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Emission inventory – a preliminary approach to primary pollutants

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Madurai is one of the most urbanized and emerging cities in India. Based on the conception of source-tracing and 'bottom-up' approach, the emission inventory was prepared using data from transport sector. The air pollutants such as CO, HC, CO_2, NO_x and particulate matter were considered and emissions estimated. The total emissions of CO, HC, CO_2, NO_x and particulate matter were found to be approximately 13.8 kilo tonne/year, 9 kilo tonne/year, 4.3 mega tonne/year, 12 kilo tonne/year and 1.02 kilo tonne/year respectively, during 2014. Three-wheelers and four-wheelers were found to be the major contributors towards emission of pollutants. This inventory study can be used to implement the mitigation strategies and also to support atmospheric modelling study.

AMBIENT air quality is the most severe environmental concern in urban areas around the world, especially in developing countries. It has become the most essential topic for atmospheric research all over the world[1–5]. Over the past two decades in many emerging countries such as China and India, the increase of vehicular population has led to a great challenge in improving national oil security, urban air quality and public health[3,6–9]. The transport sector accounts for more than 50% of gross emission in urban as well as semi-urban areas from airborne pollutants[10] and vehicle emission controls have been implemented in different stages after the year 2000. India occupies the seventh largest position in vehicle producing countries[10]. This is a reason for urban air pollution in India[11,12]. Due to the usage of older vehicles with poor vehicle maintenance, insufficient road transportation and low fuel quality, the urban air pollution is endured in alarming levels[13–16].

Emission inventory is an inventory that reveals the amount of emission discharged into the atmosphere and a detailed emission inventory is required to understand the climate change issue from regional to global scales[17]. The emissions include some of the pollutants and greenhouse gases (GHGs) that are from all sources in a certain area within a specific time span and year. Transport sector is the major anthropogenic contributor of primary pollutants and GHGs like NO_x, SO_x, CO_2, CO, particulate matter (PM), etc.[18] Several methods are available for the

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preparation of emission inventory and they depend upon the vehicle technology, age of vehicle, fuels used, emission control level and emission factor. Estimating the quantity of emission helps to understand and promote knowledge about actual emissions and it helps to spread awareness among general public and policy makers. Rapid growth of energy usage increases the emission levels which cause acid rain, precipitation changes, increase in sea level, increase in temperature leading to effects on plants, animals and human beings and also other environmental impacts. In 2012, the World Health Organization (2014) has estimated that 3.7 million premature deaths occurred worldwide due to air pollution. Increase in pollutant concentration not only affects the sustainable development but also has a great impact on the neighbouring countries. Many emission inventory studies have been focused on primary pollutants such as NO_x, SO_x, CO_x (refs 19–28). The preparation of emission inventory is essential for inputs to air quality models and also to take control measures for air pollutant release from vehicles by using alternative fuels. In the present study, vehicular emission inventory for the pollutants such as CO, HC, CO_2, NO_x and PM has been developed by using the bottom-up approach.

An emission inventory was prepared for Madurai (9°.91′N, 78°.11′E; 101 m from mean sea level), the temple city of Tamil Nadu rich in culture and heritage. The city covers 248 km^2 with a population of over 10 lakhs as per the 2011 census. Madurai experiences similar monsoon pattern with northeast monsoon and southwest monsoon, with more rain from October to December. The average annual rainfall for the Madurai district is about 85.76 cm. The hottest months are from March to July and a moderate climate persists from August to October and it experiences cold climate from November to February. The city is majorly utilized for agricultural activities and the major crop is paddy. Agricultural and biofuel burning practices, transportation and population are the sources of environmental pollution in this city. Apart from biomass burning, vehicular emission is the main source of air pollution in Madurai. People from various parts of southern districts visit Madurai for medical, educational, marketing, cargo, shopping, tourism or official purposes by vehicles. The city was classified into three parts North Madurai, South Madurai and Central Madurai. According to the city Road Transport Office (RTO) report, the number of vehicles registered in Madurai has already crossed 6 lakhs during the study period (2014). According to the state highways department report, the city is one of the seven circles of the Tamil Nadu State highway network. The state highways passing through the city are SH33, 72, 72A, 73,73A and national highways (NH-7, 45B, 208, 49), which connect various parts of neighbouring states. The total length of roads in Madurai city is about 1572.38 km which comprise different types of roads such as bus route roads, ring roads, internal roads, B.T. roads, C.C. roads, metal roads, sand roads, stone cut and tiles pave roads. The registered transport and non-transport vehicles are 39,400 and 537,866 respectively, in this city. Emissions were estimated on the basis of activity data.

Bottom-up approach is defined as one that estimates emissions for individual sources and sums all the sources to obtain state or country level estimation. The results are more accurate than a top-down approach because data are collected directly from individual sources and not derived from a national or regional estimate. The approach includes parameters such as types of roads, movement of vehicles, age of the vehicles, fuel usage and individual vehicle travelled kilometer (VKT). It is a simple approach to start data collection within the proximity of sources and the collected data are bias in nature. The spatial and temporal resolution of vehicular emissions is significant and the bottom-up approach becomes preferable in local area air quality assessment study[29]. Traffic flows show significant differences from area to area. Air pollutants may differ significantly by number of sources with varying magnitude. One of the ways to develop emission inventories is by identifying such sources.

In the present study, the data were collected from various government organizations regarding traffic survey method for the year 2014. Figure 1 shows the total number of vehicles registered in Madurai up to 2014. The bottom-up approach was carried out by using questionnaire method. To calculate the on road vehicle emission, distance travelled by an individual has been collected as VKT. Traffic census has been carried out on hourly basis
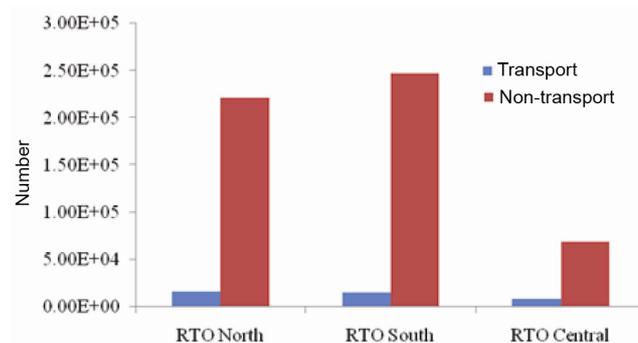

Figure 1. Total number of registered vehicles in Madurai (up to 2014).

Table 1. VKT for different vehicle types

Vehicle category	Fuel used	VKT* (km/day/vehicle)
Two-wheelers	Petrol	50
Auto rickshaws	Diesel/LPG	100
Four-wheelers	Petrol/diesel/LPG	120
Transport buses	Diesel	200
Goods vehicles	Diesel	100

*VKT, Vehicle kilometer travelled in average.

Table 2. Technological emission factors (g/km) used for transport sector

Pollutant	Model year	2W (2S/4S) P	3W (2S/4S) P	3W (4S) D	3W G	PC P	PC D
CO	1991–1996	5.64	–	–	–	–	–
	1996–2000	2.96/1.58	3.15	9.16	7.2	4.53	0.87
	2000–2005	3.02/0.93	1.37/4.47	2.09	1.7	1.3	0.37
	Post 2005	0.16/0.4	1.15/2.29	0.41		0.84	0.06
HC	1991–1996	2.89	–	–	–	–	–
	1996–2000	2.44/0.74	6.04	0.63	5.08	0.66	0.22
	2000–2005	2.02/0.65	2.53/1.57	0.16	1.03	0.24	0.26
	Post 2005	0.86/0.15	1.63/0.77	0.14		0.12	0.08
CO_2	1991–1996	23.48	–	–	–	–	–
	1996–2000	24.17/23.25	54.5	140.87	44.87	106.96	129.09
	2000–2005	29.62/33.83	62.1/57.4	173.85	68.15	126.37	154.56
	Post 2005	38.54/42.06	71.5/73.8	131.61		172.95	148.76
NO_x	1991–1996	0.04	–	–	–	–	–
	1996–2000	0.05/0.3	0.3	0.93	0.05	0.75	0.45
	2000–2005	0.03/0.35	0.2/0.61	0.69	0.04	0.2	0.49
	Post 2005	0.02/0.25	0.16/0.53	0.51		0.09	0.28
PM	1991–1996	0.01	–	–	–	0.008	–
	1996–2000	0.07/0.015	0.11	0.78	0.17	0.008	0.145
	2000–2005	0.04/0.03	0.04/0.01	0.34	0.13	0.004	0.19
	Post 2005	0.05/0.01	0.04/0.01	0.09		0.002	0.01

at different roads in the study regions. Emission inventory was generated on two different days, one on weekends and other on week days. Overall 1500 samples were taken for the present study which includes two-wheelers (2W), three-wheelers (3W) and four-wheelers (4W). For each category of vehicle, the annual total mileage (km) and annual usage of fuel have been calculated to estimate the total annual emission. Table 1 shows the average VKT used in the present study. Fuel usage in India was considered based on the assumptions that the heavy commercial vehicles including goods vehicles, lorries and trucks use diesel as fuel, motorcycles use gasoline or petrol, light vehicles such as passenger cars use diesel and gasoline as fuel and a majority of buses use diesel as fuel. This was considered for estimating the total emissions from the study area.

Various formulae and methodologies are available to prepare emission inventory. The following equation was used for estimating the emission inventory[10]. Table 2 shows the technological emission factors (EFs) that are commonly used for calculation in connection with the generation of emission inventory[30,31].

The total emission of pollutants can be calculated as

$$E_t = \sum(F \times D) \times EF, \qquad (1)$$

where E_t is emission calculated for day/year, F is the amount of fuel used, D is the distance travelled in a day by different categories of vehicles and emission factor (EF) is specific EF for pollutants.

The total emission of CO, HC, CO_2, NO_x and PM from different types of vehicles over the study area of Madurai

was estimated (Table 3). The collected samples were separated according to the types of fuel used, types of the vehicle stroke and fuels used per day. The total emissions of CO, HC, CO_2, NO_x and PM from different types of vehicles over the study area of Madurai are estimated in the present study and they were found to be approximately 0.14, 0.06, 32.6, 0.13 and 0.006 tonnes/day respectively during the year 2014. In addition, the total emissions of CO, HC, CO_2, NO_x and PM were found to be approximately 13.8 kilo tonne/year, 9 kilo tonne/year, 4.3 mega tonne/year, 12 kilo tonne/year and 1.02 kilo tonne/year during the same year respectively. The three-wheelers emitted the pollutants at higher levels compared with two-wheelers and four-wheelers (Table 3). According to RTO report, though large numbers of 2W are operated, their emissions are much lower than the emissions from 3W and 4W. Due to diverse driving situations, the vehicle emissions highly depend on its engine conditions. Demand for share-auto rickshaw (3W) was high as it is used by many people for transportation. Improper maintenance of government buses also emits high level of pollutants. These are the main contributors of air pollutants in the city. Petrol and diesel vehicles were found to emit more emissions than LPG vehicles. Higher emissions and exposure of the pollutants such as CO, HC, CO_2, NO_x and PM are the main cause for loss of consciousness, headaches, dizziness and also leads to mortality. CO, HC and NO_x are mainly emitted from domestic sector and transport sector. The high emission of CO_2 in Madurai regions is due to high population density. The unpaved and constricted roads and operation of diesel-powered generators (which are used during electricity supply failures) may

Table 3. Emissions level for various vehicles over Madurai during 2014

VT	S	CO		HC		CO_2		NO_x		PM	
		E(t/d)	E (t/yr)	E (t/d)	E (t/yr)	E (t/d)	E (t/yr)	E (t/d)	E (t/yr)	E (t/d)	E (t/yr)
2 W	2	0.003	460	0.004	609	0.12	15998	0.00008	11.57	0.00017	23.93
	4	0.004	606	0.002	277	0.375	50043	0.002	322	0.00015	14.7
3 W	D	0.06	8803	0.02	2207	14.49	1930708	0.05	7604	0.0016	218.43
	G	0.05	718	0.03	4421	1.98	264584	0.06	158	0.003	508.96
4 W	D	0.02	3266	0.01	1500	15.64	2084513	0.02	3946	0.0019	256.39

VT, Vehicle type; S, Stroke (2 & 4); D, Diesel; G, Gas; 2W, 2-wheeler; 3W, 3-wheeler; 4W, 4-wheeler.

also be a possible reason for high pollutants. There is no frequent removal of road side sand accumulation which also increases the level of particulate matter in this city. Use of old vehicles and fuel adulteration are also contribute to emission and vehicles coming from outside also increases the emission load. In traffic areas, the rate of pollution was high and it was less in the sensitive areas[32].

Factors such as unplanned roads, improper maintenance of vehicles, stack in the industries and inhabitants, unplanned traffic flow, meteorological conditions and ineffective emission control technologies are responsible for the air pollution in the city. Apart from vehicle emissions, agriculture use of pesticides and fertilizers, agricultural clearing and burning practices, open burning of garbage and burning of used tyres also make the city polluted. Increase in CO, CO_2, HC, NO_x and PM concentrations directly affect the rainfall and this in turn causes increase in temperature level. Low rainfall makes the city polluted and it affects the socio-economic benefits, hydrological impacts and changes in weather pattern. Good use of the available road space and transportation fuels is expected to reduce vehicle pollution locally and introduction of new vehicles with emission control techniques may also reduce vehicle emissions.

Several emission inventories for metropolitan areas had been studied earlier and it is difficult to compare those with the present estimated emission from the transport sector for 2014. Air pollutants emission inventory study from all over the world was compared with this present study. Jeba et al.[33] estimated the emission levels depending on the age of vehicle, engine type and the maintenance of vehicle in Madurai city. It was reported that the petrol-driven vehicles emitted more CO and it varied from 3.2% to 4.2%. Likewise, HC was found to vary from 900.6 ppm to 1120.4 ppm and CO_2 emissions were found to vary from 0.27% to 5.52% in all the vehicle categories. The authors suggested that usage of blended fuels and CNGs would reduce the pollutant load in the vehicles. Sindhwani and Goyal[11] reported that the emissions of CO and NO_x have increased nearly 77% and 29% respectively, from 2000 to 2010 in Delhi. Sahu et al.[34] generated the NO_x, PM and CO emission inventory during 2014 and found that the emissions were 5.4 Tg/yr, 693.3 Gg/yr and 10.2 Tg/yr respectively, in Delhi.

Pallavidino et al.[35] in province of Turin (metropolitan area) reported the total road transport emission of CO_2 using the bottom-up approach and it was estimated to be 3878 kt/yr. Goyal et al.[36] estimated the emissions of CO (509 tonnes/day) and NO_x (194 tonnes/day) from different types of vehicles in the year 2008–09 in Delhi. Emissions of HC showed a sharp increase in Delhi from 148 Gg in 2000 to 277 Gg in 2010 (ref. 11). An emission inventory of primary pollutants was prepared on the metropolitan area of Istanbul in 2007 which showed that the total emissions of CO and NO_x were 395224 T/yr and 70467 T/yr (ref. 37). When compared to previous study areas, the emerging study region emits low pollution load due to variations in climatic conditions, less traffic flow and less industrial activities.

This emission inventory study will promote better understanding of the current emission levels in an urban city like Madurai. Most often, the emission sources are from on-road transport sector. CO, HC, CO_2 and NO_x and PM emissions were calculated for per day and per year. The slow movement of vehicles, long waits at the signals and narrow roads which are common in this city lead to high pollution load. In the study site, the diesel-driven vehicles contribute to more emissions than LPG-driven vehicles and three wheelers with 4 strokes emitted huge emissions than the other types. Carbon dioxide and carbon monoxide emissions are the dominant sources of air pollution in the study regions. The increasing pollutant load has created a threat for long-range adverse effects on the public health of this city. The implementation of cleaner fuels like CNG which reduce the emissions in the atmosphere is vital. This emission inventory study helps to establish a database for evaluating the effectiveness of pollution control measures such as manufacturing low emission based engine, fuels and improving the energy efficiency of buildings for the sustainable development of Madurai city. Awareness among the people and increased usage of public transport are vital to improve the air quality.

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