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Climate Change

The status of air pollution attributable to automobile emissions in Mysuru: Implications for urban transport planning

Venkataramana GV[1,2]☼, Azis Kemal Fauzie[1,3], Naveen S[1]

This paper explains the interlinking impacts of population growth, urban land use, automobile transportation, and atmospheric air pollution in Mysuru, a fast growing city in south India. High growth in urbanization and industrialization has affected on tremendous change in land use pattern and increase in motor vehicle use that, in turn, threatens urban air quality and health status. Number of registered vehicles in Mysuru rises gradually at a rate of 20% per year. Highest proportion was found in the number of two-wheelers accounting for 81% of total vehicle population. However, air quality status of the city was found within the national standards, especially for SO_2 and NO_2, while PM sometimes approached the limit. An updated estimation of automobile emission has been prepared according to the recent number of registered vehicles in the district from 2010 to 2015. Mysuru daily contributes about 2 Gg gas and particulate pollutants consisting of 1.98 Gg CO_2, 37.3 Mg CO, 20.6 Mg NO_x, 14.5 Mg HC, and 3.2 Mg PM, or total about 0.08% to the Indian road transport emissions in 2015.

INTRODUCTION

Air pollution consists of various compounds with different physical and chemical properties. Some of the compounds are believed to be harmful to human health as well as to animals and vegetation. They may also have effects on climate, materials, and economical aspects.[1] WHO reported that outdoor and indoor air pollution have contributed to approximately 3 million and 7 million deaths worldwide in 2010 and 2012, respectively.[2,3] Indian metropolitan cities recently are among the most polluted areas in the world, particularly in case of particulate matter (PM). Ambient air pollution has become national problem in India since it is No. 5 most important factor to cause premature deaths and approximately 670 000 deaths in India are attributable to outdoor air pollution annually.[4]

WHO focuses on four criteria air pollutants namely nitrogen dioxide, sulfur dioxide, ozone, and particulate matter, particularly PM_{10} and $PM_{2.5}$ particles.[5] The other pollutants may also have adverse effect though the concentrations are very small. WHO has evaluated 16 organic and 12 inorganic pollutants that may have risks to human health.[6]

The recent growing concern is air pollution due to automobile emissions. Number of registered vehicles in India has gradually increased, i.e. 310 thousand in 1951, 5.4 million in 1981, 72.7 million in 2004, and 141.8 million in 2011.[7,8,9] Recently, the number reached up to 210 million in 2015[10] with an average growth of 10% per annum. The anthropogenic air pollution keeps on increasing due to industrialization and motorized transportation. Therefore, there is a need to provide a continuous monitoring data related to automobile emissions and other factors which may deteriorate air quality.

Study on air pollution has attracted lots of attention to many researchers worldwide, including in India as well. There is huge number of works aimed to estimate air pollution load from road transport sector based on the number of vehicles registered or traveled in the city roadways, but most of them evaluated only the major critical pollutants and very few of them took into account the magnitudes of trace organic and inorganic compounds.

Data regarding number of vehicles registered in 50 big and medium cities in India are easily accessible and widely provided in the Road Transport Year Book,[10] but not for Mysuru city. Hence, we proposed this present study to provide the above missing data and to dedicate the updated information regarding urbanization, industrialization, population booming, and most important, the automobile transportation in the city of Mysuru and their interconnecting impacts on urban land use and atmospheric air quality by estimating the vehicular emission loads of both major conventional and minor organic pollutants.

MATERIALS AND METHODS

The Study Area

Mysuru is one of the important cities in south India. It is a heritage city and well-known as the city of palaces. The location of the city is about 140 km southern part of state capital city, Bengaluru. Geographically, it lies at 76° 46’ E longitude and 12° 8’ N latitude and at elevation of

[1]Department of Studies in Environmental Science, University of Mysore, Manasagangotri, Mysore – 570006, Karnataka, India; [2]School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut, USA; [3]Environmental Department, Government of Karawang Regency, Karawang – 41316, West Java, Indonesia
☼*Corresponding author:* Department of Studies in Environmental Science, University of Mysore, Manasagangotri, Mysore-570006, Karnataka, India. Phone: +91 9449783475. Email: venkataraman@envsci.uni-mysore.ac.in

Table 1 Emission factors of conventional air pollutants and trace organic compounds for different types of vehicles

Vehicle type	Emission factors, g km^{-1}					Emission factors, mg km^{-1}					
	CO	HC	NO_X	CO_2	PM	Benzene	1,3-Butadiene	Formal-dehyde	Acetal-dehyde	Total Aldehyde	Total PAH
2W	2.822	1.877	0.137	27.849	0.033	0.024	0.005	0.019	0.011	0.121	0.558
3W	2.890	1.825	0.393	84.534	0.157	0.068	0.006	0.025	0.031	0.633	0.994
4W	1.601	0.335	0.431	139.383	0.042	0.135	0.038	0.018	0.002	0.077	0.129
Bus	5.830	1.606	9.200	776.462	0.929	0.361	0.014	0.078	0.028	0.763	1.553
LCV	2.023	1.109	1.716	266.204	0.492	0.156	0.094	0.044	0.005	0.079	3.755
HCV	12.650	1.500	11.570	799.945	1.603	0.012	0.012	0.077	0.010	0.111	4.284

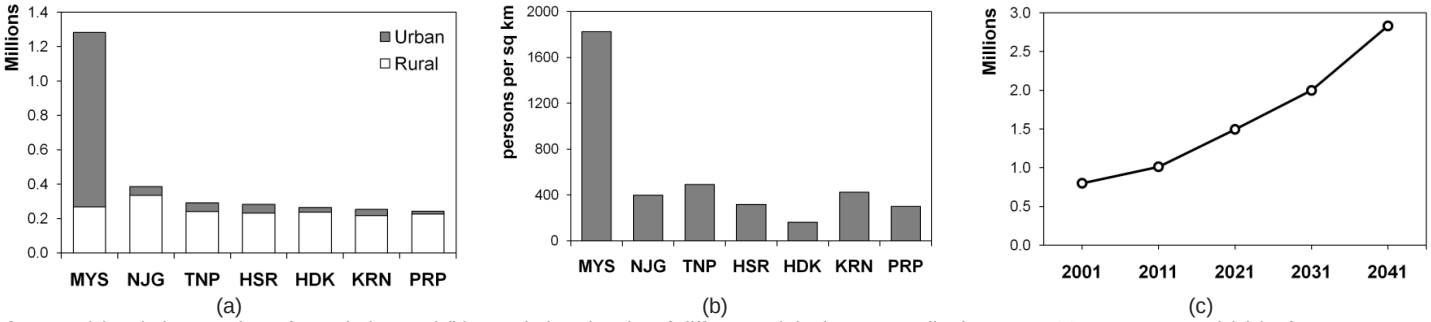


Figure 1 (a) Existing number of population and (b) population density of different taluks in Mysuru district as per 2011 census, and (c) its future projection.

770 m above mean sea level. The district has an area spread over 6307 sq km.[11] Mysuru district administratively incorporates seven taluks namely Mysuru (MYS), Nanjangud (NJG), Tirumakudal Narsipur (TNP), Hunsur (HSR), Heggadadevan Kote (HDK), Krishanaraja Nagara (KRN), and Piriyapatna (PRP). In olden days, Mysuru was regarded as one of the cleanest city in India. Nowadays, due to rapid industrialization and commercialization, the pollution level in the city has increased rapidly.[12]

Estimation of Vehicular Emissions

The daily emission of a compound generated by automobiles was estimated using the following formula.[9,13,14,15]

$$E_i = \sum_{j=1}^{n}\sum_{k=1}^{n}\left(N_{ij} \times d_j \times f_{jk}\right) \qquad (1)$$

where, subscripts i represent the location of study, j is the respective vehicle category, and k is the respective emitted compound.

E_i = emission in location i (g or mg).

N_{ij} = number of registered vehicle category j in location i.

d_j = distance traveled by respective vehicle category j (km).

f_{jk} = emission factor of compound k for vehicle category j (g km^{-1} or mg km^{-1}).

Emission factors of different compounds were determined according to the different types of vehicles (Table 1). In this present study, the factors were taken as average values of emission factors for Indian vehicles measured by considering vehicle types, fuel types, engine cylinder capacity, vehicle weight, vintages, and fuel technology used.[16] Vehicles are divided into six categories namely two-wheelers (2W), three-wheelers (3W), four-wheelers (4W), buses, light commercial vehicles (LCV), and heavy commercial vehicles (HCV).

Apart from emission factors of five major compounds, namely carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_X), total hydrocarbon (HC), and particulate matter (PM), emission factors of other trace organic compounds, like benzene (Bzn), 1,3-butadiene (Btd), formaldehyde (Fmd), acetaldehyde (Acd), total aldehyde (TAd), and total polycyclic aromatic hydrocarbons (PAH), were also measured.[16]

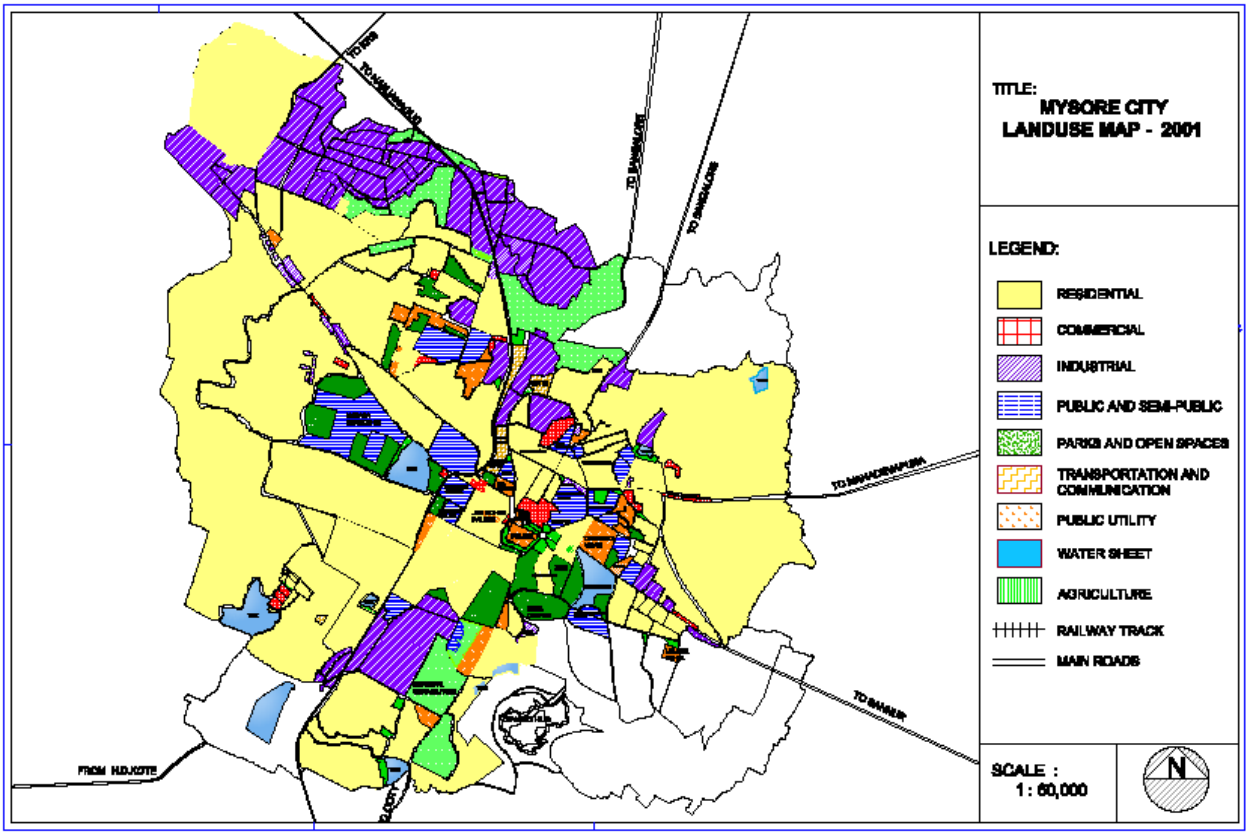
The distance traveled by vehicles per a period of time is usually determined by the annual average of vehicle utilization. While the emission estimate is calculated as per daily period, hence, the vehicle utilization should be converted into daily utilization. The values of 17, 92, 35, 274, 173, and 158 km per day are then used as assumptions to denote the daily distance traveled by the 2W, 3W, 4W, buses, LCV, and HCV, respectively.[9,17,18]

RESULTS AND DISCUSSION

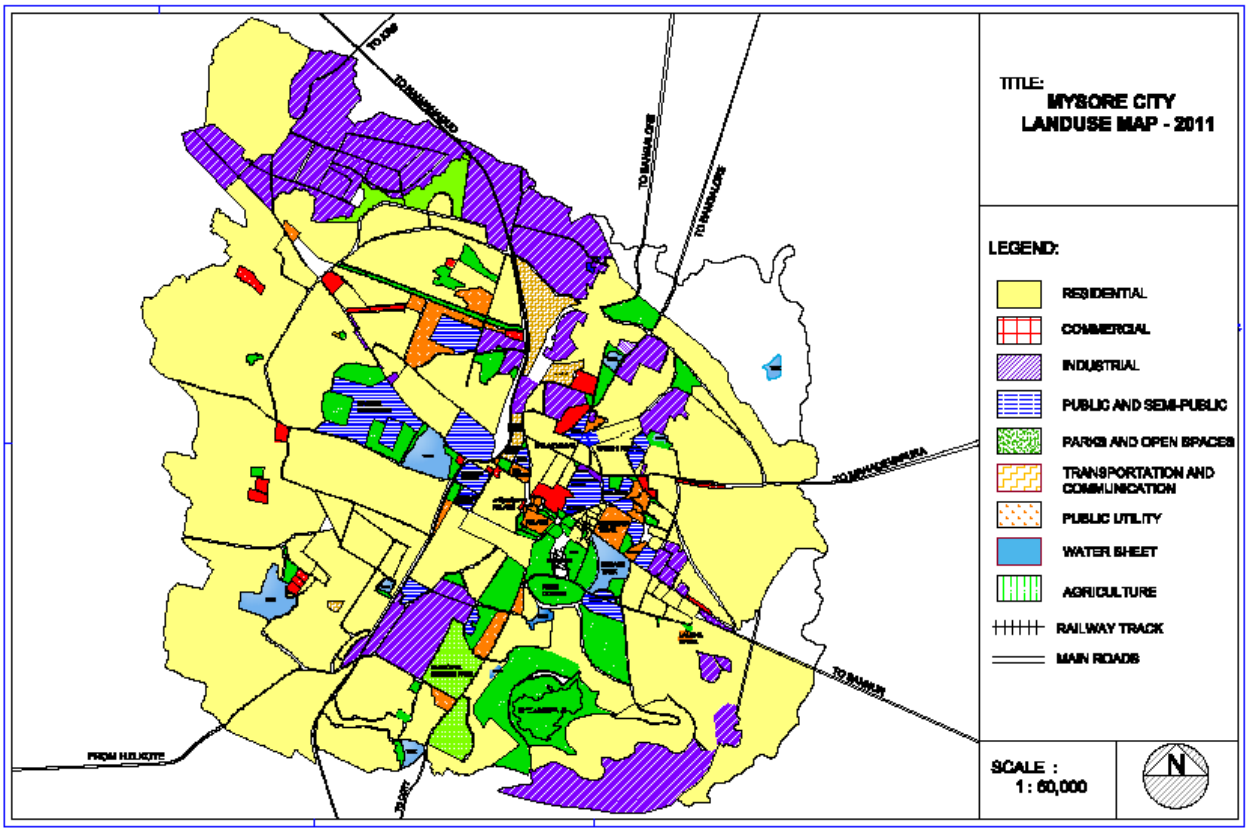
Population Status, Projection and Distribution

The district of Mysuru itself has a total population of 3 001 127 as per 2011 census.[11] Recently, the population distribution is more congested in the city in which almost half of the population lives in the core of the district (Fig. 1a). As the city is being well-connected to other taluks and districts through a branched road and rail networks, it is postulated that population in Mysuru city will grow rapidly due to faster rate urbanization.[12]

Mysuru district holds the second highest population density of 476 persons per sq km in 2011 after Bengaluru city and it is higher than state density accounting for 319 persons per sq km.[11] The population density of Mysuru city itself is accounted for 1823 persons per sq km or almost six times higher than density of the other taluks (Fig. 1b).



(a)



(b)

Figure 2 Land use pattern of Mysuru city in (a) 2001 (b) 2011.[21]

Table 2 Existing and proposed land use for the development of Mysuru.[20]

Land use category	Existing (2011)		Proposed (2031)	
	Area, hectare	% Total area	Area, hectare	% Total area
Residential	7 881	15.5	16 290	32.0
Commercial	511	1.0	826	1.6
Industrial	1 803	3.5	2 473	4.9
Public/semi-public	1 640	3.2	2 114	4.2
Public utility	149	0.3	214	0.4
Open space	771	1.5	2 527	5.0
Traffic and transportation	4 141	8.1	5 598	11.0
Agriculture	32 290	63.4	18 232	35.8
Water body	970	1.9	1 063	2.1
Forest	749	1.5	748	1.5
Special agriculture zone			306	0.6
Film city			256	0.5
Convention centre			257	0.5
Total	50 904	100.0	50 904	100.0

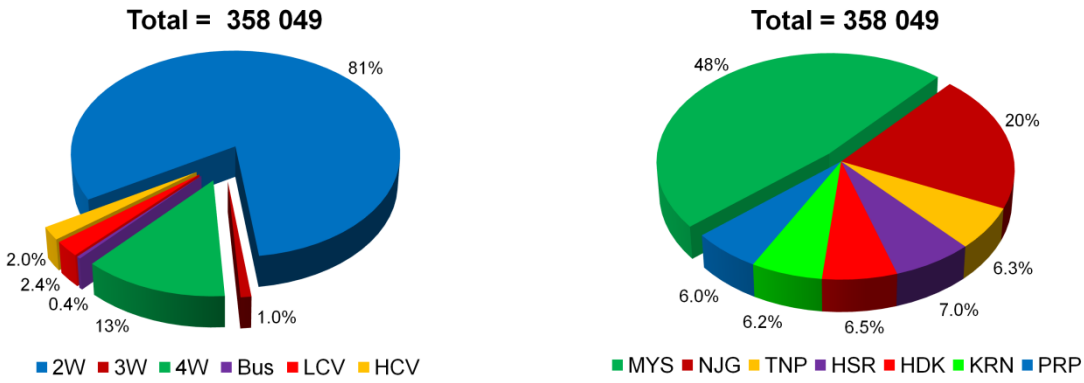
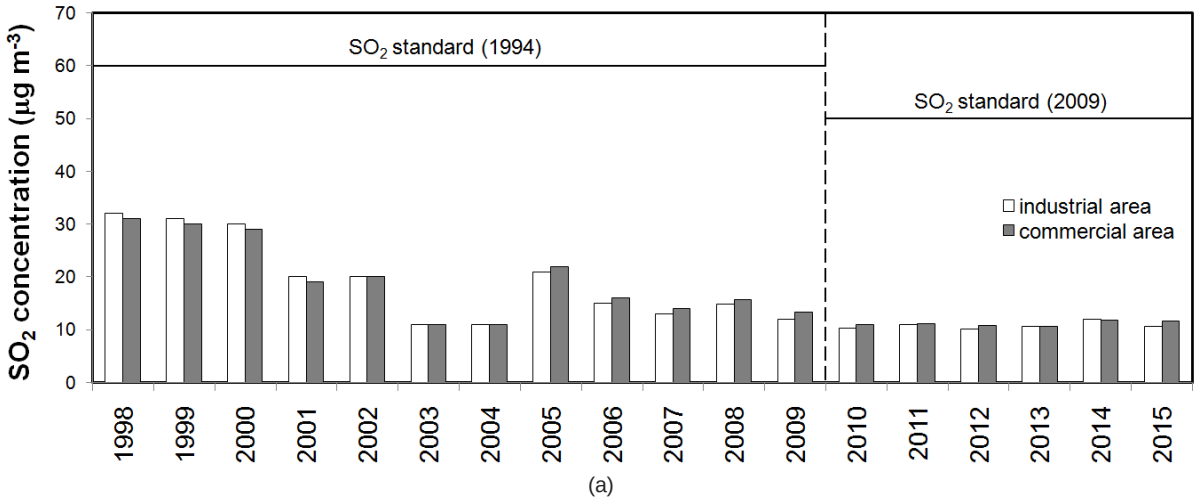


Figure 3 Share of vehicles registered in Mysuru district (a) by different vehicle types (b) at different taluks.



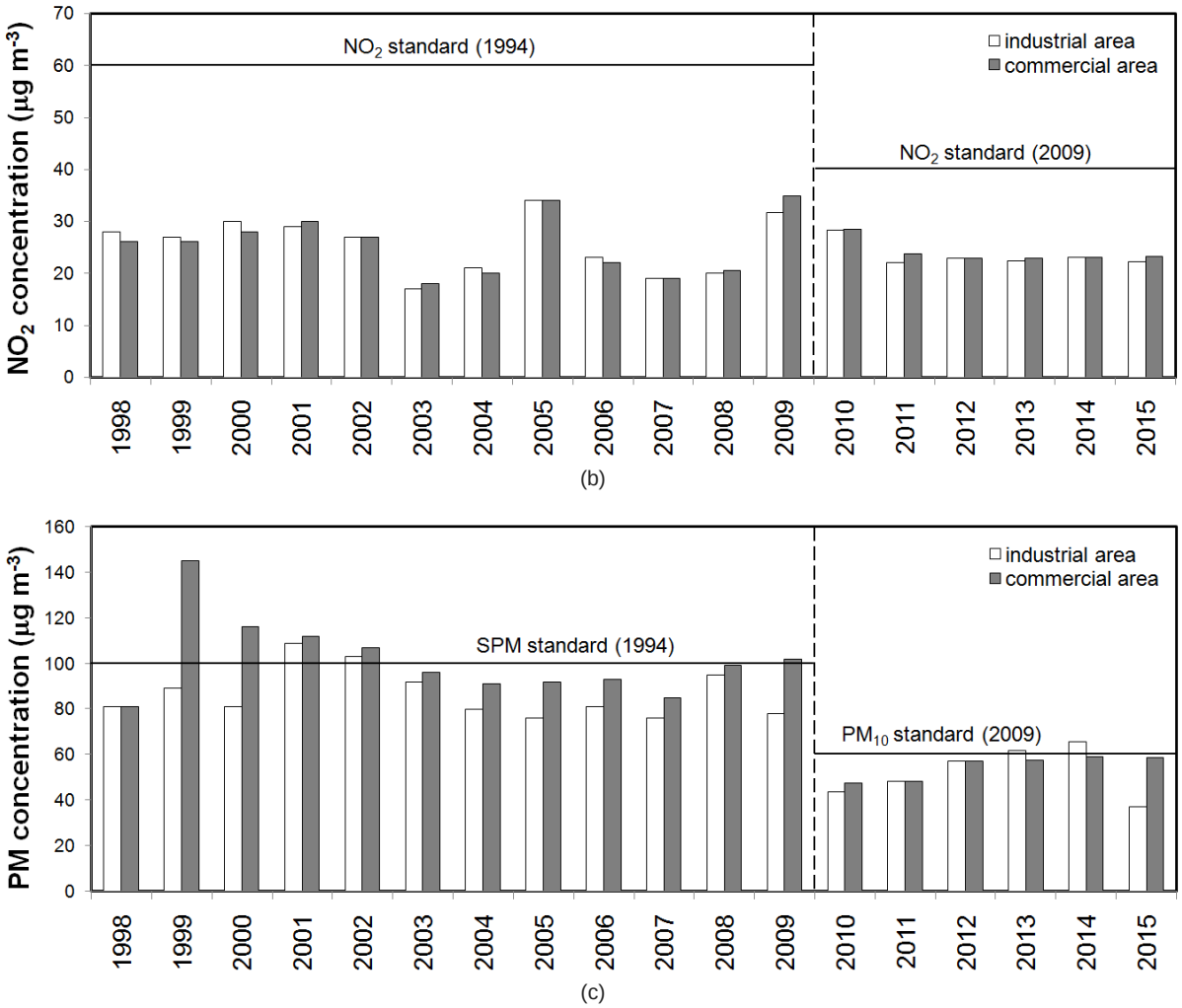


Figure 4 Annual average concentration of (a) SO_2 (b) NO_2 (c) SPM and PM_{10} compared to the National Ambient Air Quality Standards.

Table 3 Daily emissions of different compounds released by different types of vehicles in Mysuru district in the year 2015

Vehicle type	Emissions, kg					Emissions, g						Total Emissions, kg
	CO	HC	NO_X	CO_2	PM	Benzene	1,3-Butadiene	Formal-dehyde	Acetal-dehyde	Total Aldehyde	Total PAH	
2W	14 171	9 425	686	139 874	168	121	27	95	54	609	2 802	164 327
3W	919	581	125	26 894	50	22	2	8	10	201	316	28 569
4W	2 566	538	691	223 436	68	216	61	28	4	123	206	227 299
Bus	2 101	579	3 315	279 784	335	130	5	28	10	275	559	286 114
LCV	2 982	1 635	2 530	392 454	725	229	139	64	8	117	5 537	400 332
HCV	14 534	1 723	13 293	919 100	1 841	14	14	88	11	127	4 922	950 498
Total	37 273	14 480	20 641	1 981 542	3 186	732	247	311	97	1 452	14 343	2 057 139

The projected population is assessed using trend method based on working out the trend of population growth experienced during the past by a statistical analysis.[19] It is assumed that growth rates at the previous (2001) and existing decades (2011) would continue during the upcoming decade (2021) up to the design period (2031). Population in future decade (2041) has also been projected. Figure 1c shows the increasing trend per each decade. The increasing growth of population number supporting by the high population density in the city explains that urbanization is threatening the land use and environmental condition of Mysuru area.

Urban Land Use Change and Planning

The information regarding land use pattern in Mysuru was collected from Mysuru Urban Development Authority (MUDA). Urban city of

Mysuru occupies a total area of 50 904 ha (Table 2). The existing land use pattern of the city shows that the residential area is now occupying 15.5% of the total area. The dominant other uses are the traffic and transportation use. The area of open spaces is now accounting for only 1.5%.[20] Recently, there are newly-developed residential and industrial layouts in the southern part of the city around the Chamundi Hill area (Fig. 2) as formerly being an open space in 2001.[21]

The residential, industrial and commercial areas are expected to occupy 16 290, 2473 and 826 ha, respectively, as per 2031 proposed land use, showing increases from the existing land use. High population growth and uncontrolled urbanization have an effect on reducing the open spaces and agriculture layouts. If city development continues to expand horizontally, it seems that over 14 000 ha of agricultural areas will disappear in the next 20 years.

Some of the villages around Mysuru city will be incorporated under Mysuru Local Planning Area as decentralized satellite townships to foster their growth and to develop them which may help in the decongestion of the city.[19] In the near future Mysuru has been projected to be a city having multi-functional characters of culture, commerce, education, and industry.[12] This highly important status has attracted many people from other cities to come.

The mixing up of urban and suburban vehicles and their increase has had its remarkable effect on the space and speed capacity of the road. The city road network which was basically planned for slow moving vehicles and leisurely way of life has not been able to cope up with the increase in vehicle population. The above factors have tremendously resulted in overcrowding of the roads, traffic jams and delay to road users.

The existing road links in Mysuru city comprise a system of both grid and radial pattern road network which emanate from the city center towards the other urban center in the region. The grid pattern road network consists of arterial, sub-arterial, collector, and other important roads, whereas the radial pattern road network comprises the three layer ring roads namely inner, intermediate, and outer ring road.[19] Therefore, the interstate traffic which has no purpose entering the city can now use the outer ring road and the new dedicated express highway to allow fast movement and to avoid traffic congestions in the city.

Vehicle Traffic, Share and Distribution

The information regarding number of vehicles registered in the district was collected from Road Transport Office of Mysuru from 2010 to 2015. Vehicles registered before 2010 were not counted. It is evident that total number of registered vehicles in Mysuru has increased more than 130% during this five-year period, and this was dominated by the personalized vehicles consisting of two-wheelers and four-wheelers.

Two-wheelers hold the highest share at 81%, followed by four-wheelers at 13% of total vehicle number in the district (Fig. 3a). The growth of other vehicles including the three-wheelers and commercial vehicles remains stable. In contrast, buses showed a decreasing share from 0.6% in 2012 to 0.2% in 2015. The transport mode in India reflects the same preponderant share of two-wheelers at 73.5% of total vehicle population in 2015, followed by four-wheelers at 13.6%, and the similar lowest share of buses at only 1%.[10]

As per taluk wise, share of vehicles was dominated by Mysuru taluk. About 48% of total vehicles were registered in the core of the district (Fig. 3b) due to higher number of population and higher demand on road transport facilities. The domination of personalized vehicles in road-occupant population is still identified in all taluks at 95% of total vehicle number in each taluk, while buses only share maximum 0.5%.

The Mysuru residents are highly dependent on private vehicles, even though Mysuru has already public transport system using intra-city and inter-city buses. Inefficiencies of bus transport system, including less area covered by bus routes, less frequency of bus fleet, and less comfortable travel quality, become reasons for the individuals to prefer use private vehicles. The new mass rapid transit system should be initiated. Therefore, Mysuru authority's planning for the development of a monorail corridor connecting the city railway station to the outer ring road, express highway, airport, industrial area, and other important places in the city is a good option for reducing the dominance of personalized vehicles.[19]

Air Quality Status

As directed by the Central Pollution Control Board (CPCB), currently India is using the revised National Ambient Air Quality Standards (NAAQS) notified since 2009 to replace the former NAAQS 1994.[22,23] CPCB has added new pollutants and has made the values stricter than the previous standards. However, the current revised standards are still higher than the updated WHO air quality guidelines, particularly for PM_{10} and $PM_{2.5}$.[23] This is probably due to CPCB does not consider data from health-related studies when determining the safe limit of air quality standards as WHO and other countries did.

The air quality in Mysuru city has been monitored weekly by the Karnataka State Pollution Control Board of Mysuru in two sampling stations around the industrial and commercial areas. Figure 4 shows that SO_2 and NO_2 concentrations were observed within the permissible limits. Only PM_{10} concentration showed undulating trend and at some particular events closed to or even exceeded the national standard that stands at 60 $\mu g\ m^{-3}$. However, if referred to the updated WHO guidelines that require PM_{10} at 20 $\mu g\ m^{-3}$, the PM status of Mysuru may cross far away from the allowable limit.

Monthly variation of PM concentration showed alternating trend. During summer and monsoon season, it showed significant decrease, but then increased by the post-monsoon and winter season. Our previous field work study obtained important findings that ambient PM concentration was correlated with outdoor temperature, traffic flow and estimated vehicular emissions of PM_{10} and $PM_{2.5}$.[13] Other study confirmed that wind speed had an effect on ambient PM concentration.[24] Therefore, study on air pollution should always take into account the climatic condition and weather monitoring as it may have different figures on various seasons and different correlations with any meteorological variables.

Automobile Emission Status

The inventory of mobile source pollution highly depends on the number of vehicles travel in the roadway environment. It is postulated that the rate of new vehicle registration is higher than the rate of old vehicle annihilation. Therefore, the pollution load attributable to vehicular emissions will remain high in every consecutive year. Table 3 describes the daily compound emissions generated by different types of vehicles in Mysuru district. The calculation is based on the cumulative number of vehicles registered from 2010 to 2015.

The two-wheelers, despite they run only 17 km per day, but because they have high number in traffic and highest HC and TAd emission factors, emit highest quantity of HC, Fmd, and TAd. Another study also indicated that the 2W are the main contributors of CO emissions.[25] Poorly maintained vehicles were also likely to emit more CO. Some models of 2W in India still employ two-stroke (2S) engine design and the population of such type is still high, about 30% of total

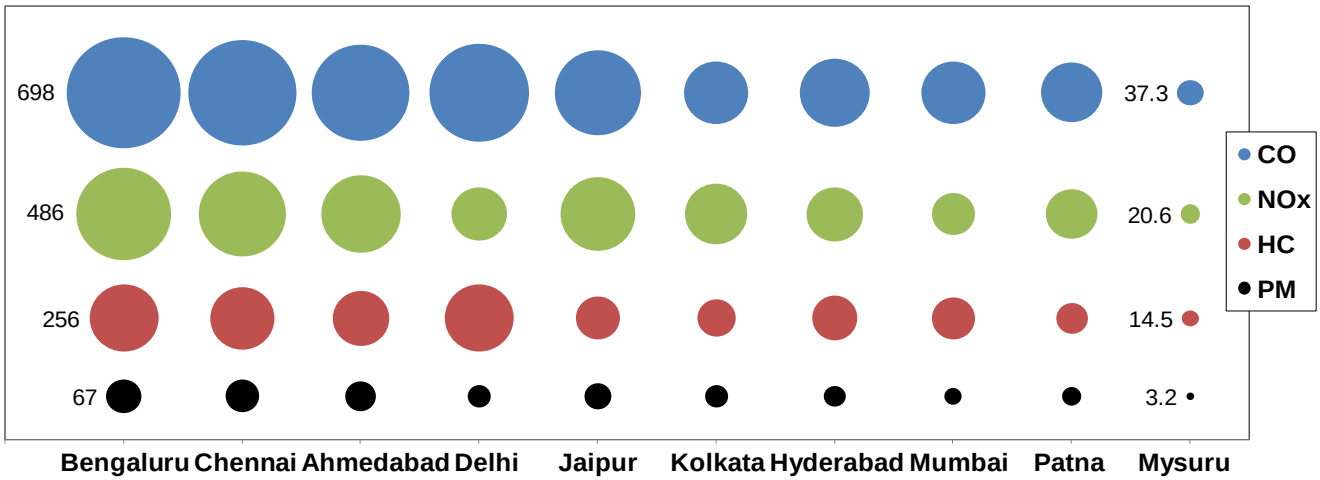


Figure 5 Comparison of road transport pollution load (metric tons per day) of four criteria pollutants in several Indian cities

2W population.[14] The 2S engine allows more partial burning of fuel, thus emits more CO, HC, and PM than the four-stroke one.[26] Therefore, it is recommended for the Government to consider the phasing out of the 2S engine vehicles.[17]

The three-wheelers emit the lowest total quantity of compounds including the lowest in CO, CO_2, NO_X, PM, Btd, and Fmd emissions. Similarly, because of their low emission factors and short travel distance, the four-wheelers emit low quantity of traffic compounds to the atmospheric air, particularly low emissions of HC, PM, Acd, and PAH.

Buses emit relatively high amount of NO_X and TAd, but less amount of HC and Btd. Moreover, buses also emit considerable amount of CO_2 and PM due to they use diesel engine which has high fuel capacity and high fuel consumption. LCV emit significant amount of total air pollutants to the roadway environment, about 400 Mg (equal to 400 metric tons) per day, particularly emit highest quantity of trace organic compounds of Bzn, Btd, and PAH. In addition, their CO_2 and PM emissions are still considerably high.

HCV generated about 40% of CO and CO_2 emissions in the district, whereas emissions of NO_X and PM by HCVs are about 60% each. HCV are regarded as the biggest contributor of total traffic emissions in Mysuru district and among all pollutant composition CO_2 holds the highest portion. This is because diesel-fueled HCV have the largest fuel consumption, thus the largest emissions of automobile fuel combustion processes. Diesel vehicles consume fuel about 300 metric tons per annum, doubled the consumption of gasoline vehicles.[27]

However, PM generates high public concern nowadays, although the proportion is relatively less among other four classical compounds. Unlike gaseous air pollutants, airborne PM, due to its higher mass density, usually resides in ground-level atmosphere near human's breathing zone. Therefore, it can easily penetrate human respiration system and cause adverse respiratory health problem.[3] In addition, it is postulated that toxic compounds may be attached in the airborne particles, including the toxic metals – As, Cd, Pb, Hg, Ni, etc. – and the carcinogenic, genotoxic, and immunotoxic polycyclic aromatic hydrocarbons (PAH),[6] though it was not well-studied. Therefore, the future growing concern is to analyze the safe ambient level of inorganic heavy metals and organic pollutants, including PAH.

The current study explained that emission load of PAH was significantly higher among other airborne organic pollutants. High amount of emitted PAH to the atmosphere has generated serious attention to the environmental authority to continuously monitor the concentration of such pollutant in the ambient air. CPCB India has made a good initiative to include benzene and benzo(a)pyrene (BaP) in its national standards,[22] as BaP is one of the widely-known PAH compounds.[6] It is also recommended to include other organic and inorganic pollutants in the standard list and set for their allowable limits.

PM emissions in the heart of Mysuru city are about half of such in the district. Biggest contributors were HCV which use diesel power. Fuel-wise emission analysis revealed that diesel is the main contributor of NO_X and PM emissions, while gasoline is the main contributor of CO and HC emissions.[25] According to US EPA, diesel vehicles were responsible for 50% of the NO_X and PM emissions.[15] The present study shows that diesel-fueled HCV contribute nearly 60% to the PM emissions in city of Mysuru.

Total gas and particle emissions of automobile transport system in Mysuru district are about 2 Gg per day. This value consists of 1.98 Gg CO_2, 37.3 Mg CO, 20.6 Mg NO_X, 14.5 Mg HC, and 3.2 Mg PM. These compound-wise values are certainly lower than the same measured in other Indian metropolitan cities (Fig. 5). Recently, Bengaluru city holds the highest road transport pollution in India replacing Delhi which was the highest in 2002.[8]

The recent number of registered vehicles in India was obtained from the Road Transport Year Book 2015.[10] It can be estimated that pollution load from road transport sector in all over Karnataka state are measured in the order of 208.56 Gg CO_2, 3.23 Gg CO, 2.56 Gg NO_X, 841.41 Mg HC, and 358.84 Mg PM, or total 216 Gg air pollutants per day, whereas in all over India are measured in the order of 2.64 Tg CO_2, 42.48 Gg CO, 32.23 Gg NO_X, 11.35 Gg HC, and 4.61 Gg PM, or total 2.73 Tg air pollutants per day. By the current findings obtained from this study, it may be stated that Mysuru contributed roughly 0.08% to the Indian road transport emissions and 0.95% to the road transport emissions in Karnataka state.

CONCLUSION

The study shows that the current growth of automobile number and emissions in Mysuru city threatens the ambient air quality, especially the PM status. The outcome of the study confirmed that diesel commercial vehicles are the biggest contributor to the emission of pollutants to the ambient air. The daily utilization of vehicles, emission factors, types of fuel and traffic density are among the contributing factors to affect the quantity of emissions. There is also an ever increasing use of

personalized vehicles among the city residents, such as two-wheelers and four-wheelers. Thus, there is a need to encourage the use of mass transit system and to adopt an effective measure to relieve traffic in towns and in the city.

Despite Mysuru contributes relatively less to the Indian road transport emissions, but due to the analysis did not count data of old vehicles registered before 2010 and due to the faster rate of vehicle ownership among the citizens, it is suggested that in the future Mysuru city will have more number of vehicles circulating the city roads, hence emit more automobile emissions than the pollution load values estimated by this present study. Therefore, an immediate proper planning in the transportation system and reduction of air pollution emission should be taken to avoid the further effects on the health status of the residents and to ensure the environmental sustainability.

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