Journal of Atmospheric Pollution, 2015, Vol. 3, No. 1, 1-8
Available online at http://pubs.sciepub.com/jap/3/1/1

DOI:10.12691/jap-3-1-1

Novel Methods for Assessing Urban Air Quality: Combined Air and Noise Pollution Approach

Anirban Kundu Chowdhury*, Anupam Debsarkar, Shibnath Chakrabarty

Department of Civil Engineering, Jadavpur University, Kolkata, India
*Corresponding author: anikc13@yahoo.co.in

Received January 15, 2015; Revised February 03, 2015; Accepted February 06, 2015

Abstract The aim of the present review work is to critically examine the methodologies and findings of the research works which collectively treated traffic related air and noise pollution in commuting microenvironments of urban areas. It is evident from the published literatures that a moderate positive correlation between concentrations of traffic related air pollutants in terms of particulate matter; oxides of nitrogen; CO; ground level O_3 and traffic noise level are common in the commuting microenvironments of cities. This may consequence correlated exposure to these environmental stressors to the subjects (e.g., thousands of pedestrian, commuters, hawkers and street dwellers) attached with the commuting microenvironments of urban areas. Prevailing meteorological condition e.g., wind speed and states of turbulent mixing within the urban canopy layer is the most prominent factor governing the degree of correlation between these environmental stressors. In these circumstances the combined air-noise exposure model may estimate the exposure of the subjects to traffic related air and noise pollution in a holistic manner and the city Noise-Air index may represent the air quality of commuting microenvironments in a holistic manner.

Keywords: *traffic, air pollution, noise pollution, commuting microenvironments, moderate positive correlation, combined air-noise exposure model, city Noise-Air index*

Cite This Article: Anirban Kundu Chowdhury, Anupam Debsarkar, and Shibnath Chakrabarty, “Novel Methods for Assessing Urban Air Quality: Combined Air and Noise Pollution Approach.” *Journal of Atmospheric Pollution*, vol. 3, no. 1 (2015): 1-8. doi: 10.12691/jap-3-1-1.

1. Introduction

Traffic is a significant source of both air and noise pollution in the commuting microenvironments of urban areas. Cardiovascular, respiratory and neuro-behavioural diseases have been found to be associated with roadway proximity, traffic related air and noise pollution exposure [2,9,13,14,17,19,21,22,24,28,31,33,35,39,48]. It is hypothesised that the air pollutants may increases blood pressure, contributes to the instability of vascular plaques, initiate cardiac arrhythmias, modifies autonomous functions, initiates oxidative stress and inflammatory reactions in brain [5,15,27,36]. Chronic exposure to higher level of traffic noise is supposed to be linked with repeated stimulation of the Hypothalamo-Pituitary-Adrenal and Sympathetic-Adrenal-Medullary axis, initiation of sub-cortical stress reactions which ultimately results stress hormone deregulation, hypertension, accumulation of intra-abdominal fat and insulin resistance [3,22,25,29]. It was reported that a moderate positive correlation between concentrations of traffic related air pollutants and traffic noise level may be associated with correlated exposure to the subjects (e.g., thousands of pedestrian, commuters, hawkers and street dwellers) attached with the commuting microenvironments of urban areas. In these circumstances sole consideration of exposure of the subjects to either traffic related air pollutants or traffic noise may result ambiguous findings in the epidemiological studies [1,16,32,42]. For this, nowadays scientists are adapting methods to estimate combined exposure of the subjects to traffic related air and noise pollution in the context of commuting microenvironments of urban areas. Formulation of combined air-noise quality index to describe the air quality of commuting microenvironments is also a promising field of urban air quality research. The aim of the present review work is to critically examine the methodologies and findings of the research works which collectively treated traffic related air and noise pollution in commuting microenvironments of urban area.

2. Quantification and Characterization of the Correlation between Concentration of Traffic Related Air Pollutant(s) and Traffic Noise Level

Correlation between a pair of variables is reported in terms of Pearson’s correlation coefficient “r” and Spearman’s rank correlation coefficient “ρ”. The magnitude of both correlation coefficients varies between -1≤ to ≤1 and they are interpreted as described in Table 1.

Table 1. Interpretation of correlation coefficients ("r" or "ρ") [49]

Range of correlation coefficients	Degree of correlation
0.80-1.00	very strong positive
0.60-0.79	strong positive
0.40-0.59	moderate positive
0.20-0.39	weak positive
0.00-0.19	very weak positive
0.00-(-0.19)	very weak negative
(-0.20)-(-0.39)	weak negative
(-0.40)-(-0.59)	moderate negative
(-0.60)-(-0.79)	strong negative
(-0.80)-(-1.00)	very strong negative

2.1. Correlation between Concentration of Particulate Matter and Traffic Noise Level

Particulate matter is one of the major air pollutants originated from the internal combustion engine of fossil fuel driven vehicles. Correlation between concentration of this criteria air pollutant and traffic noise level has been examined in detail by a number of researches (Table 2).

Table 2. Correlation between noise level and concentration of particulate matter

References	Study cities	TNC/PNC/TPN	UFP	PM_1	$PM_{2.5}$	PM_{coarse}	PM_{10}	SPM/TSP	BC
Allen et al., [1]	Chicago and Riverside	×	0.26-0.41	×	×	×	×	×	×
Boogaard et al., [4]	Dutch cities	0.21-0.60	×	×	(-0.17)-0.38	×	×	×	×
Can et al., [6]	Antwerp	0.40-0.48	0.38-0.47	×	×	×	×	×	×
Chowdhury et al., [10]	Kolkata	×	×	×	0.71	×	0.61	0.67	×
de Kluizenaar et al., [13]	Cities of Netherland	×	×	×	×	×	0.72	×	×
Gan et al., [19]	Vancouver	×	×	×	0.14	×	×	×	0.45
Klæboe et al., [24]	Oslo	×	×	×	0.39	×	0.34	×	×
Ross et al., [30]	New York	×	×	×	0.16	×	×	×	0.16
Tobias et al., [38]	Madrid	×	×	×	×	×	×	0.21	×
van Kempen et al., [40]	Schiphol-Amsterdam	×	×	×	×	×	0.20	×	×
Weber, [42]	Essen	(-0.18)-0.81	×	×	×	×	×	×	×
Weber et al., [43]	Essen	×	×	0.03-0.53	×	(-0.19)-0.34	×	×	×
Range		(-0.18)-0.81	0.26-0.47	0.03-0.53	(-0.17)-0.71	(-0.19)-0.34	0.20-0.72	0.21-0.67	0.16-0.45

TNC (total particle number concentration), PNC (particulate number concentrations), TPN (total particle number), UFP (ultrafine particulate matter), PM_1 (particulate matters have aerodynamic diameter ≤ 1 µm), $PM_{2.5}$ (particulate matters have aerodynamic diameter ≤ 2.5 µm), PM_{coarse} (difference between the particulate matters have aerodynamic diameter ≤ 10 µm and ≤ 1 µm), PM_{10} (particulate matters have aerodynamic diameter ≤ 10 µm), SPM (suspended particulate matter), TSP (total suspended particulate), BC (black carbon)

Very weak negative to very strong positive correlation was accounted between concentration of TNC (total particle number concentration) or PNC (particulate number concentrations) or TPN (total particle number) and traffic noise level. Weak positive to moderate positive correlation was accounted between concentration of ultrafine particulate matter and traffic noise level. Weber *et al.* reported very weak positive to moderate positive range of correlation between concentration of PM_1 and traffic noise level [43]. Correlation accounted between concentration of $PM_{2.5}$ and traffic noise level was within the range of very weak negative to strong positive. Weber *et al.* also reported very weak negative to weak positive range of correlation between concentration of PM_{coarse} and traffic noise level [43]. Correlation accounted between concentration of PM_{10} and traffic noise level had a range of weak positive to strong positive. Weak positive to strong positive correlation was accounted between concentration of suspended particulate matter or total suspended particulate and traffic noise level. The correlation accounted between concentration of black carbon and traffic noise level had a range of very weak positive to moderate positive. It is evident from the above discussion that the moderate positive correlations which may lead to correlated exposure to the subjects between concentration of particulate matter and traffic noise level are very frequent in commuting microenvironments of cities worldwide.

2.2. Correlation between Concentration of Oxides of Nitrogen and Traffic Noise Level

Oxides of nitrogen also originated from the internal combustion engine of fossil fuel driven vehicles. Correlation between concentration of this criteria air pollutants and traffic noise level has also been examined in detail by a number of researches (Table 3).

Table 3. Correlation between noise level and concentration of oxides of nitrogen

References	Study cities	NO	NO_2	NO_X
[1]		0.20-0.60	(-0.08)-0.46	×
[6]		0.50	0.29	0.46-0.50
[10]		×	0.69	×
Davies et al., [12]	Vancouver	×	0.53	0.64
Foraster et al., [16]	Girona	×	0.47-0.63	×
[19]		0.41	0.33	×
Ising et al., [22]	Cities of Germany	×	0.84	×
[24]		×	0.46	×
[30]		0.22	0.18	×
Selander et al., [33]	Cities of Sweden	×	0.60	×
[38]		×	0.32	0.35
[40]		×	0.30	×
Range		0.20-0.60	(-0.08)-0.84	0.35-0.64

Weak positive to strong positive correlation was accounted between concentration of NO and traffic noise level. Very weak negative to very strong positive correlation between concentration of NO_2 and traffic noise level were reported by a number of researchers. The range of correlation accounted between concentration of NO_X and traffic noise level by the researchers were of weak positive to strong positive. It is noteworthy from the above discussion that moderate positive correlation between concentration of oxides of nitrogen and traffic noise level is also very frequent like the correlations between concentrations of particulate matter and traffic noise level.

2.3. Correlation between Concentration of Other Air Pollutants and Traffic Noise Level

Ross *et al.* reported a very weak positive correlation (0.03) between concentration of total hydrocarbon and traffic noise level [30]. Beelen *et al.* reported a weak positive correlation (0.24) between concentration of background black smoke and traffic noise level [2]. A weak positive correlation (0.30) was also reported between concentration of SO_2 and traffic noise level in the research work of Tobias *et al.* [38]. They also accounted a moderate positive correlation (0.42) between concentration of ground level O_3 and traffic noise level. Very strong positive correlation (0.89, Tirabassi *et al.* [37]) between concentration of CO and traffic noise level was reported by Tirabassi *et al.* [37] and Kim *et al.* [23]. It is evident from the above discussion that like the correlated exposure of the subjects to particulate matter and traffic noise, oxides of nitrogen and traffic noise correlated exposure is also evident for the subjects to ground level O_3 and traffic noise, CO and traffic noise.

2.4. General Discussion on the Correlation between Concentration of Air Pollutant(s) and Traffic Noise Level

The degree of correlation reported between the concentration of traffic related air pollutant(s) and traffic noise level are to some extent inconsistent and varies between cities and even within cities. This might be attributed to the fact that air pollutants and noise have different mode of dispersion and/or transportation in the atmosphere. Air pollutants disperse in the atmosphere by diffusion and drift. Thus, its concentration in the atmosphere is extensively dependent on the number of sources, prevailing local meteorological condition e.g., wind speed, wind direction, vertical temperature profile of the atmosphere and background concentration of the pollutants. Noise is transmitted in the atmosphere by pressure waves that can be reflected and refracted and increased through superimposition, but otherwise have a short half-life and lower dependency on the prevailing meteorological condition than air pollutants [12].

3. Factors Influence the Degree of Correlation between Concentration of the Air Pollutant(s) and Traffic Noise Level

According to published literatures meteorological factors, traffic volume and traffic density, distance from the road and averaging time were supposed to be the governing factors which produce the variability of concentration of air pollutants and traffic noise level.

3.1. Meteorological Factors

Weber and Weber *et al.* reported that the degree of correlation between concentration of particulate matter and traffic noise level was coupled to the states of turbulent mixing within the urban canopy layer [42,43]. They reported higher turbulent mixing tended to disperse particulates more significantly on the contrary traffic noise level was found almost free from the states of turbulent mixing within the urban canopy layer. Weber also reported an identical pattern of spatial distribution of traffic noise level and inhomogeneous spatial distribution of the concentration of particulate matter during different measurement days characterized by significant variations in wind direction and the height of the atmospheric boundary layer. They accounted correlations of greater than 0.62 between traffic noise levels measured on different days in all possible combinations. But correlations between total particle number concentrations measured on different days in all possible combinations had a range of 0.18 – 0.70 [42]. On the contrary, Davies *et al.* reported that wind speed variation was not a significant factor to describe the relationship between traffic noise level and concentration of the oxides of nitrogen [12]. According to Allen *et al.* NO concentrations were most sensitive to wind direction. In contrast, traffic noise was minimally influenced by wind direction. They reported consistent correlations (0.53 – 0.74) between traffic noise level and concentration of NO to the downwind of major roads [1]. Can *et al.* approved the findings of Weber and Weber *et al.* [6, 42, 43]. They also reported a strong influence of meteorological condition on airborne pollutant variation and weak influence of the same on noise propagation. Ross *et al.* reported that both wind direction and wind speed had an influence on the correlation between the concentrations of traffic related air pollutants and traffic noise level. They accounted wind speed had a negative moderate correlation (-0.51) with the concentration of NO_2 and total hydrocarbons (-0.57), whereas a weak positive correlation (0.38) was accounted between traffic noise level and wind speed. They also pointed out that, the concentration of NO_2 and traffic noise level, concentration of total hydrocarbons and traffic noise level had higher degree of positive correlations during low-wind hours in comparison with the overall measurement period [30]. Chowdhury *et al.* accounted stronger influences of wind speed on the concentrations of different air pollutants (e.g., PM_{10} (-0.81), $PM_{2.5}$ (-0.81) and NO_2 (-0.74)) than traffic noise level (-0.47). They also accounted a stronger influences of air temperature on traffic noise level (-0.70) than the concentrations of different air pollutants (e.g., PM_{10} (-0.40), $PM_{2.5}$ (-0.45) and NO_2 (-0.55)) [10].

It is clear from the above discussion that concentration of the air pollutants are stringently modified by the prevailing meteorological condition i.e., wind speed, wind direction and states of turbulent mixing of the atmosphere of a given place whereas the effects of theses meteorological variables on the traffic noise level are insignificant.

3.2. Traffic Volume and Traffic Density

Traffic is one of the significant sources linked with both air pollution and noise pollution in urban environment. Traffic density or traffic volume is supposed to be one of the governing factors to determine the degree of correlation between concentration of air pollutants and traffic noise level. Davies *et al.* accounted that traffic density in terms of number of car or truck, road characteristics in terms of number of lanes of the nearest road and presence of major intersection nearby the monitoring station were the major contributors to the variability of traffic noise level and concentration of NO_2 and NO_X in the urban environment [12]. Weber accounted that spatio-temporal distribution of traffic noise level and concentration of particles in urban environment were closely coupled to road traffic emission [42]. Boogaard *et al.* reported that particle number concentration was influenced by the variation of local traffic density in urban environment. But they accounted local traffic density had very poor correlation with $PM_{2.5}$ concentration. They also suggested that moderate positive correlation between the concentration of traffic related air pollutants and traffic noise level was likely to be an outcome of the complex road-traffic interactions because condition of the road surface has higher impact on noise emission than emission of the air pollutants from the motorized vehicles. On the contrary, congestion and vehicle speed have higher impact on emission of the air pollutants than emissions of noise from motorized vehicles [4]. Foraster *et al.* reported average daily traffic number is a common determinant which could explain only a part of the correlation between traffic noise level and concentration of NO_2. They also reported that correlation between traffic noise level and concentration of NO_2 was stronger at locations with lower traffic density of less than 1000 vehicles/day [16]. Can *et al.* reported that traffic counts were very strong positively correlated (0.85) to traffic noise level. On the contrary correlations were weaker between traffic counts and concentrations of different air pollutants (e.g., NO_X (0.39 – 0.45), ultrafine particulate matter (0.33 – 0.42) and total particle number (0.36 – 0.42)). They also suggested that correlations between traffic counts and particle number concentrations were size dependent, which tend to decrease with increasing size as, smaller particles are short-term traffic-related, being formed in cooling exhaust plumes, while bigger particles result from slower agglomeration dynamics [6]. Unlike Foraster *et al.* they accounted that the correlation between traffic noise level and concentration of traffic related air pollutants (e.g., NO_2, ultrafine particulate matter, total particle number) were quiet similar to both the locations with lower and higher traffic density. Ross *et al.* reported that traffic noise level were weak to strong positively (0.37 – 0.64) correlated with car, truck and bus counts [30]. Chowdhury *et al.* reported weak positive correlation between the concentrations of the air pollutants (e.g., PM_{10} (0.33), $PM_{2.5}$ (0.27) and NO_2 (0.21)) and traffic count and very weak positive correlation between traffic count and traffic noise level (0.17) [10]. Chowdhury *et al.* also reported that traffic noise level of Kolkata city, India is a function of road width [11].

3.3. Distance from the Road

Distance from the road is also supposed to be a common factor influencing the concentration of the air pollutants and traffic noise level. The sound pressure level in the free field situation shows a reduction of 6 dB per doubling of distance from the source. Decay of air pollutant concentrations with increasing distance from the road is best-fitted by exponential function [20,26,44,50]. Fung *et al.* reported logarithmic transformation of distance from the road can be used as a common function to evaluate air-noise quality of a city [18]. Allen *et al.* reported that the effect of roadway proximity on the correlation between the concentration of traffic related air pollutants and traffic noise level was inconsistent across the cities. In Chicago, higher correlations (0.37 – 0.62) were noted within 100 m of the target road, while in Riverside higher correlations (0.40 – 0.71) were found between them for distances both greater than and less than 100 m from the target road [1]. Gan *et al.* also accounted inconsistent effect of road proximity on the correlations between concentration of traffic related air pollutants and traffic noise level for the major roads. They accounted the correlations between noise level and concentration of air pollutants (Table 4) was tended to be higher for the areas farther than 50 m or 150 m from highways [19].

Table 4. Road proximity and range of correlation(s) between noise level and concentration of traffic-related air pollutant(s)

Road proximity	Black carbon	$PM_{2.5}$	NO_2	NO
≤ 50 m Highway* and Major road**	0.17 – 0.26	0.02 – 0.24	0.04 – 0.34	0.14 – 0.37
> 50 m Highway* and Major road**	0.41 – 0.45	0.16 – 0.17	0.32 – 0.36	0.33 – 0.42
≤ 150 m Highway* and Major road**	0.38 – 0.46	0.03 – 0.15	0.23 – 0.30	0.35 – 0.37
> 150 m Highway* and Major road**	0.31 – 0.41	0.14 – 0.17	0.26 – 0.35	0.22 – 0.40

*Highways: 21000 – 114000 vehicles per day; **Major road: 15000 – 18000 vehicles per day

It is evident from the above discussion that effect of traffic density, traffic volume and roadway proximity on the degree of correlation between concentration of the air pollutants and traffic noise level is inconsistent.

3.4. Averaging Time

Averaging time or sampling duration was supposed to be a modifier of correlation between concentration air pollutants and traffic noise level. There are ample of chances to account some secondary air pollutant for long sampling period, but the sources of the noise in an urban environment are always primary. Boogaard *et al.* reported a weak to strong positive correlation (0.21 – 0.60) between particle number concentration and traffic noise level when 1 min averages were considered but the same correlation (0.14 – 0.31) were found much lower when 1 sec averages were considered [4]. Can *et al.* accounted higher degree of positive correlation between traffic noise level and concentration of air pollutants (e.g., NO_X (0.50), concentration of ultrafine particulate matter (0.47), and total particle number concentration (0.48)) when 60 min average was considered in comparison with 15 min averaged data (e.g., NO_X (0.46), concentration of ultrafine particulate matter (0.38), and total particle number concentration (0.40)) [6].

It is evident from the above discussion that effect of sampling duration on the degree of correlation between concentration of the air pollutants and traffic noise level is also inconsistent.

3.5. General Discussion on the Factors Influencing the Degree of Correlation between Concentration of Air Pollutant(s) and Traffic Noise Level

It is evident from the above discussion that meteorological variables e.g., wind speed and wind direction influences the concentration of air pollutants in the atmosphere in inverse proportion. The concentration of the air pollutants in the atmosphere is also highly influenced by the states of turbulent mixing of the atmosphere. On the contrary effects of meteorological variables are less important in the context of outdoor noise propagation. In most of the cases traffic volume and road characteristics has direct relation with prevailing traffic noise level. But effect of traffic volume and road characteristics on the concentration of the air pollutants is complex to some extent. Effect of distance from the road and averaging sampling time on the correlation of concentration of traffic related air pollutants and traffic noise level is inconsistent.

4. Formulation and Characterization of Combined Air-noise Exposure for Cities

Combined air noise exposure model measures the exposure to traffic related air pollution and noise pollution in a holistic and easy to comprehend manner.

4.1. Formulation of Combined Air-noise Exposure Model

Combined exposure to air pollution and noise pollution in urban microenvironments was reported in the research work of Vlachokostas *et al.* [41]. They proposed the following formulations for the assessment of combined exposure to these environmental stressors –

$$CEF(T) = \sum_{i=1}^{P} w_i \frac{E_s^k(i) - \bar{E}_t^k(i)}{\bar{E}_t^k(i)} \quad (1)$$

$$\bar{E}_t^k(i) = \int_{k=1}^{K} \int_{t=0}^{T} E(i).dt.dk \quad (2)$$

where: $CEF(T)$ is the combined exposure factor for a space in time t, $-1 \le CEF(T) \le +\infty$,

P is the number of environmental health stressors considered in the analysis, $1 \le i \le P$,

w_i is the weighting factor for environmental health stressor i,

$\bar{E}_t^k(i)$ is the average exposure of stressor i, for time t and microenvironment k (e.g., the interior of a car, the saddle of a motor- or bi-cycle, pavement used by pedestrians),

$E_s^k(i)$ is the limit value, legislative environmental quality standard [45] of exposure for stressor i and microenvironment k defined for an average exposure duration t,

K is the number of microenvironment types, $1 \le k \le K$.

4.2. Characterization of Combined Exposure Factor

Characterization of combined exposure factor (CEF) is represented in the Figure 1. Approximate zero values are characterizing poor to barely acceptable cumulative exposure. Negative values of the same are characterizing problematic situations. Whereas, CEF>1 is a very good level of cumulative exposure.

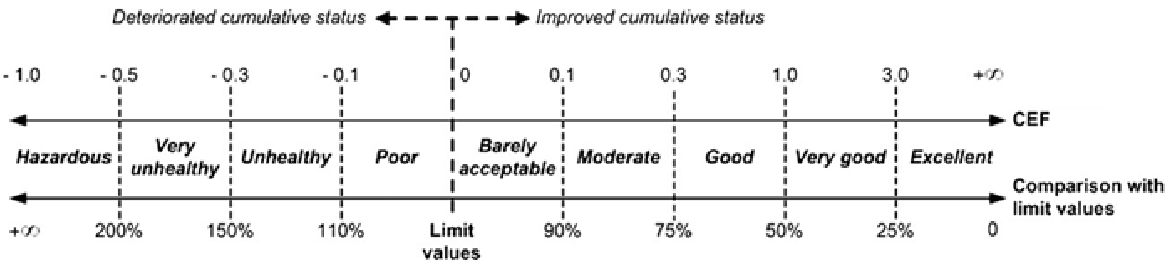

Figure 1. Characterization of combined exposure factor [41]

4.3. Estimation and Characterization of Combined Air-noise Pollution Exposure in the Context of Thessaloniki City, Greece

Vlachokostas *et al.* reported that CEF of bicyclers were comparable to CEF of pedestrians. In both the cases the numerical values of CEFs were approximately 1.5 which represented a healthy co-exposure to air and noise pollution. Pedestrian and bicycling activities were also found preferable than car driving and motorcycling. CEFs of car drivers and motorcyclists were centered to zero which represented an unhealthy co-exposure to air and noise pollution [41].

5. Formulation and Characterization of Combined Noise-air Quality Index for Cities

City Noise-Air index represents the air quality of a city in terms of air and noise pollution scenario with a single number.

5.1. Formulation of City Noise-Air Index

Silva *et al.* proposed city Noise-Air index in their research work [34]. City Noise-Air index is the weighted linear combination of two normalised indexes: cityNoise and cityAir –

$$CityNoise-Air = \left(0.5 \times cityNoise + 0.5 \times cityAir\right) \quad (3)$$

where cityNoise is the normalised index of urban noise quality and cityAir is the normalised index of urban air quality.

5.2. Interpretation of City Noise-Air Index

The numerical value of city Noise-Air index varies between 0 and 1. City Noise-Air is equal to zero when the noise level is above the legal limit and at least one air pollutant concentration is above the limit value. On the other hand, City Noise-Air is equal to one when the noise level is below the limit value and all of the air pollutant concentrations are at or below the recommended values [46]. Detailed classification of city Air-Noise index is described in Table 5.

Table 5. City Noise-Air index classification [34]

Numerical values of city Noise-Air index	Quality classification
0-0.2	Very poor
0.2-0.4	Poor
0.4-0.6	Fair
0.6-0.8	Good
0.8-1	Very good

5.3. CityAir Index Formulation

The equation for cityAir index is as described below –

$$cityAir = \sum_i w_i c_i \times \prod_i v_i \quad (4)$$

where: w_i is the relative weight of the pollutant i (Silva *et al.* considered equal weights of 0.2 for each of the five pollutants [34]),

c_i is the normalised concentration of the pollutant i,

v_i is the dummy variable of the legal limit violation $\left(L_i\right)$ of pollutant i, defined as follows: $v_i = 1$ when $c_i \leq L_i$ and $v_i = 0$ when $c_i > L_i$

To determine the normalised concentration of the pollutant i, Silva *et al.* proposed the following equation –

$$c_i = \cos^2 \alpha \quad (5)$$

where:

$$\alpha = \left[\frac{\left(x - x_a\right)}{\left(x_b - x_a\right)}\right] \times \frac{\pi}{2} \quad (6)$$

where: x is the concentration value being normalised,

x_a and x_b are control points in the function

$\cos^2 \alpha$ is a sigmoidal function which standardized the concentration of the pollutant i in the range of 0 to 1. Where zero represents the poorest air quality and one represents the best air quality. The control points of the sigmoidal functions were selected according to the following criteria: score = 0 for the concentration limit values considered in the Portuguese legislation for human health protection [34] and score = 1 for the concentration guidance values recommended by World Health Organization [46].

5.4. CityNoise Index Formulation

The equation for cityNoise index is as described below –

$$cityNoise = w \times c \times v \quad (7)$$

where: w is weight of the noise level (Silva et al. considered the weight of the noise level equal to 1),

c is the normalised score of the noise level,

v is the dummy variable of the legal limit violation $\left(L\right)$ of noise level, defined as follows: $v = 1$ when $c \leq L$ and $v = 0$ when $c > L$

In this case the normalised score of the noise level was also determined by using the Equation (5). But the control points of the function were different. Silva *et al.* selected the control points of the sigmoidal function according to the following criteria: score = 0 for the limit value of the annoyance indicator (L_{den}); and score = 1 for the limit value of the sleep indicator (L_n) [34,47].

5.5. Air Quality Classification in Terms of City Noise-Air Index in the Context of Viana do Castelo City, Portugal

Silva *et al.* reported that numerical values of city Noise-Air index varied between 0 – 0.6 in curbside environments of main and secondary roads (based on traffic volume) of the city which represented very poor to fair air quality in terms of both air and noise pollution status. Otherwise the majority of the city area had the numerical values of the index varied between 0.6 – 1 which represented good to very good air quality in terms of both air and noise pollution status [34].

5.6. General Discussion on the Combined Air-noise Exposure Model and City Noise-Air Index in the Context of Indian Cities

The combined air-noise exposure model estimates the exposure of the subjects to traffic related air and noise pollution in a holistic manner and the city Noise-Air index represents the air quality of commuting microenvironments in a holistic manner. These are equally applicable in the context of the Indian cities like Kolkata where the higher degree of positive correlation between concentration of the traffic related air pollutants and traffic noise level is reported in the research work of Chowdhury *et al.* [10]. But prior to these some modifications are required. Air-noise exposure model and city Noise-Air index may be oriented as per legislative environmental quality standard prescribed by Central Pollution Control Board of India [7,8]. For normalization process in the city Noise-Air index the minimum and maximum concentration and/or level of a pollutant may be used as control points of the sigmoidal function (Table 6).

Table 6. Definition of the control points (x_a and x_b)

Control points	Definitions
x_a	Minimum value of the concentration of the air pollutant and/or noise level during measurement which denotes the best air quality and/or lowest noise level during measurement. When $x = x_a$, the score of $x_a = 1$
x_b	Maximum value of the concentration of the air pollutant and/or noise level during measurement which denotes the worst air quality and/or highest noise level during measurement. When $x = x_b$, the score of $x_b = 0$

6. Conclusion

It is evident from the published literatures that a moderate positive correlation between concentrations of traffic related air pollutants in terms of particulate matter; oxides of nitrogen; CO; ground level O_3 and traffic noise level are common in the commuting microenvironments of cities. This may consequence correlated exposure to these environmental stressors to the subjects (e.g., thousands of pedestrian, commuters, hawkers and street dwellers) attached with the commuting microenvironments of urban areas. Prevailing meteorological condition e.g., wind speed and states of turbulent mixing within the urban canopy layer is the most prominent factor governing the degree of correlation between these environmental stressors. In these circumstances the combined air-noise exposure model may estimate the exposure of the subjects to traffic related air and noise pollution in a holistic manner and the city Noise-Air index may represent the air quality of commuting microenvironments in a holistic manner.

References

[1] Allen, R.W., Davies, H., Cohen, M.A., Mallach, G., Kaufman, J.D., Adar, S.D., 2009. The spatial relationship between traffic-generated air pollution and noise in 2 US cities. Environmental Research. 109, 334-342.

[2] Beelen, R., Hoek, G., Houthuijs, D., van den Brandt, P.A., Goldbohm, R.A., Fischer, P., Schouten, L.J., Armstrong, B., Brunekreef, B., 2009. The joint association of air pollution and noise from road traffic with cardiovascular mortality in a cohort study. Occupational and Environmental Medicine. 66, 243-250.

[3] Bluhm, G.L., Berglind, N., Nordling, E., Rosenlund, M., 2007. Road traffic noise and hypertension. Occupational and Environmental Medicine 64, 122-126.

[4] Boogaard, H., Borgman, F., Kamminga, J., Hoek, G., 2009. Exposure to ultrafine andfine particles and noise during cycling and driving in 11 Dutch cities. Atmospheric Environment 43, 4234-4242.

[5] Brook, R.D., Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., Luepker, R., Mittleman, M., Samet, J., Smith, S.C.Jr., Tager, I; Expert Panel on Population and Prevention Science of the American Heart Association, 2004. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation 109, 2655–2671.

[6] Can, A., Rademaker, M., Van Renterghem, T., Mishra, V., Van Poppel, M., Touhafi, A., Theunis, J., De Baets, B., Botteldooren, D., 2011. Correlation analysis of noise and ultrafine particle counts in a street canyon. Science of the Total Environment. 409(3), 564-572.

[7] Central Pollution Control Board of India, 2000. Ambient air quality in respect of noise. Schedule-part-II, Sec-3 (ii), Central Pollution Control Board, New Delhi, India.

[8] Central Pollution Control Board, India, 2009. National Ambient Air Quality Standards, Central Pollution Control Board Notification (18th November, 2009), New Delhi, India.

[9] Chang, T.Y., Liu, C.S., Bao, B.Y., Li, S.F., Chen, T.I., Lin, Y.J., 2011. Characterization of road traffic noise exposure and prevalence of hypertension in central Taiwan. Science of the Total Environment. 409, 1053-1057.

[10] Chowdhury, K. A., Debsarkar, A., Chakrabarty, S., 2011. A study on co-exposure to traffic related air pollution and noise for an important urban road of Kolkata city, India. Indian Journal of Air Pollution Control. XI (2), 34-40.

[11] Chowdhury, K. A., Debsarkar, A., Chakrabarty, S., 2012. Analysis of day time traffic noise level: A case study of Kolkata India. International Journal of Environmental Sciences and Research. 2(1), 114-118.

[12] Davies, H.W., Vlaanderen, J.J., Henderson, S.B., Brauer, M., 2009. Correlation between co-exposures to noise and air pollution from traffic sources. Occupational and Environmental Medicine. 66, 347-350.

[13] de Kluizenaar, Y., Gansevoort, R.T., Miedema, H.M.E., de Jong, P.E., 2007. Hypertension and road traffic noise exposure. Journal of Occupational and Environmental Medicine. 49 (5), 484-492.

[14] Delfino, R.J., Tjoa, T., Gillen, D.L., Staimer, N., Polidori, A., Arhami, M., Jamner, L., Sioutas, C., Longhurst, J., 2010. Traffic-related Air Pollution and Blood Pressure in Elderly Subjects with Coronary Artery Disease. Epidemiology. 21, 396-404.

[15] Elder, A., Gelein, R., Silva, V., Feikert, T., Opanashuk, L., Carter, J., Potter, R., Maynard, A., Ito, Y., Finkelstein, J., Oberdörster, G., 2006. Translocation of inhaled ultrafine manganese oxide particles to the central nervous system. Environmental Health Perspectives 114, 1172-1178.

[16] Foraster, M., Deltell, A., Basagana, X., Medina-Ramon, M., Aguilera, I., Bouso, L., Grau, M., Phuleria, H.C., Rivera, M., Slama, R., Sunyer, J., Targa, J., Künzli, N., 2011. Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city. Environmental Research. 111, 177-183.

[17] Freire, C., Ramos, R., Puertas, R., Lopez-Espinosa, M.J., Julvez, J., Aguilera, I., Cruz, F., Fernandez, M.F., Sunyer, J., Olea, N., 2010. Association of traffic-related air pollution with cognitive development in children. Journal of Epidemiology & Community Health. 64, 223-228.

[18] Fung, W. Y., Lee, L., W., 2011. Identifying a common parameter for assessing the impact of traffic-induced noise and air pollutions on residential premises in Hong Kong. Habitat International 35, 231-237.

[19] Gan, Q.W., McLean, K., Brauer, M., Chiarello, A.S., Davies, W.H., 2012. Modeling population exposure to community noise and air pollution in a large metropolitan area. Evioronmental Research. 116, 11-16.

[20] Hagler, G.S.W., Baldauf, R.W., Thoma, E.D., Long, T.R., Snow, R.F., Kinsey, J.S., Oudejans, L., Gullett, B.K., 2009. Ultrafine particles near a major roadway in Raleigh, North Carolina: downwind attenuation and correlation with trafficrelated pollutants. Atmospheric Environment 6, 1229-1234.

[21] Hoffmann, B., Moebus, S., Mohlenkamp, S., Stang, A., Lehmann, N., Dragano, N., Schmermund, A., Memmesheimer, M., Mann, K., Erbel, R., Jockel, K.H., 2007. Residential exposure to traffic is associated with coronary atherosclerosis. Circulation. 116 (5), 489-496.

[22] Ising, H., Lange-Asschenfeldt, H., Moriske, H.-J., Born, J., Eilts, M., 2004. Low Frequency noise and stress: bronchitis and cortisol in children exposed chronically to traffic noise and exhaust fumes. Noise & Health. 6 (23), 23-30.

[23] Kim, K., Ho, X.D., Brown, C.J.R., Oh, M.J., Park, G.C., Ryu, C.I., 2012. Some insights into the relationship between urban air pollution and noise levels. Science of the Total Environment 424, 271-279.

[24] Klæboe, R., Kolbenstvedt, M., Clench-Aas, J., Bartonova, A., 2000. Oslo traffic study-part 1: An integrated approach to assess the combined effects of noise and air pollution on annoyance. Atmospheric Environment 34 (27), 4727-4736.

[25] Lusk, S.L., Hagerty, B.M., Gillespie, B., Ziemba, R.A., 2004. Acute effects of noise on blood pressure and heart rate. Archives of Environmental Health 59, 392-399.

[26] Morawska, L., Ristovski, Z., Jayaratne, E.R., Keogh, D.U., Ling, X., 2008. Ambient nano and ultrafine particles from motor vehicle emissions: characteristics, ambient processing and implications on human exposure. Atmospheric Environment 42, 8113- 8138.

[27] Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Kreyling, W., Cox, C., 2004. Translocation of inhaled ultrafine particles to the brain. Inhalation Toxicology 16, 437-445.

[28] Orru, H., Jogi, R., Kaasik, M., Forsberg, B., 2009. Chronic Traffic-Induced PM Exposure and Self-Reported Respiratory and Cardiovascular Health in the RHINE Tartu Cohort. International Journal of Environmental Research and Public Health. 6, 2740-2751.

[29] Passchier-Vermeer, W., Passchier, W.F., 2000. Noise exposure and public health. Environmental Health Perspectives. 108 (Suppl 1), 123-131.

[30] Ross, Z., Kheirbk, I., Clougherty, J.E., Ito, K., Matte, T., Markowitz, S., Eisl, H., 2011. Noise, air pollutants and traffic: continuous measurement and correlation at a high-traffic location in New York City. Environmental Research. 111, 1054-1063.

[31] Schwartz, J., Litonjua, A., Suh, H., Verrier, M., Zanobetti, A., Syring, M., et al., 2005. Traffic related pollution and heart rate variability in a panel of elderly subjects. Thorax. 60, 455-461.

[32] Schwela, D., Kephalopoulos, S., Prasher, D., 2005. Confounding or aggravating factors in noise-induced health effects: air pollutants and other stressors. Noise & Health. 7 (28), 41-50.

[33] Selander, J., Nilsson, M.E., Bluhm, G., Rosenlund, M., Lindqvist, M., Nise, G., et al., 2009. Long-term exposure to road traffic noise and myocardial infarction. Epidemiology. 20, 272-279.

[34] Silva, T. L., Mendes, G. F. J., 2012. City Noise-Air: An environmental quality index for cities. Sustainable Cities and Society 4, 1-11.

[35] Sørensen, M., Hvidberg, M., Andersen, Z.J., Nordsborg, R.B., Lillelund, K.G., Jakobsen, J., Tjønneland, A., Overvad, K., Raaschou-Nielsen, O., 2011. Road traffic noise and stroke: a prospective cohort study. European Heart Journal. 32(6), 737-744.

[36] Sunyer, J., 2008. The neurological effects of air pollution in children. European Respiratory Journal 32, 535-537.

[37] Tirabassi, T., Fortezza, F., Bassanino, M., Lavecchia, C., 1998. Carbon monoxide concentrations evaluated by traffic noise data in urban areas. II Nouvo Cimento 21, 149-159.

[38] Tobias, A., Diaz, J., Saez, M., Alberdi, J.C., 2001. Use of Poisson regression and Box–Jenkins models to evaluate the short-term effects of environmental noise levels on daily emergency admissions in Madrid, Spain. European Journal of Epidemiology. 17 (8), 765-771.

[39] Tonne, C., Melly, S., Mittleman, M., Coull, B., Goldberg, R., Schwartz, J., 2007. A case-control analysis of exposure to traffic and acute myocardial infarction. Environmental Health Perspectives. 115 (1), 53-57.

[40] van Kempen, E., Fischer, P., Janssen, N., Houthuijs, D., van Kamp, I., Stansfeld, S., Cassee, F., 2012. Neurobehavioral effects of exposure to traffic-related air pollution and transportation noise in primary schoolchildren. Envioronmental Research. 115, 18-25.

[41] Vlachokostas, C., Achillas, C., Michailidou, V. A., Moussiopoulos, N., 2012. Measuring combined exposure to environmental pressures in urban areas: An air quality and noise pollution assessment approach. Environment International 39, 8-18.

[42] Weber, S., 2009. Spatio-temporal covariation of urban particle number concentration and ambient noise. Atmospheric Environment. 43, 5518-5525.

[43] Weber, S., Litschke, T., 2008. Variation of particle concentrations and environmental noise on the urban neighbourhood scale. Atmospheric Environment 42, 7179-7183.

[44] Weijers, E.P., Khlystov, A.Y., Kos, G.P.A., Erisman, J.W., 2004. Variability of particulate matter concentrations along roads and motorways determined by a moving measurement unit. Atmospheric Environment 38, 2993-3002.

[45] WHO (World Health Organisation), 2000. Air Quality Guidelines. WHO European Series No. 91. second ed. Copenhagen: WHO Regional Office for Europe

[46] WHO (World Health Organization) 2005, Air quality guidelines global update, meeting report. Report on a working group meeting. Bonn, Germany: WHO.

[47] WHO (World Health Organization), 2005. Night noise guidelines for Europe. WHO Regional Office for Europe.

[48] WHO, 2011. Burden of Disease from Environmental Noise. Available: http://docs.wind-watch.org/WHO-burden-of-disease-from-environmental-noise 2011.pdf (accessed 16.09.2013).

[49] www.statstutor.ac.uk/resources/uploaded/spearmans.pdf, accessed on 10.09.2013.

[50] Zhu, Y., Kuhn, T., Mayo, P., Hinds, W.C., 2006. Comparison of daytime and nighttime concentration profiles and size distributions of ultrafine particles near a major highway. Environmental Science & Technology 40, 2531-2536.