DETERMINATION OF COMBINED EXPOSURE FACTOR OF DIFFERENT TRANSPORT RELATED ENVIRONMENTAL POLLUTANTS BY ASSESSING AIR QUALITY AND NOISE LEVELS: A CASE STUDY OF DELHI

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ABSTRACT

Purpose: The purpose of this paper is to determination of Combined Exposure Factor (CEF) of different transport related environmental pollutants by assessing air quality and noise levels.

Design/methodology/approach: The CEF takes into account the potential relative uptake of each pollutant (CO, NO, NO2, O3, SO2, PM10 and PM2.5) by considering the boarding and alighting of commuters at Public Transport facility.

Findings: Combined exposure to environmental pollutants is determined based on the CEF has been estimated for South Delhi area.

Originality/value: Knowledge of exposure factor due to air and noise pollutant is not known for Delhi city.

Keywords: public health; sustainable development; developing country; exposure factor.

INTRODUCTION

Rapid increase in transport industry growth resulted environmental pressures in 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 due to transportation are considered mainly urban environment which is characterised by two environmental pressures

1. air and
2. noise pollution.

Air pollution has been considered as one of the most significant urban environmental health stressors, because public health is emerging issue that aggravates morbidity (especially respiratory and cardiovascular diseases) even at ambient level, which leads to premature mortality also. Delhi public transportation fleet was subjected several stringent norm for reduction of smog by Supreme Court Order also in US epidemics like Los angles smog, London smog, etc., are major episode and swear of devastations of air pollution and its effects on all living and non-living things. 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 (headache, dizziness and fatigue) and also may result in hearing loss and/or hearing impairment. Many research reported that noise annoyance produces a variety of negative emotions including anger, disappointment, unhappiness, anxiety and even depression or higher risk of cardio-vascular 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 we are presenting 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). This study highlights coexposure 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).

LITREATURE REVIEW

Air pollution is the most significant urban environmental health stressors, even at current ambient levels, aggravates morbidity and several other problems (Adams et al., 2001; Curtis et al., 2006;

Han and Naeher, 2006; HEI, 2010; Hoek et al., 2002; Kaur et al., 2007; 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 has been reported by several researcher (Babisch et al., 2005; Fields, 1998; Michaud et al., 2005; Murphy et al., 2009). Air and Noise limits could be taken as National Ambient Air Quality Standards (NAAQ), India or any other WHO standards (e.g. WHO, 2000) or any other limit values. Vlachokostas et al. (2012) has reported study on measuring combined exposure to environmental pressures in urban areas: 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 due to their mobility (Vellopoulou and Ashmore, 1998). To determine this a challenging task as individuals exposed 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.

A commuter and driver 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.

Continuously 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 hr sample data was 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, its selection plays an important role since modal exposure differentiation is highly expected. Meteorological and traffic burden data has been also monitored/sampled during the campaign period. Post-processing of the available information leads to microenvironments characterisation and the coexposure 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 Equation 1:

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

$$\bar{E}_i^k(i) = \int_{K-1}^{K}\int_{t-0}^{T} E(i)\bullet dt \bullet dk \tag{2}$$

Where:

1. CEF(T) for a space in time t, $-1 \leq \mathrm{CEF}(T) \leq +\infty$.
2. P Number of environmental health stressors considered in the analysis, $1 \leq i \leq P$.
3. W_i Weighting factor for environmental health stressor i.
4. $\bar{E}_i^k(i)$ Average exposure of stressor i, for time t and microenvironment k.
5. $E_s^k(i)$ Limit value of exposure for stressor i and microenvironment k.
6. Defined for an average exposure duration t.
7. K Number of microenvironment types, $1 \leq k \leq K$.

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 (MOE), which is widely used in exposure and risk assessment of environmental chemicals.

$E_s^k(i)$ 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 coexposure 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 $E_s^k(i)$. 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, for example, 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:

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

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

where,

1. CDEF(T) for a space in time t, $-1 \leq$ CDEF(T)$\leq +\infty$.
2. J Number of chemical health stressors with estimated intake considered in the analysis (e.g. air pollutants), $1 \leq j \leq J$.
3. W_j Weighting factor for chemical health stressor j.
4. $D_s^k(j)$ Upper dose equivalent to $E_j^k(j)$ for chemical health stressor j and microenvironment k for an average exposure duration t.
5. $D_t^k(j)$ 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.
6. Q_{air}^k 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.
7. $Q_{ÐÐÐ}^k$ Minimum typical minute air volume in defined microenvironments k and for a space in time t.
8. R Number of physical health stressors considered in the analysis (e.g. noise levels), $1 \leq r \leq R$.
9. W_r Weighting factor for physical stressor r.
10. $E_t^k(j)$ Average exposure of physical health stressor j for time t and microenvironment k.
11. $E_s^k(r)$ Limit value of exposure for physical health stressor r and microenvironment k defined for an average exposure duration t.
12. K Number of microenvironment types, $1 \leq k \leq K$.

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 coexposure 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 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.

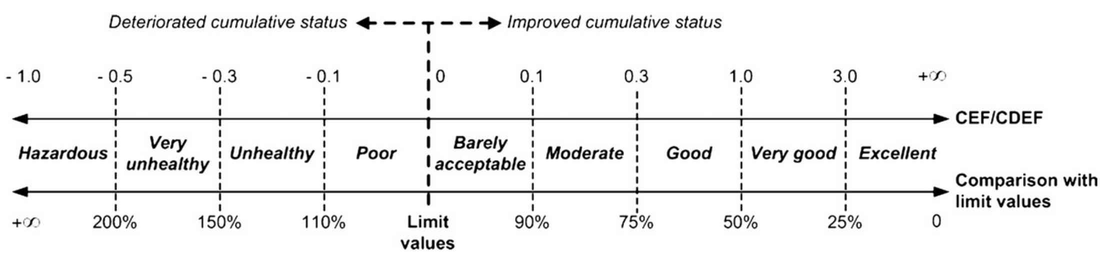

Figure 1 Representing CDF to CDEF ratio

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 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 5 to 8 min. 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 coexposure 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 coexposure 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% of commuting activity in motorcycle and 7% in buses. The objectives of the survey were to:

(i) estimate air and noise pollution levels experienced by individuals at the bus stop and who are travelling on bike in the red marked area in the study area picture;

(ii) investigate the dependence of exposure levels on the transport mode, route, street and peak hour and off peak hour and

(iii) 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 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

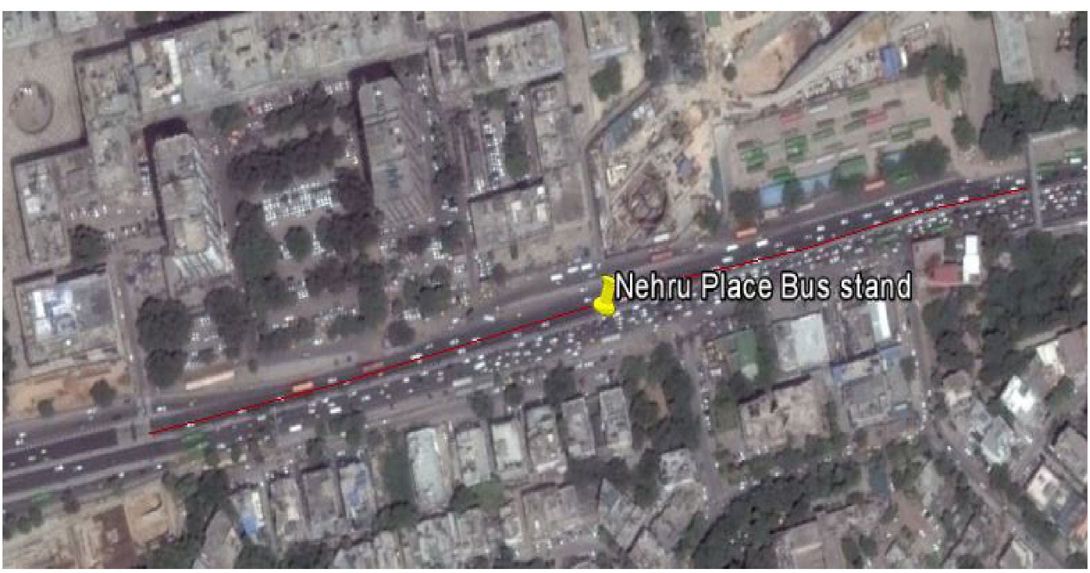

Figure 2 Case study site in Delhi City

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 am to 8 am that is, for 24 hr. 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 1 shows three level, maximum 15 min, 1 hr averages and 24 hr average exposure levels for selected modes of transport.

Table 1 Maximum 15 min, 1 hr averages and 24 hr average exposure levels for selected modes of transport

Mode	*Value*	*CO (mg/m^3)*	*NO (ug/m^3)*	*NO2 (ug/m^3)*	*SO2 (ug/m^3)*	*PM2.5 (ug/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-hr max	3.5	352	245	21	235	73.6
	24-hr 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-hr Average	5.1	483	398	19.3	295	82.7

Table 2 shows typical minute air volumes for various human types of activity (Adams, 1993; McNabola et al., 2007).

Table 2 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

Source: Adams (1993) and McNabola et al. (2007).

Estimated CEFs and CDEFs

Based on the methodology presented above the set of composite indices that capture coexposure 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, 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_{co} = 0.11, W_{NO} = 0.22, W_{NO2} = 0.20, W_{SO2} = 0.25, $W_{PM2.5}$ = 0.35 and W_{Noise} = 0.21. Based on the results of table and taking into account the interpretation of CEF/CDEF provided in Figure 3.

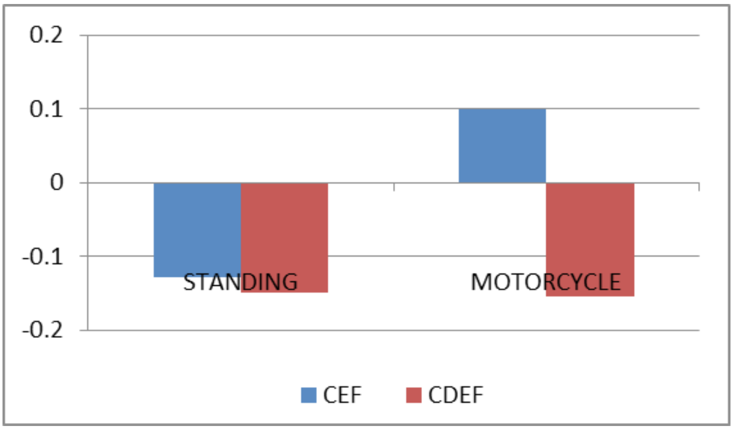

Figure 3 **CEFs and the corresponding CDEFs for the standing at bus stop and those are on Motorcycles, Nehru Place, Delhi**

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. Below 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.

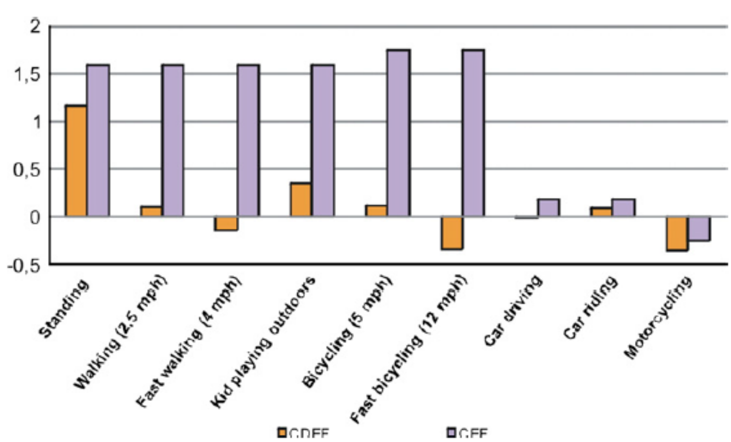

Figure 4 **CEFs and the corresponding CDEFs for types of activity in Thessaloniki city centre, Greece**

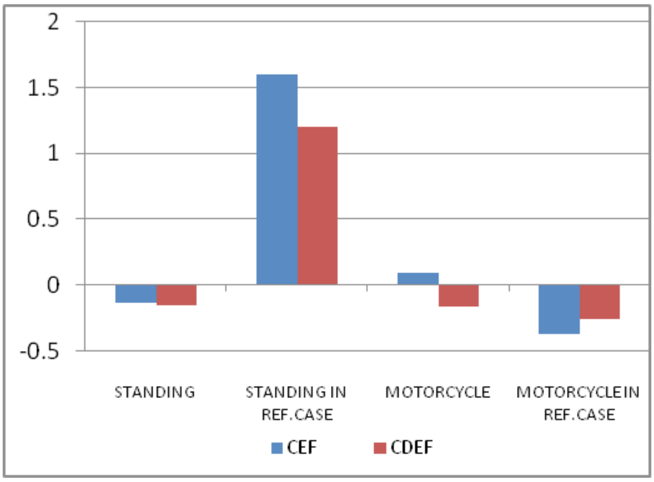

Figure 5 CEFs and the corresponding CDEFs for types of activity in Nehru Place, South Delhi

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 Thessalonki 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 Thessloniki study. It should 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 coexposure 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 coexposure factors. The CDEF takes into account the potential relative uptake of each pollutant by considering the physical activities of commuters and driver and direct insights approach that is able to capture coexposure 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.

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