Development of GIS-aided Emission Inventory of Air Pollutants for an Urban Environment

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1. Introduction

Understanding types of pollutants and their emission rates is essential for control of air pollution. The emission rates, along with the rates of various chemical reactions those take place in the atmosphere, the prevailing meteorological conditions and topographical factors determine the extent of pollutions experienced by various environmental components. An emission inventory is a quantitative detailed repository of air pollutants emitted (along with their sources) into the atmosphere from a given area for a specified time period (Behera et al., 2011). Present and future inventories are critical components of air quality planning and modeling. The ultimate goal of the pollution control planning process is to identify and achieve emission patterns that do not result in violations of ambient air quality standards. An emission inventory should be able to provide: (i) a consistent estimate of total emissions of different pollutants, (ii) the spatial and temporal distribution of pollutants, (iii) the time-specific evolution of emissions and their distributions, (iv) the identification and characterization of sources, (v) tracking progress towards attainment of National Ambient Air Quality Standards (NAAQS) and emission reduction plans, (vi) serve as the basis in modeling for prediction of pollutant concentrations in ambient air, and (vii) compliance records with allowable emission rates established by facilities and regulatory agencies.

The broad source categories of air pollution in an urban area include; (i) transport (motor vehicles and railways), (ii) commercial establishments, (iii) industrial, (iv) domestic cooking/heating, (v) fugitive dust and (vi) biomass burning. There could also be some unique or specific sources in a particular area. Procedures and reliability of emission inventory for regular point, area and line sources are well-established. However, identification and quantification of fugitive/non-point emission sources (emissions not released through stacks, vents, ducts or pipes) are quite challenging. For these sources, emission factors (EFs) (EF: a ratio that relates the emission of a pollutant to an activity level) are either not developed or, if developed, are associated with high amounts of uncertainty. The important non-point sources include: traffic related non-exhaust (NE) emissions (tire, road and brake wear, road dust), evaporative emissions, raw material handling, open crushing, and biomass and agricultural residue burning.

The development of a better emission inventory poses a challenge to air quality engineers, as it requires systematic *in situ* surveys to collect activity data and proper management system for handling these data. Therefore, it is important to develop emission inventories based on geographic information system (GIS), which could also help the policy makers for implementation of legislation (Diem and Comrie, 2001). GIS can be defined as a computer-based system for capturing, storing, checking, and manipulating data that are spatially referenced, which can be of immense utility in developing, displaying and querying an information related to emission inventory.

Unlike other criteria air pollutants, particulate matter (PM) in the atmosphere causes several problems to the community in terms of human health effects, reduced visibility and climate change (Brown et al., 2004; Behera et al., 2005; Makar et al., 2003; Zhang et al., 2010). PM can be termed as a complex mixture of organic and inorganic substances, present in the atmosphere. The size of particles is directly linked to the potential for causing health problems. USEPA is concerned about PM_{10} (PM having diameter less than 10 μm) because these particles generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects (Suh et al., 2000). The sources of PM_{10} on the basis of its origin may be either from primary sources or/and from secondary transformations (Behera and Sharma 2010a; Behera and Sharma, 2010b). Control of PM_{10} from secondary transformation is not easy, whereas primary sources responsible for PM_{10} can be controlled by regulating legislation on the policies for reductions. It is noteworthy that in the task of reduction of PM_{10} from primary sources, the secondary transformation will be controlled in parallel to some extent. The reason being PM precursor gases (e.g., nitrogen oxides (NO_x), sulfur dioxide (SO_2), ammonia (NH_3) and volatile organic compounds (VOCs)) responsible for secondary formation of PM_{10} will also be controlled from the same sources of primary PM_{10} emission.

The objective of this chapter is to present a systematic set of approaches to prepare a GIS-based emission inventory for an urban environment. We have considered development of PM_{10} emission inventory as an example. The study area is Kanpur city (latitude 26°26′ N and longitude 88°22′ E), which represents typical weather conditions and atmospheric seasonal variability in the Ganga basin (longitudes 73°30′–89°0′ E and latitudes 22°30′–31°30′ N), India (Figure 2, described later). The specific objectives of the present study are: (1) identification of sources responsible for PM_{10} pollution and source categorization, (2) collection of activity level data of identified sources, (3) methods for estimating emissions of PM_{10} from various sources, (4) selection of emission factors of identified sources, (5) development of GIS-based digitized maps, (6) development of spatially resolved GIS-based emission inventory of PM_{10} and (7) assessment of contribution of the identified sources towards the particulate pollution.

2. Materials and methods

The methodology adopted in this study consists of four steps to achieve final goal as 'emission inventory of PM_{10}' (summarized in Figure 1). In the first step, identification of sources and collection of source information including location, population, production, fuel use, height of release, temperature etc. for area, line and point sources are done. In the second step, emission factors and methodology for emission estimation are selected. Next, digitized map of the study area with 2 km × 2 km grid resolutions is evolved. In the third step, an emission inventory of PM_{10} has been developed with ArcGIS after execution of data management of activity levels. In the final step, spatially resolved map of PM_{10} emission loads over the study area is generated and the contributions of identified sources towards PM_{10} pollution are assessed.

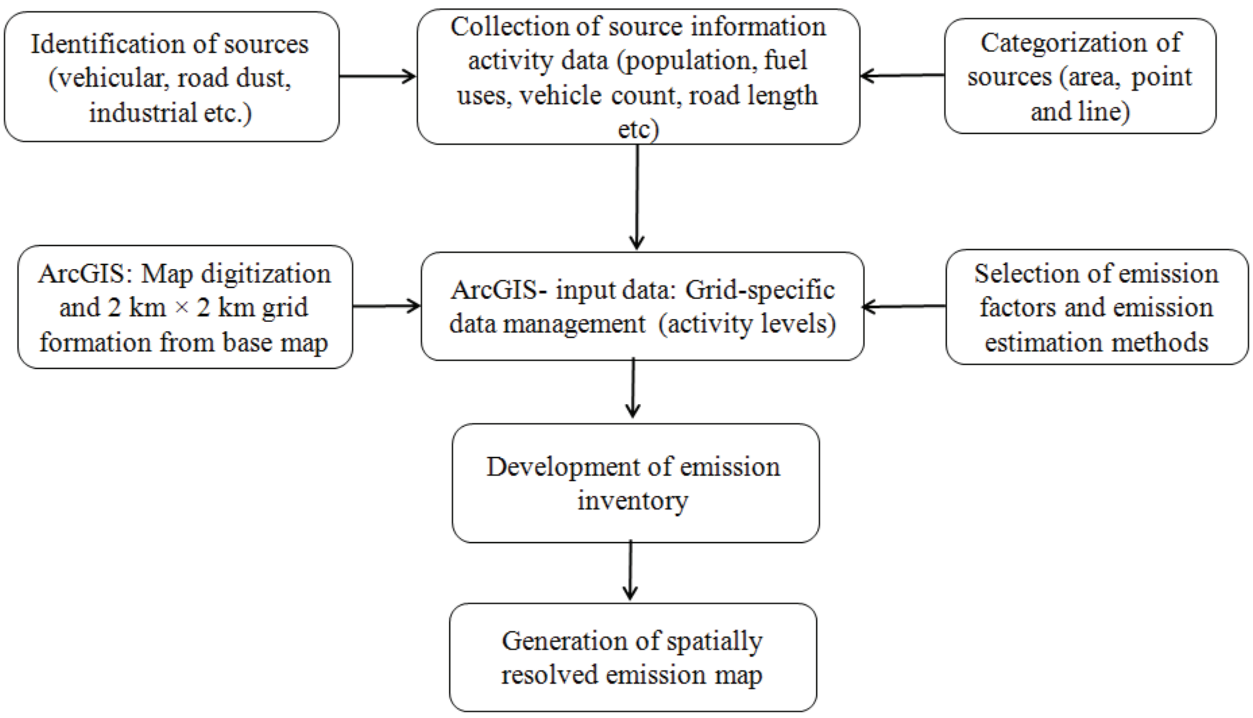


Fig. 1. Summary of the Approaches for Development of Emission Inventory

2.1 The study area

The study area (Kanpur city; Figure 2) represents typical weather conditions and atmospheric seasonal variability in the Ganga basin, India (Behera and Sharma, 2010a). The Ganga Basin is the largest river basin in India, supporting more than 40% of India's population and accounting for 26% of the Indian landmass (Figure 2). As per 2001 census, the basin has 104 urban centers (population > 0.1 million) and 7 large cities (Kanpur, Lucknow, Patna, Agra, Meerut, Varanasi and Allahabad) having a population of more than one million each. Unbridled growth of population and economy in this region has resulted in a wide range of anthropogenic activities including biomass and fossil fuel burning, industry (including coal-based power generation of more than 10000 MW), transport, mining, urbanization and agricultural activities (Behera and Sharma, 2010a). The Ganga basin is characterized to have large uncontrolled emissions of PM, SO_2, NO_x (from combustion sources) and NH_3 (from poor waste management practices). Prevailing westerly winds, dry conditions during winter and low anticyclonic winds provide favorable conditions for advection from the west and confinement of high aerosol loading over the central and eastern parts of the basin (Nair et al., 2007). As a result, consistent hazy conditions prevail from East Pakistan to Bay of Bengal.

Kanpur is a large industrial city (area 270 km^2) with population of about 4 million (census of 2001) having cotton, leather, and wool industries. Temperatures in cold weather drop to freezing, sometimes reaching a minimum of −1°C (lowest −1°C, 2004, 1968) with maximum at almost 12–14°C. In summer (April to June), the maximum temperature can go up to 47.5°C. During the rainy season (July to September), the relative humidity is generally over 70%. Thereafter, the humidity decreases, and by summer, which is the driest part of the year, the relative humidity in the afternoons becomes less than 30%. The average annual rainfall is 792 mm. About 85% of the annual normal rainfall is received during the south-west monsoon months from June to September, with August being the rainiest month. Winds are generally light and are mostly from directions between south-west and north-west (Behera at al., 2011).

The source activities of air pollution in Kanpur can be broadly classified as transport (motor vehicles and railways), commercial, industrial, domestic and fugitive dust sources. Under commercial activities, diesel/ kerosene generators are the most prevailing sources for air pollution in the city. For transport of men, mostly public transport (buses) and private diesel tempos fulfill the transport requirement for the city. The combustion of fuels like coal, kerosene, liquefied petroleum gas (LPG) and wood come under the source for domestic activities. As far as the industrial activities are concerned, the dominant source is the 200 MW coal based thermal power plant (Figure 2). Lots of small and medium scale industries are also responsible for the air pollution. In most of the institutions and offices, the diesel generators (DG) are used at the time of power failure. At several places, garbage and agricultural waste burning is a common practice, which can be an important contributor to air pollution mostly in the evening hour.

2.2 Identification of sources in the study area

The entire study area was divided into 85 grids of 2 km x 2 km. Each grid was assigned an identification number with a land use pattern based on the land use map from Central Pollution Control Board (CPCB) New Delhi. Preliminary surveys have been done at *seven important areas* (as 2 km × 2 km grids), those represent all the source categories of the study area. Based on the preliminary surveys done by the team of experts from Indian Institute of Technology (IIT) Kanpur, the major sectors of sources of PM_{10} have been classified as: (1) industry as point sources (stack height ≥ 25.0 m), (2) industry as area sources (stack height < 25.0 m), (3) vehicles, (4) domestic fuel burning, (5) paved and unpaved road dust, (6) open burning (agricultural residue burning and garbage burning), (7) hotel and restaurant fuel uses, (8) DG sets and (9) rest other sources (e.g., bakery, construction and demolition, medical waste incinerators).

2.3 Categorization of sources and collection of activity level information

The above sectors of the sources of pollution can be broadly classified into three categories: (1) point sources, (2) area sources and (3) line sources. The industries having stack height greater than or equal to 25.0 m are considered as point sources and the industries having stack height less than 25.0 m come under as area sources. Vehicular combustion sources, and paved and unpaved road dust come under line source category. All remaining sources are considered as area sources in this study.

For point source inventories, activity level was obtained through a questionnaire filled by individual plants. The questionnaire sheets collected the detailed information of the industries (i.e., details of stack diameters, stack heights, fuel type, fuel consumption usage and details of the air pollution control devices. In this study, all seven selected primary grids

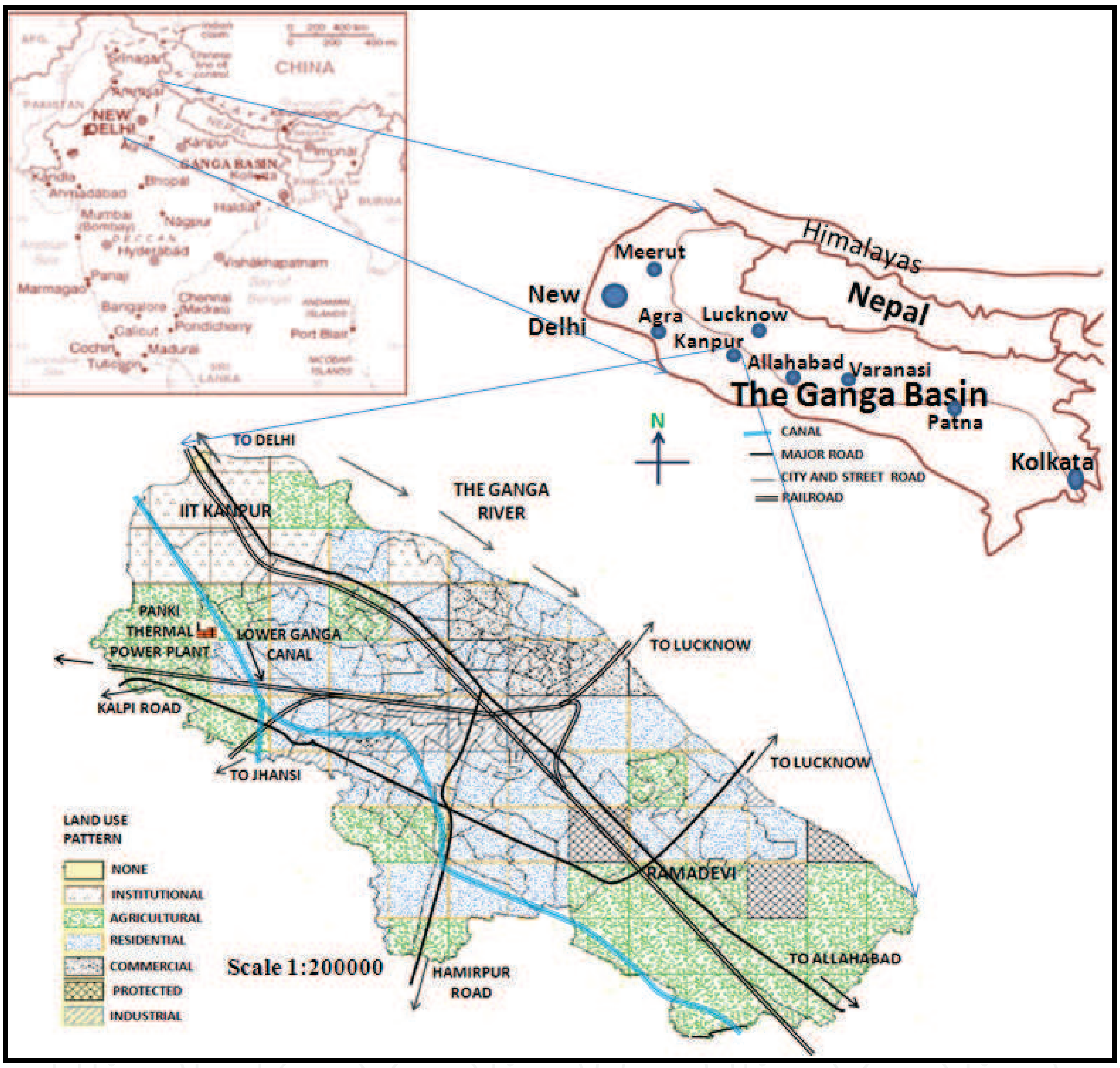


Fig. 2. The Ganga basin, India and gridded map (2×2 km) of Kanpur with land-use patterns

(2 km x 2 km) of Kanpur were surveyed thoroughly for industries as point sources by the team of IIT Kanpur. The activity data for other grids were collected from State Pollution Control Board, Kanpur.

For area source inventories, one can obtain activity level information by the either or by combinations of the two methods as: (i) surveys, and (ii) collection of data from pollution control boards. It is to be noted that the combination of methods can be used to ensure the consistency in data. Surveys can be done to get a representative sample for collection of data in some specific localities and later that can be extrapolated to other localities on the basis of population and/or land-use pattern. State, local, and central agencies such as Central Statistical Organization (CSO), maintain information on population trends, land use, business patterns, agricultural trends, fuel use, chemical production and use. These documents are often valuable resources for determining appropriate activity data or parameters for apportioning data. Several NGOs like, TERI (The Energy Research Institute, New Delhi), CSE (Center for Science and Environment, New Delhi) etc. may also have information on pollution load, inventory procedures and emission factors in Indian context.

In the present study, seven primary grids (2 km × 2 km) were subdivided into small grids (1 km×1 km) with specific grid identification numbers. The activity data were collected from all these 28 (7 x 4) sub-grids with a thorough house-to-house survey. The details of the activity level data for various area sources included in surveys were as follows: (i) production capacity, types of fuel usage, fuel consumption capacity, stack height and details of the air pollution control devices for the pollution from industries as area sources, (ii) capacity of the bakery, types of fuel usage, and daily fuel consumption for pollution from bakeries, (iii) types of fuel usage and daily consumption of each fuel for hotels, restaurants and open eat outs, (iv) type of the family (i.e., high, medium and low, based on economic strata), population of the family, types of fuel usage and daily fuel consumption for the domestic fuel burning, (v) type of the street under survey (i.e., commercial, residential activities etc.), number of garbage collection points in the street, area of the collection points and height of the collection points for pollution from garbage burning, (vi) quantity of agricultural waste generated per unit area and frequency of burning for pollution from agricultural burning, (vii) quantity of area under construction/demolition activities, (viii) capacity of DG set, fuel consumption per hour of each DG set, and (ix) quantity of medical waste.

One example on the activity data survey has been described here for garbage burning. The area of survey was done in the Juhilal Colony of Kanpur. Number of garbage collection points = 1, area of collection point = 1.0 m^2, height = 0.3 m, volume of one point = 1.0 × 0.3 = 0.3 m^3. Dry density of garbage was assumed as 800 kg/m^3. The mass of garbage at that street = 800 × 0.3 = 240 kg. Total population of that street = 200 (all are middle class). So per capita generation of garbage in that street = 240000/200=1200 g/person. This was a four-day garbage generation result. Therefore, garbage generation = 300 g/person/day. Several surveys had been undertaken in the seven primary grids to ascertain the garbage collection. Finally the data for other grids, apart from the seven primary grids, were extrapolated from the data of the seven grids.

For line source activity data, traffic survey of vehicle counts was done at 13 traffic intersections for various vehicle types (two-wheeler motorbikes, three-wheeler auto rickshaw and tempos, four-wheeler passenger cars and jeeps, light commercial vehicles and heavy duty vehicles) covering various road types (e.g., main highway, minor road, service road, etc.). Traffic count on each road in each grid was extrapolated from the data of the traffic survey. The actual road lengths for each grid were estimated from the digitized map in the ArcGIS software. The daily vehicular kilometer traveled (VKT) for all types of vehicles were estimated on the basis of the parking-lot survey done at four important locations in the city. The activity data of PM_{10} pollution from the source of paved and unpaved roads (categorized as line source) were estimated on the basis of mean weight of the vehicle fleet (tons), vehicular kilometer traveled, and silt loading on the road (details given later).

2.4 Digitization of map

GIS has been chosen in the studies related to development of emission inventories because of its usefulness for air quality modeling and it is capable of supporting the development of geospatial air quality models (Puliafito et al. 2003). The Geostatistical Analyst extension of ArcGIS (ArcMap, version 9.2; ESRI Inc., Redlands, WA, USA) was selected for this study because of its relative user friendliness and its frequent use by local authorities and research institutes for air pollution management (Leem et al. 2006; Behera et al., 2011). ArcMap is primarily used to view, edit, create, and analyze geospatial data, and it allows the user to explore data within a data set. The topographical map, issued by the Survey of India (SOI) (prepared in 1977) having scale of 1:50,000, was geo-coded as the base map in the form of polygons for geo-referencing the other maps. This base map was transformed to Universal Transverse Mercator projection with Everest 1956 as the datum. The other three maps, (a) land use, (b) road and railway intersection (from Central Pollution Control Board (CPCB), New Delhi, India), and (3) ward (smallest political unit in a city) boundary (from Kanpur Municipal Corporation) were geo-referenced with respect to the base map.

2.5 Emission estimation methods

Two fundamental approaches have been used by the air quality engineers for the development of emission inventories, i.e., top-down approach and bottom-up approach (Costa and Baldasano, 1996). Top-down approach estimates total emissions for the geographical area under study and then prorates those emissions in the different cells that constitute the spatial ambit of analysis (spatial disintegration), through parameters such as traffic, population and industrial density (Garg et al., 2002). However, the top-down approach is not appropriate at regional scale emission inventory due to many assumptions and inaccuracy present in base data itself and lack of better resolution. Bottom-up approach estimates emissions for all cells comprising selected geographical area. Bottom-up approach is preferred over top-down approach for better resolution and model performance. In this study, a detailed spatially resolved emission inventory has been developed using GIS with bottom-up approach.

The digitized map representing all 85 grids of the city with specific grid identification was embedded into ArcGIS and different files containing Arc attribute tables were created for various source categories. The activity level data for all the sources were stored in respective attribute tables for each grid. It may be noted that the largest source in the study area, the thermal power plant (coal-based), capacity of 200 MW has been accounted under point source. To obtain the total emission in a particular grid, emission from each source (within the grid) were added.

Emission from the vehicles has been calculated using the following expression:

$$E_v = \sum(\mathrm{Veh}_i \times D_i) \times \mathrm{EF}_i \tag{1}$$

Where, E_v is PM_{10} mass emission per day, i is the vehicle category, Veh is number of vehicles, D is distance traveled in km in one day by the vehicle i and EF is the mass emission factor for one kilometer (km) travel per vehicle. In this study, we have taken the Indian emission factors (CPCB 2007). The emission factors for CPCB are for different models (year of manufacturing and vehicle type) of all categories of vehicles. The emission factors

vary considerably for engine size, fuel uses and age of the vehicles. From the results of parking-lot surveys, a composite emission factors for the broad vehicular categories (two-wheeler motorbikes, three-wheeler auto rickshaw and tempos, four-wheeler passenger cars and jeeps, light commercial vehicles and heavy duty vehicles) were worked out of all individual models of the vehicles indicating fraction of various vehicle categories on the road.
Emissions from fuel burnt in households, hotels and restaurant were estimated using Eq. (3):

$$E_h = \sum(\text{Fuel}_j \times \text{EF}_j) \quad (2)$$

Where E_h is mass emission of PM_{10} per day from households, j is the fuel type (e.g. LPG, coal, wood, and kerosene), Fuel is the mass consumption of fuel per day, and EF is mass emission factor. The suitable emission factors were taken from the USEPA AP-42 in the absence of factors developed in India (USEPA 1996).
Emissions from industrial sources were estimated as:

$$E_I = \sum_i \sum_j (A_{i,j} \times \text{EF}_{i,j}) \times \left(1 - \frac{ER_{i,j}}{100}\right) \quad (3)$$

Where E_I is the mass emission of PM_{10} from industrial sources per day, i is the type of industry (boiler, cupola, smelter etc.), j is the type of fuel used, A is the quantity of fuel use, EF is the emission factor and ER overall emission reduction efficiency of devices installed (in percentage). The suitable emission factors were taken from the USEPA AP-42 in the absence of factors developed in India (USEPA 1996). These industries under point source categories were located using Leica GS-5 Global position system (GPS) receiver and the information was later utilized in dispersion modeling.
Emission from paved and unpaved road was estimated on the basis of the experimental study conducted in the city (Bhasker and Sharma 2008). The quantity of dust emissions from movement of vehicles on a paved or unpaved road can be estimated using the following empirical expression (Jaecker-Voirol and Pelt 2000):

$$E_R = \sum k(\text{sL}_i / 2)^{0.65} \times (W_i / 3)^{1.5} \quad (4)$$

Where, E_R is emission rate of size specific PM, (units same as k), i is the road type, sL is silt load (g m^{-2}) on road i, W is mean weight of the vehicle fleet (tons) on road type. k is the base emission factor for particle size range and units of interest constant (function of particle size) in g vkt^{-1} (vehicle kilometer travel) (e.g. k = 4.6 g vkt^{-1} for PM_{10}). The values of sL at various locations of the city were taken from Bhasker and Sharma (2008).
The emission from other categories of area sources were estimated as:

$$E_O = \sum_{\text{source\_cat}} (\text{Activity data}_{\text{source\_cat}}) \times (\text{Emission factor}_{\text{source\_cat}}) \quad (5)$$

Where, E_o is the emission of PM_{10} from all other source categories and source_category is the other area sources (i.e. diesel generator, open burning, construction and demolition, medical waste incinerator). Activity data is the amount of individual source category. Emission factor is the emission factor of PM_{10} by individual source category. The suitable emission factors were taken from the USEPA AP-42 (USEPA 1996).

3. Results and discussions

3.1 Thematic layers for emission inventory

The vector data of digitized maps was converted to different thematic layers to interact and to determine the locations of industries, areas of specific interest and also for editing emission factors. These thematic layers were used for computing emissions and extracting inventories. Different thematic layers were prepared including map of industrial activity, population, transportation layers, area boundaries etc. These are used to determine the surrogates as well as to identity the sources and to visually represent data. The attribute values in the map table can be edited allowing users to tweak values such as a feature's population, number of vehicles on a road in each grid etc.

The entire city was divided into 85 grids of 2 km× 2 km size (as explained earlier) and each grid was assigned a land-use pattern based on the land-use map from CPCB. After obtaining the area of the wards (having irregular boundary), population density in each ward was calculated as follows: population density (person/m^2) = population of ward (person)/ward area (m^2). The area of each ward falling inside a grid was calculated to estimate the population in the grid as:

$$\text{Grid population} = \sum_{i=1}^{N} (\text{intersected ward area}_i \times \text{density of ward}_i) \quad (6)$$

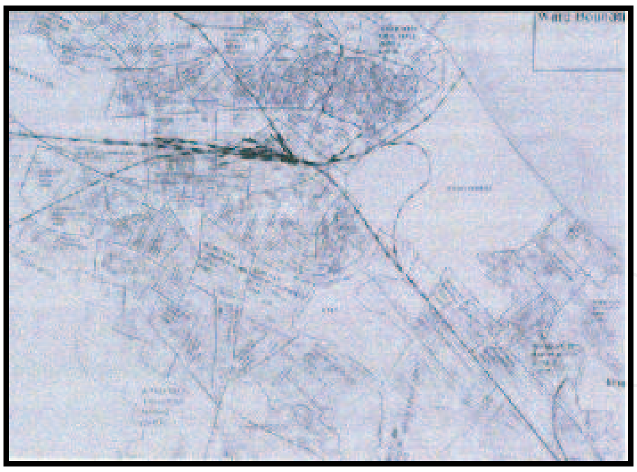
Where N is the number of wards (fraction of full ward) in that grid, and i represents a ward. Thus, the population for each grid was estimated and stored in GIS. The entire study area was assigned with six types of land-use patterns (Figure 2), i.e., residential, commercial, institutional, industrial, agricultural, and protected (military uses). Figure 3 can be referred as a detailed schematic diagram of the whole process in GIS to develop the emission inventory.

3.2 Activity level data

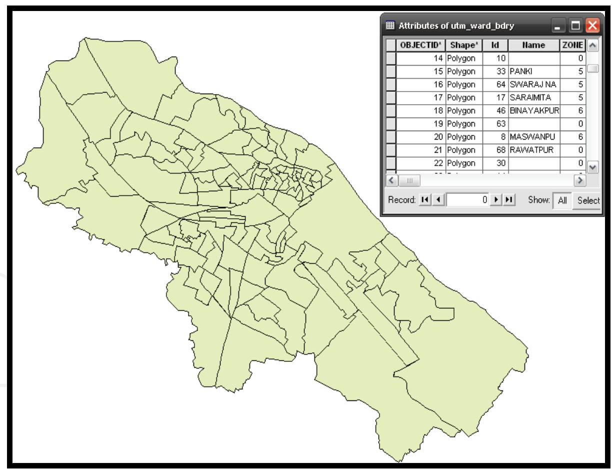
Figure 4 shows a representative traffic survey for two wheeler motorbikes held at six traffic intersections of the city. It is to be noted that traffic surveys were done at 13 traffic intersection of city. The traffic surveys revealed that two-wheeler motorbikes, three-wheeler auto rickshaw and tempos and four-wheeler passenger cars and jeeps were found to be more at the central part of the city (Rawatpur, Bada Chaurah and Colonelganj). Whereas a larger flow of heavy duty vehicles on the highways, especially the GT Road (IIT Gate and Ramadevi). Overall highest vehicular density was observed between 10:00 AM and 12:00 noon, and between 4:00 PM and 6:00 PM.

Figure 5 shows a representative of parking-lot survey for two wheeler motorbikes done at four important locations of the city in terms of engine size and year of manufacturing. This information is vital in calculating the emission from vehicles on the road. The emission factors vary considerably for engine size, fuel uses and age of the vehicles.

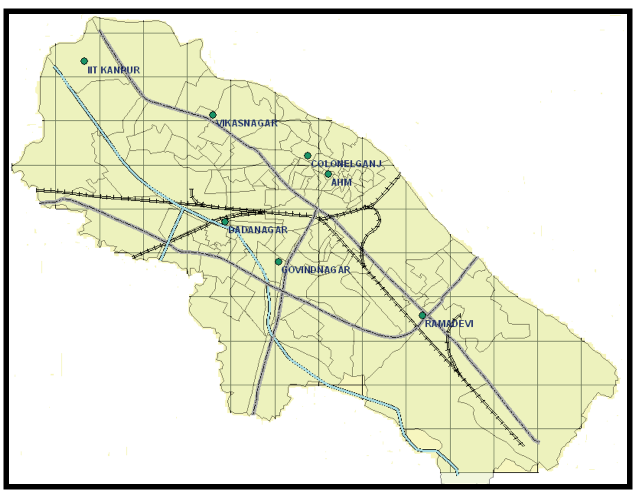
Figure 6 shows location of important industries treated as point sources (stack height ≥ 25.0 m). This figure was the map generated from the GIS and the activity data information was stored in the respective attribute tables to develop the final emission inventory.



(a) Original ward map of Kanpur

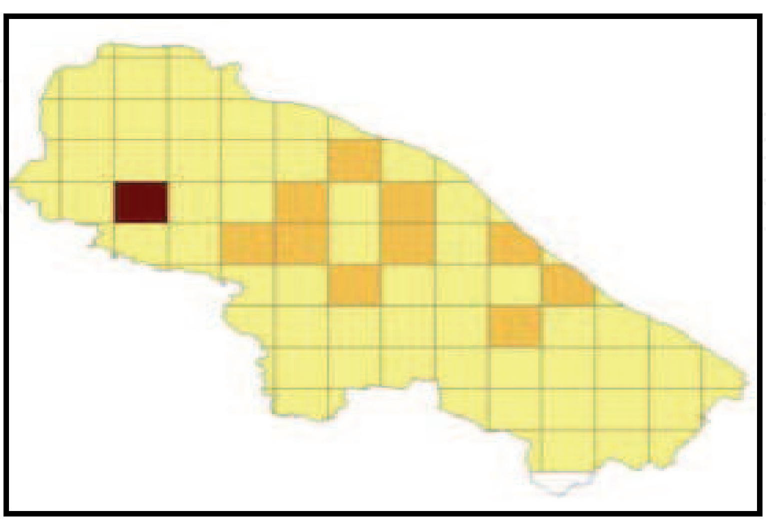


(b) Digitized Ward map with attribute table



(d) Gridded map of the city (2 km × 2 km grids)

(c) Digitized road network map for all roads



(e) Grid-wise Emission Inventory for PM_{10}

Fig. 3. Schematic Diagram of Thematic layers for GIS based Emission Inventory

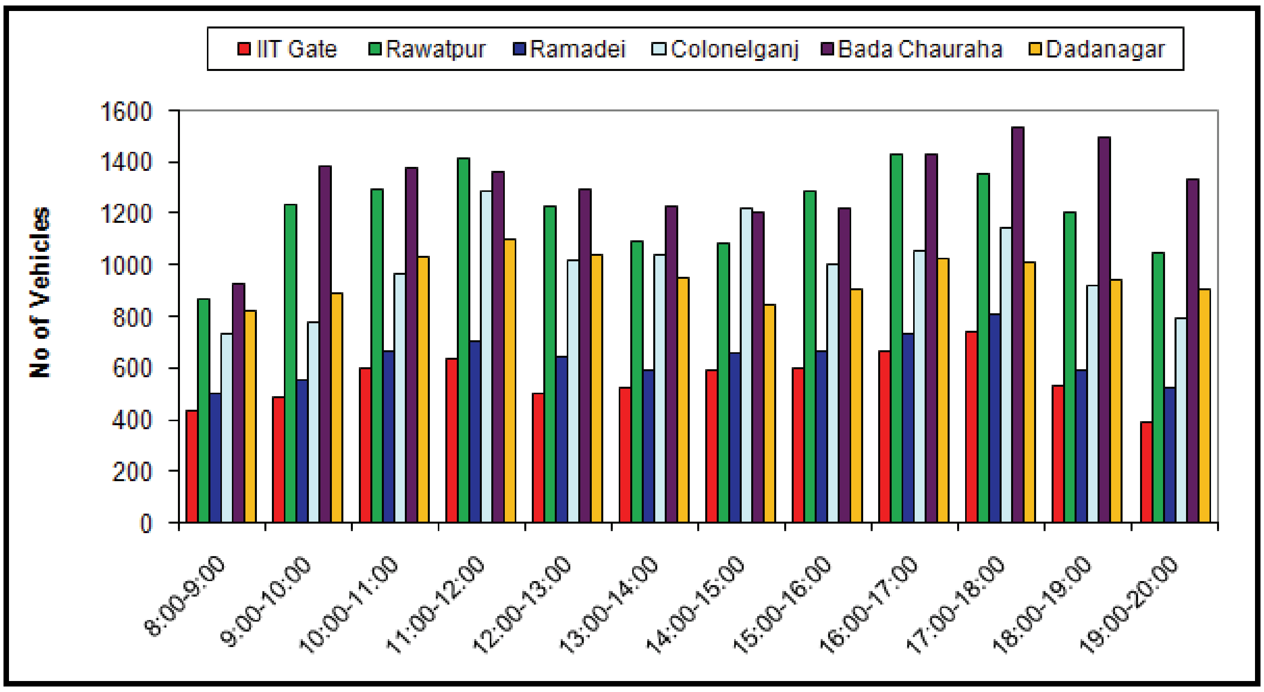


Fig. 4. Patterns of 2W Vehicles at some important traffic junctions

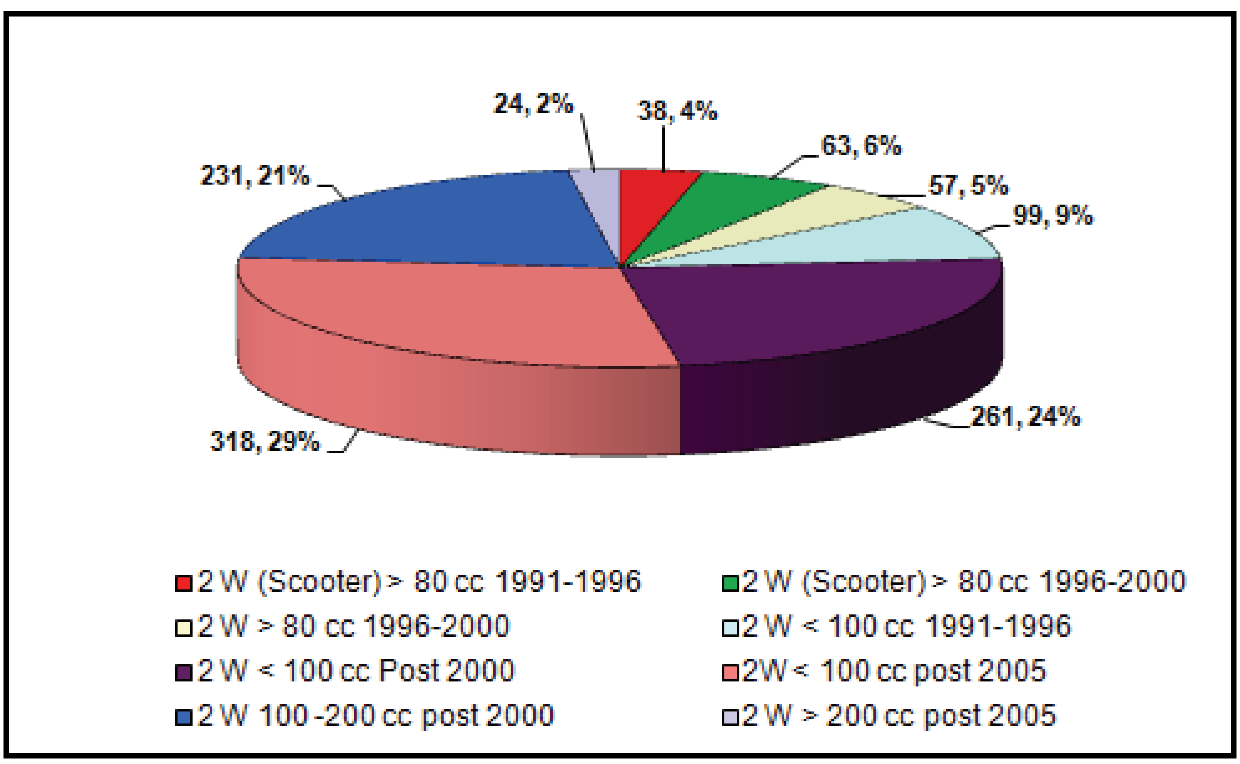


Fig. 5. Results of parking lot survey for two wheeler motorbikes (Nos, %)

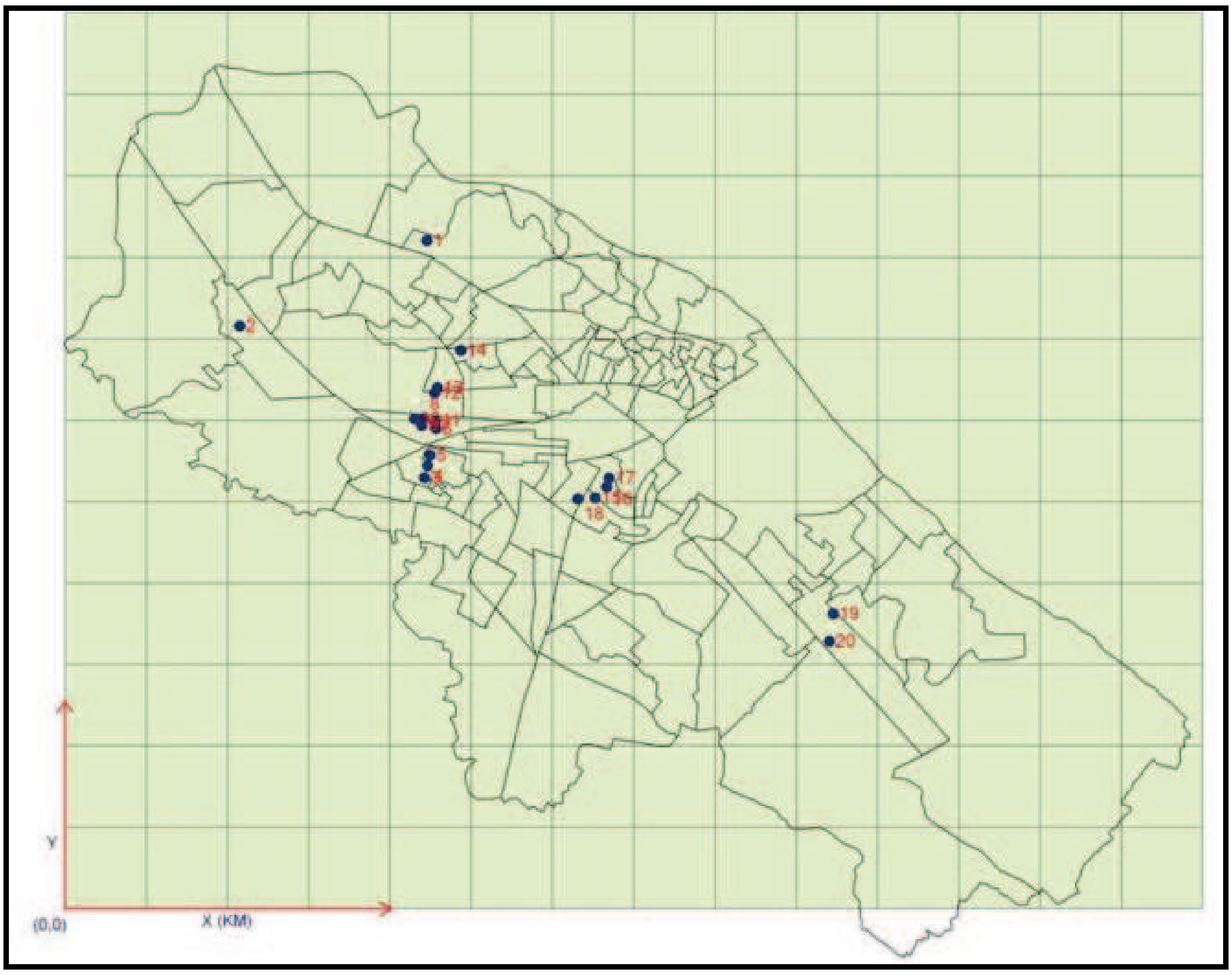


Fig. 6. Locations of point sources in Kanpur

3.3 Emission inventory of PM_{10}

Figure 7 presents emission load of PM_{10} in Kanpur from use of domestic fuel burning. Coal produces a significant pollution load, 985 kg/day, nearly 47 percent of total PM_{10} from domestic sector. Although coal is used by only a small fraction of population, PM emission factor is quite high from coal burning.

Among the vehicular sources, two-wheeler motorbikes contribute 0.14 ton day^{-1}, 3-wheeler auto and tempos as 0.90 ton day^{-1}, 4-wheeler cars and jeeps as 0.16 ton day^{-1}, light commercial vehicles (LCV) as 0.45 ton day^{-1}, and buses and trucks as 0.66 ton day^{-1}. The reason for higher contribution from buses and trucks might be due to use of diesel which has a higher emission factor. Figure 8 shows the pie chart for PM_{10} emissions from various vehicles.

Figure 9 shows the spatial distribution of PM_{10} emission loads over the study area in year 2007. The high pollution areas are identified as the city centre, where most of the pollution activities and congestion problems exist. The emission from domestic sector largely depends on population, type of fuel use in the grid. Emission from vehicles depends on the type of vehicle and type of road. Emissions from industries depend on the capacity of industries, type of fuel for combustion, stack height and particular of the particulate control devices.

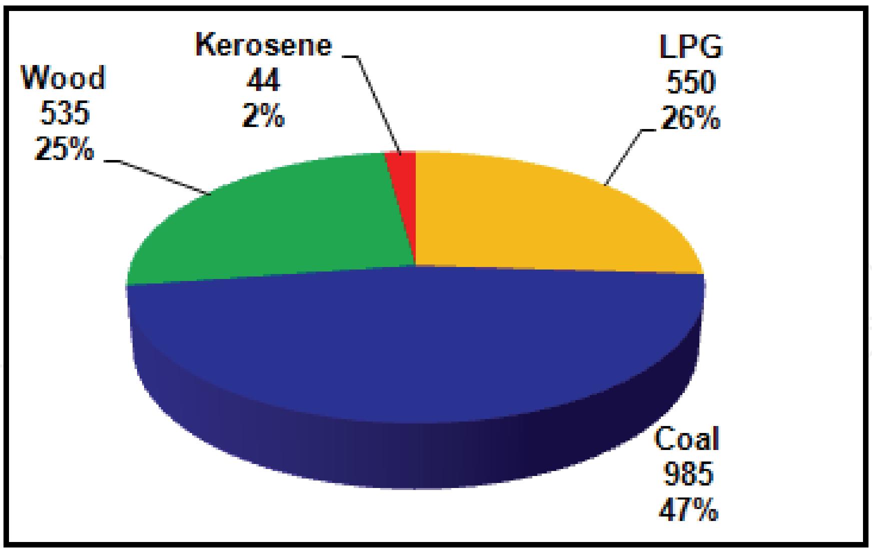


Fig. 7. PM_{10} emission in Kanpur from the domestic fuel burning (kg/d, %)

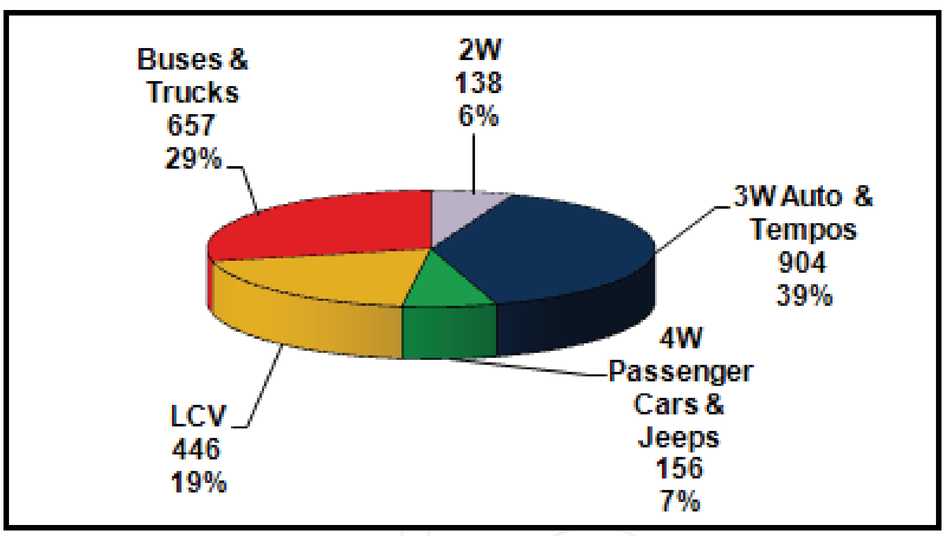


Fig. 8. PM_{10} emission in Kanpur from the vehicles (kg/d, %)

3.4 Assessment for contributions of various sources

The contribution of all identified sources for PM_{10} has been shown in Figure 10. The total emissions of PM_{10} was estimated to be about ~11.2 ton day^{-1} with an overall break-up of: (i) industrial as point sources: 2.9 ton day^{-1} (26%), (ii) industry as area sources: 0.8 ton day^{-1} (7%), (iii) vehicles: 2.3 ton day^{-1} (21%), (iv) domestic fuel burning: 2.1 ton day^{-1} (19%), (v) paved and unpaved road dust: 1.6 ton day^{-1} (15%), (vi) open burning: 1.0 ton day^{-1} (5%), (vii) hotel and restaurant fuel uses: 0.4 ton day^{-1} (4%), (viii) DG sets: 0.1 ton day^{-1} (1%), and (ix) rest other sources 0.2 ton day^{-1} (2%). The highest emission was from the industrial point sources, mainly from a 200 MW coal-based thermal power plant (Panki power plant, Figure 2). The estimated emission suggests that there are many important sources and a composite emission abatement strategy including most of the sources will be required to attain the desired air quality.

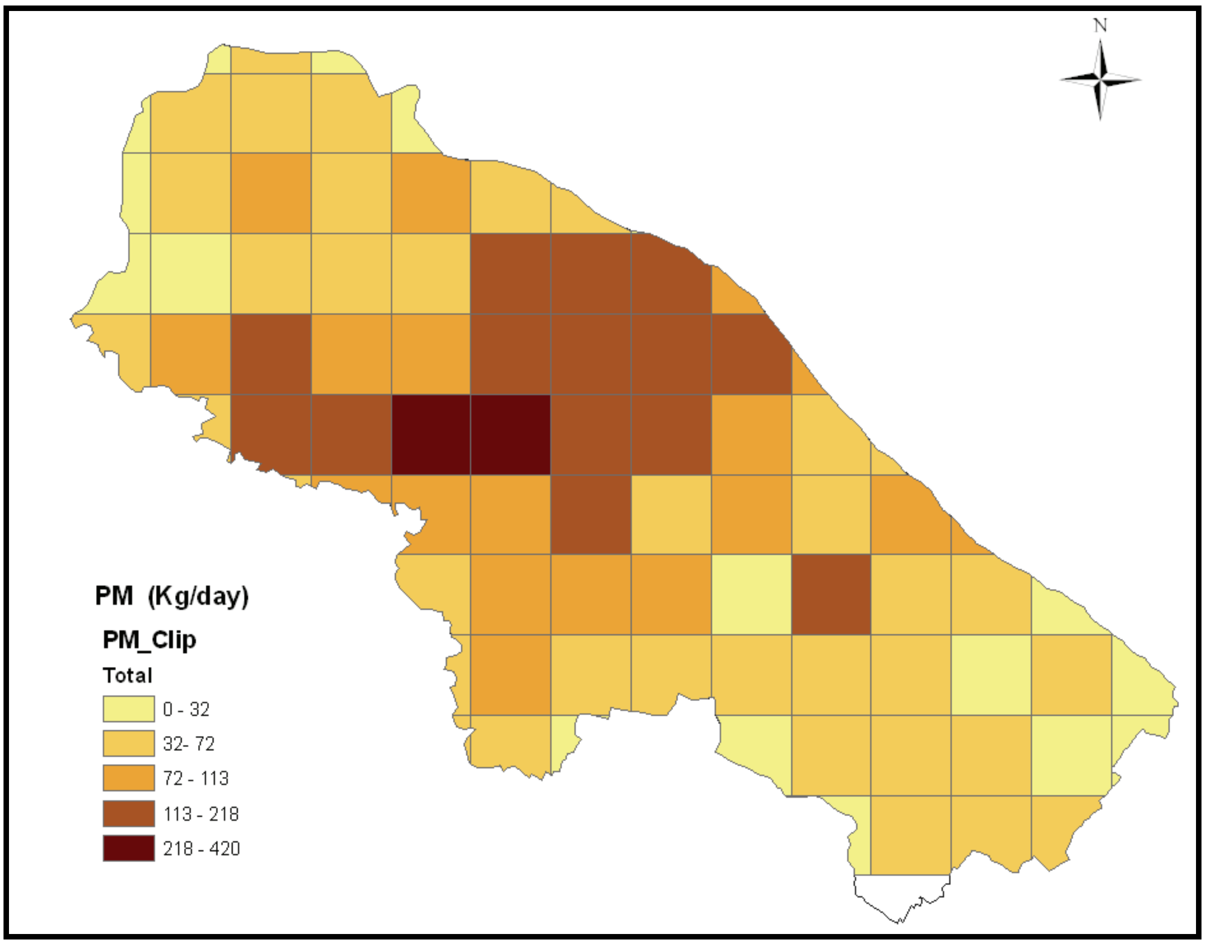


Fig. 9. Spatial Grid-wise emission inventory for PM_{10} in Kanpur

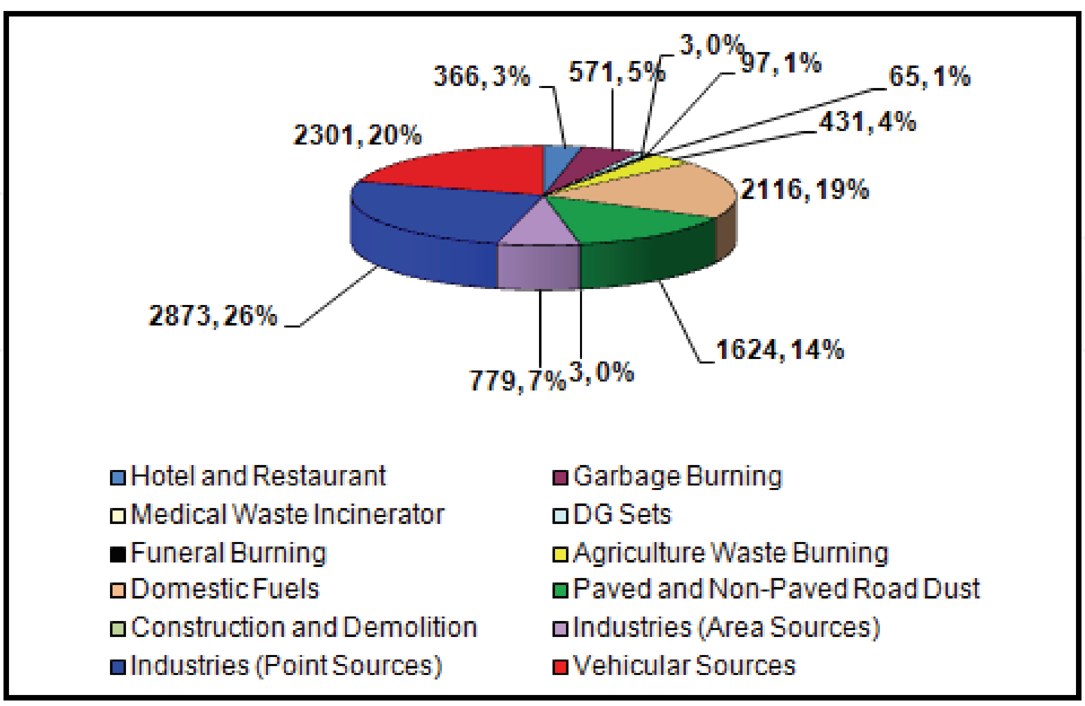


Fig. 9. Overall emission loads of PM_{10} from identified sources in Kanpur (kg/d, %)

4. Conclusions

Particulate pollution in the atmospheres of megacities becomes a major source of concern for public authorities. To understand precisely, the details of the sources responsible for particulate pollution, a PM_{10} emission inventory was carried out. The sources considered were: industries (point and area sources), vehicles, domestic and commercial fuel burning for cooking, paved and unpaved road dust, open burning, diesel generator sets and rest other identified sources. A methodology consisting of four steps was adopted for the desired PM_{10} emission inventory to be generated by using ArcGIS. The total emissions of PM_{10} was estimated to be about 11.2 ton day^{-1} with an overall break-up of: (i) industrial as point sources: 2.9 ton day^{-1} (26%), (ii) industry as area sources: 0.8 ton day^{-1} (7%), (iii) vehicles: 2.3 ton day^{-1} (21%), (iv) domestic fuel burning: 2.1 ton day^{-1} (19%), (v) paved and unpaved road dust: 1.6 ton day^{-1} (15%), (vi) open burning: 1.0 ton day^{-1} (5%), (vii) hotel and restaurant fuel uses: 0.4 ton day^{-1} (4%), (viii) DG sets: 0.1 ton day^{-1} (1%), and (ix) rest other identified sources (bakery, construction and demolition, medical waste incinerators) 0.2 ton day^{-1} (2%). The highest emission was from the industrial point sources, mainly from a 200 MW coal-based thermal power plant. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to attain the desired air quality.

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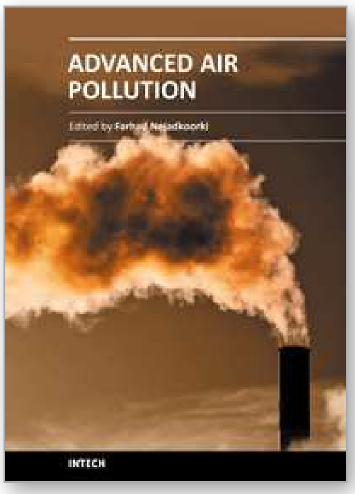

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Leading air quality professionals describe different aspects of air pollution. The book presents information on four broad areas of interest in the air pollution field; the air pollution monitoring; air quality modeling; the GIS techniques to manage air quality; the new approaches to manage air quality. This book fulfills the need on the latest concepts of air pollution science and provides comprehensive information on all relevant components relating to air pollution issues in urban areas and industries. The book is suitable for a variety of scientists who wish to follow application of the theory in practice in air pollution. Known for its broad case studies, the book emphasizes an insightful of the connection between sources and control of air pollution, rather than being a simple manual on the subject.

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