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Short communication

Assessment of the impacts of vehicular emissions on urban air quality and its management in Indian context: the case of Kolkata (Calcutta)

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Abstract

Air quality crisis in cities is mainly due to vehicular emissions. Transportation systems are increasing everywhere and the improvements in technology are insufficient to counteract growth. This paper examines the effect of vehicular emission on urban air quality and human health, and focuses on the unique features of an Indian mega city regarding its air pollution. A fact-finding survey was conducted to evaluate the status of air pollution at traffic intersections and the problem arising out of vehicular emissions in the study area. All the key pollutants are in excess of permitted levels. The severe detrimental effects of this pollution are reviewed. The problems have reached threatening dimensions. Vulnerable analysis (VA) has been carried out to evaluate the air pollution stress at different locations within the study area. Options for controlling mobile sources emissions are discussed and a strategic motor vehicle control strategy has been proposed to mitigate the air pollution in the city. Replacement of old vehicles, reformulating diesel fuel, introduction of liquid petroleum gas (LPG) and compressed natural gas (CNG), massive improvements in infrastructure and radical traffic management measures are among the actions that will need to be brought together to achieve this objective.

Keywords: Metamorphosis; In-migrants; Health effects; Malnutrition; Vehicular emission; Vulnerability index

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1. Introduction

The population of megalopolis cities, motor vehicles, motor fuel consumption, and air pollution all have increased (Walsh, 1993, Chapter 1). World motor vehicle population growth reached 700 million in the year 2000. The air quality crisis in cities is often attributers in large measure (40–80%) to vehicular emissions. Urban India depicts a picture of metamorphosis. Most cities are growing rapidly. Moreover, urban populations are growing at a faster rate than the national average (Ghose, 2002). The feudal towns have changed to industrial cities, cities into metropolis and metros into megalopolis. Existing cities are expanding, new cities are being created, and adjacent cities are merging. This rapid growth of the urban population also brings with it increasing demands for energy-based goods and services. Owing to the expanding economic base, there is an influx of population migrating from the rural areas and urban fringe to the core city in search of better quality of life. The influx of population to the existing cities stresses the overstretched infrastructure of the urban areas, which is unable to cater to the ever-growing needs of in-migrants. Transportation systems are expanding everywhere. The improved performance of technology is presently insufficient to counteract growth. Projections, therefore, consistently show worsening air quality in the cities of India in future. This congruence has contributed to urban air pollution problem directly related to motor vehicle emissions of CO, O_3, toxics and particulates (Davis, 1998). Because of sources of these emissions the public health implications (Utell et al., 1998; Anon, 1997) are substantial. An improved understanding of the association of the particulates with mortality suggests the importance of sub-micron particles (PM_{10}) to which motor vehicles are major contributors (Anon, 1995). Automobile exhausts and certain industrial pollutants contain NO_2, which by photochemical reaction produces $O_3$and effects allergic asthmatics by augmenting allergic responses (Steinberg et al., 1991). Similarly SO_2, NO, particulate matter and acid aerosols effect pulmonary function and cause inflammation of bronchial mucous (Karen and Michak, 1991; Giuseppe and Francesco, 1993). It has been observed from several studies that air pollution plays an important role in the genesis and augmentation of allergic disorder and it is described as a disease of civilized society (Dennis, 1996; Bonai et al., 1994). To evaluate such

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impacts, a fact-finding survey has been conducted to evaluate the status of urban air pollution at traffic intersections and its vulnerability index (VI) for an Indian megacity. The purpose of this paper is to highlight the severity of these issues and the immensity of the challenge of solving the problems in one of the worst polluted cities in the world Kolkata, the capital of West Bengal State is considered to be one of the most polluted megacities. A “no care” attitude, rapid and unplanned urbanization, continued growth of the metropolis (Mukherjee and Mukherjee, 1998a), uncontrolled vehicular density on insufficient badly cared road space, lack of adequate parking facilities (Kazimuddin and Banerjee, 2000), low turnover of old vehicles with too frequent breakdowns, undisciplined drivers, indifferent pedestrians together with a bad traffic management have taken the problems into threatening stage (Mukherjee et al., 1982). The use of leaded petrol fuel is higher in Kolkata than any other city (Neelman, 1993). Widespread malnutrition, poor hygiene sense and indifferent attitude among the population exacerbate and complicate the impact on human health due to multiple environmental risks (Mukherjee and Mukherjee, 1998b).

The North portion of Kolkata, which is bounded by the River Hooghly and Barrakpore Trunk (B.T.) Road starting from Shyambazar to Rathtala, was selected for the study (Fig. 1). The area is mainly residential surrounded by a cluster of industries. Two thermal power plants, a number of small-scale industries especially gold smelting industries, a burning ghat exist in the area. The area is always overcrowded with loaded trucks, as the Vivekanada Bridge is one of the entry points to Kolkata. In addition, the study area is famous for the existence of a temple at Dakshineswar, which thousands of visitors, pilgrims from India and abroad visit every day.

2. Data collection methods

Air quality monitoring stations were selected at traffic intersections in the area (Fig. 1, Table 1). The sampling was

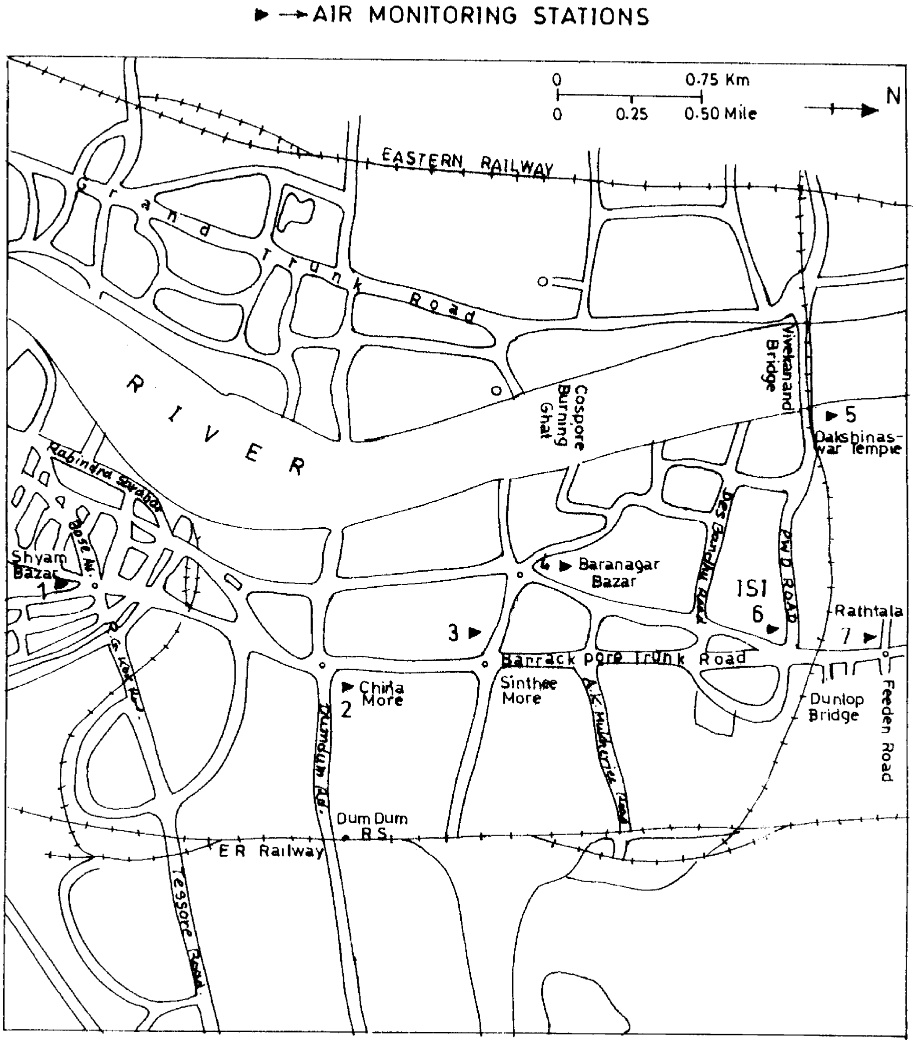

Fig. 1. Locations of air monitoring stations in the study area.

Table 1
Locations of ambient air monitoring stations

Location	Monitoring station number	Position
Shyambazar	TQ1	Intersection of the Circular Road and Bidhan Sarani
Chiriamore	TQ2	Intersection of B.T. Road and Dum Dum Road
Sinthimore	TQ3	Intersection of B.T. Road and K.N. Datta Road
Baranagar Bazar	TQ4	Intersection of G.L.T. Road and Cossipore Road
Dakshineswar Vivekananda Bridge approach	TQ5	Adjacent to Dakshineswar Railway Station
Dunlop Bridge	TQ6	At the intersection of B.T. Road and P.W.D. Road
Rathtala	TQ7	In front of the Kamarhati Municipality office

conducted twice each week (one a holiday and one a working day) during October to December 2002. Air samples were collected from 8:00 to 20:00 h in three 4 h shifts corresponding to morning (8:00–12:00 h), mid-day (12:00–16:00 h) and afternoon (16:00–20:00 h) (Banerjee et al., 1996) Micrometeorological data were collected on the roof top of the Indian Statistical Institute (ISI) main building continuously during the air monitoring period with respect to wind direction, wind velocity, humidity and temperature (Ghose and Majee, 2000a).

The collection of samples of suspended particulate matter (SPM), was by high volume sampler (HVS) and respirable dust particulate matter (PM_{10}) by respirable dust sampler (RDS) (Ghose, 1989; Ghose and Majee, 2000b). Both HVS and RDS were manufactured by Envirotech Ltd., New Delhi. HVS, having impingers (bubbler trains) in series with sodium tetrachloromercurate as absorbing solution, were operated at an average flow rate of 0.5 l/min. for collection of SO_2 (as per IS: 5182, Part II 1969) for 24 h. In the case of collection of NO_x, sodium hydroxide was used as absorbing solution and collected at an average flow rate of 0.5 l/min for 24 h (as per IS: 5182, Part IV 1976). The impinger samples were put in iceboxes immediately after sampling and transferred to a refrigerator prior to analysis (Ghose and Banerjee, 1995). The samples were analysed spectrophotometrically, using West and Gake methods and Jackob and Hocheiser modified methods for analysis of SO_2 and No_x, respectively (APHA, 1977). SPM and RPM were computed after weighing the filter paper (GF/A) before and after sampling. The filter paper was conditioned in a dry atmosphere before weighing (Ghose et al., 1999).

For the determination of CO in air, samples were collected in a glass tube with stopcocks at either end. The air sample was collected by HVS at the rate of 0.2 l/min for 5 min in a vacuum (700 cm^3 of Hg) tube. From the tube a syringe drew an air sample and a known volume of air sample was injected into the injector of a Gas Chromatograph column (for CO Porapack-Q with mithanizer and for HC only Porapack-Q) using a carrier gas. For determination of Pb in SPM four circles of 18 cm^2 were cut from the filter paper on which SPM sample was collected. These were digested in hot 1:1 HNO_3 and the solution was analyzed by atomic absorption spectrophotometer (AAS).

3. Results

The objective of collecting the data was to evaluate status of vehicular emissions and their impacts on air quality in the study area. The mean SPM concentration at the traffic air quality monitoring station ranged between ~739.3 $\mu g/m^3 \pm 20\%$. This concentration exceeds the permissible limit of Central Pollution Control Board (CPCB) (200 $\mu g/m^3$) at all the locations. The shift wise (morning time, noon time and afternoon time) mean SPM concentrations showed a reduction in shift II (12:00–16:00 h) when there was less traffic movement than in the other two shifts (Fig. 2(a)). RPM concentration (Fig. 2(b)) varied from 286.5 $\mu g/m^3$ (at TQ4) to 421.4 $\mu g/m^3$ (at TQ5) and so exceeded the permissible limit of 100 $\mu g/m^3$ everywhere.

No_x concentration (Fig. 2(c)) ranged between 125.9 $\mu g/m^3$ (at TQ4) and 233.7 $\mu g/m^3$ (at TQ5). All values of No_x concentration exceeded the permissible limit of 80 $\mu g/m^3$and the maximum concentration of No_x was recorded at station TQ5 (270 $\mu g/m^3$, shift I). SO_2 concentration (Fig. 2(d)) ranged between 52.2 $\mu g/m^3$ (atTQ4) and 105.9 $\mu g/m^3$ (TQ1) with an overall average of 79.3 $\mu g/m^3$ compared with the permissible limit of 80 $\mu g/m^3$.

CO concentration (Fig. 2(e)), ranged between 3616.4 $\mu g/m^3$ (at TQ4) and 6786.2 $\mu g/m^3$ (at TQ1), which is to be compared with the CPCB limit of 2290 $\mu g/m^3$. The concentration increased from shift I to shift III.

The concentration of Pb (Fig. 2(f)) ranged between 0.302 $\mu g/m^3$ (at TQ4) to 0.708 $\mu g/m^3$ (TQ2), where as the CPCB limit of Pb is 0.5 $\mu g/m^3$. The shift wise variation of Pb concentration was found to be 0.649, 0.569 and 0.584 $\mu g/m^3$, respectively.

During the period of survey, temperature varied from 7 to 30.2 °C with an average of 18.6 °C, average humidity was 73.2%, average wind speed was 2.4 km/h, usually from the NW. No rainfall was observed during the study period but low visibility was observed during some days due to dense fog early in the morning. Some times altostratus clouds were

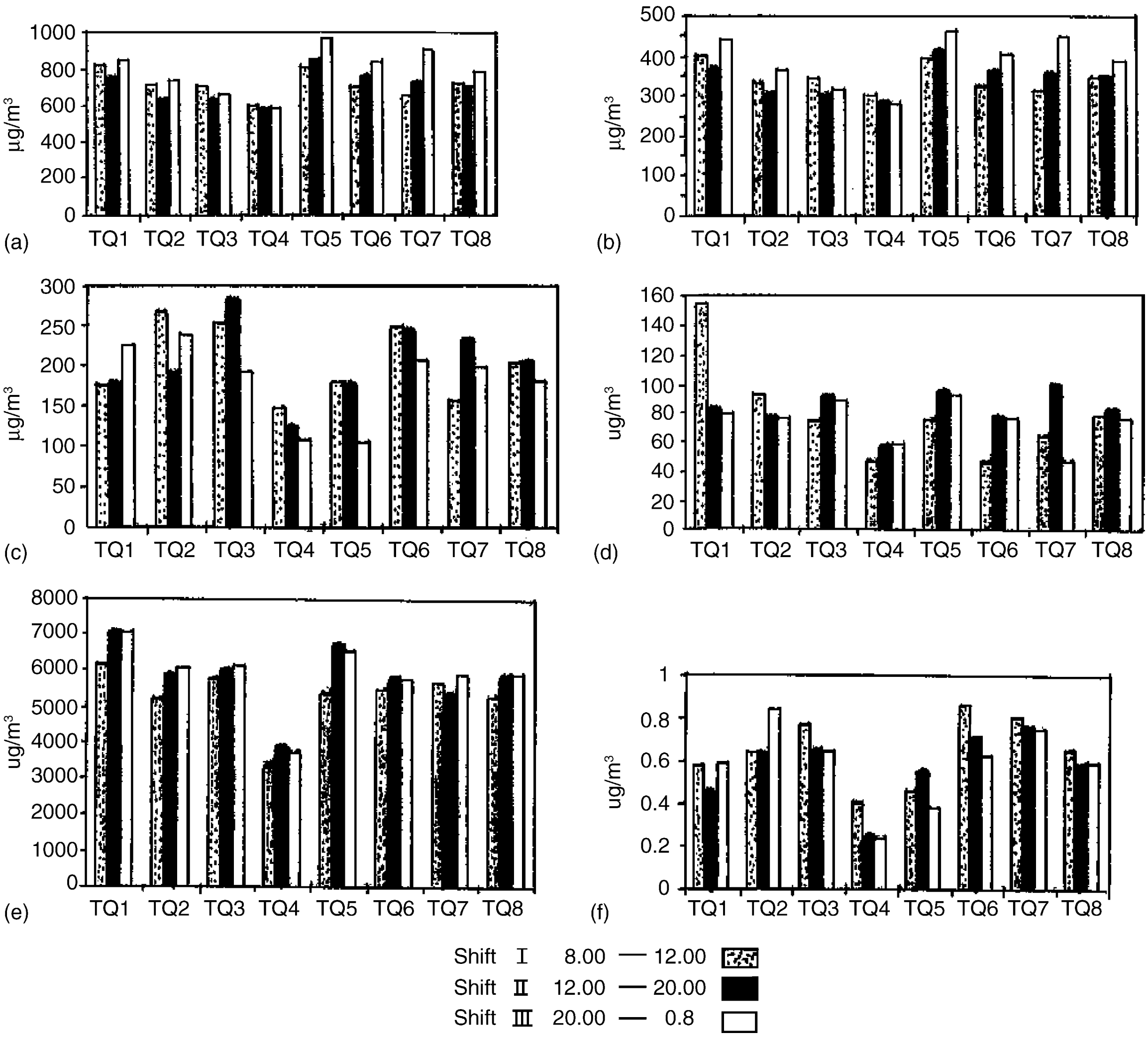

Fig. 2. Shiftwise concentrations of: (a) SPM, (b) RPM, (c) NO_x, (d) SO_2, (e) CO and (f) Pb at traffic intersections.

visible in the sky and substantial reduction of sunshine was observed.

4. Discussion

Pollutant particulate matters, which remain suspended due to buoyancy, are in the sub-micron range, i.e. 10^{-6} m in diameter. An improved understanding of the association of the particulates with morbidity suggests that the importance of sub-micron particles (PM_{10}) to which motor vehicles are major contributors (Anon, 1995). Total exposure to an individual to a specific pollutant is determined by the concentration of contaminant and the duration of its exposure (Spingler and Dockery, 1981). Exposure to indoor and outdoor air quality is different because they always with time and diurnal pattern (TERI, 1995). Certain air-borne dust such as pollen, fungal spores, house dust mite and animal dander (Tilak, 1989) cause allergic reactions in the respiratory system upon inhalation, such as allergic rhinits, topic dermises and asthma (Fernandes, 1995; Arruda et al., 1992). Secondary photolytic reactions in the atmosphere with organic fractions and oxides of nitrogen and sulphur further increases the PAH concentration (Schoential, 1964). These are of marked environmental concern due to air pollution as several of them are either known or suspected carcinogens (Hoffman and Winder, 1968; Andrews et al., 1978).

The status of air pollution data in the city of Kolkata reveals that the pollutants have exceeded the permissible limit stipulated by CPCB. It has been reported that more than 10,000 premature deaths occurred in Kolkata in 1995 due to SPM (Kazimuddin and Banerjee, 2000). The actual health damage caused by dust particles depends upon its nature and composition (Binder et al., 1976). According to the Health Care Institute of India, there is an alarming rise in number of patients in Delhi hospitals with respiratory problems (Indian Express, 1996). The Pb level in the blood was found to be 25.6 µg/dl in Kolkata (compared with 6.0 µg/dl in Tokyo (Misra and Khandekar, 1994). Most of the developed western countries have adopted 25 and 1.5 µg/dl as he safe limits for blood Pb levels in adults and children respectively. (Neelman, 1993). In view of toxicity at all levels, options have been expressed to adopt 10 μg/dl as blood Pb limit for general population (Boeck, 1986). The economic statistics reveal the increasing contribution of urban areas to the gross domestic product (GDP), they had contributed only 29% GDP in 1950–1951, 47% during 1980–1981 and increased to 60% by 2000–2001. Rapid technological advancement represents only the real hope for fulfilling the legitimate aspirations of the peoples of India for a higher standard of living without severe deterioration of the environment (Streets et al., 1999).

Approximately 70% of the total pollution load of the city is contributed by automobile exhaust. Unplanned increases in vehicles especially by two-stroke engine vehicles have brought the ambient air to an alarming level. These petrol driven three wheelers emit large quantities of unburned hydrocarbons beside carbon monoxide and particulate (Ferguson, 1990). The mode of public transport system of Kolkata comprises buses, taxies, auto rickshaws, metro rails, tram and ferry services (motor launches). The mode of main public transport is by bus, especially private bus. Most of these buses are very old. and the exhaust emission level of these buses is much higher than the permissible limit. Approximately 820,000 vehicles play the city streets and 4500 new vehicles are added every month (Anon, 1996). Due to constricted road space (only 6%) and unplanned traffic, normal vehicular movements become restricted, which increases the fuel consumption as well as increasing exhaust emission (Wijetleke and Krunatune, 1995).

5. Vulnerability analysis (VA)

The objective of developing a vulnerability index is to identify zones in which the environment including human population is at some stage of stress due to pollution. The information developed in VA provides the basis to set priorities for planning of abatement measures and asking various polluters to setup a budget for research, pilot studies, critical facilities etc. A total vulnerable score ($\mathrm{VS_T}$) can be obtained from the following expression:

$$\mathrm{VS_T} = \sum_{i=1}^{n} X_i T_i$$

where X_i is the concentration of ith air pollutant, T_i the toxicity weighing factors for ith air pollutant, and n the number of air pollutants.

The toxicity weighing factors in this analysis are from World Bank (1992) as given below:

Pollutant	Relative weight
Lead	85
No_x	4.5
PM_{10}	2.3
SO_2	1.4
CO	0.04
Dust	0.9

The Vulnerability index has been calculated on the basis of VTr of threshold concentrations for residential and sensitive areas

Total vulnerability score ($\mathrm{VS_T}$)	Vulnerability index (VI)
>4420	Very high
4420–3315	Medium high
3315–2210	High
2210–1661	Medium high
1661–1113	Medium
1113–517	Low
<517	Very low

VA was carried out at traffic intersections taking into consideration the mean values of pollutants and the results are given in Table 2. VI is rated high at all locations.

Table 2
Vulnerability analysis at traffic intersections

Station	Vulnerability scores (VS)						$\mathrm{VS_T}$	VI
	SPM	RPM	NO_x	SO_2	CO	Pb		
TQ1	731	919	909	148	172	46	3025	High
TQ2	628	761	1092	115	228	60	2284	High
TQ3	601	732	1184	120	237	59	2897	High
TQ4	529	659	592	76	145	26	2027	High
TQ5	790	969	719	123	248	40	2889	High
TQ6	694	833	1008	92	225	62	3004	High
TQ7	649	852	923	103	224	66	2817	High
Overall	665	818	926	111	225	51	2796	High

6. Options reducing mobile source emissions

Options for reducing air pollution form mobile sources include replacing old vehicles, maintaining vehicles more effectively, using alternative cleaner fuels, reformulating fuels, improving traffic management, expanding mass transit systems and improving the road capacity (Calvert et al., 1993). In Kolkata, the lead concentration exceeded the permissible limit of CPCB Most of the vehicles are diesel driven and SPM concentration was also found to be high. The cost of reformulating diesel oil is high, but it should be high priority to reduce SPM. Liquid petroleum gas (LPG) and compressed natural gas (CNG) should be introduced in a phased manner. Catalytic converters that reduce exhaust emission and emission standards of vehicles should be enforced strictly.

Kolkata grew up so haphazardly that improving the infrastructure is a logistic and economic nightmare. Keeping the main arterial road pothole-free, footpaths and widening the roads wherever possible should be given top priority. The proportion paved road space to the total space in Kolkata has only 6% compared to Delhi—20%, Mumbai—16% whereas ideally it should be 25–30%. Improved practices for managing traffic can reduce congestion significantly. Improvements could include such incentives and disincentives as restricting use of main arteries, encouraging car pooling, providing incentives to use public transport, improving public transit system or establishing new ones, taxing cars entering the city limits, imposing steeper parking fees, and imposing an environmental tax on automobiles. Traffic management and road improvements should be given high priority to reduce the air pollution in Kolkata. The canal network should be developed for transportation, the circular railway should be made much more efficient and regular, and metro railway should be expanded. Health benefits should be included in the analyses for justification for any subsidies.

7. Motor vehicle control strategies

In general, emissions from motor vehicles are minimized if they can operate at a steady-state speed of ∼50 km/h. Improvements in urban infrastructure can, therefore, result in a net decrease in vehicular emissions, all other factors being equal. But infrastructure improvements may even act as an incentive to faster growth in vehicular fleet. So improved traffic flow may offer only a short-term improvement in urban traffic movements and only short-term reduction in emissions. The uncontrolled growth of the vehicle fleet following the improvement to the road system represents the worst outcome, in terms of urban air quality. In order to prevent this from happening, it is also necessary to develop and implement a strategy for the reduction in vehicle emissions.

Elements of a vehicle emission control strategy range from short-term, early action measures to long-term policy and technological research actions. A diverse range of measures is essential to the success of the programme. In the development of vehicle control strategies, a cost/benefit analysis should be undertaken in which the control measures, and effectiveness are all taken into account. This analysis should lead to a further classification of measures as short, mid and long-term and as high, medium and low priorities. At that stage, policy and decision-makers can balance the program goals and the resources. A successful program will incorporate several component measures. Reliance on a single measure will take years to exert a measurable influence on the fleet. Some other measures can achieve more rapid results. There are some widely quoted statistics about the highly skewed distribution of emissions in a vehicle population to the effect that 75% of the emissions are produced by 25% of the vehicles. The logical implication is that a program that would identify those vehicles to meet the average emission rate of the rest of the fleet which would result in an overall reduction of about two thirds. Therefore, there is a great requirement for a vigorous and stringent inspection and maintenance (IM) program to affect this measure. A similar reduction in emissions through the penetration of new vehicles into the fleet would take much longer. The strategy for vehicle emission control will, in all cases, involve a number of different measures. Each must be assessed in terms of feasibility and cost/benefit in each specific application.

8. Conclusion

This study reveals that air pollution at traffic intersections in Kolkata is critical and the problem has reached threatening dimensions. Even with the introduction of advanced emissions control technology, motor vehicles remain the dominant sources of urban air pollution. Addressing this problem requires a better understanding of the source and cause of emissions and an effective means of addressing in-use emissions. The uncontrolled growth of the vehicle fleet following the improvement to the road system represents the worst outcome, in terms of urban air quality. There is a great requirement for a stringent inspection and maintenance (IM) programs in the city. There is no well-defined guideline for the assessment of urban air pollution and no systematic study has been reported for Indian cities. The methodology adopted may be useful in similar situations in India and elsewhere.

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