadside schools at two primary roads (Suci and Djuanda roads) and data on traffic volume, traffic composition, and vehicle speed. The measurement was conducted between school hours during one daytime only at locations representing roadside, front of the school, and schoolyard. We recorded important noise level parameters (Leq, L10, L50, L90) and analyzed the correlation between each parameter. The Calculation of Road Traffic Noise (CoRTN) model was applied to predict the traffic noise at specific distances from the road. The predominant vehicle was motorcycles, which accounted for 79.1% and 67.1% of the total vehicle volume on Suci on Djuanda segments, respectively. Heavy vehicles accounted for <1%. The majority of measured Leq, L10, L50, L90 exceeded the maximum limit for roadside and school zone set by the international and national standards (<55 dBA). The CoRTN model performed better in Djuanda than in Suci segment. More measurement locations and times could better assess exposure to traffic noise levels at roadside schools using the CoRTN model. The results of this study are expected to be a recommendation for developing knowledge-based policies and measures to reduce the impact of traffic noise on students

Keywords: road traffic noise, noise level, CoRTN mode

1. INTRODUCTION

1.1 Research Background

Environmental noise pollution in urban areas is one of the most important environmental threats to the public health worldwide^(1,2), with the road traffic being a major cause⁽³⁾. According to the World Health Organization (WHO), at least 100 million inhabitants were exposed to road traffic noise levels beyond the maximum limit in urban areas in Europe, and over 1.6 million healthy years of life are lost due to exposure to road traffic noise in Western Europe region⁽³⁾.

Exposures to road traffic noise pollution at excessive levels have proven short-and long-term effects on health. These include sleep disruption, hypertension, heart disease, and hearing loss^(4,5). There is also evidence of some noise exposures may be worse for particular vulnerable population groups such as school children⁽⁶⁾ because of their lack of ability to control environmental stressors⁽⁴⁾. It was reported that school children in urban areas and exposed to long term excessive ambient noise levels have shown stress symptoms, and decrease the cognitive ability such as reduced learning ability, reading skills, language development, memory, motivation and concentration⁽⁷⁾. Moreover, children attending schools located in busy roadways are more likely to have reduced learning concentrations and lower academic tests⁽⁸⁻¹⁰⁾. Road traffic noise levels have shown gradients with distance from roads⁽¹¹⁾, suggesting children studying at near roads could have the highest exposures. Van Kamp et al. (2013) found that these effects on school children were observed at traffic noise levels above 50 dBA⁽⁶⁾. A reliable estimation of the exposure to ambient noise at roadside schools is therefore important for health risk assessment purposes.

Earlier studies investigating traffic noise pollution in urban areas have used various methods for noise predictions, including traffic noise models. The Calculation of Road Traffic Noise (CoRTN) approach is among the available models applied to predict the level of noise originating from road traffic sources⁽¹²⁾ in areas with a low and high proportions of motorcycles⁽¹³⁾. Both measurements and predictions of road traffic noise levels at particular locations are essential for roadway planning and for designing the noise abatement plan.

Bandung is the third most populous city in Indonesia and one of the fastest-growing cities in West Java Province, Indonesia. The city experiences rapid population growth, urbanization, infrastructure development, as well as road network and transportation expansion which potentially results in a subsequent increase in traffic-related noise. Many schools in Bandung

are located in the adjacent of major roads or heavily travelled roadways. A previous study had reported the measured noise levels in a school in Bandung was 66.06 dBA which above the maximum limit according to the national standard for a school environment⁽¹⁴⁾. However, there are limited assessments of exposure to traffic-related noise at roadside schools in Bandung. These efforts are important to mitigate traffic-related noise and prevent the adverse impacts on school children.

1.2 Aims of Study

This study aims are: (1) to assess the ambient level of traffic noise at selected primary roadside schools in Bandung City Indonesia; (2) using real-time measured noise level as well as the CoRTN model predicted noise levels; and (3) propose future mitigation and adaptation measures to reduce the impact of exposure to traffic-related noise at roadside schools.

2. MATERIALS AND METHODS

2.1 Area of Study

This study was conducted in Bandung City, the capital of West Java Province, Indonesia. The city is one of the largest metropolitan cities in Indonesia, with about 2.5 million inhabitants in 2019⁽¹⁵⁾. The rate of vehicle growth was 11% annually, substantially exceeded Bandung's population growth rate (0.47%)⁽¹⁵⁾. The vehicle fleet consists of private cars, motorcycles, heavy vehicles (buses and trucks). The number of registered vehicles in 2019 was 1,251,080 units of two-wheeled vehicles and 536,973 units of four wheels vehicles⁽¹⁵⁾.

2.2 Data Collection

2.2.1 Site selection

The traffic-related noise in urban setting is presented by two arterial or primary roads with high traffic volume: Jalan Surapati – Cicaheum (Suci road) and Jalan Ir H Djuanda (Djuanda road). The primary road was categorized based on the Decree of the Minister of Public Works and Public Housing Number 245 of 2015⁽¹⁶⁾. One roadside school located at Suci and Djuanda roads was chosen as case studies. The length of the roadside school was determined as the road segment length, with characteristics were being adequate for the application for CoRTN model: straight segment with asphalt mixture surface course, had two lanes for each direction and flat gradients. The location of selected road segments as shown in Figure 1.

(a) Suci road segment

(b) Djuanda road segment

Figure 1. Location of selected road segments and sampling locations in Bandung, Indonesia

2.2.2 Measurement of Traffic Noise level

The traffic noise level was measured using a Sound Level Meter (SLM Luthron 2310L), with procedures based on the method measuring the ambient noise level (SNI 8427:2017) and Decree of the Minister of Environment Number 48 of 1996 on Noise Level Standard. The sound level meter was placed at 1.20–1.50 m height from the ground surface to avoid the reflections from the ground, and the microphone of the instrument was set perpendicular to the axis of the road lane. The noise measurement points were located in the middle of the road segments to better capture the influences of road characteristics on traffic noise.

The duration of each measurement at each sampling location was 10 minutes with data record every 5 seconds to determine 10-minute equivalent continuous sound pressure levels (L10) in dBA. For maintaining accuracy, the sound level meters were calibrated at the beginning and end of each measurement day. We also documented weather condition such as rain/dry, ambient temperatures, and wind as well as other noise sources. The levels of noise

parameters were measured only between the school hours during one day-time of weekdays to capture the highest noise levels and the time when most noise exposures occur during school hours. The traffic noise was measured in different measurement periods during the school hours at particular distances from the road. The measurement in Suci road segment was conducted from 23 September 2019 in the early morning (07.00), morning (09.00), and noon (12.00), at following distances from the road: 5 m (point-1), 8 m (point-2), 15 m (point-3), and 32 m (point-4). Meanwhile, for Djuanda road segment, the measurement was conducted between 20–21 May 2019 in the early morning (07.00), morning (09.00), afternoon (15.00) and evening (17.00) at distances of 5 m (point-1), 15 m (point-2), and 25 m (point-3) from the road. The selected point-1 represented the noise levels at roadside, point-2 represented the school front, and point-3 and point-4 represented the schoolyard environment. Figure 2 illustrates the typical cross-section of both road segments and measurement locations.

(a) Suci road segment

(b) Djuanda road segment

Figure 2. Typical cross section of selected road segments and sampling locations.

2.2.3 Measurement of Traffic Characteristics

The measured traffic characteristics, which included volume and composition of traffic, and average vehicles speed along each road segment were measured simultaneously with the noise levels measurements. A 15-minute total number of vehicles along each segment were recorded for two vehicle categories: heavy vehicles or vehicles with an unladen weight exceeding 1,525 kg, light vehicles with a maximum unladen weight of 1,525 kg, and two-wheeler vehicles or motorcycles. The heavy-duty vehicles included buses and trucks, while light vehicles included four-wheeler passenger vehicles such as private cars, taxis and small vans. The composition of heavy vehicles (%) was then determined for the CoRTN modeling purposes. The traffic volume and composition were measured following the Guidelines for Manual Traffic Numeration Survey (Pd.T-19 2004-B)⁽¹⁷⁾. The average of individual speeds was calculated based upon the time interval that selected vehicles took to go through the road segment, as described in the Guideline for Survey and Traffic Travel Time Calculation No.001/T/BMKT/1990. It was assumed that the speed of each vehicle remained unchanged along the road segment and was calculated as follows:

$$V = \frac{3,6J}{W} \dots\dots\dots(1)$$

Where

V = vehicle's speed (km/hour); J = length of road segment (m); W = time (second).

2.2.4 Perception of Individuals on Traffic Noise and Its Effects

Perceived exposure to traffic noise, as well as perception and knowledge of traffic noise and its effects, were identified through a questionnaire. A simple random sampling was conducted during the same measurement period of noise and traffic characteristics. The sampling subjects were teacher, students, and non-academic staffs of the schools, and the number of selected subjects were determined based on Slovin formula as follows:

$$n = \frac{N}{(1+Ne^2)} \dots\dots\dots(2)$$

Where n is the size of samples, N is the size of the population (96 teachers, 96 non-academic staff, and 1,144 students), and e is the error margin (10%). In total, 94 subjects were selected, included 8 teachers, 8 non-academic staff, and 80 students. The results from the questionnaires, the measured and the CoRTN predicted noise levels were then considered for

developing recommendation for future mitigation of traffic noise.

2.3 Data Analysis

2.3.1 Traffic noise level

The traffic noise levels at each receiver point were expressed as continuous equivalent A-weighted sound level (LAeq) to represent noise intensity as perceived by the human ear. The statistical percentage sound level such as L10, L50, and L90 was also used to represent the noise level that was exceeded during 10%, 50%, and 90% of the measurement period, respectively. The predicted noise level was expressed as L10, 1 hour.

2.3.2 Prediction of noise level by CoRTN model

The CoRTN model predicts an hourly basic noise level at particular locations for a given one hour reference time at an average vehicle speed of 75 km/hour, with heavy vehicles composition of 0%, and the road gradient was 0%^(18,19). The predicted basic noise level was then adjusted to consider the composition and speed of the vehicles, the nature of road surface, nonzero road gradient, and the effects of distance from the source line⁽¹⁹⁾.

The basic hourly noise level was expressed in dBA and was calculated using the following equation:

$$L_{Basic} = 42.2 + 10\log 10q \dots\dots\dots(3)$$

where L_{Basic} was the basic hourly noise level; q was the hourly total traffic volume that included all heavy and light vehicles as well as motorcycles. The adjustment of a measured average of traffic speed and proportion of heavy vehicles were as follow:

$$C_{speed} = 33 \text{ Log}10 \left(V + 40 + \frac{500}{V} \right) + 10 \text{ Log} 10 \left(1 + \frac{5p}{V} \right) - 68.8 \text{ dBA} \dots\dots\dots(4)$$

where C_{speed} was speed correction; V was hourly average speed; and P was the proportion of heavy vehicles on each road segment given by:

$$p = \frac{100f}{q} \dots\dots\dots(5)$$

where f was determined as the heavy vehicles flow per hour. For a nonzero road gradient, the adjustment for road gradient or G (%) was calculated by:

$$C_{gradient} = 0.3 G \text{ dBA} \dots\dots\dots(6)$$

The basic noise level was also adjusted for the effects of distance from the source, the characteristics of the ground surface, and reflections from surrounding buildings. The distance correction was determined by this equation:

$$C_{\text{distance}} = -10 \log_{10} \left(\frac{d'}{13.5} \right) \text{ dBA} \dots \dots \dots (7)$$

where d' was the distance of the shortest slant between the traffic and the receiver/measurement point, while d was the shortest horizontal distance from the traffic, which was assumed at least of 4m-length. d' was calculated as $((d + 3.5)^2 + h^2)^{0.5}$, where h was the vertical distance between the source and the receiver. The correction for the ground cover was calculated as the function of the shortest horizontal distance (d), the average height (H), and the absorbing ground proportion (I) from the traffic source to the reception point (Table 1).

Table 1. Correction of ground reflection

Road characteristics	Correction
$0.75 < H < (d+5)/6$	$5.2 \log_{10} (6H - 1.5 / (d + 3.5))$
$H < 0.75$	$5.2 \log_{10} (3 / (d + 3.5))$
$H \geq (d + 5)/6$	0

Subsequently, the correction of ground reflection was added to the basic noise level:

$$C_{\text{reflection}} = 1.5 \left(\frac{\theta'}{\theta} \right) \text{ dBA} \dots \dots \dots (8)$$

where θ' was the the road angle view (in degrees), and θ was the sum of reflecting angles from the opposite facades/buildings to the receptor.

Finally, the predicted noise level determined as L10 predicted as follows:

$$L10 \text{ predicted} = L_{\text{basic}} + C_{\text{speed}} + C_{\text{gradient}} + C_{\text{reflection}} \dots \dots \dots (9)$$

The predicted noise levels were then compared with the corresponding measured noise level to evaluate the CoRTN model application. The differences between the predicted and the measured noise level should not exceed 3 dBA as suggested by the Federal Highway Administration.

3. RESULTS AND DISCUSSION

The data collected included real-time traffic noise level, traffic composition, volume, vehicle speed, and characteristics of road segments measured simultaneously. There were no obstacles or disturbances (such as accidents or obstructed traffic) observed during the measurement.

3.1 Traffic Characteristics

The observed mean speed of the vehicles, traffic volume, the ratio of heavy vehicles to the total traffic volume for each vehicle type is presented in Table 2.

Table 2. Measured traffic volumes (vehicles/hour) and mean speed (km/hour)

Measurement Location/ Time	Traffic volume (vehicles per hour)					Vehicle speed (km/hour)		
	Total	MC	LV	HV	%HV	MC	LV	HV
Suci segment:								
Early morning	8628	7230	1262	136	1.6	46.3	34.2	29.8
Morning	10816	8378	2335	103	0.9	60.8	36.4	34.0
Noon	7578	5767	1692	119	1.6	64.9	36.2	32.9
Average	9007	7125	1763	119		57.3	35.6	32.2
Djuanda segment:								
Early morning	7977	5795	2145	37	0.5	50.7	38.6	33.4
Morning	6429	4223	2135	71	1.1	44.0	34.0	30.6
Afternoon	4534	3050	1459	25	0.6	41.5	31.2	29.3
Evening	7539	4705	2776	58	0.8	38.9	30.6	28.9
Average	6620	4443	2129	48		43.8	33.6	30.6

Remark: MC: Motorcycle, LV: Light Vehicles, HV: Heavy vehicles, %HV: proportion of heavy vehicle to traffic volume.

The results show that the highest hourly traffic volume (vehicles/hour) during each measurement period occurred on Suci road segment. The Suci segment links the populated area to the downtown which comprised the center of commercial activities, and public administration

and services. The observed vehicle fleets on both road segments predominantly comprised two-wheeler vehicles (motorcycles), corresponding to approximately 79.1% of the traffic volume on Suci and 67.1% on Djuanda segments. Traffic congestion in Bandung City has made the

motorcycle as one of the most preference vehicles to a large number of Bandung inhabitants. The light vehicles accounted for about 32.1% of traffic volume on Djuanda and 19.6% on Suci road segments. On the other hand, the proportions of heavy vehicles on both road segments were small, corresponding to less than 1% of the traffic volume. The observed results were in line with the vehicle number in West Java Province, which increased annually by 12.6% from 2012 to 2016, with motorcycles being the dominant vehicle, accounted for 72.2% in 2019⁽¹⁵⁾.

The traffic peak hours occurred during the early morning at Suci road segment and morning at Djuanda road segment. Meanwhile, the lowest traffic volume at both road segments occurred

during the afternoon. Mornings are typical rush hours in Bandung because most people move to the workplace, school or regular activities for the day during the time course. The observed mean speed of vehicles was 28.9–50.7 km/hour on Djuanda segment and 32.9–64.9 km/hour on Suci segment, as shown in Tabel 2. On both selected road segments, the mean speed of motorcycles yields the highest value, while the lowest mean speed was observed for heavy vehicles.

3.2 Measured Traffic Noise Level

The measured traffic noise levels at both road segments were determined as percentile noise levels (L90, L50, L10) and Leq (1hour) and presented in Table 3.

Table 3. Measured traffic noise level at suci road segment

Measurement location	Measurement period	L90	L50	L10	Leq (1hour)
Suci road segment:					
point -1	Early morning	73.0	76.4	81.5	80.5
	Morning	74.0	76.9	82.3	79.1
	Noon/Afternoon	70.8	84.9	88.9	86.2
point-2	Early morning	64.8	67.2	75.4	70.9
	Morning	70.3	74.7	80.7	77.0
	Noon/Afternoon	64.9	69.9	76.2	71.8
point -3	Early morning	65.4	73.6	80.0	75.8
	Morning	64.5	68.6	74.6	70.7
	Noon/Afternoon	75.5	78.6	83.3	80.4
point-4	Early morning	68.7	74.2	84.9	76.4
	Morning	70.2	66.3	72.4	72.6
	Noon/Afternoon	68.7	74.2	84.9	74.1
Djuanda road segment:					
point -1	Early morning	67.4	72.9	78.0	76.2
	Morning	72.8	74.8	67.9	76.5
	Afternoon	69.3	70.1	67.6	78.2
	Evening	68.2	72.6	81.8	78.0
point-2	Early morning	63.3	71.3	76.1	72.9
	Morning	70.3	73.3	74.8	73.9
	Afternoon	65.2	69.1	74.4	71.4
	Evening	65.8	73.1	77.3	76.0
point -3	Early morning	57.0	50.2	58.6	57.2
	Morning	56.1	58.7	53.4	59.7
	Afternoon	57.0	58.8	60.3	60.1
	Evening	54.7	58.6	60.6	61.6

The observed equivalent noise level (Leq) overall measurement locations and time were in the range of 70.1–86.2 dBA in Suci road segment and 57.2–78.2 dBA in Djuanda road segment. Specifically, the roadside equivalent noise levels were 79.1–86.2 dBA in Suci segment, and 76.2–78.2 dBA in Djuanda segment. The measured roadside noise levels are comparable to that in one of the monitoring locations in Kendari City, Indonesia with the roadside noise level of 74–79 dBA and traffic volume of 3500–4500 vehicles per

hour⁽²⁰⁾. The results are also within the range of roadside noise levels in other urban areas such as Taiyuan in China⁽²¹⁾ and Makurdi Town in Nigeria⁽²²⁾.

Background noise which L90 represented, ranged between 64.8 and 74.0 dBA at Suci segment. Lower level of background noise was observed at Djuanda segment with a range of 54.7–72.8 dBA (Table 3). The background noise level most likely corresponds to a noise level generated by a nearby source, for which road traffic activities on both segments. The L50 noise

values were recorded 66.3–84.9 dBA for Suci road segment; and 50.2–74.8 dBA for Djuanda segment. At the same time the peaks in the noise (L10) ranged from 72.4–88.9 dBA in Suci segment 60.3–81.8 dBA in Djuanda segment.

The contribution of L90 and L10 to the equivalent noise level (Leq) was identified by conducting a correlation analysis between Leq and L90 and L10. The correlation coefficient between the pair of noise parameters is summarized in Table 4. A strong positive correlation between Leq and L50 (>0.9) may indicate the accuracy of the measurements at both road segments since the L50 value represents the mean of the noise level⁽²³⁾. The equivalent continuous noise level in Djuanda segment can be explained by the variation in the background noise levels as indicated by the strong correlation between Leq and L90 (Table 4). The results may confirm that the road traffic noise was the predominant source of the background noise level. For Suci segment, however, the correlation coefficients between the Leq and L90; and Leq and L10 may suggest that the noise can be attributed to the background noise levels sensitivity to occasional peaks or short-duration noisy events such as noise from congested traffic⁽²⁴⁾.

Table 4. Pearson correlation coefficients between noise parameter

Location	Leq and L90	Leq and L50	Leq and L10
Suci segment	0.53	0.94	0.67
Djuanda segment	0.85	0.92	0.72

For both selected road segments at any measurement time, the equivalent noise levels gradually decreased by the distance from the traffic source, as demonstrated in Figure 2. The highest noise level occurred at the roadside, where the distance from the traffic source was at the nearest, whereas the minimum noise level was observed at the farthest distance. The results were consistent with those reported by other road traffic noise studies in urban areas⁽²⁵⁾. It was suggested that the distance between a road traffic source and a receiver location could affect the noise levels. Each time the distance from the traffic sources doubles, the noise levels at the receiver decreases by three-decibel⁽²⁶⁾.

The observed noise levels on the primary road near the educational area were above the permissible limit during the day-time of Leq 65 dBA set by the WHO (65 dBA). The observed Leq values were also considered high for noise-sensitive areas such as schools' outdoor environment, which exceeded the guideline values for annoyance set at 55 dBA by the WHO (WHO Guidelines for Community noise, 1999).

These observed noise levels reflect the facts that traffic-related noise pollution in Bandung City, particularly at roadside schools was ubiquitous. Long term exposure to noise levels above the permissible limit may negatively affect school children's cognitive ability and skills such as reading, problem solving, attention, and memory⁽¹⁰⁾, as well as on standardized academic test scores⁽⁹⁾.

Previous studies had reported that the main factors contributing the traffic noise levels were greater traffic volume and higher vehicles speeds^(8,27). The vehicle fleet composition is also an important factor in determining traffic noise levels since motorcycles and heavy vehicles are found to be noisier than light vehicles⁽²⁸⁾. As seen in Table 2, the equivalent traffic noise level of busier traffic flow, higher vehicles speed, and greater proportion of heavy vehicles was Suci road segment higher than that of the Djuanda segment, which had lower traffic flow, vehicles speed, and proportion of motorcycles and heavy vehicles. The noise level was found higher along the busiest roads⁽²⁹⁻³¹⁾. Specifically, motorcycles have been reported as noisy as heavy vehicles and thus make a significant contribution to the noise level⁽³²⁾. Thus, the proportion of motorcycle in Suci segment which was higher than that of the Djuanda segment might explain the higher traffic noise levels at Suci segment.

The minimum equivalent noise level was observed at the roadside of Suci segment (79.1 dBA) with corresponding heavy vehicles ratio of 0.95% (Table 2). The noise levels reached ≥80.5 dB (A) when the ratio of heavy vehicles ranged between 1.57–1.58%. The observed results might be suggested that the number of heavy vehicles is possibly an important factor for traffic noise in Suci segment as evident by the smaller proportion of heavy vehicles that have consequently reduced the noise level, in line with those reported by Swain & Goswami (2014)⁽²⁴⁾. Heavy vehicles such as trucks produced more noise due to their axle loads and the propulsion system of the exhaust or engines^(27,33). In addition, the highest roadside noise levels also occurred when the average speed of motorcycles and light vehicles were at the fastest (64.9 km/hour for motorcycle and 36 km/hour for light vehicles). These results consistent with a previous study reporting the most significant contribution of tyre-road interaction for light vehicles and motorcycles to noise types of roads are needed.

3.3 Predicted Traffic Noise Level by CoRTN model

This current study used the CoRTN model for traffic noise prediction in Bandung city with high use of motorcycles. The differences of L10

between the measured and predicted for both Suci and Dago road segments as shown in Figure 3. The range of the differences was -4.3–7.3 dBA for Suci segment and -4.1–1.3 dBA for Djuanda segment. The largest differences among the six measurements and predictions in Suci road segment were an overestimation of 7.3 dBA at distance of 15m from the road in the morning, and an underestimation of 6.3 dBA at distance 15m from the road. The CoRTN model overestimated the L10 noise levels at most of the location and time of the measurement on this road segment, although the differences between the measured and predicted L10 were in the range of 2–6 dBA as reported by a previous study applying the CoRTN model in Hong Kong⁽³⁴⁾. Mak

et al. (2016) had reported an overestimation of at least 10 dBA may occur when the CoRTN model was adopted in an area when buildings are located at both sides of the road⁽³⁵⁾.

For Djuanda road segment, the largest alterations were an overestimation of 4.1 dBA and 4.0dBA which occurred in the early morning at distances of 5 m and 15 m, respectively. However, the majority of L10 differences values in Djuanda road segment less than the maximum limit of 3 dBA as suggested by the Federal Highway Administration and fairly consistent with the measured noise levels at corresponding measurement points and time as seen in Figure 3.

Figure 3. Measured and predicted CORTN noise levels at Suci and Djuanda road segments. Error bars represent standard deviations from the measured values.

Earlier studies conducted in Taiwan, India, Vietnam, Thailand, and Macau have applied CoRTN models to predict traffic noise in urban areas of which motorcycles occupied more than half of the total traffic volume^(13,35,37). These studies report the good performance of the CoRTN models since the differences between the measured and predicted noise level of <3 dBA⁽³⁷⁾. However, our current study used a smaller number of sites compared with those earlier studies that have used a larger number of monitoring sites and the measurement was conducted during one day-time only. On the other hand, the measured noise levels may vary over time, particularly between the weekends and weekdays. More measurement locations and

times can improve the assessment of exposure to traffic noise levels using the CoRTN model. This is because errors may decrease when longer measurement periods such as 18-h averaging measurement periods (e.g. between 06:00 and 24:00) are of used⁽³⁸⁾.

Figure 4 shows the map of the predicted noise levels exposures in both schools. It is notable from the figure that high levels of noise are evident along the roadside, front of the schools, and the schoolyard. The map also shows that the classrooms were located in yellow, green, and blue zones, indicating both students and teachers were exposed to noise levels exceeding the maximum permitted noise level for schools (55 dBA).

Figure 4. Noise maps of predicted CORTN noise levels at (a) Suci and (b) Djuanda road segments.

3.4 Perception of traffic-related noise and its effects

The responses given by the respondents (students and teachers) to the questionnaire identified their opinions regarding exposure to traffic noise at school and its effects. The results can be useful to find appropriate strategies. Table 5 shows the results collected from the questionnaires. There were 58.6% of the total respondents have known the definition of noise. Around 17.2% agreed that the schools have noise problems in the classroom, 18.2% in the school yard, and 39.8% in the roadside due to the traffic-related noise from the nearby main road. While 51.5% of the respondents know about the

Indonesia's noise acts and regulations, less than 50% of the respondents agree that noise problem must be controlled and know the effect of noise pollution on health. These results indicate that the awareness of public on the effects of noise and their interest in controlling the traffic-related noise still need to be developed. The negative impacts because of the noise exposures in both schools identified from the questionnaires were disturbance during studying-teaching (21.2%), reducing the ability to focus (15.2%), health effects include headache and hearing problem (12.4%), communication trouble (16.2%), and mental stress which accounted for 12.1% of the total respondents.

Table 5. Results of questionnaires on perception and knowledge about traffic noise and its effects

Questions		Agree (%)
A. Perception on traffic-related noise		
1	Knowledge about the definition of noise	58.6
2	Noise problem inside the classroom due to traffic-related activities	17.2
3	Noise problem in front of the class room due to traffic-related activities	18.2
4	Noise problem in the outdoor due to traffic-related activities	39.8
5	Knowledge and awareness of any acts/regulations concerning noise pollution.	51.5
6	Knowledge of the effect of noise pollution on health	43.4
7	Noise problem must be controlled	35.5
B. Effect of noise		
1	Disturbance during studying/teaching	21.2
2	Affecting the ability to focus	15.2
3	Trouble communicating	16.2
4	Headache / hearing disturbance	12.4
5	Emotional balance disturbance (mental stress)	12.1

3.5 Future mitigation and adaptation strategies for traffic-related noise

The results of both measurements and predictions show that noise problems due to traffic-related sources exist in both schools' areas since the noise levels were in a critical range. Therefore, it is important to develop measures to reduce the noise pollution from the main road. The recommendation of the measures was proposed by considering data gained from the results of noise measurements and CoRTN predictions as well as questionnaires which were administered to the school's students and teachers. Accordingly, the recommendation of noise mitigation measures was focused on the noise sources (traffic activities) and pathways as follow: (1) traffic flow limitation and vehicle speed reduction; (2) noise barriers implementation; and (3) noise insulation of school building facade.

(1) Traffic flow limitation and vehicles speed reduction

Traffic noise mitigation measure has the potential to affect a significant reduction in exposure at roadsides⁽³⁹⁾. Previous studies demonstrate that substantial reductions in the exposure to traffic-related noise can be achieved through the limitation of traffic flows and associated traffic speeds in the study area⁽³⁷⁾. The potential reduction can be achieved by limiting traffic range between 2 and 5 dBA⁽³⁸⁾. If traffic flow limitation is carried out through the limitation of heavy vehicles passing the roads by up to 10%, then the noise level can be reduced by 3.5 dBA⁽³⁹⁾. In general, the reductions of noise achieved by implementing speed reductions are less than those by traffic flow reduction⁽³⁹⁾. Nonetheless, maintaining vehicles speed within the range of 30 to 60 km/hour could reduce the noise level up to 5 dBA⁽⁴⁰⁾. Each of these proposed strategies or combinations of traffic flow limitation and vehicles speed reduction strategies do not require high costs but effective enough for reducing traffic-related noise and the changes on the space and built environment are minimal. However, legal permits and coordination with the relevant government/local agencies are important to limit human exposure to road traffic noise in urban areas. Moreover, considering the schools are located on primary roads, law enforcement should be involved to ensure the successful of this measure plan.

(2) Noise barriers implementation

The use of noise barriers could be used strategically in urban areas at roadside⁽³⁹⁾. The proposed strategies include the use of vegetations and construction of barriers, which

could reduced the noise levels by 1–5 dBA by selecting adequate appropriate trees and bushes. The selected vegetations could be planted in the front of the roadside schools at Suci and Djuanda road segments as Murphy & King (2011) suggested through vegetation barrier erected 2 and 3 m along the roadways⁽³⁹⁾. Constructing low barriers along both schools could also reduce the noise levels by 3 dBA. Further noise reduction could be obtained by applying an absorbing surface to the existing barrier⁽³⁹⁾. Noise barriers implemented for mitigation, however, relatively result in localized impact, costly, requires land, and may reduce the aesthetics of the environment⁽⁴¹⁾. However, it is important to obtain financial supports for implementing this measure thus not be a burden for children studying at these schools.

(3) Noise insulation on school building façade

Insulation on the facade of the school building can be carried out by replacing existing windows with double or triple glazed windows. This method can reduce noise levels from 15 to 25 dBA, and it is expected indoor noise level can be maintained between 38 and 44 dBA⁽⁴²⁾. The method is appropriate to be applied in high density areas such as city centers, as well as school and office buildings⁽⁴²⁾. Yet changes in the environmental aesthetic as well as high cost for development and maintenance are the main challenges. External funding is needed to support the implementation of this noise mitigation strategy.

4. CONCLUSIONS

Traffic was the main source of noise within the roadside school's environment located in Djuanda and Suci road segments. The roadside noise levels of the primary road were above the permissible level set by WHO and the Ministry of Environment (65 dBA). The measured and CoRTN model predicted traffic-related noise levels in the front of the school and schoolyard have exceeded the recommended outdoor noise level limit of 55 dB for educational institution environment. The CoRTN can be applied for predicting the noise in urban settings such as Bandung where motorcycles posed of at least one-third of the total vehicle fleet. However, further study is necessary to generate more reliable predicted traffic noise levels through the most recent traffic data, and more reliable traffic-noise measurements. The mitigation and adaptation measures for mitigating traffic noise levels at the source and pathways that can be applied include limiting traffic flow and vehicle speed, implementing of noise barriers, and

insulating noise at the building façade. Yet, a further study assessing the feasibility of these proposed measures would be beneficial.

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