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Study of traffic noise in urban street canyons of Bengaluru city

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In urban street canyons, external noise environment is a critical restriction to the opening of building windows for natural ventilation. The high external noise intensities are often used to substantiate the utilization of air conditioning systems in residential and commercial buildings. Therefore, a systematic method of examining the noise levels in urban street canyons is essential if the potential for natural ventilation is to be estimated. The noise levels and natural ventilation in urban street canyons depend on many aspects such as existing street dimensions, height of buildings and traffic density. A study has been carried out in a street to examine the variation in noise levels vertically in order to provide technical inputs on natural ventilation potential in urban street canyons. In this study, a number of noise measurements were made in urban street canyons of Bengaluru City, in residential and commercial areas with respect to aspect ratio (height of building/street width) changing from 1.0 to 4.0. With the help of measured data, a statistical model was developed. A linear regression analysis has been used. The model can be used to predict variation of noise level in vertical direction in urban street canyons. The variation of noise level is found to be a function of street width and height of a building above the street level, but the highest level of reduction is almost entirely a function of the aspect ratio. The rate of attenuation of foreground noise (L_{10}) is greater than the background noise (L_{90}) with height.

Keywords: Aspect ratio, noise attenuation, traffic noise, urban street canyon.

CANYON-like streets in urban areas vary considerably in width and in the height of the buildings which border them[1]. The facades of some of the buildings are plain and some have balconies. A majority of buildings in residential streets as well as some of the office buildings in commercial streets has balconies. The facades at ground level can be even more complex. The ground floor is generally set back with colonnades.

Some noise measurements were taken in street canyons of Bengaluru city. The measurements were made to assess the effect of noise level in the vertical direction above street level. This study aims to provide guidance about the effect on the external noise environment of the street width, aspect ratio and the height of the location above street level. This requires assessment of the relative significance of the direct sound and the reverberant noise level in the street canyon. Other important factors to be considered are the traffic density and noise associated with it in the street. The ratio of the height of the buildings in street canyons (H) to the width of the street (w) is known as the 'aspect ratio' (AR) of the street with assumption that the buildings on either side are at same height. However in reality, this may not be the case. In this study, the average height of the buildings in street canyons has been taken to get AR = $(H_1 + H_2)/2w$ (Figure 1). The facade of building also varies considerably with and without balconies.

Noise measurements were made in Bengaluru at nine selected street canyons comprising residential zone, commercial zone, silent zone and heavy traffic zone (Table 1). In each street, canyon measurements were taken outside the windows of buildings. The aim of these noise measurements was to assess the vertical variation of noise level with respect to measurement location above

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Table 1. Field data collected from study locations

| Study location | Vehicle passing in 15 min | | | | Street width (m) | AR | Balconies | Grade | Estimated speed (km/h) | Traffic ½ way |
	Heavy	Light	Medium	Total						
B.T.M. Layout	32	176	266	587	14.0	1.1	0	0	20–50	2
Jayanagar 4th Block	21	185	193	239	14.0	1.5	0	0	15–40	1
Hanumanth Nagar	8	107	82	98	4.5	3.6	2	–5%	25–30	1
Shivaji Nagar	17	83	107	207	7.0	2.3	0	0	30–25	2
Indian Express near Vidhana Soudha	33	182	206	608	15.0	1.1	0	0	25–30	2
M.G. Road	26	216	378	490	7.5	4.0	1	0	15–30	2
K.R. Market	42	153	359	354	7.2	1.8	0	0	20–30	2
Yeswanthpur	12	126	178	216	6.8	1.8	1	+5%	25–40	0
Malleswaram	8	77	107	192	6.5	3.2	1	0	30–40	1

Existence of balconies (0: none, 1: one side of the street, 2: both sides), gradient of the street (+: uphill), the usual traffic speed in km/h and whether the traffic was moving in one or both directions.

$$AR = (H_1 + H_2)/2w$$
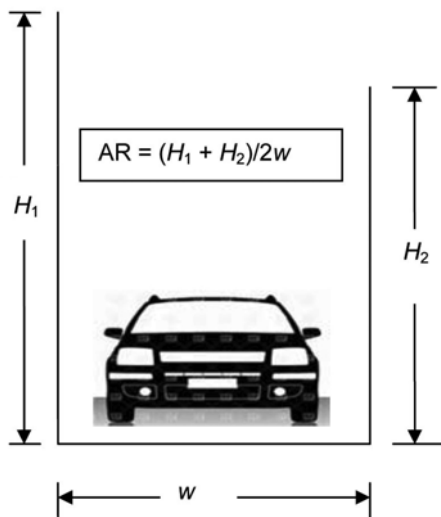
Figure 1. Dimensions and aspect ratio of a street.

the street level. The noise measurements were taken in street canyons for aspect ratios varying from 1.0 to 4.0 and varying traffic volume (Table 1).

The traffic composition consists of light vehicles (scooter/motorcycle), medium vehicles (car/jeep/van/autorickshaw) and heavy vehicles (trucks/bus)[1,2]. At the time of the measurements, the heavy vehicles were less in number, but there was a high occurrence of light and medium type of vehicles (about 75%, Table 1) which appears to be the major source of noise. Vehicle speed in the study area varies from 10–50 km/h and in some places traffic flow was frequently interrupted by traffic signal and the roads often got crowded. The Bruel and Kjaer Model-2250 logging sound level meters were used for noise measurements.

In each street canyon, noise measurements were taken simultaneously at street level and at each floor level for 15 min (Table 2). At the street level, the sound level meter was mounted on a tripod placed 1 m in front of the facade[3]. At each floor level, the readings were taken in the balcony at approximately 1 m from the building. In a place where there is no balcony in the building, the readings were taken with the arm stretched out through a window. The number of vehicles was counted using hand-held counters during noise measurements for 15 min and a note was made for any unusual events during that period such as sirens of police vehicle, ambulance, VIP vehicle, etc.

Data collected in the study areas were entered into a database. The database included following parameters for each time and measurement spot shown in Tables 1 and 2.

- Height of measuring point above street level (h) in m
- Aspect ratio of street canyon (AR)
- Street width (w), in (m)
- Total number of vehicle (n), in vehicles per hour
- L_{eq}, L_{10}, L_{90} (A-weighted) (dB) (street level and at different heights).

For each location above street level, variation of noise attenuation with street level was calculated for each measure L_{eq}, L_{10}, L_{90} (dB). The data which was collected in 15 min at each street location has been subdivided into three 5 min sessions. Then, the field data was analysed using a statistical package (SPSS). The terms in the regression equation and coefficient of determination, R^2 are presented in Table 3. The L_{eq} is dependent on n, w and h of which the terms n and h were more significant.

From Table 3, it is noted that the regression coefficients for each 5 min sessions are not significantly different from each other or from those for the entire 15 min period. The noise level increases with the number of vehicles and reduces with height above the street.

Regression coefficients for the variation of ΔL_{eq}, the noise reduction, with different heights and street width are presented in Table 4. The parameters such as vehicle density (n) and aspect ratio (AR) are added slightly to the strength of the relationship.

Table 2. Traffic noise levels for each street measured during field survey

Study location	Height above street (m)		L_{A90} (dB)			L_{Aeq} (dB)			L_{A10} (dB)		
	Minimum	Maximum	Street	Low	High	Street	Low	High	Street	Low	High
B.T.M. Layout	9.3	21.5	73.2	70.8	69.4	83.6	81.3	79.2	87.6	84.3	82.9
Jayanagar 4th Block	6.5	36	71.6	70.8	68.5	81.7	80.1	78.5	83.9	82.5	81.3
Hanumanth Nagar	11.5	21	69.4	69.1	68.3	80.2	79.7	78.1	82.6	81.9	80.7
Shivaji Nagar	8.5	24	71.5	71.4	70.6	82.7	81.3	80.6	84.2	83.5	82.1
Indian Express near Vidhana Soudha	9.5	22	74.1	73.8	72.9	84.2	83.2	81.5	86.8	85.3	84.4
M.G. Road	28	32	75.7	74.0	72.8	87.6	85.3	82.7	89.5	87.7	86.0
K.R. Market	8	18.5	77.8	77.2	76.3	87.4	86.1	85.2	89.8	88.2	87.5
Yeswanthpur	6.5	17.5	72.8	71.6	69.7	81.5	81.2	79.6	84.2	83.0	82.3
Malleswaram	9.5	32	70.6	70.3	69.1	80.4	78.9	77.6	82.6	81.3	80.4

Table 3. Regression coefficients (± SE) in the equation $L_{eq} = \alpha + \beta n + \gamma h$

	Coefficient for 5 min sessions			
	1	2	3	All 15 min
Traffic volume n (β)	0.00363 ± 0.00040	0.00465 ± 0.00034	0.00423 ± 0.00056	0.00475 ± 0.00052
Height above street h (γ)	-0.221 ± 0.012	-0.232 ± 0.062	-0.249 ± 0.040	-0.241 ± 0.061
Constant (α)	72.8 ± 1.2	73.0 ± 1.4	75.0 ± 1.3	74.0 ± 1.6
R^2	0.72	0.69	0.70	0.72

All terms are significant at ≤1%.

Table 4. Regression coefficients (± SE) in the equation $\Delta L_{eq} = \alpha + \lambda w + \gamma h$

	Coefficient for 5 min sessions			
	1	2	3	All 15 min
Street width w (λ)	-0.216 ± 0.077	-0.265 ± 0.067	-0.278 ± 0.055	-0.215 ± 0.060
Height above street h (γ)	0.137 ± 0.061	0.139 ± 0.051	0.155 ± 0.038	0.132 ± 0.049
Constant (α)	3.31 ± 1.31	3.61 ± 1.14	3.64 ± 0.86	3.44 ± 1.02
R^2	0.61	0.66	0.70	0.70

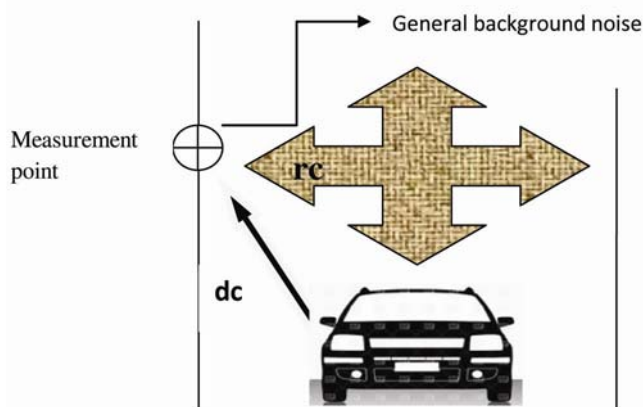All terms are significant at ≤1%.

Figure 2. Noise sources: direct component (*dc*), reverberant component (*rc*) and background noise.

In the same way, the regression coefficients for each 5 min session are not significantly different from each other or from those for the entire 15-minutes session. The

noise reduction increases with the street height and decreases with increase in the street width. Similar observations were made by Nicol *et al.*[4]. The above basic analysis indicates that there is a preferential order of the parameters relating noise level to traffic volume, street dimensions and location above the street level. A noise prediction model is developed for urban street canyons at different heights and then calibrated using the data obtained in this study.

The road traffic noise measured at various locations in the canyons comprises direct sound and reverberant sound (Figure 2). The component reverberant sound is a type of reverberation which is not diffused, but consists primarily of flutter echoes between the facades lining the street[4]. Hence, the sound pressure equation is

$$p^2 \propto S(dc + rc), \tag{1}$$

where, *p* is sound pressure, *S* sound power, *dc* direct sound component and *rc* is reverberant sound component.

Table 5. Comparison of regression coefficients for three 5-min sessions of noise monitoring with entire 15-min session

Coefficient of	5 min session			15 min session
	1	2	3	
D (a)	12.34 ± 2.43**	13.22 ± 2.50**	14.12 ± 2.70**	12.31 ± 2.66**
RV (b)	4.13 ± 5.50	4.61 ± 7.82*	3.81 ± 7.90*	4.22 ± 5.80
Constant (c)	-333 ± 369	-363 ± 535	-341 ± 658*	-321 ± 490
R^2	0.73	0.71	0.69	0.70

Symbols * and ** refer to significance of the coefficient at the 5% and 0.1% level, respectively (all coefficients $\times 10^4$).
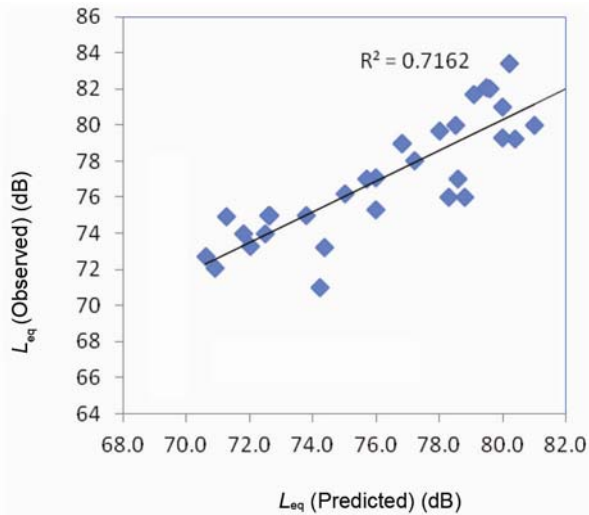

Figure 3. Comparison of L_{eq} observed with L_{eq} predicted.

The direct sound component is considered as a line source for the road traffic. For a line source, dc is inversely proportional to the distance from the noise source[4]. For the street width (w) and height of the location above the street level (h) and the assumed noise source is in the middle of the road; then the distance between source and receiver is given by

$$d = ((w/2)^2 + h^2)^{1/2}. \tag{2}$$

The reverberant sound component depends upon the absorption area. The open top of the street canyon is taken to be a perfect absorber and is expressed as area per metre of street width[4]. The absorption coefficients of the road surface and facades are considered as 0.04. Then, the absorption area is $(1.04\,w + 0.08\,h)$. If the aspect ratio of the street is AR $= h/w$, then expression becomes

$$W = w\,(1.04 + 0.08\text{AR}). \tag{3}$$

The sound power (S) is assumed to be proportional to the number of vehicles per hour. Hence, there are two possible expressions: for line sources (attenuation according to linear distance) or point sources (attenuation according to square of distance). The linear source model was found to correlate best with these data[4]. The expressions were developed into the following form

$$p^2 = \text{a}\,(n/d) + \text{b}\,(n/W) + \text{c}. \tag{4}$$

$$L_p = 10\,\log_{10} p^2. \tag{5}$$

$$L_p = 10\,\log_{10}\,[n(\text{a}/d + \text{b}/W) + \text{c}], \tag{6}$$

a, b and c are constants, where a is concerned with the direct sound component; b is reverberant sound component and c is any background noise entering the street canyon. In general, the role of c is small.

The purpose of this study is to provide a method for estimating the reduction in noise level with the height. In eq. (6), L_p value relates to height above the street level (h) through the variable d. An estimation of values of the constants a, b and c will enable the change of L_p with h to be determined. Using multiple regression analysis, the values of the constants a, b and c have been estimated.

In order to verify how these results agree with the theoretical model presented above, values were calculated for n/d (D) and n/W (RV) (W as in eq. (3)). In the case of D, different values were calculated depending on whether the noise is the greatest judge to be coming from the centre of the road (eq. (2)), or one-third, one-quarter or two-thirds the way across the lane.

Regression analysis was performed for sound pressure (p^2) versus combinations of these variables, primarily to determine which combination has the best explanatory power (Table 5). The higher coefficients of determination compared to the linear regressions for L_{eq} with h and n is shown in Table 5. It also indicates that the theoretical relationship developed above gives a good model of the spatial variation of p^2.

The above regression equation coefficients (Table 5) suggests that RV is less significant than D in finding p^2. A value for p^2 against D alone has been added. The exact value of D or RV is not important. The higher coefficient of determination (in the region of 0.70) is compared to the linear regressions for L_{eq} with h and n. It also suggests that the theoretical relationship developed above gives a good model of the spatial variation of p^2. The variability in R^2 suggests that there is benefit in including the term in RV.
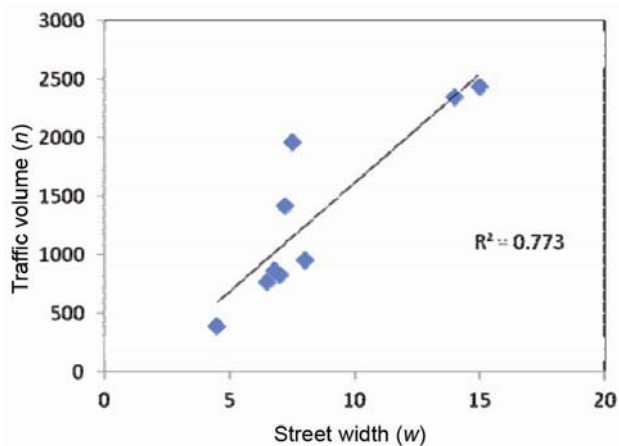
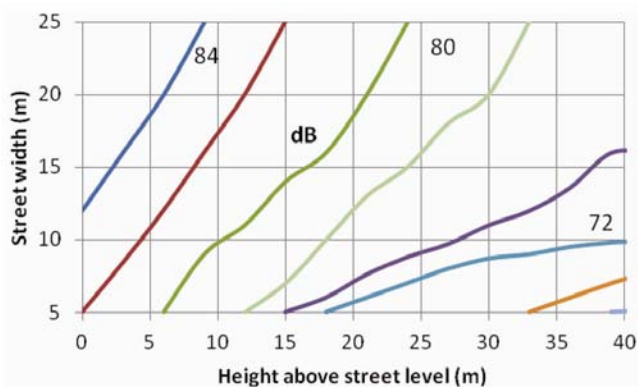**Figure 4.** Relation between traffic volume (vehicles/hour) versus street width (m).

Figure 5. Prediction of noise levels for different street widths and heights above street level.
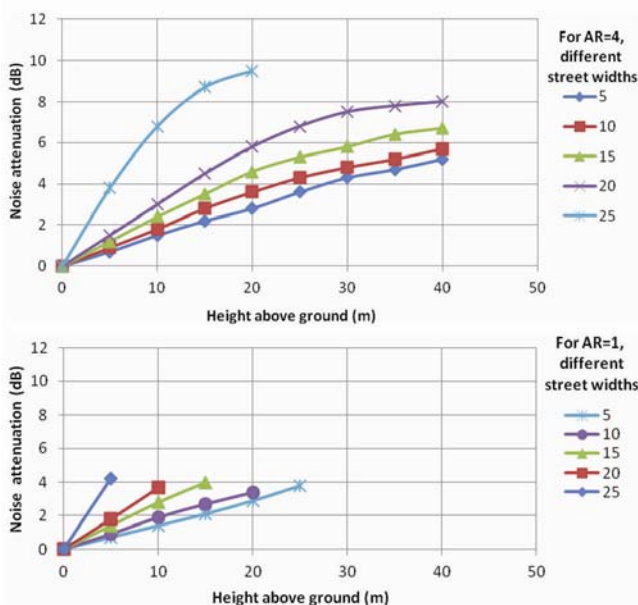

Figure 6. Variation of noise attenuation with height for various street widths, aspect ratios 4 and 1.

Regression analysis gives optimal values for the constants a, b and c (eq. (4), Table 5) as follows: a = 123,816, b = 42,271 and c = −3,121,563

The regression equation for p^2 on D and RV using the data from the whole 15 min is

$$p^2 = 12.3 \times 10^4 D + 4.23 \times 10^4 \, RV - 312 \times 10^4, \qquad (7)$$

then,

$$L_{eq} = 10 \, \log_{10} p^2, \qquad (8)$$

where L_{eq} is the traffic noise level at height h above the street level. The term D depends on three variables, h, w and n. The number of vehicles per hour n is assumed to be proportional to the noise generated. The term RV includes two variables (n and w) as one with AR of the canyon. The value of c is negative because p^2 cannot be negative. This value may be due to a curvature in the relationship in which the linear regression cannot be taken into account. The cause of c on the value of p^2 is generally small in all cases. Figure 3 shows that the observed values are well-predicted by the calculated values ($R^2 = 0.716$).

From the above analysis, it is found that the traffic level is a function of street width. The results of the analysis of these data show that the correlation between n and w is 0.773 and the regression relationship obtained from Figure 4 is

$$n = 185 \times w - 245. \qquad (9)$$

Based on simplifying assumption, values of the predictable noise level at different heights for a particular street width can be determined using Figure 5. From eq. (9), the predictable noise level in the street canyons becomes purely a function of the geometry of the street. The predicted noise level in Bengaluru at different street widths and heights above the street is shown in Figure 5.

The noise level at different heights in the street canyon and the noise attenuation are calculated at different heights from street level. Figure 6 shows the variations in noise attenuation for aspect ratios 4 and 1. From Figure 6, it is observed that the attenuation is for a given street width and street height is independent of aspect ratio and maximum level of reduction at the top of the canyons is reasonably varied by street width.

Figure 7 shows the variation of noise attenuation (L_{eq}) for different values of height above the street and street width.

The correlation between the measured and predicted noise attenuation from the measured data in 15 min in Bengaluru is shown in Figure 8 and it indicates best agreement between the two.

The maximum value of noise attenuation is at the top of the canyon between the given values of the aspect

ratio. It can be calculated using the theoretical eqs (7) and (8) and taking the difference between L_{eq} at the top of the canyon ($h = H$) and the street level ($h = 0$). The noise attenuation at the top of the canyon that can be calculated using the eq. (10) is given below.

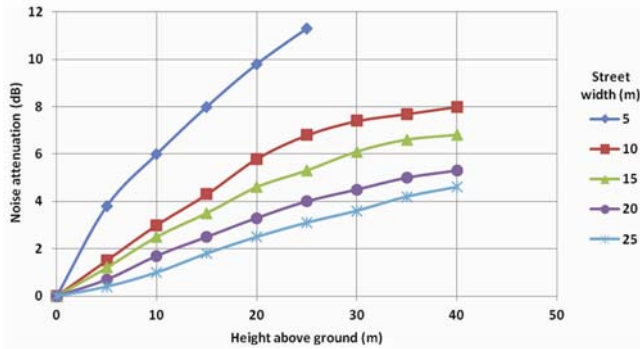$$\Delta L_{AeqH} = L_{eq0} - L_{eqH} = 10 \log_{10} [p_0^2/p_H^2], \tag{10}$$

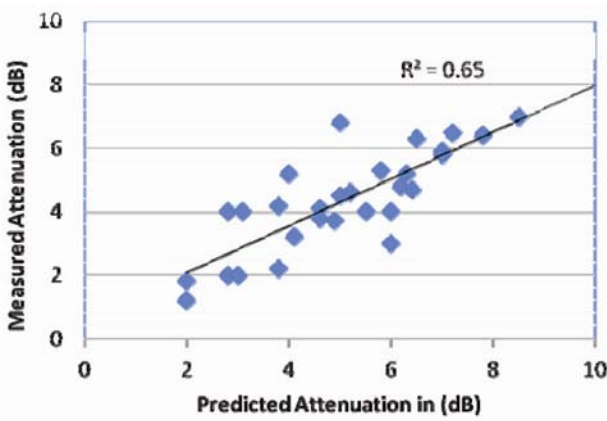**Figure 7.** Variation of noise attenuation with height above the street for various street widths.

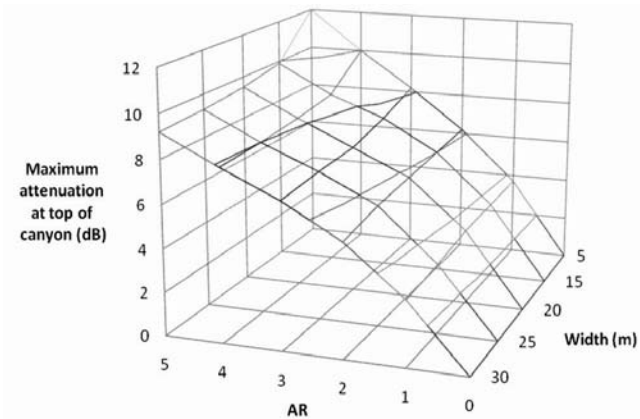**Figure 8.** Comparison of measured attenuation values and predicted values.

Figure 9. Variation of ΔL_{Aeq} with the aspect ratio and street width.

where

$$p_0^2 = \frac{an}{\dfrac{w}{2}} + \frac{bn}{w(1.05 + 0.1AR)} + c$$

$$= \frac{n}{w}\left(\frac{2a + b}{(1.04 = 0.08AR)} + \frac{cw}{n} \right) \tag{11}$$

and

$$p_H^2 = \frac{n}{w}\left(\frac{a}{\sqrt{(AR^2 + 0.5^2)}} \right) + \left(\frac{b}{(1.04 + 0.08AR)} \right) + \left(\frac{cw}{n} \right). \tag{12}$$

From $H = w \times AR$ and eq. (9) above

$$\Delta L_{Aeq} =$$

$$\left(\frac{\dfrac{2a + b}{(1.04 + 0.08AR)} + \dfrac{cw}{(137w - 306)}}{\left(\dfrac{a}{(\sqrt{AR^2 + 0.5^2})} + \dfrac{b}{(1.04 + 0.08AR)} + \dfrac{cw}{(185w - 245)} \right)} \right). \tag{13}$$

Figure 9 shows the variation of ΔL_{Aeq}, and the maximum value of the reduction at the top of the canyon with AR
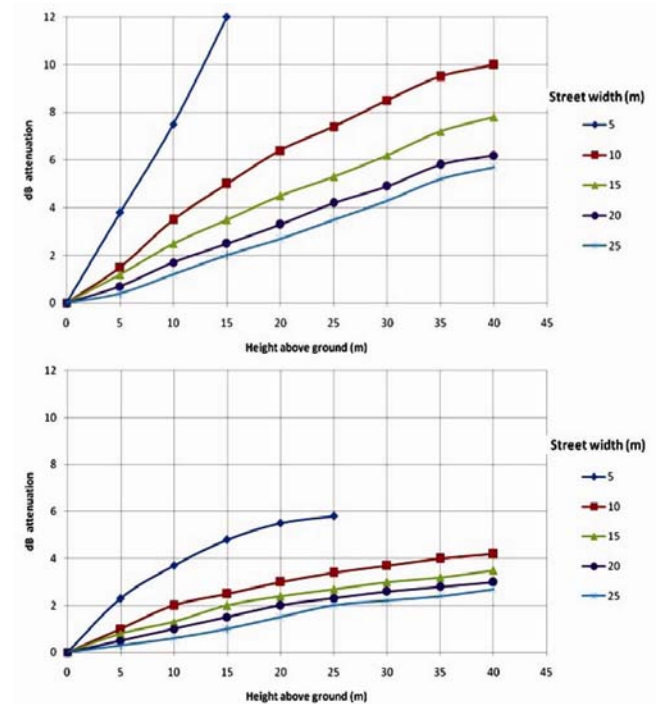

Figure 10. Variation of noise attenuation in L_{90} and L_{10} with height above the street for various street widths.

Table 6. Coefficients a, b and c obtained from regression analysis using eq. (4) (significance P and R^2 for the regression on p^2)

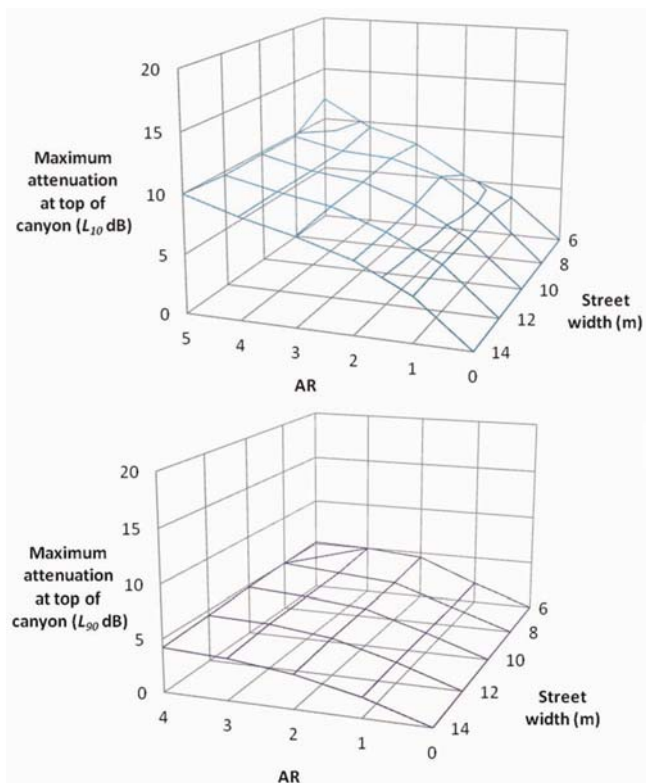|	a	P	b	P	c	P	R^2
$p^2(L_{eq})$	1.23×10^5	0.022	4.22×10^4	0.223	-3.12×10^6	0.316	0.700
$p^2(L_{10})$	2.97×10^5	0.027	9.56×10^4	0.146	-1.21×10^6	0.225	0.813
$p^2(L_{90})$	8.31×10^4	0.013	1.97×10^4	0.014	-1.01×10^6	0.206	0.641

Figure 11. Noise attenuation variation of L_{10} and L_{90} with aspect ratio and street width.

and w. It is observed that ΔL_{AeqH} mainly depends on AR and w. The variation of attenuation mainly depends on AR (Figure 9) except where the width of the street is narrow.

The data analysis for L_{10} and L_{90} is performed in a similar way to that of L_{eq}. The values of the constants a, b and c for the L_{eq}, L_{10} and L_{90} measures of noise are shown in Table 6. In the cases of L_{eq} and L_{10}, the terms for b are not statistically significant, shows that the direct component of noise dominate. In L_{90}, both the terms a and b are significant.

Figure 10 shows the attenuation of L_{10} and the L_{90}. The attenuation of the L_{90} is relatively small, shows that the background noise level reduces more gradually and the loud noises more rapidly with increase in height above the street level.

The maximum possible attenuation of noise L_{10} and L_{90} is shown in Figure 11. The maximum attenuation of the L_{10} is more affected by the AR than either L_{90} or L_{eq} (Figure 9).

A statistical noise prediction model has been developed for street canyons in Bengaluru city from collected field data. The model of noise includes direct and reverberant components of sound in the street canyon. Results of the study show that the noise level in street canyons increases with traffic volume and decreases with the height above the street level. Noise attenuation increases with the height when compared to that at street level, but decreases with increase in street width. The model has been calibrated with field data collected from the other study locations. The calibration results show that the noise reduction is a function of street width and height above the street level. Further, it is also observed that the maximum attenuation is almost a function of aspect ratio with a little effect of street width in a street canyon. In relation with L_{eq}, the rate of noise attenuation with height is greater for L_{10} and lesser for L_{90}.

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