

Assessment of Particulate Exposure in Different Transport Medium at Two Contrasting Land Uses of Bangalore



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Abstract In the last few decades, India has witnessed a sharp rise in vehicle population in all the major cities of India. Increase in both public and private transport sectors has augmented the air pollutant concentrations beyond permissible limits. Though the number of studies on vehicular pollution has increased in last few years, however, studies on assessment of personal exposure and health risk assessment in different transport mediums are limited. In Indian cities, the general commute time from home to workplace is quite high (approximately 1.5–4 h to and from home to work place). Bangalore is reported to be one among the top ten metropolitan cities in the world which is considered to be the most congested city resulting in increased commute time by several folds during peak hours. The present study provides an insight to personal exposure and health risk assessment while travelling in various transport medium such as a two wheeler (a Bike), three wheeler (an Auto) and a four wheeler (a Bus) in 2 land use patterns, i.e. commercial and industrial area. Exposure monitoring of PM₅ (particulate matter with aerodynamic diameter less than 5 µm) using personal sampler (EnviroTech APM 801) was carried out considering two road maps in commercial and industrial areas for 35 days (2 samples per day during peak and non-peak hours) while travelling in auto, bus and bike. The total sampling time was 1.5–2 h in different days in each medium with the speed of vehicle maintained identical. Studies on human exposure to vehicular pollution were made under different scenarios with respect to windows (either open or close) in bus and side cover (either open or close) in auto during both peak and non-peak hours. Exposure during weekends was also investigated. In addition, chemical characterizations of PM₅ for 15 elements (Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Na, Ni, Pb, Sr and Zn) were carried out using inductively coupled plasma optical electron spectroscopy, and cancer risk was assessed for carcinogenic elements.

Keywords PM₅ · Exposure analysis · Industrial · Commercial · Travel medium

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B. Laishram and A. Tawalare (eds.), *Recent Advancements in Civil Engineering*, Lecture Notes in Civil Engineering 172,

https://doi.org/10.1007/978-981-16-4396-5_36

1 Introduction

The problem of air pollution has assumed serious proportions in some of the major metropolitan cities of India. Recent studies showed an increasing trend in particulate pollution across the country. A total of 37 cities in 2014 from India were recorded in worst 100 cities with elevated PM_{10} contamination [1]. The increased concern of scientific community towards particulate pollution is due to its toxic compositions such as heavy metals, carcinogenic elements, poly aromatic hydrocarbons and black carbon which get emitted from various anthropogenic sources. Among the various sources, vehicular sources were reported to be one among the top contributors to the urban air pollution [2]. In the last few decades, India is witnessing a tremendous increase in vehicular population due to significant improvement in both public and private transport sectors. Further, in urban areas, large no of population are exposed to these elevated particulate concentrations. Short- and long-term exposure to high and low pollutant concentrations can result in various diseases such as asthma, bronchitis, lung- and heart-related disease, allergies and even cancer. The total deaths attributed to air pollution were reported to be more than 1.1 million in India [3]. Alarming increase of particulate pollution in urban areas has resulted in numerous studies based on ambient air quality monitoring at different fixed sites such as traffic intersections and industrial area but studies focusing on personal exposure monitoring due to increased traffic pollution are very limited in India. Past studies have reported metropolitan cities like Delhi, Mumbai, Bangalore, Kolkata, etc. face high congestion throughout the year which increases the exposure period of passengers during every day travel [4, 5]. The increased commute time not only adversely impacts the economy of a country but also had a huge impact on personal exposure of people residing in cities [5, 6]. Studies on assessment of exposure and health risk assessment during travel in different types of transport medium are very important for developing countries as in Indian cities the commute time from the work place to home is quite high and is reported in the range of 1.5–4 h based on the land use and medium of travel. Present study is focused on Bangalore which is the capital of Karnataka. The capital city has seen a vigorous urbanization, industrialization and infrastructural development in a very short time period. Bangalore is one of the biggest IT hubs in India. The industrial and IT job opportunities in the city have attracted people across the country for their livelihood which lead to increase in vehicular population, congestion, unplanned development and expansion of the city, and augmented the pollutant concentrations beyond permissible limits in different regions.

In the present study, an attempt was made to understand the exposure concentration in 3 different travel medium in 2 contrasting land uses. In addition, various scenarios, weekday and weekend variation of exposure were investigated.

2 Methodology

2.1 Study Area Description

Bangalore is one of the metropolitan cities which have become the “silicon valley” of India in a very short span. The rapid multidimensional development of the city has boosted up the growth in various fields such as infrastructure, road network, vehicular population, and small and medium scale industries in and around the city centre. Bangalore metropolitan city spreads over an area of 709 Km². Total population of the area is 84.3 lakh based on 2011 Census report which is expected to have reached up to 1.2 crore in 2020, and the annual vehicular growth rate of the city was reported to be 10.6% [7, 8]. Bangalore has a dry and cold climatic condition during most of the time of the year. The average relative humidity of Bangalore during monitoring campaign was observed in the range of $37 \pm 5\%$, and the temperature was in the range of 22 ± 3 °C. Bangalore has 2 major industrial hubs in the southern and northern outskirts of the city namely Jigani Bommasandra industrial area and Peenya industrial area [8]. In the present study, we have considered the Jigani industrial area which is dominated by various metal industries, granite industries, pharmaceutical, chemical manufacturing and research development units, automobile component manufacturing and repair shops, etc. Figure 1 illustrates road map followed at commercial and industrial areas.

2.2 Instrumentation, Sampling and Analysis

PM₅ exposure sampling using personal sampler (Envirotech APM 801) was carried out at 2 different land uses (commercial and industrial area) in different transport micro environment (auto, bus and bike). Also, personal exposure monitoring during

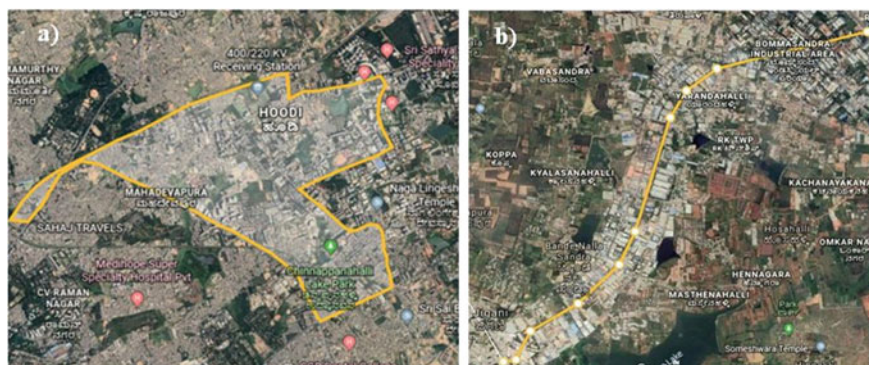


Fig. 1 Road map followed at the **a** commercial and **b** industrial area

different scenarios such as windows (either open or close) in bus and side sheet (either open or close) in auto during both peak and non-peak hours was carried out. Exposure monitoring during weekends was also carried out. A total of 35 samples were collected in auto, bus and bike during peak and non-peak hours with a sampling time of 1.5–2 h during weekdays and weekends. Speeds of vehicles were kept in the range of 10 ± 5 km/hr during peak hours (based on the average speed of bus) and 25 ± 5 km/hr during non-peak hours. PM₅ exposure concentration was quantified by gravimetric principle. Further the filter papers were analysed for 15 elements such as Aluminium (Al), Barium (Ba), Calcium (Ca), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Potassium (K), Magnesium (Mg), Sodium (Na), Nickel (Ni), Lead (Pb), Strontium (Sr) and Zinc (Zn) using ICP OES (Systronics AST 0231) by following the standard operating procedure provided by United States Environment Protection Agency [9].

2.3 Quantification of Cancer Risk

International agency of research has classified carcinogenic elements into various categories based on potency of carcinogenicity. Among the elements analysed in the present study, Cd, Cr and Ni are established carcinogens and are placed under group 1 category. Pb is a possible carcinogen and placed under group 2B category. Excess cancer risks of Cd, Cr, Ni and Pb were quantified based on their concentration and air inhalation unit risks [10].

2.4 Source Identification Through Enrichment Factor

Enrichment factor (EF) method is one of the source identification methods used to estimate crustal and non-crustal origin of elements. It is a qualitative method. In the present study, aluminium is considered as the reference material assuming its contribution solely from earth's crust [11]. The enrichment factors of elements were quantified by the ratio of air concentration of elements and aluminium to the crustal concentration of the element and aluminium. The crustal concentration of the elements and aluminium was obtained from the literatures [11]. The average concentration in both land uses was considered for quantification of EF. Enrichment factor of 1 denotes crustal origin and suggests both crustal and non-crustal origin when EF reaches 5. EF of more than 5 denotes non-crustal origin and if the value reaches 10 it signifies major contribution from human induced sources.

2.5 *Quality Assurance and Control*

Filter paper was desiccated 24 h prior to weighing. Filter blanks were collected during every step of monitoring and analysed following the same procedure of samples. Personal sampler was calibrated before starting the monitoring process by the system engineer of EnviroTech. The concentration values provided here are blank corrected.

3 Results and Discussion

3.1 *Variation of PM₅ Exposure in Auto, Bus and Bike*

The average PM₅ exposure concentration in bus during peak hours (average of morning and evening peaks) with normal condition (window/ side drape open) at the commercial area was 695 $\mu\text{g}/\text{m}^3$ in bus, 1522 $\mu\text{g}/\text{m}^3$ in auto and 1387 $\mu\text{g}/\text{m}^3$ in bike and at industrial area the exposure was 845, 1822 and 1887 $\mu\text{g}/\text{m}^3$ in bus, auto and bike, respectively. The concentration at morning peak hours (8AM–10AM) was found to be higher than the evening peaks (6PM–8PM) which may be due to the opening of schools, colleges, industries and shops at approximately same time in the morning. However, the staggered closing time during evening resulted in reduction in pollutant concentration during evening peak hours. Buses at both the land uses were observed to have least exposure which could be due to higher sitting height. Comparatively lower exposure height of auto and bike than bus might have resulted in higher exposure in both land uses. Higher exposure concentration of autos could be due to its confined structural design which restricts the dispersion of particulates. Also, re-suspension of road dust could contribute to the exposure levels inside the auto due to lower height of exposure. In both the land uses, the exposure concentration in bike was high. Figure 2 represents the morning and evening exposure concentration in bus, auto and bike. At the industrial site, the exposure concentration was observed highest while travelling in autos and at the commercial area bike travel resulted in highest exposure concentration followed by autos. The exposure concentration in all the three travel mediums and land uses was observed several folds higher than the daily average ambient air quality standard of coarse and fine particulate matter (Daily National Ambient air quality standard for PM_{2.5} = 60 $\mu\text{g}/\text{m}^3$ and PM₁₀ = 80 $\mu\text{g}/\text{m}^3$) [12].

3.2 *Exposure Analysis During Different Window Condition*

For buses, PM₅ concentration variation during windows closed condition showed an average weekday reduction of 21% during peak hours. Similarly, for autos, the

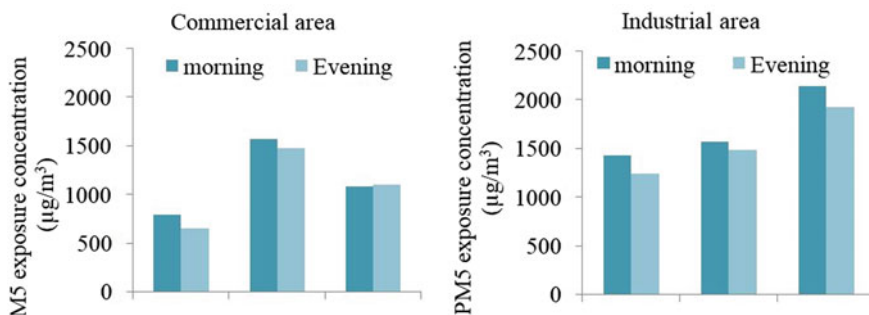


Fig. 2 Average PM5 exposure concentration during morning and evening peak hours at commercial and industrial areas

peak hour reduction with closed side sheets was observed to be 41% (Fig. 3). During non-peak hours, reduction in exposure concentration with respect to peak hours in the buses was 16% during weekdays at the commercial area which could be due to less traffic movement resulting in reduction of vehicular emissions and reduction in upward dispersion of large size road dust particles to the higher sitting height of buses [13–15]. However, in autos, the reduction was comparatively less (9%) probably due to lowering of exposure height of people sitting in autos and results in high exposure of both re-suspension and exhaust particulate emissions. Similar results were also observed at the industrial location with a reduction in exposure concentration by 19% and 12% in buses and autos during non-peak hours of weekdays, respectively, which could be due to significant reduction in frequency of government buses during non-peak hours at the industrial area. During weekend, the vehicular movement and frequency of buses reduce considerably in both commercial and industrial area. Reductions of personal exposure in bike were 44% during weekend compared to weekdays (Fig. 3).

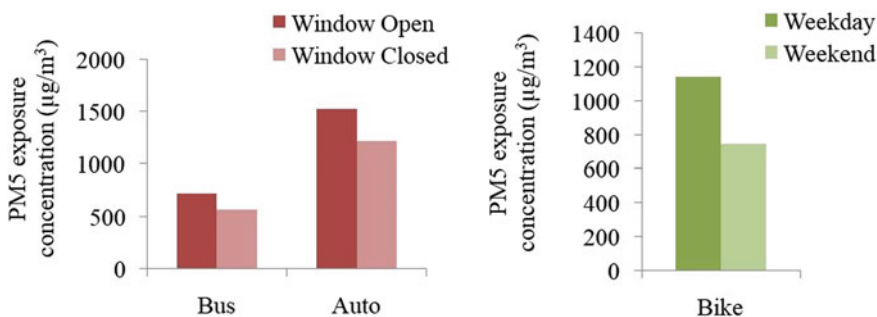


Fig. 3 Variation in exposure concentration in buses and auto during different window operation at commercial area and exposure in bike during weekdays and weekends

3.3 Variation of PM_5 Bound Metal Exposure in Auto, Bus and Bike

Among heavy metals exposure concentration, Ni and Cd exceeded the National Ambient Air Quality Standards (NAAQS). Ni was 1.17, 1.5 and 1.2 times and Cd was 1.24, 2.21 and 2.04 times higher than NAAQS standards (Ni = 20 ng/m³ and Cd = 5 ng/m³) in bus, auto and bike, respectively. The elements analysed in the present study could have both natural anthropogenic origins. Past studies reported elements such as Ca, Al, Sr, Fe and Na could have contributed from re-suspension of road dust, construction activities and natural earth crust [10]. Further abrasion action of vehicle tyre and road surface result in emission of Zn and Ba at the vicinity [10]. Elements such as Cr, Fe and Cd could be contributed from the direct vehicle tail pipe [16]. Similarly, at the industrial area metal industries, granite industries, biomedical and chemical industries could contribute to the pollutant concentration in addition to vehicular emissions. At the industrial area, the roads are encroached by small shops and street vendors which reduce the effective road width for traffic movement there by increasing the stagnation of particulate concentration. Figure 4 illustrates the average PM_5 bound abundant and trace elemental concentrations.

3.4 Cancer Risk Assessment of Heavy Metals

The excess cancer risk was highest for bike in all three travel medium followed by auto and bus. Cancer risk due to heavy metals in different transport environment

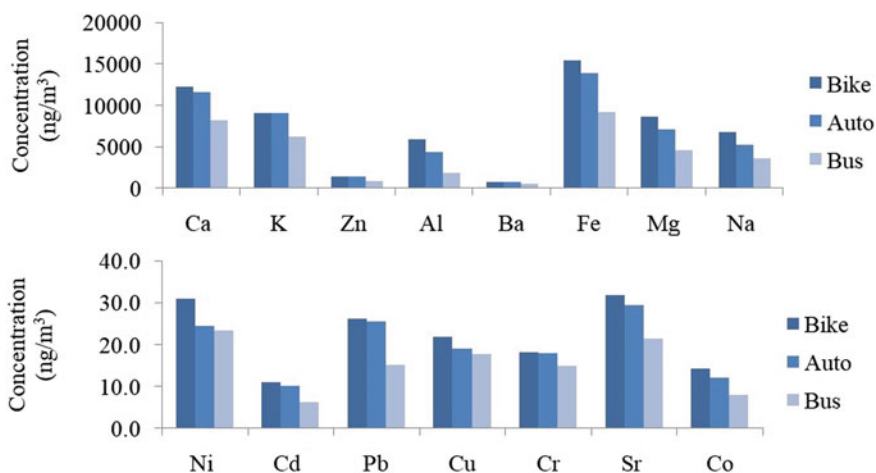


Fig. 4 Abundant and trace metal exposure concentration in Bike, auto and bus (averaged for both commercial and industrial area)

Table 1 Cancer risk due to heavy metals

Pollutant	IUR	Excess cancer risk (10^{-6} population)		
	$(\mu\text{g}/\text{m}^3)^{-1}$	Bike	Auto	Bus
Cd	1.8×10^{-3}	39.6	18.36	11.16
Cr	1.2×10^{-2}	36.2	36	30
Ni	2.4×10^{-4}	7.3	5.88	5.59
Pb	1.2×10^{-5}	0.31	0.30	0.18

was provided in the Table 1. The average exposure metal concentrations at commercial and industrial area were considered for quantification of cancer risk. Total cancer risk with respect to heavy metals in bike, auto and bus was 64, 61 and 47 per million populations.

3.5 Estimation of Enrichment Factor

In the present study, for auto, Sr was having an EF of close to 1 which denotes its natural crustal origin. K, Ca and Na had EF less than 5 suggesting both non-crustal and crustal origin. Ba, Cd, Co, Cr, Cu, Fe, Mg, Ni, Pb and Zn were observed to be highly enriched which suggests the anthropogenic origin of these elements. Similar results were observed for bike and bus. Past studies have also reported similar results as obtained in the present study [10].

4 Conclusions

PM₅ personal exposure assessment in different transport medium such as auto, bus and bike was carried out in two selected roads of industrial and commercial areas of Bangalore city using personal sampler. The study was carried out to understand the exposure in business as usual and varying operational scenarios. Sampling was taken during peak and non-peak hours of weekdays and weekends. In addition, samples during various vehicular operational scenarios corresponding to window and side drupe conditions (open/close) were collected. The exposure monitoring results at the commercial area indicated highest exposure concentration in auto followed by bike and least exposure in bus. Similarly, at the industrial area, the highest exposure was observed in bike followed by auto and bus. Results revealed that closing of windows during peak hours in buses and auto-rickshaw during weekdays can reduce the exposure by 21% and 41%, respectively. At both the commercial and industrial location, morning peak hour showed a higher exposure which could be reduced to a certain extent through a staggered opening pattern of work places. Further, at both the locations, significant reduction in concentration

was observed during weekends due to decreased frequency of government and private vehicles. Particulate bound Ni and Cd concentration at both land uses were observed to be exceeding the NAAQS which demands a detailed source apportionment studies in Bangalore city. Excess cancer risk was estimated to be highest for Cr followed by Cd, Ni and Pb in both land uses and transport mediums.

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