The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/2042-5945.htm

Estimation of combined exposure factor due to the impact of different transport related environmental pollutants air quality and noise level in Delhi city

Ravindra Kumar, Errampalli Madhu and Anil Maan
Transportation Planning Division,
CSIR-Central Road Research Institute (CRRI), New Delhi, India
Sanjeev Sinha
Transportation Engineering Section,
National Institute of Technology Patna, Patna, India, and
Nasim Akhtar
Transportation Planning Division,
CSIR-Central Road Research Institute (CRRI), New Delhi, India

Abstract

Purpose – The purpose of this paper is to estimate combined exposure factor (CEF) due to impact of different transport-related environmental pollutants, air quality and noise level in Delhi city.

Design/methodology/approach – The Estimation of CEF takes into account the potential relative uptake of each pollutant (CO, NO, NO_2, O_3, SO_2, PM10 and $PM_{2.5}$) by the boarding and alighting of commuters at Public Transport facility and using motorcycle. With the help of CRRI mobile air pollution monitoring laboratory and previous CRRI reports.

Findings – Combined exposure to environmental pollutants is determined based on the taking weighting factor of pollutant stressor. Results shows average stressor for CO, NO, NO_2, SO_2, $PM_{2.5}$ and noise were 2.79 mg/m^3, 331.83, 210.25, 16.70, 241.3883 μg/m^3, and 72.5 dB(A), respectively. Similarly for motorcyclist, results shows average stressor for CO, NO, NO_2, SO_2, $PM_{2.5}$ and noise were 5.1 mg/m^3, 483, 398, 19.3, 295 μg/m^3, and 82.7 dB(A), respectively. The results show higher exposure value for motorcyclist.

Originality/value – Knowledge of exposure factor due to air and noise pollutant for bus commuter in sitting and standing and motorcyclist is not known for Delhi city.

Keywords Public health, Sustainable development, Developing country, Exposure factor

Paper type Research paper

The authors would like to thank the Director CRRI and to specially thank the experts who kindly participated in the study and the colleagues, for their contribution to the field measurements campaign. This paper has been published in a conference proceedings publication by WASD in 2015.

World Journal of Science, Technology and Sustainable Development
Vol. 12 No. 4, 2015
pp. 269-280
Emerald Group Publishing Limited
2042-5945
DOI 10.1108/WJSTSD-05-2015-0028

Introduction

Commuters or drivers in traffic streams are exposed to many environmental factors within their local environment while standing and waiting for buses, chemical emissions in form of particles, air pollutants due to traffic, environmental noise due to traffic, etc. These chemical, physical, and biological factors play an important role in people's health, especially in the development and progression of disease. Assessment of exposure of commuters or drivers to environmental factors is an important component and integral part of their health risk assessment. To achieve this fundamental shift towards trans-disciplinary research is required to understand the link of exposure and health sciences. Rapid increase in transport industry growth in developing countries has resulted in environmental pressures in the form of pollution, population, global warming, green house effects, etc. apart from the several other direct or indirect effects of globalisation, industrialisation, modernisation on all living and non-living things.

In this research paper, urban environment in terms of environmental pressures for commuters and drivers during transportation are considered mainly urban transportation environment which is characterised by two environmental pressures: air and noise pollution. Globally, air pollution is considered as one of the most significant urban environmental health stressors, due to its impact on public health which resulted into morbidity (especially respiratory and cardiovascular diseases) even at ambient level, and also leads to premature mortality. Delhi public transportation fleet was subjected to several stringent norm for reduction of smog by Supreme Court order. Similar laws have been enacted in the USA for problems like Los Angeles smog, London smog, etc. which are major episode and swear of devastations of air pollution and its effects on all living and non living things. This shows that road traffic remains the most important source of local air pollution which can cause adverse effects on health and environment.

Similar to air pollution, excessive exposure to noise pollution can reduce the quality of life in forms of headache, dizziness, and fatigue and may also result in hearing loss and/or hearing impairment. Many researchers have reported that noise annoyance produces a variety of negative emotions including anger, disappointment, unhappiness, anxiety and even depression or higher risk of cardiovascular diseases. Also, major sources of noise pollution are road traffic, mainly engine noise, tyres frictional noise, horn or siren noises.

The combination of noise and air pollutions represents a significant environmental hazard to public health. So, here in this research paper, a combined exposure of these stressors with a methodological approach developed to assess combined environmental pollution exposure based on field campaign of South Delhi (Nehru Place) is presented. This study highlights co-exposure to several environmental pollutants in urban areas based on the formulation of two indices the combined exposure factor (CEF) and combined dose and exposure factor (CDEF). Results shows average stressor for CO, NO, NO_2, SO_2, $PM_{2.5}$ and noise were 2.79 mg/m^3, 331.83, 210.25, 16.70, 241.3883 μg/m^3, and 72.5 dB(A), respectively. Similarly for motorcyclists, results shows average stressor for CO, NO, NO_2, SO_2, $PM_{2.5}$ and noise were 5.1 mg/m^3, 483, 398, 19.3, 295 μg/m^3, and 82.7 dB (A), respectively. The results show higher exposure value for motorcyclist.

Literature review

Air pollution is the most significant urban environmental health stressors, even at current ambient levels as it aggravates morbidity and causes several other problems

(Curtis *et al.*, 2006; Hoek *et al.*, 2002; Katsouyanni *et al.*, 2001; Künzli *et al.*, 2000; Pope *et al.*, 2011). Also, regular reports of World Health Organization (WHO) are warning about these above mentioned facts. Similarly, noise pollution and its effects on all living and non-living things have been reported by several researchers (Fields, 1998; Babisch *et al.*, 2005; Michaud *et al.*, 2005). Air and noise limits could be taken as National Ambient Air Quality Standards, India or any other WHO standards (e.g. World Health Organization (WHO), 2000) or any other limit values. Vlachokostas *et al.* (2012) have reported study on measuring combined exposure to environmental pressures in urban areas on an air quality and noise pollution assessment approach for types of activity in Thessaloniki city centre, Greece.

Methodology

In current urban area citizens spend a substantial portion of their time in urban spaces where exposures to pollutants are often highly elevated. Therefore, an urban microenvironment needs to be characterised regarding its environmental quality to understand a combined exposures to commuters (e.g. Lewalle, 1999; Han and Naeher, 2006; Health Effects Institute (HEI), 2010) due to their mobility. This is a challenging task to determine because individuals exposed to are not only restricted to those in motor vehicles but also pedestrians, people standing/waiting around traffic congested streets (e.g. bus stops), people living or working in trafficked roads, etc., are included. In this paper an integrated personal exposure assessment methodological framework is presented. The main goal is urban microenvironments' characterisation and combined exposure assessment. Many studies have been done in past in developed country but in developing country different traffic and surrounding are available that requires different approach for the evaluation of the exposure assessment in terms of combined air and noise pollution on citizens. Environmental and air quality status are important factors to take account as a selection criterion for a potential study site within a wider study area.

Commuters and drivers on roads could experience both static (e.g. waiting in a bus stops, metro station for a considerable period of time) and dynamic exposure during commuting and driving. In this sense, the density of receptors exposed, both dynamically and statically, should also be under consideration. Furthermore, since road traffic is responsible for significant proportions of environmental pollutants in the urban areas, particularly traffic burden is also a critical criterion to be taken into account. All the above criteria are required in order to choose the study site and some typical microenvironments (e.g. roads, street canyons, pavements, squares, pedestrian zones, junctions, etc.) within this area.

Continuous monitoring of exposure is difficult to measure in field. Thus, it is important to select the monitoring periods (hours, days, months) during which sampling measurements but due huge expenses of such monitoring 24-hour sample data were collected during study in peak and off peak hour traffic. Due to limitation of budget, many parameters could not covered environmental pollutants/microenvironments. Especially for the mode of transport, and its selection plays an important role since modal exposure differentiation is highly expected. Meteorological and traffic burden data have been also monitored/sampled during the campaign period. Post processing of the available information leads to microenvironments characterisation and the co-exposure analysis.

Combined exposure of stressors

Vlachokostas *et al.* (2012), reported methodology which is further explained below. Exposure assessment of stressors should be easy-to understand, easily applicable, effective in real field. So that decision makers, transportation planners, or even a common man can apply it to understand the reality of the actual scenario of exposure to pollutants in their environment in a combined manner, rather than viewing specific health stressors separately for urban planning and environmental sustainability. One of a possible combined air quality and noise exposure assessment approach is being considered in the definition of the proposed concept. The CEF is represented algebraically with the following equation:

$$\mathrm{CEF}(T) = \sum_{i=1}^{p} wi\,.\frac{E_s^k(i) - \bar{E}_i^k(i)}{\bar{E}_i^k(i)} \tag{1}$$

$$\bar{E}_{i}^{k}(i) = \int_{k=1}^{K}\int_{t=o}^{T} E(i).dt.dk \tag{2}$$

where CEF(T) for a space in time t, $-1 \leqslant \mathrm{CEF}(T) \leqslant +\infty$; P is the number of environmental health stressors considered in the analysis, $1 \leqslant i \leqslant P; W_i$ the eighting factor for environmental health stressor $i; \overline{E}_i^K(i)$the average exposure of stressor i, for time t and microenvironment $k; EiK(i)$ the limit value of exposure for stressor i and microenvironment k defined for an average exposure duration t; and K the number of microenvironment types, $1 \leqslant k \leqslant K$.

Regarding microenvironment types, it should be emphasised that each transport mode can be considered as a type of microenvironment in which the commuter spends the corresponding amount of time. It should be noted that the numerator of the CEF represents the margin of exposure, which is widely used in exposure and risk assessment of environmental chemicals.

$E_i^K(i)$ could be the legislative or WHO environmental quality standard (e.g. WHO, 2000) or any other exposure level that can be considered as a limit value, associated with an average exposure duration.

On this basis, CEF captures co-exposure to several environmental health stressors, both carcinogenic and non-carcinogenic, with the weighted average of sub-indices that express the relative weight of themeasured exposure concentrations compared to $E_i^K(i)$. However, it should be noted that the choice of $E_s^K(i)$ is also related to average exposure duration t.

On top of the CEF concept, and in order to take into account the potential relative uptake of chemical environmental stressors (e.g. by considering the physical activities of each citizen) the CDEF is also proposed. CDEF, which is principally based on the CEF formulation, emphasises on the relative intake of environmental stressors such as air pollutants, in an attempt to provide a correction to the CEF value by characterising a microenvironment in terms of the potential dose of the exposed citizen and not just the exposure. However,when the relative intake is not appropriate to use, e.g. in physical stressors such as noise, then the CDEF formulation keeps the CEF rationale, since the dose approach cannot be used for all types of environmental health stressors.

CDEF is defined as:

$$\mathrm{CDEF}(T) = \sum_{(j=1)}^{J} W_j \frac{D_s^k(j) - D_t^k(j)}{D_t^k(j)} + \sum_{(r=1)}^{R} W_r \frac{E_s^k(r) - E_t^k(r)}{E_t^k(r)} \tag{3}$$

$$D_t^k(j) = \frac{Q_{air}^k}{Q_{air,min}^k} E_t^k(j)$$

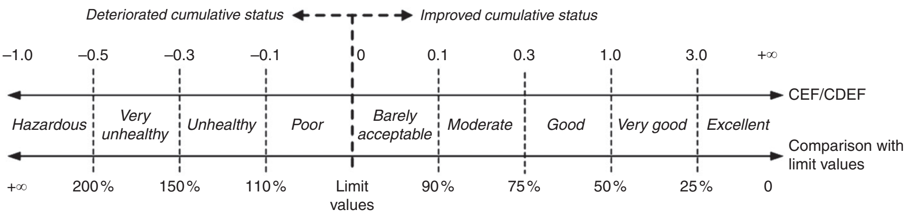
where CDEF(T) for a space in time t, $-1 \leqslant \text{CDEF}(T) \leqslant +\infty$; J is the number of chemical health stressors with estimated intake considered in the analysis (e.g. air pollutants), $1 \leqslant j \leqslant J$; W_j the weighting factor for chemical health stressor j; $D_s^K(j)$ the upper dose equivalent to $E_j^K(j)$ for chemical health stressor j and microenvironment k for an average exposure duration t; $D_t^K(j)$ the average dose that can be attributed to $E_t^K(j)$, based on the estimated relative uptake of pollutant j for time t and the microenvironment k; Q_{air}^K the typical minute air volume (l/min), which is the product of the average respiratory rate (breaths/min) and the volume per breath, in a defined microenvironment k and for a space in time t; $Q_{air,min}^k$ the minimum typical minute air volume in defined microenvironments k and for a space in time t; R the number of physical health stressors considered in the analysis (e.g. noise levels), $1 \leqslant r \leqslant R$; W_r the weighting factor for physical stressor r; $E_s^K(j)$ the average exposure of physical health stressor j for time t and microenvironment k; $E_s^K(r)$ the limit value of exposure for physical health stressor r and microenvironment k defined for an average exposure duration t; and K the number of microenvironment types, $1 \leqslant k \leqslant K$.

Correction to CEF indicator is required, because when chemical health or pollutant stressors are included in the analysis, the fact that microenvironments where the exposed citizen presents more physically exerting behaviour (e.g. fast bicycling) may appear to be as highly impacted as others with less physically exerting behaviour, when the factor of breathing rate is taken into consideration. However, the CEF/CDEF concept aims to depict in an easy-to-use and easy-to communicate manner combined environmental pressures in urban areas. The methodology outlined develops composite indices that capture co-exposure to several environmental health stressors. Figure 1 indicates the relative scale of CEF/CDEF and provides a complete picture of how this concept relates to actual exposure levels and what values correspond to negligibly low, moderate or high cumulative exposure.

Based on the characterisation of cumulative exposure that is depicted in Figure 1 approximate zero values are characterising poor to barely acceptable cumulative exposure (CEF/CDEF = 0 stands for microenvironments where pressures are approximate to limit values in average). Similarly for all other CEF/CDEF values.

Case study application in New Delhi

We selected one of the busiest part New Delhi that is Nehru Place. Nehru Place is a large commercial, financial, and business centre in Delhi, India. Nehru Place is a prominent commercial area in South Delhi and houses the headquarters of several



Source: Vlachokostas (2012)

Figure 1. Representing CDF to CDEF ratio

Indian firms and rivals with other financial centres in the metropolis like Connaught Place, Gurgaon, Bhikaji Cama Place, Rajendra Place and Noida. It is widely considered to be a major information technology hub of South Asia. Nehru Place is accessible by all forms of public transport, as it lies next to the Outer Ring Road, an arc that encompasses major parts of South Delhi, and the bus services are very frequent, usually once every five to eight minutes. Private taxis are also available, as well as a paid parking for cars and motorcycles. The famous Baha'i faith Lotus temple is also located close by. Now Nehru Place is accessible by Delhi Metro. The nearest metro stations include Nehru Place and Kalkaji Mandir.

On this basis, standard routes were selected to assess human co-exposure to both chemical and physical stressors on the bus terminal stop as shown in Figure 2. This is Outer Ring Road designated to represent typical paths selected by commuter and driver. The routes include a variety of roadway types passing mainly through commercial, shopping streets and high-density building/receptor areas. Some of them are canyon type preventing the dispersion of vehicle emissions.

No comprehensive study of co-exposure assessment to air and noise pollution, at least up to the authors' knowledge, has been carried out in South Delhi up to now. The analysis to follow examines air and noise pollution levels at Nehru Place Bus Terminal Stop. The modes of transport selected account for approximately 50 per cent of commuting activity in motorcycle and 7 per cent in buses (Source CRRI Report). The objectives of the survey were to: estimate air and noise pollution levels experienced by individuals at the bus stop and who are travelling on bike in the

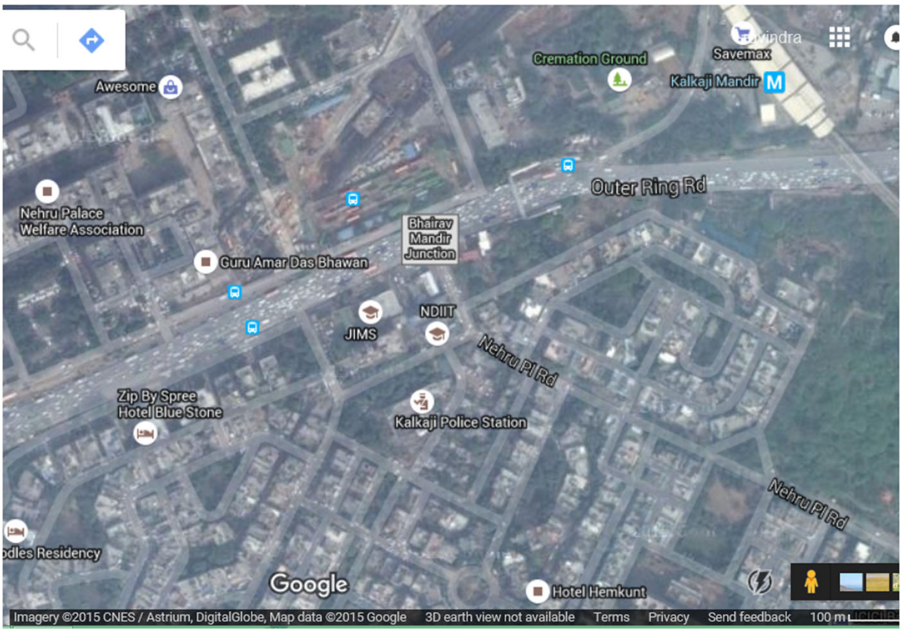


Figure 2.
Case study site in Delhi City

Sources: Imagery@2015CNES/Astrim, Digital Globe Mapdata @Google red marked area in the study area picture; investigate the dependence of exposure levels on the transport mode, route, street and peak hour and off peak hour; and capture the relative weight of the exposure concentrations to the stressors under consideration in different microenvironments and/or transport modes with the CEF/CDEF composite indices.

Data sampling

An extensive survey (with the help of Mobile Air Pollution Monitoring Laboratory of CRRI, CRRI annual reports and previous studies) has been designed in order to provide detailed information on CO, NO, NO_2, SO_2, $PM_{2.5}$ and noise pollution outdoor levels in the main transport modes and along heavy traffic routes in the area under consideration. All guidelines provided by the manufacturer were followed closely to ensure that quality controlled data were collected. Measurements were performed during 8 a.m. to 8 a.m., i.e. for 24 hours. These timings describe the exposure at different stages through the day.

Meteorological data were obtained from a local weather station located in the centre of the area under consideration. Noise pollution measurements were also conducted.

Results and discussion

Data analysis

The underlying mechanisms governing the dispersion of the air and noise pollution differ significantly. However, regardless of meteorological and traffic conditions, a direct comparison of the two pressures was ensured in our case study. Table I shows three level, maximum 15 min, 1 h averages and 24 h average exposure levels for selected modes of transport (Table II).

Estimated CEFs and CDEFs

Based on the methodology presented above, the set of composite indices that capture co-exposure to six environmental stressors are calculated for Nehru Place Bus Terminal Stand and those are moving on motorcycles from A to B marked as a red line in study area picture. Especially for the CDEFs, a set of typical minute air volumes for various routinely performed daily activities is adopted from the analytical work of Adams (1993) and McNabola *et al.* (2007).

For weighting factor calculations different methods were present but our criterion was to have expert's advice. Most of the experts argued that air pollution epidemiological researcher agreed on quantifiable associations to health endpoints,

Mode	Value	CO (mg/m^3)	NO ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	Noise (dB(A))
Sitting and standing (state of rest) at bus stop	15 min max.	3.8	398	280	23	260	74.8
	1 h max.	3.5	352	245	21	235	73.6
	24 h average	2.79	331.83	210.25	16.70	241.38	72.5
Motorcycle	15 min max.	7.2	602	488	27.5	325	85.3
	24 h average	5.1	483	398	19.3	295	82.7

Table I. Maximum 15 min, 1 h averages and 24 h average exposure levels for selected modes of transport which can be further based on a broad consensus regarding strong epidemiological evidence. Many State-of-the-art stated research has found consistent associations between air pollution and various outcomes, but for noise pollution the evidence is not too broad, at least compared to air pollution. In developing country such study are very less. Ten local experts were interviewed and the average weighting factors for the basic scenario were determined as follows; $W_{\text{CO}} = 0.11$, $W_{\text{NO}} = 0.22$, $W_{NO_2} = 0.20$, $W_{SO_2} = 0.25$, $W_{PM_{2.5}} = 0.35$ and $W_{\text{Noise}} = 0.21$. Based on the results of table and taking into account the interpretation of CEF/CDEF provided in Figure 3.

Comparison of result

Vlachokostas *et al.* (2012), measured combined exposure to environmental pressures in urban areas for an air quality and noise pollution assessment approach. Figure 4 is representing CEFs and the corresponding CDEFs for types of activity in Thessaloniki city centre whose exposure factors were developed based on different health stressor as compared to this study.

Though comparison with the reference case study it is not possible as far as in terms of stressors are concerned because in Thessaloniki study. In Thessaloniki study main stressors were considered mainly VOC, CO, benzene, and noise as their physical and chemical health stressors. But in this paper we have compared the values of CEF and CDEF in terms of microenvironments or in terms of modes of transports only motorcycle. The result in Figure 5 shows the standing, and motorcycles have lesser exposure factor as compared to Thessaloniki study. It should

Table II. Typical minute air volumes for various human types of activity

Type of activity	l/min
Sitting (state of rest)	9
Standing	11
Walking (2.5 mph)	24
Bicycling (5 mph)	25
Car driving	11
Motorcycling	11

Sources: Adams (1993), McNabola *et al.* (2007)

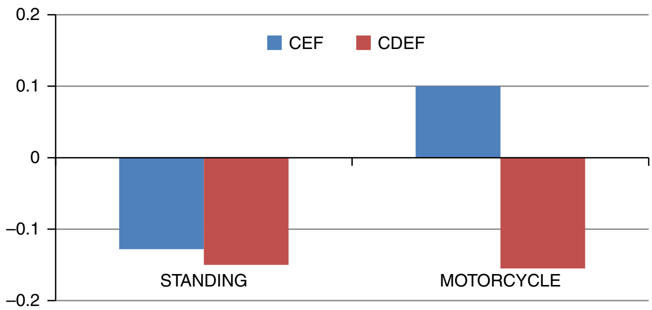
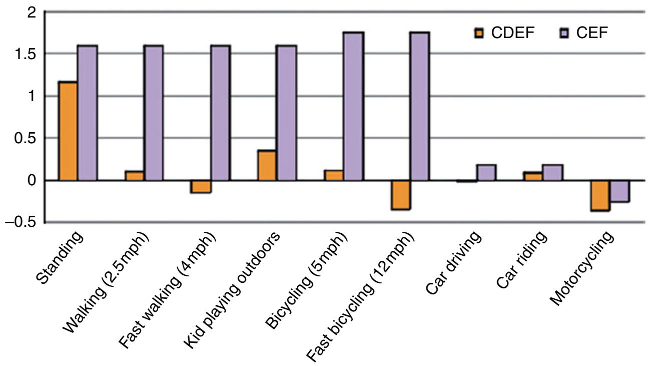


Figure 3. CEFs and the corresponding CDEFs for the standing at bus stop and those are on Motorcycles, Nehru Place, Delhi

be noted that this is just a demonstration research and still many parameters needs to be collected.

Conclusions

A methodological approach is presented in this analysis in order to provide a holistic and easy-to-comprehend combined exposure assessment to several environmental health stressors, both chemical and physical. A co-exposure assessment for air and noise pollution was carried out for the Nehru Place Bus Terminal Stop of South Delhi, in a comprehensive, long-term, exposure study. Commuters experienced air and noise pollution in the heavily trafficked and congested routes of the area under consideration during rush and non-rush hour. It is important to note that the levels found during rush hour periods, at bus stop and along heavy traffic routes, represent the exposure of a significant number of people using these path segments on a daily basis. The importance of measuring combined exposure to several environmental health stressors is highlighted with the definition of co-exposure factors. The CDEF takes into account the potential relative uptake of each pollutant by considering the



Source: Vlachokostas (2012)

Figure 4. CEFs and the corresponding CDEFs for types of activity in Thessaloniki city Centre, Greece

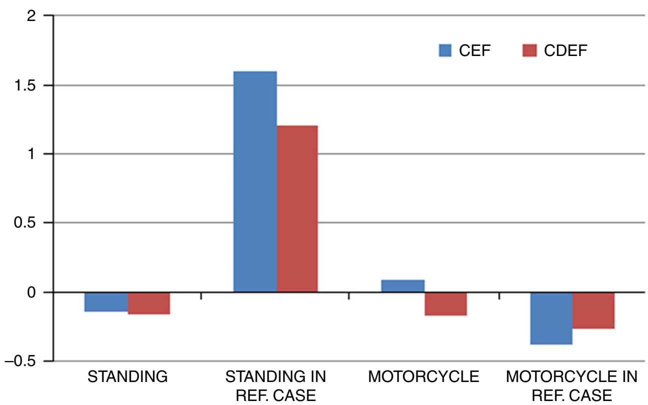


Figure 5. CEFs and the corresponding CDEFs for types of activity in Nehru Place, South Delhi

physical activities of commuters and driver and direct insights approach that is able to capture co-exposure to several environmental, both chemical and physical, health stressors. There is need of considering all environmental pollution in urban areas in a more holistic and synergetic way for better understanding of exposure factor.

References

Adams, W.C. (1993), "Measurement of breathing rate and volume in routinely performed daily activities", final report, prepared for the California Air Resources Board, Human Performance Laboratory, Physical Education, Department, University of California, Davis, CA, April.

Babisch, W., Beule, B., Schust, M., Kersten, N. and Ising, H. (2005), "Traffic noise and risk of myocardial infarction", *Epidemiology*, Vol. 16 No. 1, pp. 33-40.

Curtis, L., Rea, W., Smith-Willis, P., Fenyves, E. and Pan, Y. (2006), "Adverse health effects of outdoor air pollutants", *Environ Int*, Vol. 32 No. 6, pp. 815-830.

Fields, J.M. (1998), "Reactions to environmental noise in an ambient noise context in residential areas", *J AcoustSoc Am*, Vol. 104 No. 4, pp. 2245-2260.

Han, X. and Naeher, P.L. (2006), "A review of traffic-related air pollution exposure assessment studies in the developing world", *Environ Int*, Vol. 32 No. 1, pp. 106-120.

Health Effects Institute (HEI) (2010), "Panel on the health effects of traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects", Special Report No. 17, Health Effects Institute, Boston, MA.

Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P. and van den Brandt, P.A. (2002), "Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study", *Lancet*, Vol. 360 No. 9341, pp. 1203-1209.

Katsouyanni, K., Touloumi, G., Samoli, E., Gryparis, A., Le Tertre, A., Monopolis, Y., Rossi, G., Zmirou, D., Ballester, F., Boumghar, A., Ross Anderson, H., Wojtyniak, B., Paldy, A., Braunstein, R., Pekkanen, J., Schindler, C. and Schwartz, J. (2001), "Confounding and effect modification in the short term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project", *Epidemiology*, Vol. 12 No. 5, pp. 521-531.

Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Horak, F. Jr, Puybonnieux-Texier, V., Quénel, P., Schneider, J., Seethaler, R., Vergnaud, J.C. and Sommer, H. (2000), "Public health impact of outdoor and traffic-related air pollution: a European assessment", *Lancet*, Vol. 356, pp. 795-801.

Lewalle, P. (1999), "Risk assessment terminology: methodological considerations and provisional results", *Terminology Stand Harmonization*, Vol. 11 No. 2, pp. 1-28.

McNabola, A., Broderick, B.M. and Gill, L.W. (2007), "Optimal cycling and walking speed for minimum absorption of traffic emissions in the lungs", *J Environ Sci Health A*, Vol. 42 No. 13, pp. 1999-2007.

Michaud, D.S., Keith, S.E. and McMurchy, D. (2005), "Noise annoyance in Canada", *Noise Health*, Vol. 7 No. 27, pp. 39-47.

Pope, C.A., Brook, R.D., Burnett, R.T. and Dockery, W.D. (2011), "How is cardiovascular disease mortality risk affected by duration and intensity of fine particulate matter exposure? An integration of the epidemiologic evidence", *Air QualAtmos Health*, Vol. 4 No. 11, pp. 5-14.

Vlachokostas, Ch., Achillas, Ch., Michailidou, A.V. and Moussiopoulos, N. (2012), "Measuring combined exposure to environmental pressures in urban areas: an air quality and noise pollution assessment approach, *Environmental International*, Vol. 39, pp. 8-18.

World Health Organisation (WHO) (2000), *Air Quality Guidelines*, WHO.

Further reading

Adams, H.S., Kenny, L.C., Niewenhuijsen, M.J., Colvile, R.N., McMullen, M.A.S. and Khandelwal, P. (2001), "Fine particle (PM2.5) personal exposure levels in transport microenvironments, London, UK", *Sci Total Environ*, Vol. 279 Nos 1-3, pp. 29-44.

Central Road Research Institute (2013), "Report on SUSTARN", Central Road Research Institute, New Delhi.

Crump, K.S. (1994), "Risk of C6H6 induced leukemia: a sensitivity analysis of the pliofilm cohort with additional follow-up and new exposure estimates", *J Toxicol Environ Health*, Vol. 42 No. 2, pp. 219-242.

About the authors

Dr Ravindra Kumar earned his PhD (Engineering) at the Edinburgh Napier University (UK) and a Master's Degree (Engineering) at the University of Roorkee (now the Indian Institute of Technology). He has been working for the premiere Central Road Research Institute India for the last 16 years and is a Principal Scientist in the Transport Planning Department, also experienced as Research Fellow at the Transport Research Institute, Edinburgh. His current research focuses on GIS Application, travel behaviour and its impacts, transportation and road network planning, evaluating and mitigating the environmental impacts, assessment of road transport on urban air quality, with a special focus on rehabilitation and resettlement planning, real-world driving cycle and vehicular emission using advanced instruments and developing emission factors based on onboard, micro simulation and chassis dynamometer. He supervises a number of under-and postgraduate project students, besides research and consultancy research. He is a Life Member of the Indian Road Congress, and a Member of CILT UK. He has completed over 20 sponsored research and consultancy projects, published more than 40 research papers in various journals and presented at national and international conferences. Dr Ravindra Kumar is the corresponding author and can be contacted at: ravindra261274@yahoo.co.in

Dr Errampalli Madhu is a Principal Scientist in Central Road Research Institute (CRRI), New Delhi and has an experience of about 15 years in R&D and Consultancy activities in the field of transport planning, traffic flow modelling and microscopic simulation, intelligent transportation systems, road safety audit, computer application in transport modelling such as fuzzy logic, neural network, etc. He is a recipient of Japanese Government Scholarship (Monbugakusho) 2004-2008 and completed PhD during this period at the Gifu University, Japan. He has received Bronze Medal from IRC two times for the publications in the year 2004 and 2011. He has also received best article award received by the ASRTU in 2009 for his publication in *Indian Journal of Traffic Management* and Session best presentation in SCIS & ISIS 2006, University of Tokyo, Japan. He has published about 80 research papers in various SCI, refereed and conference proceeding.

Anil Maan is a Bachelor of Technology (BTech) from the Delhi Technological University, Delhi in Environmental Engineering and completed his BTech with First Division (2010-2014) and currently working as a Research Intern in CSIR-Central Road Research Institute, Delhi.

Sanjeev Sinha is presently a Professor and a Head of the Department of Civil Engineering at the National Institute of Technology Patna, India. He had obtained his Doctoral Degree from the Asian Institute of Technology, Thailand and his Master's Degree from the Indian Institute of Technology Roorkee, India. He has over 19 years of teaching experience at the bachelor's and master's level in the field of Traffic and Transportation Engineering. He is a Recipient of Khosla

Commendation Award of the IIT Roorkee for the year 2002. He had published over two dozen research papers in various international and national journals and conferences. He had guided about 20 master's dissertation and presently he has three doctoral research scholars and six master's student. He is the State Technical Agency (STA) Coordinator for PMGSY (a central government scheme for construction of rural roads in India) and also the Coordinator for the World Bank project of Technical Education Quality Improvement Program (TEQIP) for the National Institute of Technology Patna. He has been principal investigator for various research and consultancy-related projects.

Dr Nasim Akhtar is a Senior Scientist in the Transportation Planning Division at CSIR-Central Road Research Institute (CRRI), New Delhi in India.