Status of Pollution Generated from Road Transport in Six Mega Cities

CENTRAL POLLUTION CONTROL BOARD

(Ministry of Environment ,Forest& Climate Change)

website : cpcb.nic.in

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FOREWORD

Country has experienced an unprecedented economic growth in the recent decades. Urban air pollution is a major problem across the country, the emissions from the TRANSPORT sector significantly impacts ambient air quality in cities for the following reasons:

- The number of urban centres in the country has risen sharply over the last two decades ;
- Presently there are 46 cities having million plus population ;
- The vehicular ownership and public road transport in cities are on the sharp increase ;
- The source apportionment conducted by CPCB through various institutions was done in six major cities indicated that the transport sector is one of the predominant source contributing towards $PM_{2.5}$ and NOx concentration.

Estimation of emission loads is essential to ascertain the share of various emitting sources to the total emission load generated in a region as this enable the understanding of various strategies to be adopted in reducing the emission loads. Due to data gap on the above matter CPCB initiated a study 'Status of pollution generated from road transport sector in six cities of the country' , the cities identified were Hyderabad, Kolkata, Ahmedabad, Patna, Lucknow, and Solapur.

For each of the six cities surveyed the report provides (a) emission inventory of vehicular sources along with estimation of total vehicular load vis-à-vis contribution of different categories of vehicles (b) projected emission loads under various future pollution control scenarios and (c) Action Plan for vehicular pollution control along with cost benefit analysis of various control options.

I would like to record appreciation of the work executed by the team at M/s TERI and co-ordination of Ms. Meetu Puri and Ms. Mita Sharma from Head Office at Delhi along with Ms. Anjana Kumari and Shri R.C. Saxena from Zonal Office . It is hoped that this report will serve as a referral study for developing Urban Air Quality Management Plans

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March, 2015

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1. Introduction

1.1 Background

During the last two decades India has seen an unprecedented economic growth. The number of urban centres in the country has risen sharply. There are now 53 million plus cities in the country which accommodates its residents in relatively smaller regions. Higher population densities not only lead to enormous demand for resources but also degradation of environmental quality.

Air pollution generated by human activities has adversely affected the lives of millions of people and caused great economic damage to ecosystems and society. Urban air pollution is a major problem across the country. Rural to urban migration, growth in mobility demands, demands for power and industrial production has led to deterioration of air quality in urban centres. More than 80% of cities in India where air quality is monitored do not meet the standard of air quality prescribed by the Government of India.

Transport sector has always been a significant contributor in emission estimates of cities. The source apportionment studies conducted in the six major cities of the country have shown that transport has significant contributions in $PM_{2.5}$ and NOx concentrations. Moreover, the lower height of release of vehicular emissions leads to higher exposure. WHO has recently classified diesel exhausts as Class-I carcinogens (WHO, 2012)

Estimation of emission loads is an essential step in order to estimate the share of various sources in the total emission load in a region. It also helps in understanding the potential of various strategies in reducing the emission loads in a region. However, there has been a gap in data availability for emission loads in different Indian cities.

In this respect, CPCB has taken up a study to know the 'status of pollution generated from road transport sector' in six cities of the country, namely Hyderabad, Kolkata, Ahmedabad, Patna, Lucknow, and Solapur. The study has been executed by TERI.

1.2 Objectives

The objectives of the study were as follows:-

1. Development of emission inventory of vehicular sources in selected 6 cities (Hyderabad, Kolkata, Ahmedabad, Patna, Lucknow, and Solapur)
2. Estimation of total vehicular load (both tail-pipe and evaporative emissions)
3. Estimation of contribution of different categories of vehicles towards total vehicular emission load and identification of category contributing the most

1.3 Scope of the work

1. Collection of primary data on different type of vehicles (population count) in use/on road, average distance travelled by each type of vehicle, their inspection and maintenance schedule/practice adopted.
2. Collection of secondary data on vehicular emissions through appropriate/authorized agencies.
3. Analysis of primary as well as secondary data using appropriate techniques as being used by internationally reputed agencies viz. USEPA.
4. Estimation of vehicular emission load in terms of CO, VOC, NOx, SOx, $PM_{2.5}$, 1,3 Butadiene, Benzene, Carbonyls, Ammonia and the Greenhouse gases namely CO_2, N_2O, and CH_4.

5. Evaluation of various factors (fuel quality, vehicle technology, driving pattern, topography etc.,) effecting emission load from vehicle and development of correction factors for the realistic estimation of the emission loads.
6. Estimation of emission load from various categories of road vehicles in six cities
7. Identification of the vehicle category contributing maximum towards total emission loads for each parameter.
8. Projection of vehicle emission load under various scenarios (different type of alternate fuel used, optimal I & M, traffic management, introduction of mass transport system, etc.).
9. Preparation of road map/action plan for reducing vehicular pollution in these cities.

1.4 Approach

The study aimed at inventorisation of emissions of different pollutants from vehicular sources. The sources of emissions from transport included tailpipe and evaporative sources. Emission inventory is developed using the following basic approach:-

Emission loads = Activity data x Emission factors

Inventorisation process includes collection of activity data from secondary sources for different sectors, and selection of appropriate emission factors. The overall approach of the study is presented in Figure 1.1.

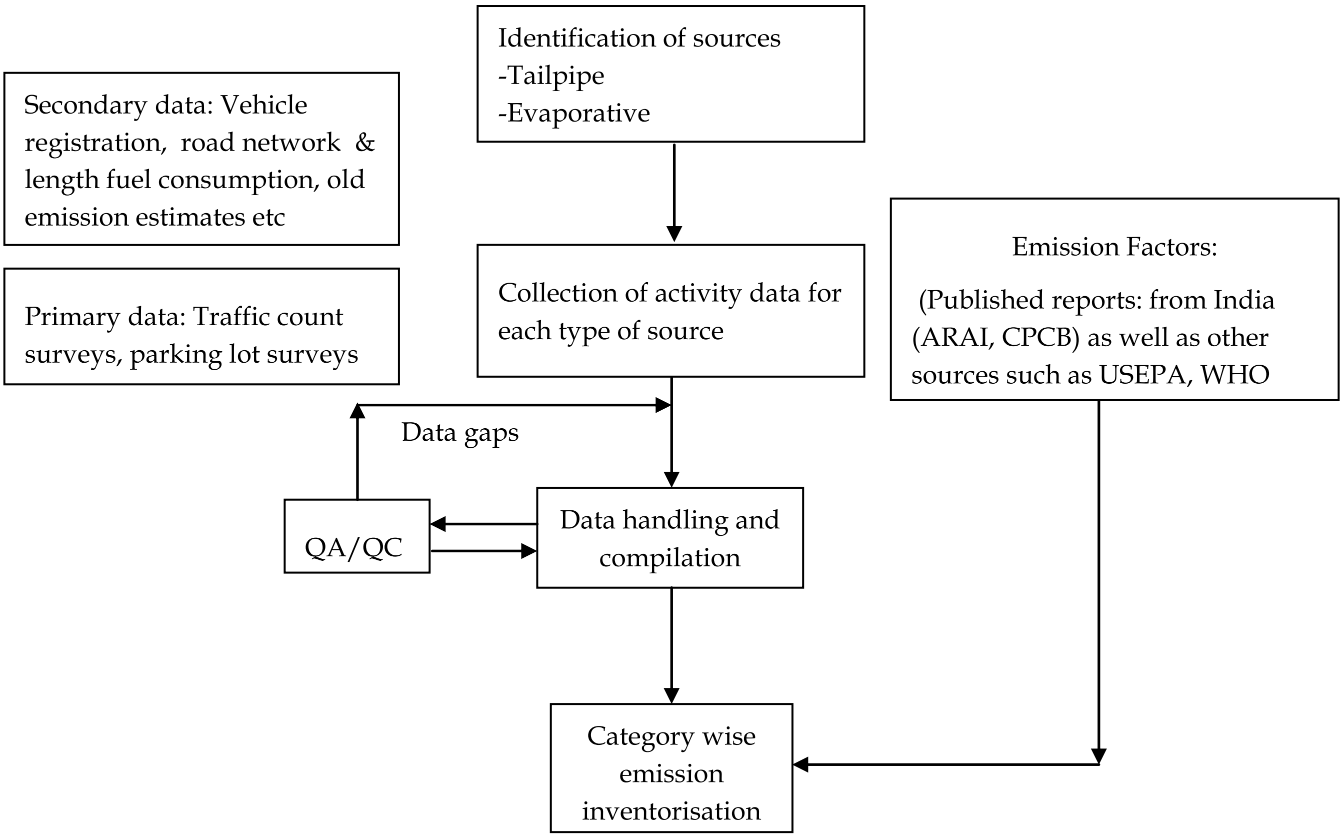


Figure 1.1 Overall approach of emission inventorisation of vehicular sources in different cities

1.5 Project activities and deliverables

1.5.1 Reconnaissance survey

Reconnaissance surveys were carried out in each of the selected cities to study the vehicular movement patterns, road networks, I&M scenario, public transport systems etc. These surveys also helped in identification of sites for conducting traffic counts and parking lot surveys. Major vehicular sources were identified from published literature as well as by discussions with relevant stakeholders such as CPCB and concerned local authorities.

1.5.2 Collection of activity data

Maps of every city were procured, to mark the study domain, from appropriate authorized agency. ***Secondary data*** on registered vehicle numbers, existing emission estimates, road networks and lengths, oil consumption in vehicular sector were also collected from various Government and other reliable sources.

Primary surveys were carried out to supplement the secondary data and fill in the gaps. Traffic count surveys were carried out on different categories of roads existing in the city. Average vehicle counts were estimated on these different categories of the roads. The surveys helped accounting for:-

1. Actual number of vehicles on road in the cities
2. Variation of vehicles on different categories of roads
3. Attrition rates of the vehicles
4. Transit vehicles in the cities

Parking lot surveys were also carried out to understand the existing fleet of vehicles and their distributions. The parameters studied include:

1. Model and make of vehicles
2. Vintage
3. Technology
4. Fuel mix
5. Average daily distance travelled
6. Occupancy
7. Mileage

Surveys were also carried out to estimate the evaporative emissions from fuel pumping stations and fuel tanks.

1.5.3 Selection of emission factors

Extensive literature review was carried out to decide the emission factors for various pollutants (PM, CO, HC, NOx, SO_2, 1,3-butadiene, benzene, carbonyls, NH_3, CO_2, N_2O, and CH_4). As far as possible Indian emission factors (ARAI, CPCB) have been used. However, in absence of the same, emission factors published by USEPA and GAINS-ASIA were used for computing emission loads.

1.5.4 Emission inventorisation

Tailpipe emissions

Emission inventory for the vehicular sources has been prepared for tail pipe emissions using three different approaches in this study, described below.

Approach –I

Approach-I is based on secondary data of registered vehicles collected from RTO and transport departments of different cities. Emissions were estimated for various pollutants using the following approach:

Emissions = Number of registered vehicles x daily VKT x emission factor

However, for application of appropriate emission factors registered vehicles data has to be divided into different sub-categories of make, model, vintage and fuel categories. This information was obtained from parking lot surveys. An example of the divisions made is shown in Figure 1.2.

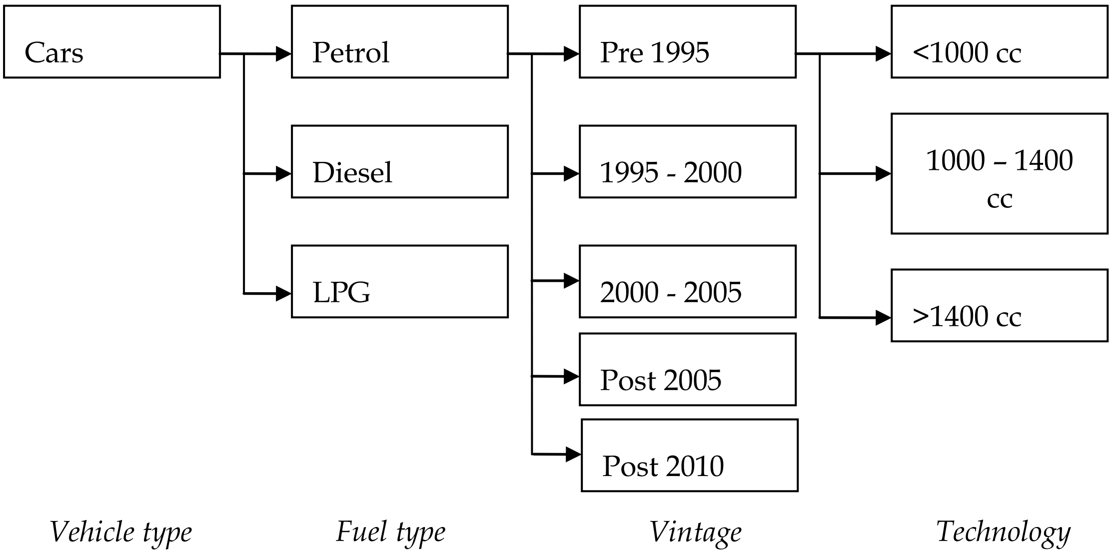


Figure 1.2: Example of the sub-divisions made for inventorisation of pollutants from road transport sector

Approach –II

Approach-II is based on primary traffic count surveys at different categories of roads in the cities. Traffic count surveys take into account the actual on-road vehicles and account for vehicle attrition rates, as well as vehicles transiting from the city in the estimation.

Traffic count surveys were carried out at arterial, sub-arterial/connector and minor/local category roads. Emissions were estimated for various pollutants using the following approach:

Emissions = Traffic count on road x road length x emission factor

However, for application of appropriate emission factors, traffic count data has to be divided into different sub-categories of make, model, vintage and fuel categories. This information was obtained from parking lot surveys. An example of the sub-divisions made is shown in Figure 1.2.

Emission loads from vehicular sector were analysed and vehicle categories having higher share have been identified and reported in this study.

Approach III

Real world driving patterns have been found to be significantly different from the prescribed test cycle procedures. In approach-III the real world driving patterns were fed into the USEPA approved IVE model to estimate emissions for different categories of vehicles. GPS surveys were carried out for different vehicle category to establish their driving patterns in various cities. This involved variation of vehicle speed and altitude to establish the impact of these factors on emissions from the vehicles.

Emissions from evaporative sources

Most evaporative emissions of VOCs emanate from the fuel systems (tanks, injection systems and fuel lines) of petrol vehicles. Evaporative emissions from diesel vehicles are considered to be negligible due to the presence of heavier hydrocarbons and the relatively low vapour pressure of diesel fuel, and can be neglected in calculations.

Evaporative emissions from vehicle during delivery of fuel to service station and during vehicle refuelling

Evaporative emissions from the sector are released during two main processes ; a) during loading of fuel from tankers to the underground fuel tank at the station and b) during fuelling of the vehicles from the petrol station.

Loading losses

Emissions from loading of gasoline from tankers to the underground tanks in the gasoline stations are estimated using the following expression

$$L_L = 12.46\,\frac{SPM}{T}$$

Source : AP 42 (USEPA)

L_L = Loading loss, lb/10^3 gal of liquid loaded

S = Saturation factor

T = Bulk temp of liquid loaded ^oR

P = True vapor pressure of liquid loading

M = Molecular weight of vapors, pound per pound mole

True vapor pressure (P) is calculated using the Reid vapor pressure value and stock temperature of petrol as follows

$$P = \exp\left\{\left[\left(\frac{2{,}799}{T+459.6}\right) - 2.227\right]\mathrm{Log}_{10}(RVP) - \left(\frac{7{,}261}{T+459.6}\right) + 12.82\right\}$$

Source : AP-42, Section 7.1

Where,

P = Stock true vapor pressure, in pounds per square inch (psia) absolute.

T = Stock temperature, in degrees Fahrenheit.

RVP = Reid vapor pressure, in pounds per square inch (psia).

The loading loss in different cities has been estimated using the factor (L_L) derived from above mentioned equations applied to the total fuel consumption data collected from different cities.

Evaporative emissions during vehicle refuelling:

The evaporative emissions are estimated for vehicle refuelling activity using the procedure described in the USEPA AP-42 methodology. Vehicle refuelling emissions are generated when the vapour in the automobile tank are displaced by the dispensed gasoline. Uncontrolled displacement losses from vehicle refuelling for a particular set of conditions were calculated using the equation given below:

$$E_R = 264.2\{(-5.909) - 0.0949(\Delta T) + 0.0884(T_D) + 0.485(RVP)\}$$

Source: AP-42

E_R = Refuelling emissions, mg/L

ΔT = Difference between temperature of fuel in vehicle tank and temperature of dispensed fuel, ^oF

T_D = Temperature of dispensed fuel, ^oF

RVP = Reid vapor pressure, psia

Reid vapor pressure values for the gasoline are adopted from the fuel specification from the MoPNG, 2002. A primary survey was carried out to establish the relationship between the temperature of fuel in the vehicle tank, temperature of the dispensed fuel and corresponding ambient temperature in the six cities. The temperature measurements were carried out using a calibrated digital thermometer. The survey was carried out at different petrol pumps in various cites to account for seasonal and diurnal variations in temperature. The survey dataset was used to establish correlations between temperature of vehicle tank, dispensed fuel, and ambient temperature. The coefficient of correlation was found to be satisfactory (>90%) and the equation obtained through the analysis was further used for the calculation of temperature of the dispensed fuel and temperature of fuel in vehicle tank for different temperatures observed across the year. The monthly variations of temperature in the six cities are adopted from 30 years average datasets of IMD.

Monthly fuel consumption data for all cities was collected from respective oil companies which were used for the estimation of emissions from loading and refuelling losses as shown in the equation below.

Evaporative emissions = Fuel Consumption x (L_L + E_R)

1.5.5 Evaluating the effect of different parameters on emission inventories

The effect of different parameters like fuel quality, vehicle technology, and topography was taken into account while developing emission inventories for road transport sector in the six cities. The sulphur content in the fuel was assessed based on the fuel quality prescribed for different cities in the Auto Fuel Policy (MoPNG, 2002). It was observed that except in Patna, all other cities are supplied with BS-IV quality of fuel i.e. 50 ppm sulphur content in petrol and diesel. However Patna is supplied with BS-III quality fuel with sulphur content in diesel and petrol at 350 and 150 ppm respectively. This would have implications over the SO_2 emissions from the vehicles.

Through the parking lot surveys the technological distribution of different vehicles was adjudged. The driving pattern and topographical changes in the cities were assessed and IVE model was used to develop factors representing the effect of these factors on emission estimates.

1.5.6 Emission projection and scenario analysis

Emission estimates for the vehicular sector for different cities has been projected for next 10 years using existing developmental plans. This took into account the growth in population and vehicles, introduction of emission and fuel quality norms, existing and planned public transport infrastructure etc.

In view of reducing the emissions loads from the transport sector alternate scenarios were also developed. Scenarios consist of different strategies to reduce emissions loads from the sector e.g.

1. Introduction of advanced emission norms BS-V/BS-VI
2. Installation of diesel oxidation catalyst (DOC) and diesel particulate filter (DPF) devices in diesel vehicles
3. Introduction of cleaner fuels
4. Improvement in inspection and maintenance for vehicles
5. Enhancement of public transport system based on compressed natural gas (CNG)

Emission reduction potential of each strategy has been estimated.

1.5.7 Preparation of road map/action plan

A detailed report on emission inventory of the 6 cities has been prepared following the above methodology. Based on the findings, an action plan/road map has also been drafted to reduce the share of transport emissions and hence improve the air quality in different cities. The road map states the actions needed to be performed, the responsible agencies and applicability in different cities.

2. City Characteristics

An accurate emission inventory is an essential step to develop a comprehensive air quality management plan. For accurate and comprehensive inventorisation of the emissions from the transport sector, it is necessary to understand the city characteristics and traffic patterns. Understanding of various city features like landuse patterns, population densities, road networks, and traffic characteristics which helped in deciding the locations suitable for carrying out traffic surveys. This in turn helped in getting more accurate estimation of on-road vehicles, driving patterns, distribution of vehicles on different categories of roads, attrition rates etc. The six cities studied in the present project are shown in Figure 2.1

SOURCE: Google Earth

Figure 2.1: Location of 6 cities in India

The six cities selected for this city are important cities in the country (four being the state capitals) and also among the identified hotspot cities in terms of air pollutant levels. Table 2.1 presents the comparative view of city characteristics.

Table 2.1 Comparative view of city characteristics

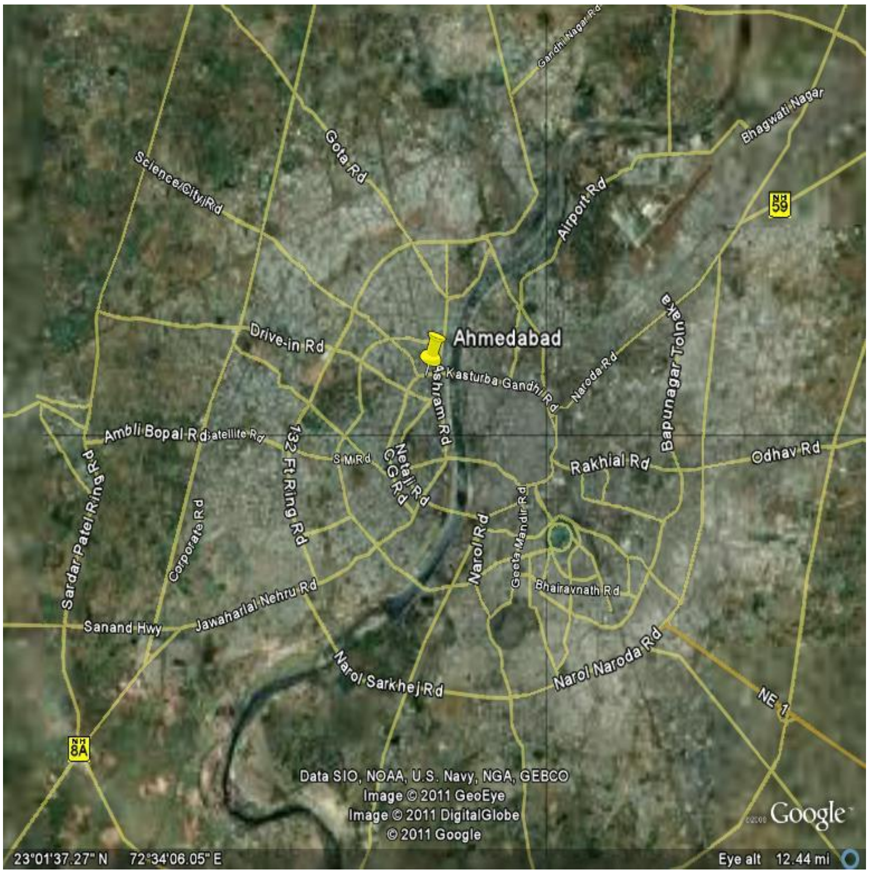
	Ahmedabad	Hyderabad	Kolkata	Lucknow	Patna	Solapur
Area (Sq. Km)						
• MC	190.84	591	615.49	143	99.45	178.57
• UA	350	778	1851	162	146.16	
Population (Million)						
• 2001	4.5	5.7	4.5	2.2	1.4	0.87
• 2011*	5.6 (M.corp.)	6.8 (Greater Hyderabad M.corp.)	4.5 (M.corp.)	2.8 (M.corp.)	1.7 (M.corp.)	0.95 (M.corp.)
Registered vehicles 2011 (000)	2823	3033	445	1211	658	457
% growth (last 5 years)	9%	16%	-8%	11%	9%	7%
City highlights	Commercial capital of the state	Known as second silicon valley in India after Bangalore	3rd most populous city in India and 13th in the world.	Manufacturing, commercial and retailing hub	2nd important business center in eastern India	Large number of small and medium industries
Public transport system	BRTS started	Bus based multi modal transport system (MMTS)	Good PTS based on suburban railways, metro, trams, buses	Insufficient PTS based on taxis, buses etc.	Insufficient PTS based on buses, auto rickshaws local trains	Minimal PTS based on buses

*Source: Census 2011

Preliminary review of the characteristics of the 6 cities (Ahmedabad, Hyderabad, Kolkata, Lucknow, Patna, and Solapur) is presented in the subsequent sections.

2.1 Ahmedabad

Ahmedabad is located at 23°02′N 72°35′E in the State of Gujarat at an elevation of 53 metres (174 ft). The city is the seventh largest metropolis in India and the largest in the state of Gujarat. In western India, Ahmedabad has been one of the most important centres of trade and commerce. River Sabarmati cuts the city into two parts: eastern walled city and western Ahmedabad on either side of its banks. The Ahmedabad Municipal Corporation (AMC) area is spread over 190.84 sq. km and the Ahmedabad urban agglomeration (AUA) area is about 350 sq. km. Population in AUA has increased from 4.5 million in 2001 to 5.6 million in 2011. Satellite image of the Ahmedabad city is shown in Figure 2.2



SOURCE Google Earth

Figure 2.2 Satellite image of Ahmedabad city in the State of Gujarat

Ahmedabad is the administrative centre of Ahmedabad district and also was the capital of Gujarat from 1960 to 1970; the capital was shifted to Gandhinagar thereafter. Like the other major cities of country, Ahmedabad is witnessing a major construction boom.

2.1.1 Climate

The climate in Ahmedabad is hot and semi-arid. Other than the monsoon season, the climate is dry. In the months of March to June—the temperature reaches average daily maximum of 42 °C and in the months of January it reaches to a average daily minimum of 12°C. Cold northerly winds are responsible for a mild chill in January. The city receives an annual rainfall of about 803 mm through the southwest monsoon, mainly during June to September. The average number of rainy days is mere 36 but infrequent heavy rains cause flooding of the river. Average climatological data (1951-80) for Ahmedabad city is presented in Table 2.2.

Table 2.2 Average climatological data (1951-80) for Ahmedabad city

Month	Mean Temperature(°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Maximum	Daily Minimum			HAIL	Thunder	FOG	SQUALL
Jan	28.4	11.7	2.6	0.3	0.0	0.2	0.2	0.0
Feb	31.3	13.8	1.1	0.2	0.0	0.2	0.1	0.0
Mar	36.0	18.8	1.0	0.1	0.0	0.5	0.1	0.2
Apr	39.9	23.4	0.9	0.1	0.0	0.7	0.0	0.1
May	41.8	26.2	6.0	0.4	0.0	1.2	0.0	0.3
Jun	38.4	27.0	108.7	5.0	0.0	4.5	0.0	1.4
Jul	33.3	25.7	265.3	11.3	0.0	4.8	0.0	0.6
Aug	31.9	24.8	219.8	10.7	0.0	3.0	0.0	0.4
Sep	33.4	24.1	171.9	6.2	0.0	3.2	0.0	0.5
Oct	35.8	20.9	10.8	0.7	0.0	1.1	0.1	0.2
Nov	33.2	16.5	8.9	0.6	0.0	0.3	0.0	0.1
Dec	29.8	13.0	2.6	0.2	0.0	0.2	0.2	0.0
Annual	34.4	20.5	803.4	35.8	0.0	19.9	0.7	3.8

SOURCE IMD

2.1.2 Spatial patterns

City of Ahmedabad has witnessed a change in landuse patterns in the last decade. Changing landuse patterns in the city during 1997-2011 are shown in Table 2.3.

Table 2.3 Existing and proposed Land Use of AMC area

	Existing Land use (1997)		Proposed land use for AMC (2011)	
S. No.	**Designation**	**% of Total Area**	**Designation**	**% Total Area**
1	Residential	34.92	Residential	43.7
2	Commercial	2.47	Walled city and Village sites (Gamtal)	3.38
3	Industrial	15.37	General Industrial	10.51
4	Open/vacant Land	23.44	Special Industrial	4.12
5	Village Site/Gamtal	4.69	Commercial	1.38
6	Education	1.8	Agriculture/Recreational/Open space/gardens	8.61
7	AMC plots	2.45	Education	2.03
8	Hospitals	0.52	Area under reservations now designated as special development area	10.25
9	Burial Grounds/grave yards	0.45	Roads and railways	11.10
10	Water Bodies	4.46	Water bodies (including rivers)	4.92
11	Roads	7.47		
12	Railway Land	1.96		

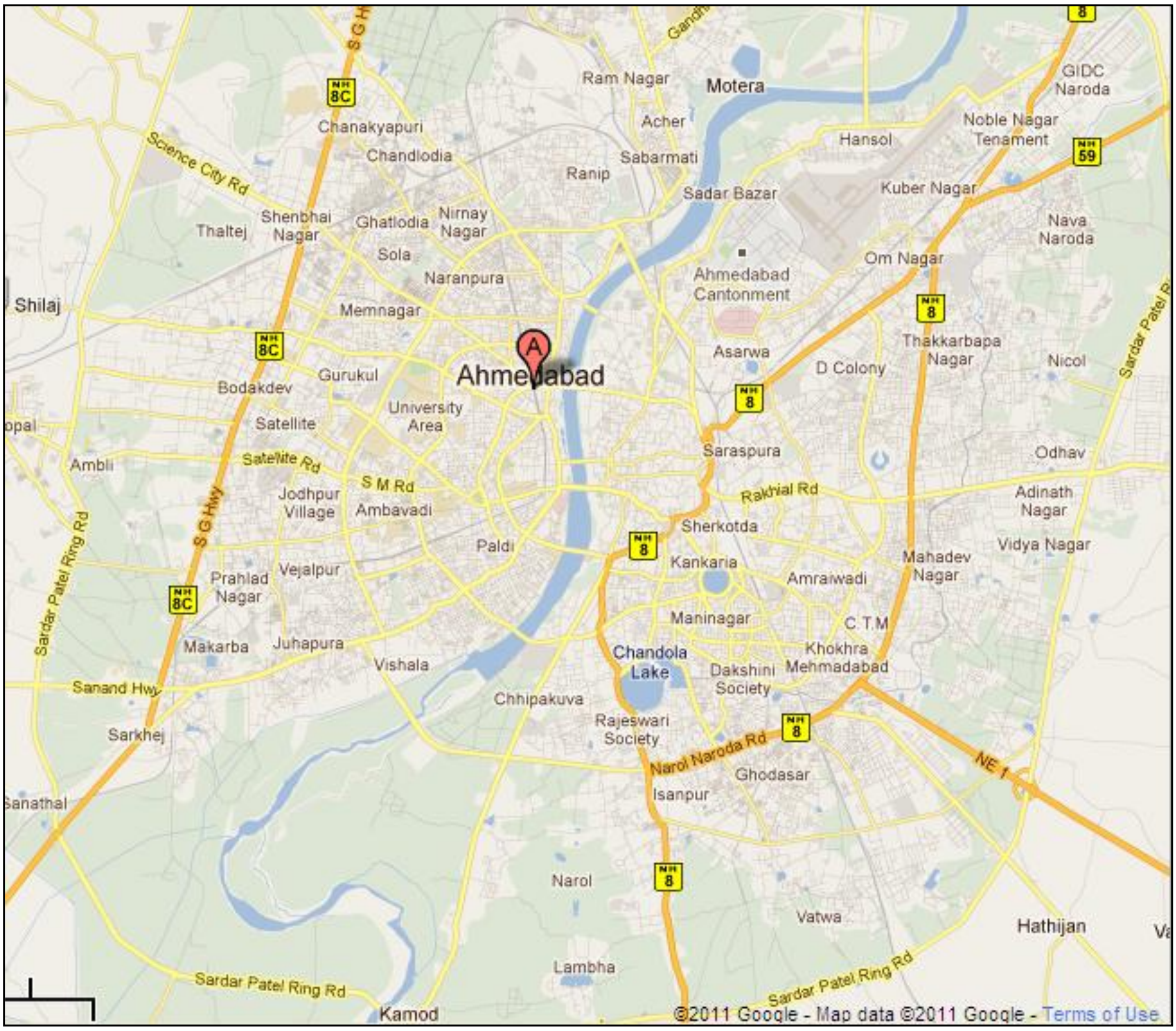
SOURCE : CDP 2005

There is a clear increase in the residential areas from 35% in 1997 to 44% proposed in 2011.

2.1.3 Road and traffic characteristics

Figure 2.3 shows the road network in the Ahmedabad city which would be further studied to assess traffic patterns in the city. Western part of the city has developed as a mainly residential area and the eastern part has the industrial estates. Thus, in the morning the traffic flow is very heavy from west to east and vice-versa in the evening leading to serious traffic congestion and frequent traffic jams on the city roads during morning and evening peak periods.

The road map of the Ahmedabad city is shown in Figure 2.3.



SOURCE Google map

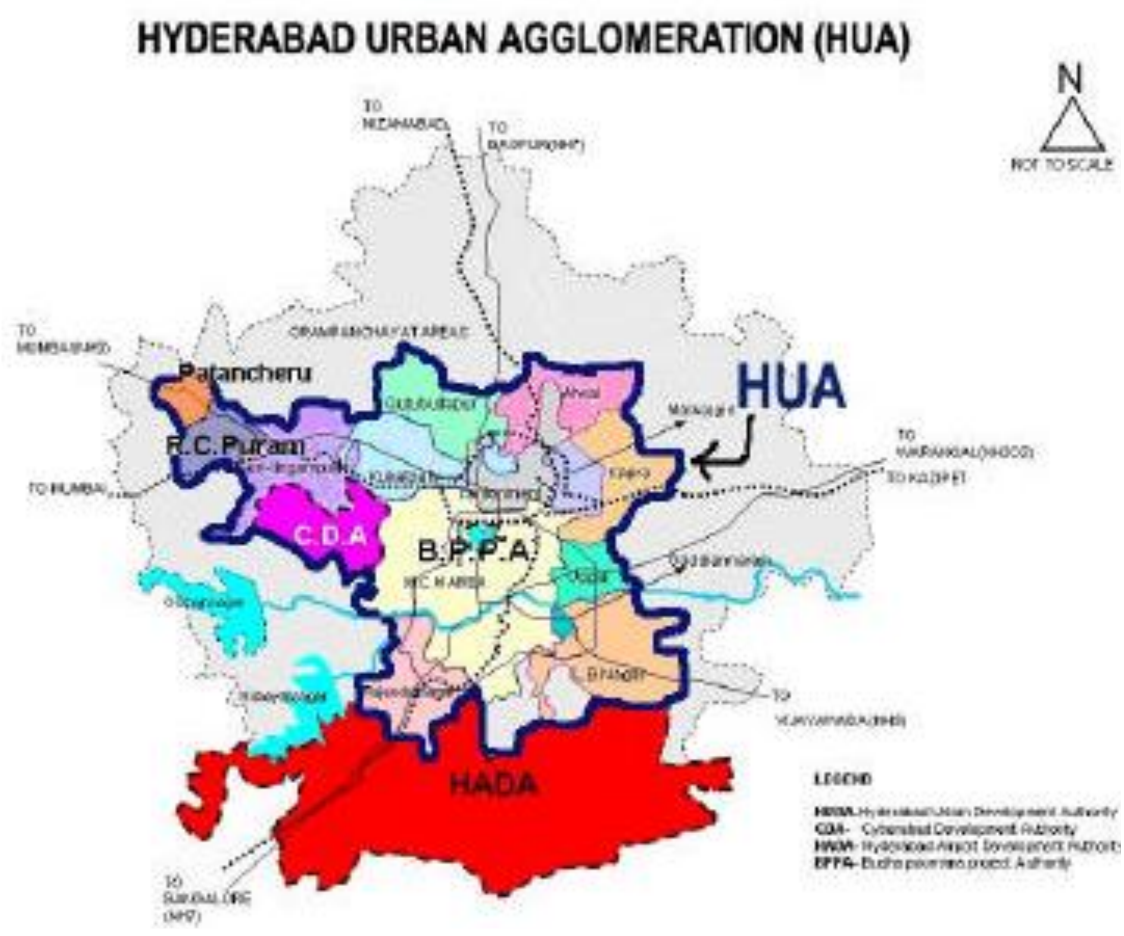
Figure 2.3 Road network in Ahmedabad city

Auto rickshaws and buses are the most popular forms of public transport in the city. Bus service is run by the Ahmedabad Municipal Transport Service (AMTS). In 2005, AMTS began a drive to convert all of its petrol and diesel engine buses to run on compressed natural gas (CNG) engines to reduce the effects of air pollution. Moreover, a number of auto rickshaws in Ahmedabad were also switched to CNG to reduce pollution.

A BRTS (Bus rapid transit system) has been developed by Gujarat Infrastructure Development Board (GIDB) for the city of Ahmedabad. First corridor connecting Pirana to R.T.O. was opened to public in 2009. Gujarat Government and Ahmedabad Mahanagar Sevasadan had initiated the Ahmedabad Metro feasibility study. Recently, a 10.9 km East-West metro line has also been proposed initially for the city.

2.2 Hyderabad

Hyderabad is the capital of the State of Andhra Pradesh. River Musi flows through the major portion of Hyderabad and the Hussain Sagar Lake in the north of the city effectively separates Hyderabad from its twin city Secunderabad. Hyderabad is the sixth most populous city and sixth-most populous urban agglomeration in India. Hyderabad urban agglomeration is shown in Figure 2.4 and satellite image of the city is shown in Figure 2.5.



SOURCE CDP, 2006a

Figure 2.4 Hyderabad urban agglomeration

SOURCE Google Earth

Figure 2.5 Satellite image of the Hyderabad city in the State of Andhra Pradesh

2.2.1 Climate

The climate in Hyderabad is a combination of tropical wet and dry climate. The city experiences hot summers during February to early June, rains during June to early October and pleasant winters from late October to early February. The city does not receive heavy rains (812 mm) and the number of rainy days is mere 51. Temperature goes up to average daily maximum of around 39 °C in May, and reaches to a average daily minimum of 14°C in December. Maximum rainfall happens during the months of July to September. It can be concluded that for most parts of the year the weather and climate of Hyderabad remains quite moderate, except the summer months of April to June. The highest maximum (day) temperature ever recorded was 45.5 °C in 1966, while the lowest minimum (night) recorded temperature was 6.1 °C in 1946. Average climatological data (1951-80) for Hyderabad city is presented in Table 2.4.

Table 2.4 Average climatological data (1951-80) for Hyderabad city

Month	Mean Temperature(°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Minimum	Daily Maximum			HAIL	Thunder	FOG	SQUALL
Jan	14.7	28.6	3.2	0.3	0.0	0.3	3.9	0.0
Feb	17.0	31.8	5.2	0.4	0.0	0.7	0.5	0.2
Mar	20.3	35.2	12.0	0.9	0.1	2.0	0.0	0.9
Apr	24.1	37.6	21.0	1.8	0.0	6.2	0.0	3.7
May	26.0	38.8	37.3	2.7	0.0	6.3	0.0	3.7
Jun	23.9	34.4	96.1	7.6	0.0	6.3	0.0	4.2
Jul	22.5	30.5	163.9	10.6	0.0	2.7	0.0	3.2
Aug	22.0	29.6	171.1	10.1	0.0	2.9	0.0	2.3
Sep	21.7	30.1	181.5	8.9	0.0	6.5	0.0	1.1
Oct	20.0	30.4	90.9	5.7	0.0	3.6	0.4	0.3
Nov	16.4	28.8	16.2	1.6	0.0	0.4	0.9	0.0
Dec	14.1	27.8	6.1	0.4	0.0	0.0	1.0	0.0
Annual	20.2	32.0	812.5	51.0	0.1	37.9	6.7	19.6

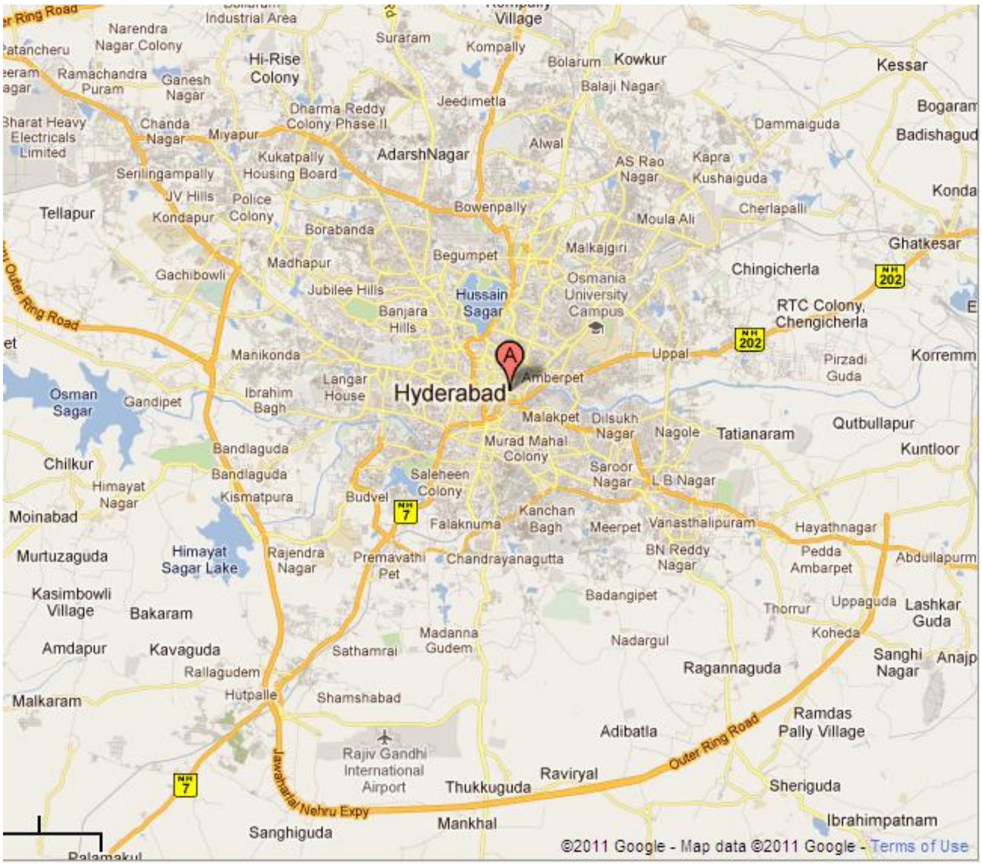
SOURCE IMD

2.2.2 Spatial patterns

In the Hyderabad urban agglomerate region, residential area constitutes 44% followed by 12% under open ground and agriculture. The mixed use is around 6.2 %. There is also an increase in the institutional land uses than envisaged in the zonal development plan (ZDP). The area under roads is around 7%.

2.2.3 Road and traffic patterns

The city has radial and orbital form of road network development. The recent growth trend is more in the west / south directions of Hyderabad. Three National Highways, NH9 (connecting Vijayawada in the eastern side and Mumbai in the west), NH7 (connecting Bangalore in south and Nagpur in north) and NH202 (connecting Hyderabad to Warangal) pass through the CBD of the city (Figure 9). Five State Highways SH1, SH2, SH4, SH5 and SH6 start from the city centre and diverge radially connecting several towns and district headquarters within the State in all directions. The road network of Hyderabad is very dense and congested due to narrow roads, heavy encroachments, and high pedestrian and slow moving vehicle concentration. As per the existing land use plan, the area under roads is only 9-10% in MCH area. Road network of Hyderabad city is presented in figure 2.6 below:



SOURCE Google Map

Figure 2.6 Road network of Hyderabad

Hyderabad city has multiple options for public transport. Along with the traditional local buses, private auto and taxi services, specific services such as Multi Modal Transport System (MMTS[1]) are also available. The local train operations in the city have been introduced in the city in 2003. The current network extends to about 50 kilometres with 26 stations, served by 10 rakes.

2.3 Kolkata

Kolkata is a metropolitan city and the capital of the State of West Bengal. Kolkata is known as the commercial capital of East India. The city is on the east bank of the Hooghly river and accommodates 4.5 million residents in the metropolitan area and around 15.7 million including suburbs. Kolkata is the third most populous metropolitan area in India and the thirteenth most populous urban area in the world. The Kolkata Metropolitan Area (KMA) stretches over 1851 sq.km enveloping as many as 41 urban local bodies (ULBs) including three Municipal Corporations and 24 *Panchayat Samities*. Satellite image of the Kolkata city is shown Figure 2.7

[1] MMTS is a sub-urban commuter rail system in Hyderabad which is complemented by the local trains. MMTS is a joint partnership of Government of Andhra Pradesh and the South Central Railways.

SOURCE Google Earth

Figure 2.7 Satellite image of Kolkata city in the State of West Bengal

2.3.1 Climate

Kolkata is known to have a tropical wet-and-dry climate. Summers are hot and humid. The mean daily maximum temperature is observed during April or May (around 36 °C). Winters could only be experienced for only about two and a half months, with temperatures going down to average daily minimum of 14°C during December and January. The highest ever recorded temperature is 43.9 °C and the lowest is 5 °C.

Rainy season starts with the South-West monsoon brought by the Bay of Bengal during June and September. Total rainfall received in the city is around 1,641 during 82 rainy days. The city receives 2,528 hours of sunshine per annum, with the maximum sunlight occurring in March. Kolkata has been suffered due to several cyclones in past. Average climatological data (1951-80) for Kolkata city is presented in Table 2.5.

Table 2.5 Average climatological data (1951-80) for Kolkata city

Month	Mean Temperature(°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Minimum	Daily Maximum			HAIL	Thunder	FOG	SQUALL
Jan	13.9	26.6	16.8	0.9	0	0.4	7.0	0.0
Feb	16.9	29.7	22.9	1.5	0.0	1.9	5.6	0.7
Mar	21.7	34.0	32.8	2.3	0.1	3.8	2.1	1.9
Apr	25.1	36.3	47.7	3.0	0.1	6.4	0.1	4.0

Month	Mean Temperature(°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Minimum	Daily Maximum			HAIL	Thunder	FOG	SQUALL
May	26.4	36.0	101.7	5.9	0.1	9.4	0.1	4.9
Jun	26.5	34.1	259.9	12.3	0.0	12.2	0.0	3.7
Jul	26.1	32.2	331.8	16.8	0.0	11.0	0.0	1.3
Aug	26.1	32.0	328.8	17.2	0.0	12.8	0.0	1.3
Sep	25.8	32.2	295.9	13.4	0.0	15.0	0.1	1.3
Oct	24.0	31.9	151.3	7.4	0.0	7.9	0.6	0.7
Nov	18.9	29.8	17.2	1.1	0.0	0.3	1.9	0.1
Dec	14.3	27.0	7.4	0.4	0.0	0.1	6.1	0.0
Annual	22.1	31.8	1641.4	82.2	0.3	81.2	23.6	19.9

2.3.2 Spatial patterns

The east-to-west dimension of the city is quite narrow, stretching from Hooghly River in the west to eastern metropolitan bypass in the east. The city has mainly expanded in the north-south direction and the different zones are popularly known as north, central and south Kolkata. The landuse patterns in the city are presented in Table 2.6.

Table 2.6 Land use pattern in KMA (1991)

S. No.	Land Use Category	Percentage
1	Residential	31.2%
2	Industrial	5.9%
3	Commercial	--
4	Recreational	0.9%
5	Transportation	5.4%
6	Institutional	2.5%
7	Mixed Built up	8.3%
8	Vacant	45.3%
9	Total	100%

SOURCE: Comprehensive Mobility Plan (CMP), 2008

2.3.3 Road and traffic patterns

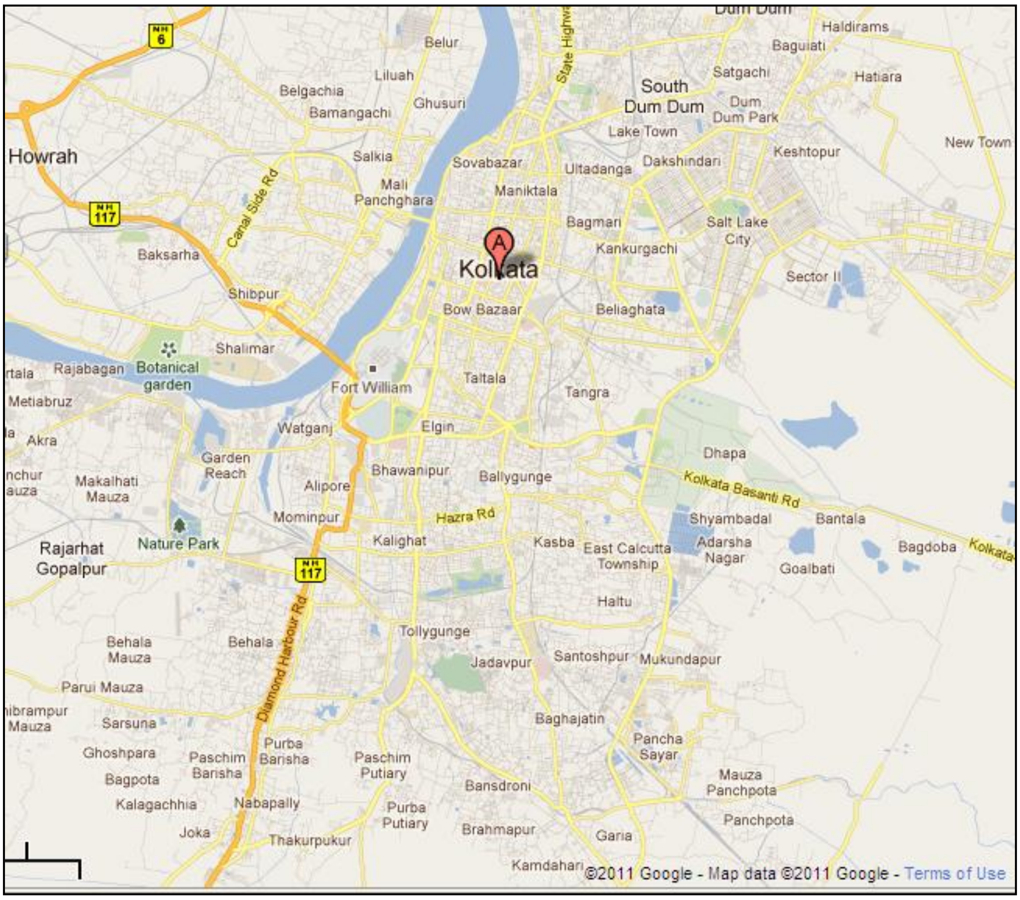
The arterial road network in KMA consists of regional roads including National and State Highways, arterial roads, inner arterial and sub-arterial network. The arterial road network in Kolkata was developed along the following seven major radial traffic corridors[2]:

- North Corridor from Barrackpore and Kalyani through Barrackpore Trunk Road.
- North-East Corridor from Barasat, Bangladesh Border and North-Eastern India through NH – 34 and NH - 35.
- South-East Corridor from Sonarpur and Baruipur through Garia- Sonarpur Road as well as the South-Western West Bengal.
- South West Corridor from Budge Budge.
- Southern Corridor from Southern West Bengal State through Diamond Harbour Road.
- West Corridor from Western part of West Bengal, other parts of Eastern India and Mumbai through NH - 6, Kona Expressway and Vidyasagar Bridge.

[2] CMP, 2008

- North-Western KMA area and whole Northern India through NH - 2 and Vivekanand Bridge

The road network in the Kolkata city is shown in Figure 2.8.



SOURCE Google map

Figure 2.8 Kolkata Road Map

Main traffic characteristics as presented in the CMP, 2008 are:

- The maximum fast moving traffic flow was on Park Circus Road and V. I. P. Road having 1,11,080 and 1,01,208 PCU respectively.
- The highest number of slow moving traffic is on NH – 34 and 35 which passes through an area highly congested area.
- GT Road also has a high ratio of slow moving traffic as it passes through Howrah which is a very densely populated with no infrastructure for pedestrians.

Compared to other Indian cities, the public transport system in Kolkata is better. Public transport exists mainly in the forms of the Kolkata suburban railway, trams, the Kolkata metro, and buses. The suburban railway network is quite extensive and reaches to the distant suburbs.

Kolkata has the privilege of having the first metro underground rail system in the country. It was started in 1984 and it runs parallel to the River Hooghly in the north-south direction and covers about 22.3 km. Other than that, many other lines have been built to serve other areas of Kolkata such as Howrah and Bidhan Nagar.

Other than the rail systems, buses are also quite popular mode of transport and are run by both government agencies and private operators. Moreover, Kolkata is the only city in the country to have a tram network which ply only in certain areas of the city.

Hired taxis and auto rickshaws are the other forms of transport in the city. Consequently, private vehicle ownership in the city is comparatively less when compared to other major cities in the country.

Kolkata is also a major river port of eastern India. The port provides passenger services to Port Blair and also cargo services to various ports in India and abroad. Then there are ferries to connect Kolkata with its twin city of Howrah.

2.4 Lucknow

Lucknow is the capital of India's most populous state, Uttar Pradesh and is situated about 500 km southeast of New Delhi in the heart of the state. Lucknow is one of the fastest growing cities and is rapidly emerging as a manufacturing, commercial and retailing hub.

Situated in the heart of the great Gangetic plain, Lucknow city is surrounded by its rural towns and villages. The more densely populated areas of the city are on the southern bank of the River Gomti and several planned residential colonies have been developed to the north of the River. Figure 2.9 shows the satellite image of the city.

SOURCE: Google Earth

Figure 2.9 Satellite image of Lucknow city in the State of Uttar Pradesh

Currently Lucknow Municipal Corporation accommodates a population of about 2.8 million. According to census of 2011 Lucknow is the largest urban area in Uttar Pradesh. Today, Lucknow is not only a major market & trading city in Northern India, but is also emerging as a centre for producers of goods and services. Real estate is another booming sector of the economy in the city.

2.4.1 Climate

Lucknow experiences a warm and humid subtropical climate along with cooler and dry winters. The summer season extends from April to June, with average daily maximum temperatures going up to 41 C. Rainy season extends in the city from mid-June to mid-September, and receives an average rainfall of about 1021 mm mostly from the south-west monsoon. The average number of rainy days is 47. In winters, the average daily minimum temperatures go down to 7 C in the month of January. Fog is quite common from late December to late January. Average climatological data (1951-80) for Lucknow city is presented in Table 2.7.

Table 2.7 Average climatological data (1951-80) for Lucknow city

Month	Mean Temperature(°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Minimum	Daily Maximum			HAIL	Thunder	FOG	SQUALL
Jan	6.9	22.6	21.9	1.6	0.1	1.1	3.6	0.0
Feb	9.3	26.0	11.2	1.1	0.1	2.0	0.8	0.2
Mar	14.2	32.2	7.7	0.7	0.2	2.5	0.2	0.8
Apr	20.5	38.1	4.9	0.5	0.0	2.0	0.0	1.0
May	24.7	40.5	16.5	1.0	0.2	3.7	0.2	1.3
Jun	27.1	38.7	107.4	4.2	0.0	7.2	0.0	1.4
Jul	26.1	33.6	294.3	11.6	0.1	11.2	0.0	1.3
Aug	25.6	32.5	313.9	13.1	0.0	10.3	0.1	0.6
Sep	24.3	33.0	180.6	7.4	0.0	7.0	0.2	0.6
Oct	19.0	32.5	45.2	2.0	0.0	2.0	0.4	0.5
Nov	11.8	28.9	3.8	0.3	0.0	0.3	0.3	0.0
Dec	7.4	24.1	7.3	0.7	0.0	0.6	4.0	0.0
Annual	19.0	31.8	1021.5	47.1	0.8	13.2	4.3	0.0

SOURCE IMD

2.4.2 Spatial Patterns

The current land use of the Urban Agglomeration excluding that of the Cantonment is shown in Table 2.8. The Master Plan 2021, which is the source of the information, estimates that Lucknow covered an area of 16,270 hectares in 2004-05. Compared to 1987 when the area was estimated at 9170 hectares, there has been a 77.4% increase in the total area in 2004-05. Trends in land uses has been interesting, especially the fact that residential use has grown dramatically in comparison to all other uses, although there has also been notable growth in commercial, industrial and public service land use. The total Municipal area as per 2001 census is 143 sq.km.

With the radial growth of the city, the Cantonment has gradually been engulfed and is today more centrally located. A Ring Road system has been developed to connect the new development around the Old City and the Cantonment and the Trans-Gomti areas.

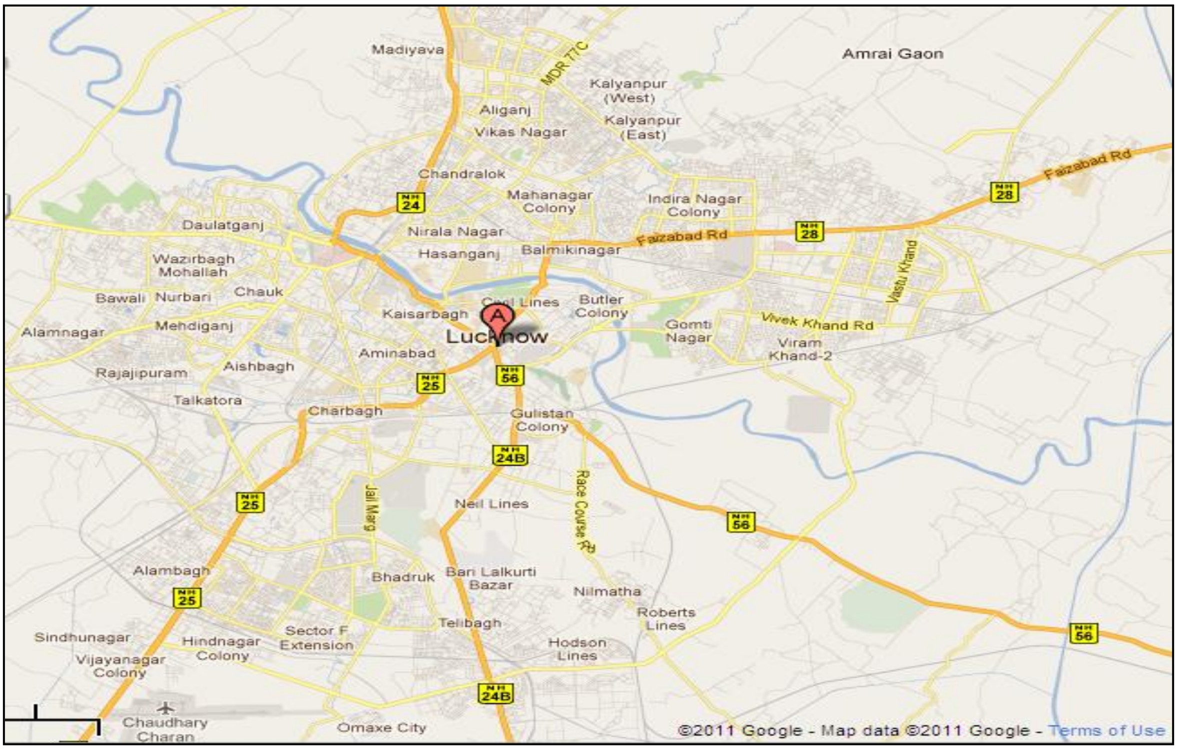
Table 2.8 Existing land use Lucknow city area (Hectares)

	1987		2004-05		Growth percentage
Land use	**Area**	%	**Area**	%	
Residential	4,485.98	48.92	8,945.00	54.98	99.40
Commercial	223.77	2.44	360.00	2.21	60.88
Offices	474.69	5.18	560.00	3.44	17.97
Industrial	596.22	6.50	990.00	6.08	66.05
Parks/Playgrounds	346.48	3.78	435.00	2.67	25.55
Public Services	902.02	9.84	1,410.00	8.67	56.32
Traffic	952.00	10.38	1,240.00	7.62	30.25
River/water bodies	193.66	2.11	310.00	1.91	60.07
Open land	996.14	10.86	2,020.00	12.42	102.78
Total	**9,170.96**	**100.00**	**16,270.00**	**100**	**77.43**

SOURCE: CDP 2006 c

2.4.3 Road and traffic characteristics

The main traffic generating areas in Lucknow are Lucknow Railway Station, Charbagh Bus Stand, Vidhan Sabha, Secretariat, and the commercial areas in the central parts of the city. The main artery of Lucknow City, Station Road-Vidhan Sabha Marg, remains extremely congested throughout the day. The traffic situation in main commercial areas that include some heritage zones like Hazrat Ganj has become worrisome. Major road network in the city is shown in Figure 2.10.



SOURCE Google maps

Figure 2.10 Road network of Lucknow city

Major modes of public transport in the city are taxis, city buses, and auto rickshaws CNG has been introduced recently as an auto fuel for air pollution control. The city bus service is run by Lucknow Mahanagar Parivahan Sewa which has an entirely CNG based fleet. These buses cover around 35 routes in the city.

The city is also served by railways, having stations in different parts of the city. The main railway station is Lucknow Railway Station at Charbagh. Lucknow is a major junction with links to all major cities of the state and country

2.5 Patna

The history of Patna city goes back to the earliest dawn of civilization when it was known as Pataliputra. Presently known as Patna, the state capital of Bihar, is located between Latitude: 25° 37' North and Longitude: 85° 12' East, at an altitude of 53 meters. The city lies on the south bank of the Ganga River with other rivers like Sone, Gandak and Punpun in its vicinity. The satellite image of the city is shown in Figure 2.11. The city is approximately 35 km long and 16 km to 18 km wide.

SOURCE Goggle Earth

Figure 2.11 Satellite image of Patna city in the State of Bihar

The population in Patna Municipal Corporation is about 1.7 million according to the 2011 census of India.

2.5.1 Climate

Patna experiences a humid subtropical climate. There are hot summers during the months of March to early June. The temperatures rose to a average daily maximum of 39 °C. Patna receives a moderate average rainfall of 1003 mm and average number of rainy days are 49. The monsoon season extends from late June to late September. Winter season in the city starts from November and extends upto February. The temperatures fall upto an average daily minimum of 9°C in January. Highest temperature ever recorded is 46.6 °C(In,1966) and lowest ever is 2.3 °C (in,2003). Average climatological data (1951-80) for Patna city is presented in Table 2.9.

Table 2.9 Average climatological data (1951-80) for Patna city

Month	Mean Temperature(°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Minimum	Daily Maximum			HAIL	Thunder	FOG	SQUALL
Jan	9.2	23.3	18.9	1.3	0.0	0.9	6.4	0.1
Feb	11.6	26.5	10.7	1.1	0.0	1.3	2.1	0.0
Mar	16.4	32.6	11.4	1.0	0.0	2.1	0.3	0.1
Apr	22.3	37.7	7.6	0.9	0.0	1.9	0.1	0.7
May	25.2	38.9	33.3	2.0	0.1	4.3	0.0	1.8
Jun	26.7	36.7	134.2	6.4	0.0	8.6	0.0	0.9
Jul	26.2	33.0	305.8	13.2	0.0	11.0	0.1	0.2
Aug	26.1	32.4	274.4	12.8	0.0	11.8	0.1	0.1
Sep	25.4	32.3	226.9	9.8	0.0	9.6	0.4	0.1
Oct	21.8	31.5	93.8	3.3	0.0	2.9	1.2	0.3
Nov	14.7	28.8	8.9	0.4	0.0	0.2	3.7	0.0
Dec	9.9	24.7	4.1	0.5	0.0	0.1	7.1	0.0
Annual	20.8	31.9	1003.4	48.6	0.6	19.7	4.8	0.2

2.5.2 Spatial pattern

Within the Patna urban agglomerate (PUA) the most densely populated wards are along the banks of river Ganga (301 to 900 persons per ha). The wards with lower density are along the southern and western side where the density varies from 100 to 300 persons per ha. The predominant land use in the PUA is residential which constitutes 60.88% of the total area. Of this 91.7% is unplanned (Refer table 2.10). About 52% of the commercial land use is predominant ribbon development along the major roads. Within the Patna municipal corporation (PMC) area, mixed land use dominates along all the major arterial roads. There is a predominance of educational uses and Social infrastructure facilities whereas recreational use constitutes only 1.56%, and industrial use only 1.76%.

Table 2.10 Existing land use within Patna urban agglomeration area

S. No.	Land Use	Area (Ha)	Total Area (Ha)	Percentage
1	Residential		8230	60.88%
	Residential Planned	438		
	Apartments	202		
	Residential Organic/ Unplanned	7548		
	Slums	42		
2	Commercial		298	2.20%
	Commercial	134		
	Commercial (Predominant Ribbon development)	155		
	Agricultural Marketing Yard	9		
3	Public-Semi Public		651	4.82%
	Administrative	211		
	Educational	236		
	Medical	154		
	Religious	32		

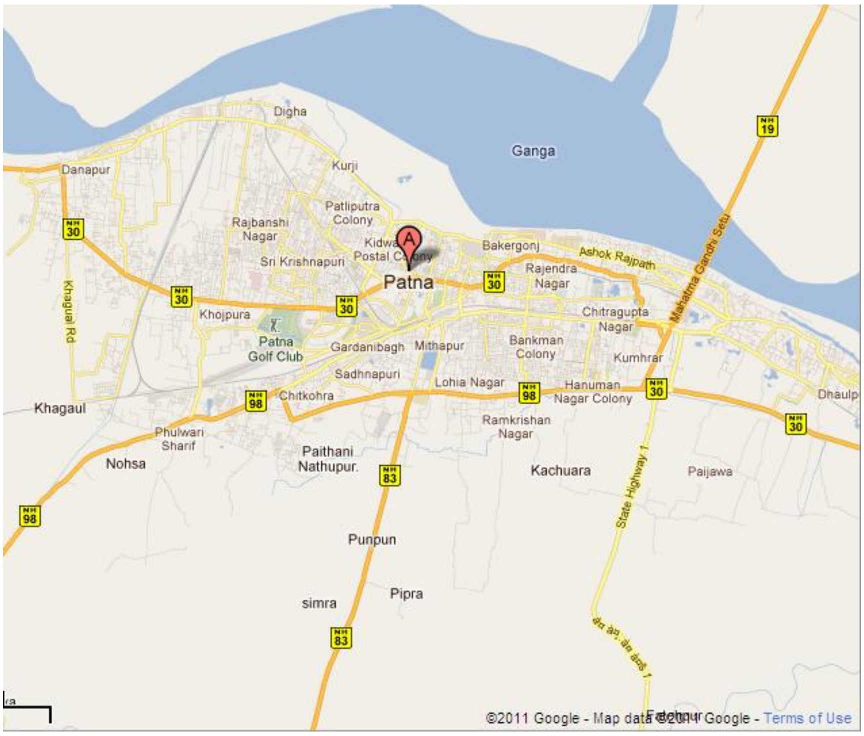
S. No.	Land Use	Area (Ha)	Total Area (Ha)	Percentage
	Grave Yards and Cremation Grounds	18		
4	Recreational		212	1.56%
	Clubs, Cinemas			
	Parks and Playground			
5	Industrial		238	1.76%
6	Transportation		1050	7.77%
7	Water Bodies		164	1.14%
8	Agriculture		2591	18.88%
9	Vacant Land		145	0.99%
	Total Land		13,579	100%

SOURCE CDP 2006 d

2.5.3 Road and Traffic characteristics

The physical expansion of Patna city is linear from east to west for a length of 30km and an average width of 3-4km from river Ganga in north, Punpun in south and Sone in the west.

The total length of surfaced road in Patna Urban area is 1500km, out of which 90% is municipal road and 10% are state level roads. The major corridors are, Ashok Raj Path, Patna Danapur road, Baily road, Harding road, and Kankarbagh road. The location of wholesale market in north within Patna city and transport nagar on south in the outskirts, leads to heavy movement of the LCVs and other small good carriages for to and fro transportation of goods and commodities from wholesale areas namely Kankarbagh, Ashok Rajpath, and Meethapur (CDP, 2006). The road network in the city is shown in Figure 2.12.



SOURCE: Google map

Figure 2.12 Road network of Patna city

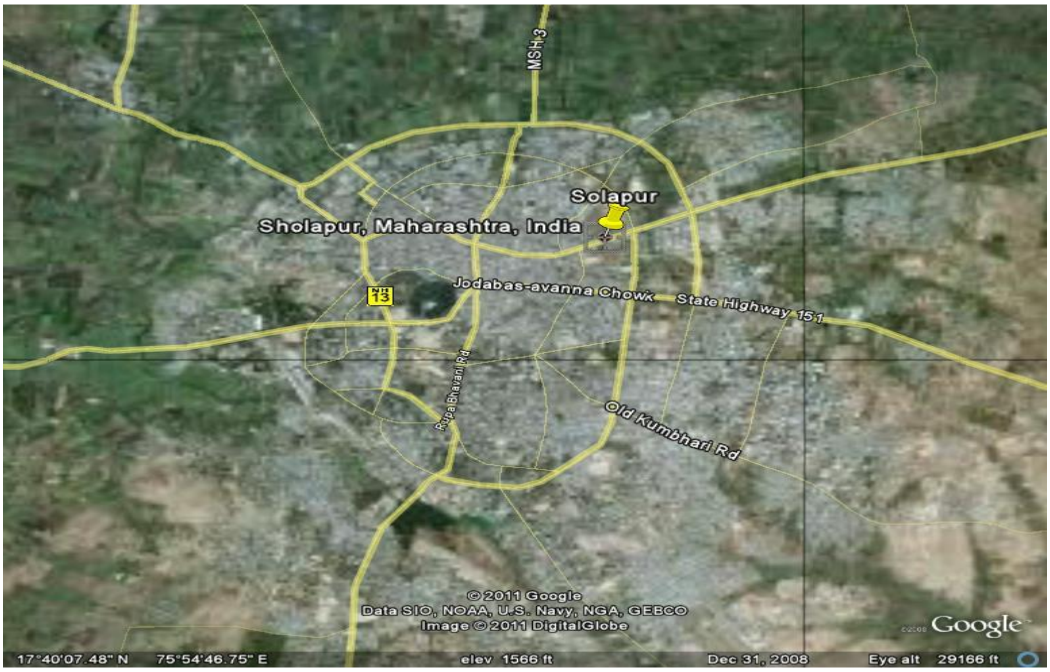
The total road length in the city is about 1500 km. The wholesale market and transport market located close to each other creates high traffic between these two. The public transport options are very limited in the city and most common mode of transport are non-motorized/slow moving vehicles.

Limited public transportation in the city is mainly by buses, auto rickshaws and local trains. BSRTC (Bihar State Road Transport Corporation) has started city bus service in all the major routes in the city..

2.6 Solapur

Solapur district is one of the important districts in Maharashtra covering an area of 14, 844.6 sq.kms. Out of the total area of the district 338.8 sq.kms (2.28%) is urban area whereas remaining 14505.8 sq.kms. (97.72%) is rural area. The district is having 11 Talukas and is surrounded by Ahmednagar and Osmanabad districts in the north, Osmanabad and Gulbarga (Karnataka State) in the East, Sangli and Bijapur (Karnataka State) in the South and Pune, Satara districts in the West.

Solapur Municipal Corporation (SMC) was established on 1964, with 23.23 km² area. However, later the City limits were gradually expanded to 178.57 km². As per the Census 2011, a population of 9.5 lakhs resides in the Municipal Corporation of Solapur. The satellite image of the city is shown in Figure 2.13.



SOURCE Google Earth

Figure 2.13 Satellite image of Solapur city in State of Maharashtra

2.6.1 Climate

Solapur has dry (arid and Semi-arid) climate and experiences three distinct seasons: summer, monsoon and winter. The temperature goes up to average daily maximum of around 40 °C in May. The warmest months in Solapur are April and May. The highest temperature ever recorded is 48°C in 1988. Rainy season in the city extends from June to September amounting to nominal rainfall of 759 mm in about 45 rainy days. Winter season begins in November and lasts till the end of February with the average daily minimum temperatures going down to 16 °C. Average climatological data (1951-80) for Solapur city is presented in Table 2.11.

Table 2.11 Average climatological data (1951-80) for Solapur city

Month	Mean Temperature(°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Minimum	Daily Maximum			HAIL	Thunder	FOG	SQUALL
Jan	16.0	30.9	2.2	0.1	0.0	0.1	0.0	0.0
Feb	18.0	34.0	4.6	0.4	0.0	0.4	0.1	0.0
Mar	21.6	37.4	3.8	0.3	0.0	1.5	0.0	0.0
Apr	24.8	39.7	11.2	1.3	0.0	5.1	0.1	0.0
May	25.3	40.1	36.9	2.7	0.0	3.6	0.0	0.0
Jun	23.4	35.0	111.5	6.9	0.0	4.6	0.0	0.0
Jul	22.4	31.7	138.8	9.1	0.0	1.4	0.0	0.0
Aug	21.9	31.0	137.3	8.6	0.0	1.9	0.0	0.0
Sep	21.6	31.8	179.8	9.0	0.0	4.6	0.0	0.0
Oct	20.9	32.5	97.4	5.0	0.0	2.4	0.0	0.0
Nov	17.9	31.0	23.2	1.5	0.0	0.7	0.0	0.0
Dec	15.5	30.0	4.8	0.4	0.0	0.1	0.1	0.0
Annual	20.8	33.8	759.8	45.3	0.0	26.4	0.3	0.0

SOURCE IMD

2.6.2 Road and traffic characteristics

Network in the city is shown in Figure 2.14. Public transport in Solapur is primarily provided by buses operated by Solapur Municipal Transport (SMT) and auto rickshaws.

SOURCE Google map

Figure 2.14 Road map of Solapur city

3. Air quality in the six cities

Under the Air (Protection & Control of Pollution) Act of 1981, the role of the government in preventing the deterioration of air quality was outlined, and later reinforced by the Environment (protection) Act of 1986. This was to be achieved through constant monitoring of air pollution and air quality, and with this aim in mind, the Central Pollution Control Board (CBCP) established the National Ambient Air Quality Monitoring Network in 1985, now known as the National Air Monitoring Programme (NAMP). This programme involves the measurement of air quality in each state of the country, and comparing the levels of selected pollutants in different regions. The areas selected for monitoring may experience high industrial activity or increased vehicular emissions or population density. The NAMP network consists of 342 operating stations covering one hundred and twenty seven 127 cities/towns in 26 states and 4 Union Territories of the country (CPCB).

To monitor the presence of pollutants in the atmosphere and create effective programmes to control pollution level, it was necessary to develop air quality standards that specify the quality of air necessary to protect the health and livelihoods of people. These National Ambient Air Quality Standards (NAAQS) were adopted in 1982 and were revised in 1994. The pollutants so measured at each station are respirable suspended particulate matter (RSPM), suspended particulate matter (SPM), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Sampling is carried out twice a week, to generate a total of 104 samples in a year (CPCB, 2006). The National Ambient Air Quality Standards are revised in 2009 and are presented in Table 3.1

Table 3.1 National Ambient Air Quality Standards

Pollutant	**24-hourly standard (μg/m³)**	**Annual standard (μg/m³)**
SO_2	80	50
NOx	80	40
PM_{10}	100	60
$PM_{2.5}$	60	40
Ozone	180*	100**
Lead	1	0.5
CO	4000*	2000**
NH_3	400	100
As (ng/m³)		6
Benzene		5
BaP(ng/m³)		1
Ni (ng/m³)		20

* 1-Hourly , ** 8-Hourly

Source : CPCB

National Ambient Air Quality Standards: the levels of air quality necessary, with an adequate margin of safety, to protect the public health, vegetation and property. (Source: CPCB, 2009)

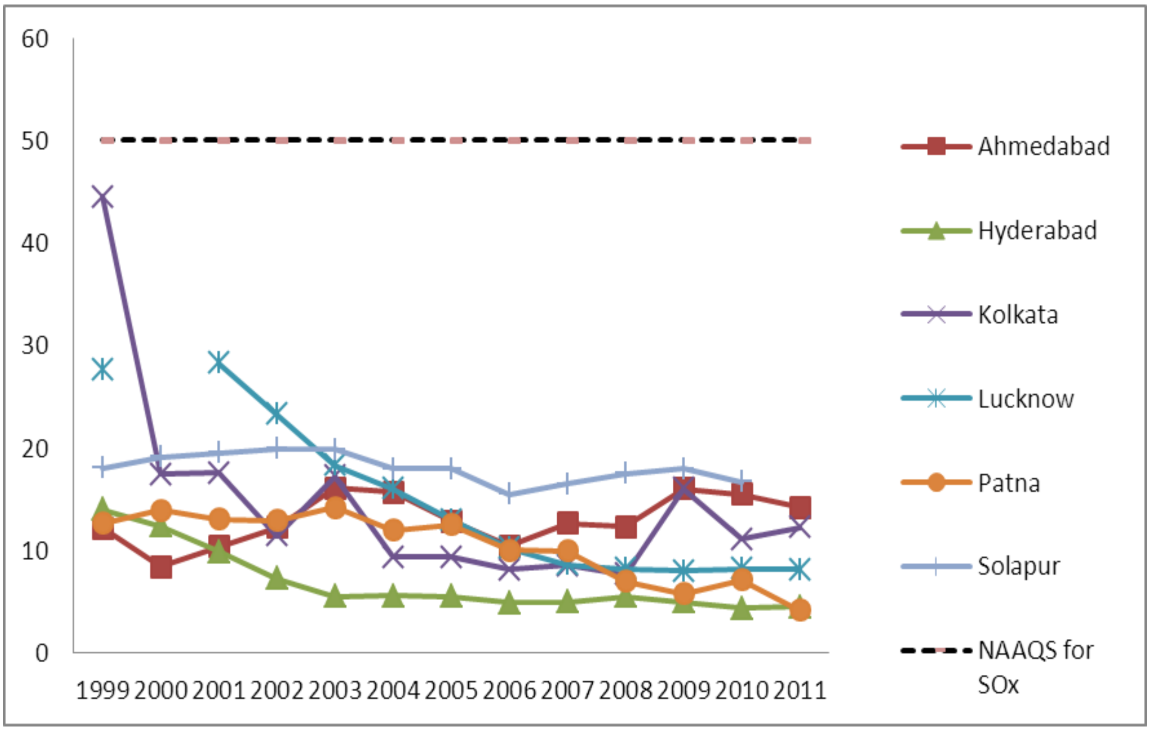
Air quality monitoring results are classified into low, moderate, high or critical levels of pollution, based on the amount they exceed the notified standards for each pollutant. Locations in the low category fall within the air quality limits and are unlikely to violate the standards in the future, whereas locations with moderate pollution may violate the air quality standards in the future. High and critical pollution locations violate the notified standards, but by different margins.

Whereas pollutants were once generated from combustion of fossil fuels in industrial or power generating processes, the sources have expanded to include those emitted by petrol and diesel engines of vehicles. Carbon monoxide (CO), oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and particulate matter are all rising as a result of increased traffic density, especially in the urban centres of the country.

3.1 Comparative evaluation of air quality in six cities

3.1.1 Sulfur Dioxide

Sulfur dioxide (SO_2) is formed when fuel containing sulfur: crude oil, coal and ore, is burned. Thermal power plants, petroleum refining processes and diesel driven vehicles are all sources of sulfur dioxide. Sulphur in diesel contributes to particulate emissions in the exhaust stream of the vehicle and later in the atmosphere. Exposure to sulfur dioxide may lead to respiratory and pulmonary defects, or an exacerbation of existing symptoms like asthma; a decrease in visibility, or acid rain. Levels of SO_2 pollution may be more harmful when combined with particulate matter. The levels of SO_2 from 1999 to 2011 in the six cities of study are given in Figure 3.1. The trends of SO_2 levels in each city are compared and plotted against the National Ambient Air Quality Standard for SO_2 (50 µg/m^3) as revised by the CPCB in 2009.



Source NAMP data

Figure 3.1 Annual average concentration of SO_2 (µg/m^3) in six Indian Cities during 1999-2011

Most cities did not experience critical or even high levels of SO_2 pollution. There is an overall decrease of SO_2 levels in all the cities during 1999 to 2011. This is due to the introduction of improved quality of fuel with reduced sulphur content. Gasoline has also experienced a reduction in sulfur content through Bharat Stage II, which reduced the maximum sulfur content of gasoline to 0.05% of total mass from 2001 – 2005. From 2005 onwards, Bharat Stage III reduced the sulphur content in petrol and diesel respectively to 150 ppm and 350 ppm respectively. Recently, adoption of BS-IV norms in 13 cities has reduced the sulphur to 50 ppm levels (Table 3.2).

Table 3.2 Progressive reduction of sulphur content in petrol and diesel for meeting different vehicular emission norms

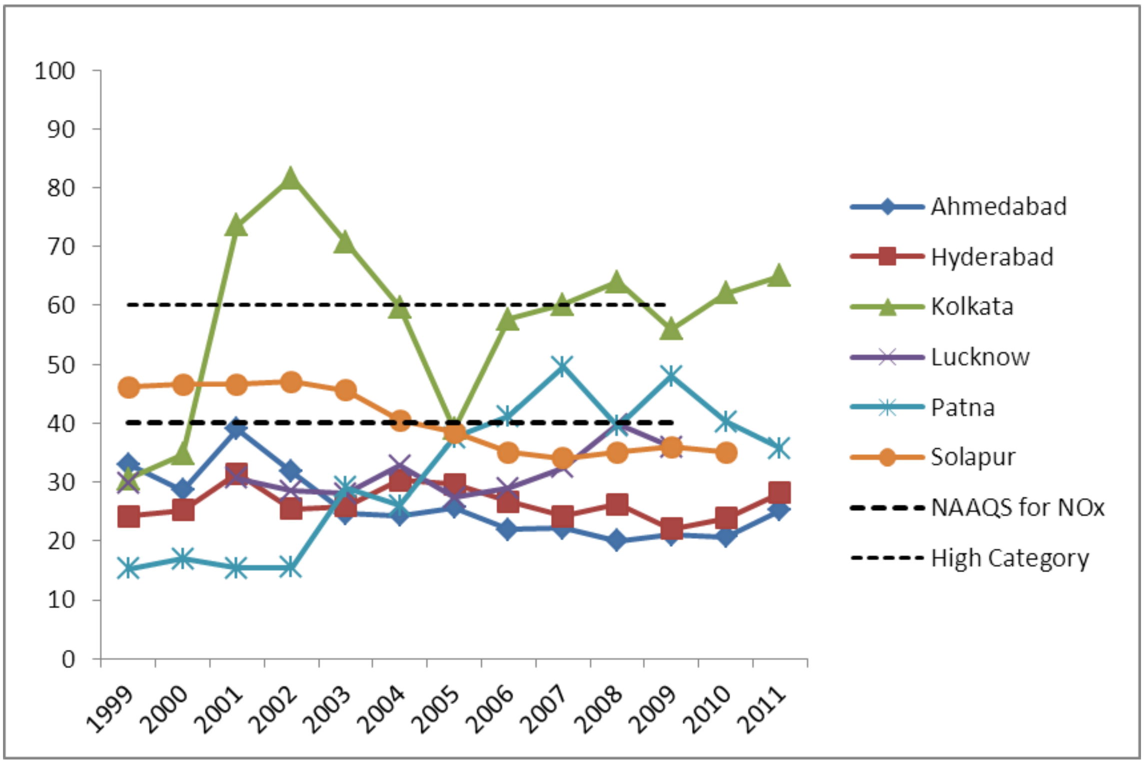
Specification	Sulphur Content	
	Petrol	Diesel
BIS petrol spec. (IS2796: 2000) BIS diesel spec. (IS 1460: 2000) [3]	0.05% for notified areas and 0.1% for rest	0.05% for notified areas and 0.25% for rest
Fuel quality specification required to meet Bharat Stage II emission norms (By 2005 in entire country)	0.05%	0.05%
Fuel quality specification required to meet Euro III equivalent emission norms (By 2005 in 11 cities and 2010 in entire country)	0.015%	0.035%
Fuel quality specification required to meet Euro IV equivalent emission norms (by 2010 in 13 cities)	0.005%	0.005%

Currently, SO_2 levels are within the standards in all the 6 cities and are found to be highest in Solapur, followed by Ahmedabad and Kolkata.

3.1.2 Oxides of Nitrogen

Oxides of nitrogen (NO_x) are formed during combustion processes at high temperatures, for example in vehicles, DG sets, or industrial processes. They exist as nitric oxide (NO), or the more toxic nitrogen dioxide (NO_2), or N_2O which is a green house gas. Exposure to nitrogen oxides increases susceptibility to infections, pulmonary diseases and impaired functioning of the lungs. Even short-term exposure causes respiratory problems in vulnerable populations. Moreover, it is an important pre-cursor of ground level Ozone formation. The levels of NO_x monitored in six cities considered in the study during 1999 to 2011 are given in Figure 3.2. The levels are compared against the National Ambient Air Quality Standard for NO_x (40 $\mu g/m^3$) as revised by the CPCB in 2009.

3 Improvements in petrol and diesel qualities facilitated adoption of India 2000 (Euro I equivalent) emission norms in the entire country and Bharat stage II emission norms in notified areas



SOURCE NAMP, CPCB

*High category is 1.5 times the standard

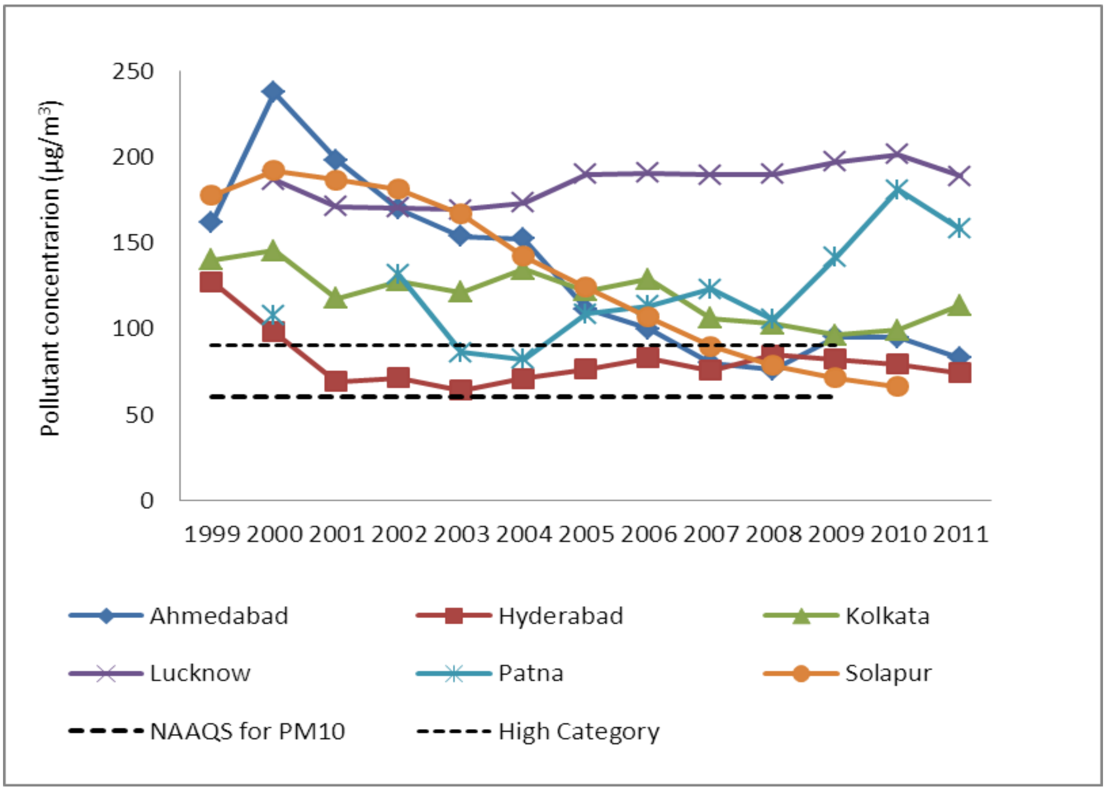
Figure 3.2 Annual average concentration of NO_2 (µg/m^3) in six Indian Cities during 1999-2011

All the cities have registered an increase in the NO_x levels over the last twelve years (1999-2011). Kolkata has shown very high levels of NO_x since the year 2000 accounting for rapid vehicular growth. NOx concentrations in Patna have also grown steadily and violated the standards. In rest of the cities, though the concentrations are within the standards but considering the rapid growth of vehicles, this could be of major concern in future.

Vehicular emissions are the main source of NO_x, and various measures have been taken to reduce emissions. They include introduction of advanced vehicular emission norms, improved vehicular technologies, improvements in mass transport systems etc. However, in many cases, the interventions to reduce NO_x emissions are strongly negated by the vast increase in the number of vehicles in the cities.

3.1.3 Respirable Suspended Particulate Matter

Respirable Suspended Particulate Matter (RSPM or PM_{10}) may include dust, ash or soot; or secondary particulates as products of chemical reactions in the atmosphere. Particulate matter is particularly harmful in its finer forms when it enters deep into the lungs and bloodstream. Exposure can lead to decreased lung function, respiratory problems, chronic bronchitis and heart attacks. Sources include vehicles, industries, power plants, biomass burning, road dust re-suspension etc. The levels of PM_{10} present in our six cities of study between 1999 and 2011 are given in Figure 3.3 and compared against the National Ambient Air Quality Standard for PM_{10} (60 µg/m^3). The levels of RSPM in these cities are critically high.



SOURCE NAMP, CPCB

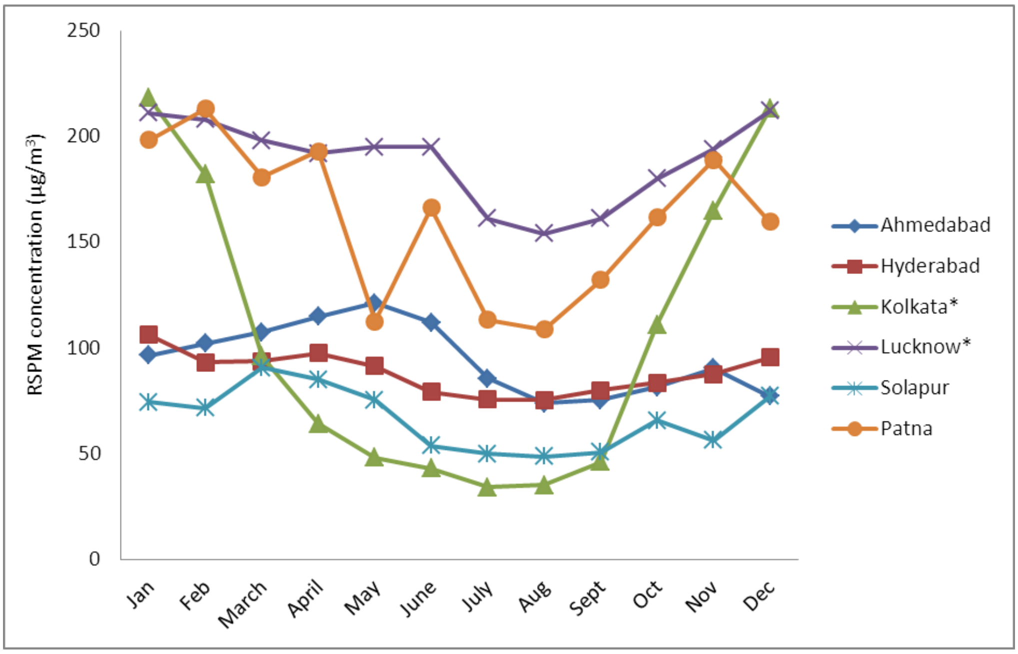
*High category is 1.5 times the standard

Figure 3.3 Annual average concentration of RSPM (µg/m³) in six Indian cities during 1999-2011

RSPM is a clear pollutant of immediate concern in these 6 cities as all of them violate the standard.

However, on a positive note, the cities of Ahmedabad and Solapur show distinct downward trend, but Patna, Hyderabad, and Lucknow have depicted increasing or steady concentrations of RSPM. The reduction in sulphur and aromatic content in the fuels have allowed for engine and combustion processes improvement and hence resulted in lower emissions of PM from vehicles.

Figure 3.4 depicts the seasonal variation in the monitored RSPM concentrations in different cities. As can be seen from the seasonal trend RSPM levels drop noticeably in almost all the cities during the monsoon season owing to the rain down-wash effect. Cities like Lucknow, Kolkata and Patna, which has a distinct winter season, shows higher concentrations mainly due to inversion conditions leading to accumulation of the pollutants.

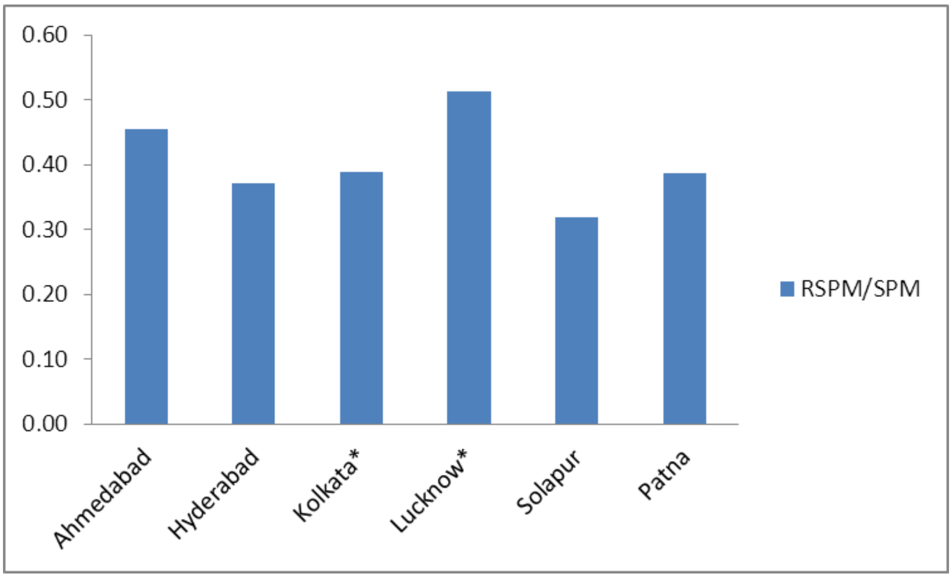


SOURCE NAMP, CPCB

Average of all stations. *2011 data

Figure 3.4 Seasonal variation of RSPM (µg/m³) in the six cities in 2010

The ratio of RSPM/SPM is shown in the Figure 3.6 for different cities. Lucknow is the highest ratio depicting higher contribution of anthropogenic activities in the dust and Solapur which is known to have higher contributions of natural sources shows the lowest ratio.



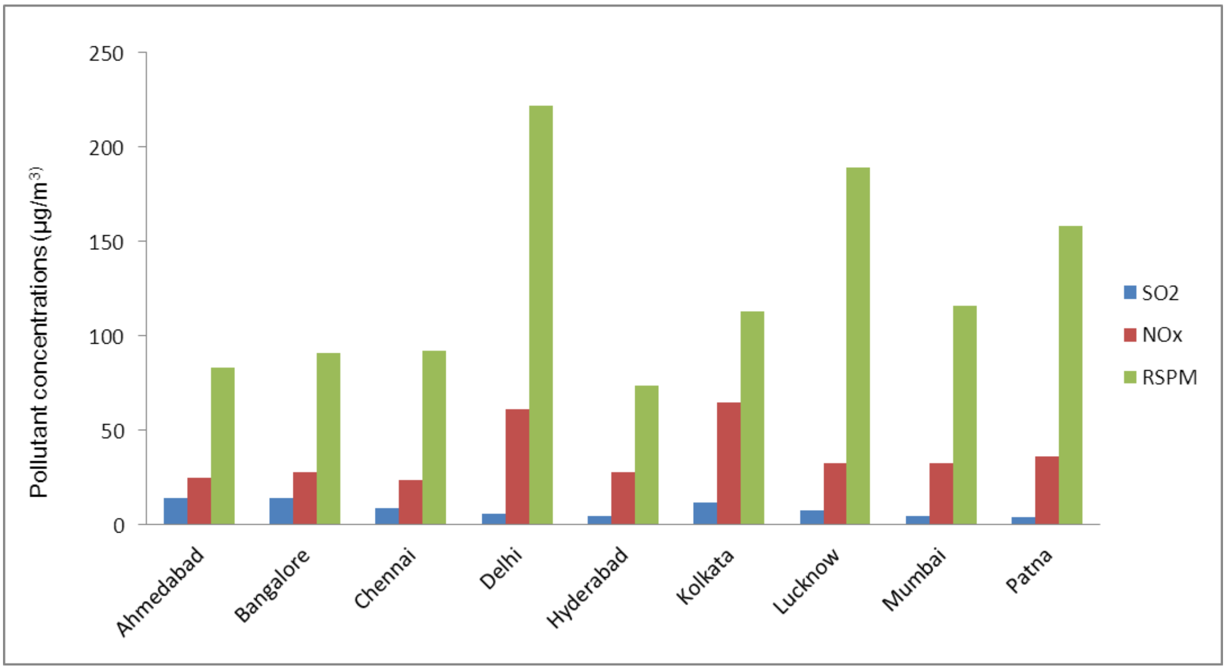
SOURCE NAMP, CPCB

Average of all stations. *2011 data

Figure 3.5 RSPM/SPM ratios across six cities in 2010

3.1.4 Comparison with other major cities

Figure 3.6 illustrates a comparison of the six cities of study with several tier -1 cities, namely Bangalore, Chennai, Delhi and Mumbai for 2008. Delhi experiences the highest RSPM levels, followed by Lucknow, Patna, Mumbai and Kolkata. Most cities have low levels of SO_2 and NO_x emissions, but all the RSPM levels exceed the annual NAAQS of 60 µg/m3.



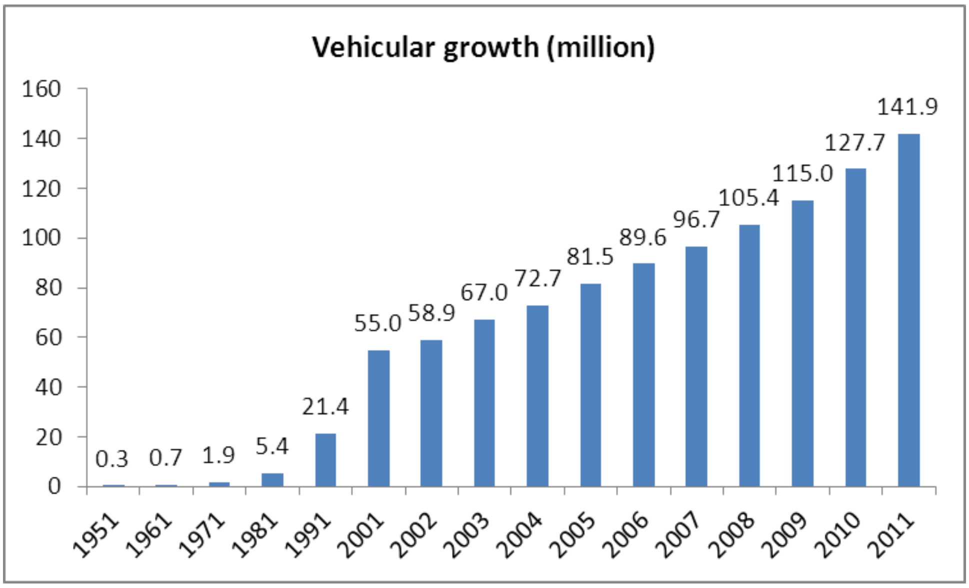
SOURCE Environmental information system (ENVIS), CPCB

Figure 3.6 Comparison of air quality in different cities in 2011

4. Vehicular growth in six cities

4.1 Vehicular growth in India

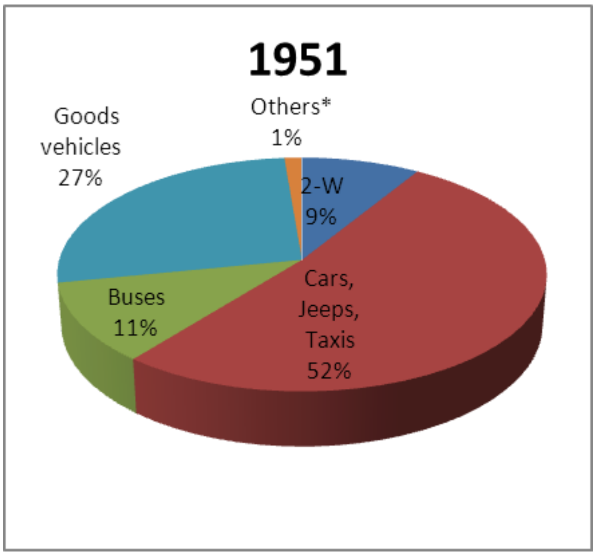
With the growth of India, mobility demands have also grown many folds. 0.3 million registered vehicles in 1951 have grown to more than about 141 million in 2011 (Figure 4.1).

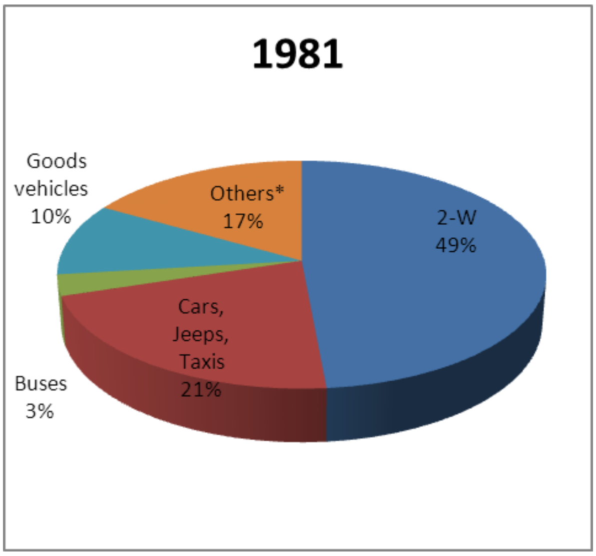


SOURCE MoRTH, SIAM

Figure 4.1 Growth of vehicles in India (1951-2011)

The growth has been phenomenal in case of two-wheelers and their share from 9% in 1951 increased to 72% in 2010. However, in the last decade, the rate of growth in number of cars has also picked up. Lack of efficient public transport system in most of cities and growing travel demands have only fuelled the growth of private vehicles in the country.





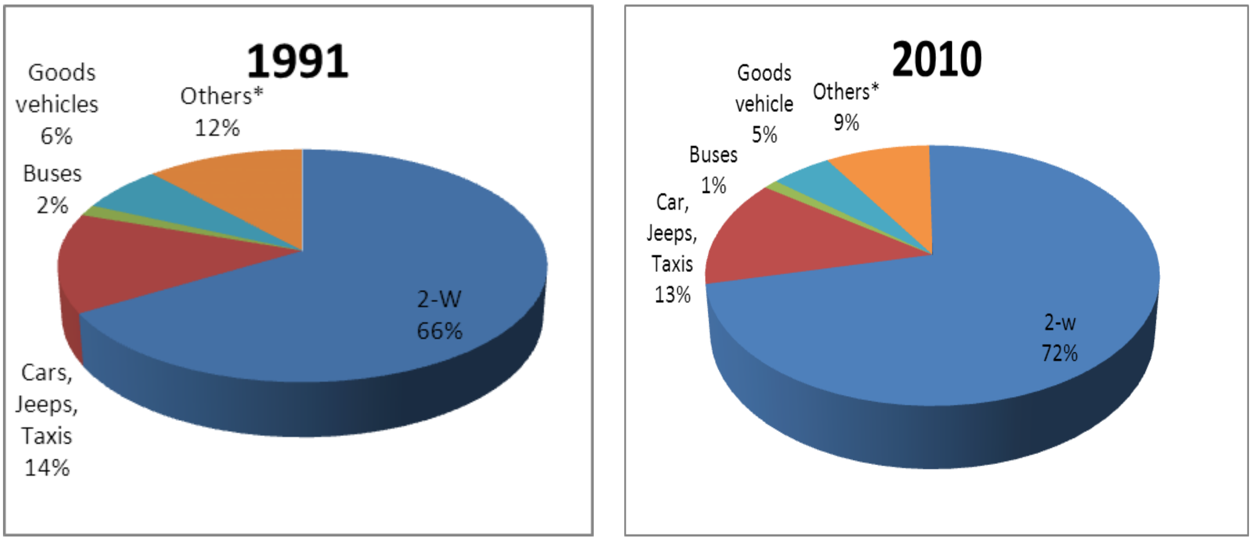
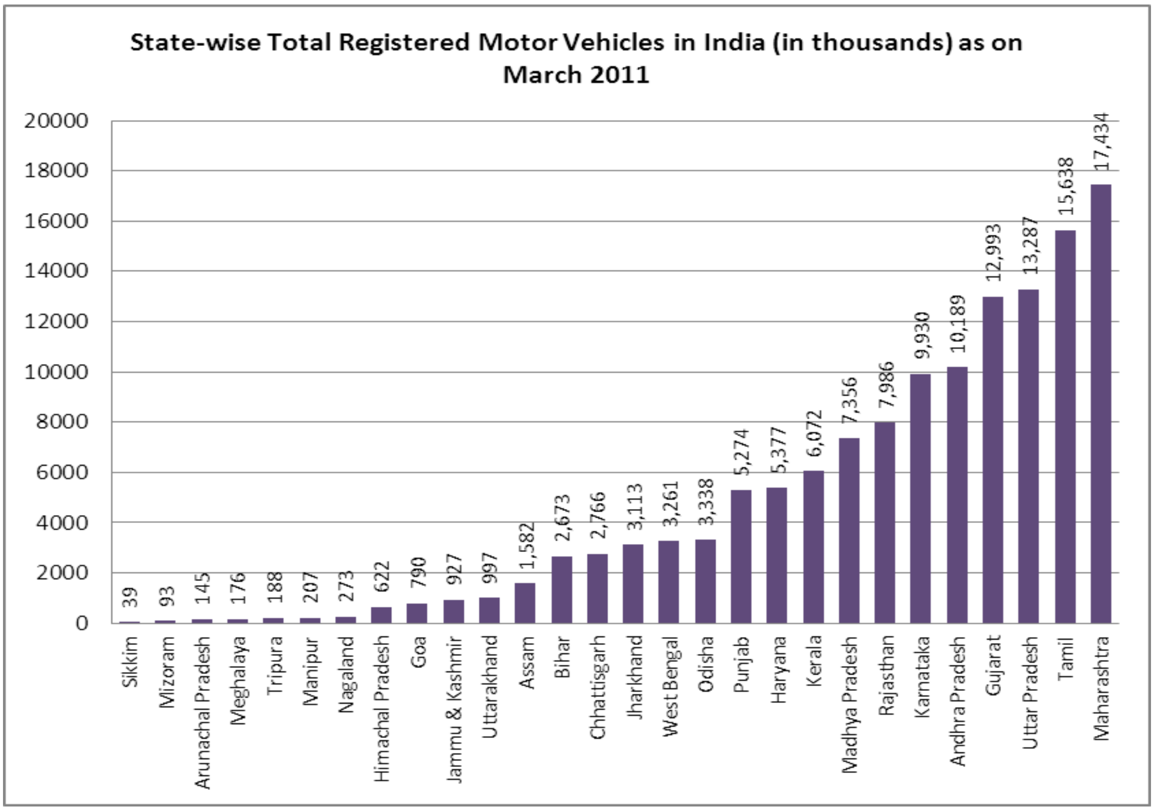


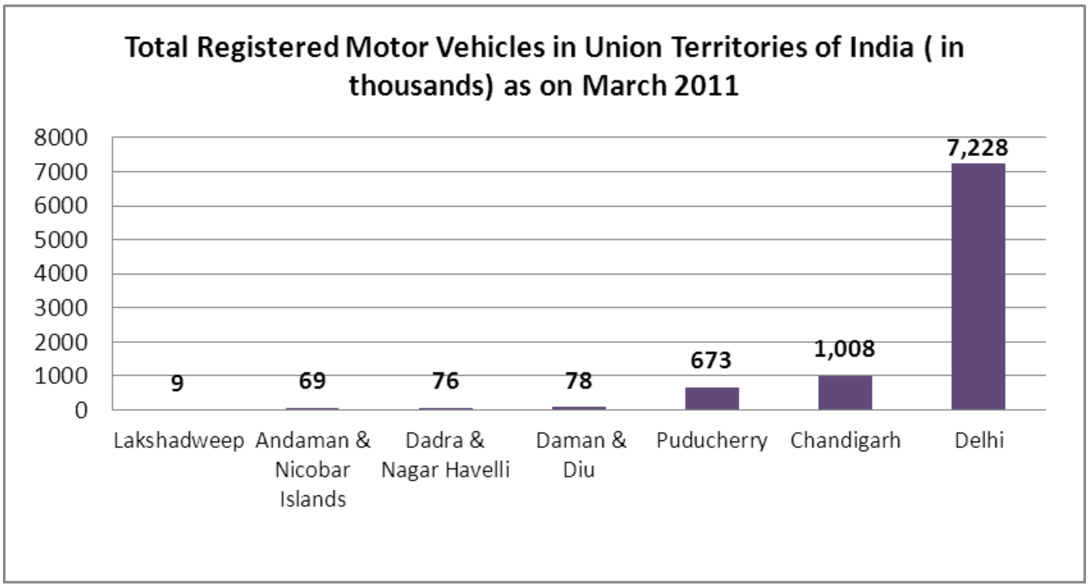
Figure 4.2 Share of different categories of vehicles in different years in India

State-wise registered vehicles in India are shown in Figure 4.3, and vehicles registered in different UTs of the country are presented in Figure 4. 4, with Maharashtra, Tamil Nadu, and U.P. topping the list.



SOURCE Road Transport Year book (2009-10) & (2010-11), Ministry of Road Transport & Highways (2012)

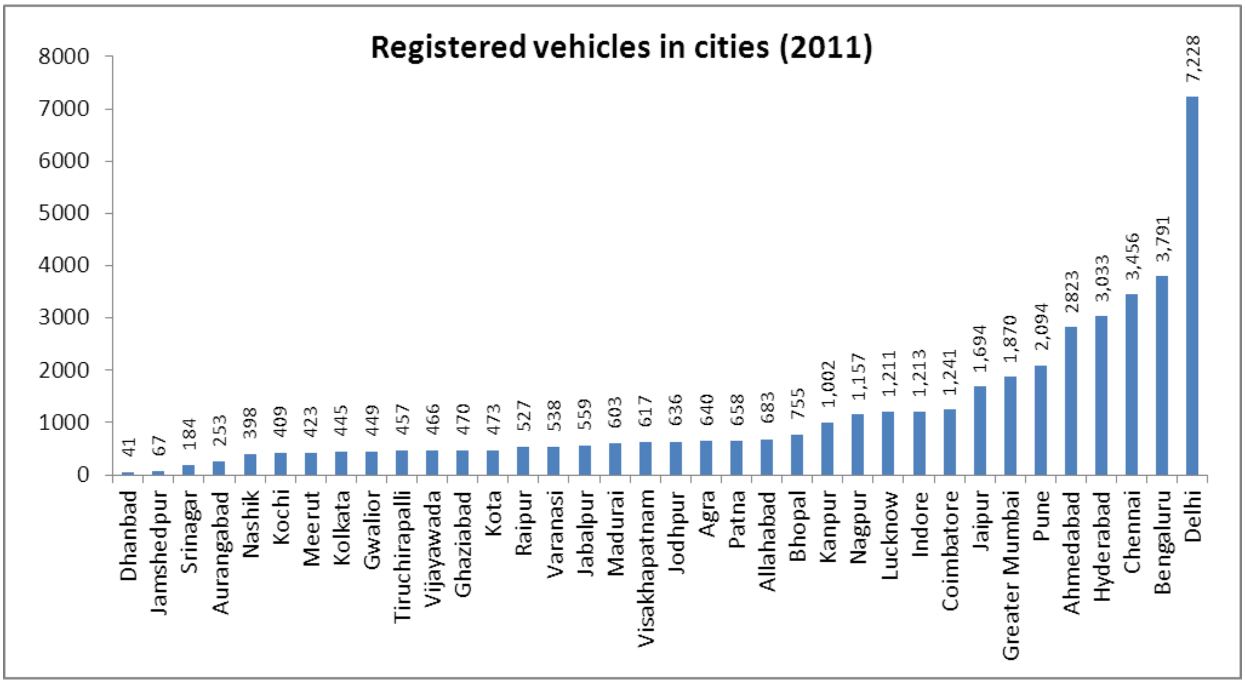
Figure 4.3 Registered motor vehicles in different states of the country in 2011



SOURCE Road Transport Year book (2009-10 & 2010-11)

Figure 4.4 Registered motor vehicles in different UTs of the country in 2011

Motor vehicles registered in various cities of the country are shown in Figure 4.5 which shows that Delhi, Bangalore, Chennai and Hyderabad have the maximum numbers. Mumbai and Kolkata show lesser numbers depicting the availability of somewhat better public transport systems.



SOURCE Road Transport Year book (2009-10 & 2010-11), Ministry of Road Transport & Highways (2012)

Figure 4.5 Motor vehicles registered in various cities of the country in 2011

Although the growth of vehicles is enormous but the number of vehicles per 1000 people in the country are still much less than the developed world (Table 4.1). It can easily be concluded that there is still lot of scope for vehicular growth in India, and as a result the automobile sector is expected to grow rapidly.

Table 4.1 Vehicular penetration in select developed & developing countries (2009)

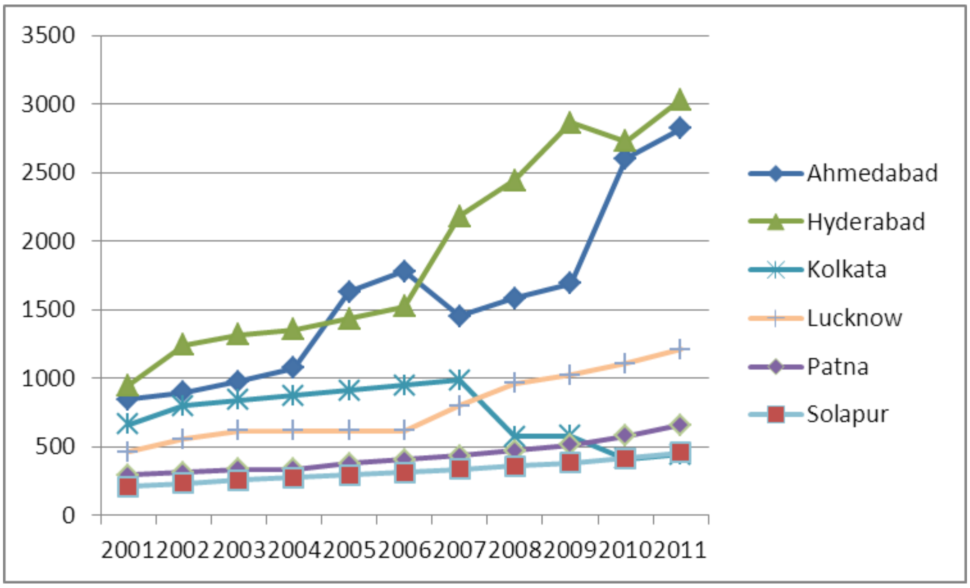
	Per 1000 person		
Country	**Passenger Cars**	**Total Vehicles***	**Two Wheelers**
Developed			
U.S.A	450.8	834.4	25.5
U.K	462.3	547.4	21
Japan	319.5	605.1	11.8
Germany	501.6	597.6	43.4
Australia	550.8	713.7	26.5
France	495.4	641.1	43.5
Developing			
Mexico	181	273.8	10.2
Malaysia	298.3	648.5	314.2
China	27.1	105.8	68.3
Korea	256.8	382.8	37.3
India	10.8	100.8	72.3

*Total Vehicles include passenger cars, buses + coaches, vans + lorries and Two wheelers

SOURCE: MoRTH 2011

4.2 Registered vehicles in 6 cities

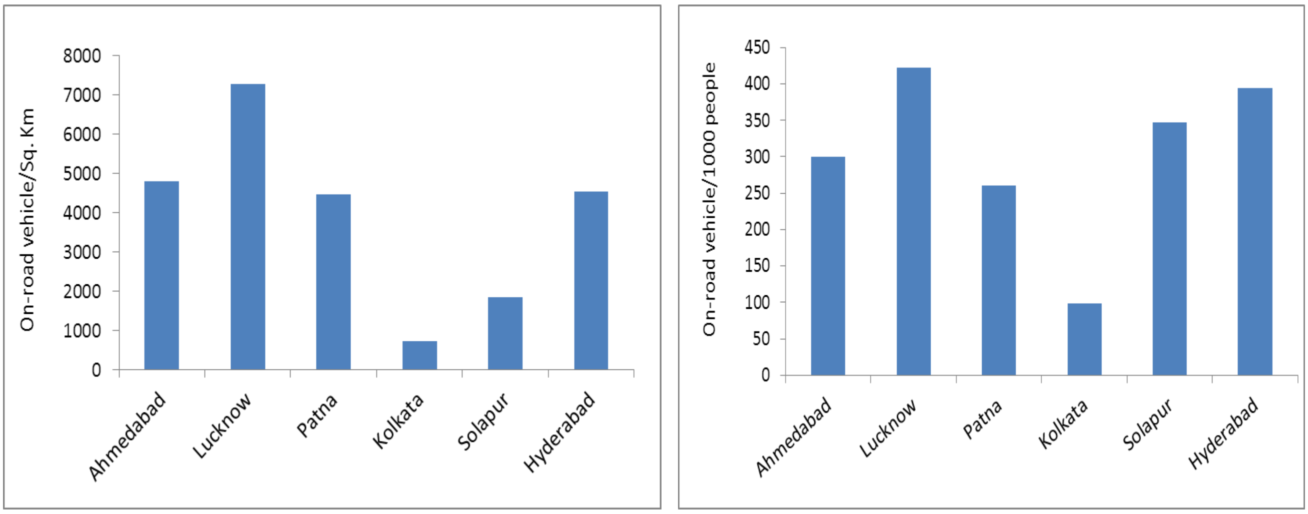
The six cities considered in the present study are the growing cities in the country. Due to increased mobility demands, the growth of vehicles has also been phenomenal. The growth of registered vehicles in the 6 cities during 2001-09 is shown in Figure 4.6.



DATA SOURCE MORTH, 2011-12, MORTH, 2009-11

Figure 4.6 Growth of registered vehicles in the 6 cities during 2001-11

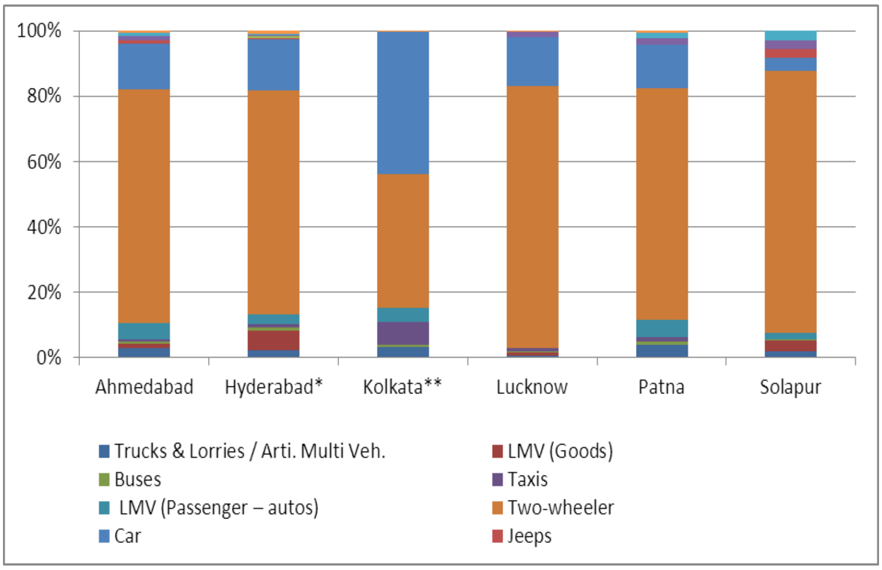
While the vehicles grew at a faster rate in Hyderabad and Lucknow (15%), negative growth was registered accounting for attrition of 15 years old vehicles in Kolkata. Other cities, Ahmedabad, Patna and Solapur registered similar growth rates in between 8-10%. The on-road vehicle per thousand population is shown in Figure 4.7.



SOURCE MoRTH, 2011 and CENSUS 2001

Figure 4.7 Number of estimated on-road vehicles per thousand people residing in the six cities in 2009

The distribution of vehicles in the 6 cities is presented in Figures 4.8, which shows that there is a dominance of number of two wheelers in these cities except Kolkata, where the share is just 31%. Share of cars including taxis in the total vehicular fleet is very high in Kolkata (38%) and just 7% in Solapur. Share of buses is less than 2% depicting absence of an efficient bus-based public transport system in most of the cities.



SOURCE MoRTH, 2011

Figure 4.8 Category-wise distribution of vehicles in the 6 cities

Category wise total registered vehicles in the six cities are presented in Table 4.2.

Table 4.2 Category wise registered vehicles in the 6 cities as on March, 2012

Categories	Ahmedabad	Hyderabad*	Kolkata**	Lucknow	Patna	Solapur
Trucks & Lorries / Multi-axled/Articulated Veh.	22741	120718	15235	6683	28776	8811
LMV (Goods)	43408	96642	(a)	14452	(a)	15602
Buses	25961	27686	4316	3098	6020	598
Taxis	8261	32917	31807	6195	10666	864
LMV (Passenger – autos)	83752	125485	19429	7195	37007	8852
Two-wheeler	1213454	2370955	202602	1052717	505940	366327
Car	239558	558081	222069	183288	98425	17908
Jeeps	18254	8975	(b)	16932	26604	12329
Omni buses	…	28855	…	181	…	
Tractor	13073	7019	(c)	19012	15070	13096
Trailers	7694	1691	46	1361	10160	12669
Others	5955	7551	802	3591	4221	165
Total	1682111	3386575	496306	1314705	742889	457221

SOURCE MoRTH 2012
**: Live vehicles after cancellation of vehicles registered prior to 1.1.1993
…: Not reported
(a) : Included in Multiaxled/Articulated vehicles
(b) : Included in cars
(c) : Included in Trailers

5. Methodology for conducting traffic surveys

In the present study, vehicular activity in different cities has been assessed using three types of vehicle surveys. Traffic count surveys were carried out to assess travel demand in the city based on actual on-road vehicles. Parking lot surveys were conducted to assess the distribution of vehicles (based on type, vintage, model and fuel), their usage, occupancy and maintenance practices within the city. Finally, global positioning system (GPS) based surveys were carried out to study the driving patterns of different vehicles based on the city characteristics. Details of the methodology followed for conducting these surveys are explained in subsequent sections.

5.1 Traffic volume count surveys

Traffic volume count surveys are conducted to measure the volume of traffic on the city roads for a given interval of time.

The purpose of carrying out the traffic volume count in this study was to use the data collected from the surveys to estimate the traffic volume on-road in the six selected cities. Manual method for traffic counts has been used. 'Manual methods use field personnel to count and classify traffic flowing past a fixed point' (Kadiyali, 1997). Data was collected for each direction of travel.

An analysis was then carried out to assess number of different category of vehicles plying on various types of roads on a given day. Eight different landuse categories including residential (high, medium and low densities), commercial, industrial, mixed etc., were chosen in each city to carry out traffic counts on various types of roads. A representative sample of traffic counts was collected from major, connector and minor roads in the different landuse categories in the cities. Based on traffic count, vehicle kilometer travelled (VKT) for different categories of roads were estimated using road length of the respective road categories (CPCB, 2010).

VKT = Traffic count (Major or minor roads) x Road length (Major or minor road)

The VKT estimated from this approach was compared with the VKT estimated from registered vehicles data.

VKT = Registered vehicles x daily km travelled (parking lot survey)

Difference in the two approaches is expected on account of

a) Outside registered vehicles plying in the city
b) Older vehicles registered in the city not plying anymore
c) Registered vehicles moving out of the city etc.

5.1.1 Survey locations

Traffic counts were carried out on samples of representative arterial (primary arterial[4] and secondary arterials[5]) connector (larger urban roads linking local roads to the arterial

4 Main roads other than motorways and expressways joining significant centres of population and/or providing for national and inter-regional traffic flow

5 Roads joining smaller and larger centres of population to nearby primary arterials or linking between primary arterials

network)[8] and local roads (roads providing direct access for residential and other areas of development in urban areas)[6] in the selected cities. Number of roads in each category of roads was decided based on:

- Consultations with city –level authorities and local transport experts.
- Secondary literature review (city development plans, comprehensive mobility plans, and master plans etc.)

Certain characteristics like road network, population density, land use patterns and other factors impacting traffic flow has also been taken into account to ascertain the number of roads to be surveyed in each city.

5.1.2 Frequency of sampling

To start with, a preliminary traffic count survey at 2 locations in each city was carried out for 7 days. Standard deviations within the days were calculated for different locations.The standard deviation was found to be within the satisfactory range and hence the traffic count surveys were carried out for two days in each city. Representative sample was taken for each hour of the day to estimate traffic count on a certain type of road in each city.

5.2 Parking lot/fuel pump Survey

Parking lot surveys are carried out to understand the existing fleet of vehicles and there mobility patterns. It is an important step to estimate emissions from the road transport sector. While number of vehicles playing in a city can be estimated using the RTO data or traffic count surveys, but the distribution of vehicles as per the models, fuel-mix, technology and vintages can only be studied using the results of the parking lot surveys. The surveys also reveal the daily distances travelled by different categories of vehicles in various cities. This depends on city characteristics like landuse, topography, income levels, and availability of public transport etc.

In the current project, parking lot surveys were carried out in all 6 cities. The parameters studied includes: model and make of vehicles, vintage, technology, fuel used, average daily distance travelled, occupancy, mileage etc. A questionnaire was developed to conduct the survey (Annexure I), which was initially pilot tested and improved, before employing it for actual surveying.

Results of surveys were used to distribute the vehicles into subcategories based on their technology and vintage. Total travel demand in the cities in terms of VKT (vehicle kilometer travelled) and PKT (passenger kilometers travelled) were estimated using survey outputs.

Parking lot surveys were done at several locations to represent the fleet of the vehicles in a city. Sample size for carrying out the surveys was decided based on the following factors:

1. Minimum acceptable level of precision (95%)
2. Confidence interval (5%)
3. Time and resources available

Sample size was calculated using following formulae (Cochran (1977):

$$ss = t^2 * (p) * (1 - p) \div c^2$$

6 Transit Planning Policy Manual Version 1, http://www.nzta.govt.nz/resources/planning-policy-manual/docs/planning-policy-manual-appendix-3A.pdf

ss : Sample size

t : t value (1.96 for 95% confidence level or 0.05 alpha value)

p : percentage picking a choice, expressed as a decimal (0.5 used for sample size needed), p* (1-p) is measure to estimate variance and will produce the maximum possible sample size when both are equal i.e. p = 1-p = 0.5. So, sample size obtained by assuming p = 0.5 is big enough to ensure precision.

c : confidence interval, expressed as decimal or acceptable margin of error

Alpha value (t) represents the level of risk the researcher is willing to take that true margin of error may exceed the acceptable margin of error. In most of the research studies alpha level of 0.05 or 0.01 is used (Bartlett et. al., 2001) and in Cochran formula, alpha level is incorporated by using t value based on selected alpha level.

If sample size exceeds 5% of population, following correction factor is applied

Correction factor

$$New\ ss = ss \div \{1 + ss \div pop\}$$

Where

pop: Population

In the present context, 95% precision with ±5% confidence interval (for categorical data, 5% confidence interval or margin of error is assumed (Bretlett et. al., 2001)) was used to estimate minimum sample size for parking lot surveys in different cities. Based on recent registered vehicles, data sample size calculations has been done for all six cities. A sample size of about 4000 different categories of vehicles was taken to carry out the questionnaire based parking lot surveys in each city.

5.3 GPS based surveys for driving patterns

Driving cycle is a sequence of vehicle operating conditions (idle, acceleration, steady state and deceleration) developed to represent typical pattern in an urban area. In India, driving cycle (IDC) was developed by Gandhi et. al., in 1983 to quantify fuel consumption based on field study in Delhi (Nessamani and Subramanian 2006). Later in 1985 , ARAI collected extensive data in Mumbai, Chennai, Bangalore and Pune to develop standardized /legislative IDC. From 2000 onwards, India has adopted Modified Indian Driving Cycle (MIDC) for cars.

Neesamani and Subramanian in 2006 had observed the driving profile in Chennai city and compared it with the IDC. Study has shown that IDC differs considerably from real world driving conditions. Real world driving has frequent speed fluctuations and sharp acceleration and de-acceleration as compared to IDC. According to Gunsler, 1993 these sharp fluctuations in driving patterns could increase emission rates by increasing the air to fuel ratio.

In present study driving patterns was studied by using private vehicles driven by professional drivers. GPS based instrument was used to ascertain variations in speed and altitude while traversing the city roads.

The GPS surveys were carried out for three types of vehicle categories i.e. 2-wheelers, cars and buses. Driving patterns followed by the three vehicle categories in the different cities were monitored using the speed, acceleration and topographical profiles. Significant share of road lengths were traversed to collect a representative sample of driving patterns in each city.

Survey was carried out on weekdays and it was ensured that there were no unusual conditions that could induce abnormal traffic characteristics in the selected corridors during the surveys.

Vehicles with GPS based tracking devices were driven in traffic flow to record second-by-second positional information and topography. Since test vehicle travelled at representative speed of traffic, actual traffic profile has been captured. A second person along with driver was also present to note down the starting and ending time of each trip which was then matched with the GPS time, odometer readings and durations. At the end of each day, trip data was downloaded and quality of collected data was checked and finally used for analysis.

Information collected using these surveys have been used in the IVE model for emission estimation in all the six cities.

6. Traffic surveys

Traffic surveys in the cities were conducted in two phases: reconnaissance and actual survey phase. The results of traffic surveys conducted in the six cities are presented in this chapter.

6.1 Reconnaissance survey

Traffic surveys which are the primary data collection component of this study were initiated with reconnaissance surveys in all the six cities. During each reconnaissance visit the concerned state pollution control boards, municipal authority / corporation, oil companies, and transport department, etc. were contacted. The project objectives were explained to them in detail to get their opinion about survey locations as well as for collecting requisite secondary data. Since the local authorities have good knowledge about the city, they were approached for selection of appropriate survey sites in the respective cities. Reconnaissance surveys also helped in understanding the traffic movement in the cities, major traffic location, type of vehicles, fuel usages etc. Landuse patterns were also visually seen to finally select surveys locations in different land-uses. Secondary datasets such as air quality data at local air quality monitoring stations, data of annual registration of vehicles, oil consumption data, landuse and road network maps of the cities, or any other pre-existing relevant information was collected during the reconnaissance visits

Figure 6.1 Traffic movement during reconnaissance visit in Patna

6.2 Road selection using spatial analysis

Spatial data, such as road network of each city, land-use (LU) patterns and administrative boundaries were collected from the respective local authorities during the reconnaissance survey, and these were further digitized using GIS software. The municipal boundaries of the six cities were identified as the study domain which was divided into grids of 2x2 km^2 using GIS. The administrative (ward) boundary map and the road network map of the city were then overlaid over the selected study domain. This led to the recognition of landuse patterns, road lengths, population and other important attributes in all the different grids of 2x2 km^2.

The overlay of landuse map over the study domain identified the predominant land-use of different grids. Based on this, all the grids in the study domain were categorized in to different land-use land cover (LULC) classes, which are:

1. Residential
   a) Highly populated (RH)
   b) Moderately populated (RM)
   c) Less populated (RL)
2. Commercial (C)
3. Industrial (I)
4. Mixed (M)
5. Public purposes (PP)
6. Others (O)

Considering higher number of grids falling in the residential landuse category, it is sub-divided into three types based on their population densities (RM, RH, and RL). From the entire study area, eight representative grids were selected covering each type of land-use categories. Figures 6.2a, b, c, d, e and f show the eight grids falling under different land-use/population categories in Ahmedabad, Lucknow, Kolkata, Patna, Hyderabad and Solapur respectively. Three different categories of roads (arterial, connector and local) were selected in each of the identified grids representing the different landuse categories for conducting traffic count surveys.

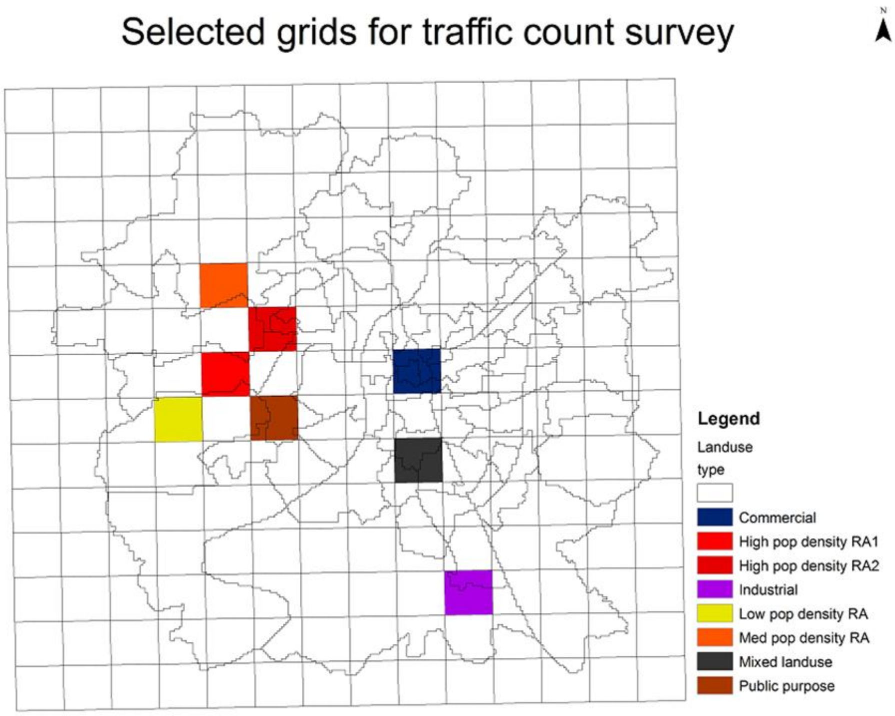


Figure 6.2a Selected grids for traffic count surveys in the city of Ahmedabad

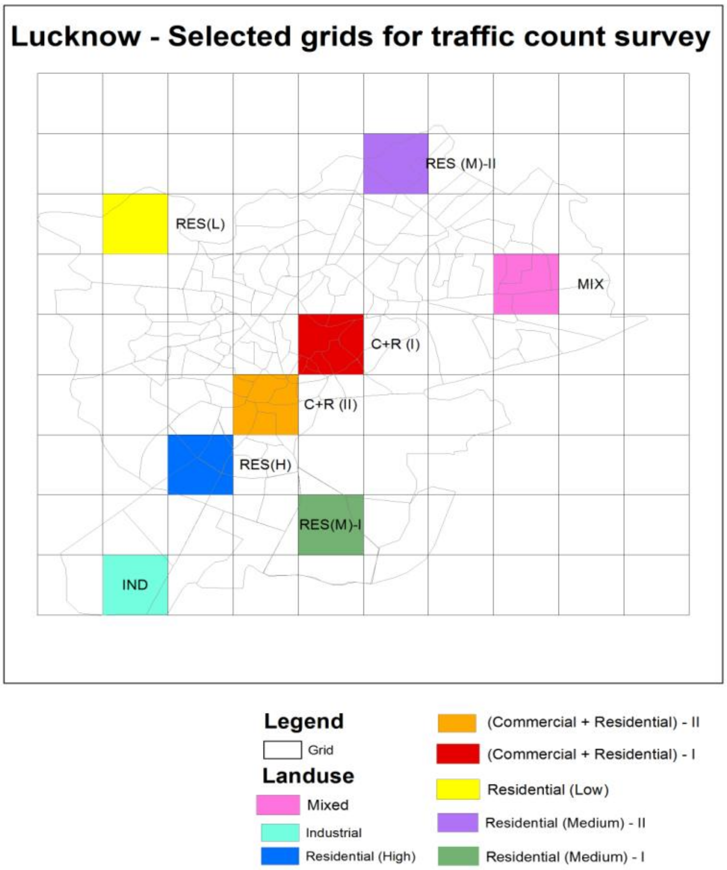


Figure 6.2b Selected grids for traffic count surveys in the city of Lucknow

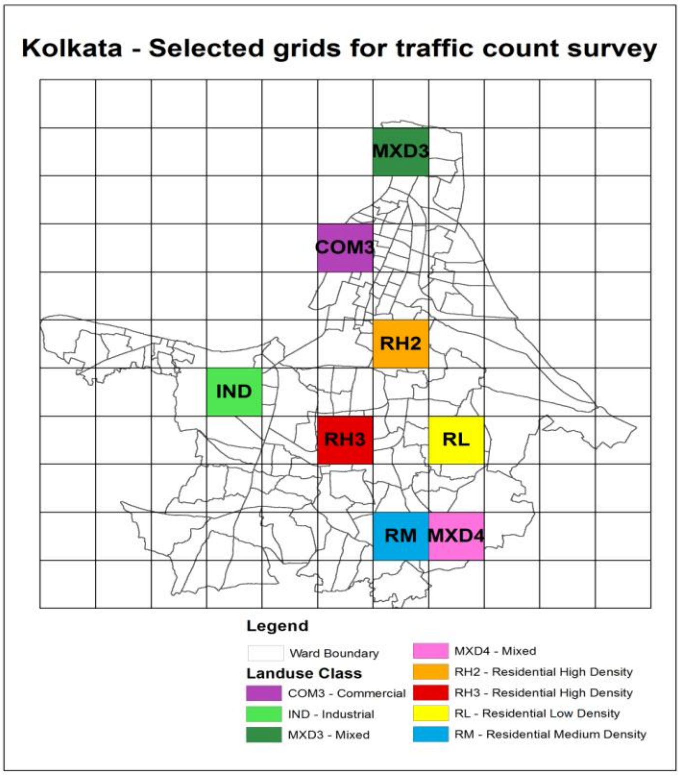


Figure 6.2c Selected grids for traffic count surveys in the city of Kolkata

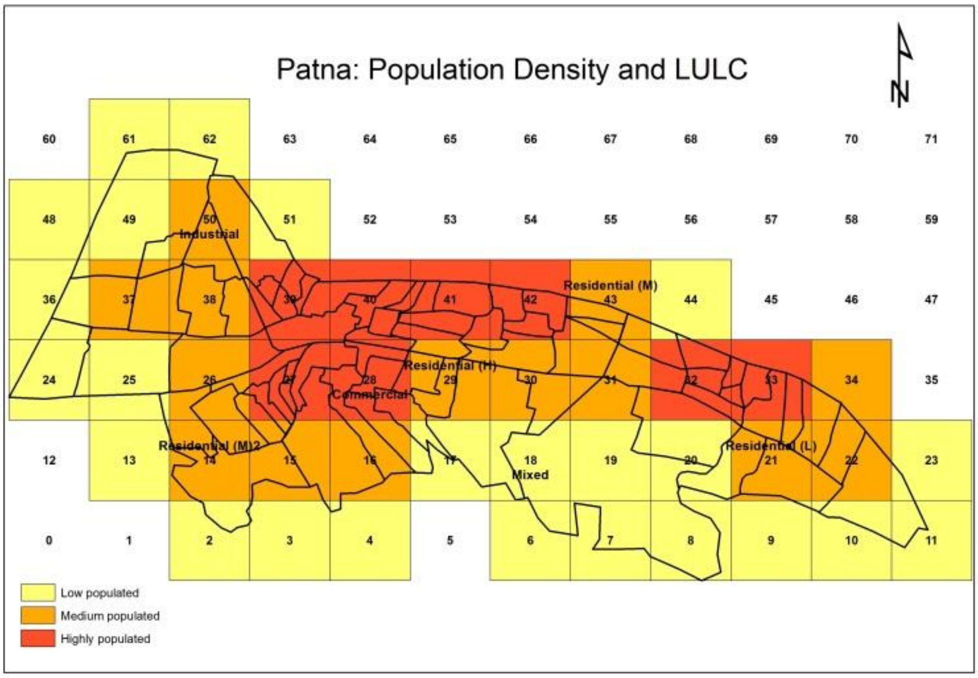


Figure 6.2d Selected grids for traffic count surveys in the city of Patna

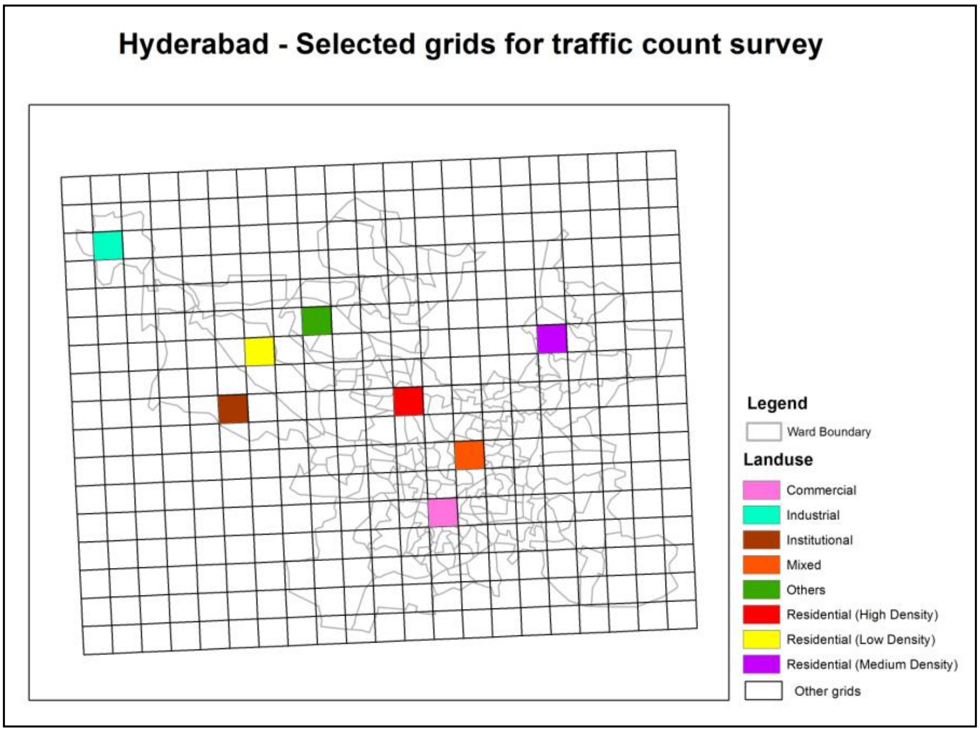


Figure 6.2e Selected grids for traffic count surveys in the city of Hyderabad

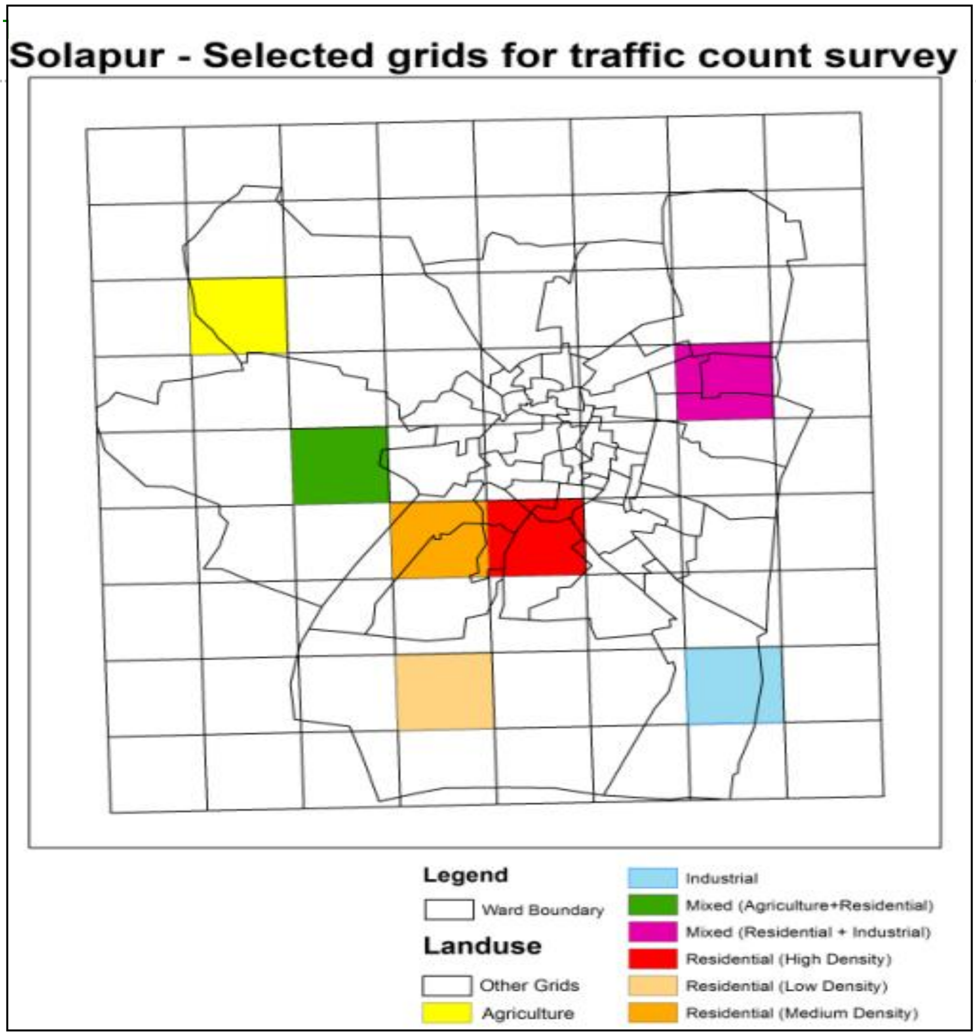


Figure 6.2f Selected grids for traffic count surveys in the city of Solapur

Eight selected grids of different land-use were studied for their road networks. The road network in all the cities was digitized using Google earth and ArcGIS. Further all the roads were classified into one of the three categories, namely: arterial, connector and local based on their properties (refer to section 5.1.1). Based on the overlaid road network map on the study domain and actual visual inspection of the sites, 24 locations (3 in each grid) were selected to carry out the actual traffic count surveys. Figures 6.3a,b,c,d,e and f show the overlaid map of road network over the gridded map of Ahmedabad, Lucknow, Kolkata, Patna, Hyderabad and Solapur city respectively.

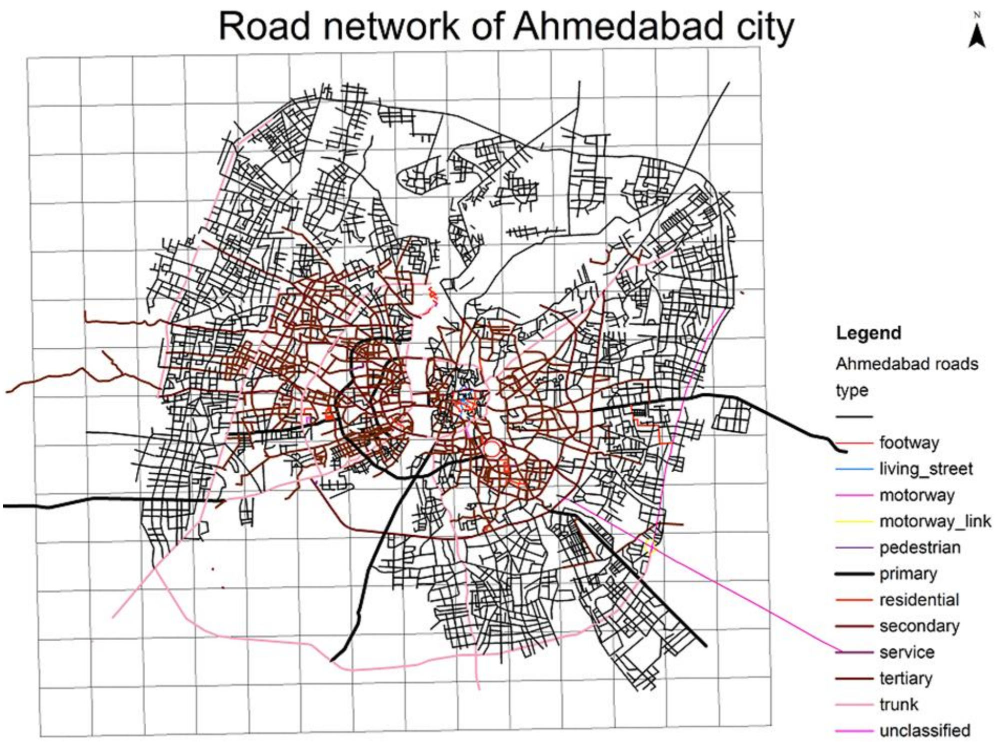


Figure 6.3a Road network of Ahmedabad city

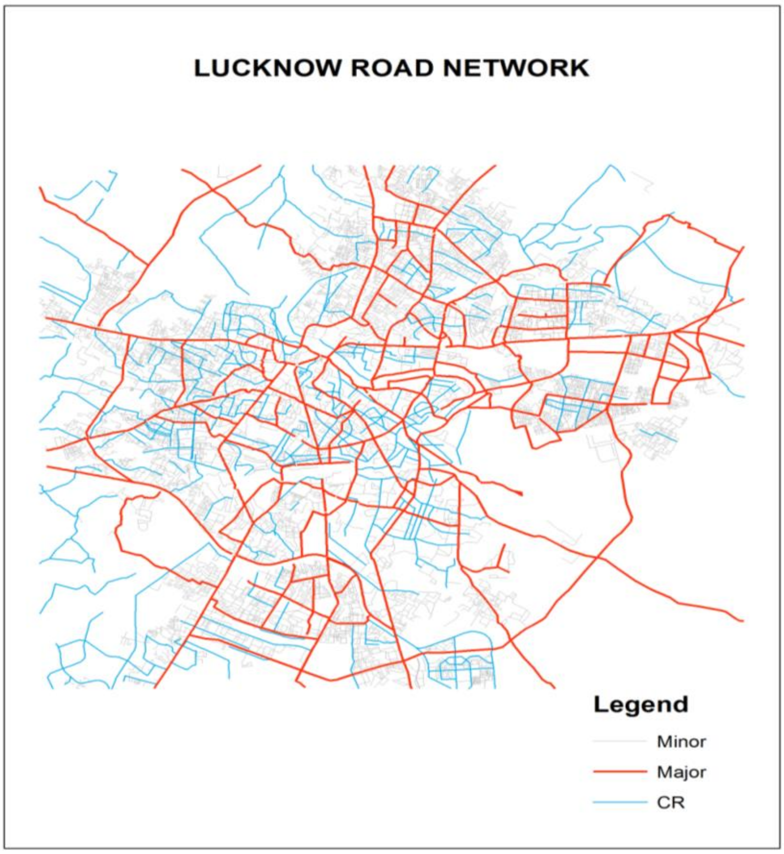


Figure 6.3b Road network of Lucknow city

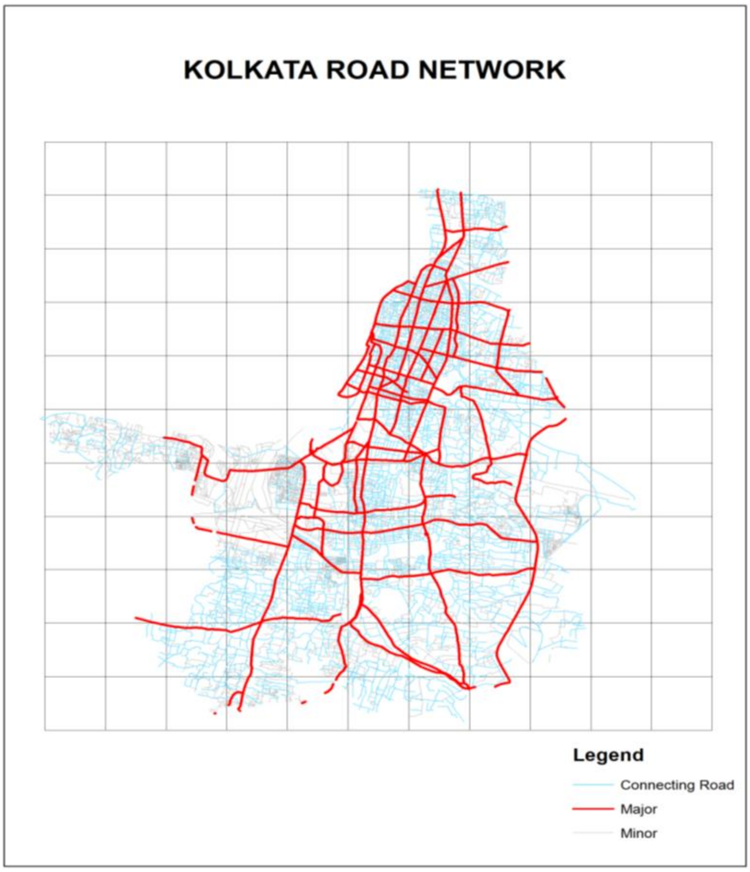


Figure 6.3c Road network of Kolkata city

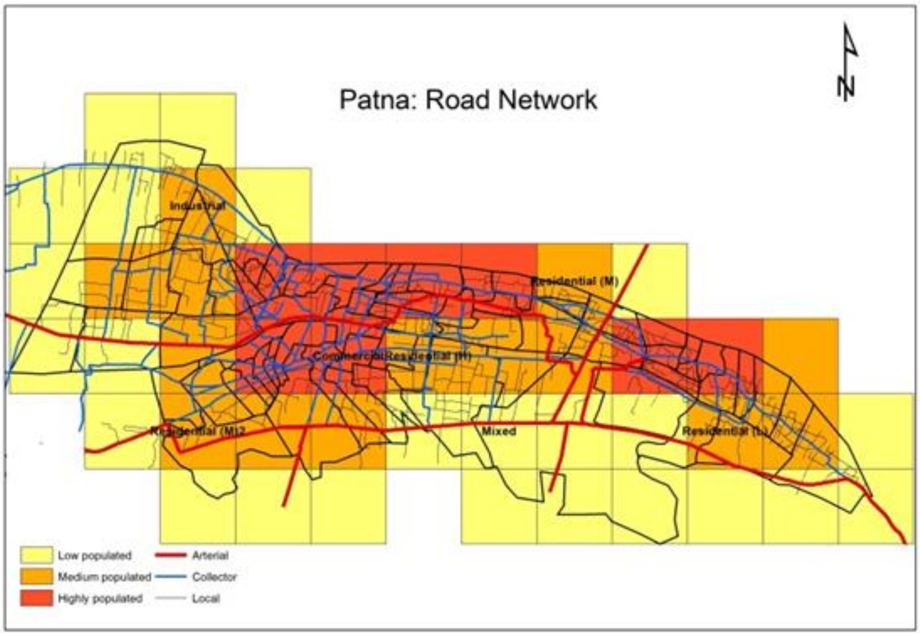


Figure 6.3d Road network of Patna city

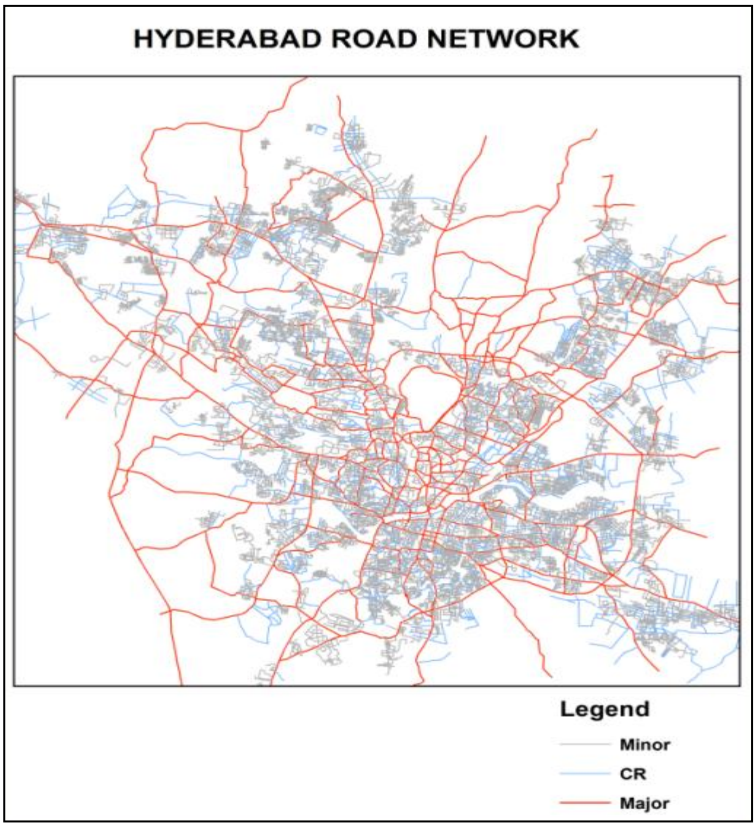


Figure 6.3e Road network of Hyderabad city

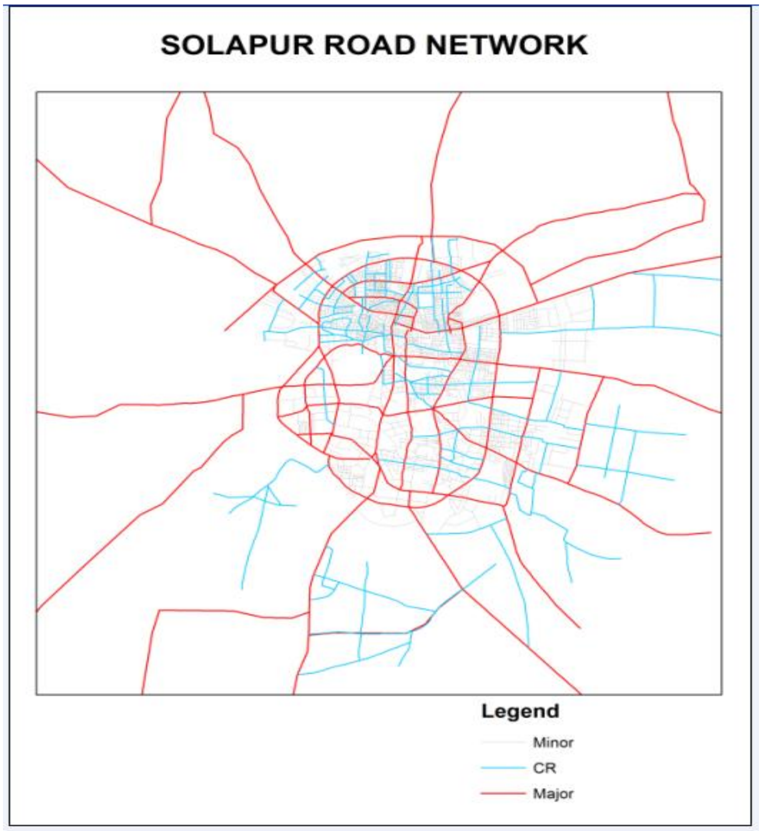


Figure 6.3f Road network of Solapur city

6.3 Traffic survey results

Traffic count survey was carried out by manual counting method through a team of surveyors. In each of the location, traffic count data was collected in both directions (up and down traffic). Representative sample was taken for each hour of the day to estimate the total traffic volume flowing in 24-hours through a road mid-block. In addition to these, parking lot surveys were also carried out to understand the vehicular distribution and daily kilometres travelled.

The report presents the results of the traffic survey conducted in all six cities.

6.3.1 Traffic count survey

The following figures shows the traffic count surveys carried out in the year 2012 at various locations in different cities.

Figure 6.4 Traffic count and parking lot surveys in different cities

6.3.1.1 Variation of traffic across different roads and land-uses

The results of traffic count survey show that the traffic volume at the arterial roads was the highest followed by other category roads (Figure 6.5). Arterial roads in Hyderabad show the highest number of vehicles across the six cities, followed by others. Kolkata shows the lowest number of vehicles as also seen in its statistics of registered vehicle data. The number of vehicles per thousand population in Kolkata is also much less than the other cities (Figure 6.6). The vehicular density (number of vehicles/km^2 area of the city) is found to be highest for Lucknow which also is evident in the higher traffic counts observed on different roads.

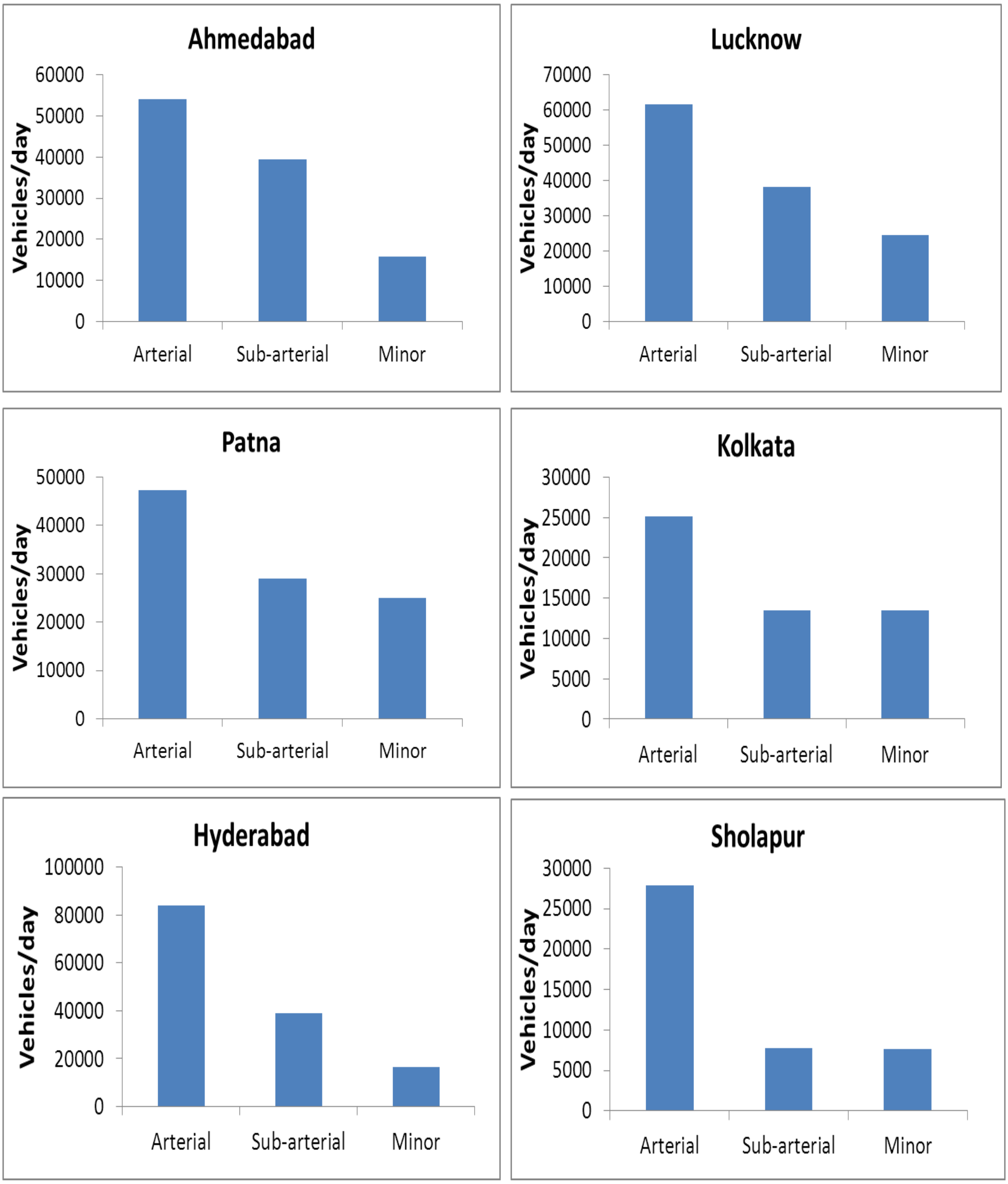


Figure 6.5 Average vehicle volume at different road types, on weekdays in different cities

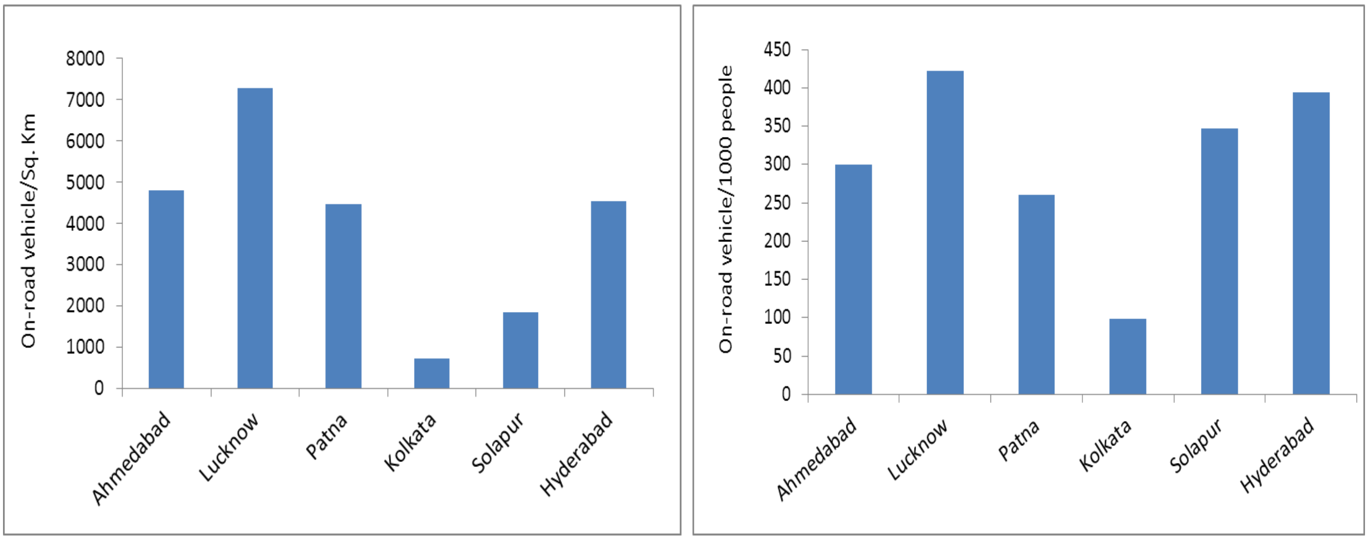
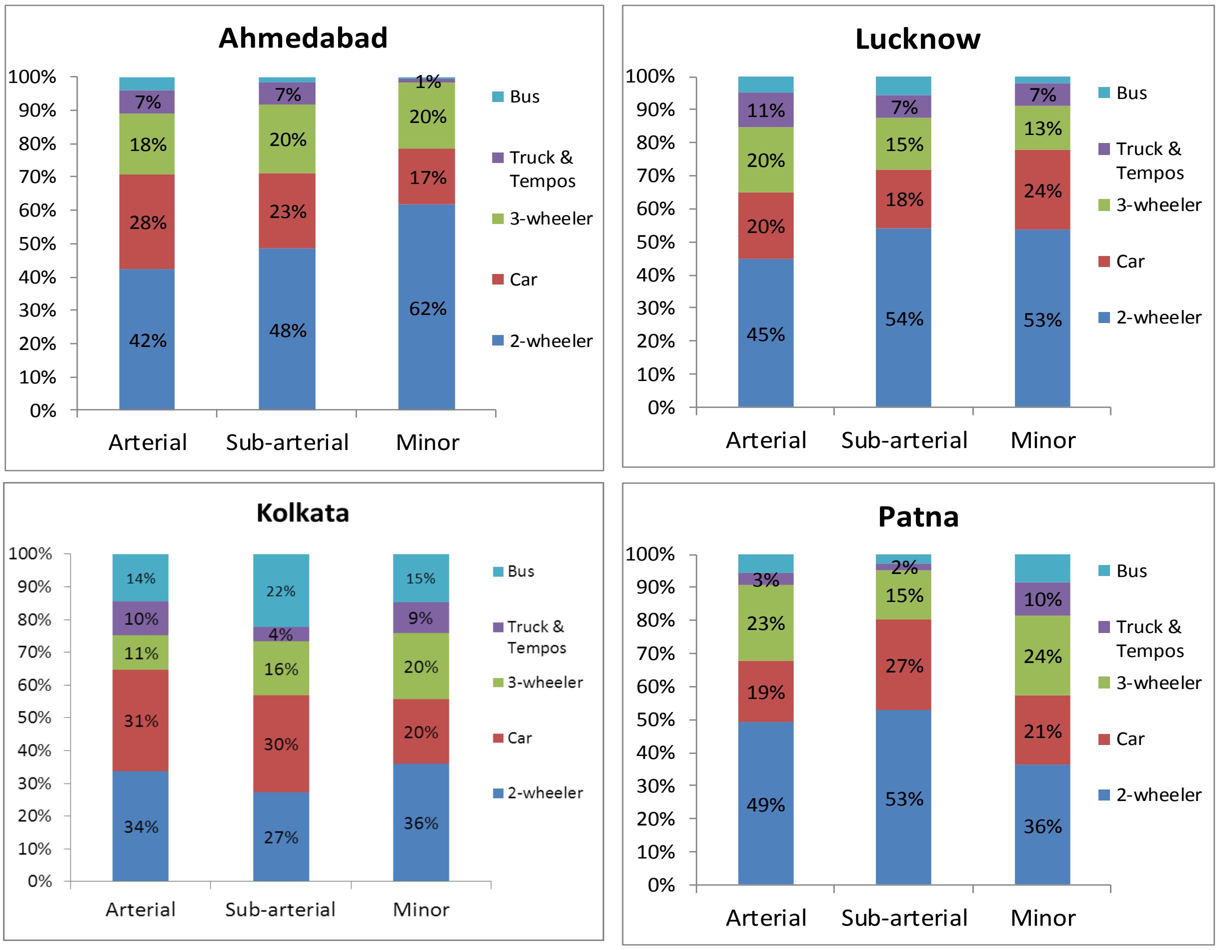


Figure 6.6 Vehicles per 1000 people and per sq. km in different cities

Figure 6.7 shows the category wise distribution of vehicles on different types of roads in various cities. The share of two wheelers is found to be highest followed by cars, three wheelers, truck & tempos and buses. Also, higher number of buses and trucks are found on the arterial and sub-arterial roads as compared to minor roads. The share of buses is found to be considerably higher in Kolkata showing the public preference towards public transport.



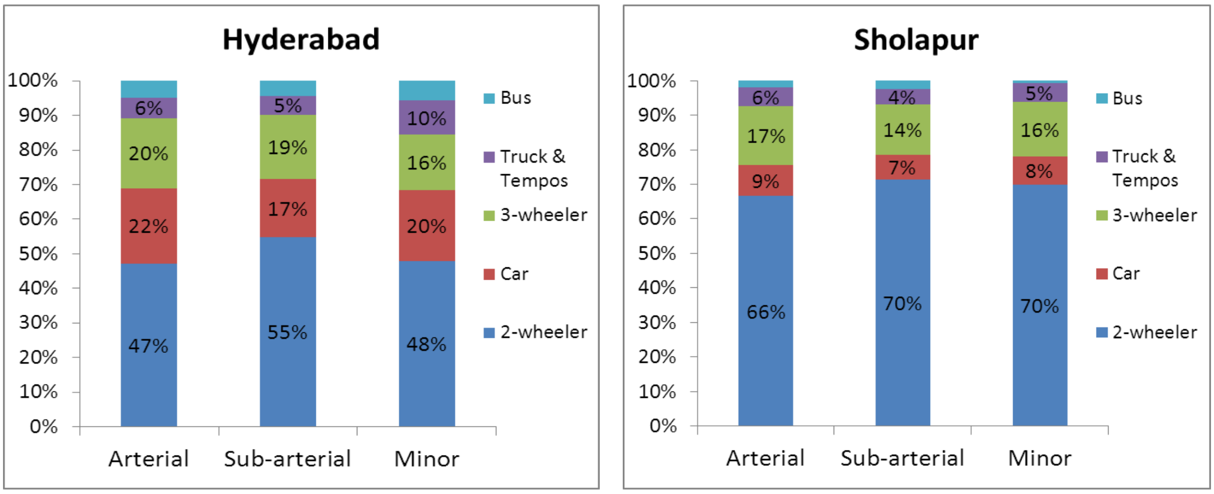
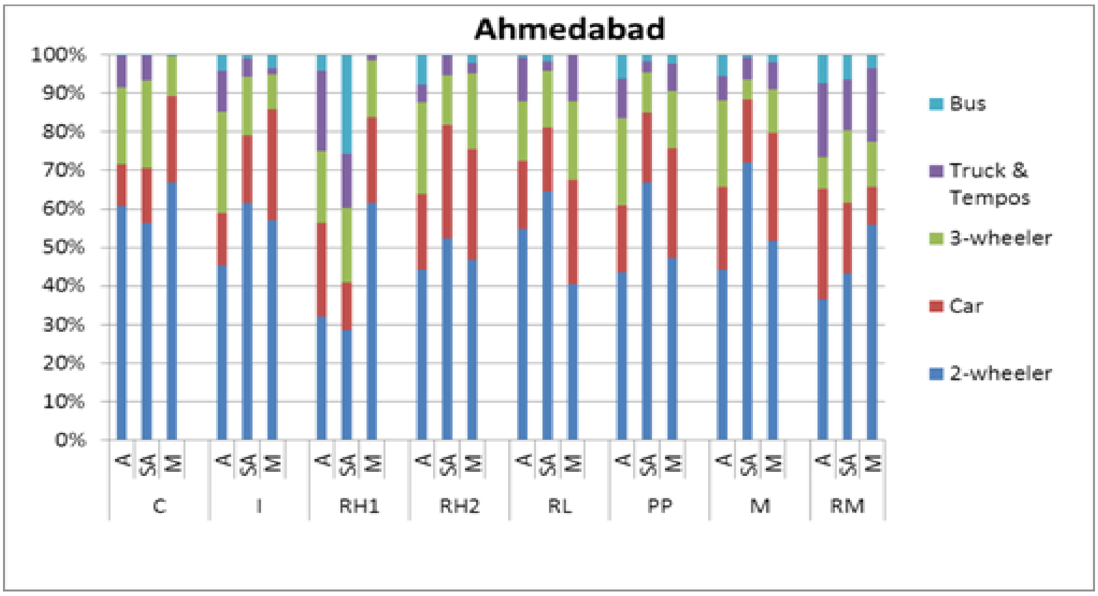


Figure 6.7: Category wise distribution of vehicles on different types of roads in various cities

Landuse-wise distribution of vehicles in different cities is shown in Figure 6.8. Higher numbers of heavy vehicles are depicted in the industrial zones.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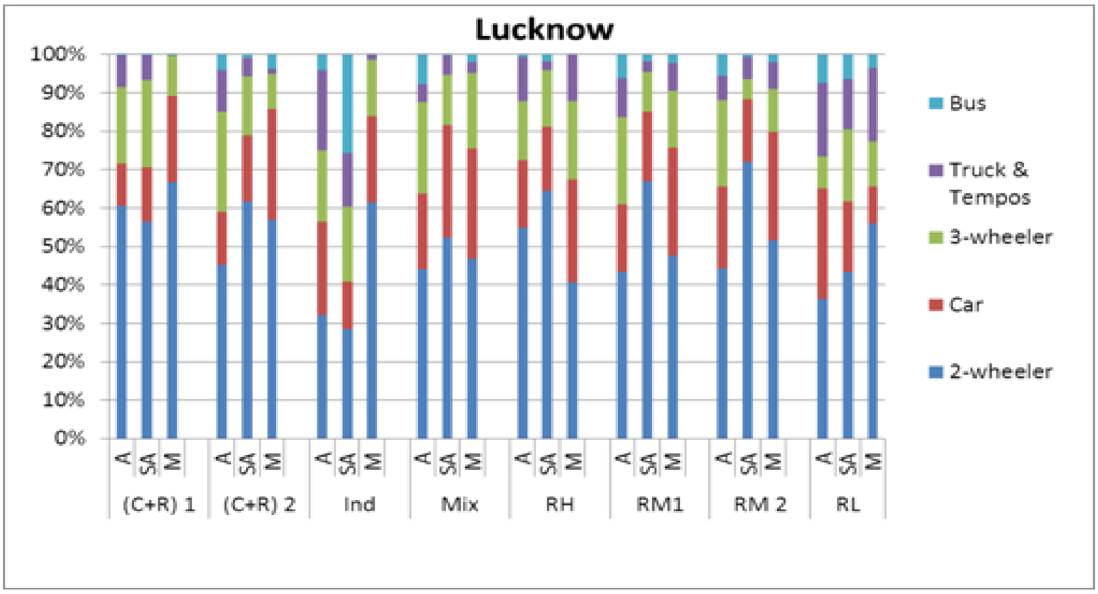
Car
2-wheeler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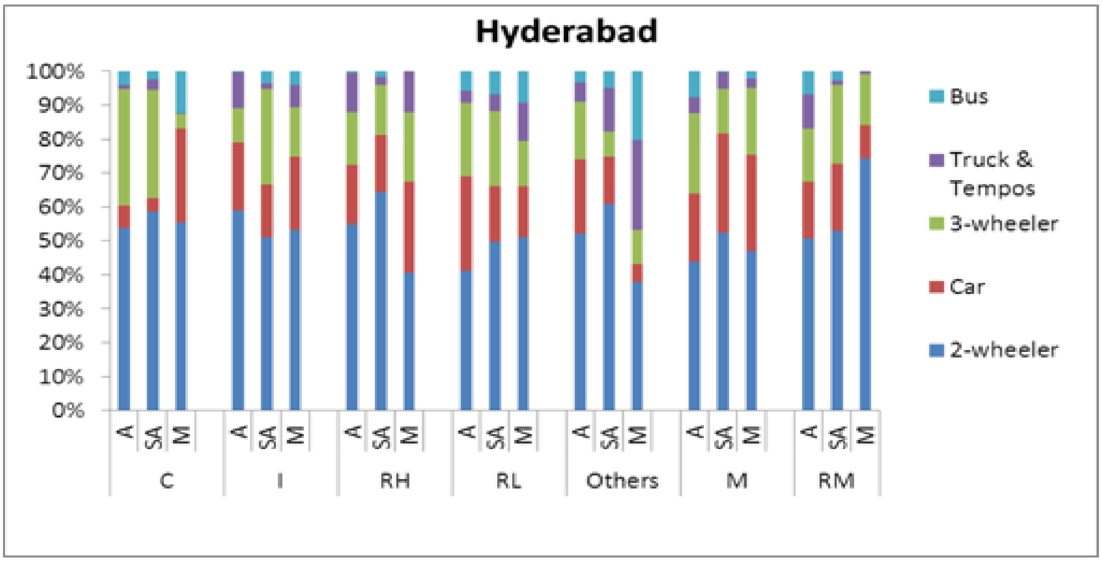
Car
2-wheeler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Car
2-wheeler

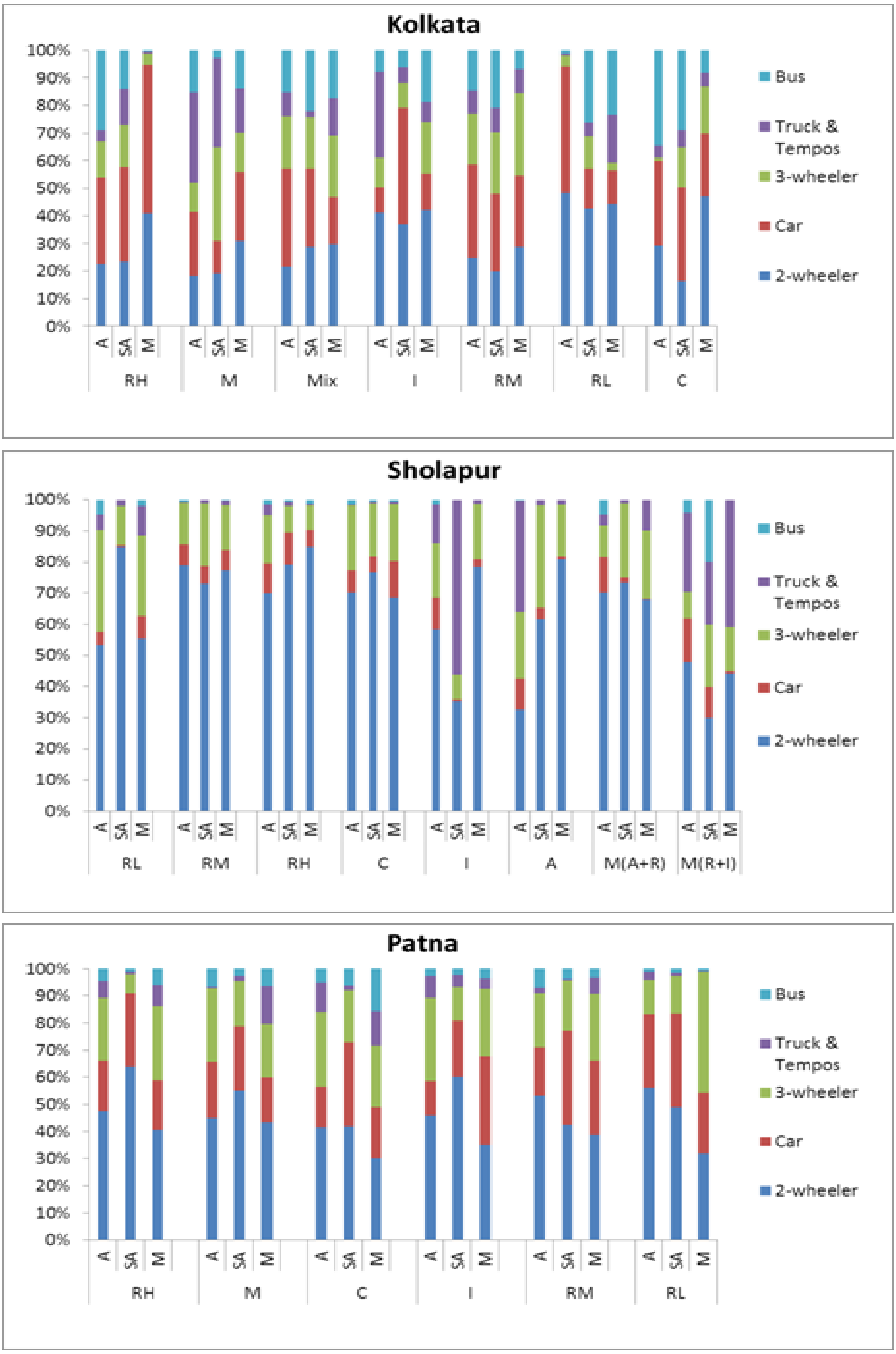

Figure 6.8 Percentage distribution of different vehicles counted at different survey locations (roads) in six cities

The usage of three-wheelers as the para-transit mode is also very common and in absence of very good public transport system, this becomes an important mode of commuting. In all cities, private vehicles account for majority of traffic on all three category of roads while commercial vehicles especially trucks are seen largely on arterial roads. Public transport constitutes minimally in Patna, Lucknow and Solapur but constitutes significantly in Kolkata. Two wheelers are quite prominent in all categories of roads across the six cities, but it is most dominant in Solapur as compared to other cities.

6.3.2 Parking lot surveys

Parking lot surveys in different cities were carried out as a part of this study. The questionnaire prepared for the survey was conducted on around 4000 participants in each city owning different categories of vehicles. The surveys were random for each category of vehicles without any bias to fuel, age, model or any other factor. The results of the surveys for different aspects of vehicles are shown below.

6.3.2.1. Vintage

The survey results reveal certain facts about the vintage of the vehicles plying in different cities.

In case of two wheelers, more than 60% of the vehicles are post 2005. More than 90% three-wheelers in Ahmedabad and Lucknow are post-2005, while Kolkata has 45% of its three-wheelers as post 2005. More than 70% cars are newer (i.e. registered post 2005) (Table 6.1).

Table 6.1: Vintage wise distribution of vehicle categories in different cities.

		Pre 95	1995-2000	2000-05	2005-10	Post 2010
2w	Patna	3%	9%	12%	42%	33%
	Lucknow	4%	18%	8%	32%	39%
	Ahmedabad	0%	1%	12%	43%	44%
	Kolkata	1%	1%	41%	39%	18%
	Hyderabad	0%	8%	36%	20%	36%
	Solapur	0%	0%	33%	16%	51%
3w	Patna	6%	6%	13%	45%	30%
	Lucknow	0%	1%	4%	56%	38%
	Ahmedabad	0%	0%	0%	39%	61%
	Kolkata	1%	1%	53%	35%	10%
	Hyderabad	0%	2%	42%	37%	19%
	Solapur	1%	14%	37%	13%	35%

		Pre 95	1995-2000	2000-05	2005-10	Post 2010
Car	Patna	1%	3%	9%	48%	39%
	Lucknow	1%	4%	4%	51%	41%
	Ahmedabad	0%	0%	4%	33%	63%
	Kolkata	2%	1%	25%	31%	41%
	Hyderabad	0%	1%	4%	67%	27%
	Solapur	1%	3%	15%	38%	43%
Bus	Patna	0%	2%	8%	61%	28%
	Lucknow	0%	7%	7%	64%	22%
	Ahmedabad	5%	6%	28%	20%	41%
	Kolkata	8%	5%	38%	41%	9%
	Hyderabad	0%	0%	37%	44%	19%
	Solapur	3%	8%	19%	39%	31%
Truck	Patna	0%	2%	6%	47%	45%
	Lucknow	8%	19%	10%	40%	23%
	Ahmedabad	0%	10%	22%	51%	17%
	Kolkata	15%	6%	44%	31%	5%
	Hyderabad	0%	6%	34%	50%	10%
	Solapur	0%	11%	24%	37%	29%

6.3.2.2 Daily kilometre travelled

Information was also collected for the daily km travelled by each type of vehicle in the city and is represented in Figure 6.9. Buses, particularly the inter-city ones, which ply continuously throughout the day, cover the maximum distances. Private two-wheeler vehicles on an average run about 28-47 kilometres a day in different cities. Smaller cities like Lucknow, Patna and Solapur also harbour a very high number of commercial 3-wheelers which ply as shuttle services between destinations carrying groups of 6-8 people at a time. On an average these passenger 3-wheelers cover a distance of about 75-90 km per day in different cities. Cars traverse about 42-79 km per day on an average in different cities according to the parking lot survey results.

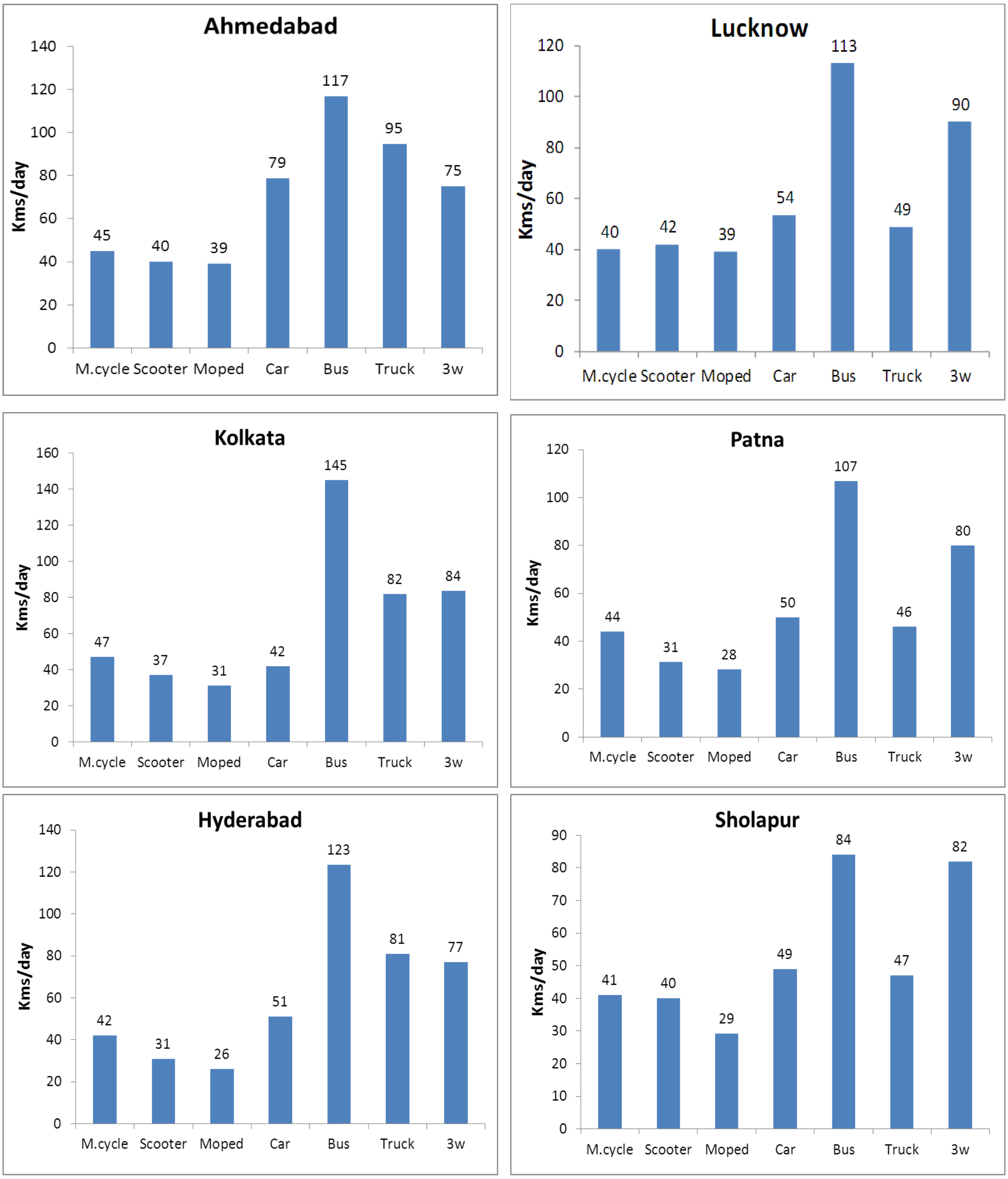

Figure 6.9 Average daily kilometres travelled by different categories of vehicles in six cities

6.3.2.3 Occupancy

Figure 6.10 shows the average occupancy of different category of vehicles based on the parking lot surveys. Higher occupancy is visible in buses (30-57). Ahmedabad shows the highest occupancy owing to bigger buses plying in the city. Auto-rickshaws show occupancy of 2.2-8 depicting the different sizes of three-wheelers plying in different cities

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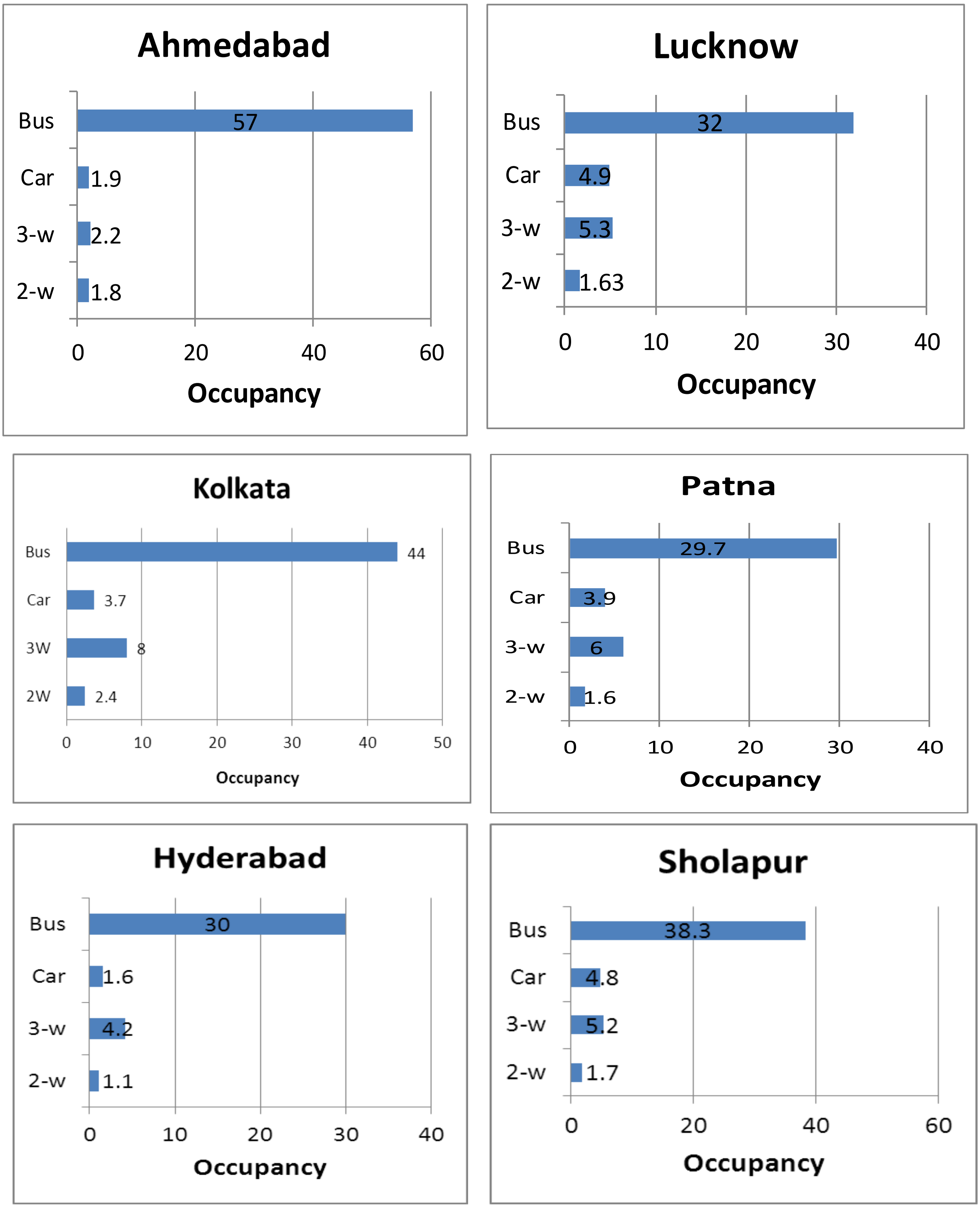


Figure 6.10 Average occupancy of different categories of vehicles in different cities

6.3.2.4 Engine starts and stops

Questionnaire surveys also revealed the starts and stops made by different category of vehicles during a day. Survey reveals that public vehicles (passenger auto-rickshaws and buses) switch on/off their engine higher number of times than other type of vehicles. Lesser numbers were observed for private vehicle owners (Figure 6.11).

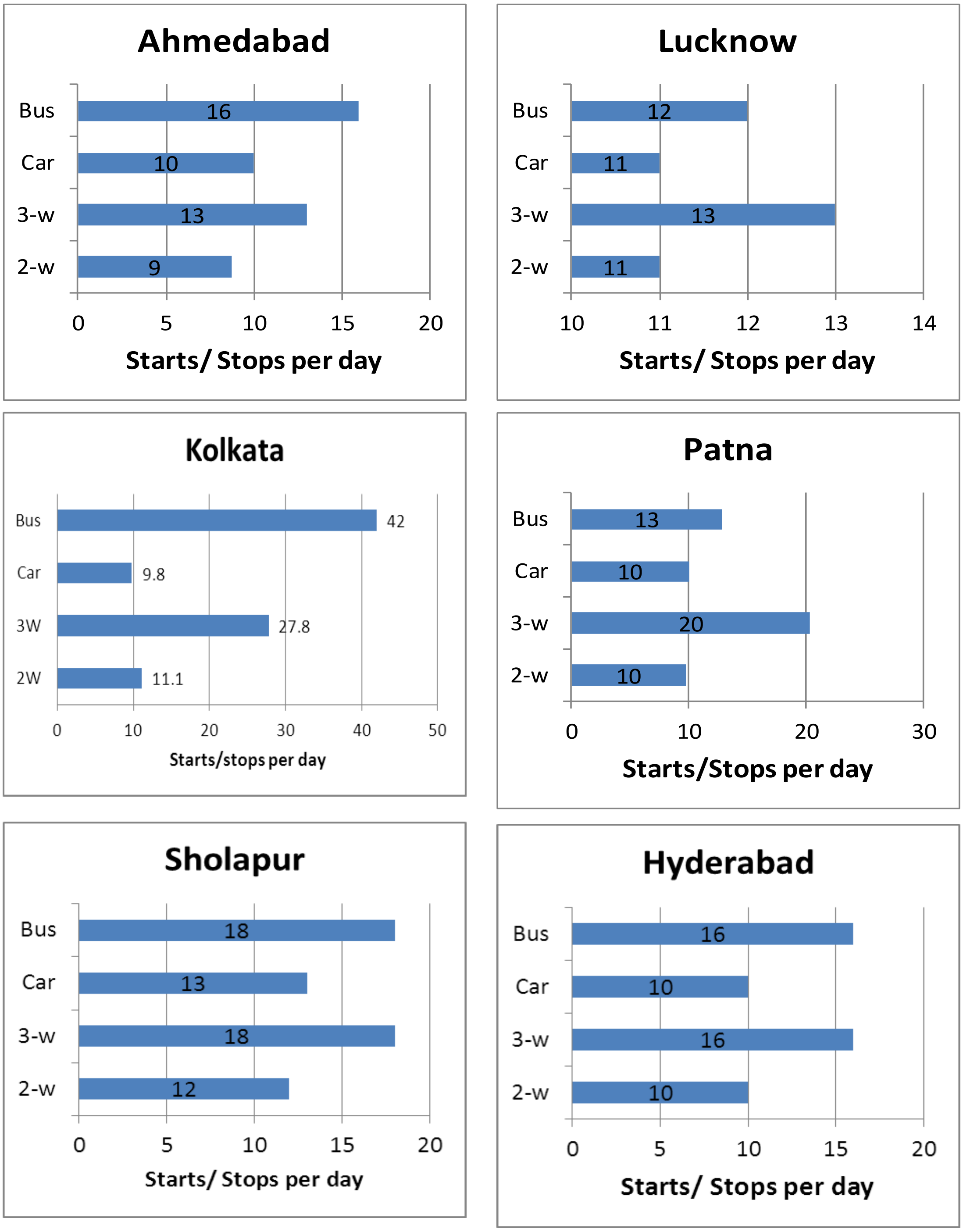


Figure 6.11 Average number of engine starts and stops of various categories of vehicles in different cities based on parking lot surveys

6.3.2.5 Servicing schedule

Questions related to average maintenance schedule of different category of vehicles were also asked, which varied between various vehicle types (Figure 6.12).

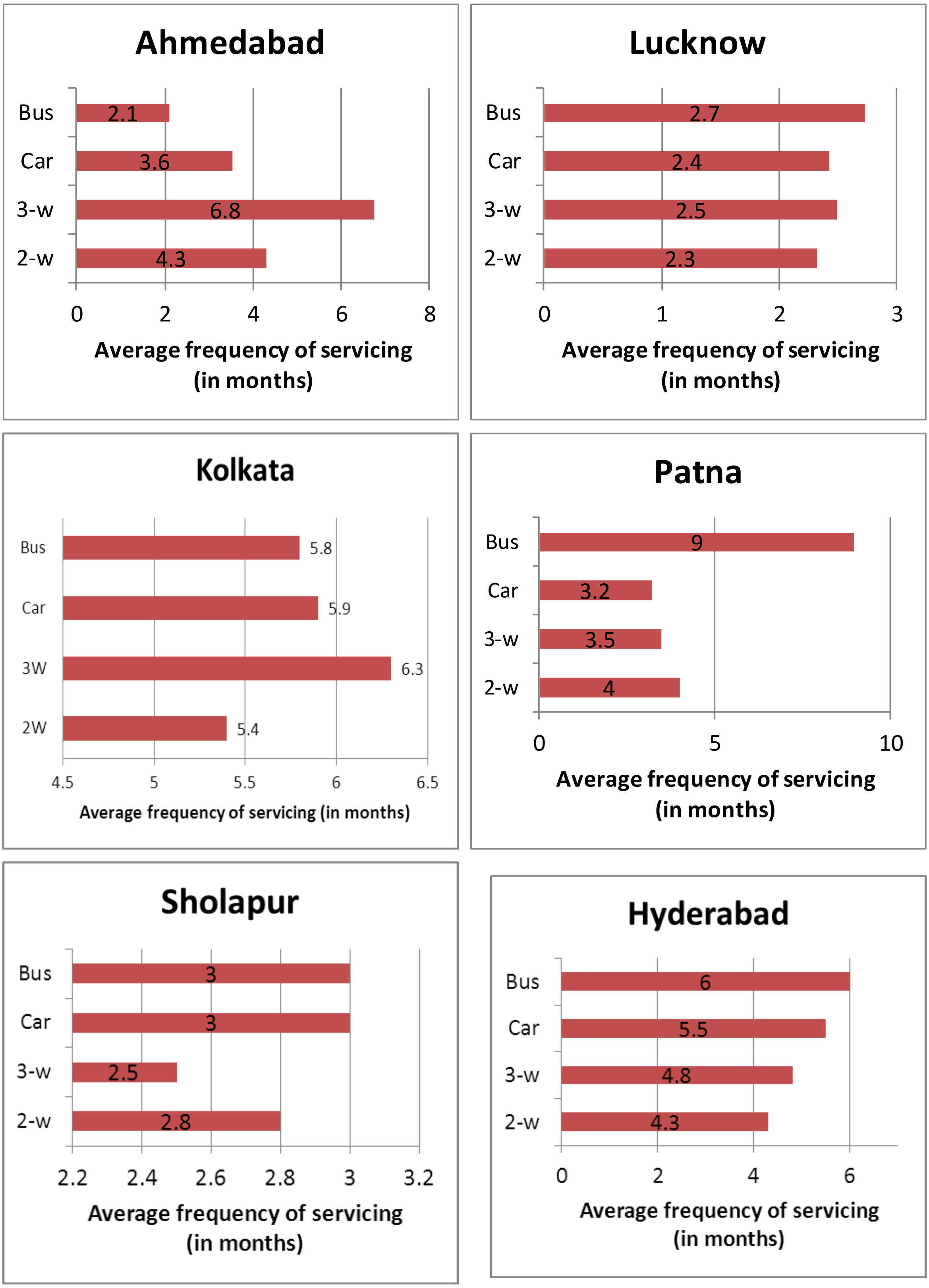


Figure 6.12 Average frequency of servicing of different categories of vehicles in six cities

6.3.2.6 Fuel-wise distributions

Parking lot surveys also revealed useful information about the fuel wise distribution of different category of vehicles. Table 6.2 shows that 43-60% cars (including taxis) run on petrol in different cities. Amongst these six cities, Ahmedabad and Lucknow are supplied with CNG hence 86% and 46% of three-wheelers respectively, run on CNG in the two cities.

Table 6.2 Fuel wise distribution of different category of vehicles in the six cities

Type	City	Petrol	Diesel	Gas
Car	Ahmedabad	43%	34%	23%
	Lucknow	56%	40%	4%
	Kolkata	60%	40%	0%
	Patna	56%	44%	0%
	Hyderabad	53%	40%	7%
	Solapur	51%	42%	7%*
3-w	Ahmedabad	7%	7%	86%
	Lucknow	6%	48%	46%
	Kolkata	60%	37%	3%*
	Patna	45%	55%	0%
	Hyderabad	36%	39%	26%
	Solapur	24%	34%	42%*
Bus	Ahmedabad	0%	59%	41%
	Lucknow	0%	58%	42%
	Kolkata	0%	100%	0%
	Patna	0%	100%	0%
	Hyderabad	0%	95%	5%
	Solapur	0%	100%	0%

*LPG

7. Emission inventory

This chapter presents the estimates of emissions from the road transport sector in six cities – Ahmedabad, Lucknow, Kolkata, Patna, Hyderabad and Solapur. Emissions of different cities are estimated using the two approaches, one being the conventional approach of using registered vehicles and the other using the actual traffic count to assess on-road vehicular movement. The information collected in parking lot surveys about the type distribution of on-road vehicles is used in both the approaches.

7.1 Emission Factors

Emission factors play a vital role in computing the emissions from a typical vehicle category. In the current study, indigenous emission factors developed by ARAI, 2011 are used. ARAI, 2011 is the compilation of extensive work carried out on developing emission factors for on-road vehicles of different categories which followed different vehicular emission norms (Pre-BS, BS-I, BS-II, BS-III) during different time frames. However, to assess the emission factors for BS-IV norms the reductions assumed in CPCB, 2011 has been used (Annexure-II). For methane, ammonia and N_2O the emission factors have been adopted from GAINS-ASIA database.

It is to be noted that Lucknow, Kolkata, Ahmedabad, Hyderabad and Solapur are in the list of 13 cities where advanced fuel quality and vehicular emission norms were implemented earlier than rest of the country. In the year 2010, Patna was still at BS-III standard of fuel quality and vehicles, while the other five cities moved to BS-IV. Hence, corresponding changes have been made for adopting suitable emission factors for different cities based on the road map suggested in the Auto Fuel Policy (MoPNG, 2002).

7.2 Emission inventory

Emission inventory is prepared for the cities using two broad approaches- 1) Registered vehicles, 2) Traffic counts. For both the approaches emissions are estimated using the standard 5 step methodology however with different datasets collected using secondary and primary sources, respectively. The 5 steps followed are presented in Table 7.1.

Table 7.1 Methodology for emission estimation

S.No	Step	Approach-I	Approach-II
1	Assessing the number of vehicles	Vehicle registrations	Traffic counts
2	Analysing the distribution of vehicles based on vintages, technologies, and fuel types	Parking lot surveys	Parking lot surveys
3	Computation of vehicle kilometre travelled (VKT) for all sub-categories of vehicles	Registered vehicles and parking lot surveys	Traffic counts and road length
4	Selection of emission factors for each sub-category	ARAI, 2011, CPCB, 2011	ARAI,2011, CPCB, 2011
5	Computation of emissions	VKT x Emission factor	VKT x Emission factor

Approach-I estimates the VKT using the registered vehicles data and the data collected on daily kilometre travelled by different categories of vehicles. Life of vehicles has been assumed to be 15 years for the computation of VKT.

On the other hand Approach-II uses primary traffic count surveys carried out at different road categories in the 8 grids (depicting various land-uses of a city) for computation of the VKT. The traffic count information of the 8 grids is used to extrapolate for the whole city based on the land-use categories and population densities (PD) as depicted in Figure 7.1.

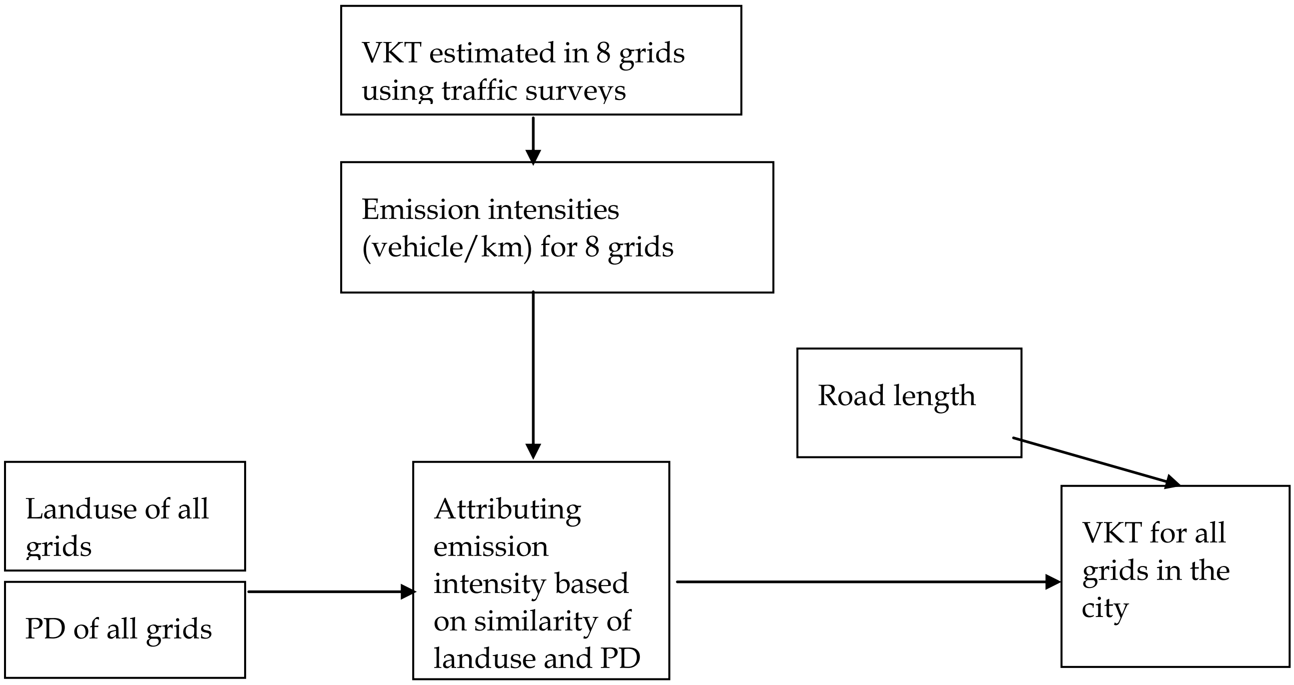


Figure 7.1 Extrapolation method used for emissions assessment of the city based on 8 survey grids.

This methodology has been standardised during the source apportionment studies carried out in 6 major cities (CPCB, 2011) of India.

7.2.1 Ahmedabad

Total VKT by different vehicle categories has been estimated for the city of Ahmedabad using the two approaches. Figure 7.2 shows the differences observed in the two approaches which could be attributed to the influx of vehicles registered outside, into the city or vice versa. Ahmedabad being an industrial hub attracts lot of traffic from outside as well. The presence of many highways in the city also leads to influx of vehicles from outside of the city.

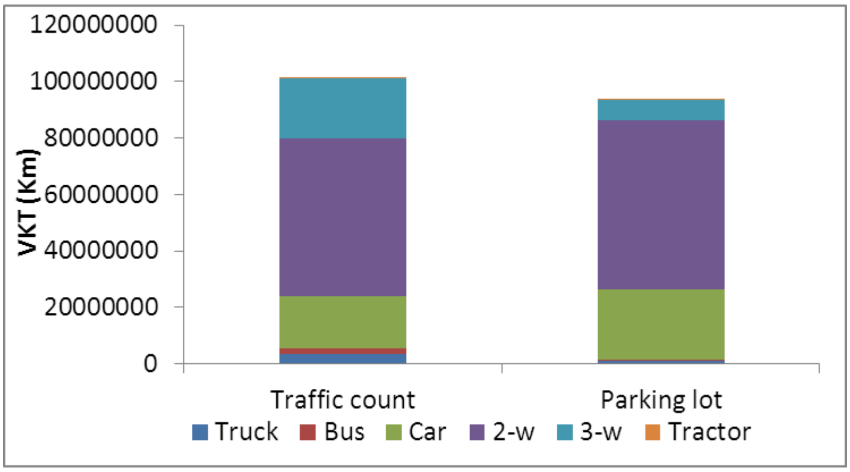


Figure 7.2 Comparison of VKT estimates using the two approaches based on registered vehicles and traffic counts in Ahmedabad

It is to be noted that overall there is marginal difference of 7% in the two approaches and hence points towards reliability of the estimates. Moreover, the VKT estimates are also compared with the actual fuel consumption data for the city collected from the oil the companies.

7.2.1.1 Emissions

VKT estimated for different sub-categories of vehicles using the two approaches are multiplied with the respective emission factors to arrive at the emission estimates of the city. The final emissions estimated using the approach based on actual traffic count surveys are presented in Table 7.2.

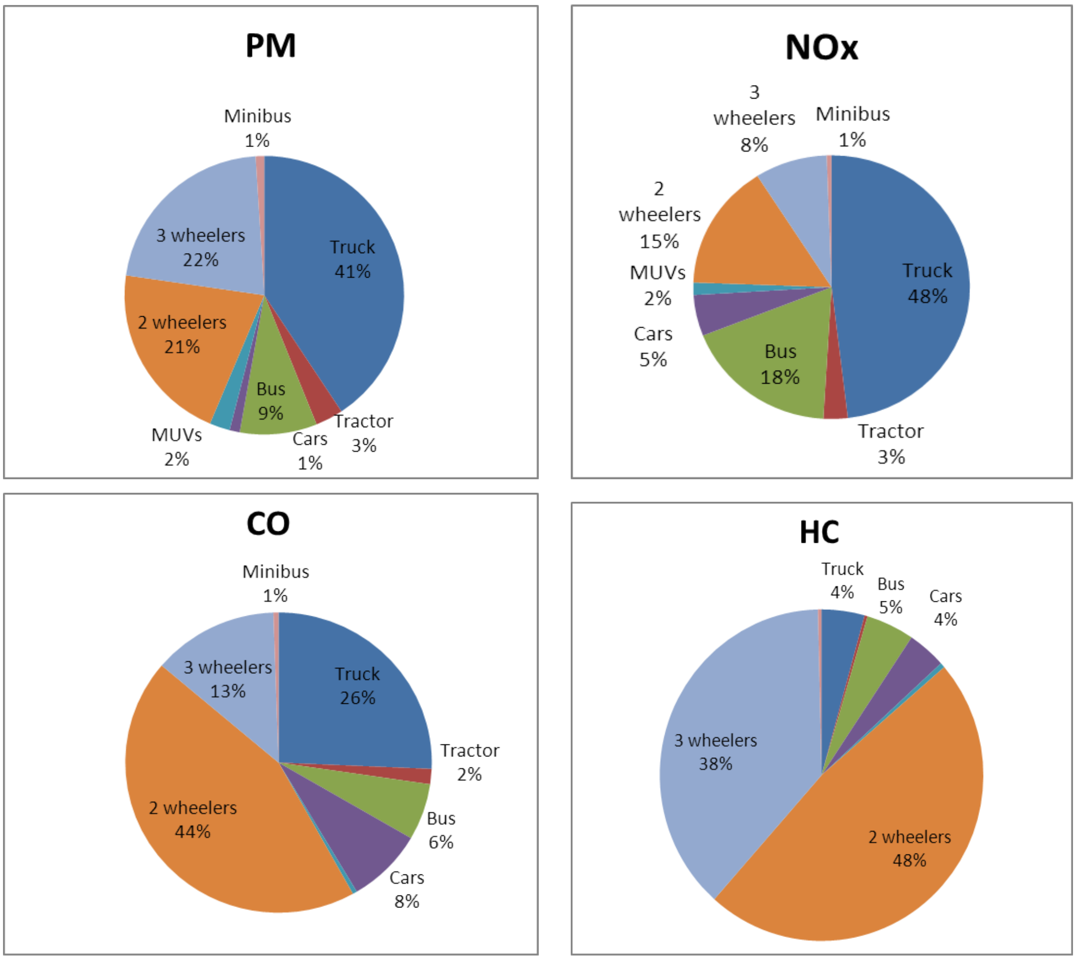
Table 7.2 Emission inventory of road transport sector in Ahmedabad city

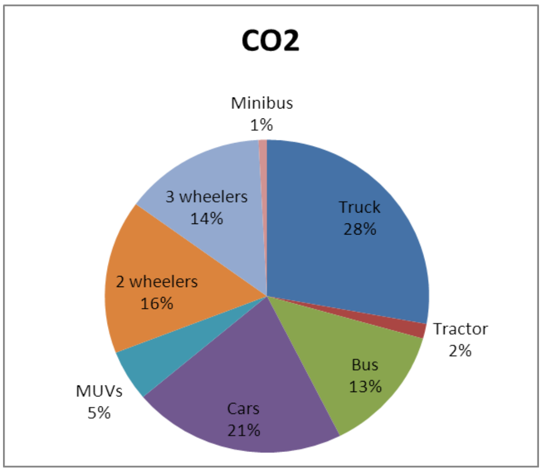
Pollutants		**Emissions**
(tonnes / day)	CO	128.8
	HC	74.9
	NOx	75.8
	CO_2	10361.7
	PM	7.7
	SO_2	0.3
	N_2O	0.3
	CH_4	10.4
	NH_3	0.8
(g/day)	Benzene	1353.6

Pollutants		Emissions
	1-3 Butadiene	543.2
	Acetaldehyde	771.5
	Total Aldehyde	2980.2
	Total PAH	63796.7

Road transport sector in the city of Ahmedabad contributes to almost 7.7 tonnes PM per day. The emissions of gaseous pollutants such as NOx, CO, HC, and SO_2 are 75, 129, 75, and 0.3 T/d respectively. Lower emissions of SO_2 can be attributed to reduction in sulphur content of the fuels.

Category wise contribution of different vehicles in the emission loads of different pollutants is shown in Figures 7.3.





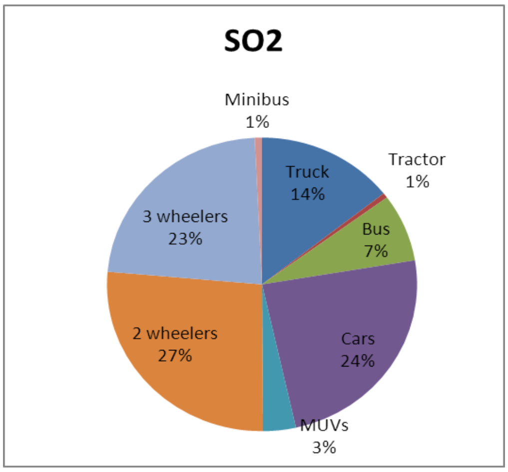


Figure 7.3 Shares of different vehicle categories in emissions of various pollutants from road transport sector in Ahmedabad city

Figure 7.3 shows that two-wheelers contribute to 21% of PM emissions in Ahmedabad. Trucks (41%), three-wheelers (22%), and buses (10%) also have high shares in the overall PM emissions. NOx emissions are mainly dominated by heavy duty diesel based vehicles like buses (19%) and trucks (48%). Two-wheelers with their very high numbers on road also contribute 15%. Pollutants like CO and HC are mainly emitted from the petrol driven vehicles. Two wheelers contribute to 44% and 48% in CO and HC emissions. SO_2 and CO_2 emissions are fuel based and show that two wheelers, cars and trucks consume the maximum share of energy used in the road transport sector in the city and hence lead to higher contribution to SO_2 and CO_2 emissions. It is to be noted that share of cars is small in other pollutant emissions because of better emission control through implementation of BS-norms. However, with growing economy, the share of cars is expected to rise in future. Table 7.3 presents the vehicle categories which contribute maximum towards the emissions of different pollutants.

Table7.3 Vehicle categories contributing maximum towards emissions of different pollutants in Ahmedabad

Parameter	**Vehicle category contributing the most**	**Percentage share in total emissions**
CO	2 wheelers	44%
HC	2 wheelers	48%
NOx	Trucks	48%
CO2	Trucks and Cars	28% and 21%
PM	Trucks and 3-wheelers	41% & 22%
SO2	2 wheelers and cars	27% and 24%

Grid-wise distribution of emissions of different pollutants is shown in Figure 7.4.

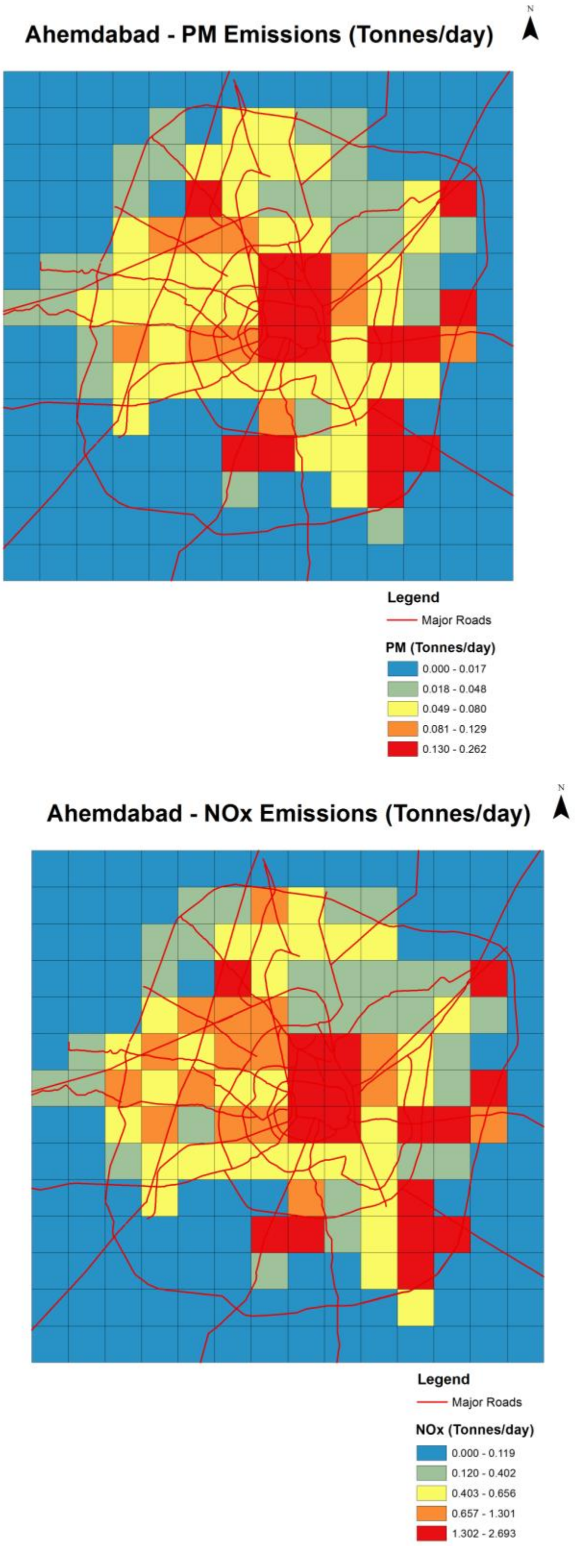


Figure 7.4 Grid-wise distribution of PM and NOx emissions in Ahmedabad city

7.2.2 Lucknow

Total VKT by different vehicle categories has been estimated for the city of Lucknow using the two approaches. Figure 7.5 shows the differences observed in the two approaches which could be attributed to the influx of vehicles registered outside into the city. Lucknow being a capital city attracts lot of traffic from outside also. The presence of many highways in the city also leads to influx of vehicles from outside of the city.

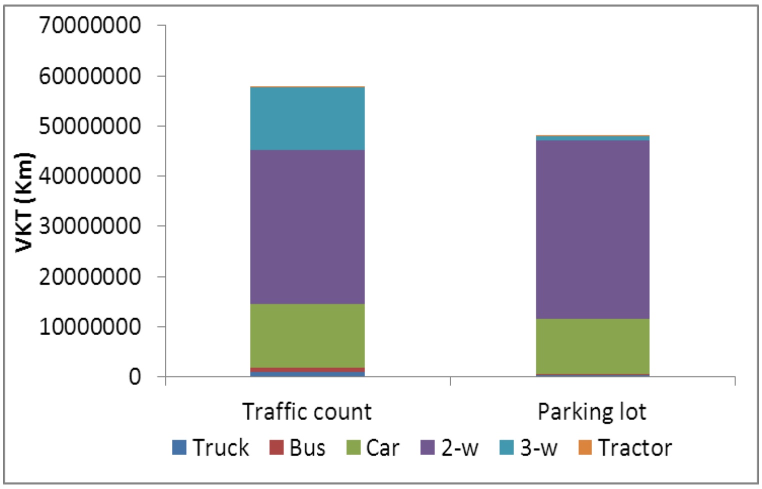


Figure 7.5 Comparison of VKT estimates using the two approaches based on registered vehicles and traffic counts in Lucknow

It is to be noted that overall there is marginal difference of 17% in the two approaches and hence points towards reliability of the estimates. Moreover, the VKT estimates are also compared with the fuel consumption data for the city collected from the oil companies.

7.2.2.1 Emissions

VKT estimated for different sub-categories of vehicles using the two approaches are multiplied with the respective emission factors to arrive at the emission estimates of the city. The final emissions estimated using the approach based on actual traffic count surveys are presented in Table 7.4.

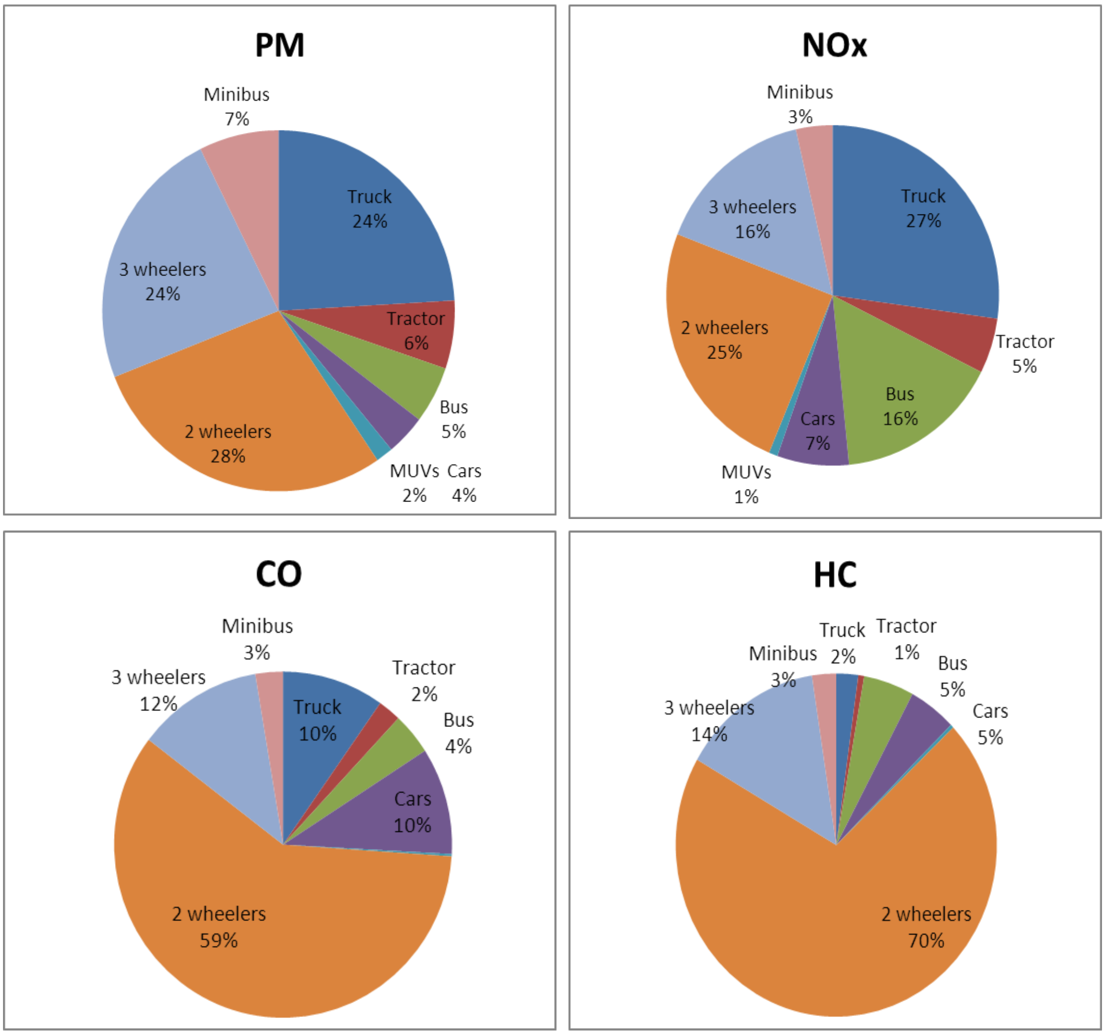
Table 7.4 Emission inventory of road transport sector in Lucknow city

Pollutants		**Emissions**
(tonnes / day)	CO	86.70
	HC	34.4
	NOx	37.0
	CO_2	4399.1
	PM	3.6
	SO_2	0.2
	N_2O	0.2
	CH_4	5.3
	NH_3	0.6
(g/day)	Benzene	890.2

Pollutants		Emissions
	1-3 Butadiene	591.1
	Acetaldehyde	339.5
	Total Aldehyde	1587.2
	Total PAH	29740.1

Road transport sector in the city of Lucknow contributes to almost 3.6 tonnes or PM per day. The emissions of gaseous pollutants such as NOx, CO, HC, and SO2 are 37, 87, 34, and 0.2 T/d respectively. Lower emissions of SO_2 can be attributed to reduction in sulphur content of the fuels.

Category wise contribution of different vehicles in the emission loads of different pollutants is shown in Figures 7.6.



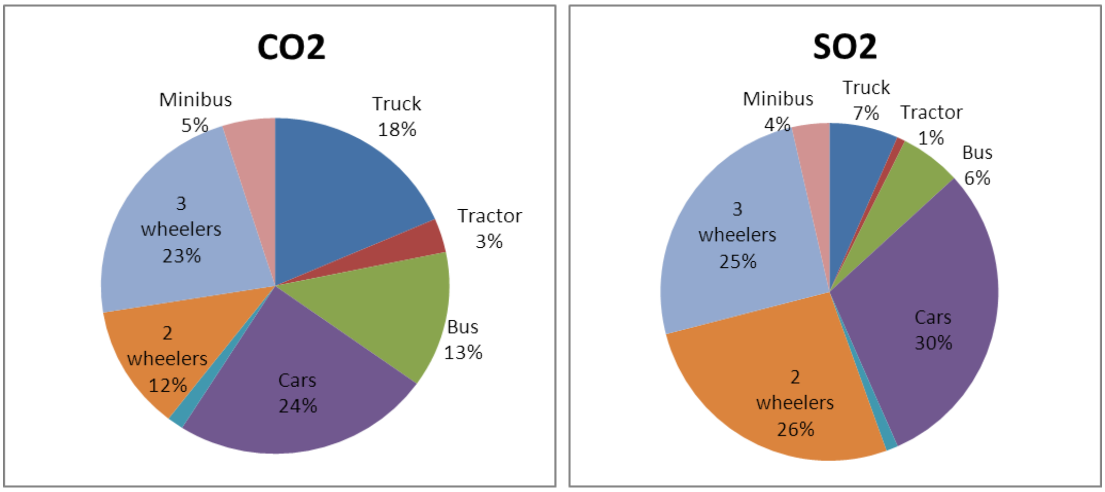


Figure 7.6 Shares of different vehicle categories in emissions of various pollutants from road transport sector in Lucknow city

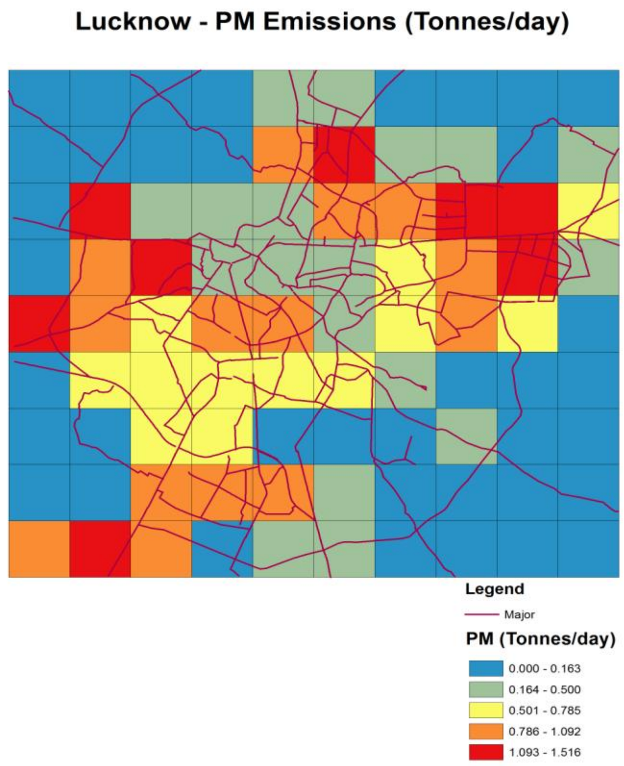
Figure 7.6 shows that two-wheelers contribute to 28% of PM emissions in Lucknow. Trucks (24%), three-wheelers (24%), and buses (12%) are other categories with higher share in the PM emissions. NOx emissions are mainly dominated by heavy duty diesel based vehicles like buses (19%) and trucks (27%). Two-wheelers with their very high numbers on road also contribute 25%. Pollutants like CO and HC are mainly emitted from the petrol driven vehicles. Two wheelers contribute to 59% and 70% in CO and HC emissions. SO_2 and CO_2 emissions are fuel based and show that cars and 3 wheelers consume the maximum share of energy used in the road transport sector in Lucknow city and hence lead to higher contribution to SO_2 and CO_2 emissions. It is to be noted that share of cars is small in other pollutant emissions because of better emission control through implementation of BS-norms. However, with growing economy, the share of cars is expected to rise in future. Table 7.5 presents the vehicle categories which contribute maximum towards the emissions of different pollutants.

Table7.5 Vehicle categories contributing maximum towards emissions of different pollutants in Lucknow

Parameter	Vehicle category contributing the most	Percentage share in total emissions
CO	2 wheelers	59%
HC	2 wheelers	70%
NOx	Trucks	27%
CO2	Cars and three wheelers	24% and 23%

Parameter	Vehicle category contributing the most	Percentage share in total emissions
PM	2 wheelers, 3 wheelers and Trucks	28%, 24% and 24%
SO2	Cars & two-wheelers	30% and 26%

Grid-wise distribution of emissions of different pollutants is shown in Figure 7.7.



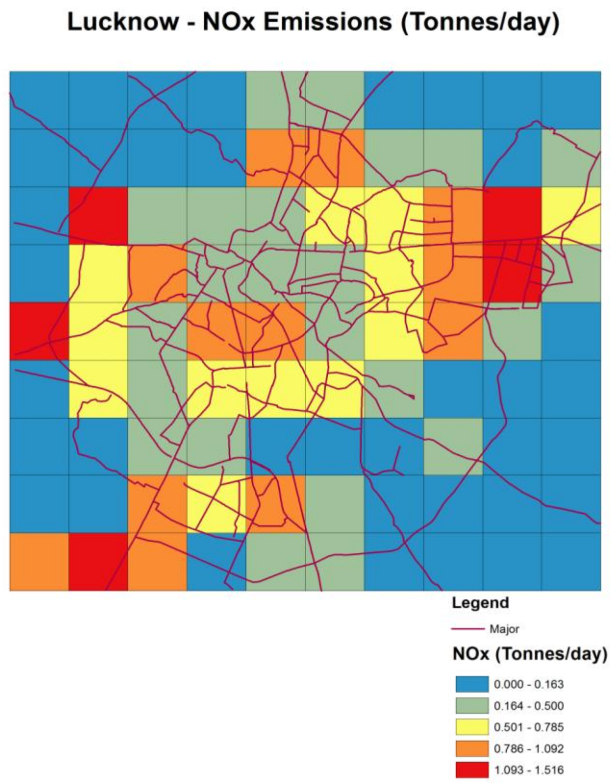


Figure 7.7 Grid-wise distribution of PM and NOx emissions in Lucknow city

7.2.3 Kolkata

Total VKT by different vehicle categories has been estimated for the city of Kolkata using the two approaches. Figure 7.8 shows the differences observed in the two approaches which could be attributed to the flow of traffic from city to the outskirts. Kolkata city (Municipal corporation area) being closely associated with Howrah, 24 Parganas (North) and 24 Parganas (South) districts has a lot of influx as well as outflow of vehicles from and to these areas.

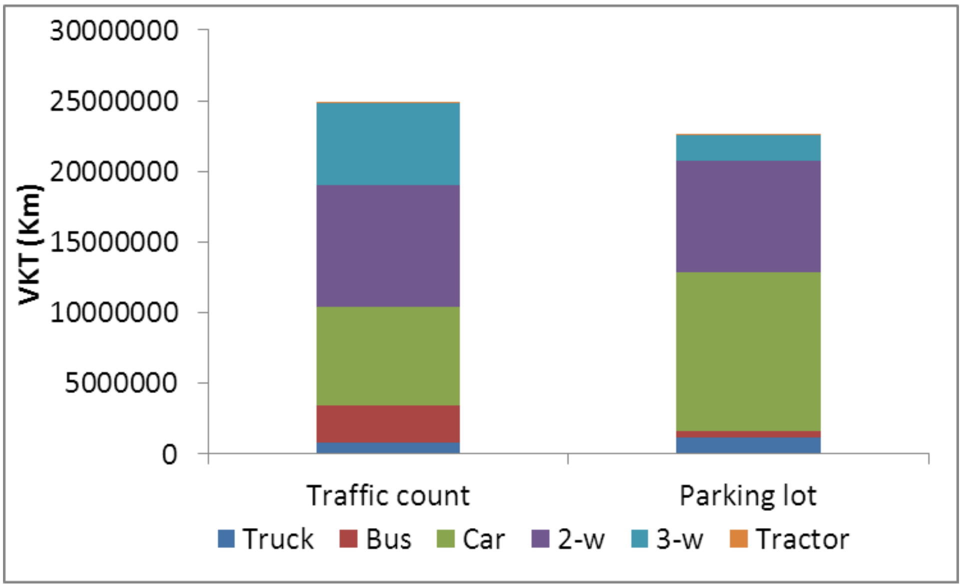


Figure 7.8 Comparison of VKT estimates using the two approaches based on registered vehicles and traffic counts in Kolkata

It is to be noted that overall there is marginal difference of 9% in the two approaches and hence points towards reliability of the estimates. Moreover, the VKT estimates are also compared with the fuel consumption data for the city collected from the oil companies.

7.2.3.1 Emissions

VKT estimated for different sub-categories of vehicles using the two approaches are multiplied with the respective emission factors to arrive at the emission estimates of the city. The final emissions estimated using the approach based on actual traffic count surveys are presented in Table 7.6 .

Table 7.6 Emission inventory of road transport sector in Kolkata city

Pollutants		Emissions
(tonnes / day)	CO	59.6
	HC	19.6
	NOx	44.3
	CO_2	5126.8
	PM	4.6
	SO_2	0.15
	N_2O	0.08
	CH_4	0.72
	NH_3	0.13
(g/day)	Benzene	1890.4
	1-3 Butadiene	1077.6
	Acetaldehyde	153.6
	Total Aldehyde	937.0
	Total PAH	30556.2

Road transport sector in the city of Kolkata contributes to almost 4.6 tonnes PM per day. The emissions of gaseous pollutants such as NOx, CO, HC, and SO_2 are 44, 60, 20, and 0.15 T/d respectively. Lower emissions of SO2 can be attributed to reduction in sulphur content of the fuels. High NOx emissions are due to the presence of diesel based buses.

Category wise contribution of different vehicles in the emission loads of different pollutants is shown in Figures 7.9.

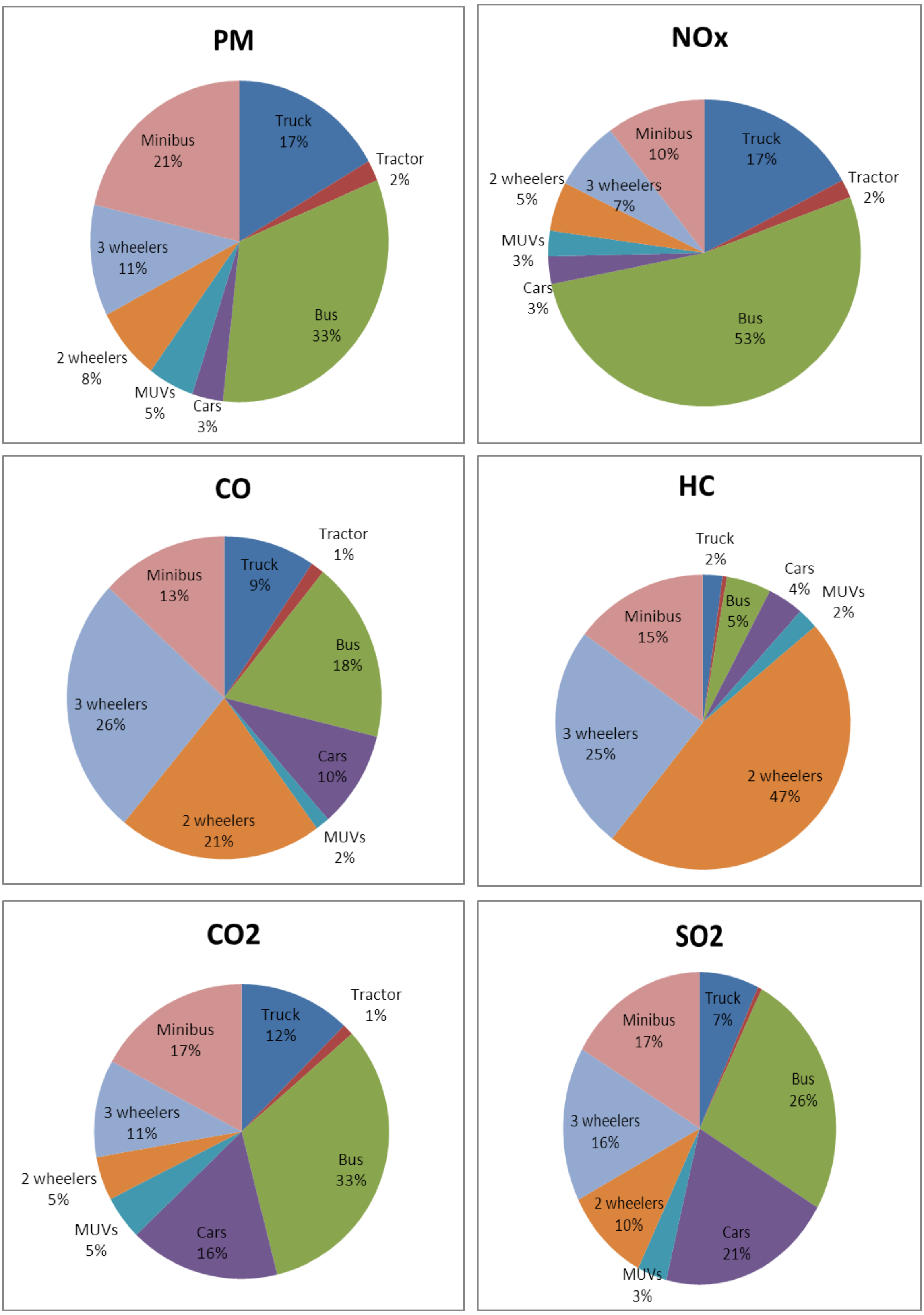


Figure 7.9 Shares of different vehicle categories in emissions of various pollutants from road transport sector in Kolkata city

Figure 7.9 shows that buses (including mini bus) contribute to 54% of PM emissions in Kolkata. Trucks (17%), three-wheelers (11%), and two-wheelers (8%) have other higher share in the PM emissions. NOx emissions are mainly dominated by heavy duty diesel based vehicles like buses (63%) and trucks (17%). Two-wheelers also contribute 5% in the NOx emissions. Pollutants like CO and HC are mainly emitted from the petrol driven vehicles. Two wheelers contribute to 21% and 47% in CO and HC emissions. SO_2 and CO_2 emissions are fuel based and show that buses and cars consume the maximum share of energy used in the road transport sector in the city and hence lead to higher contribution to SO_2 and CO_2 emissions. It is to be noted that share of cars is small in other pollutant emissions because of better emission control through implementation of BS-norms. However, with growing economy, the share of cars is expected to rise in future. Table 7.7 presents the vehicle categories which contribute maximum towards the emissions of different pollutants.

Table 7.7 Vehicle categories contributing maximum towards emissions of different pollutants in Kolkata

Parameter	**Vehicle category contributing the most**	**Percentage share in total emissions**
CO	3 wheelers	26%
HC	2 wheelers	47%
NOx	Buses	63%
CO_2	Buses and cars	50% and 21%
PM	Buses and Trucks	54% & 17%
SO_2	Buses and cars	43% and 24%

Grid-wise distribution of emissions of different pollutants is shown in Figure 7.10.

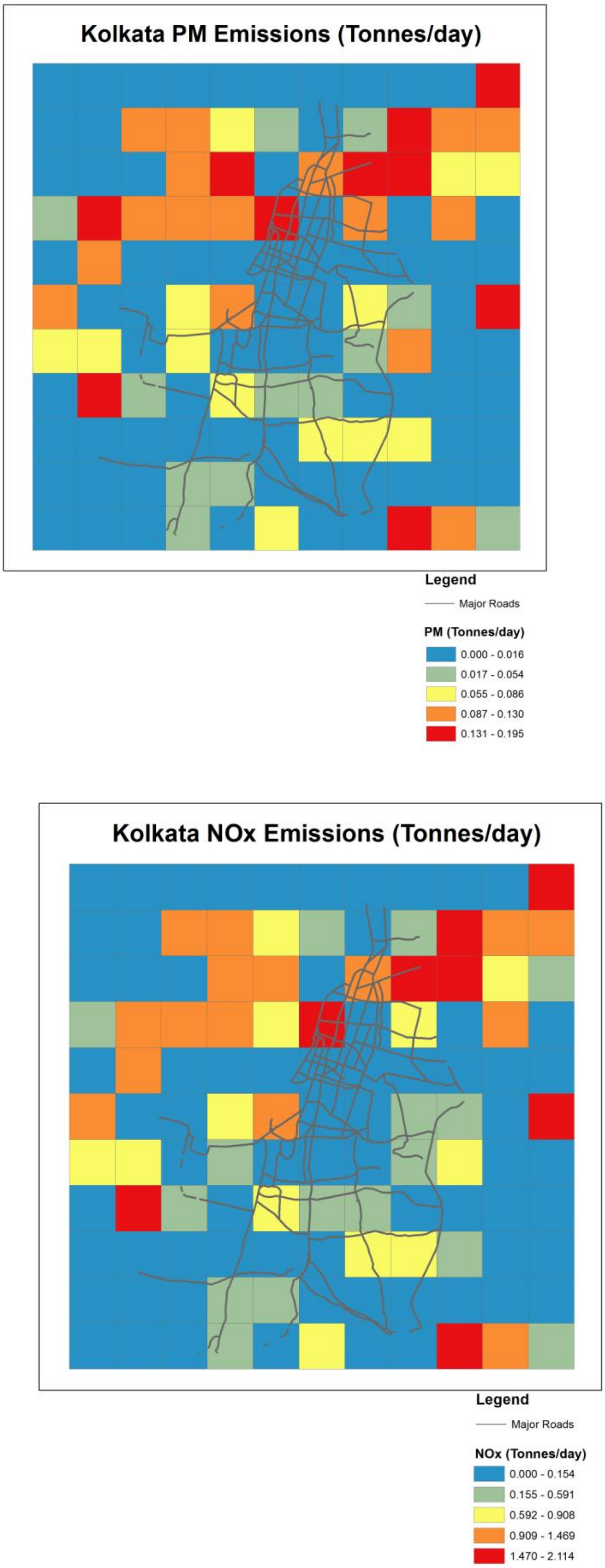


Figure 7.10 Grid-wise distribution of PM and NOx emissions in Kolkata city

7.2.4 Patna

Total VKT by different vehicle categories has been estimated for the city of Patna using the two approaches. Figure 7.11 shows the differences observed in the two approaches which could be attributed to the influx of vehicles registered outside into the city. Patna being a capital city attracts lot of traffic from outside also.

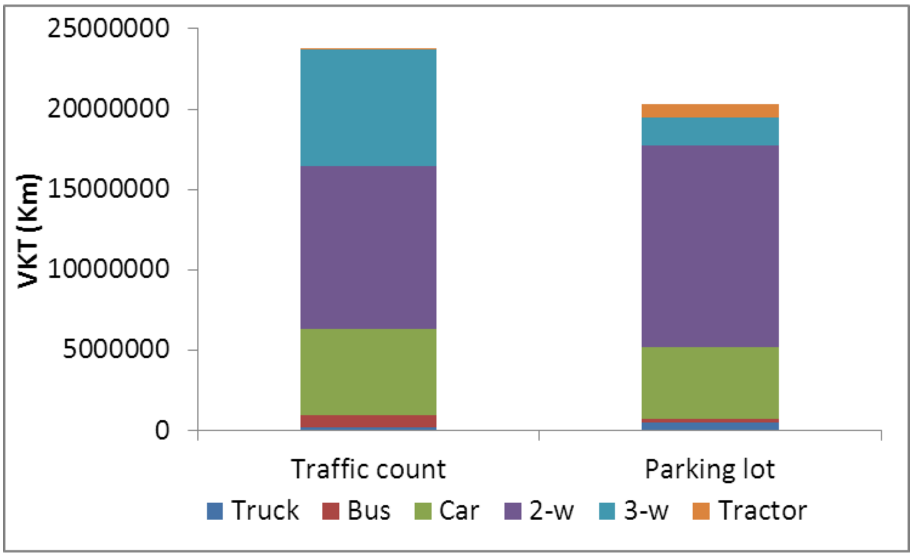


Figure 7.11 Comparison of VKT estimates using the two approaches based on registered vehicles and traffic counts in Patna

It is to be noted that overall there is a difference of 15% in the two approaches and hence points towards reliability of the estimates. Moreover, the VKT estimates are also compared with the actual fuel consumption data for the city collected from the oil companies.

7.2.4.1 Emissions

VKT estimated for different sub-categories of vehicles using the two approaches are multiplied with the respective emission factors to arrive at the emission estimates of the city. The final emissions estimated using the approach based on actual traffic count surveys are presented in Table 7.8.

Table 7.8 Emission inventory of road transport sector in Patna city

Pollutants		Emissions
(tonnes / day)	CO	51.5
	HC	18.1
	NOx	21.4
	CO_2	2963.9
	PM	3.0
	SO_2	0.5
	N_2O	0.08
	CH_4	0.58
	NH_3	0.16
(g/day)	Benzene	1439.4
	1-3 Butadiene	644.7
	Acetaldehyde	149.0
	Total Aldehyde	690.3
	Total PAH	23294.5

Road transport sector in the city of Patna contributes to almost 3 tonnes or PM per day. The emissions of gaseous pollutants such as NOx, CO, HC, and SO_2 are 21, 52, 18, and 0.5 T/d respectively. Lower emissions of SO2 can be attributed to reduction in sulphur content of the fuels.

Category wise contribution of different vehicles in the emission loads of different pollutants is shown in Figures 7.12.

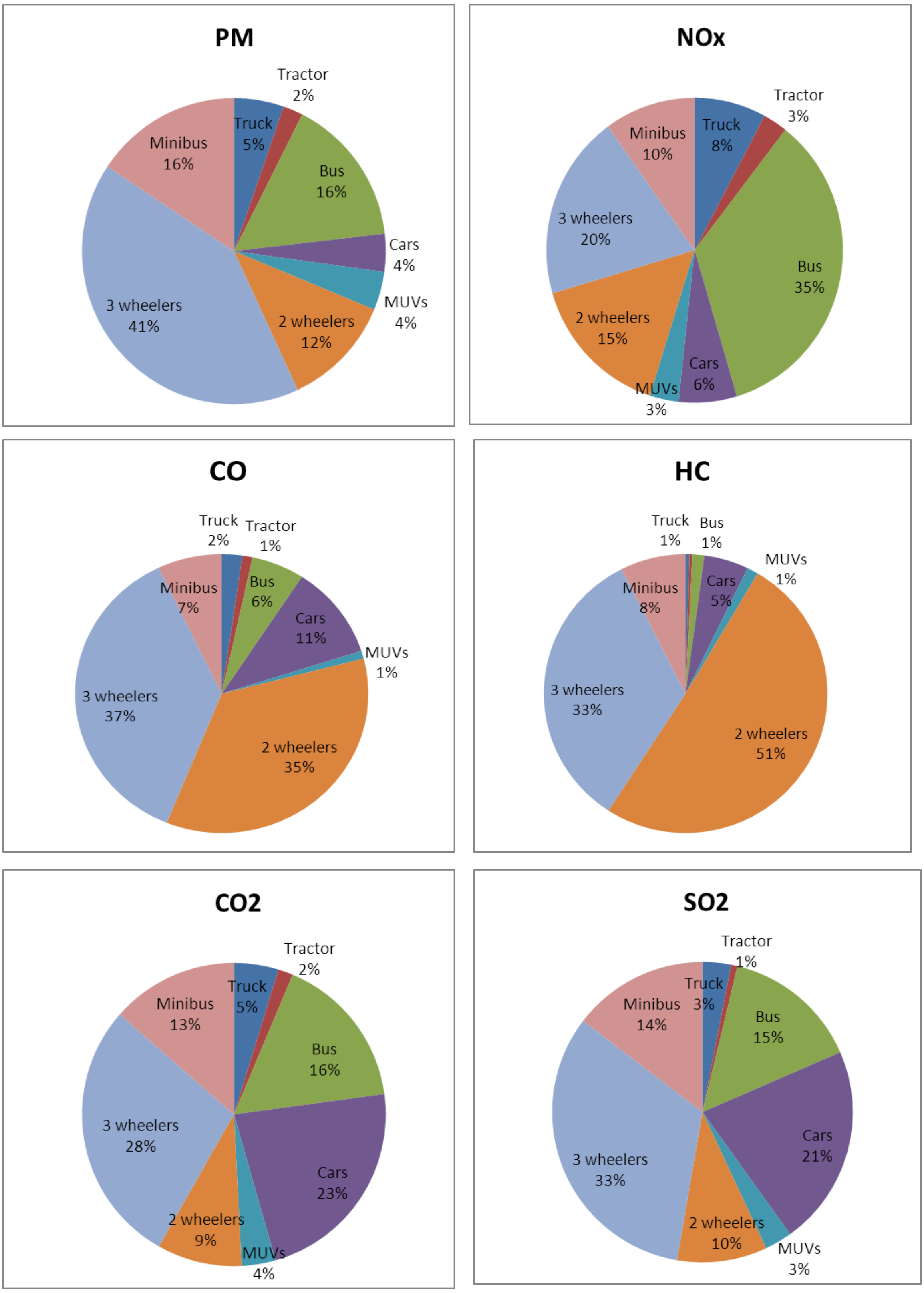


Figure 7.12 Shares of different vehicle categories in emissions of various pollutants from road transport sector in Patna city

Figure 7.12 shows that three-wheelers (41%) are contributing maximum to the PM emissions followed by buses (32%). NOx emissions are mainly dominated by diesel based buses (45%). On the other hand, pollutants like CO and HC are mainly emitted from the petrol driven two wheelers. SO_2 and CO_2 emissions are fuel based and show that three-wheelers, cars and buses consume the maximum share of energy used in the road transport sector in the city and hence lead to higher contribution to SO_2 and CO_2 emissions. Share of cars is quite small in the overall pollutants estimated. However, with growing economy, their share is expected to rise in future. Table 7.9 presents the vehicle categories which contribute maximum towards the emissions of different pollutants.

Table 7.9 Vehicle categories contributing maximum towards emissions of different pollutants in Patna

Parameter	Vehicle category contributing the most	Percentage share in total emissions
CO	3 and 2 wheelers	37% & 35%
HC	2&3 wheelers	51% & 33%
NOx	Buses	45%
CO2	Buses and 3 wheelers	29% & 28%
PM	3 wheelers and buses	41% & 32%
SO2	3 wheelers and buses	33% & 29%

Grid-wise distribution of emissions of different pollutants is shown in Figure 7.13.

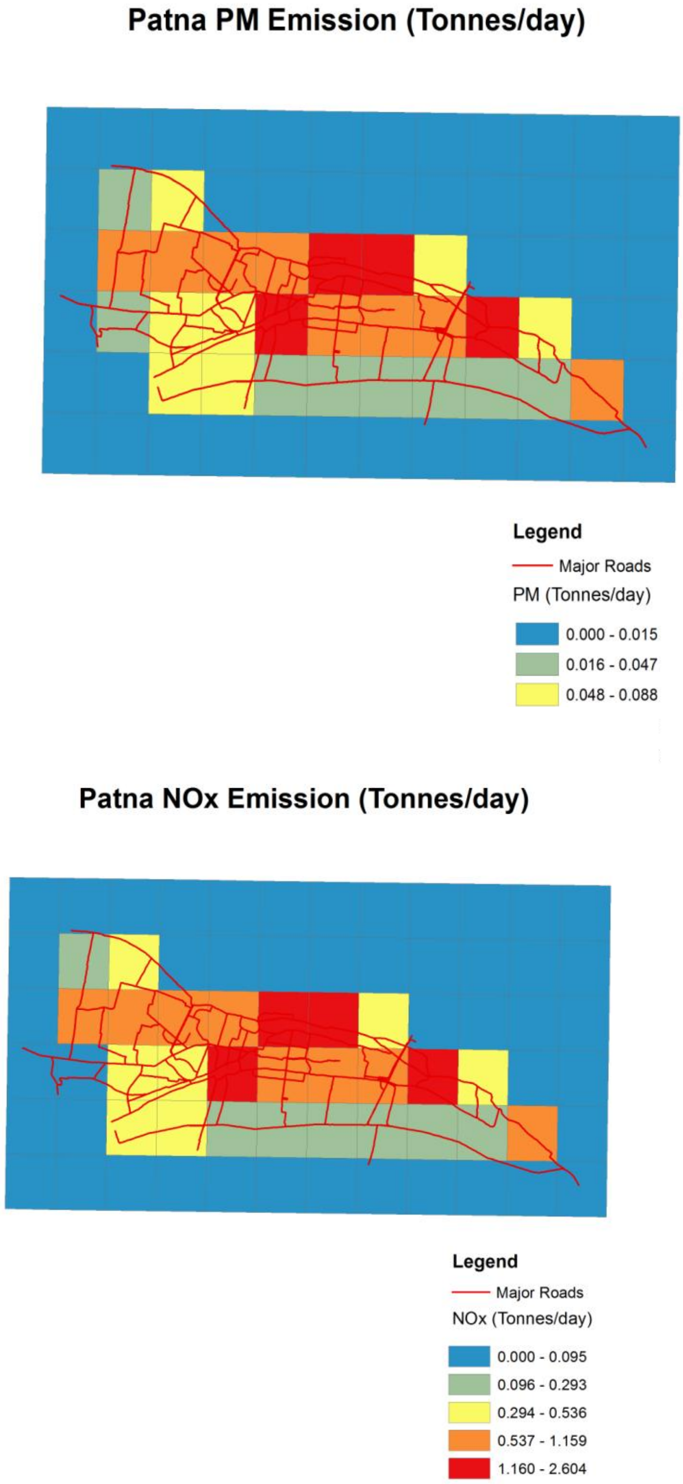


Figure 7.13 Grid-wise distribution of PM and NOx emissions in Patna city

7.2.5 Hyderabad

Total VKT by different vehicle categories has been estimated for the city of Hyderabad using the two approaches. Figure 7.14 shows the differences observed in the two approaches which could be attributed to the influx of vehicles registered outside into the city. Hyderabad being a state capital city attracts lot of traffic from outside also.

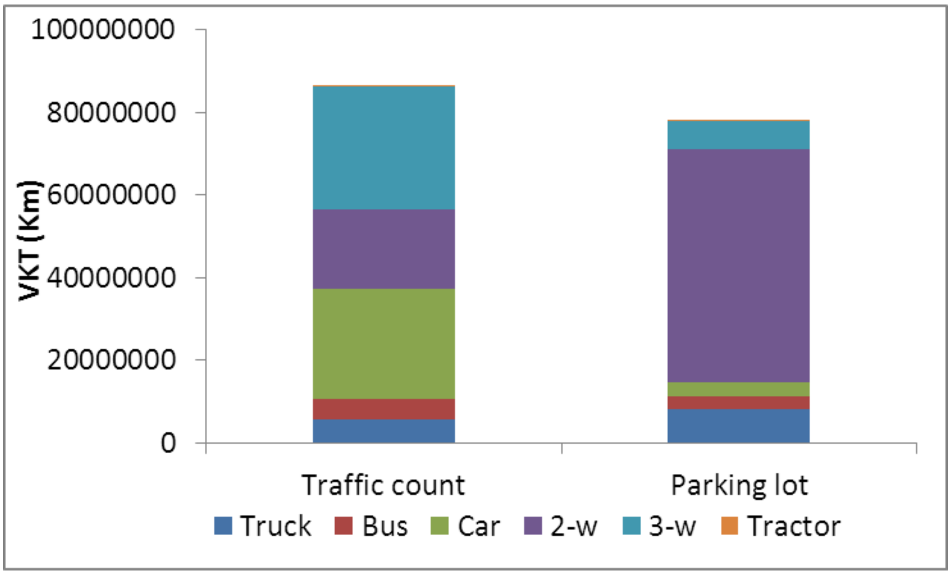


Figure 7.14 Comparison of VKT estimates using the two approaches based on registered vehicles and traffic counts in Hyderabad

It is to be noted that overall there is difference of 10% in the two approaches and hence points towards reliability of the estimates. Moreover, the VKT estimates are also compared with the fuel consumption data for the city collected from the oil companies.

7.2.4.1 Emissions

VKT estimated for different sub-categories of vehicles using the two approaches are multiplied with the respective emission factors to arrive at the emission estimates of the city. The final emissions estimated using the approach based on actual traffic count surveys are presented in Table 7.10.

Table 7.10 Emission inventory of road transport sector in Hyderabad city

Pollutants		Emissions
(tonnes / day)	CO	212
	HC	59
	NOx	138
	CO_2	15284
	PM	11.9
	SO_2	0.5
	N_2O	0.4
	CH_4	5.2
	NH_3	1.1
(g/day)	Benzene	1699.3
	1-3 Butadiene	1526.3
	Acetaldehyde	0.0
	Total Aldehyde	1049.8
	Total PAH	5588.2

Road transport sector in the city of Hyderabad contributes to almost11.9 tonnes of PM per day. The emissions of gaseous pollutants such as NOx, CO, HC, and SO_2 are 138, 212, 59, and 0.5 T/d respectively. Lower emissions of SO_2 can be attributed to reduction in sulphur content of the fuels.

Category wise contribution of different vehicles in the emission loads of different pollutants is shown in Figures 7.15

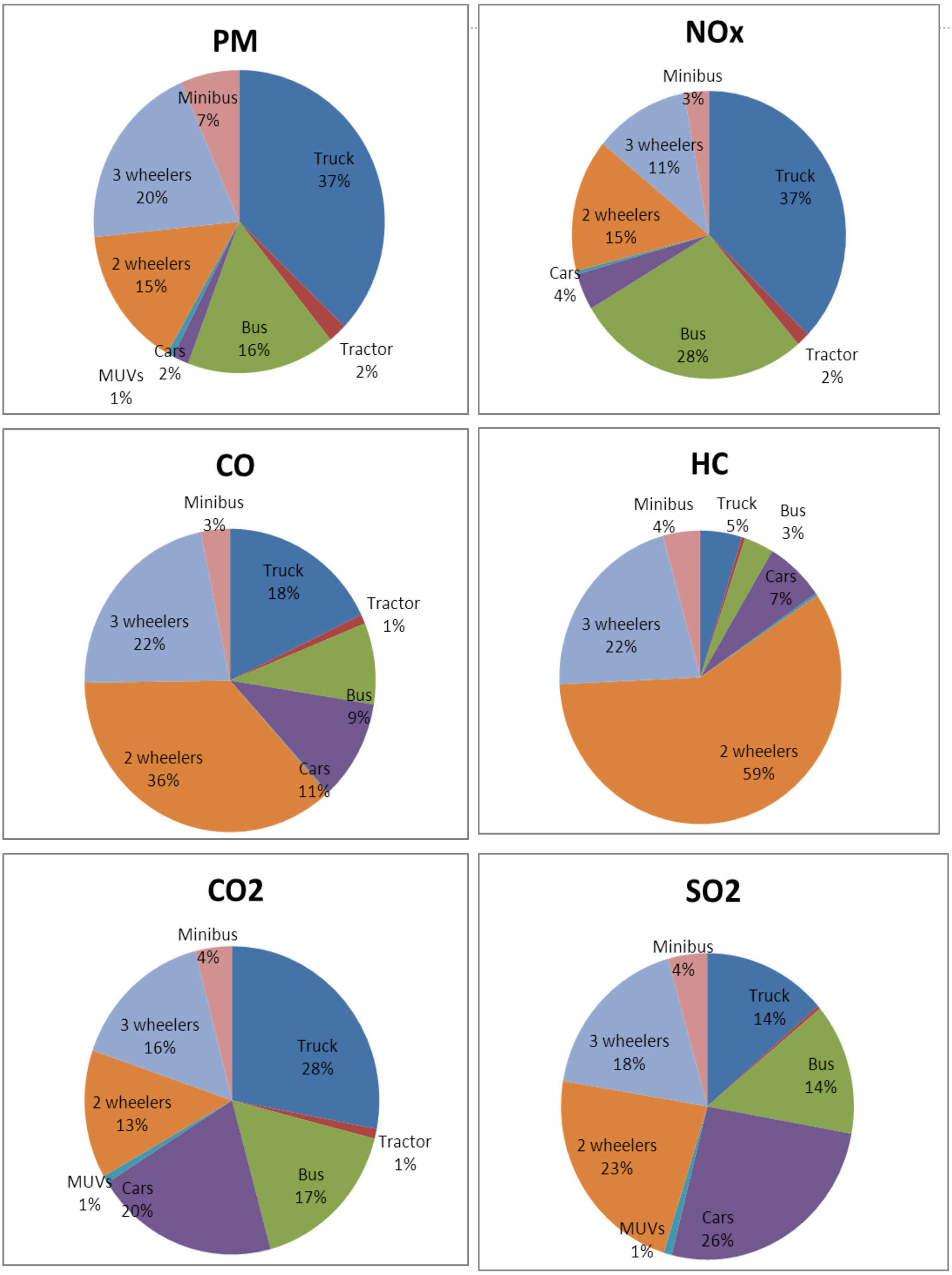


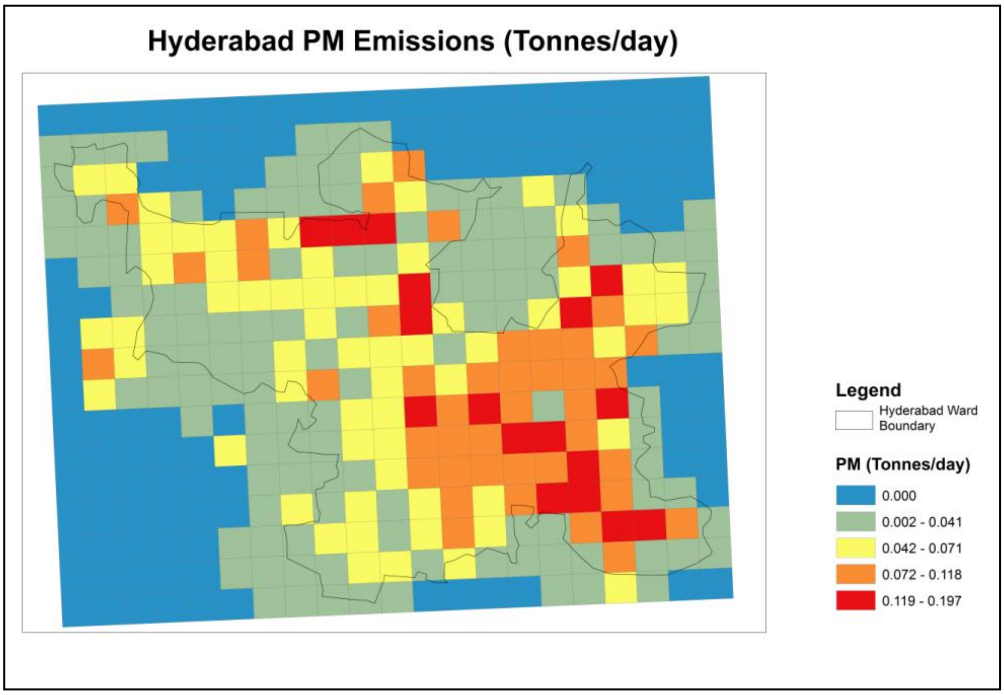
Figure 7.15 Shares of different vehicle categories in emissions of various pollutants from road transport sector in Hyderabad city

Figure 7.15 shows that trucks, 3-wheelers and buses are contributing maximum to PM and NOx emissions. On the other hand, pollutants like CO and HC are mainly emitted from the petrol driven two wheelers. SO_2 and CO_2 emissions are fuel based and show that cars and two wheelers consume the maximum share of energy used in the road transport sector in the city and hence lead to higher contribution to SO_2 and CO_2 emissions. Table 7.11 presents the vehicle categories which contribute maximum towards the emissions of different pollutants.

Table 7.11 Vehicle categories contributing maximum towards emissions of different pollutants in Hyderabad

Parameter	Vehicle category contributing the most	Percentage share in total emissions
CO	2 wheelers	36%
HC	2 wheelers	59%
NOx	Trucks and Buses	37% and 28%
CO2	Trucks	28%
PM	Trucks	37%
SO2	Cars and 2 wheelers	27% and 23%

Grid-wise distribution of emissions of different pollutants is shown in Figure 7.16.



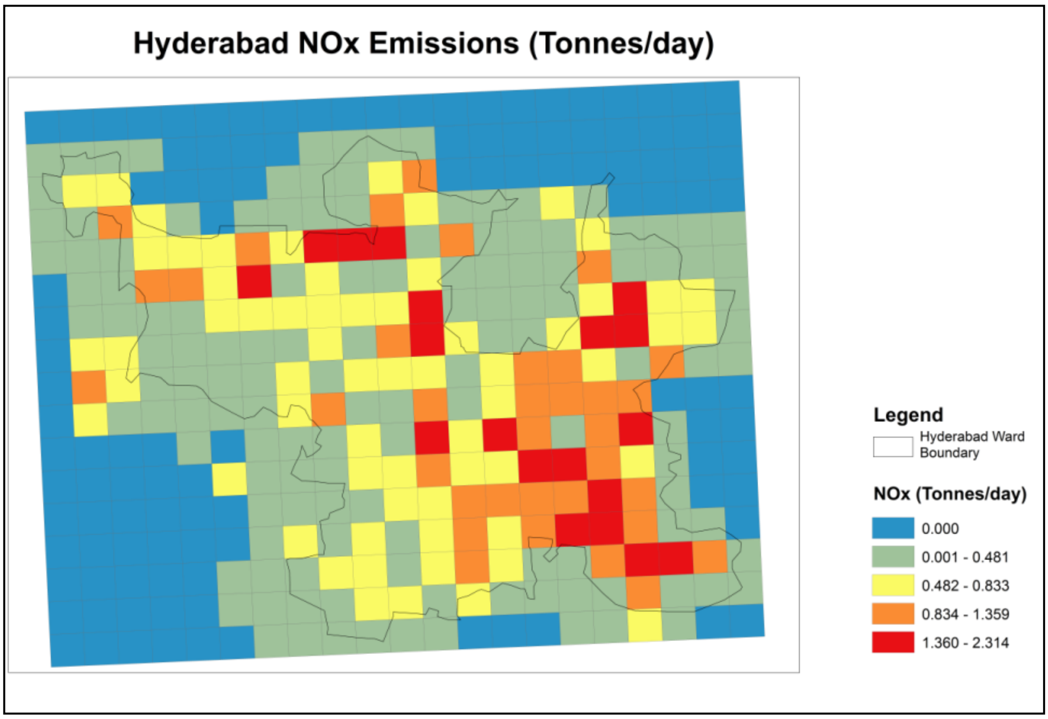


Figure 7.16 Grid-wise distribution of PM and NOx emissions in Hyderabad city

7.2.6 Solapur

Total VKT by different vehicle categories has been estimated for the city of Solapur using the two approaches. Figure 7.17 shows the differences observed in the two approaches. The traffic count approach shows lower VKT estimates and depicts lesser presence and usage of registered vehicles. The vehicles registered in Solapur may also be catering to mobility demands outside Solapur city limits.

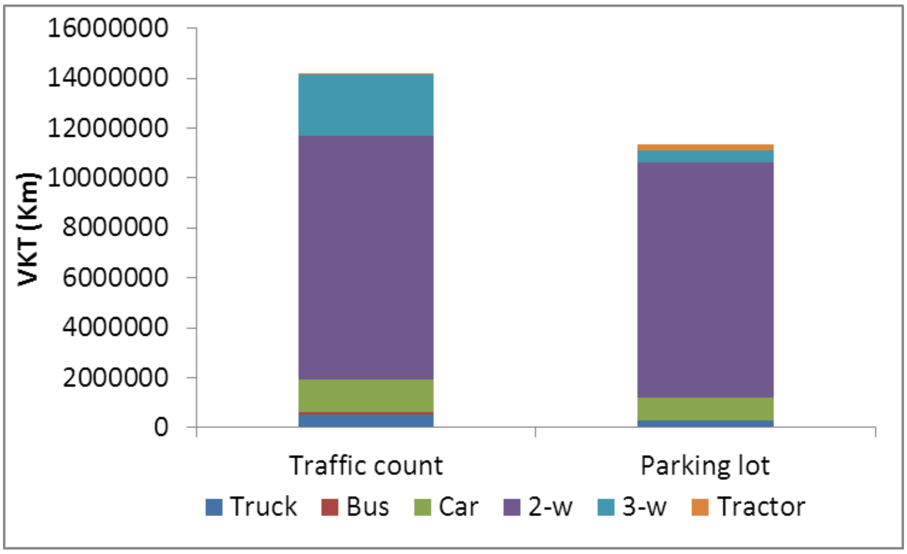


Figure 7.17 Comparison of VKT estimates using the two approaches based on registered vehicles and traffic counts in Solapur

It is to be noted that overall there is difference of 20% in the two. Moreover, the fuel consumption derived from the VKT estimates are also compared with the fuel consumption data for the city collected from the oil companies.

7.2.4.1 Emissions

VKT estimated for different sub-categories of vehicles using the two approaches are multiplied with the respective emission factors to arrive at the emission estimates of the city. The final emissions estimated using the approach based on actual traffic count surveys are presented in Table 7.12.

Table 7.12 Emission inventory of road transport sector in Solapur city

Pollutants		Emissions
(tonnes / day)	CO	19.14
	HC	6.63
	NOx	10.49
	CO_2	930.73
	PM	1.10
	SO_2	0.04
	N_2O	0.04
	CH_4	0.44
	NH_3	0.15
(g/day)	Benzene	151.80
	1-3 Butadiene	130.63
	Acetaldehyde	175.28
	Total Aldehyde	619.23
	Total PAH	9569.92

Road transport sector in the city of Solapur contributes to almost 1.1 ton of PM per day. The emissions of gaseous pollutants such as NOx, CO, and HC are 10.5, 19, and 6.6 T/d respectively.

Category wise contribution of different vehicles in the emission loads of various pollutants is shown in Figures 7.18.

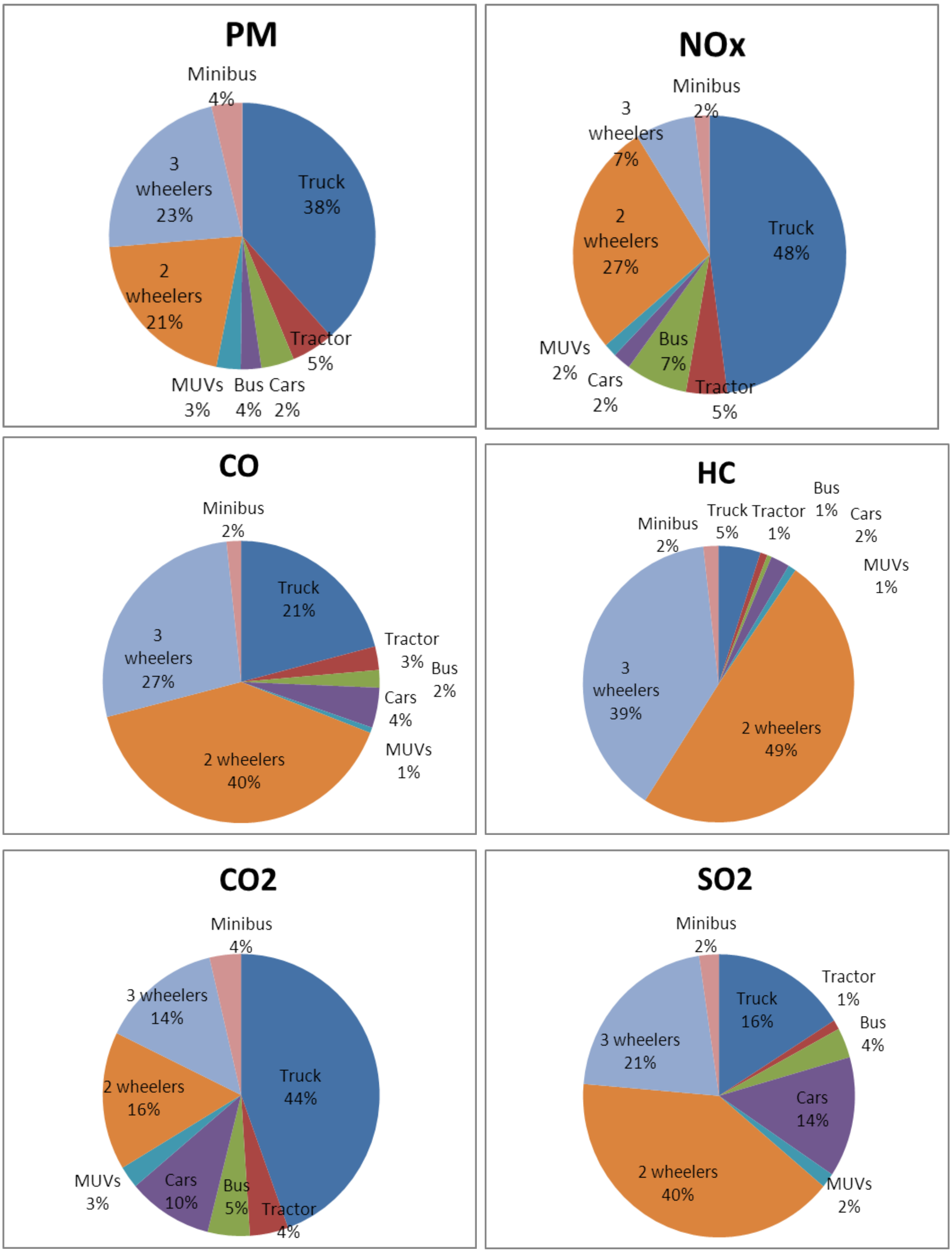


Figure 7.18 Shares of different vehicle categories in emissions of various pollutants from road transport sector in Solapur city

Figure 7.18 shows that trucks are contributing maximum to PM (38%) and NOx (48%) emissions. Two and three wheelers have the next highest share in PM and NOx emissions. On the other hand, pollutants like CO and HC are mainly emitted from two and three wheelers. SO_2 and CO_2 emissions are fuel based and show that trucks and two and three wheelers consume the maximum share of energy used in the road transport sector in the city and hence lead to higher contribution to SO_2 and CO_2 emissions. Table 7.13 presents the vehicle categories which contribute maximum towards the emissions of different pollutants.

Table 7.13 Vehicle categories contributing maximum towards emissions of different pollutants in Solapur

Parameter	**Vehicle category contributing the most**	**Percentage share in total emissions**
CO	2 wheelers	40%
HC	2 wheelers	49%
NOx	Trucks & 2-wheelers	48% and 27%
CO2	Trucks & 2-wheelers	44% and 16%
PM	Trucks and 3 wheelers	38% and 23%
SO2	2 wheelers and 3 wheelers	40% and 21%

Grid-wise distribution of emissions of different pollutants is shown in Figure 7.19.

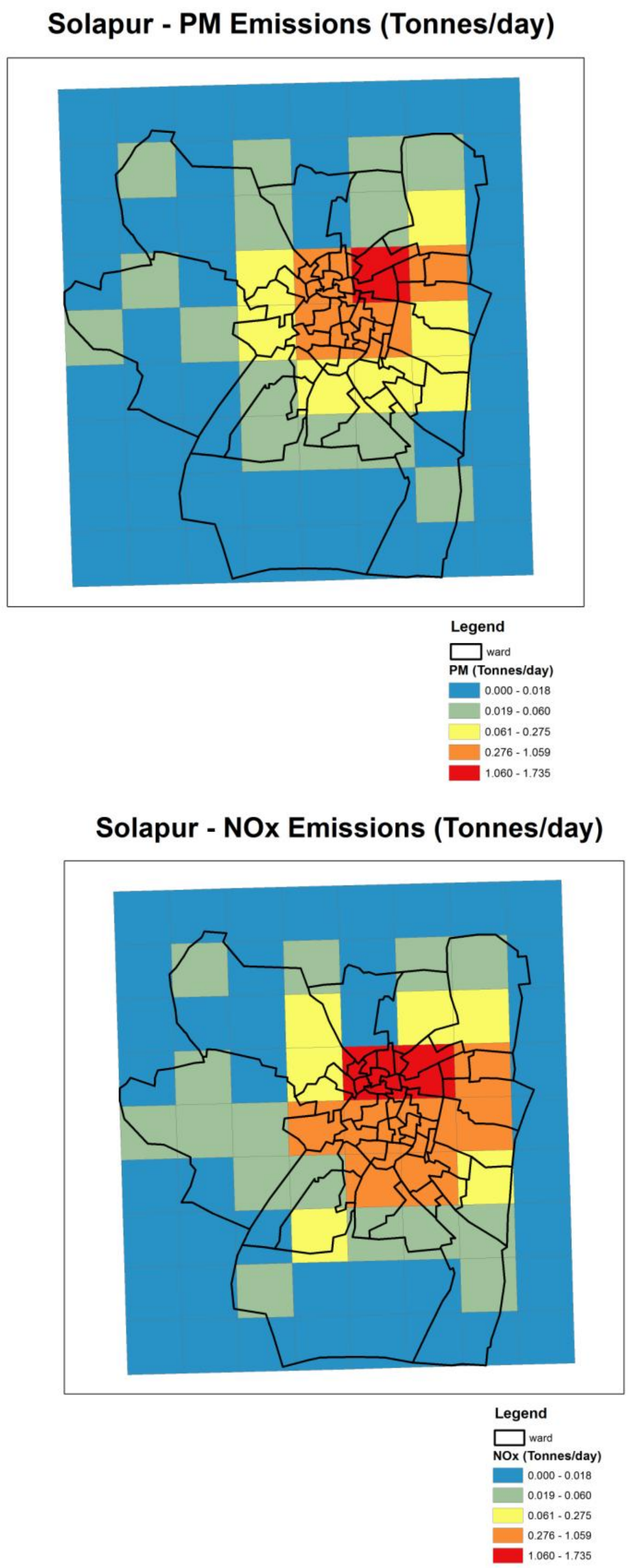


Figure 7.19 Grid-wise distribution of PM and NOx emissions in Solapur city

7.2.4.2 Comparative analysis of cities

An analysis is carried to compare the emissions of various cities (Figure 7.19a). Hyderabad being the largest shows highest PM emissions followed by Ahmedabad. Kolkata despite lesser number of vehicles on road shows significant PM emissions due to the presence of older fleet. Lucknow and Patna also show comparable PM emissions despite their differences in number of vehicles, this is mainly due to the fact that CNG is introduced in Lucknow and Patna is still on BS-III fuel quality and emission norms. Solapur being the smallest city shows the lowest but significant emission loads.

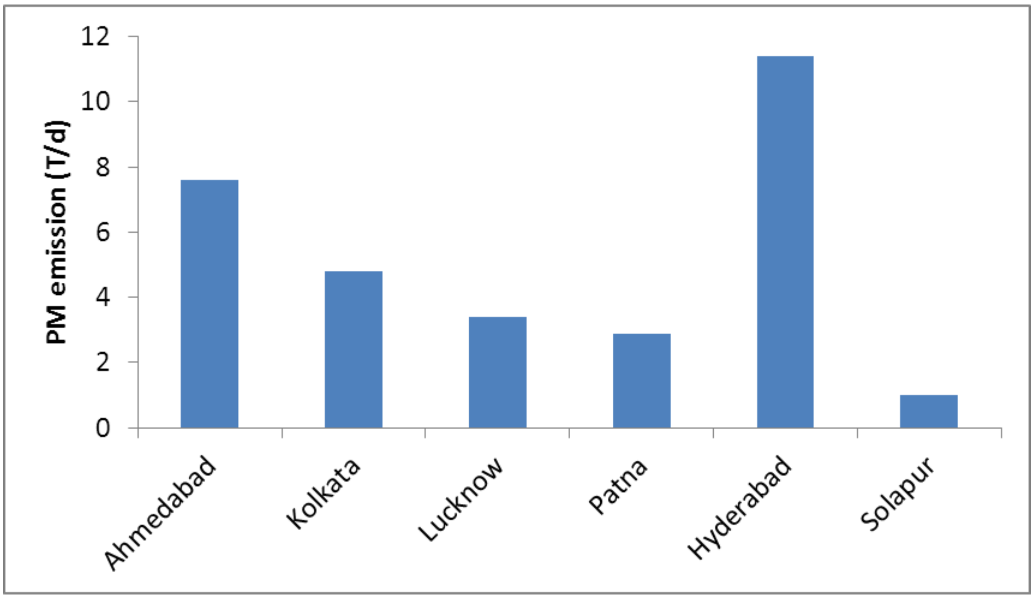


Figure 7.19a Total PM emissions (T/day) estimated in the six cities

Figure 7.19b and 7.19c show the PM and NOx emissions estimated in the six cities per lakh of vehicular population. The results are compared with the emission inventories of the other cities estimated in the source apportionment studies (CPCB, 2011).

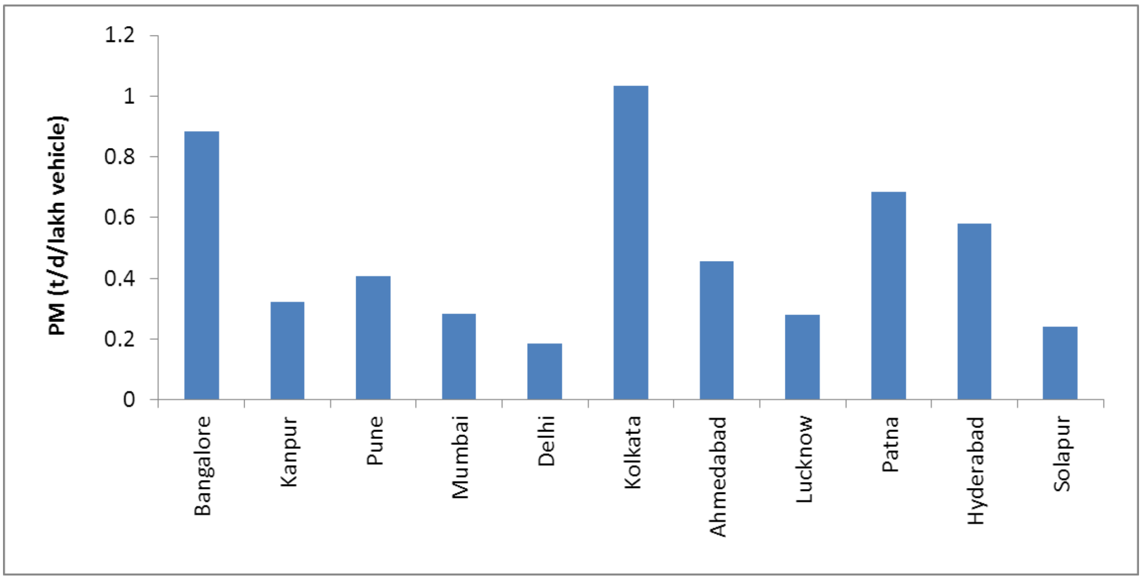


Figure 7.19b PM emissions estimated in the six cities per lakh of vehicular population

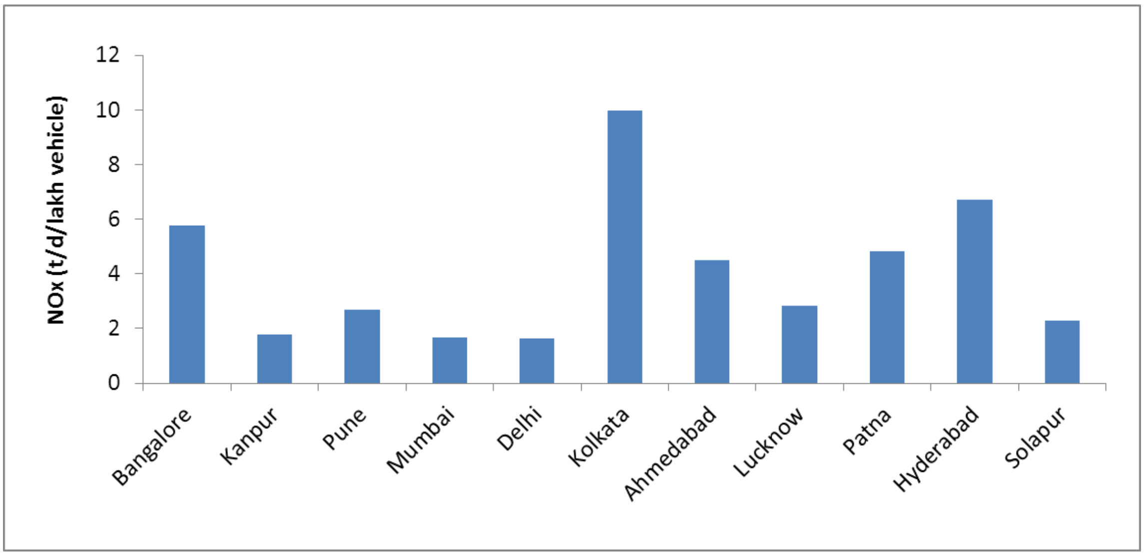


Figure 7.19c NOx emissions estimated in the six cities per lakh of vehicular population

The emissions estimated in the current study seem to be in range when compared with other cities. The cities where CNG has been introduced show lower PM emissions per lakh vehicular population. Emission per lakh population for Kolkata seems to be higher than rest of the estimates because of the higher shares of older vehicles in the overall fleet.

Figure 7.20 shows the ratio of NOx to PM emissions which is also in similar ranges except for Hyderabad and Kolkata where NOx is very high owing to diesel based buses. The ratio is also found to be higher in the cities having CNG (Ahmedabad) depicting better control of PM emissions.

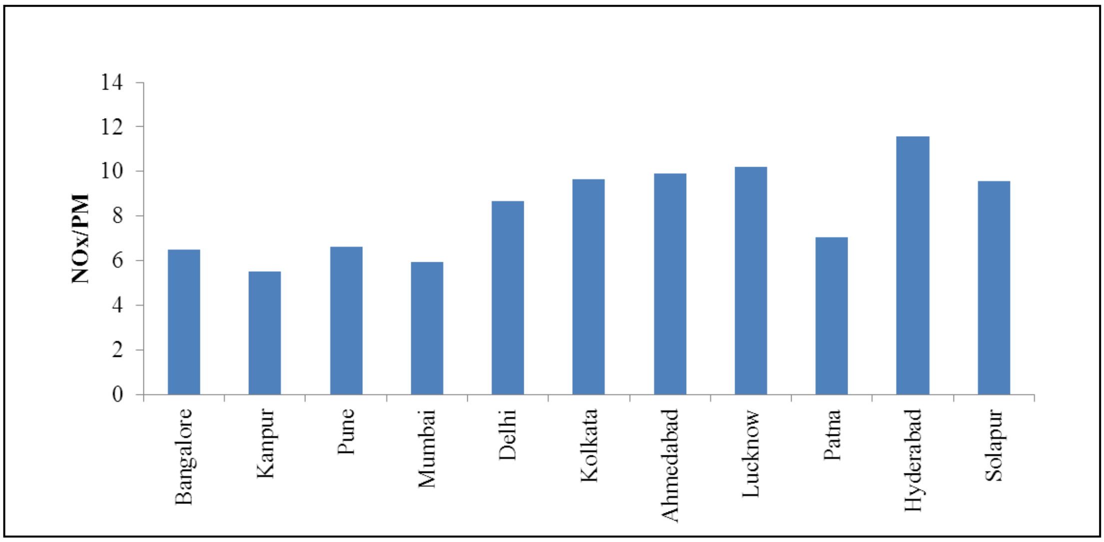


Figure 7.20 NOx to PM emission ratio in different cities

7.2.4.3 Comparative analysis with previous estimates

The current estimates of pollutant emissions from the road transport sector are compared with previous studies. Table 7.14 shows PM emissions in the current and previous studies.

Table 7.14 Comparison of current PM emission estimates (T/d) with previous studies

Cities	Current	Guttikunda and Jawahar, 2010	Other estimates
Hyderabad	11.9	13.0	(2011) 12.18 , EPTRI, 2005
Solapur	1.1	-	(2003) 0.57 Solapur Action plan
Kolkata	4.6	4.0	(2002) 10.8, Auto Fuel Policy
Lucknow	3.6	3.6	
Ahmedabad	7.7	7.6	
Patna	3.0	3.4	

The estimates are found to be quite close to the previous estimates and reflect reliability. Minor variations could be observed due to differences in methodologies and timeframes.

8. Emission modelling based on real-world driving conditions

Emission factors and norms across the world are established based on particular driving cycles. However, internationally; it has been observed that there are considerable differences between the driving cycles and real-world driving conditions. This leads to real-world emissions and fuel consumptions being higher than expected. This section of the report assesses the real-world driving conditions in the 6 Indian cities and compares them with the Indian driving cycles followed for different categories of vehicles. The emissions of different categories of vehicles are modelled based on real driving conditions using the USEPA approved International Vehicle Emissions (IVE) model.

IVE Model

The International Vehicle Emissions (IVE) model is a computer model for estimating emissions from vehicles. The model takes into account vehicular technologies, fuel quality, driving conditions, and topography for computing emissions of different local air pollutants, greenhouse gas emissions, and toxic pollutants. The IVE model was developed as a joint effort of the University of California at Riverside, College of Engineering – Center for Environmental Research and Technology (CE-CERT), Global Sustainable Systems Research (GSSR), and the International Sustainable Systems Research Center (ISSRC).

The emission estimation process followed in the IVE model is shonw in equation 1. The base emission rates (B) are multiplied with a series of correction factors (K) to estimate the adjusted emission rate (Q) from each vehicle type. The correction factors (K) are based on metrological conditions, topography, and fuel quality.

$Q[t] = B[t]* K(1)[t] *K(2)[t]*.....K(x)[t]$ -----------------(1)

Thereafter, the equation 2 weights the adjusted emission rate by the travel fraction and type of driving for each technology.

$Q = \Sigma t \{f[t] * \Sigma d [Q[t] * \bar{U} FTP *f[dt] * K[dt]]\} / \bar{U} C$ ------------------------(2)

Where

B[t] Base emission rate in for each technology (start (g/start) or running (g/km))

Q[t] Adjusted emission rate for each technology (start (g/start) or running (g/km))

f[t] Fraction of travel by a specific technology

f[dt] Fraction of time of each type of driving or fraction of soaks by a specific technology

Ū FTP average velocity of the LA4 driving cycle (a constant (kph))

Ū C Average velocity from the specific driving cycle, as input by user in Location File (kph)

Real world driving conditions in six cities

Real world driving patterns were measured in the six cities through GPS based instruments. Speed and altitude variations were captured at equal intervals of one second. The surveys were carried out for about 24 hours of driving in each city covering different types of roads and area categories. It is to be noted that the survey does not include driving outside dense, congested cities (driving on highways) which can also lead to higher speed-acceleration profiles than the optimal ones and hence higher fuel consumption and emissions. The surveys were carried out for three vehicular categories i.e. motor cycles, cars and buses. The speed-acceleration profiles for cars measured in different cities are presented in Figure 8.1. It is revealed that due to heavy congestion observed in most cities, vehicles were found to be spending higher shares of their driving time with low speeds. The profiles were also compared with the Modified Indian Driving Cycle (MIDC) on which type approval emission norms are tested.

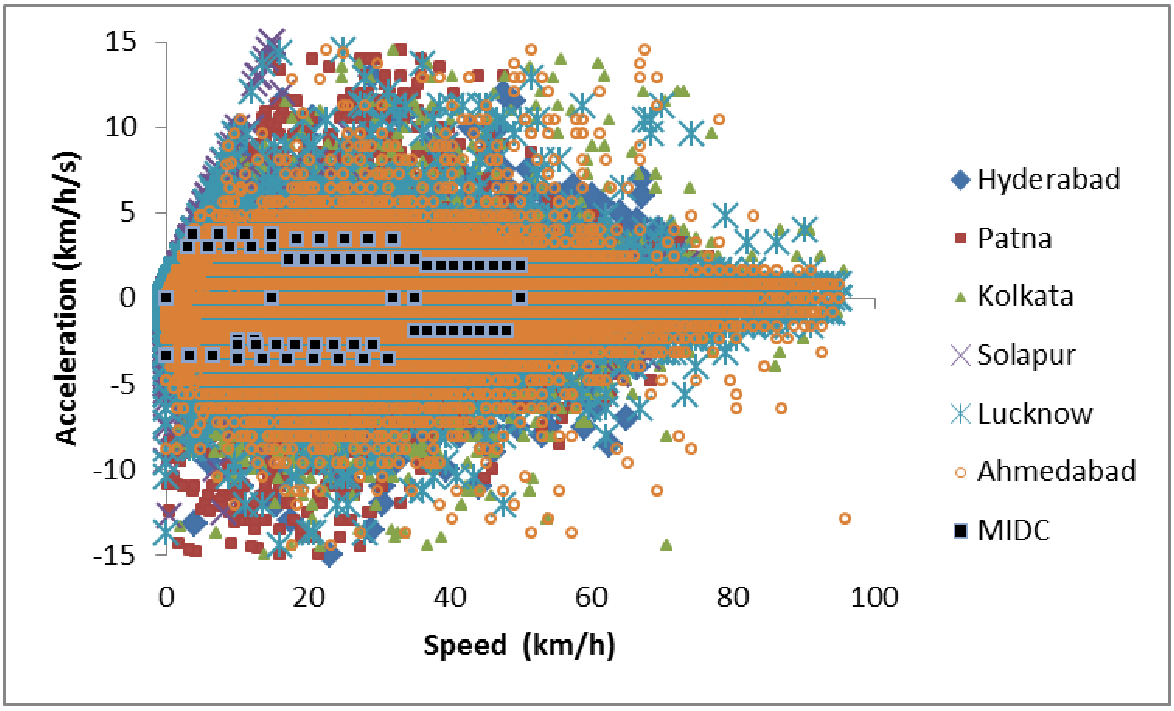


Figure 8.1 Speed acceleration profiles observed in different cities compared with MIDC.

The driving cycle for different categories of vehicles (cars, two-wheelers, and buses) are distinctly different and not representative of the actual driving conditions in the six cities. Higher shares of time consumed in lower speeds (due to congestion) and significantly higher speeds and accelerations observed in the six cities show drastic differences with the currently used MIDC.

Emission modelling

Real driving characteristics were fed in the IVE model along with other relevant city specific information and model runs were performed for different time of days. It was observed that during the peak times (i.e.8-10 AM and 6-8 PM) the vehicular speeds go down drastically. The average speeds observed in different cities are shown in Figure 8.2.

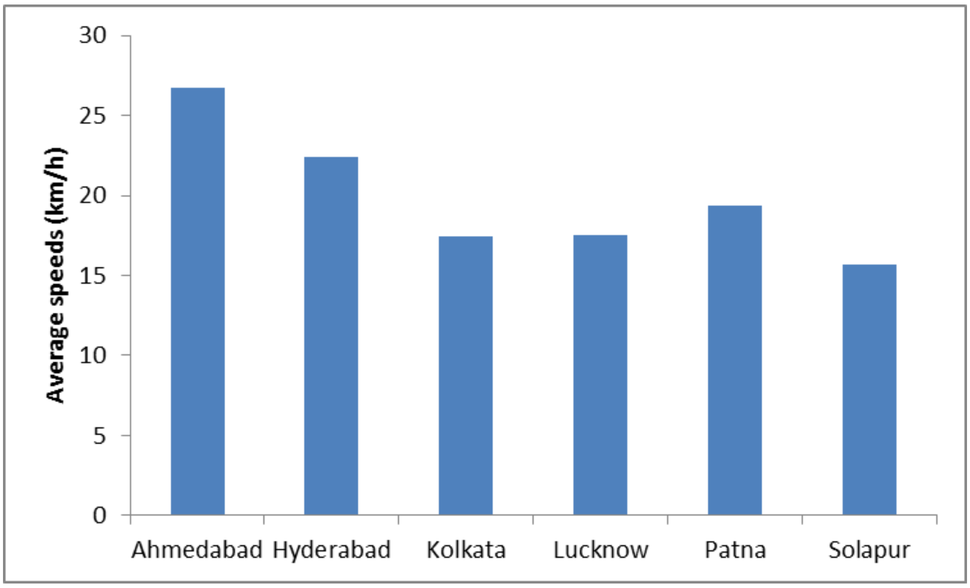


Figure 8.2 Average speeds (km/h) observed for cars in different cities

IVE results were analysed for the two main pollutants of concern i.e. PM and NOx. Correlations have been developed with PM and NOx emissions with varying speed profiles estimated by the IVE model. Figures 8.3, 8.4 and 8.5 show the variations of PM and NOx emissions with changing average speeds for different categories of vehicles across different cities. The emissions are varying due to varying driving conditions observed across the time of the day. It is to be noted that during most of the day the vehicles emit more than the emission factors developed on prescribed driving cycles.

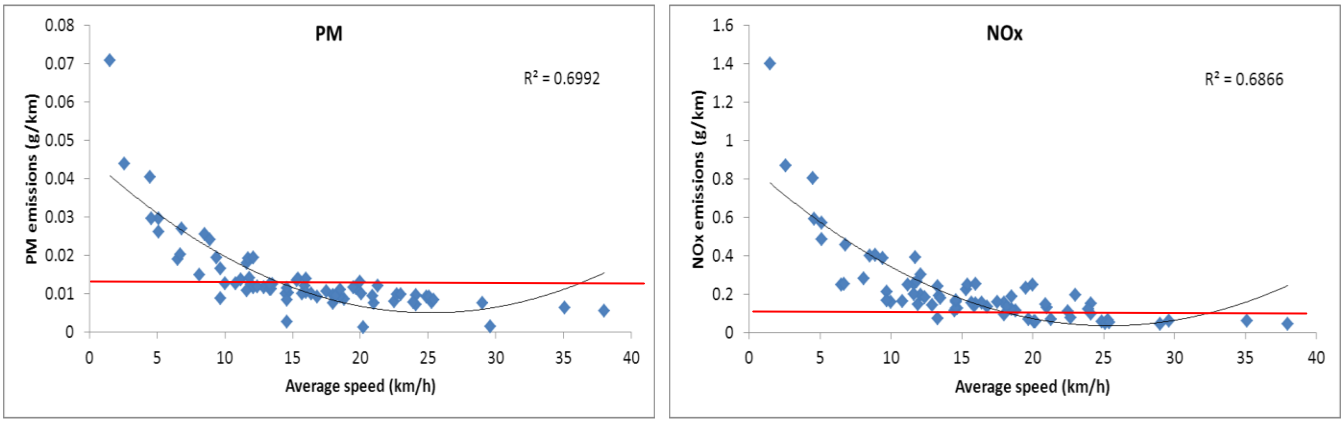


Figure 8.3 PM and NOx emissions (g/km) from Motor Bikes varying with average speeds observed in the six cities

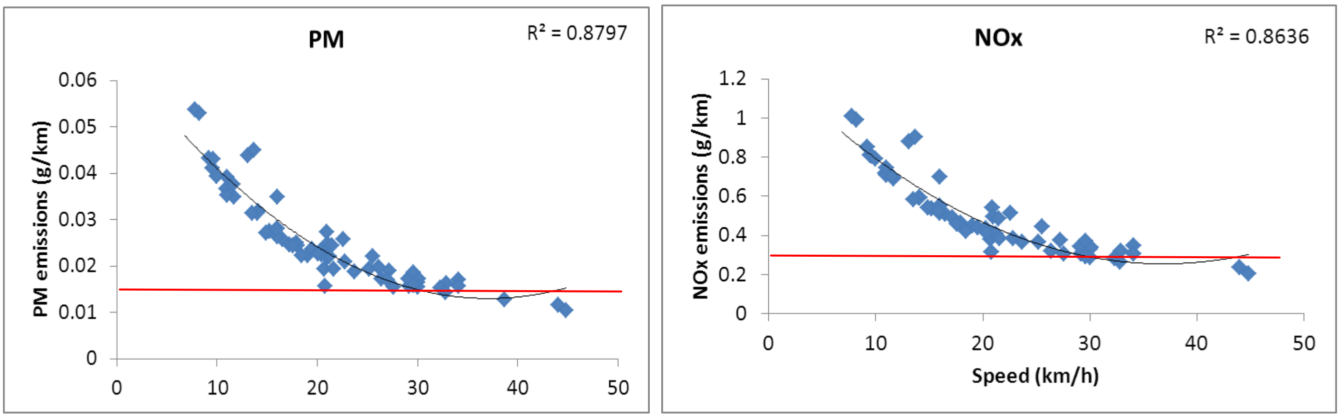


Figure 8.4 PM and NOx emissions (g/km) from diesel cars varying with average speeds observed in the six cities

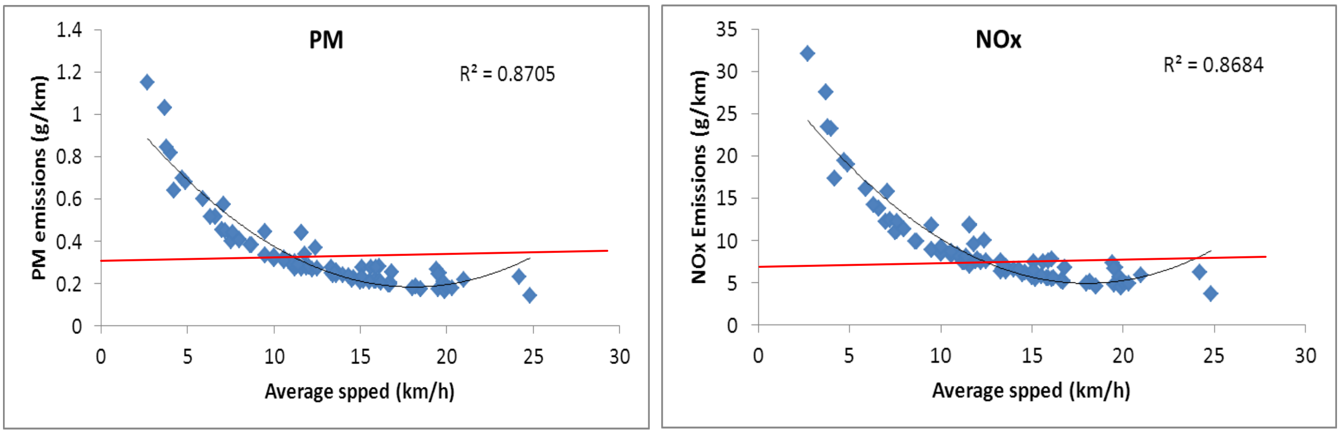


Figure 8.5 PM and NOx emissions (g/km) from buses varying with average speeds observed in the six cities

The effects of congestion have been found to be present in the form of lower vehicle speeds which can lead to increased emissions from the vehicles. This is consistent with the findings of international studies on similar subjects. Huang et. al., 2013 showed that a bus emits highest NOx in the high vehicle specific power (VSP) and low-speed bin depicting starting and accelerating under heavy load conditions. Chen et. al., 2007 also attribute higher emissions during low speeds with frequent acceleration and decelerations.

The differences in the ARAI emission factors developed on prescribed driving cycles and the ones modelled using actual driving conditions observed in the six cities are presented in Table 8.1.

Table 8.1 Differences observed between ARAI emissions factors developed on prescribed driving cycles and emissions resulting from IVE model based on real world driving cycles observed in the 6 cities

Vehicle type	ARAI, 2011, emission factors (g/km)	IVE results (g/km)	Differences (ratio of IVE results with ARAI emission factors)
PM			
Motor Bike – BS-III	0.013	0.008-0.019	0.64-1.49
Car – BS-III	0.015	0.020-0.027	1.34-1.79
Bus – BS-III	0.3	0.29-0.44	0.97-1.49
NOx			
Motor Bike – BS-III	0.15	0.053-0.31	0.35-2.1
Car – BS-III	0.28	0.41-0.55	1.47-1.98
Bus – BS-III	6.53	6.6-12.4	1.02-1.91

The IVE model analysis shows that real world emissions from different categories of vehicles could be higher than the emissions calculated using the emission factors developed over the prescribed driving cycles. Based on the speeds encountered in different cities the PM emissions of buses were estimated to be 0 to 49% higher than the emission factor approach. Hence the real world emission inventories could be more than estimated through the emission factor approach. The results of IVE model could be validated with real world testing of vehicular emissions using portable emissions measurement systems (PEMS) equipment.

9. Emissions from evaporative sources

The two major sources that are responsible for emissions from motor vehicles basically arise from tailpipe and evaporative modes. Vapours or fumes which are not emitted by the exhaust system, but escape from the fuel tank, carburettor and crankcase contribute to evaporative loses in mainly petrol driven vehicles. Most evaporative emissions emanate from the fuel systems (tanks, injection systems and fuel lines) of gasoline powered vehicles. Evaporative emissions from vehicles mainly consist of light (C_4 to C_6) hydrocarbons. Evaporative emissions are the major component out of the total vehicle hydrocarbon (HC) emissions. In general, evaporative emissions are found to be higher in summer due to its direct relationship with ambient temperature.

Volatile organic compounds are known to have severe health impacts. In addition to this, they are also recognised as one of the important pre- cursors of ground level Ozone formation. Ozone is formed by the photochemical reaction of HC and NO_x in the presence of sunlight. Despite, improvements in the emission norms for control of tail-pipe emissions, the problem of evaporative emissions is still a matter of concern. Designs of fuel filling system, daily variation in ambient temperature, volatility of the fuel and different driving conditions are some of the factors that are known to impact degree of evaporative emissions from petrol driven vehicles. It is to be noted that there have been no standards for control of evaporative losses from vehicles in India.

Evaporative emissions from diesel vehicles are considered to be negligible due to the presence of heavier hydrocarbons and the relatively low vapour pressure and low volatility of diesel fuel, and hence are neglected in calculations.

Results

Based on the methodology discussed in chapter 1, the evaporative emissions from the road transport sector in different cities are estimated and are shown in Figure 9.1.

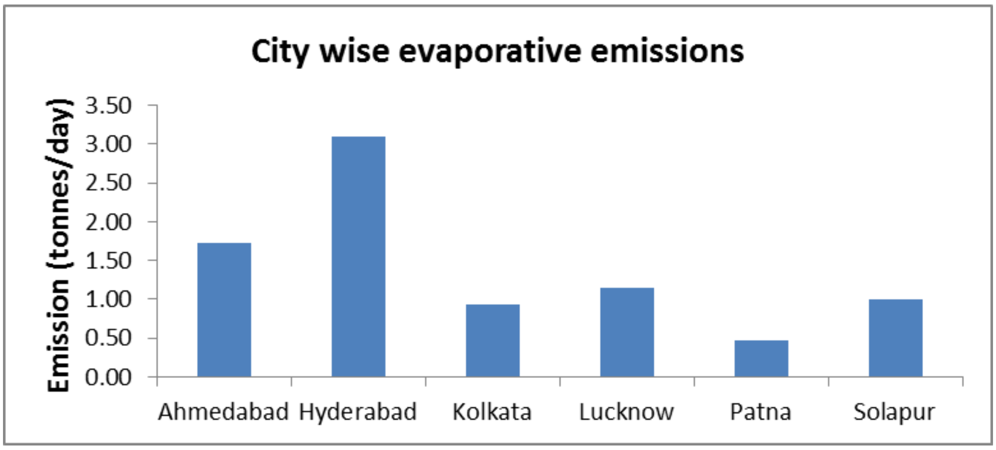


Figure 9.1 Evaporative HC emission loads in different cities from road transport sector

The evaporative emissions across various cities ranged between 0.47 and 3.10 tonnes/day. The emissions through evaporative sources were found to be maximum in Hyderabad city and minimum in Patna city. This can be attributed to the differences in the quantity of fuel consumed in each city. Other than the total fuel consumed, meteorology of the city also plays an important role in defining the quantities of evaporative emissions. The monthly variation of hydrocarbon emission estimates for various cities is plotted in Figure 9.2 given below.

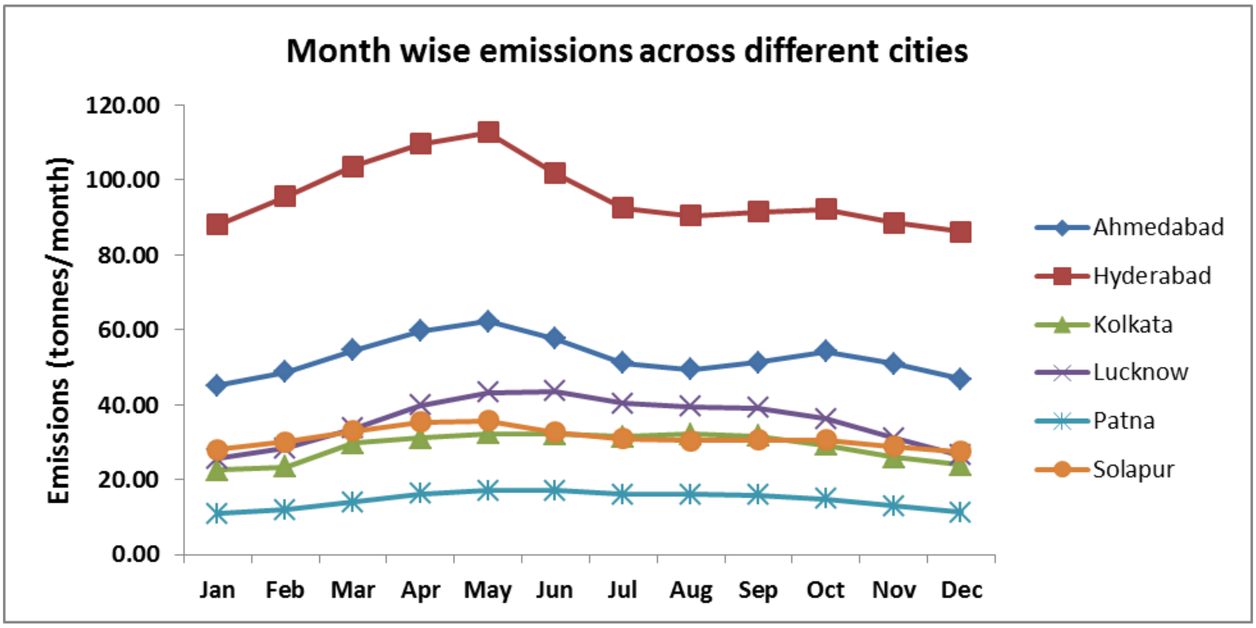


Figure 9.2 Monthly variation of evaporative emissions in the six cities

It is evident that evaporate emissions in all cities were found to be high in summer months due to their sensitivity with the ambient temperature. It should also be noted that increase in ambient temperature in turn increases the temperature of the dispensing fuel and also the temperature of fuel in vehicle tank (this temperature also increases by heat from the engine and exhaust system)– the two factors further affecting the emission from evaporative sources.

It is also evident that cities with distinct summer and winter seasons, like Lucknow and Patna are found to be following the same trend and the trends in other cities like Ahmedabad, Hyderabad and Solapur are found to be similar. Comparatively higher hydrocarbon emission in Hyderabad city throughout the year is also attributed to the high volume of petrol sold in this city as compared to other five cities.

Adoption of emission control technologies like vapour recovery system (VRS) and on-board refuelling vapour recovery (ORVR), introducing suitable design features in the vehicle tank are some of the measures to reduce fugitive emissions. At the moment, very few installations of these systems have been made in some cities.

10. Emission projection and scenario analysis

Emission estimates for the vehicular sector for different cities were projected for the year 2025 using existing developmental plans. Various factors such as the growth in population and vehicles, introduction of emission and fuel quality norms, existing and planned public transport infrastructure etc. were taken into account for these projections. In the BAU scenario, BS-IV emission norms were assumed to be present across all cities for all vehicles (other than trucks which are assumed to be on BS-III) except for Patna which is assumed to be on BS-III norms in 2025.

In view of reducing emissions from the transport sector six alternate scenarios have also been developed for each city. The strategies considered to build each scenario are described below:

1. *BS-V scenario*: Introduction of advanced emission norm BS-V from 2015 (in trucks, LCVs, buses, cars, and MUVs)

2. *BS-VI scenario*: Introduction of advanced emission norm BS-VI from 2015 (in trucks, LCVs, buses, cars, and MUVs)

3. *DPF scenario*: Installation of DPFs in diesel vehicles (cars, buses and 3-wheelers)

   It is assumed in this scenario that introduction of diesel particulate filters (DPFs) will lead to a reduction of 90% PM emissions in diesel vehicles.

4. *CNG scenario*: Introduction of cleaner fuel CNG (for buses, 3-wheelers and half of the car population)

   In this scenario it is assumed that CNG will be introduced in the cities where it is currently not present and all buses, 3 wheelers and half of the car population will be switched. In cities where it is already present it is assumed that the coverage will become 100% irrespective of current levels.

5. *I&M scenario*: Improvement in inspection and maintenance (I&M) for vehicles

   It is assumed here that improvement in I&M will lead to a reduction of 26.25, 18.75 and 3.75% reduction in CO, HC and NOx respectively in petrol driven cars. While in diesel vehicles 25% reduction in PM emissions is assumed with improvement in I&M system. These numbers are based on the percentage reductions attributed to I&M implementation in the EU (adapted from '*Case studies comparing the EU experience with the experience of USA and other countries, 2004*').

6. *PTS scenario*: Enhancement of public transport system (based on CNG)

   In this scenario 50% of passenger km travelled (PKT) in private mode (2-wheelers and cars) is assumed to shift to public mode (CNG buses).

The numbers of vehicles in the six cities have been projected for the year 2025 based on the city development plans (CDP) and travel demand projections given in different transport related studies in various cities. In case of Patna, Lucknow and Solapur the travel demand projections were not available and were derived based on regression between the growth rates of the state GDP with the growth in number of vehicles over the past ten years. The freight transport is assumed to grow with the population on the basis that they cater to the demands of the city residents. The growth rates assumed for the six cities to project the vehicular population in the year 2025 have been listed out in Table 10.1.

Table 10.1 Vehicular growth rates assumed in different cities (2012 to 2025)

City	Vehicular growth rate (in 13 years)	Goods vehicle growth rate in 13 years (truck, tempo and tractor)
Ahmedabad[a]	64%	28%
Hyderabad[b]	69%	48%
Kolkata[c]	72%	20%
Patna	200%	34%
Lucknow	148%	50%
Solapur	177%	47%

[a] Detailed project report, Ahmedabad bus rapid transit system plan (ABRTS), 2008
[b] Comprehensive transportation plan (CTS) of Hyderabad Metropolitan Development Authority, 2012
[c] Comprehensive development plan (CDP), Kolkata metropolitan area

The projected vehicular fleet for the year 2025 was used to estimate emissions of different vehicle categories in the six cities. Alternate scenarios of emissions were developed for the year 2025. The road transport sector emissions projected for the year 2025 in BAU scenario and reduction potentials of various alternate scenarios are illustrated in Table 10.2.

Introduction of advanced emission norms BS-V in different cities can lead to reduction in NOx emissions in the range of 13-35% along with reduction in PM emissions by 13-43% with respect to BAU scenario. And introduction of BS-VI can bring in a reduction of 20-45% in NOx emissions and 13-43% in PM emissions across different cities. Cities like Lucknow show lower impact of BS-V/VI norms as they have higher contribution of 2 and 3 wheelers in emissions (Figure 7.6) which are assumed to remain on the current norms only.

Installation of DPF in diesel vehicles can lead to significant reductions of PM as high as 36-56% across the six cities.

In the CNG scenario, a reduction of 2-16% is estimated in PM emissions. It is comparatively lower than other strategies since in 2025 the major share of PM emissions are expected to be from heavy duty trucks, as in the BAU scenario they are assumed to be complying with BS-III emission norms even in the year 2025. Hence the reduction observed due to CNG vehicles (buses, cars and 3-wheelers) is eclipsed by the high share of truck emissions.

Introduction/enhancement of CNG bus based public transport system could reap tremendous benefits in terms of PM emissions in cities like Solapur (55%), Patna (40%) and Lucknow (23%) where the existing PTS is inadequate and needs improvements.

Improvements in I&M system in various cities could lead to about 7-13% reduction in overall PM emissions. An improved I&M system is also a pre-requisite for other scenarios like BS-V/BS-VI/DPF/CNG/PTS, to maintain the compliance of emissions in real world conditions.

Table 10.2 Emission reduction potential of each alternate scenario as compared to BAU for different cities in 2025

Cities	Pollutants	BAU (t/day)	Percentage reductions of different scenarios as compared to BAU					
			BS-V	BS-VI	DPF	CNG	I&M	PTS
Ahmedabad	NOx	127.6	-23%	-33%		-2%		5%
	PM	7.1	-28%	-28%	-47%	-2%	-11%	-19%
Hyderabad	NOx	154.5	-22%	-35%		-2%		13%
	PM	8.0	-28%	-28%	-51%	-5%	-13%	-8%
Kolkata	NOx	42.8	-20%	-39%		-3%		2%
	PM	1.9	-33%	-33%	-56%	-7%	-11%	-18%
Patna	NOx	65.3	-35%	-45%		-2%		-20%
	PM	5.5	-43%	-43%	-53%	-16%	-12%	-40%
Lucknow	NOx	58.3	-13%	-20%		-1%		11%
	PM	4.3	-13%	-13%	-36%	-7%	-7%	-23%
Solapur	NOx	16.9	-19%	-28%				-36%
	PM	1.2	-19%	-19%	-39%	-3%	-9%	-55%

11. Action Plan

Based on the emission estimates and share of different vehicle categories in different cities, strategies have been identified and actions for their implementation have been suggested. The potential of the strategies has also been evaluated in previous chapter on future projections. The strategies have been identified under the broad spectrum of AVOID, SHIFT and IMPORVE spectrums. While AVOID strategies can lead to the reduction in the mobility demands, SHIFT strategies like enhancement of public transport will encourage people to switch to cleaner and efficient modes of transport. On "Improvement", it was identified that progressive advancement of emissions norms is a must to mitigate emissions from the sector in the longer run. Emissions from existing vehicles also need to be controlled by taking measures which have immediate effect. These may include commissioning of effective I&M systems, retrofitting with DOC/DPFs, and restrictions over old commercial vehicles. Introduction of cleaner gaseous fuels can be considered in the cities where it is logistically possible. The strategies are listed below in Table 11.1.

Table 11.1 Action plan to reduce vehicular emissions in the cities

Strategy	**Responsible Agency / agencies**	**Remarks**	**Applicability ***
National scale interventions			
Uniform fuel quality and vehicular emissions norms Progressive improvement of vehicular emission norms (BS-V, BS-VI)	MoRTH, MoPNG, Ministry of Heavy Industry and Public Enterprises, MoEF, Oil companies, Automobile manufacturers	Dual policy on auto-fuels should be discontinued and road map should be developed well in advance to plan the progressive improvement of emissions norms and corresponding fuel quality norms. This will ensure introduction of cleaner vehicles within and outside the cities.	Patna specifically will benefit as it is currently at a lower norm than the rest of five cities. All cities
Effective Inspection and maintenance regime for vehicles	Transport Department, Traffic police	Greater coverage of vehicles for I&M activities; Capacity development in terms of infrastructure for fully computerized testing/certification and training of personnel. Linkage of all PUC centres to a central location for better data capture and analysis.	All cities

State/city scale interventions			
Installation of pollution control devices (DOC/DPF) in all diesel vehicles	Transport department	This could be useful in reducing emissions from existing fleet of vehicles. However, for the devices to function at best possible efficiencies, 10-ppm sulphur fuel (BS-V) is prerequisite. Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction.	Hyderabad, Patna, Kolkata as they have shown higher reduction potential in this strategy
Strengthening of Public transport system	MoUD, Municipal corporation, Transport Department, Urban Development Authority	Adequate funding mechanism is required for improving public transportation system. Public-private partnership models to be explored. Metro network needs to be progressively expanded.	Lucknow, Patna, Solapur have shown the highest impact of PTS on pollutant emissions
Ban on old commercial vehicles (10 year) in the city	Transport department	Old trucks entering the city should be discouraged /banned. Planning for gradual phase out of old vehicles within the city with due advance notice. Careful evaluation of socio-economic impact of banning old vehicles. Cost-benefit analysis of banning old vehicles. In the long run, a ban/ higher tax on private vehicles too (> 15 years) could be looked into. Fiscal incentives / subsidies for fleet renewal could be considered.	Kolkata showing the highest share if older commercial vehicles, will show the highest impact.
By-passing of transiting traffic.	Transport department, PWD	Peripheral highways to be developed around the cities so that transiting vehicles do not need to enter the cities	Lucknow, Patna, Solapur

Reduction in private vehicle usage/ ownership	Min. of Finance, State and City Government	A pre-requisite for curbing the growth of private vehicles is the provision of an effective mass based transport system. Strategies such as costlier parking, higher excise duties/sales tax on private vehicles, levying congestion tax, and measures to encourage car-pooling would be helpful.	Lucknow, Patna, Solapur
Improve traffic flow	Traffic police, Municipal corporation, Transport department	Synchronization of signals, one way roads, flyovers, widening of roads, removal of encroachments, staggering of office timings to reduce peak flow and congestion. Application of IT tools for traffic management (Intelligent transport system)	Kolkata, Solpaur, Patna, Lucknow
Prevention of fuel adulteration	Govt. of India, Oil companies, Food and civil supplies department	Re-assess subsidy on kerosene, strict vigilance and surveillance actions, better infrastructure in terms of testing laboratories	All cities
Introduction of cleaner fuel such as CNG	MoRTH, MoPNG, Transport Department,Oil companies	To begin with buses and 3 wheelers could be converted to cleaner fuels / CNG through appropriate policy interventions For private vehicles it has to be a voluntary action.	Patna, Kolkata, Hyderabad
Installation of Vapour Recovery Systems	Oil Companies	This makes economic sense to not only reduce the emissions but also save fuel	All cities

* Although strategies are applicable to all cities, there impact may be more in the ones listed in the column

The cost-benefit analysis of these strategies is very important, but it is presently not in the scope of this study. However, a broad level cost-benefit analysis of some of these strategies has been presented for National scale in India in Ramanathan et al, 2014 and Sharma et al, 2014. The same has been reproduced in Table 11.2 to provide a general idea to the reader about the implementation costs and valuation of health benefits accrued from introduction of some of these strategies in India.

Table 11.2 Cost benefit analysis of various options

Area	Scenario	Description	PM10 reduction (Tons) wrt BAU	Avoided mortalities	Health Benefit (Million INR) (Value of Statistical Life approach)#		Cost of program (Million INR)*	Total Cost (million INR)/ton of PM red.	Benefit to cost ratio		Remarks
			2010-2030		Low est.	Higher est.			Low est.	High est.	
Fuel and vehicle technology	ALT-I	Introduction of BS-IV all across the country by 2015	936	103151	3135399	5332632	1264710	1351	2.5	4.2	Cost of Fuel and vehicle upgradation
	ALT-II	Introduction of BS-IV all across the country by 2020	484	53339	1709876	3039167	790354	1633	2.2	3.8	Cost of Fuel and vehicle upgradation
	ALT-III	Introduction of BS-IV all across the country by 2015 and BS-V in 2020	1035	114061	3485146	5954280	3469688	3352	1.0	1.7	Cost of Fuel and vehicle upgradation
	ALT-IV	Introduction of BS-IV all across the country by 2015 and BS-VI in 2020	1156	127396	3912615	6714072	3912038	3384	1.0	1.7	Cost of Fuel and vehicle upgradation
Alternate fuel	CNG	Converting 70% buses, cars, and 3-	300	51509	1565671	2662866	1472712	4914	1.1	1.8	Cost of CNG pipeline @ Rs

Area	Scenario	Description	PM10 reduction (Tons) wrt BAU	Avoided mortalities	Health Benefit (Million INR) (Value of Statistical Life approach)#		Cost of program (Million INR)*	Total Cost (million INR)/ton of PM red.	Benefit to cost ratio		Remarks
		wheelers to CNG									65 million / km pipeline
In-use vehicle manage ment	RETRO	Retro-Fitment of 50% of existing BS-III/IV truck/bus with DPF @ 80% efficiency	789	105435	3204823	5450708	2622128	3322	1.2	2.1	Cost of Fuel and vehicle retrofittment
	FM	Fleet modernization of 50% existing truck/bus to BS-VI vehicles	970	125350	3810179	6480286	6948251	7162	0.5	0.9	Cost of Fuel and fleet modernisation @ cost of new bus 1.2 million, and truck for 1.5 million
	I&M	Implementation of effective I&M system	403	62836	1909986	3248472	157680	392	12.1	20.6	Cost of I&M Infrastructure

* includes capital (annualized based on life of infrastructure) and O&M costs for the period 2015-2030
BAU: Based on the current plans and policies. BS-III all across India and BS-IV in 13 cities
Low and high end values of health benefits are based on VSL-elasticity factor of 0.5 and 1 with income growth, respectively

It may be noted that all the interventions show satisfactory benefit to cost ratios. Fleet modernisation which shows lower benefit to cost ratio only needs to be employed selectively for some categories of vehicles in selected zones where air quality is of serious concern. Health benefits are found to be highest for introduction of clean fuels and vehicle emission standards, although, with higher costs. However, considering the state of air quality in India cities and high share of transport sector, it makes all sense to move to stringent standards of fuel quality and vehicular emissions. Retro-fitment of vehicles show a good benefit to cost ratio, however technical feasibility in Indian context needs to be further investigated. Commissioning effective I&M programs is the most cost effective strategy to reduce health impacts, although the overall potential to reduce PM is limited. Provision of CNG can also significantly reduce PM emissions and health impacts, but its reach is going to remain limited and hence there is need to provide cleaner liquid automotive fuels for widespread betterment of air quality.

12. Way forward

The project aimed at developing emission inventories for the road transport sector in the six cities. This involved the basic understanding of the city characteristics, road networks, and mobility modal shares. Reconnaissance surveys were carried out along with the collection of secondary data. Primary surveys were carried out in the six cities to adjudge the traffic movements and vehicle usage patterns. Driving patterns were also measured through GPS based surveys. Based on the two approaches 1) registered vehicles (using parking lot surveys), and 2) actual traffic counts, travel demands were estimated for the cities. The share of different vehicles in the overall demand was estimated. Based on established emission factors in Indian context, emission inventory for the road transport sector in the 6 cities has been prepared and presented in the report.

The emissions of the 6 cities show a wide variation due to differences in the characteristics, mobility demands, applied vehicular emission norms and fuel quality. Hyderabad accommodating the largest fleet of vehicles shows the highest emission from the vehicular sector. Solapur being the smallest shows the lowest emission rates. Kolkata although is more dependent on public modes of transport, but the presence of older fleet increases the emissions significantly. With the introduction of CNG in Lucknow and Ahmedabad, the growth of emission is somewhat arrested.

The emission estimates developed using the emission factor approach has been contrasted with the approach using actual driving patterns in the real world conditions in the six cities. The use of IVE model shows that emissions from different vehicle categories could be much higher than those estimated through the emission factor approach. This is mainly due to lower speed observed in the cities due to congestion. Ahmedabad which shows relatively higher speeds of traffic is more close to the emission estimated through the emission factor approach. In Kolkata, very low vehicle speeds result in much higher emissions per unit of distance travelled.

The report also assesses the evaporative emissions from transport sector and finds that the overall fuel consumption and the meteorology play an important role. The advanced vapour recovery systems are the need of hour to control these emissions at the source.

The tail-pipe emission estimates are also projected for the year 2025 to suggest directional inputs for their control. Various scenarios evaluated for control of emissions in these cities show that advancement of fuel quality and vehicular emissions norms may lead to maximum reduction in vehicular emissions loads. Installation of DPFs in existing vehicles could also lead to significant reductions; however, the efficiency of its working depends heavily on the quality of fuels provided. It can be concluded that in order to achieve maximum emission reduction, it is best to adopt a combination of different strategies simultaneously. Strategies such as enhancement of public transport in the city are the prerogative of the local or state level government, while introduction of advanced emission norms needs to be brought in across the nation at the central level. The improvement of I&M system is must to maintain the compliance of emissions in the real world conditions.

The outcomes of the project could provide useful inputs to the policy makers in designing their strategies for vehicular pollution control at the city level. The database prepared in the study could be extremely useful to expand the research in future to relevant areas such as:

a. Source apportionment studies to a ascertain sector specific strategies to improve air quality in these cities
b. Real world testing of vehicular emissions using PEMS.

c. Transport planning studies accounting for environmental impacts
d. Developing plans for controlling evaporative emissions from the sector
e. Assessment of health and other impacts due to vehicular sector in the cities

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Annexure-I

Survey form for traffic count surveys (Screen line survey and cordon survey)

Survey form for traffic count surveys

Date		Count Station number		Direction	
Location		Section (To/From)		Road Name & No.	

Time ↓	Vehicle Categories											
	Bus	Mini-bus	Car	2 wheeler			3-wheelers		Trucks	LCVs	Tractor/ Trailers
				Scooter	Motorcycle	Mopeds	Passenger	Goods			
6-6:15											
7-7:15											
8-8:15											
9-9:15											
10-10:15											
11-11:15											
12-12:15											
1-1:15											
2-2:15											
3-3:15											
4-4:15											
5-5:15											
6-6:15											
7-7:15											
8-8:15											
9-9:15											
10-10:15											

Remarks: Normal day / Rain / Procession / or any other activity

Questionnaire to conduct parking lot survey for Passenger Vehicles – Vehicle Information

Questionnaire Code:			
Date			
Location			
Name of Surveyor			
Name of Supervisor			
Codes	Questions	Responses	Remarks
	Do you use this vehicle for private use or for commercial purposes (eg. as a taxi)?	(1) Private (2) Commercial	
	Vehicle Type (Whether a; Car / Scooter (2 or 4stroke) / Motor-cycle (2 or 4stroke) / Moped (2 or 4stroke) / Passenger Auto (2 or 4 stroke) / Goods Auto (2 or 4 stroke) / Mini-bus / Big Bus / State Bus / Truck / LCV / Tractor / Trailer)		
	What make is your engine of? (For eg. Ashok Leyland, Tata, Maruti etc.)		
	In which year was your vehicle registered? (Registration year) (In case of CNG/LPG vehicles, model date is the date of kit fixation)		
	Which fuel do you use in your vehicle?	*Petrol Diesel CNG LPG*	
	How much mileage does your vehicle give (in Kms/Liter)?		
	What is the maximum capacity of your vehicle?		
	How many people normally travel in your vehicle?		
	Fuel Consumption (within the city): In Litres per month Fuel bill per month		
	How frequently do you get your vehicle serviced (I &M schedule) - (After how many Kms or months)?		
	How many numbers of times you start and stop your vehicle per day?		
	Total Number of Kms travelled per day (within the city limits) Weekdays Weekends		

Annexure-II

Emission factors

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
LCV Diesel (<3000 cc)	1991-96	3.070	2.280	3.030	327.290	0.998	0.543	0.009	0.198	0.012	0.296	8.128
LCV Diesel (<3000 cc)	1996-2000	3.000	1.280	2.480	333.310	0.655	0.202	0.215	0.118	0.006	0.217	3.774
LCV Diesel (>3000 cc)	BSI	3.660	1.350	2.120	401.250	0.475	0.196	0.415	0.003	0.008	0.022	8.268
LCV Diesel (>3000 cc)	BSII	3.660	1.350	2.120	401.250	0.475	0.196	0.415	0.003	0.008	0.022	8.268
LCV Diesel (>3000 cc)	BSIII	3.660	1.350	2.120	401.250	0.475	0.196	0.415	0.003	0.008	0.022	8.268
LCV Diesel (>3000 cc)	BSIV	2.650	0.946	1.484	401.250	0.081	0.137	0.291	0.002	0.006	0.016	5.796
HCV Diesel Truck (>6000cc)	1991-2000	19.300	2.630	13.840	837.500	1.965	0.020	0.018	0.093	0.020	0.137	4.598
HCV Diesel Truck (>6000cc)	BSI	6.000	0.370	9.300	762.390	1.240	0.005	0.007	0.061	0.000	0.084	3.971
HCV Diesel Truck (>6000cc)	BSII	6.000	0.370	9.300	762.390	1.240	0.005	0.007	0.061	0.000	0.084	3.971
HCV Diesel Truck (>6000cc)	BSIII	6.000	0.370	8.630	762.390	0.420	0.005	0.007	0.061	0.000	0.084	3.971
HCV Diesel Truck (>6000cc)	BSIV	4.345	0.259	6.041	762.390	0.071	0.003	0.005	0.043	0.000	0.059	2.783
HCV Diesel Bus (>6000 cc)	1991-96	13.060	2.400	11.240	817.520	2.013	0.153	0.031	0.101	0.015	0.126	1.012

Vehicle Category	**Vintage**	**gm/km**					**mg/km**					
		CO	**HC**	**NOx**	**CO2**	**PM**	**Benzene**	**1-3 Butadiene**	**Formaldehyde**	**Acetaldehyde**	**Total Aldehyde**	**Total PAH**
HCV Diesel Bus (>6000 cc)	1996-2000	4.480	1.460	15.250	920.770	1.213	0.101	0.009	0.102	0.003	0.119	3.652
HCV Diesel Bus (>6000 cc)	BSI	3.970	0.390	11.500	668.000	0.795	0.013	0.002	0.010	0.014	0.046	0.283
HCV Diesel Bus (>6000 cc)	BSII	3.970	0.390	11.500	668.000	0.795	0.013	0.002	0.010	0.014	0.046	0.283
HCV Diesel Bus (>6000 cc)	BSIII	3.920	0.160	6.530	602.010	0.300	0.010	0.010	0.052	0.008	0.146	1.372
HCV Diesel Bus (>6000 cc)	BSIV	2.838	0.112	4.571	602.010	0.051	0.007	0.007	0.037	0.006	0.102	0.961
HCV CNG Bus (>6000 cc)	Post 2000	3.720	3.750	6.210	806.500	0.044	0.000	0.000	0.000	0.000	0.000	0.000
HCV CNG Bus (>6000 cc)	Post 2010	3.720	3.750	4.347	806.500	0.035	0.000	0.000	0.000	0.000	0.000	0.000
Passenger Cars (Petrol) (<1000 cc)	1991-96	4.750	0.840	0.950	95.650	0.008	0.213	0.132	0.018	0.011	0.045	0.158
Passenger Cars (Petrol) (<1000 cc)	1996-2000	4.530	0.660	0.750	106.960	0.008	0.000	0.007	0.001	0.000	0.008	0.186
Passenger Cars (Petrol) (<1000 cc)	BSI	1.300	0.240	0.200	126.370	0.004	0.000	0.003	0.003	0.001	0.009	0.096
Passenger Cars (Petrol) (<1000 cc)	BSII	1.300	0.240	0.200	126.370	0.004	0.000	0.003	0.003	0.001	0.009	0.096
Passenger Cars (Petrol) (<1000	BSIII	0.840	0.120	0.090	126.370	0.002	0.000	0.003	0.003	0.001	0.009	0.096

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
cc)												
Passenger Cars (Petrol) (<1000 cc)	BSIV	0.361	0.060	0.048	126.370	0.002	0.000	0.002	0.002	0.001	0.004	0.048
Passenger Cars (Petrol) (1000-1400 cc)	1991-96	3.010	0.190	0.120	126.500	0.006	0.001	0.003	0.003	0.001	0.008	0.132
Passenger Cars (Petrol) (1000-1400 cc)	1996-2000	3.010	0.190	0.120	126.500	0.006	0.001	0.003	0.003	0.001	0.008	0.132
Passenger Cars (Petrol) (1000-1400 cc)	BSI	3.010	0.190	0.120	126.500	0.006	0.001	0.003	0.003	0.001	0.008	0.132
Passenger Cars (Petrol) (1000-1400 cc)	BSII	3.010	0.190	0.120	126.500	0.006	0.001	0.003	0.003	0.001	0.008	0.132
Passenger Cars (Petrol) (1000-1400 cc)	BSIII	1.945	0.095	0.054	126.500	0.003	0.001	0.003	0.003	0.001	0.008	0.132
Passenger Cars (Petrol) (1000-1400 cc)	BSIV	1.294	0.095	0.064	126.500	0.002	0.000	0.002	0.002	0.001	0.004	0.066
Passenger Cars (Petrol)(>1400 cc)	1991-96	2.740	0.190	0.210	142.860	0.006	0.001	0.000	0.009	0.001	0.010	0.464
Passenger Cars (Petrol)(>1400 cc)	1996-2000	2.740	0.190	0.210	142.860	0.006	0.001	0.000	0.009	0.001	0.010	0.464

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
Passenger Cars (Petrol)(>1400 cc)	BSI	2.740	0.190	0.210	142.860	0.006	0.001	0.000	0.009	0.001	0.010	0.464
Passenger Cars (Petrol)(>1400 cc)	BSII	2.740	0.190	0.210	142.860	0.006	0.001	0.000	0.009	0.001	0.010	0.464
Passenger Cars (Petrol)(>1400 cc)	BSIII	0.840	0.120	0.090	172.950	0.002	0.000	0.000	0.000	0.000	0.010	0.050
Passenger Cars (Petrol)(>1400 cc)	BSIV	0.361	0.060	0.048	172.950	0.002	0.000	0.000	0.000	0.000	0.005	0.025
Passenger Cars (Diesel) (<1600cc)	1991-96	0.870	0.220	0.450	129.090	0.145	1.596	0.313	0.026	0.000	0.081	0.101
Passenger Cars (Diesel) (<1600cc)	1996-2000	0.870	0.220	0.450	129.090	0.145	1.596	0.313	0.026	0.000	0.081	0.101
Passenger Cars (Diesel) (<1600cc)	BSI	0.720	0.140	0.840	156.760	0.190	0.039	0.053	0.021	0.002	0.042	0.149
Passenger Cars (Diesel) (<1600cc)	BSII	0.300	0.260	0.490	156.760	0.060	0.039	0.053	0.021	0.002	0.042	0.149
Passenger Cars (Diesel) (<1600cc)	BSIII	0.060	0.080	0.280	148.760	0.015	0.002	0.001	0.089	0.003	0.092	0.211
Passenger Cars	BSIV	0.047	0.048	0.140	148.760	0.008	0.001	0.000	0.044	0.002	0.046	0.105

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
(Diesel) (<1600cc)												
Passenger Cars (Diesel) (1600-2400cc)	1991-96	0.660	0.250	0.610	166.140	0.180	0.003	0.012	0.040	0.001	0.124	0.130
Passenger Cars (Diesel) (1600-2400cc)	1996-2000	0.660	0.250	0.610	166.140	0.180	0.003	0.012	0.040	0.001	0.124	0.130
Passenger Cars (Diesel) (1600-2400cc)	BSI	0.660	0.250	0.610	166.140	0.180	0.003	0.012	0.040	0.001	0.124	0.130
Passenger Cars (Diesel) (1600-2400cc)	BSII	0.546	0.159	1.139	201.752	0.057	0.003	0.012	0.040	0.001	0.124	0.130
Passenger Cars (Diesel) (1600-2400cc)	BSIII	0.660	0.250	0.610	166.140	0.014	0.003	0.012	0.040	0.001	0.124	0.130
Passenger Cars (Diesel) (1600-2400cc)	BSIV	0.521	0.150	0.305	166.140	0.008	0.002	0.007	0.024	0.000	0.075	0.078
Passenger Cars (CNG)(<1000cc)	1991-96	0.850	0.790	0.530	149.360	0.001	0.000	0.000	0.011	0.002	0.013	0.016
Passenger Cars (CNG)(<1000cc)	1996-2000	0.850	0.790	0.530	149.360	0.001	0.000	0.000	0.011	0.002	0.013	0.016
Passenger Cars (CNG)(<1000cc	BSI	0.060	0.460	0.740	143.540	0.006	0.000	0.000	0.011	0.002	0.013	0.016

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
)												
Passenger Cars (CNG)(<1000cc)	BSII	0.060	0.460	0.740	143.540	0.006	0.000	0.000	0.011	0.002	0.013	0.016
Passenger Cars (CNG)(<1000cc)	BSIII	0.060	0.460	0.740	143.540	0.006	0.000	0.000	0.011	0.002	0.013	0.016
Passenger Cars (CNG)(<1000cc)	BSIV	0.060	0.460	0.740	143.540	0.006	0.000	0.000	0.011	0.002	0.013	0.016
Passenger Cars (LPG)(1000-1400cc)	1991-96	6.780	0.850	0.500	130.850	0.001	0.004	0.006	0.015	0.010	0.025	0.060
Passenger Cars (LPG)(1000-1400cc)	1996-2000	6.780	0.850	0.500	130.850	0.001	0.004	0.006	0.015	0.010	0.025	0.060
Passenger Cars (LPG)(1000-1400cc)	BSI	0.600	0.360	0.010	131.190	0.002	0.001	0.000	0.001	0.001	0.002	0.015
Passenger Cars (LPG)(1000-1400cc)	BSII	0.600	0.360	0.010	131.190	0.002	0.001	0.000	0.001	0.001	0.002	0.015
Passenger Cars (LPG)(1000-1400cc)	BSIII	0.600	0.360	0.010	131.190	0.002	0.001	0.000	0.001	0.001	0.002	0.015
Passenger Cars (LPG)(1000-1400cc)	BSIV	0.600	0.360	0.010	131.190	0.002	0.001	0.000	0.001	0.001	0.002	0.015

Vehicle Category	Vintage	gm/km					mg/km					
		CO	**HC**	**NOx**	**CO2**	**PM**	**Benzene**	**1-3 Butadiene**	**Formaldehyde**	**Acetaldehyde**	**Total Aldehyde**	**Total PAH**
MUV Diesel (<3000cc)	1991-96	2.490	1.390	1.700	163.560	0.570	0.013	0.006	0.014	0.000	0.015	1.789
MUV Diesel (<3000cc)	1996-2000	1.380	1.390	0.650	189.480	0.560	0.006	0.059	0.000	0.003	0.030	5.040
MUV Diesel (<3000cc)	BSI	1.940	0.890	2.460	242.010	0.480	0.008	0.006	0.000	0.003	0.006	2.604
MUV Diesel (<3000cc)	BSII	1.940	0.890	2.460	242.010	0.480	0.008	0.006	0.000	0.003	0.006	2.604
MUV Diesel (<3000cc)	BSIII	0.250	0.190	0.670	255.980	0.096	0.268	0.040	0.014	0.008	0.037	0.125
MUV Diesel (<3000cc)	BSIV	0.198	0.114	0.335	255.980	0.053	0.161	0.024	0.009	0.005	0.022	0.075
Moped (2 Stroke)(<80cc)	1991-96	11.410	7.700	0.020	15.370	0.060	0.004	0.002	0.000	0.000	0.004	0.001
Moped (2 Stroke)(<80cc)	1996-2000	2.970	2.770	0.030	21.130	0.060	0.002	0.004	0.006	0.023	0.040	0.225
Moped (2 Stroke)(<80cc)	Post 2000	0.450	3.100	0.040	29.690	0.060	0.001	0.003	0.002	0.001	0.005	0.002
Moped (2 Stroke)(<80cc)	Post 2005	0.460	0.600	0.020	36.810	0.018	0.001	0.000	0.037	0.007	0.044	1.750
Moped (2 Stroke)(<80cc)	Post 2010	0.308	0.402	0.013	36.810	0.018	0.001	0.000	0.025	0.005	0.030	1.173
Scooter (2 Stroke) (<80cc)	1996-2000	5.200	2.510	0.040	24.240	0.049	0.001	0.002	0.004	0.005	0.014	0.012
Scooter (2 Stroke) (<80cc)	Post 2000	2.370	2.050	0.030	27.080	0.049	0.002	0.003	0.011	0.000	0.018	0.280
Scooter (2 Stroke) (<80cc)	Post 2010	1.191	1.030	0.015	36.810	0.049	0.001	0.001	0.006	0.000	0.009	0.141

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
Scooter (2 Stroke) (>80cc)	1991-96	6.000	3.680	0.020	24.750	0.073	0.006	0.004	0.000	0.017	0.031	2.248
Scooter (2 Stroke) (>80cc)	1996-2000	5.100	2.460	0.010	25.050	0.073	0.001	0.007	0.003	0.000	0.004	0.001
Scooter (2 Stroke) (>80cc)	Post 2000	2.760	2.160	0.030	33.310	0.025	1.037	0.055	0.008	0.002	0.020	0.001
Scooter (2 Stroke) (>80cc)	Post 2005	0.160	0.860	0.020	38.540	0.057	0.011	0.012	0.040	0.057	0.121	1.008
Scooter (2 Stroke) (>80cc)	Post 2010	0.107	0.576	0.013	38.540	0.046	0.007	0.008	0.027	0.038	0.081	0.675
Motorcycle (2 Stroke) (<80cc)	1991-96	5.640	2.890	0.040	23.480	0.060	0.009	0.008	0.002	0.000	0.008	0.004
Motorcycle (2 Stroke) (>80cc)	1996-2000	2.960	2.440	0.050	24.170	0.073	0.000	0.008	0.000	0.001	0.001	0.001
Motorcycle (2 Stroke) (>80cc)	Post 2000	2.960	2.440	0.050	24.170	0.073	0.000	0.008	0.000	0.001	0.001	0.001
Motorcycle (2 Stroke) (>80cc)	Post 2010	1.487	1.226	0.025	24.170	0.013	0.000	0.004	0.000	0.000	0.001	0.000
Moped (4 Stroke) (<100cc)	Post 2000	0.810	0.500	0.290	20.090	0.010	0.003	0.006	0.000	0.004	0.009	0.337
Moped (4 Stroke) (<100cc)	Post 2010	0.407	0.251	0.146	20.090	0.010	0.002	0.003	0.000	0.002	0.004	0.169
Scooter (4 Stroke) (>100cc)	1991-96	0.930	0.650	0.350	33.830	0.015	0.005	0.017	0.006	0.001	0.009	0.006
Scooter (4 Stroke) (>100cc)	1996-2000	0.930	0.650	0.350	33.830	0.015	0.005	0.017	0.006	0.001	0.009	0.006
Scooter (4 Stroke) (>100cc)	Post 2000	0.930	0.650	0.350	33.830	0.015	0.005	0.017	0.006	0.001	0.009	0.006

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
Scooter (4 Stroke) (>100cc)	Post 2005	0.400	0.150	0.250	42.060	0.015	0.002	0.013	0.105	0.058	0.172	1.520
Scooter (4 Stroke) (>100cc)	Post 2010	0.268	0.101	0.168	42.060	0.012	0.001	0.009	0.070	0.039	0.115	1.018
Motorcycle (4 s) (<100cc)	1991-96	3.120	0.780	0.230	22.420	0.010	0.004	0.002	0.001	0.002	0.005	0.923
Motorcycle (4 s) (<100cc)	1996-2000	1.580	0.740	0.300	23.250	0.015	0.001	0.003	0.010	0.002	0.017	0.512
Motorcycle (4 s) (<100cc)	Post 2000	1.650	0.610	0.270	24.970	0.035	0.002	0.010	0.003	0.000	0.010	1.575
Motorcycle (4 s) (<100cc)	Post 2010	0.829	0.307	0.136	24.970	0.013	0.001	0.005	0.002	0.000	0.005	0.792
Motorcycle (4 s) (100-200cc)	Post 2000	1.480	0.500	0.540	24.820	0.035	0.017	0.002	0.001	0.000	0.002	0.000
Motorcycle (4 s) (100-200cc)	Post 2010	0.744	0.251	0.271	24.820	0.028	0.009	0.001	0.001	0.000	0.001	0.000
Motorcycle (4 s) (>200cc)	Post 2005	0.720	0.520	0.150	45.600	0.013	0.002	0.002	0.006	0.005	0.011	0.460
Motorcycle (4 s) (>200cc)	Post 2010	0.482	0.348	0.101	45.600	0.010	0.001	0.001	0.004	0.004	0.007	0.308
Three Wheelers (2Stroke) (<200cc)	1996-2000	3.150	6.040	0.300	54.500	0.110	0.006	0.005	0.043	0.011	0.062	2.976
Three Wheelers (2Stroke) (<200cc)	Post 2000	1.370	2.530	0.200	62.410	0.045	0.003	0.004	0.016	0.018	0.036	1.961
Three Wheelers (2Stroke)	Post 2005	1.150	1.630	0.160	71.500	0.043	0.005	0.008	0.105	0.198	0.395	2.050

Vehicle Category	Vintage	gm/km					mg/km					
		CO	HC	NOx	CO2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH
(<200cc)												
Three Wheelers (2Stroke) (<200cc)	Post 2010	0.771	1.092	0.107	71.500	0.034	0.004	0.005	0.071	0.133	0.265	1.374
Three Wheelers (4Stroke) (<200cc)	1991-96	4.590	1.630	0.600	56.500	0.012	0.004	0.003	0.006	0.001	0.022	0.514
Three Wheelers (4Stroke) (<200cc)	1996-2000	4.590	1.630	0.600	56.500	0.012	0.004	0.003	0.006	0.001	0.022	0.514
Three Wheelers (4Stroke) (<200cc)	Post 2000	4.590	1.630	0.600	56.500	0.012	0.004	0.003	0.006	0.001	0.022	0.514
Three Wheelers (4Stroke) (<200cc)	Post 2005	2.290	0.770	0.530	73.800	0.015	0.001	0.000	0.013	0.013	0.061	0.495
Three Wheelers (4Stroke) (<200cc)	Post 2010	1.534	0.516	0.355	73.800	0.012	0.000	0.000	0.009	0.008	0.041	0.332
Three Wheeler Diesel (<500cc)	1996-2000	9.160	0.630	0.930	140.870	0.782	0.018	0.001	0.016	0.005	0.023	0.799
Three Wheeler Diesel (<500cc)	Post 2000	2.090	0.160	0.690	173.850	0.347	0.018	0.001	0.016	0.005	0.023	0.799
Three Wheeler Diesel (<500cc)	Post 2005	0.410	0.140	0.510	131.610	0.091	0.012	0.011	0.007	0.006	0.017	1.185
Three Wheeler Diesel (<500cc)	Post 2010	0.205	0.083	0.423	131.610	0.046	0.007	0.007	0.004	0.003	0.010	0.699
Three Wheeler	Post	1.000	0.260	0.500	77.700	0.015	0.036	0.004	0.007	0.001	0.009	0.404

Vehicle Category	Vintage	gm/km					mg/km					
		CO	**HC**	**NOx**	**CO2**	**PM**	**Benzene**	**1-3 Butadiene**	**Formaldehyde**	**Acetaldehyde**	**Total Aldehyde**	**Total PAH**
CNG OEM 4S (<200cc)	2000											
Three Wheeler CNG Retro 2S (<200cc)	Post 2000	0.690	2.060	0.190	57.710	0.118	0.005	0.006	0.005	0.007	0.015	0.324
Three Wheeler LPG (Retrofit 2S) (<200cc)	1996-2000	7.200	5.080	0.050	44.870	0.171	0.006	0.017	0.008	0.004	0.014	0.336
Three Wheeler LPG (Retrofit 2S)(<200cc)	Post 2000	1.700	1.030	0.040	68.150	0.130	0.006	0.017	0.008	0.004	0.014	0.336
Tractor		9.88	1.09	9.73	799.95	1.09	0.01	0.01	0.07	0.01	0.09	3.78