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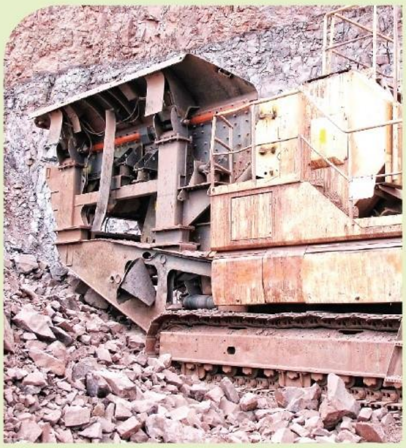
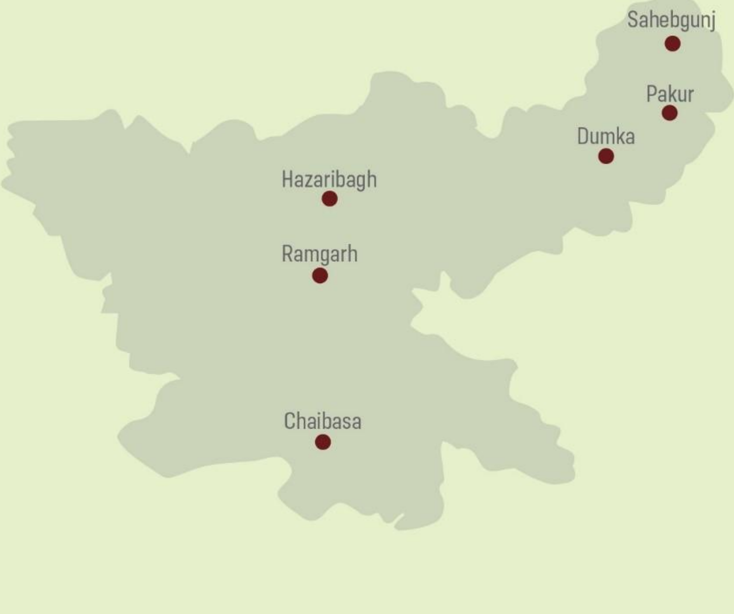
Air Pollution Emission Inventory for **Six Cities in Jharkhand**





Air Pollution Emission Inventory for Six Cities in Jharkhand

Center for Study of Science, Technology and Policy
April 2023

Designed and edited by CSTEP

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(The author list provided assumes no particular order as every individual contributed to the successful execution of the project.)

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Executive Summary

Jharkhand is a mineral-rich state in India. Its cities have access to various solid fuels and proximity to several heavy industries. These factors, along with the movement of traffic (public and goods), contribute to air pollution in the state.

The Ministry of Environment, Forest and Climate Change (MoEFCC), under the Government of India (GoI), launched the National Clean Air Programme (NCAP) for the mitigation of air pollution in non-attainment cities. However, owing to the unavailability of reference-grade monitoring data, air pollution levels in cities in Jharkhand (other than Dhanbad) have not been quantified. To better understand the air pollution scenario in cities other than non-attainment cities in Jharkhand, the current study developed emission inventories (EIs) for six cities, namely, Sahibganj, Dumka, Pakur, Chaibasa, Hazaribagh, and Ramgarh.

The study analysed different sectors and their corresponding activities contributing towards air pollution during April 2019–March 2020. Domestic fuel consumption, commercial fuel consumption, industries (processes and fuel consumption), construction and demolition, open burning (municipal solid waste burning and space heating), transportation (tailpipe emissions), and resuspension of road dust were considered while developing the EIs. The study quantified emissions from these sources at the airshed level (including the cities). The airshed was defined based on prominent polluting sources around a city area. Then, the estimated emissions were spatially distributed at a horizontal resolution of 1 km × 1 km. The EIs were developed for the base year 2019 for particulate matter (PM_{10} and $PM_{2.5}$), sulphur dioxide (SO_2), and oxides of nitrogen (NO_X). Airshed and city-level emissions are presented below.

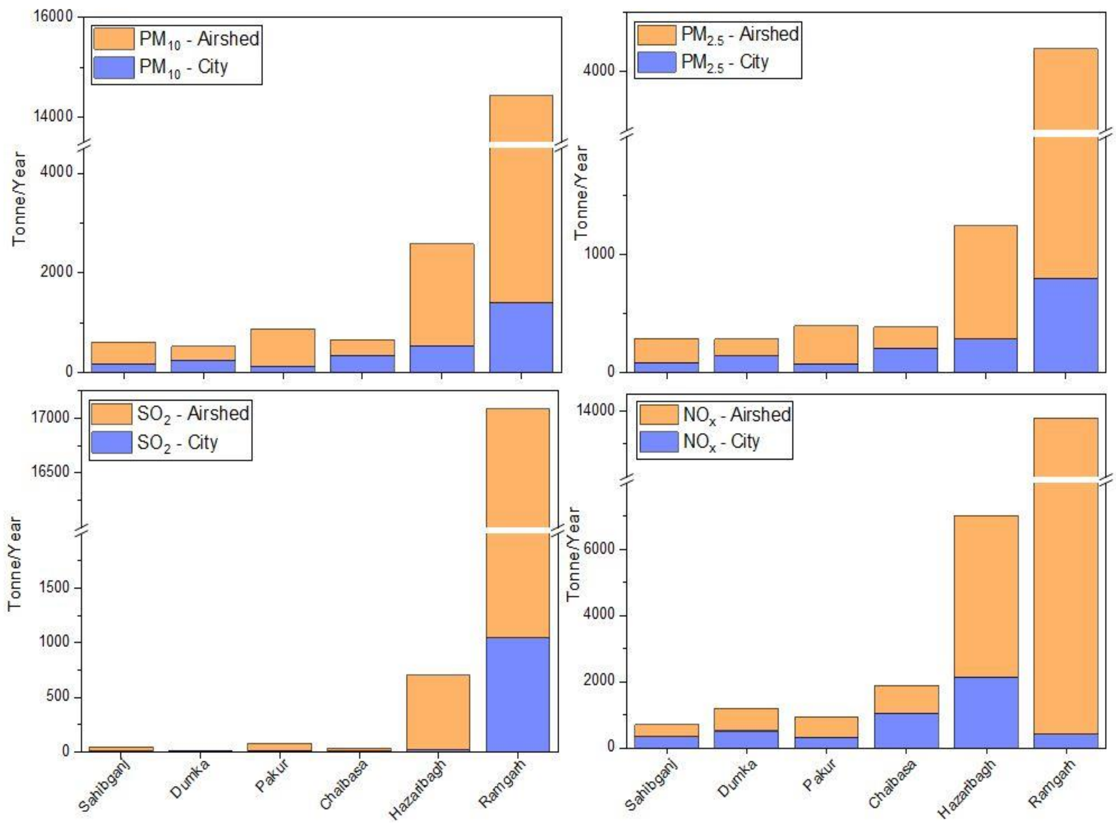

Figure E1: PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions at the city level vs airshed level for the base year 2019-20

Total emissions in the study cities were defined by land-use and land-cover (LULC). Owing to the presence of heavy industries within the airshed, all pollutant emissions were the highest in Ramgarh, followed by Hazaribagh. Changes in LULC resulted in alterations in sectoral contributions in the study cities. Among the study cities, other than Ramgarh, transportation was one of the largest emitting sources of $PM_{2.5}$. Due to the presence of heavy industries within Ramgarh, industrial contribution towards total $PM_{2.5}$ emissions was the largest. Significant NO_X emissions, mainly contributed by the transportation sector, were observed in Hazaribagh.

Sahibganj: For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 607, 286, 44, and 684 tonnes/year, respectively, whereas those in the town area were 158, 81, 3, and 336 tonnes/year, respectively. Open burning (including space heating) was the largest contributor to total $PM_{2.5}$ emissions in the city area, followed by transportation, road dust, and the domestic sector. Domestic sector, brick kilns, and transportation were the major sources of PM_{10}, SO_2, and NO_X emissions over the airshed.

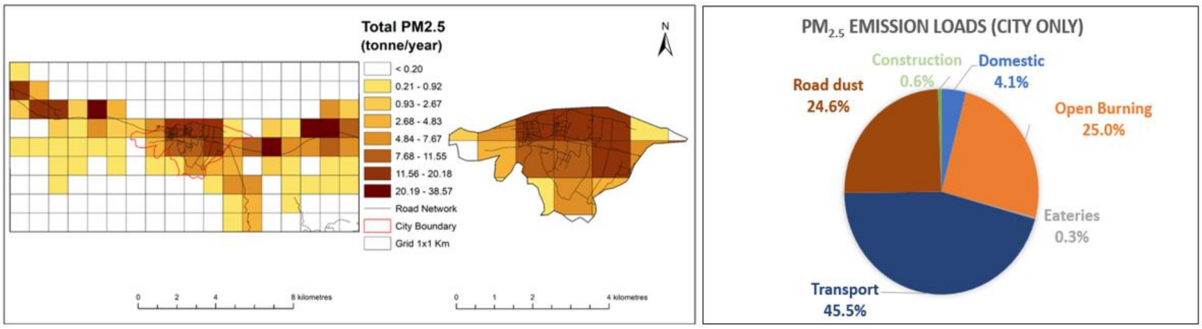

Figure E2: Spatial distribution of $PM_{2.5}$ emissions over Sahibganj and its airshed and sectoral contribution in the city area

Dumka: For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 519, 281, 11, and 1178 tonnes/year, respectively, whereas those in the city area were 241, 137, 8, and 499 tonnes/year, respectively. The transport sector was the largest contributor to $PM_{2.5}$ emissions within the city, followed by road dust, open burning, domestic sector, and eateries. Over the airshed, the domestic sector was a major source of SO_2 emissions, whereas transport was a major source of PM_{10} and NO_X emissions.

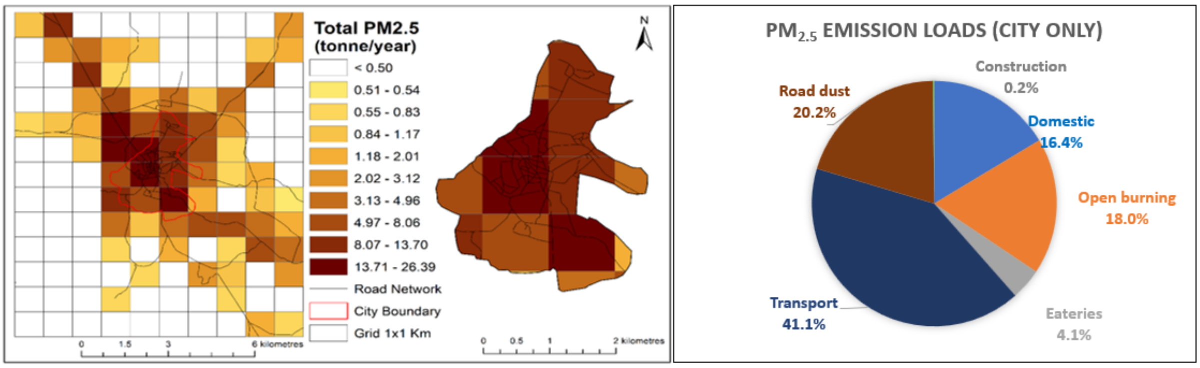

Figure E3: Spatial distribution of $PM_{2.5}$ emissions over Dumka and its airshed and sectoral contribution in the city area

Pakur: PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 876, 392, 74, and 927 tonnes/year, respectively, whereas those in the city area were 117, 71, 10, and 317 tonnes/year, respectively. Within the city, transport was the major contributor to $PM_{2.5}$ emissions, followed by open burning, domestic sector, and road dust. Mining, domestic sector, and transport were the major contributors to PM_{10}, SO_2, and NO_X emissions over the airshed.

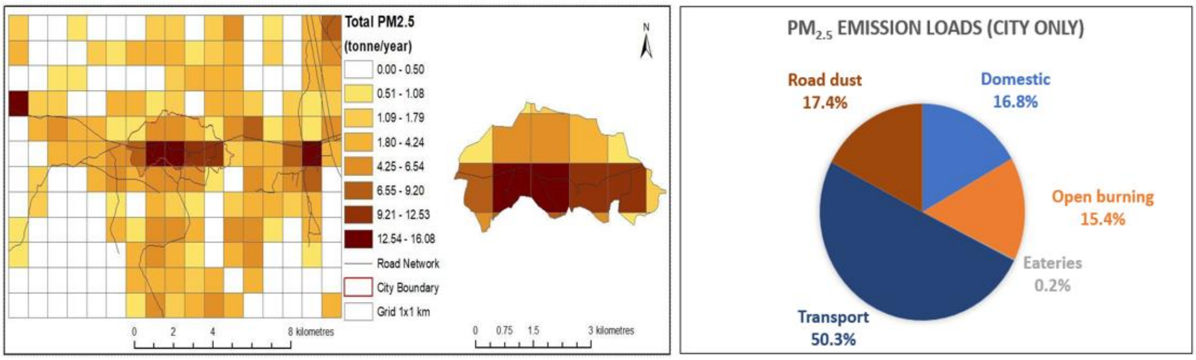

Figure E4: Spatial distribution of $PM_{2.5}$ emissions over Pakur and its airshed and sectoral contribution in the city area

Chaibasa: PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 654, 383, 31, and 1876 tonnes/year, respectively, whereas those in the city area were 334, 206, 2, and 1039 tonnes/year, respectively. Within the city, the transport sector was the major contributor to $PM_{2.5}$ emissions, followed by domestic sector, road dust, and open burning. Road dust, brick kilns (in the airshed), and transport were the largest contributors to $PM_{2.5}$, SO_2, and NO_X emissions, respectively, over the airshed.

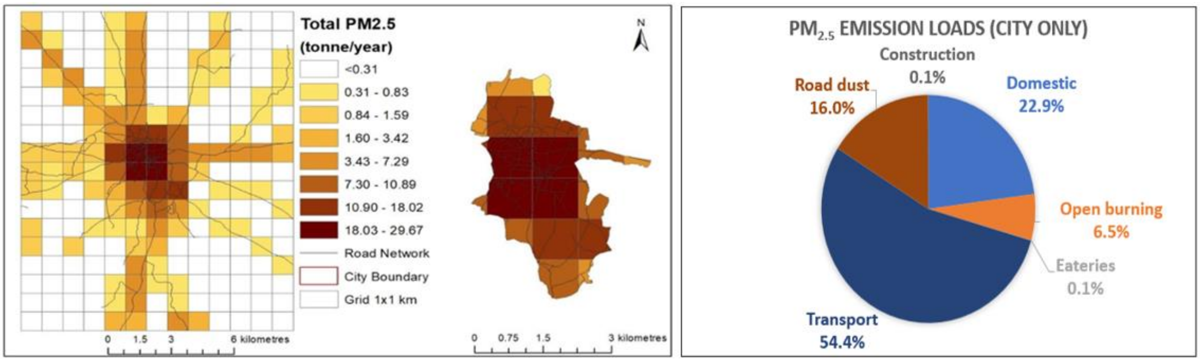

Figure E5: Spatial distribution of $PM_{2.5}$ emissions over Chaibasa and its airshed and sectoral contribution in the city area

Hazaribagh: For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 2583, 1245, 699, and 7000 tonnes/year, respectively, whereas those in the city area were 533, 283, 2133, and 15 tonnes/year, respectively. Total $PM_{2.5}$ emissions indicated that transport, road dust, open burning, and domestic sector were the major contributors to $PM_{2.5}$ emissions within the city. Road dust, industries (airshed), and transport were the major contributors to PM_{10}, SO_2, and NO_X emissions, respectively, over the airshed.

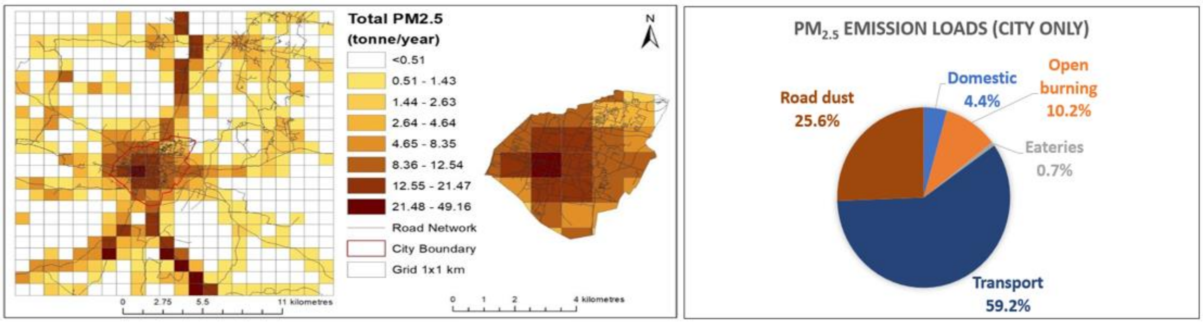

Figure E6: Spatial distribution of $PM_{2.5}$ emissions over Hazaribagh and its airshed and sectoral contribution in the city area

Ramgarh: For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 14426, 4192, 17087, and 13778 tonnes/year, respectively, whereas those in the city area were 1424, 801, 1041, and 396 tonnes/year, respectively. Within the city, industries were the major contributors to total $PM_{2.5}$ emissions, followed by domestic sector, transportation, open burning, mining, and road dust.

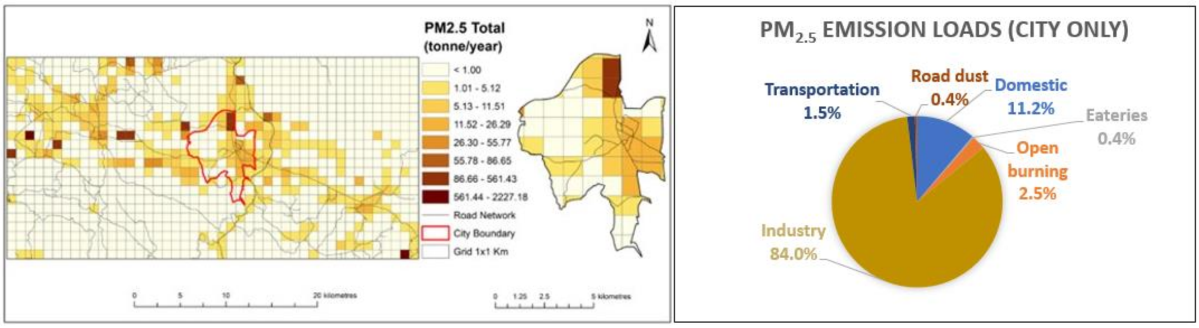

Figure E7: Spatial distribution of $PM_{2.5}$ emissions over Ramgarh and its airshed and sectoral contribution in the city area

Reduction in emissions in the study cities requires holistic approaches. A large portion of transport emissions are generated from heavy commercial vehicles plying through the cities (owing to the presence of major roads within the cities and freight movement due to industries). New roads bypassing the city area need to be constructed to reduce the sectoral share of transportation. End-to-end pavement to reduce road dust and dust suppression systems in the industries for fugitive dust control are needed. Further, industries should be encouraged to use cleaner fuels, along with mandatory compliance (with third party auditing), to significantly reduce emissions in these cities. Industries need to be shifted from Ramgarh city area for reducing the total emissions. Clean fuel penetration and reduction of solid fuel usage within the domestic sector will also help in reducing the emissions from the city area.

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Abbreviations

BS-VI	Bharat Stage VI
CPCB	Central pollution control board
DG	Diesel generator
EF	Emission factor
EI	Emission inventory
FO	Furnace oil
GIS	Geographic Information System
GoK	Government of Karnataka
HCV	Heavy commercial vehicle
KVA	Kilovolt ampere
LCV	Light commercial vehicle
LER	Low emission reduction
LPG	Liquefied petroleum gas
LTO	Landing and take-off
LULC	Land use land cover
MoEFCC	Ministry of Environment, Forest and Climate Change
MSW	Municipal solid waste
NAAQS	National Ambient Air Quality Standards
NCAP	National Clean Air Programme
NFHS	National Family Health Survey
NO_X	Oxides of nitrogen
PM_{10}	Particulate matter with a diameter of 10 microns or less
$PM_{2.5}$	Particulate matter with a diameter of 2.5 microns or less
PPAC	Petroleum Planning and Analysis Cell
RDF	Refuse-derived fuel
SO_2	Sulphur dioxide
VKT	Vehicle kilometres travelled

1. Introduction

In recent years, air pollution has become a hazardous challenge impacting the ecosystem. In total, 22 of the 30 most polluted cities globally are located in India, with frequent exceedances in the National Ambient Air Quality Standard. In 2017, air pollution was responsible for over 1.1 million premature deaths in India, of which 56% were attributed to exposure to outdoor pollution (Health Effects Institute, 2020). Further, air pollution in India resulted in a 3% GDP loss in 2019 (Health Effects Institute, 2020).

Rapid industrial growth has accelerated the deterioration of air quality in several cities in Jharkhand. However, due to poor air quality monitoring systems in the state, it is difficult to determine the most polluting cities. Thus, considering the serious health impacts of air pollution on the population, a systematic control and abatement strategy is the need of the hour. An emission inventory (EI) with a detailed estimation of emission loads from various sectors as well as their spatial distribution will help the cities and state administration in formulating sectoral control strategies for air pollution mitigation.

In the current study, a detailed EI has been developed based on the sectoral fuel use and activity data from ground-level surveys as well as secondary data. Six cities, namely, Ramgarh, Hazaribagh, Sahibganj, Dumka, Pakur, and Chaibasa, were selected for developing the EI. The findings of this report will help in understanding the spatial and temporal trends of emissions over the selected cities and their airshed and in devising steps to be taken for abatement.

1.1. Geographical Information

Jharkhand is located in the Chota Nagpur Plateau in eastern India and has a mostly humid and subtropical climate. It is the 15th largest state by area and the 14th largest by population. Known for its rich mineral reserves, Jharkhand accounts for 40% of the mineral deposits in India. Mining and mineral extraction are major industries and sources of wealth for the state. Large deposits of coal and iron ore have been the backbone of industrial growth in several cities in Jharkhand. Mining- and quarrying-associated activities have an overall contribution of 11% to the state's GDP and provide support to many downstream industries and thermal power generation. Iron, steel, coal, and power industries are the major industries in the state and have played a key role in the state's economic growth. Hindustan Copper Ltd, Tata Steel Ltd, Steel Authority of India Ltd, Hindalco Industries Ltd, Coal India Ltd, and Jindal Steel and Power Ltd are the major organisations in terms of production and revenue generation for the state.

1.2. Study Objectives

This study aimed to explore the various polluting sectors in six cities (Ramgarh, Hazaribagh, Sahibganj, Dumka, Pakur, and Chaibasa) and their share towards the particular city's total emission load. The study objectives are outlined below:

- Sector-wise identification of anthropogenic pollution sources and corresponding activities
- Estimation of the sectoral emission load share for the six cities
- Distribution of grid-wise (1 km × 1 km grid) emission load

1.3. Study Approach

The study developed EIs for six cities in Jharkhand by estimating emissions from different polluting sources and their corresponding activities. A literature review was performed to analyse the pollution landscape in the cities. After gaining an understanding of sectoral activities contributing to air pollution, survey (domestic and commercial fuel consumption and fuel station surveys) and secondary data were collected for different polluting activities. Furthermore, based on these data, sectoral emissions were estimated and spatially distributed for the study cities.

1.4. Structure of the Report

Section 2 of this report describes the demography of the cities and the study areas. Section 3 describes the methodology used for the development of the EI. It includes the description of the data collected for different sectors and the procedure for calculation of sectoral emission load using emission factors (EFs) obtained from the Central Pollution Control board (CPCB), European Environmental Agency (EEA), United States Environment Protection Agency (USEPA), and literature review. The Results and Discussion section (Section 4) gives an account of the EIs developed for the six cities including the sectoral load of emissions and fuel use for the cities and airshed as well as the spatial distribution in the grid showing sector-wise high emission hotspots in the city and airshed area. Section 5 of this report delineates the key measures towards air pollution mitigation.

2. Study Area

An EI is a detailed estimate of pollutant emissions from all sources during a particular time period in a particular geographical area. EI development helps us identify the important polluting sources in a specific area. The following steps are involved in the development of an EI for a specific area: (i) listing of the types of polluting sources, (ii) determination of the type of pollutant emissions from different sources, (iii) listing of pollutant EFs of relevant sources, (iv) identification of the type of control technology used within the sources, (v) determination of the number and size of similar sources in a given area, and (vi) obtaining the total emissions after summing up the similar pollutant emissions from each source.

An EI for six cities (Sahibganj, Pakur, Dumka, Chaibasa, Hazaribagh, and Ramgarh) was developed for the base year 2019 (April 2019–March 2020). Various pollutants such as particulate matter (PM_{10} and $PM_{2.5}$), SO_2, and NO_X were considered in the EI.

Figure 1 presents the airshed considered for the six cities in Jharkhand. All airshed areas were created to accommodate the entire city area and any industrial units around the city. Table 1 presents the city area and the considered airshed for the six study cities.

Table 1: City and airshed areas considered for the six study cities

	Sahibganj	Dumka	Pakur	Chaibasa	Hazaribagh	Ramgarh
City area (km²)	13	9.2	11.08	9.2	53.94	37.68
Airshed area (km × km)	18 × 9	10 × 13	17 × 12	13 × 17	22 × 24	31 × 40

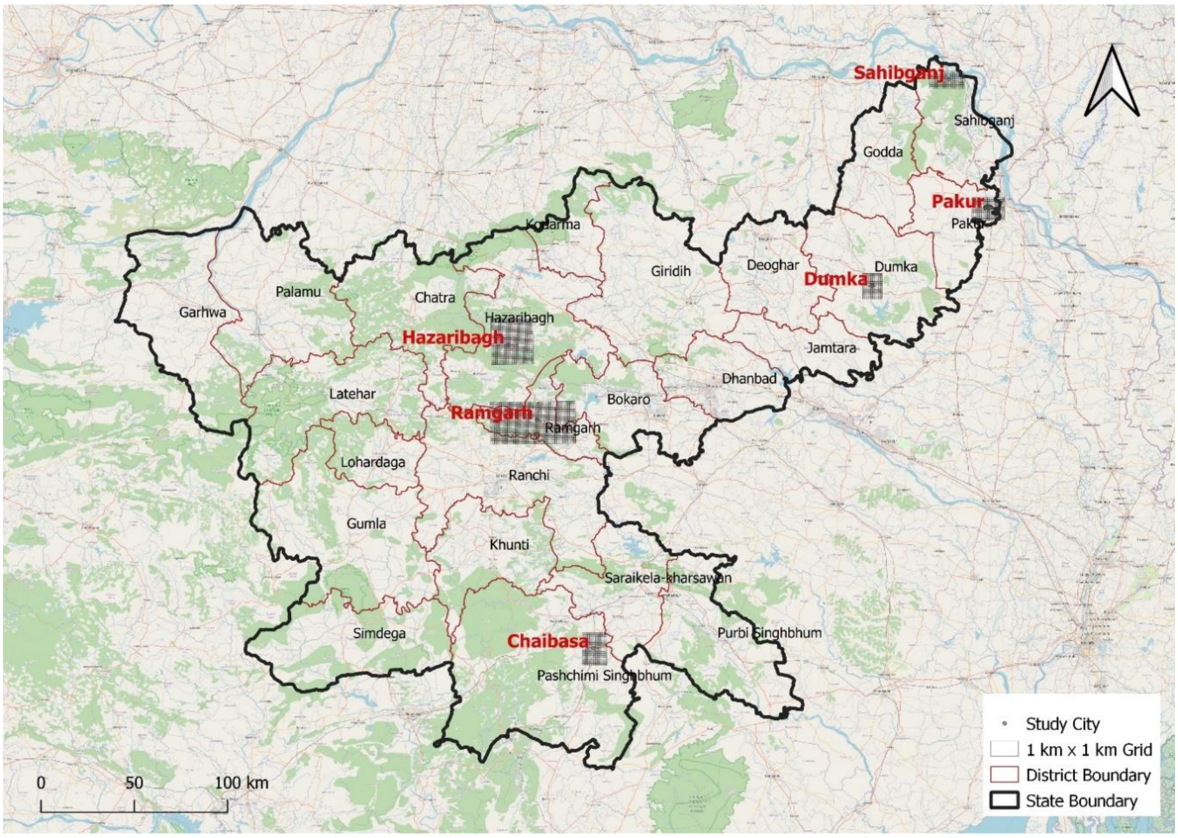

Figure 1: Locations of the study cities in Jharkhand

2.1. Demography

All six cities within the study area varied in terms of area, population, industries, road length, and vehicle count (Table 2). The population of Hazaribagh, Sahibganj, and Ramgarh was higher than that of Dumka, Pakur, and Chaibasa. The number of brick kilns present in Ramgarh airshed was higher than that in the other cities, whereas Hazaribagh had the highest number of stone crushers, followed by Pakur, Sahibganj, Ramgarh, and Chaibasa. Except Hazaribagh and Ramgarh, none of the cities had any large industries within their airshed. The presence of such large industries impacted the overall emission share in Hazaribagh and Ramgarh. Detailed city-level profiles are described in the following sections.

Table 2: Demography of the study cities

	Sahibganj	Dumka	Pakur	Chaibasa	Hazaribagh	Ramgarh
City area (km^2)	13	9.2	11.08	9.2	53.94	37.68
Population (2019)	1,15,000	50,285	57,196	74,298	1,56,520	1,08,167
Number of BKs in the airshed	6	-	-	5	15	93
Number of SCs in the airshed	102	-	151	10	240	80
Number of SMs in the airshed	30	-	30	2	14	29
Industries	-	-	-	-	S-1, C-2, RM-2, and FP-1	S-7, C-1, RM-1, FP-2, G-1, TPPs-1, R-7, CM-10, and IS-7
Number of vehicles plying	82190	152259	43247	100789	405430	129302
Road length within the airshed (km)	41	51.4	47.8	160	138	180

S: Sponge, C: Cement, RM: Rice mills, F: Food processing, G: Glass, TPPs: Thermal power plants, R: Refractories, IS: Iron and steel, CM: Coal mine, BK: Brick kilns, SM, Stone mines, SC: Stone crushers

2.1.1. Sahibganj

Sahibganj is a municipality in the district of Sahibganj, Jharkhand, and also serves as the district headquarters. The town covers an area of 13 km^2 and lies at an altitude of ~16 m above the mean sea level. Sahibganj municipality ranks 13th in terms of population in Jharkhand, with a population density of 9823 persons/km^2. According to Census 2011, the decadal growth rate of the town's population was 10%. The study domain (airshed) considered here was 18 × 9 km^2, with a spatial resolution of 1 km × 1 km. Table 3 presents the town demography.

Table 3: Demography of Sahibganj town

Sahibganj town profile	
Town population (Census, 2011)	88,084
Households in the town (Census, 2011)	17,076
Town slum population (Census, 2011)	2,193
Town population in 2019 (Town sanitation plan, 2019)	1,15,000
Households in the town in 2019 (Town sanitation plan, 2019)	22,293
Town slum population in 2019 (Town sanitation plan, 2019)	2,863
Percentage of the slum population in 2019	2.5%
Percentage increase in the town population from 2011 to 2019	30%

Industrial profile:

Farming is a major economic activity in the neighbourhood of Sahibganj town. The town and its neighbourhood have no large-scale industries. The town vicinity is endowed with a large number of handloom units. The traditional cottage and village industries run by the people in this region include *tussar* (silk) rearing, village blacksmithing, carpentry, handloom weaving, rope making, bidi making, earthenware making, and stoneware making. Several small-scale industries have been set up in the town neighbourhood. Most of these units involve brick making, mining, and quarrying-related activities.

Mining and mineral-based industries such as brick kilns were the major polluting industries in the town vicinity (Figure 2). There were 6 brick kilns, 30 stone mines, and 102 stone crushers in and around Sahibganj.

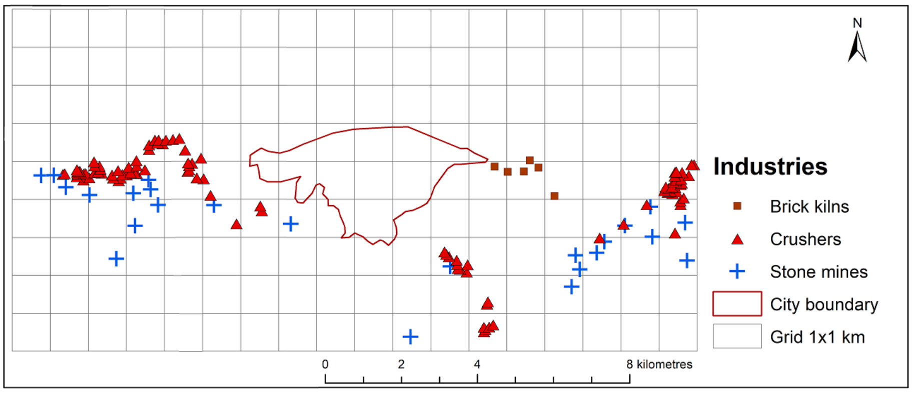

Figure 2: Industrial locations in Sahibganj

In addition to traditional sources such as domestic cooking and heating, passenger vehicles, road dust, commercial cooking, and solid waste burning, fugitive dust emissions from mining and stone crushing activities, use of biomass and coal in brick kilns, and vehicle exhaust of heavy-duty trucks were the major emission sources in the town and its vicinity.

2.1.2. Dumka

Dumka is a municipality in the district of Dumka, Jharkhand, and serves as the district headquarters. The town covers an area of 9.2 km^2 and lies at an altitude of ~137 m above the mean sea level. Dumka municipality has a population density of 7775 persons/km^2. According to Census 2011, the decadal growth rate of the town's population was 5.2%. The study domain (airshed) considered here was 10 × 13 km^2, with a spatial resolution of 1 × 1 km. Table 4 presents the summary of the town demography.

Table 4: Demography of Dumka town

Dumka town profile	
Town population in 2011 (Census, 2011)	47,306
Households in the town in 2011 (Census, 2011)	8,995
Town slum population in 2011 (Census, 2011)	9,898
Town population in 2019 (Town sanitation plan, 2019)	50,285
Households in the town in 2019 (Town sanitation plan, 2019)	9,561
Town slum population in 2019 (Town sanitation plan, 2019)	10,425
Percentage of slum population in 2019	21%
Percentage increase in the town population from 2011 to 2019	6.3%

Industrial profile:

Farming is the major economic activity in the neighbourhood of Dumka town. There are no medium- and large-scale industries within the town and its vicinity; however, a large number of silk production units are located in the town vicinity. No mining and mining-related activities were noted in the study domain.

2.1.3. Pakur

Pakur is a municipality in the district of Pakur, Jharkhand, and also serves as the district headquarters. The town covers an area of 11.08 km^2 and lies at an altitude of ~138 m above the mean sea level. Pakur municipality ranks 25th in terms of population in the state of Jharkhand, with a population density of 5,405 persons/km^2. According to Census 2011, the decadal growth rate of the town's population was 27%. The study domain (airshed) considered here was 17 × 12 km^2, with a spatial resolution of 1 km × 1 km. **Error! Reference source not found.** presents the summary of the town demography.

Table 5: Demography of Pakur town

Pakur town profile	
Town population in 2011 (Census, 2011)	45,840
Households in the town in 2011 (Census, 2011)	9,333
Town slum population in 2011 (Census, 2011)	8,296
Town population in 2019 (Town sanitation plan, 2019)	57,196
Households in the town in 2019 (Town sanitation plan, 2019)	11,644
Town slum population in 2019 (Town sanitation plan, 2019)	9,864
Percentage of slum population in 2019	17%
Percentage increase in the town population from 2011 to 2019	25%

Industrial profile:

Farming is the major economic activity in the neighbourhood of Pakur town. The town and its neighbourhood have no large-scale industries. Unlike other regions of Jharkhand, it is not rich in major minerals. Nonetheless, Pakur is renowned for the stone industry. The town contains a large number of stone mines and crushers (Figure 3). Approximately 30 mines and 151 crushers are in operation with the support of a huge labour force in the vicinity of the town. However, in the absence of major industries and employment opportunities, the economic options are limited to agriculture.

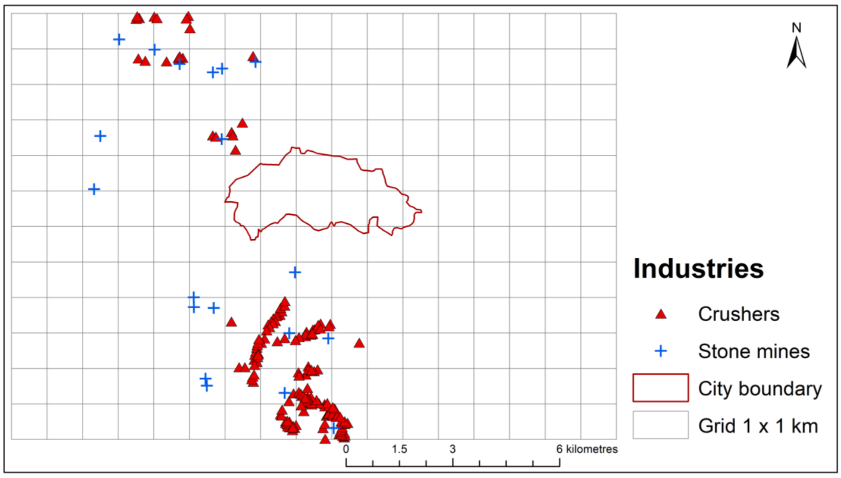

Figure 3: Industrial locations in and around Pakur

Fugitive dust emissions from mining and stone crushing activities, use of coal and wood in brick kilns, and vehicle exhaust of heavy-duty trucks are the major emission sources in the town and its vicinity, besides traditional sources such as domestic cooking and heating, passenger vehicles, road dust, commercial cooking, and solid waste burning.

2.1.4. Chaibasa

Chaibasa is a municipality in the district of West Singhbhum, Jharkhand, and serves as the district headquarters. The town covers an area of 9.2 km² and lies at an altitude of ~222 m above the mean sea level. Chaibasa municipality ranks 15th in terms of population in the state of Jharkhand, with a population density of 8,089 persons/km². According to Census 2011, the decadal growth rate of the town's population was 9.2%. The study domain (airshed) considered here was 13 × 17 km², with a spatial resolution of 1 km × 1 km. **Error! Reference source not found.** presents the summary of the town demography.

Table 6: Demography of Chaibasa

Chaibasa town profile	
Town population in 2011 (Census, 2011)	69,565
Households in the town in 2011 (Census, 2011)	13,751
Town slum population in 2011 (Census, 2011)	11,906
Town population in 2019 (Town sanitation plan, 2019)	74,298
Households in the town in 2019 (Town sanitation plan, 2019)	14,686
Town slum population in 2019 (Town sanitation plan, 2019)	13,150
Percentage of slum population in 2019	18%
Percentage increase in the town population from 2011 to 2019	7%

Industrial profile:

Farming is the major economic activity in the neighbourhood of Chaibasa town. The town and its neighbourhood have no medium- and large-scale industries. Unlike other regions of Jharkhand, this town is not rich in major minerals. Few unorganised sectors, such as brick kilns, mining, and quarry-related activities, were observed in the neighbourhood (Figure 4).

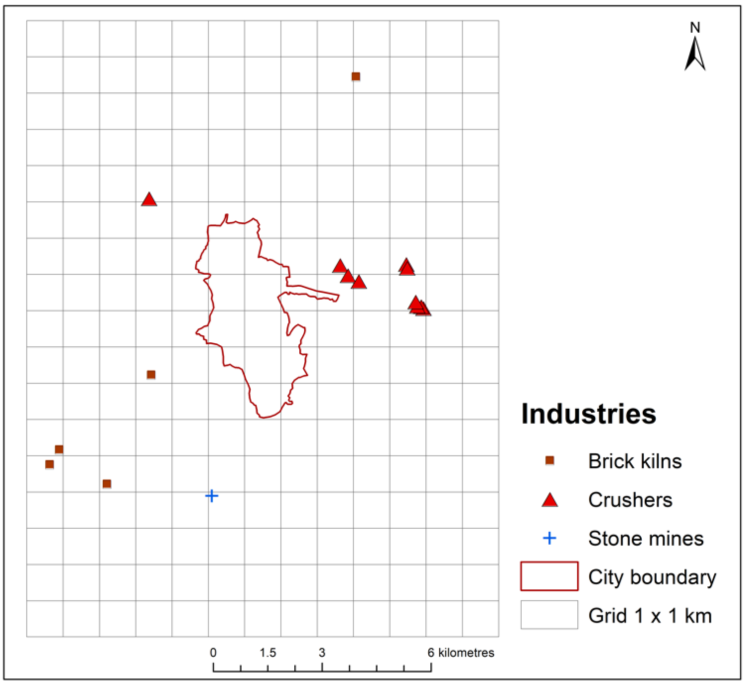

Figure 4: Industrial locations around Chaibasa

2.1.5. Hazaribagh

Hazaribagh is a municipal corporation in the district of Hazaribagh, Jharkhand. The city is part of the Northern Chota Nagpur division of the state and lies at an altitude of ~620 m above the mean sea level. Hazaribagh municipality ranks 5th in terms of area and 6th in terms of population in the state of Jharkhand. According to Census 2011, the decadal growth rate of the city's population was 12%. Table 7 presents the summary of the airshed and city size, geographical layout, and population. The study domain (airshed) considered here was 22 × 24 km^2, with a spatial resolution of 1 × 1 km.

Table 7: Demography of Hazaribagh

Hazaribagh town profile	
City area (km^2)	53.94
City population in 2011 (Census, 2011)	1,42,489
Households in the city in 2011 (Census, 2011)	25,794
City slum population in 2011 (Census, 2011)	14,896
City population in 2019 (City sanitation plan, 2019)	1,56,520
Households in the city in 2019 (City sanitation plan, 2019)	28,333
City slum population in 2019 (City sanitation plan, 2019)	17,712
Percentage of slum population in 2019	11.3%
Percentage increase in the city population from 2011 to 2019	9.8%

Industrial profile:

Farming is the major economic activity in the neighbourhood of Hazaribagh city. Hazaribagh district is endowed with 34.81% of forest area. Forest provides basic raw materials to a number of important industries in the city, namely, furniture, match box, paper, rayon, construction, railway sleepers, and wooden poles. Hazaribagh is also one of the industrialised cities in Jharkhand. Like other regions of Chota Nagpur, the city's neighbourhood is also endowed with mineral resources such as coal, limestone, quartz, quarry stone, and sand. Mining and mineral-based industries, such as steel, cement, and brick kilns, and food manufacturing industries were the major polluting industries located in the vicinity of the city (Figure 5).

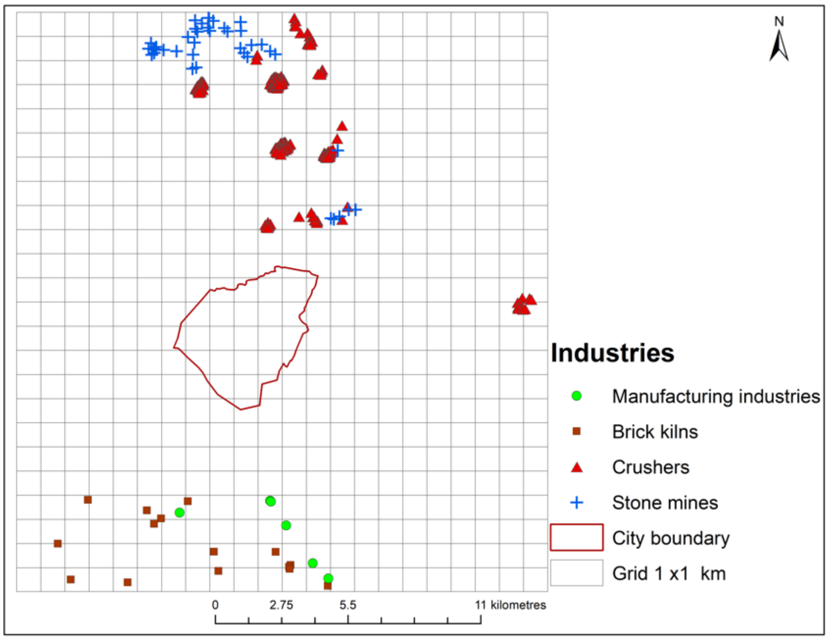

Figure 5: Industrial locations in Hazaribagh

2.1.6. Ramgarh

Ramgarh is a cantonment town in the district of Ramgarh, Jharkhand. The district was carved out from the erstwhile district Ramgarh. The town lies in the sub-humid region of the Northern Chota Nagpur division of the state and is situated at an altitude of ~332 m above the mean sea level. It covers an area of 37.68 km^2. According to Census 2011, the decadal growth rate of the town's population was 11.2%. The study domain (airshed) considered here was 45 × 22 km^2, with a spatial resolution of 1 km × 1 km. Table 8 presents the summary of the town demography.

Table 8: Demography of Ramgarh

Ramgarh town profile	
Town population in 2011 (Census, 2011)	88,781
Households in the town in 2011 (Census, 2011)	14,615
Town population in 2019 (Town sanitation plan, 2019)	1,08,167
Households in the town in 2019 (Town sanitation plan, 2019)	17,806
Percentage increase in the town population from 2011 to 2019	22%

Industrial profile:

The neighbourhood of the town is endowed with a large and rich deposit of coal and other minor minerals such as limestone and quarry stone. Rajrappa, Sirka, Argada, Saunda, Sayal, Urimari, Bhurkunda, Sugai, Rauta, Burakhap, and Patratu are the major coalfields in the neighbourhood of the town. Ramgarh is an important industrial town in East India. Several mineral-based industries like steel, sponge iron, cement, refractory, and thermal power plants are established owing to the availability of coal and other minerals. The vicinity of the town has abundant sponge iron and iron and steel industries due to the vast availability of iron ore and coal in this region. Figure 6 highlights the industrial locations in the city.

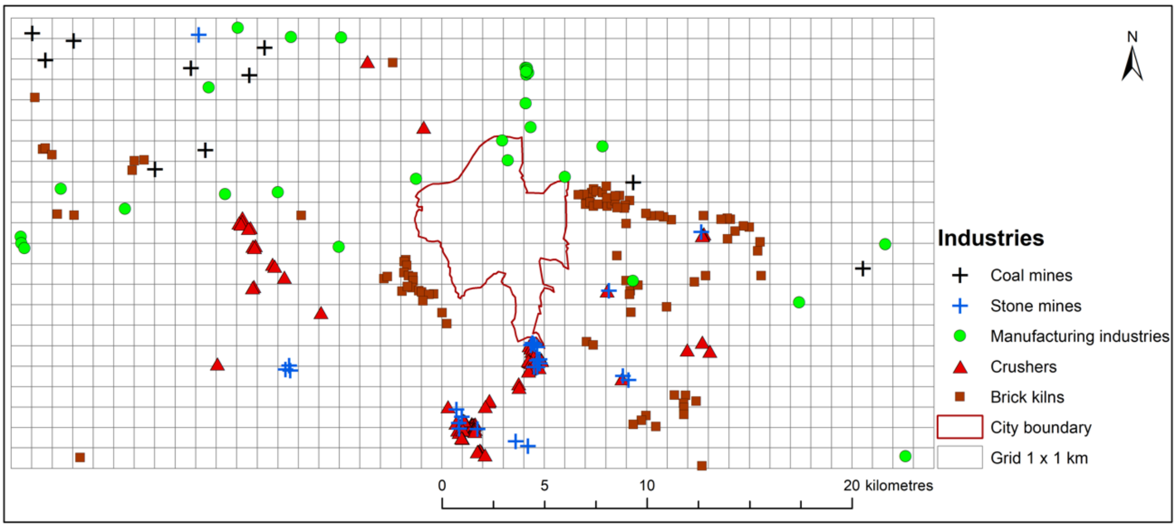

Figure 6: Industrial locations in Ramgarh

3. Methodology

An EI accounts for sectoral emissions within a predefined geographic boundary during a specific time period. In this study, emissions from industries, brick kilns, mining, stone crushers, domestic and commercial cooking, open burning, and transportation, as well as dust from different activities (construction and road dust), were considered.

3.1. EI

Emissions from road transportation:

The emissions from road transportation mainly depend on the type and vintage of the vehicle and the fuel used. Road transport emissions were computed using the following equation:

$$E_T = \sum_{i=1}^{m} VKT_i \times EF_i \quad \textbf{(1)}$$

where E_T is the total emission from transportation, VKT_i is the total vehicle kilometres travelled for a given period for different vehicle types (i), and EF_i is the emission factor for different vehicle types (i), which is based on the vintage of the vehicle and fuel used.

VKT is the average trip distance that a person undertakes daily using a particular mode of transport. VKT is determined based on urban form, land use, density patterns, and town size. Generally, VKT values are greater for an unplanned town and lower for a town with mixed land-use and high street density. In this study, the VKT data for different vehicle types were obtained from a transportation survey conducted at various petrol pumps in six cities. Vehicle statistics were obtained from the Department of Transportation and VAHAN database based on different vehicle types (two-wheelers, autos, cars, light commercial vehicles [LCVs], and heavy commercial vehicles [HCVs]), fuel types (petrol and diesel), and vintage classes (<5-years old, 5–10-years old, and 10–15-years old). EFs developed by the Automotive Research Association of India for different vehicle categories, fuel, and vintage were used for the estimation of emissions. The vehicle EFs were adjusted by the deterioration of vehicle engines with age.

Emissions from different vehicle categories were distributed in grids using fractions of road network density (ϒ) and population density (δ). The emissions from two- and three-wheelers were distributed only by the population density because these vehicles are typically used for last-mile connectivity. Emissions from HCVs, LCVs, and cars were distributed using both fractions of road network density and population density, as given in Table 9.

Table 9: Weightage factor for different vehicle categories for distribution of emissions in grids

Weightage factor	Two-wheelers	Cars	Autos	Light commercial vehicles	Heavy commercial vehicles
ϒ	0	0.3	0	0.6	0.7
δ	1	0.7	1	0.4	0.3

Source: Hakkim et al., 2021

Emissions from resuspension of road dust:

Dust already present on the roads gets resuspended because of the continuous movement of vehicles. Road dust emissions are mainly dependent on the silt loading (silt mass [<75 µm] per unit area of travel surface) and average weight of all vehicles travelling on the road. Road dust emissions from paved roads were computed using the AP-42 methodology, as follows:

$$E_a = [k\,(sL)^{0.91} \times (W)^{1.02}]\left(1 - \frac{P}{4N}\right) \times VKT_w \quad \textbf{(2)}$$

where E_a is the total emission from road dust (tonnes/year), k is the particle size multiplier (g/VKT), W is the weighted average weight of all vehicles travelling on the road (tonne), sL is the silt load (g/m^2), P is the number of days with at least 0.254 mm of precipitation, N is the averaging period (365 days), and VKT_w is the weighted average kilometres travelled of all vehicles on the road (km). In this study, the particle size multiplier (k) for $PM_{2.5}$ and PM_{10} was taken as 0.15 and 0.62 g/VKT, respectively (USEPA, 2011). Silt load (sL) for Indian roads is around 0.37 g/m^2. The number of wet days in a city was obtained from the World Weather Online portal (district-level statistics; www.worldweatheronline.com). Road dust emissions were distributed in grids based on the road network.

Emissions from the domestic sector:

Domestic emissions were estimated based on household fuel consumption for cooking as given below:

$$E = N_i \times C_i \times EF_i \quad \textbf{(3)}$$

where N_i is the total number of households using fuel i, C_i is the average household consumption of fuel i, and EF_i is the corresponding emission factor of fuel i.

Domestic emissions were computed separately for slums and non-slums in the city. For slums, household fuel consumption data were obtained from the domestic survey conducted in selected slums in six cities. For non-slums, liquefied petroleum gas (LPG) was considered the dominant fuel, with an average household consumption of one cylinder per month. The sample size for the domestic survey was calculated using Cochran's formula, with a 95% confidence level and 10% precision (Bartlett et al., 2001). The total number of households in a city in 2019 was obtained from the city sanitation plan (MoHUA, 2020) or projected based on Census (2011) and using geometric progression. EFs estimated by Pandey et al. (2017), Das et al. (2019), and the CPCB were used in the study.

Households in the airshed excluding the city area most likely used solid fuels for cooking. Clean fuel penetration rate (at the district level) obtained from the National Family and Health Survey (NFHS, 2019) and the type of solid fuel used for cooking (at the district level) obtained from the Census 2011 were used to compute the domestic emissions in the airshed excluding the city area. Fuel consumption was calculated based on household specific energy consumption computed from the domestic survey.

The domestic emissions were distributed in grids using population density. The gridded population was obtained from the Global Human Settlement Layer for 2015 and projected for 2019.

Emissions from industries:

Industrial emissions are broadly classified into area and point sources. Area sources include mining and stone crushing. Point sources (stack-based emissions) include industries with elevated stacks such as cement, iron and steel plants, brick kilns, and thermal power plants. Industrial emissions were estimated based on fuel consumption or unit production as given below:

$$E_i = F_i \times EF_f \text{ or } P_i \times EF_p \quad \textbf{(4)}$$

where E_i is the total emission from industry i (tonnes/years), F_i is the fuel consumed during the specific process in the industry i (tonnes), EF_f is the emission factor based on fuel type (kg/tonnes), P_i is the total production (tonnes) of the industry i, and EF_p is the emission factor based on unit production of the industry (kg/tonnes).

Stack-based industrial emissions: These emissions are associated with the combustion of fuel used in the industrial process. These stacks are connected to combustion equipment such as boilers, thermic fluid heaters, and kilns and furnaces.

Table 10 presents the details of industrial processes contributing to air pollution within the study domain. The quantity of fuel used in industries is mainly dependent on the size of the combustion equipment and production quantity. The fuel type used in industries is dependent on the availability of fuel in its vicinity or the by-product generated during the process. For instance, rice husk and bagasse are the by-products of rice and sugar production during milling and are used as fuel or co-fired with other fuels in the combustion equipment.

Table 10: Process sources of emissions from stack-based industries and fuels used in industries

Activity	Process sources	Fuels
Sponge iron	Inclined rotary kiln (direct reduced iron)	C
Cement	Grinding/crushing of raw materials and clinkers	Fugitive
	Rotary kiln	C
Rice mills	Boilers	RH
	Hullers and de-huskers (removal and separation of husk)	Fugitive
Food processing	Boilers	HSD
Iron and steel	Inclined rotary kiln and melting furnace	C and CG
Refractories	Down draught kiln	C
Glass	Glass melting furnace	C
Brick making	Fixed-chimney Bull's kiln	C (main fuel) and W (initial firing of the kiln to remove moisture)

C: Coal, RH: Rice husk, HSD: High-speed diesel, CG: Coal gas, W: Wood

Stone mining and stone crushers: These are unorganised industrial sectors that play a significant role in providing employment to unskilled labours in the local region. Although these industries are the backbone of the local economy, they are responsible for various environmental and health hazards owing to the release of a substantial amount of fine fugitive dust emissions. Exposure to elevated concentrations of fine and coarse dust particulates can cause various respiratory diseases, such as pneumoconiosis, bronchitis or emphysema, and silicosis. Table 11 presents the process sources of fugitive emissions from stone mining and crushing.

Table 11: Sources of fugitive emissions from stone mining and crushing

Activity	Process sources	Scale of emissions
Mining	Blasting	Negligible
	Drilling	High
	Loading and hauling	High
Stone crushing	Primary crushing and screening	Small
	Secondary crushing and screening	Medium
	Tertiary crushing and screening	High
	Loading and hauling	High

Highly polluting industries were identified using satellite imagery on the Geographical Information System (GIS) platform. Fuel consumption and production statistics were obtained from the Environmental Clearance and Annual Reports of the industries. In case production or fuel consumption statistics were unavailable, the area of the industry was used as a substitute to compute fuel consumption. Specific fuel consumption expressed per unit area of an industry (kg/m^2) was multiplied with the plant area to obtain the fuel consumption.

Emissions from open burning:

The emission estimation from waste burning was uncertain due to the sparsity of data and difficulty in collecting data on the amount of wastes burned in Indian cities. Around 5%–12% of the collected waste is estimated to be burned throughout the country. The waste burned is estimated based on the quantity of waste generated, collection efficiency, and quantity of waste processed. Open burning includes solid waste burning and winter burning. The emissions from solid waste burning are mainly dependent on the amount of waste generated at source. The amount of solid waste burned at source was obtained using the following equation:

$$M_s = P_c \times MSWGR \times \delta \times P_{frac} \times \eta \times 365 \quad \textbf{(5)}$$

where M_s is the amount of municipal solid waste (MSW) burnt at source (kg/yr), P_c is the population of the city, MSWGR is the per capita MSW generation rate (kg/day), δ is the fraction of combustible MSW (0.57 was used in the study; Das et al., 2018), P_{frac} is the fraction of the population burning wastes (10% was used in the study), and g is the burning/oxidation efficiency (fraction; 0.4 was used in the study; Das et al., 2018). The amount of solid wastes burned was then multiplied with the EF to obtain the emission load of the city. EFs listed by Das et al., (2018) were used for the emission estimation.

In addition, heating practice in households during winter (space heating) is another major burning activity. Such winter burning emissions were estimated based on the amount of solid fuel consumed by a household, as shown below:

$$E = N_i \times C_i \times EF_i \quad \textbf{(6)}$$

where N_i is the total number of households using solid fuel i, C_i is the average household consumption of solid fuel i, and EF_i is the corresponding emission factor of solid fuel i.

The fuel consumption data were obtained from the household survey and Census 2011 (data on solid fuel usage in households). EFs estimated by Pandey et al. (2017), Das et al. (2019), and the CPCB were used in the study. Similar to domestic emissions, open burning emissions were distributed in grids.

Emissions from eateries:

Among commercial establishments, eateries utilised the largest share of fuel (particularly for cooking). Along with LPG, coal/charcoal was used in most eateries. The number of eateries and their locations were obtained through web scraping (Google Maps). Further, the emission load was estimated based on fuel consumption using the following equation:

$$\mathrm{E} = n \times F \times EF \quad \textbf{(7)}$$

where E is the total emission from eateries (tonnes/year), n is the number of eateries in a given area, F is the average fuel consumption in eateries (LPG, coal, or wood; kg/year), and EF is the fuel-specific emission factor (g/kg). The emissions were distributed in grids based on their locations.

Emissions from construction activities:

Dust emissions arising from construction activities are an environmental nuisance, both within the site and beyond the boundary. Dust from various construction and demolition activities generates particles of varying sizes and can cause serious health issues ranging from eye irritation to respiratory problems. Loading and unloading activities, digging, compacting, heavy-duty construction equipment movement, and other operations can emit significant fine fugitive emissions. To estimate emissions from these activities, we assumed that fugitive dust emissions were related to the acreage affected by the construction activity.

The emissions from construction activities were estimated based on the area disturbed over the construction period. To determine the built-up area in the airshed, datasets from 10-m resolution Sentinel-2 satellite were used. Data from the same time frame (May) in 2019 and 2020 were used to ensure cloud-free data. The data were pre-processed for required atmospheric correction, and the final data were post-processed to obtain the area under construction. The emissions from construction activities were estimated using the following equation:

$$E = A \times d \times EF \quad \textbf{(8)}$$

where A is the total emission from construction activities (tonnes/year), A is the construction area (acres), d is the duration of the construction activity (3 months was used in this study), and EF is the construction emission factor (acre-month).

Assumption and Limitations:

Due to the unavailability of data, we adopted the silt load values (0.37 g/m^2) from a Bengaluru EI study (TERI, 2010). Due to geographical changes and differences in road type, the silt loads can be different from the assumed value, which may have led to bias in the estimated emissions (resuspension of road dust). Further, a survey was not conducted to estimate fuel usage for space heating during winter months and secondary data were used instead. In addition, although few cities had agricultural land within the airshed, emissions from agricultural practices were not estimated due to lack of data (fuel used in water pump and generators, use of agricultural machinery such as tractors and tiling machines, and amount of agri-residue burned).

3.2. Survey Methodology

Field surveys were conducted to validate the data obtained from the state departments and to determine the pollution scenario in the cities. Domestic and commercial fuel consumption surveys along with fuel station surveys were conducted to better quantify solid fuel usage and vintage of vehicles plying in the cities. Domestic surveys were conducted in slums to better evaluate the extent of LPG and solid fuel usage in households. Commercial fuel consumption surveys were conducted to determine the size of restaurants and their fuel usage. Transportation surveys were performed at petrol bunks to determine the vintage and VKT of vehicles.

Domestic survey:

The domestic field survey was conducted in the study cities to ascertain and quantify solid fuel consumption by the lower economic strata in the city. The questionnaire was designed based on the research questions, after which the stratification and identification of slums were performed. The slums were chosen based on the stratification criteria that considered the slum's geographic location, whether it had been relocated or renovated, if it had been notified, and its size. The data from the domestic survey were analysed to quantify the fuel consumption in slum households.

Eateries survey:

The sample size was targeted to represent the commercial locations within a study city. Under the survey, restaurant types and the average quantity of fuel used on a daily basis, along with fuel used for power backup, in each establishment were covered. The eateries were further categorised on the basis of their footfall and availability of a tandoor facility.

Fuel station survey:

Field surveys were conducted at petrol bunks across the city for more precisely determining the fuel consumption and vintage of cars plying in the city. Petrol pumps in the cities were mapped on the GIS platform and then divided based on four quadrants. The survey locations (sample size) were determined based on the total number of fuel stations present in each quadrant. The survey was conducted for 5 days in a week, covering a weekend and 4 weekdays.

4. Results

4.1. Survey Results

Transportation, domestic, and eateries surveys were conducted in the six study cities. The following sections discuss the key survey results in the cities. City-specific results are presented in the EI section.

4.1.1. Transportation Survey

In total, 5723 vehicles were surveyed at 32 petrol bunks across the study cities. The survey revealed that 39%–69% of the two-wheelers in these cities were less than 5-years old, with Dumka having the highest share (69%) of newer two-wheelers and Hazaribagh having the lowest (39%; Table 12).

In terms of three-wheelers, petrol vehicles were dominant in Dumka, Pakur, and Ramgarh, with an increase in the percentage of petrol vehicles in the last 5 years. Diesel three-wheelers were mainly observed in Sahibganj, Chaibasa, and Hazaribagh, whereas petrol three-wheelers accounted for 0–1% of all vehicles in these three cities. This survey also highlighted an increase in the percentage of petrol cars and a decrease in the percentage of diesel cars in the last 5 years. Dumka had the highest percentage of newer LCVs, followed by Pakur. Sahibganj had the highest share of older LCVs (more than 10-years old). We also found that 2%–3% of the LCVs plying in these cities were registered between 1970 and 1980. The survey results indicated that 32%–63% of the vehicles plying in these cities were aged less than 5 years, 30%–40% were aged between 5 and 10 years, and 14%–37% were aged more than 10 years. Sahibganj and Chaibasa had a high share of older vehicles, whereas Dumka and Pakur had a high percentage of newly registered vehicles. However, the survey did not capture HCVs, as they were restricted within the town during the daytime (survey was performed during the day).

Table 12: Vintage of vehicles plying in the study cities

Study city	Vintage of vehicles																	
	Less than 5 years						5–10 years						More than 10 years					
	2w	3W-D	3W-P	Car-D	Car-P	LCV	2W	3W-D	3W-P	Car-D	Car-P	LCV	2W	3W-D	3W-P	Car-D	Car-P	LCV
Sahibganj	47	27	1	22	11	19	36	34	-	17	10	22	27	23	-	11	30	59
Dumka	69	22	22	13	53	71	24	14	17	5	10	21	7	17	8	10	8	7
Pakur	48	5	32	5	64	50	32	12	30	17	3	25	20	16	5	8	5	25
Chaibasa	47	27	-	9	14	35	28	14	-	15	30	33	25	59	-	10	23	32
Hazaribagh	39	45	-	15	30	31	38	48	-	17	27	35	23	7	-	7	5	33
Ramgarh	49	10	23	11	21	37	38	19	20	20	21	43	14	21	6	24	4	20

2W: two-wheeler; 3W-D: three-wheeler diesel; 3W-P: three-wheeler petrol; LCV: light commercial vehicle

4.1.2. Domestic Survey

The survey covered 457 households across 14 urban slums in five cities in Jharkhand. This survey did not include Ramgarh, as slum information for this town was not available. Table 13 presents the percentage share of fuels and their consumption in slum households. The survey revealed that Sahibganj and Hazaribagh had the highest percentage (>50%) of households that used LPG exclusively. However, despite increased LPG adoption, households utilised solid fuels in Pakur and Chaibasa. Most households used mixed fuels (solid fuels and LPG) for non-cooking purposes, such as water heating. LPG penetration in Dumka and Chaibasa slums was the lowest (<9%). Accessibility of wood from dense forest areas in the vicinity of these towns resulted in reduced adaptability to LPG. The survey found predominant coal use in Hazaribagh and Pakur slums owing to easy accessibility of coal from the coal mines located in their vicinity. The use of dung cake was only observed in Sahibganj slums.

Table 13: Average fuel consumption (kg/month) for cooking in slum households in the study cities

City	Coal (C)#	LPG (L)*	Dung cake (D)#	Wood (W)#	Mixed
Sahibganj	60 (14%)	1 (62%)	60 (5%)	120 (19%)	-
Dumka	90 (14%)	1 (7%)	-	-	C:60 + W:90 (77%)
Pakur	55 (16%)	1 (15%)	-	-	C: 50 + L:1 (69%)
Chaibasa	-	1 (9%)	-	350 (55%)	W:70 + L:1 (39%)
Hazaribagh	60 (48%)	1 (52%)	-	-	-

** represents LPG fuel consumption (expressed in terms of the number of cylinders used/month)*
 # represents fuel consumption (expressed in terms of kg/month)
% indicates the proportion of households

The relationship between household income and fuel usage is depicted in Figure 7. Household income was positively correlated with LPG consumption (Pearson's r = 0.31–0.44; $p < 0.05$), which indicates that household income is an important variable for the adoption of LPG exclusively in slums. LPG adoption was observed in households with a monthly income of at least INR 6000 in Chaibasa and at least INR 10000 in Dumka and Pakur. Further, the access to LPG refills is another critical factor that determines the exclusive usage of LPG. The average consumption of coal and wood in slum households ranged between 55 and 90 kg/month and 120 and 350 kg/month, respectively.

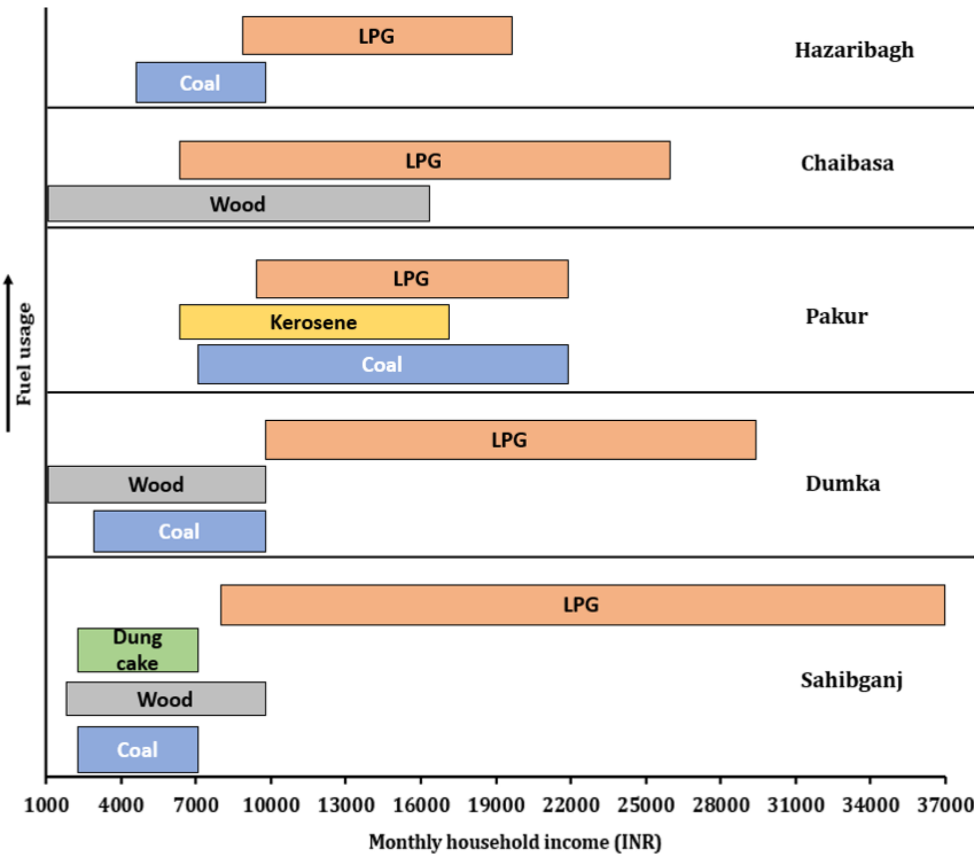

Figure 7: Relationship between fuel consumption and household income

4.1.3. Commercial Survey

Restaurants were classified into three categories (small, medium, and large) based on their daily footfall (Table 14). The survey covered 300 restaurants across the six study cities. Fuel mix in small restaurants varied significantly. The percentage of small restaurants using LPG in these cities varied between 50% and 78% (Table 15). High LPG adoption in small restaurants was observed in Sahibganj, followed by Chaibasa, Dumka, and Hazaribagh. Small restaurants in Pakur predominantly used mixed fuel (coal and LPG), with a high proportion of coal in the fuel mix. Solid fuel (coal) consumption was found to be dominant in Ramgarh and Hazaribagh. Restaurants in these cities used coal as the main fuel, as it is easily available from the coal mines located in their neighbourhood. Medium restaurants (except those in Ramgarh) predominantly used LPG as the main fuel. These restaurants used solid fuel only for specific cuisines such as barbeque and tandoori food items. Large restaurants exclusively used LPG.

Table 14: Share of restaurant types (%) in the study cities

Type of restaurant	Study city					
	Sahibganj	Dumka	Pakur	Chaibasa	Hazaribagh	Ramgarh
Small (daily footfall < 100)	36	61	5	81	64	67
Medium (100 ≤ daily footfall ≤ 500)	64	39	95	10	18	33
Large (daily footfall > 500	-	-	-	9	18	-

Table 15: Percentage of restaurants using solid fuel, LPG, and mixed fuel

City	Small restaurants			Medium restaurants			Large restaurants		
	S	L	Mixed (S + L)	S	L	Mixed (S + L)	S	L	Mixed (S + L)
Sahibganj	22	78	-	-	100	-	-	-	-
Dumka	-	65	35	-	-	100	-	-	-
Pakur	-	-	100	-	19	81	-	-	-
Chaibasa	-	68	32	-	-	100	-	-	100
Hazaribagh	50	50	-	-	100	-	-	100	-
Ramgarh	84	16	-	42	-	58	-	-	-

** S: Solid Fuel, L: LPG*

4.2. Emission Inventory

We examined various polluting sectors and their activities and estimated the total emission load in the airshed and cities. Table 16 presents the total emission load of pollutants (PM_{10}, $PM_{2.5}$, SO_2, and NO_X) estimated for the base year 2019.

Among the study cities, PM_{10} and $PM_{2.5}$ emissions were found to be the highest in Ramgarh, followed by Hazaribagh, Pakur, Sahibganj, Chaibasa, and Dumka. Although the population of Ramgarh was less than that of Sahibganj and Hazaribagh, high PM_{10} and $PM_{2.5}$ emissions over the airshed could be attributed to the presence of a large number of heavy industries within the city and the neighbourhood. Similarly, for Pakur, although the population was less than that of other cities (except Dumka), high population density was responsible for high PM emissions over the airshed (contributed by domestic sector, open burning, transport, and road dust).

Table 16: Total emission load of pollutants (PM_{10}, $PM_{2.5}$, SO_2, and NO_X) estimated for the base year 2019

City	Airshed size (km × km)	Total population (2019)	Emission loads in the airshed (tonnes/yr)				Emission loads in the city (tonnes/yr)			
			PM_{10}	$PM_{2.5}$	SO_2	NO_X	PM_{10}	$PM_{2.5}$	SO_2	NO_X
Sahibganj	18 × 9	1,15,000	607	286	44	684	158	81	3	334
Dumka	10 × 13	50,285	519	281	11	1178	241	137	8	499
Pakur	17 × 12	57,196	876	392	74	927	117	71	10	317
Chaibasa	13 × 17	74,298	655	383	31	1876	334	206	2	1039
Hazaribagh	22 × 24	1,56,520	2583	1245	699	7000	533	283	15	2133
Ramgarh	31 × 40	1,08,167	14426	4192	17087	13778	1424	800	1041	396

Emissions in Sahibganj, Dumka, and Chaibasa attributed to more than 50% of the total PM emissions (majorly from domestic sector, transport, road dust, and open burning) arising from the airshed. However, at Pakur and Hazaribagh, more than 75% of the PM emissions (majorly from transport, domestic sector, open burning, road dust, and industries) arose from the airshed excluding the city area. At Ramgarh, more than 70% of the PM emissions (mainly from industries) arose from the airshed excluding the city area.

Road dust was a major contributor to PM_{10} emissions in Dumka, Chaibasa, and Hazaribagh, whereas domestic sector, mining, and industries were the major contributors in Sahibganj, Pakur, and Ramgarh, respectively. $PM_{2.5}$ emissions were predominantly contributed by transport in Dumka, Chaibasa, and Hazaribagh. The domestic sector was found to be the major contributor to $PM_{2.5}$ emissions in Sahibganj and Pakur, whereas industries contributed significantly in Ramgarh. SO_2 emissions were mainly contributed by industries in Sahibganj, Chaibasa, Hazaribagh, and Ramgarh. Domestic contribution to SO_2 emissions was the highest in Pakur and Dumka. High NOx emissions were attributed to transport in Sahibganj, Dumka, Pakur, Chaibasa, and Hazaribagh, whereas industries had the highest contribution to NOx emissions in Ramgarh.

Figure 8 presents the sectoral contribution to $PM_{2.5}$ emissions in the six study cities. Transport was the highest contributor to $PM_{2.5}$ emissions in Dumka, Pakur, Chaibasa, and Hazaribagh and the second-highest contributor in Sahibganj. Commercial vehicles (HCVs and LCVs) were the main contributors to transport emissions in all cities. These vehicles accounted only for 6%–15% of the vehicles plying in the cities but contributed around 87%–96% of the transport $PM_{2.5}$ emissions. Two- and three-wheelers contributed about 3%–7.3% and 0.1%–5% of the transport emissions, respectively. Cars contributed between 0.01% and 1.6% of the transport emissions, with petrol cars contributing the lowest. National highways, followed by major roads, in the cities accounted for a major share of the transport $PM_{2.5}$ emissions.

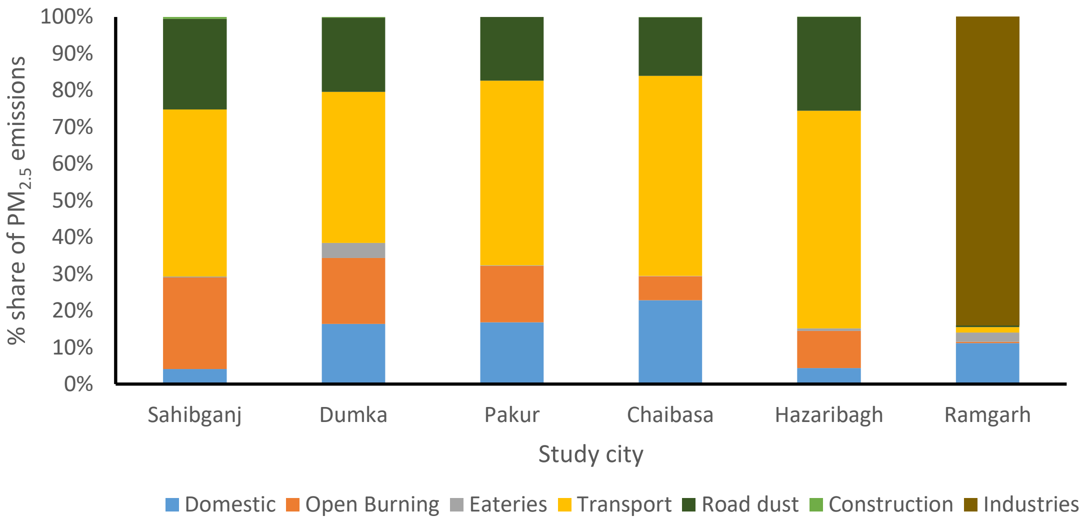

Figure 8: Sector-wise contribution to $PM_{2.5}$ emissions for the base year 2019-20 (considering city area only)

Open burning was the highest contributor to $PM_{2.5}$ emissions in Sahibganj and the second-highest contributor in Pakur. In addition, open burning (including burning of solid waste generated and solid fuel for heating purposes) considerably contributed to $PM_{2.5}$ emissions in Dumka, Chaibasa, and Hazaribagh. The estimated amount of solid wastes burned in the cities ranged between 445–2155 tonnes/year, with the highest amount in Hazaribagh and the lowest in Pakur. Among burning activities, space heating during winter was the highest contributor to $PM_{2.5}$ emissions in all cities, with the highest emissions in Hazaribagh and the lowest in Dumka.

Road dust was the second-highest contributor to $PM_{2.5}$ emissions in Dumka and Hazaribagh and the third-highest contributor in Sahibganj. A major share of the road dust $PM_{2.5}$ emissions in the study cities was contributed by national highways, followed by major roads and state highways.

Industries were the major contributors to $PM_{2.5}$ emissions in Ramgarh. Nearly 82% of the total $PM_{2.5}$ emissions were contributed by stack-based industries in Ramgarh. Use of coal as fuel in sponge iron and steel plants located in the city were mainly responsible for the high emissions. In other cities, no polluting industries were identified within the city area.

The domestic sector was the second-highest contributor to $PM_{2.5}$ emissions in Chaibasa (22.9%) and Ramgarh (11.2%). Domestic emissions in the cities were mainly attributed to slum households using solid fuel for cooking. Easy accessibility of solid fuel (coal and wood) in the city's neighbourhood and the low economic status of people in slums prevent them from adopting cleaner fuel. The domestic sector also considerably contributed to $PM_{2.5}$ emissions in Dumka and Pakur. Domestic emissions in Sahibganj and Hazaribagh were relatively low owing to comparatively high LPG penetration in the slums.

Contributions from construction activities and eateries were low in all cities. The rise in built-up area in these cities ranged between 0.14 and 0.8 acres within the cities. Further, as the scale of construction activities was mostly residential, very low emissions were observed from the construction sector. Eateries in the study cities were mostly small (daily footfall < 100) and used solid fuels—coal and wood—as co-fuel along with LPG, which attributed to a small percentage of $PM_{2.5}$ emissions.

4.2.1. Sahibganj

Sectoral emission estimation:

Domestic fuel consumption:

The domestic survey was conducted in selected slums inward Habibpur and Dhobi Jharna in Sahibganj town. The survey revealed that 13% of slum households used coal, 17% used biomass, 10% used dung cake, and 60% used LPG for cooking. The average frequency of cooking in slums was found to be twice per day.

The total consumption of coal, biomass, dung cake, and LPG in Sahibganj town was 69, 186, 22, and 3876 tonnes/year, respectively. For the airshed other than the town area, the consumption of domestic fuels was determined based on the Petroleum Planning and Analysis Cell (PPAC, 2016) and National Family Health Survey (NFHS, 2019) as well as Census (2011) district statistics, assuming the airshed other than the town area possessed nearly the same socioeconomic status as that of the district. The proportion of households using domestic fuels and their consumption in the airshed other than the town area are presented in Table 17.

Table 17: Percentage of households using domestic fuels and their consumption in the airshed beyond the town area

Type of fuel	Share (%)	Average fuel consumption (PPAC, 2016)				
		L (Cylinder/ month)	W (kg/month)	C (kg/month)	DC (kg/month)	K (kg/month)
LPG (L) (NFHS, 2019)	17	1				
Wood (W) (Census, 2011)	68.5		150			
Coal (C) (Census,2011)	7			29		
Dung cake (DC) (Census, 2011)	7				132	
Kerosene (K) (Census, 2001)	0.12					4

The total consumption of LPG, biomass, coal, dung cake, and kerosene in the airshed was estimated to be 373, 12419, 635, 635, and 0.5 tonnes/year, respectively. For the town area, PM_{10}, $PM_{2.5}$, NO_X, and SO_2 emissions from the domestic sector were estimated to be 4.43, 3.4, 11, and 0.4 tonnes/year, respectively. For the airshed area, PM_{10}, $PM_{2.5}$, NO_X, and SO_2 emissions from the domestic sector were estimated to be 122, 98, 20.2, and 6 tonnes/year, respectively. The total emissions (from the airshed area) were spatially distributed over the airshed area on the basis of the population density (Figure 9).

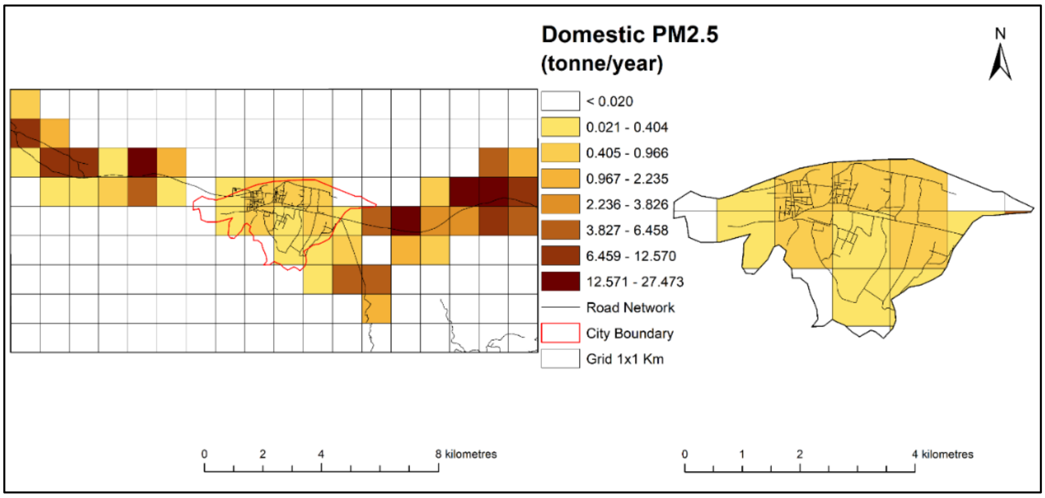

Figure 9: Spatial distribution of $PM_{2.5}$ emissions from the domestic sector in Sahibganj

It was evident that emissions from the domestic sector were more concentrated in the outskirts of the town. The main reason for the higher emissions was the high population density coupled with a high number of households using solid fuel for cooking (82.6%). Easy accessibility of wood from dense forest areas in the vicinity and low economic status prevent people from using clean fuel. For the town area, domestic emissions contributed only about 4% of the total emissions for all pollutants, which were mainly emitted from slum areas (with prevalent biomass use). High emitting grids associated with domestic emissions included Ganga Parshad, Samda Nala, Rampur, and Chhota Pagaro.

Commercial eateries:

The field survey was conducted at selected restaurants located in different parts of the town. We found that fuel use in restaurants varied by size and daily customer footfall. We divided the surveyed restaurants into two categories (small and medium restaurants; Figure 10). The percentage of restaurants using solid and clean fuels and their average fuel consumption are presented in Table 18. Medium restaurants predominantly used LPG as the main fuel, whereas wood was the dominant fuel in few small restaurants. Easy availability of wood in the vicinity of the town at a lower cost hindered these small restaurants from adopting LPG. The average specific energy consumed in a year in medium restaurants was more than 1.7 times the energy consumed in small restaurants.

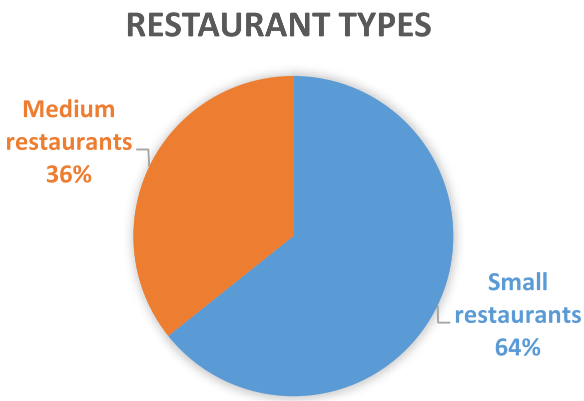

Figure 10: Share of restaurant types in Sahibganj

Table 18: Percentage of restaurants using solid and clean fuel and their average fuel consumption

	Percentage (%)	Fuel consumption		Annual specific energy consumption (GJ)
		Wood (kg/month)	LPG (19 kg cylinder/month)	
Small restaurants (footfall < 100)				
Wood	22	450		91.8
LPG	78		10	102.6
Medium restaurants (footfall 100–500)				
LPG	100		17	174.2

Data on the number of restaurants and their locations were obtained using Google API and then geo-located on the grids. About 33 restaurants were identified in the airshed. The total consumption of wood and LPG in eateries in Sahibganj town was estimated to be 25 and 83 tonnes/year, respectively. PM_{10}, $PM_{2.5}$, NO_X, and SO_2 emissions from eateries were estimated to be 0.25, 0.2, 0.26, and 0.005 tonnes/year, respectively. Only 14% of the restaurants used wood for cooking; however, they contributed about 83% of the total $PM_{2.5}$ emissions from eateries.

The spatial distribution of emissions from eateries was based on the number and type of eateries in each grid. Of note, emissions from the eateries sector were more concentrated within the town. Emissions from eateries were greater in the areas with more commercial activities and major roads, such as Rasulpur Dahla, Naya Tola, Santinagar, and Chota Panchgar (Figure 11). Overall, emissions from small restaurants (footfall < 100) were more than four times the emissions from medium restaurants. Kitchen staff was the potential receptor being constantly exposed to $PM_{2.5}$ emissions, and their exposure should be curtailed.

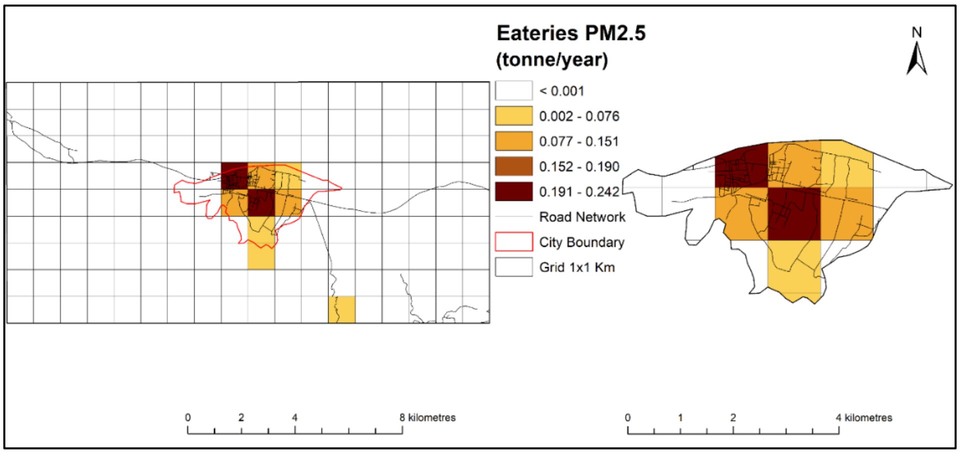

Figure 11: Spatial distribution of $PM_{2.5}$ emissions from eateries in Sahibganj

Transport emissions:

In most Indian cities, transportation is one of the major contributors to air pollution. Transport growth is largely influenced by demographic growth as well as economic growth. Like other cities, the increase in population and economic activities led to an increase in vehicular population in the town, with an average annual vehicular growth rate of 13%. Year-wise cumulative vehicle registration in Sahibganj is shown in Figure 12.

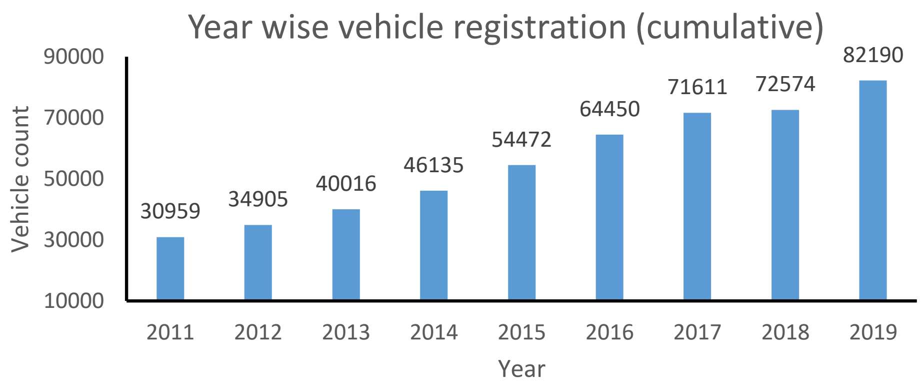

Figure 12: Vehicle registration details

The transportation survey was performed at petrol bunks to determine the vintage and VKT of vehicles. In total, 863 vehicles were surveyed at five petrol bunks. From this survey, we determined the share of age of vehicles plying in Sahibganj and share of four-wheelers and three-wheelers on the basis of fuel types (petrol or diesel). Figure 13 and Figure 14 present the vintage and VKT of the vehicles plying in Sahibganj. The survey results revealed that 33% of the vehicles plying in Sahibganj were aged less than 5 years, 30% were aged between 5 and 10 years, and 38% were aged more than 10 years. The survey did not capture HCVs, as HCVs were restricted inside the town during the daytime (the survey was conducted during the day).

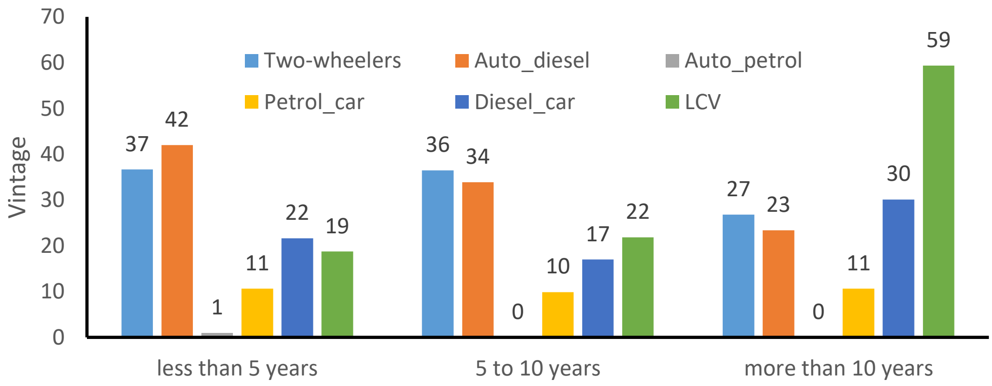

Figure 13: Vintage of vehicles

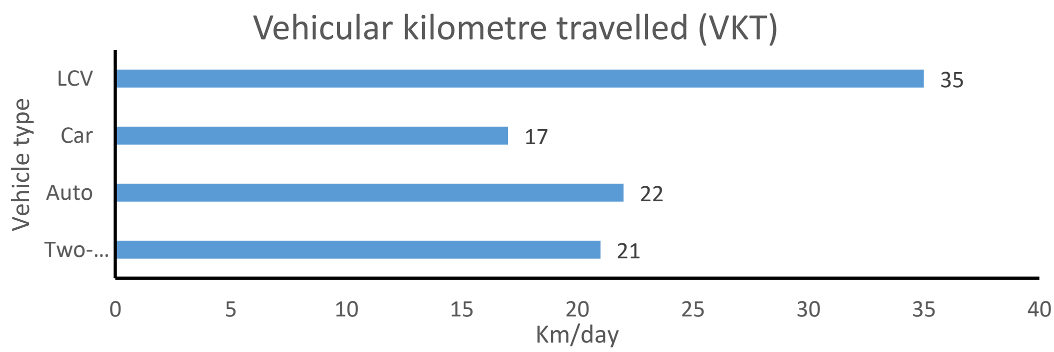

Figure 14: Vehicular kilometre travelled (VKT) for different vehicle types

Tailpipe emissions were estimated based on the VKT data obtained from the transportation survey and vehicle statistics obtained from the transport department and VAHAN database. The share of types of vehicles plying on road in Sahibganj is shown in Figure 15.

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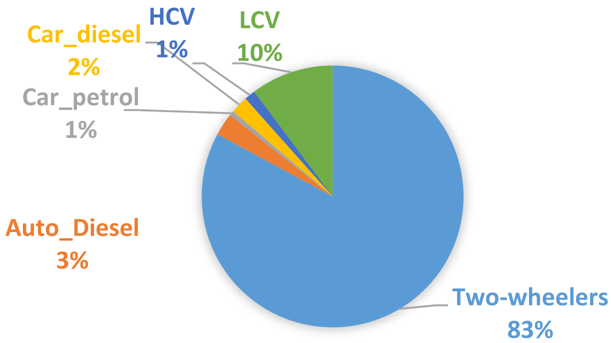

Figure 15: Share of vehicles plying in Sahibganj

The contribution of tailpipe emissions towards PM_{10}, $PM_{2.5}$, and NO_X pollutants was estimated to be 82, 76, and 643 tonnes/year, respectively. HCVs and LCVs contributed around 19% and 70% of the total PM emissions, respectively, of which 29% of HCV emissions and 41% of LCV emissions were emitted from vehicles aged more than 10 years. HCVs (including buses) and LCVs constituted only 1% and 10% of total vehicles plying in Sahibganj, respectively, but contributed 19% and 70% of the total PM load from transportation, respectively. Two-wheelers and diesel autos contributed about 6.8% and 2.6% of the PM emissions, respectively, whereas diesel cars and petrol cars contributed about 1.5% and 0.1%, respectively. Overall, 18% of the PM emissions from two-wheelers were emitted from vehicles aged >10 years. $PM_{2.5}$ emissions from different vehicle types are shown in Figure 16.

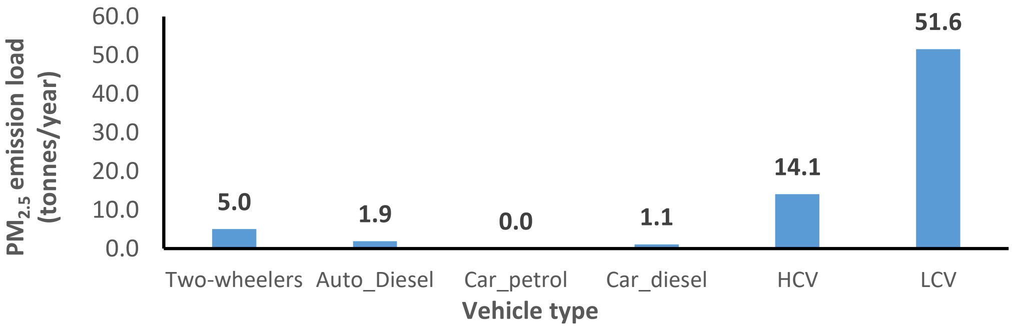

Figure 16: $PM_{2.5}$ emission load from different vehicle types

Transport emissions were distributed based on the population density and fraction of road networks. The total length of national highways, state highways, and major roads in the airshed was 20, 5, and 16 km, respectively. Vehicular emission was found to be high on main and arterial roads in the town because of the high heterogeneous traffic volume. The emission on these roads was contributed by the movement of mixed traffic (including HCVs). Emissions from these roads attributed to only 33% of the transport PM share. The major share of transport PM emissions was contributed by state and national highways, mainly emitted from HCVs. National Highway 33 and State Highway 18 contributed 39% and 11% of transport PM emissions (Figure 17).

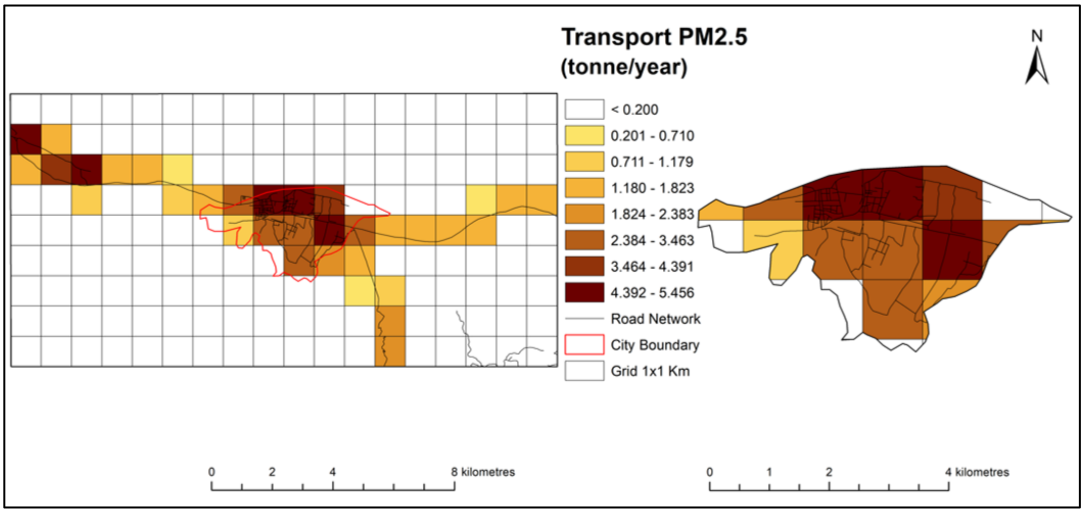

Figure 17: Spatial distribution of $PM_{2.5}$ emissions from the transport sector in Sahibganj

Resuspension of dust:

Other than tailpipe emissions, vehicular movement is responsible for the resuspension of dust. For the estimation of road dust emissions, road type data were also considered in addition to road network data. The EF for road dust varies with the road type (paved or unpaved), vehicle share, and climatic conditions. The emission from resuspension of dust was estimated to be 169 tonnes/year for PM_{10} and 42 tonnes/year for $PM_{2.5}$. Around 33% of PM emissions from road dust were contributed by the arterial and main roads in the town, and the major share of road dust PM emissions was contributed by roads located outside the town (Figure 18).

The resuspension of dust is directly dependent on vehicular movement. Hence, the spatial distribution of emissions is similar to that of transportation emissions. End-to-end pavement and removal of silt from the road surface may help reduce road dust emissions to a large extent.

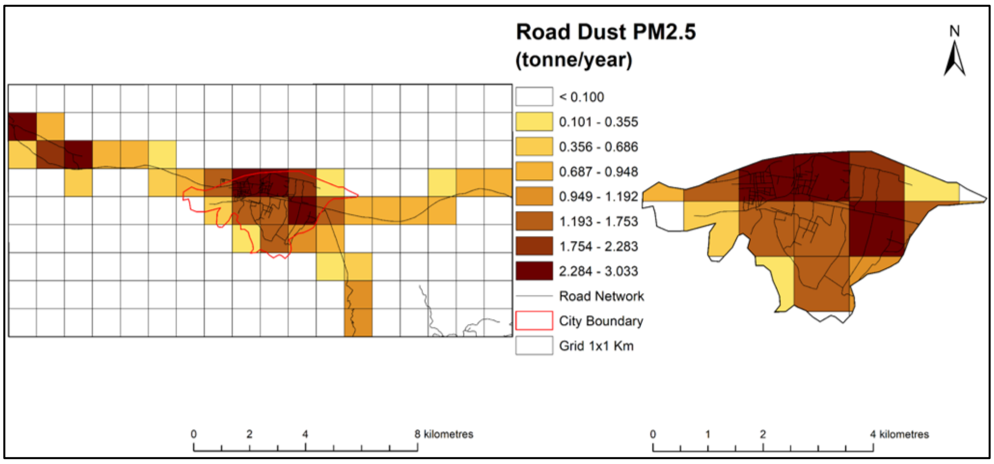

Figure 18: Spatial distribution of $PM_{2.5}$ emissions from road dust in Sahibganj

Industrial emissions:

In terms of industrial pollution, Sahibganj's airshed has both stack and fugitive emission sources. The town's vicinity is endowed with many stone mining and stone-based industries, such as stone crushers, which are responsible for a significant amount of fugitive emissions. The major pollutant from fugitive emissions was particulate matter, particularly PM_{10} and $PM_{2.5}$.

Stone mines and stone crushers were scattered in the eastern, western, and south-eastern parts of the Sahibganj airshed. Overall, 30 stone mines were identified in the airshed, with an area of 826 acres and production of 2.4 million tonnes/year. The EEA Tier 1 method was used to quantify the emissions from stone mining and stone crushers. The PM_{10} and $PM_{2.5}$ emissions (Figure 19) from stone mining in the airshed were estimated to be 120.4 and 12 tonnes/year, respectively.

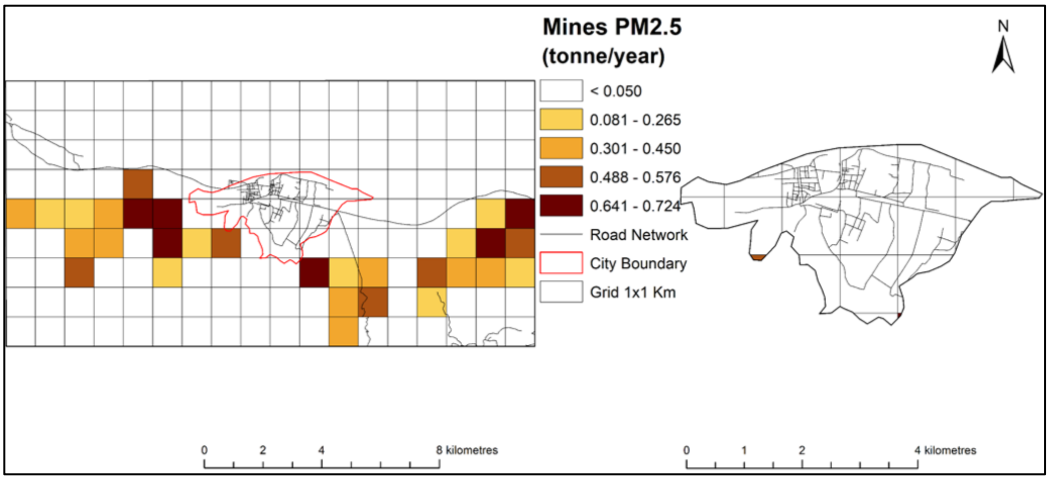

Figure 19: Spatial distribution of $PM_{2.5}$ emissions from mining in Sahibganj

Further, 102 stone crushers were identified in the airshed and were located in the airshed other than the town area. The total production of stone crushers in the Sahibganj airshed was around 2 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions (Figure 20) from stone crushers in the airshed were estimated to be 2.4 and 1.2 tonnes/year, respectively.

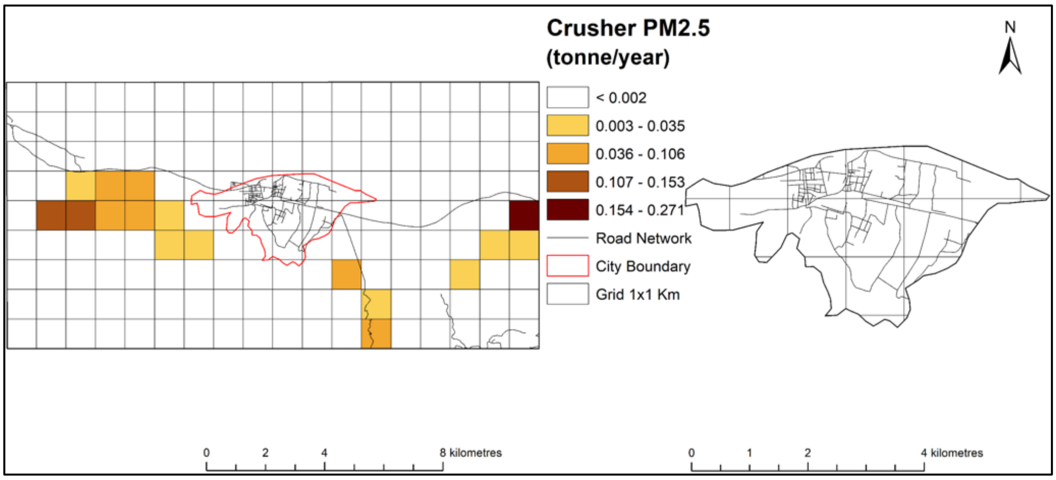

Figure 20: Spatial distribution of $PM_{2.5}$ emissions from stone crushers in Sahibganj

Brick kilns were mostly located in the eastern region of the airshed. Emissions from brick kilns were uncontrolled and estimated based on the production of the units. The total production of brick kilns in the airshed was estimated to be around 0.05 million tonnes/year. Total thermal energy produced by coal and wood consumed by the brick kilns was estimated to be 23 TJ/year. The emission from brick kilns was estimated to be 43 tonnes/year for PM_{10}, 9 tonnes/year for $PM_{2.5}$, and 33 tonnes/year for SO_2. The spatial distribution of emissions is shown in Figure 21.

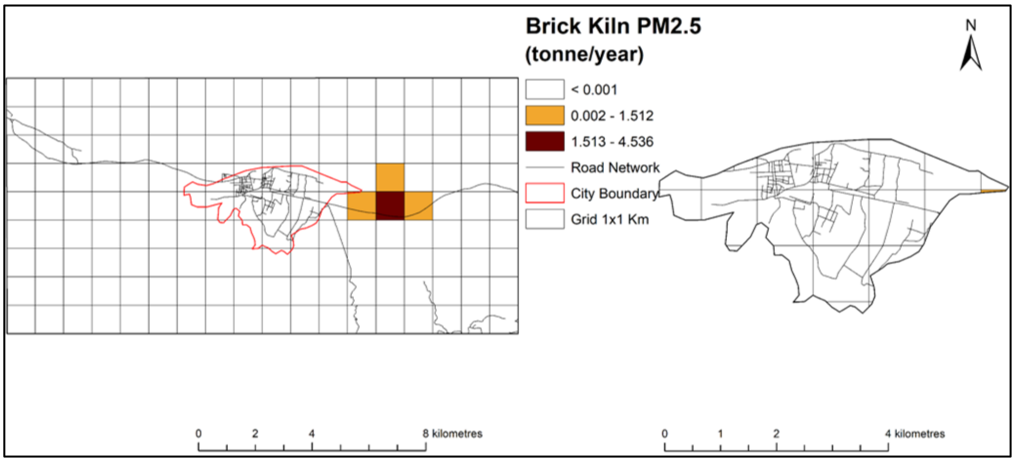

Figure 21: Spatial distribution of $PM_{2.5}$ emissions from brick kilns in Sahibganj

Open burning:

The emission estimation from waste burning was uncertain due to the sparsity of data. In India, around 5%–12% of collected waste is burned. The amount of waste burned is estimated based on the quantity of waste generated, collection efficiency, and quantity of waste processed. The per capita generation of waste in Sahibganj was 290 g/day, and the total waste generated in the town was 26 TPD. It was estimated that around 937 tonnes of solid wastes generated are being burned every year in the airshed.

Emissions from space heating were calculated based on the proportion of households using different solid fuels for heating. Nearly 88% of households used wood as the primary fuel, followed by coal (12%), for space heating during winter in Sahibganj (Census, 2011). Consumption data (wood = 1 kg/household/day; coal = 1 kg/household/day) were obtained from the field survey. The 4-month winter period was considered for the estimation. Total consumption of biomass and coal in the airshed was estimated to be 6220 and 493 tonnes/year, respectively.

The total emission from open burning was 58 tonnes/year for PM_{10}, 46.3 tonnes/year for $PM_{2.5}$, 9.4 tonnes/year for NO_X, and 3.8 tonnes/year for SO_2. The emissions were distributed in the airshed based on the population density. The highest emissions were observed from areas such as Rasulpur Dahla, Naya Tola Sakrogarh, Hatai Parisar, and Jharna colony (Figure 22). About 40% of the open burning emissions were contributed by the burning activities occurring within the town.

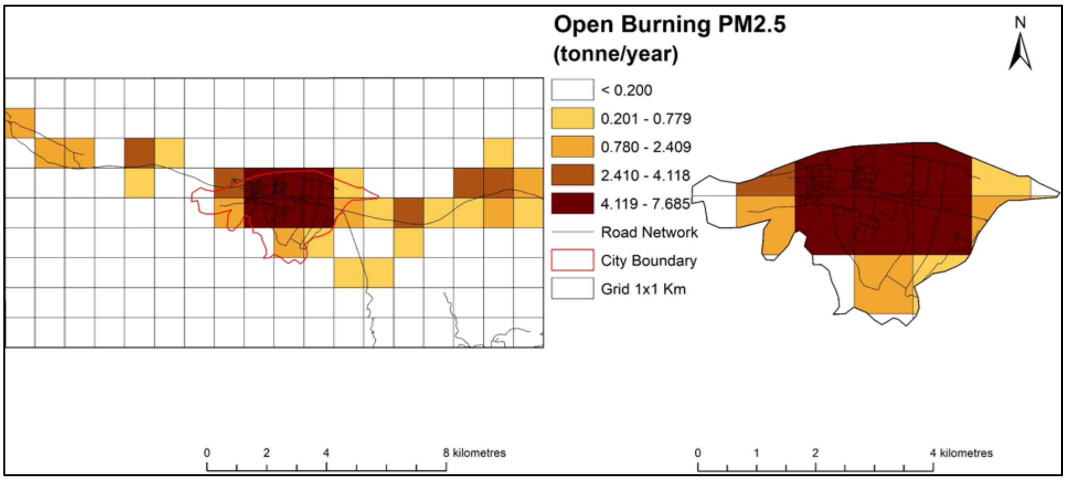

Figure 22: Spatial distribution of $PM_{2.5}$ emissions from open burning in Sahibganj

Construction and demolition:

These emissions were estimated based on the rise in built-up areas in a time frame and the duration of that construction activity. During 2019–2020, we detected a rise of around 2.3 and 4.9 acres in the built-up area in the town and airshed, respectively. The emission from construction sites was estimated to be 6.1 tonnes/year for PM_{10} and 1.1 tonnes/year for $PM_{2.5}$. The emissions were distributed in the airshed based on satellite imagery. The construction activities were scattered across the airshed, with a majority of the sites lying in the town vicinity, and the scale of construction activities was mostly residential (Figure 23). The construction activities within the town accounted for 69% of the total PM emissions from construction.

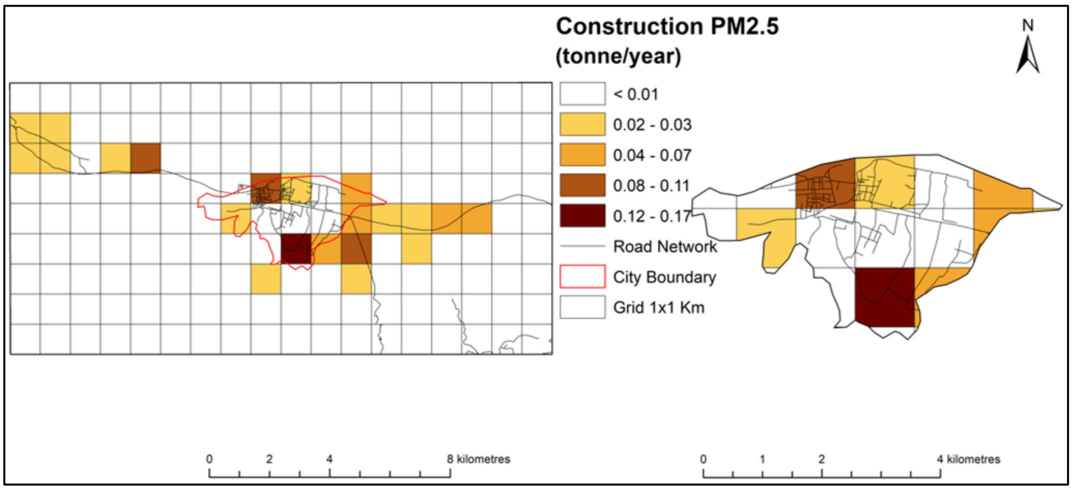

Figure 23: Spatial distribution of $PM_{2.5}$ emissions from construction in Sahibganj

Total emission load:

For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 607, 286, 44, and 684 tonnes/year, respectively, whereas those in the town area were 158, 81, 3, and 336 tonnes/year, respectively. The sectoral contribution of $PM_{2.5}$ emissions in Sahibganj town and its airshed is shown in Figure 24.

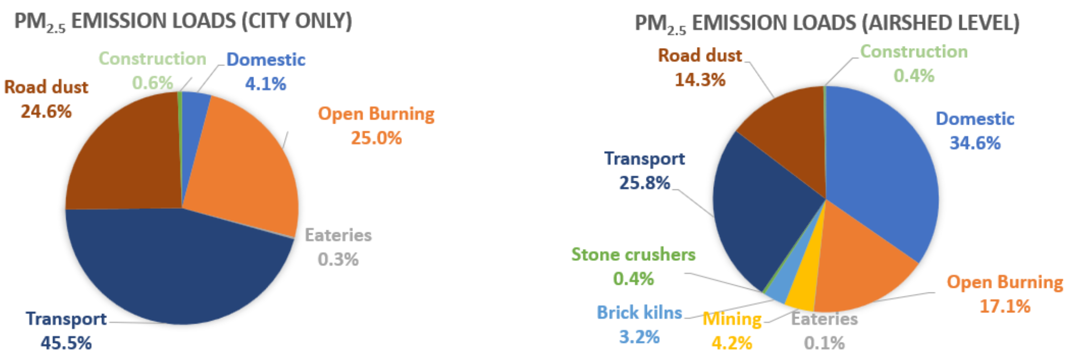

Figure 24: Sectoral contribution of $PM_{2.5}$ emissions at the a) city level and b) airshed level

Total $PM_{2.5}$ emissions over the airshed indicated the domestic sector as the major contributor, followed by open burning, transportation, and road dust, whereas within the town, open burning was the major contributor, followed by transportation, road dust, and the domestic sector. Contributions from eateries, mining, construction, brick kilns, and stone crushers were relatively less. Domestic sector, brick kilns, and transport were the major sources of PM_{10}, SO_2, and NO_x emissions, respectively, over the airshed.

The high emitting grids in the airshed other than the city area included Bhawanichauki (sources: domestic ~ 50%, transport ~ 27%, road dust ~ 15%, and open burning ~ 7.5%), Samda Nala (sources: domestic ~ 85% and open burning ~ 13%), Rampur (sources: domestic ~ 78%, open burning ~ 11%, and transport ~ 5%), and Chhota Pagaro (sources: domestic ~ 71%, brick kilns ~ 12%, and open burning ~ 11%). The spatial distribution of $PM_{2.5}$ emissions is presented in Figure 25. The spatial distribution of PM_{10}, SO_2, and NO_x emissions is provided in the Annexure (Figure A1–Figure A22).

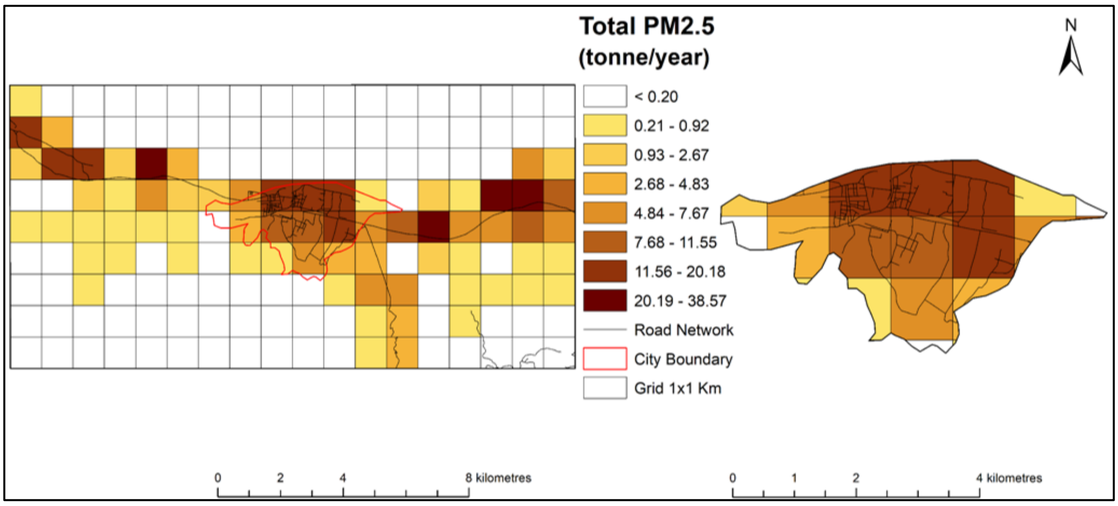

Figure 25: Spatial distribution of $PM_{2.5}$ emissions in Sahibganj

4.2.2. Dumka

Sectoral emission estimation:

Domestic:

The domestic survey was conducted in selected slums inward Gandhi Nagar ward-5, Gandhi Nagar ward-11, Panchayat Zila, and Rasikpur in Dumka town. The survey revealed that 15% of slum households used coal, 55% used biomass, 22% used mixed fuel (coal and wood), and 8% used LPG for cooking. The average frequency of cooking in the slums was twice a day. The average fuel consumption for cooking in a slum household is presented in Table 19. The average consumption of energy for cooking in a slum household in Dumka town was found to be 22 GJ.

Table 19: Average fuel consumption for cooking in a slum household in Dumka town

Type of fuel	Share (%)	Average fuel consumption (PPAC, 2016)		
		L (cylinder/month)	W (kg/month)	C (kg/month)
LPG (L)	7	1		
Wood (W)	55		150	
Coal (C)	14			90
Mixed fuel (C+W)	22		90	60

The total consumption of coal, wood, and LPG in Dumka town was estimated to be 630, 2507, and 1331 tonnes/year, respectively. For the airshed other than the town area, the consumption of domestic fuels was determined based on PPAC (2016) and NFHS (2019) as well as Census (2011) district statistics, considering the airshed other than the town area possessed nearly the same socioeconomic level as that of the district. The total consumption of LPG, biomass, coal, dung cake, and kerosene in the airshed was estimated to be 114, 8122, 601, 228, and 1.3 tonnes/year, respectively. In the city area, PM_{10}, $PM_{2.5}$, NO_X, and SO_2 emissions from the domestic sector were estimated to be 28.4, 22.5, 8.1, and 3.7 tonnes/year, respectively. In the airshed area, PM_{10}, $PM_{2.5}$, NO_X, and SO_2 emissions from the domestic sector were estimated to be 79, 63.4, 12.8, and 4.8 tonnes/year, respectively. The total emission (from the airshed area) was spatially distributed over the airshed based on the population density. Of note, emissions from the domestic sector were more concentrated in the outskirts of the city. The main reason for the higher emissions was the high population density coupled with a large number of households using solid fuel for cooking (81%). Accessibility of biomass from dense forest areas in the vicinity, availability of coal at a lower price, inaccessibility of LPG, and low economic status prevent people from using clean fuel. In the town area, domestic emissions contributed only about 35% of the total emissions for all pollutants, which were mainly emitted from slum areas (with prevalent coal and wood use). High polluting grids associated with domestic emissions included Dudhani, Mahuadhangal, Bagnocha, Naya Para, and Professor's Colony (Figure 26).

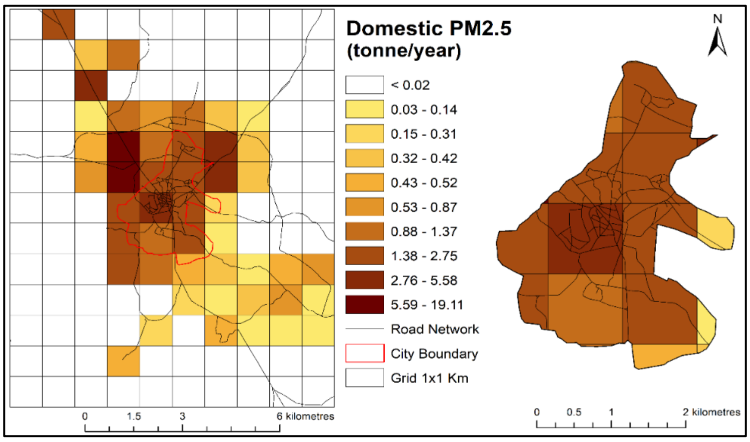

Figure 26: Spatial distribution of $PM_{2.5}$ emissions from the domestic sector in Dumka

Commercial cooking:

The field survey was performed at selected restaurants located in different parts of the town. We found that fuel use in restaurants varied by size and daily customer footfall. We divided the surveyed restaurants into two categories (small and medium restaurants) (Figure 27). The percentage of restaurants using solid and clean fuels and their average fuel consumption are presented in Table 20. Both small and medium restaurants predominantly used LPG as the main fuel along with wood and coal as the concurrent fuel. Easy accessibility of wood and coal in the vicinity of the town at a lower cost drives restaurants to use solid fuels beside LPG. The fuel source location (for wood and coal) for small and medium restaurants lied between 0.1 and 3 km. The average specific energy consumed in a year in small restaurants using mixed fuel (308 GJ) was 1.4 times higher than that consumed in medium restaurants (212 GJ).

The survey also revealed that 95% of the small restaurants used invertors during power cuts, whereas medium restaurants predominantly used diesel generators (97% of the surveyed restaurants) with an average diesel consumption of 23 L/month.

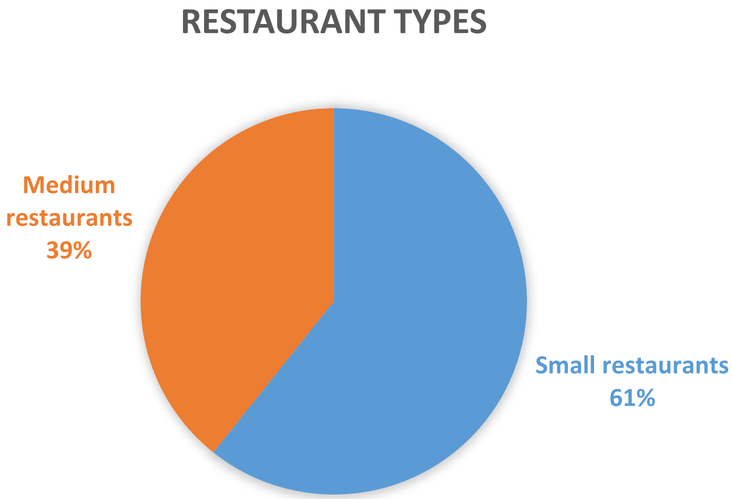

Figure 27: Share of restaurant types in Dumka

Table 20: Fuel consumption share among restaurants in Dumka

	Percentage (%)	Fuel consumption			Annual specific energy consumption (GJ)
		Wood (kg/month)	Coal (kg/month)	LPG (19 kg cylinder/month)	
	Small restaurants (footfall < 100)				
Restaurants using mixed fuel (wood, coal, and LPG)	35	225	975	5	308
Restaurants using LPG	65			7	71.8
	Medium restaurants (footfall = 100–500)				
Restaurants using LPG	100			8	212

Data on the number of restaurants and their locations were obtained using Google API and then geo-located on the grids. About 107 restaurants were identified in the airshed. The total consumption of LPG, wood, and coal in eateries in Dumka town was estimated to be 120, 110, and 462 tonnes/year, respectively. PM_{10}, $PM_{2.5}$, NO_X, and SO_2 emissions from eateries were estimated to be 5.7, 4.5, 2.5, and 1.18 tonnes/year, respectively.

The spatial distribution of emissions from eateries was based on the number and type of eateries in each grid. Notably, emissions from the eateries sector were more concentrated within the town area. Emissions from eateries were higher in the areas with more commercial activities, such as Mahuadangal, Bagnocha, and Naya Para (Figure 28). The high consumption of coal and wood in eateries contributed up to 98% of the total pollutant emissions. Overall, small restaurants (footfall < 100) using solid fuels emitted 1.6 times higher emissions than medium restaurants.

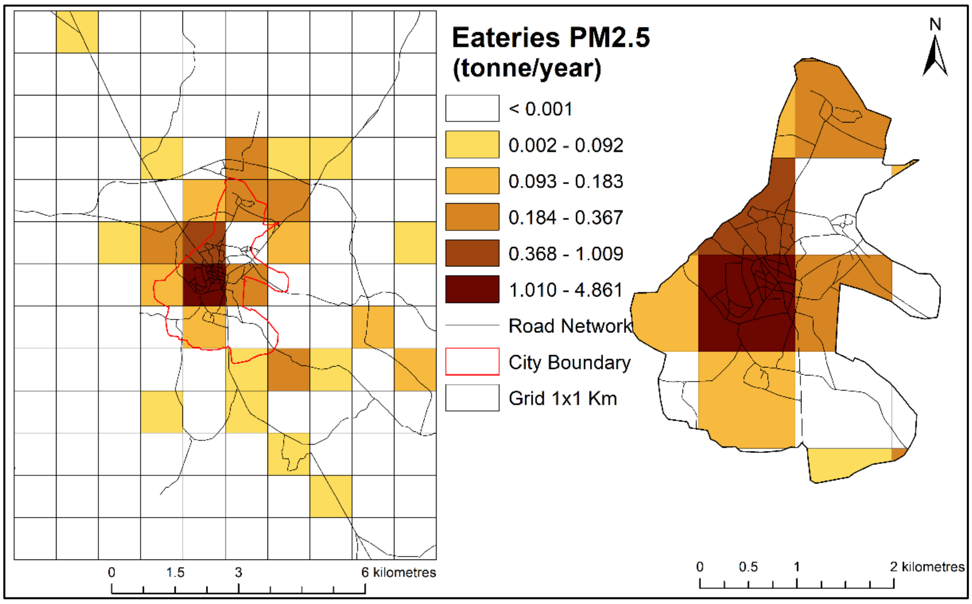

Figure 28: Spatial distribution of $PM_{2.5}$ emissions from eateries in Dumka

Transport emissions:

The transportation survey was performed at petrol bunks to determine the vintage and VKT of vehicles. In total, 638 vehicles were surveyed at four petrol bunks. From this survey, we determined the share of age of vehicles plying in Dumka and the share of four-wheelers and three-wheelers based on fuel type (petrol or diesel). Figure 29 and Figure 30 present the vintage and VKT of the vehicles plying in Dumka, respectively. The survey results revealed that 63% of the vehicles plying in Dumka were aged less than 5 years, 23% were aged between 5 and 10 years, and 14% were aged more than 10 years. The survey did not capture HCVs, as HCVs were restricted inside the city during the daytime (survey was conducted during the day).

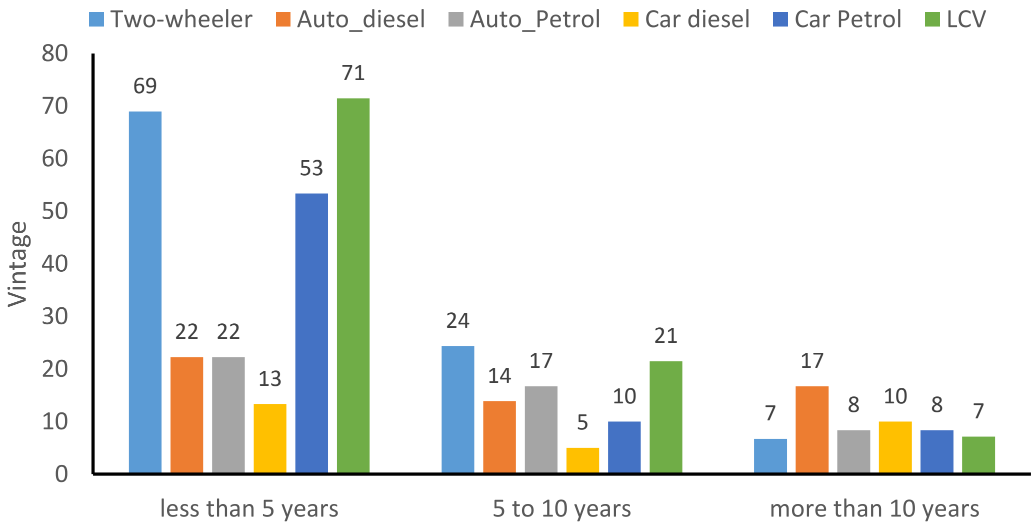

Figure 29: Vintage of vehicles plying in Dumka

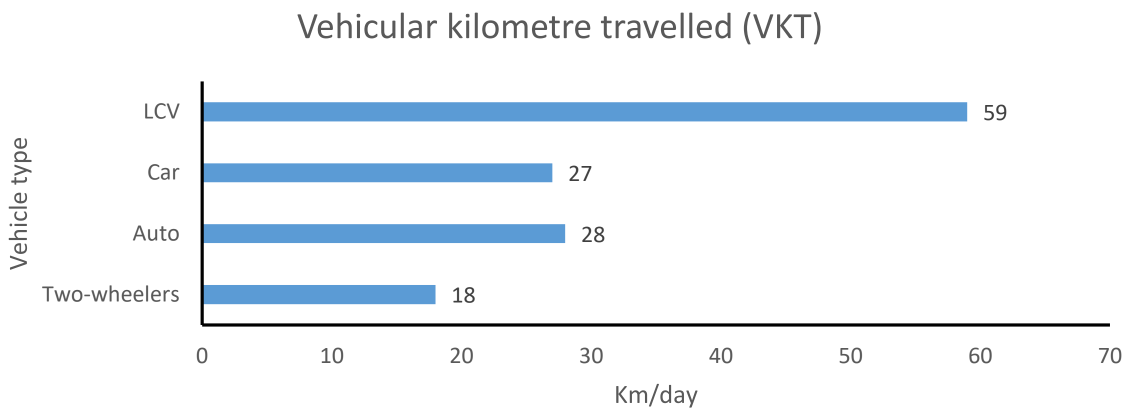

Figure 30: VKT of vehicles plying in Dumka

Tailpipe emissions: Like other cities, increase in population and economic activities led to an increase in vehicular population in Dumka, with an average annual vehicular growth rate of 23%. The year-wise cumulative vehicle registration in Dumka is shown in Figure 31.

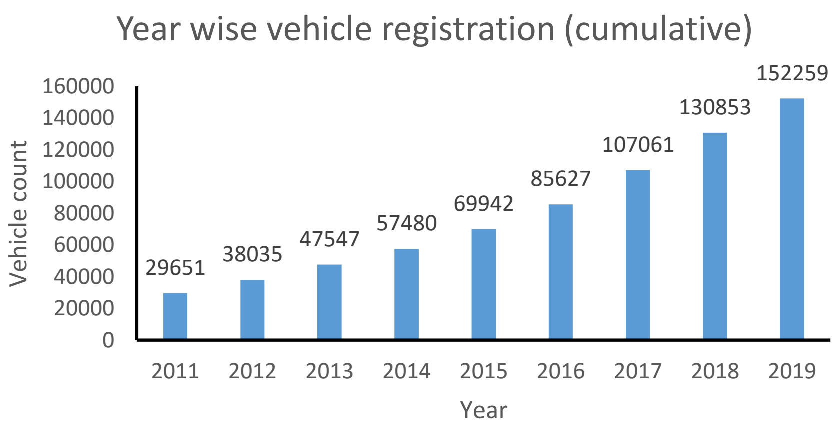

Figure 31: Year-wise vehicle registration in Dumka

Tailpipe emissions were estimated based on the VKT data obtained from the transportation survey and vehicle statistics obtained from the transport department and VAHAN database. The share of vehicles plying on road in Dumka is shown in Figure 32.

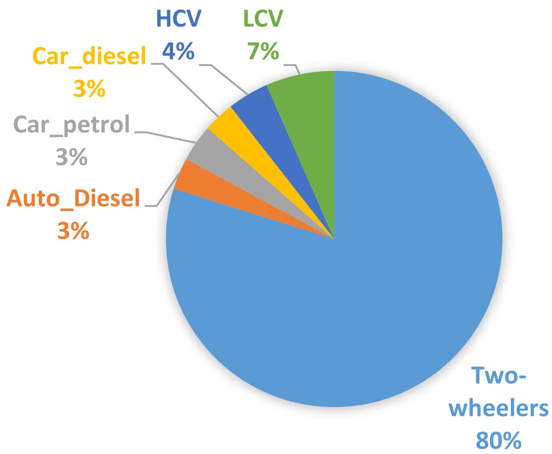

Figure 32: Share of vehicles plying in Dumka

Tailpipe emissions were estimated to be 142 tonnes/year for PM_{10}, 103 tonnes/year for $PM_{2.5}$, and 1155 tonnes/year for NOx. HCVs and LCVs contributed around 62% and 30% of the PM emissions, respectively, of which 86% of HCV emissions and 32% of LCV emissions were attributed to vehicles aged >10 years. HCVs (including buses) constituted only 4% of the total number of vehicles plying in Dumka but contributed 62% of the PM emission load from transportation. Two-wheelers and diesel autos contributed about 4.8% and 2.2% of the PM emissions, respectively, whereas diesel cars and petrol cars contributed about 1.1% and 0.1%, respectively. Overall, 21% of PM emissions from two-wheelers were emitted from vehicles aged >10 years. $PM_{2.5}$ emissions from different vehicle types are shown in Figure 33.

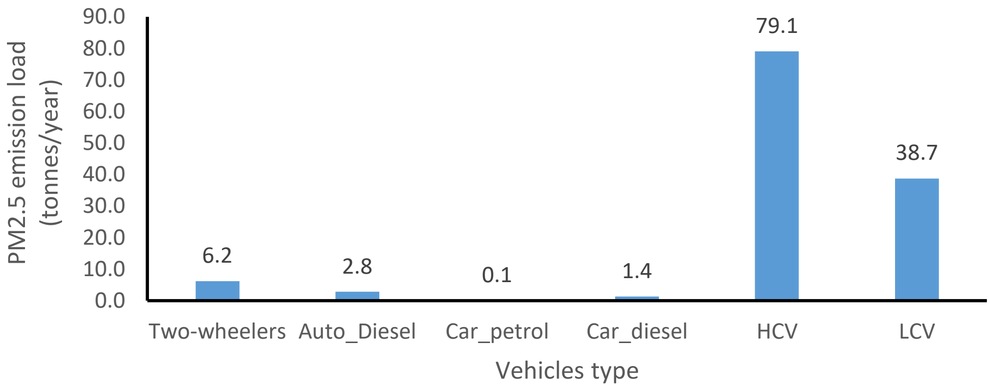

Figure 33: Contribution of different vehicle types to the $PM_{2.5}$ emission load

Transport emissions were distributed based on the population density and fraction of road networks. The total length of national highways, state highways, and major roads in the airshed was identified to be 15, 8.4, and 28 km, respectively. Vehicular emissions were found to be high on main and arterial roads in the town because of the high heterogeneous traffic volume. The emission on these roads was contributed by the movement of mixed traffic (including HCVs). Emission from these roads attributed to only 29% of the transport PM emission load. The major share of the transport PM emissions was contributed by state and national highways, mainly emitted from HCVs and LCVs. National Highway 144A and State Highway 18 contributed 43% and 12% of the transport PM emissions, respectively (Figure 34).

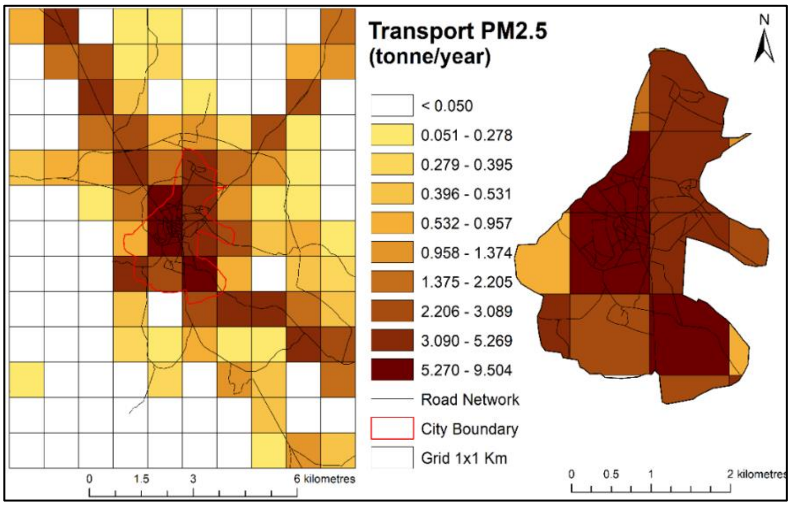

Figure 34: Spatial distribution of $PM_{2.5}$ emissions from the transport sector in Dumka

Resuspension of dust:

In addition to tailpipe emissions, vehicular movement and bad road infrastructure are responsible for the resuspension of dust. For the estimation of road dust, road type data were also considered in addition to road network data. The EF for road dust varies with the road type (paved or unpaved), vehicle share, and climatic conditions. The emission from resuspension of dust was estimated to be 269 tonnes/year for PM_{10} and 64 tonnes/year for $PM_{2.5}$. Overall, 29% of the PM emissions from road dust were contributed by arterial and main roads in the city, and the major share of the road dust PM emissions was contributed by roads located outside the city (Figure 35).

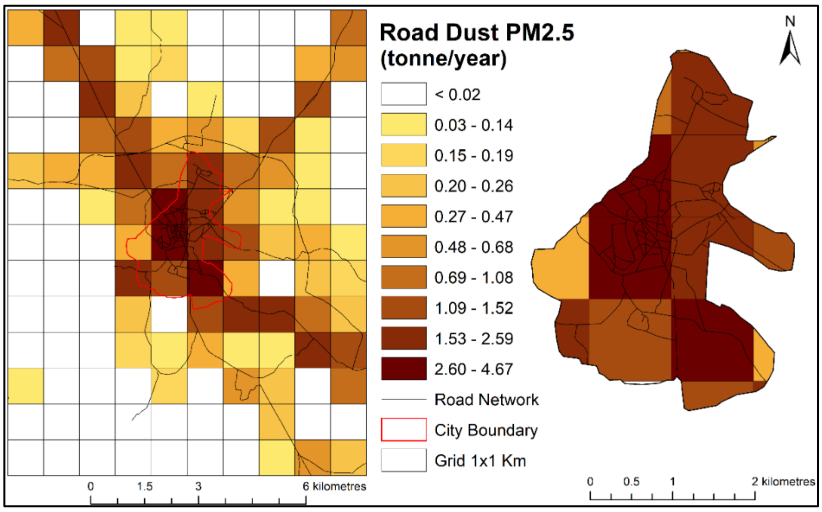

Figure 35: Spatial distribution of $PM_{2.5}$ emissions from road dust in Dumka

Open burning:

The per capita generation of waste in Dumka was 519 g/day, and the total waste generated in the town was 26 TPD. It was estimated that around 954 tonnes of solid wastes generated are being burned every year in the airshed.

Emissions from space heating were calculated based on the proportion of households using different solid fuels for heating. Nearly 97% of the households in Dumka used wood as the primary fuel for space heating during winter, followed by coal (3%; Census, 2011). Consumption data (wood = 1 kg/household/day; coal = 1 kg/household/day) were obtained from the field survey. The 4-month winter period was considered for the estimation. Total consumption of biomass and coal in the airshed was estimated to be 3,569 and 42 tonnes/year, respectively.

The total emission from open burning was calculated to be 33 tonnes/year for PM_{10}, 27 tonnes/year for $PM_{2.5}$, 5.8 tonnes/year for NO_X, and 1 tonnes/year for SO_2. The emissions were distributed in the airshed based on the population density. The high emitting grids included Bagnocha, Naya Para, and Professor's Colony (Figure 36). About 81% of the open burning emissions were contributed by the burning activities occurring within the town. Regular door-to-door collection of waste and proper auditing of the waste collection mechanism will reduce garbage burning to a large extent.

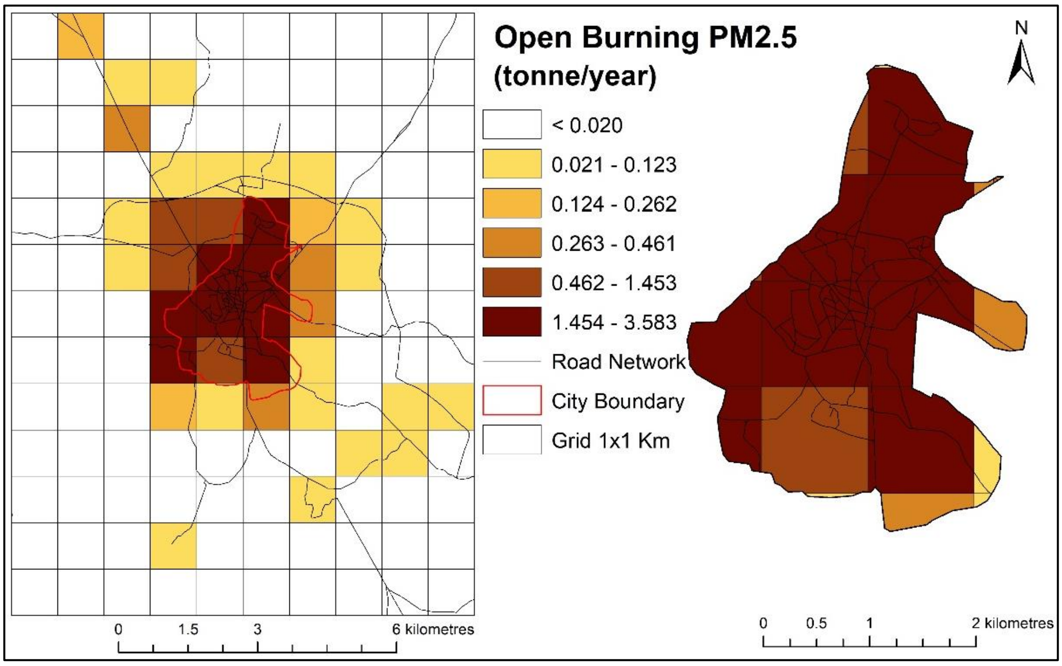

Figure 36: Spatial distribution of $PM_{2.5}$ emissions from open burning in Dumka

Construction and demolition:

These emissions were estimated based on the rise in built-up areas in a time frame and duration of that construction activity. During 2019–2020, we identified around 1.2 and 3.75 acres rise in the built-up area in the town and airshed, respectively. The emission from the construction sites was estimated to be 4.7 tonnes/year for PM_{10} and 0.8 tonnes/year for $PM_{2.5}$. The emissions were distributed in the airshed based on satellite imagery. The construction activities were majorly concentrated within the town and its vicinity, and the scale of construction activities was mainly residential (Figure 37). The construction activities within the town accounted only for 30% of the total PM emissions from construction.

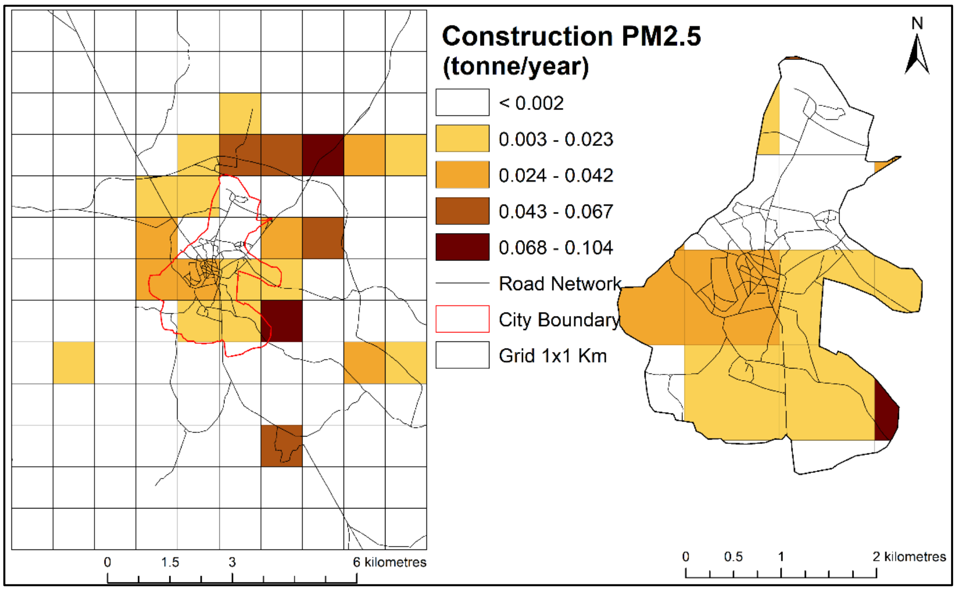

Figure 37: Spatial distribution of $PM_{2.5}$ emissions from construction in Dumka

Total emission load:

For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 519, 281, 11, and 1178 tonnes/year, respectively, whereas those in the city area were 241, 137, 8, and 499 tonnes/year, respectively**.** The sectoral contribution of $PM_{2.5}$ emissions in Dumka town and its airshed is shown in Figure 38. Within the city, the total $PM_{2.5}$ emissions indicated that transport was the major contributor, followed by road dust, open burning, domestic, and eateries. However, over the airshed, transport was the major contributor, followed by road dust, domestic, open burning, and eateries. Contributions from construction were minor within the city as well as over the airshed. The domestic sector was a major source of SO_2 emissions, whereas transport was a major source of PM_{10} and NOx emissions. The high emitting grids within the city (Bagnocha, Naya Para, LIC colony, and Police Line) were mainly attributed to sources such as transport, road dust, domestic, eatery, and open burning, whereas those outside the city (Dudhani, Mahuadangal, Sarsabad, and Haripur) were mainly attributed to transport, road dust, and domestic sector. The spatial distribution of $PM_{2.5}$ emissions is presented in Figure 39. The spatial distribution of PM_{10}, NO_X, and SO_2 emissions is provided in the Annexure (Figure A23–Figure A39).

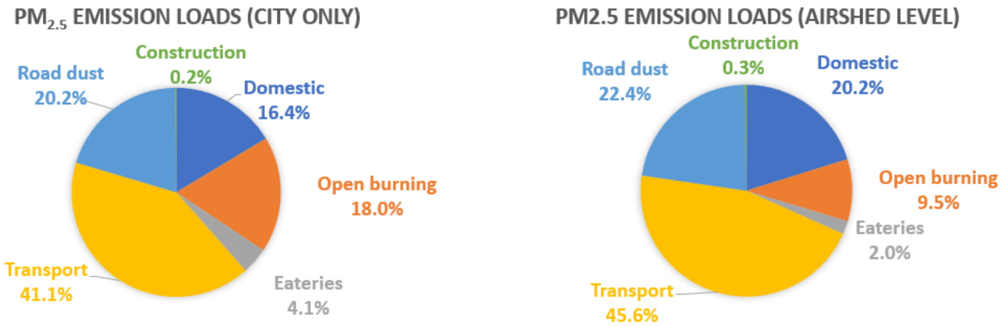

Figure 38: Sectoral contribution of $PM_{2.5}$ emissions at the a) city level and b) airshed level in Dumka

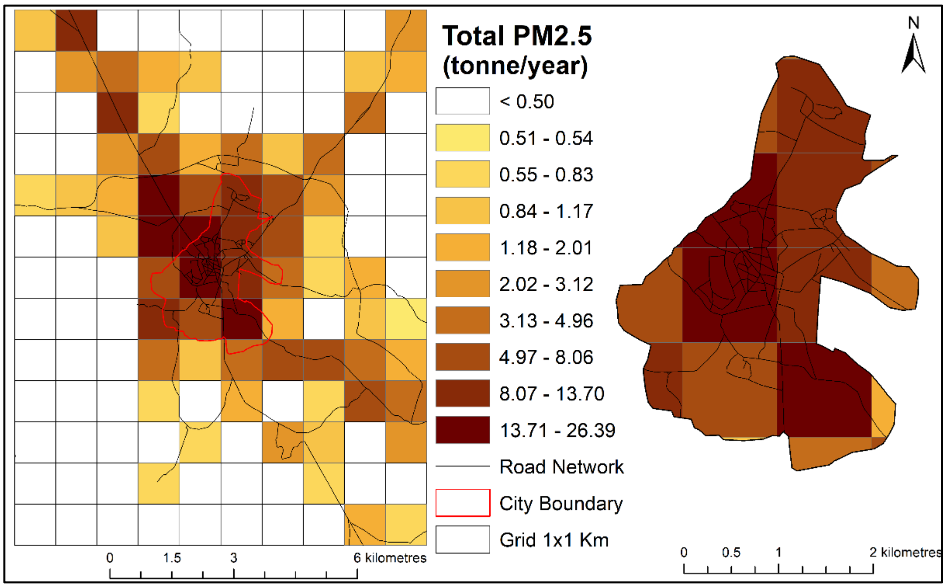

Figure 39: Spatial distribution of total $PM_{2.5}$ emissions in Dumka

4.2.3. Pakur

Sectoral emission estimation

Domestic sector:

The domestic survey was conducted in selected slums inward Kadan Pada, Laddu Aam Bagan, and Raja Para in Pakur town. The survey revealed that 69% of slum households used coal and LPG as the mixed fuel, 16% used coal, and 15% used kerosene and LPG as the mixed fuel. The average frequency of cooking in slums was twice a day. The average fuel consumption for cooking in a slum household is presented in Table 21.

Although about 83% of slum households had LPG connections, these households used coal and kerosene along with LPG for cooking. The average consumption of energy for cooking in a slum household in Pakur town was 25 GJ.

Table 21: Average fuel consumption for cooking in a slum household in Pakur town

Type of fuel used	Percentage (%)	Fuel consumption		
		Coal (C) (kg/month)	Kerosene (K) (l/month)	LPG (L) (cylinders/month)
Mixed fuel (C+L)	69	50		1
Coal	16	55		
Mixed fuel (K+L)	15		2	1

The total consumption of coal, LPG, and kerosene in Pakur town was estimated to be 1401, 832, and 8 tonnes/year, respectively. For the airshed other than the town area, the consumption of domestic fuels was determined based on the PPAC (2016) and NFHS (2019) as well as Census (2011) district statistics, considering the airshed other than the town area possessed nearly the same socioeconomic level as that of the district. The total consumption of LPG, biomass, coal, dung cake, and kerosene in the airshed was estimated to be 1235, 2897, 10,690, 1,862, and 10 tonnes/year, respectively.

For the town area, emissions from the domestic sector were estimated to be 15.3 tonnes/year for PM_{10}, 11.8 tonnes/year for $PM_{2.5}$, 7.1 tonnes/year for NO_X, and 7.3 tonnes/year for SO_2. For the airshed area, emissions from the domestic sector were estimated to be 164 tonnes/year for PM_{10}, 133 tonnes/year for $PM_{2.5}$, 23.3 tonnes/year for NOx, and 56.4 tonnes/year for SO_2. The total emissions (from the airshed area) were spatially distributed over the airshed based on the population density. Of note, emissions from the domestic sector were more concentrated in the outskirts of the town. The high emitting grids (Nimtita, Jaladipur, Bhasaipaikar, Kismat Kadamsai, Sitapahari, and Mahadeb Nagar) were scattered across the airshed (Figure 40).

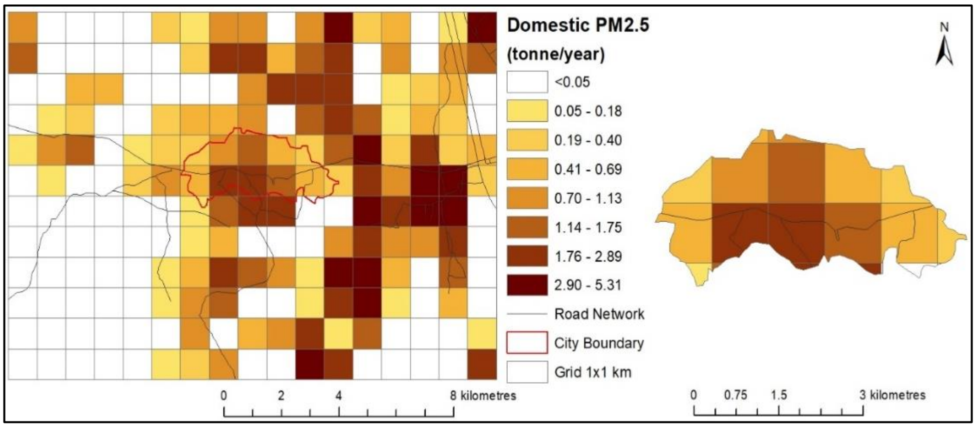

Figure 40: Spatial distribution of $PM_{2.5}$ emissions from the domestic sector in Pakur

The main reason for the higher emissions was the high population density coupled with a large number of households using solid fuel for cooking (82%). Accessibility of biomass from dense forest areas in the vicinity, availability of coal at a lower price, and low economic status prevent people from using clean fuel. In the town, domestic emissions contributed only about 9% of the total emissions for all pollutants, which were mainly emitted from slum areas (with prevalent coal and kerosene use). Although the LPG penetration rate was very high, accessibility of solid fuels at a lower cost drove the public to use solid fuels along with LPG.

Commercial cooking:

The field survey was performed at selected restaurants located in different parts of the town. We found that fuel use in restaurants varied by size and daily customer footfall. We divided the surveyed restaurants into two categories (small and medium restaurants; Figure 41). The percentage of restaurants using solid and clean fuels and their average fuel consumption are presented in Table 22. Both small and medium restaurants predominantly used LPG as the main fuel along with coal as the concurrent fuel. Easy accessibility of coal in the vicinity of the town at a lower cost drove the restaurants to use coal along with LPG. We also found that some speciality restaurants used coal for preparing barbeque and tandoori food items. The average specific energy consumed in a year in small restaurants using mixed fuel (318 GJ) was 1.04 times higher than that in medium restaurants (270 GJ).

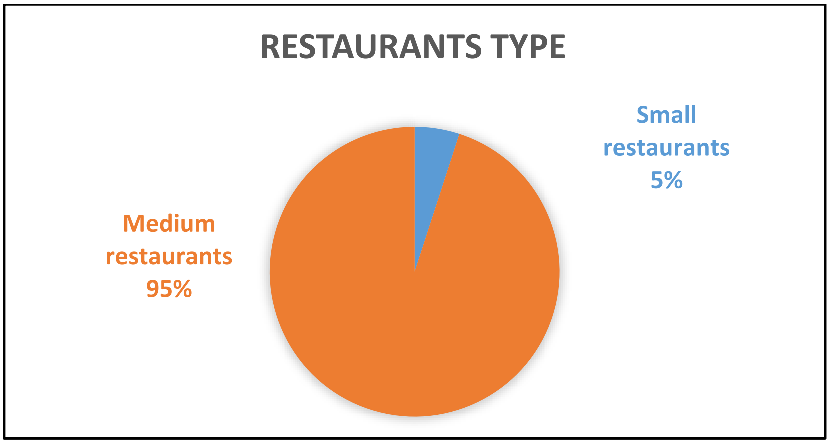

Figure 41: Share of restaurant types in Pakur

We also found that 65% of the surveyed restaurants used invertors during power cuts and 35% of the restaurants used diesel generators with an average diesel consumption of 24 L/month.

Table 22: Percentage of restaurants using solid and clean fuel and their average fuel consumption

Fuel used in restaurants	Percentage (%)	Fuel consumption		Annual specific energy consumption (GJ)
		Coal (C) (kg/month)	LPG (L) 19 kg cylinder/month)	
Small restaurants (footfall < 100)				
Mixed fuel (C+L)	100	32	3	318
Medium restaurants (footfall = 100–500)				
L	19		6	62
Mixed fuel (C+L)	81	30	4	310

Data on the number of restaurants and their locations were obtained using Google API and then geo-located on the grids. About 47 restaurants were identified in the airshed. The total consumption of LPG and coal in eateries in Pakur town was estimated to be 58 and 88 tonnes/year, respectively. The emission from eateries was estimated to be 1 tonnes/year for PM_{10}, 0.7 tonnes/year for $PM_{2.5}$, 0.3 tonnes/year for NO_X, and 0.5 tonnes/year for SO_2.

The spatial distribution of emissions from restaurants was based on the number and type of eateries in each grid. It was evident that emissions from the eateries sector were more concentrated within the town. Emissions from eateries were higher in the areas with more commercial activities and major roads such as Tulshi Nagar, Harindanga Bazar, Gobindpur, and Shivpuri Colony (Figure 42). Restaurants with a high consumption of coal contributed up to 98% of the total pollutant emissions from eateries. Overall, medium restaurants using solid fuels emitted more than double the emissions from small restaurants.

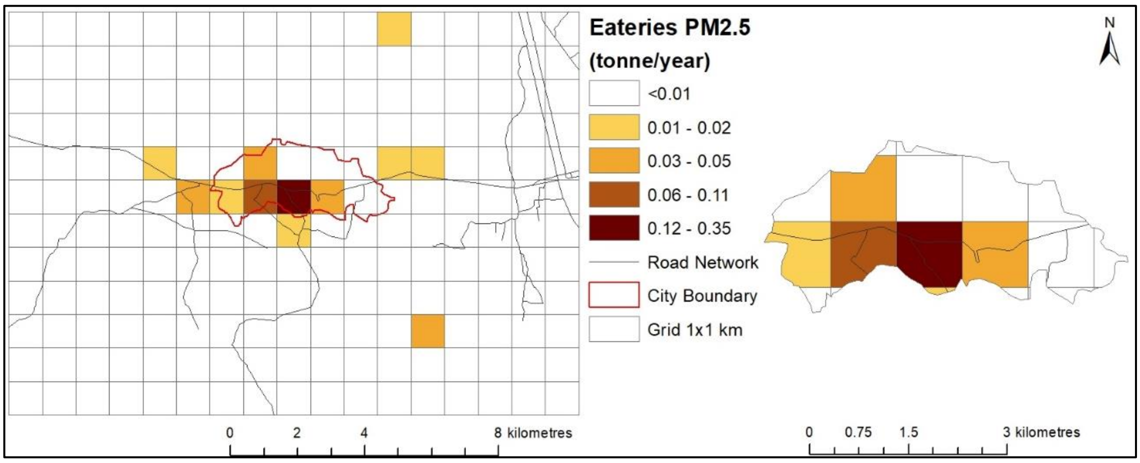

Figure 42: Spatial distribution of $PM_{2.5}$ emissions from eateries in Pakur

Transport emissions:

The transportation survey was performed at petrol bunks to determine the vintage and VKT of vehicles. In total, 715 vehicles were surveyed at five petrol bunks. From this survey, we determined the share of age of vehicles plying in Pakur and share of four-wheelers and three-wheelers on the basis of fuel type (petrol or diesel). Figure 43 and Figure 44 present the vintage and VKT of the vehicles plying in Pakur, respectively. The survey results revealed that 51% of the vehicles plying in Pakur were aged less than 5 years, 30% were aged between 5 and 10 years, and 19% were aged more than 10 years. The survey did not capture HCVs, as HCVs were restricted inside the town during the daytime (survey was conducted during the day).

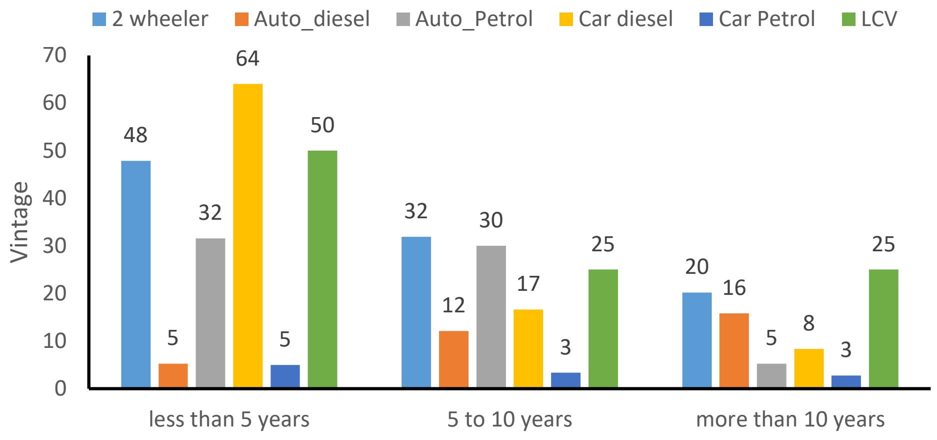

Figure 43: Vintage of vehicles plying in Pakur

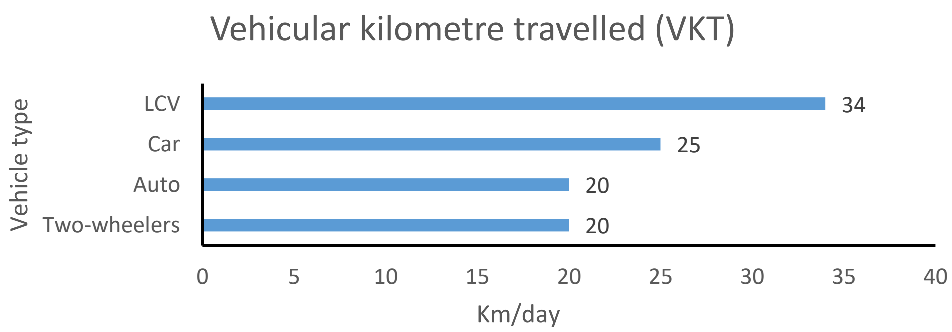

Figure 44: VKT of vehicles plying in Pakur

Tailpipe emissions: In most Indian cities, transportation is one of the biggest contributors to air pollution. Transport growth is largely influenced by demographic growth as well as economic growth. Similar to other cities, increase in population and economic activities led to an increase in vehicular population in the town, with an average annual vehicular growth rate of 27%. The year-wise cumulative vehicle registration in Pakur is shown in Figure 45.

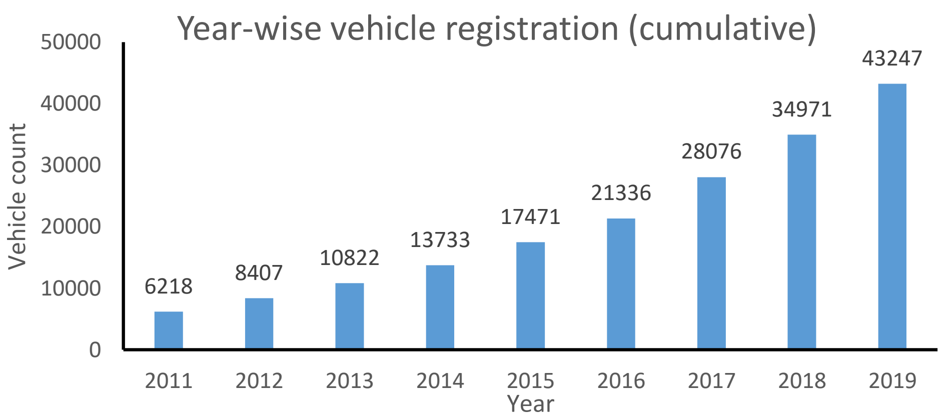

Figure 45: Year-wise vehicle registration in Pakur

Tilepipe emissions were estimated based on the VKT data obtained from the transportation survey and vehicle statistics obtained from the transport department and VAHAN database. For calculating emissions from HCVs, VKT was assumed to be 80 km. The share of vehicles plying on road in Pakur is shown in Figure 46.

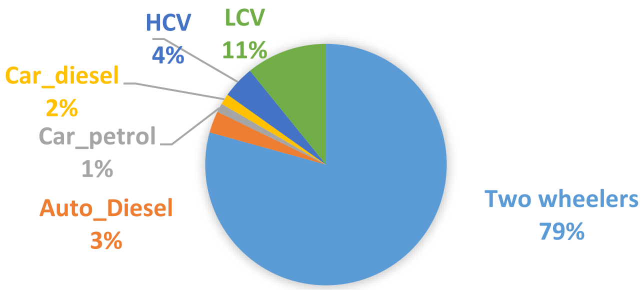

Figure 46: Share of vehicles plying in Pakur

Tailpipe emissions were estimated to be 113 tonnes/year for PM_{10}, 104 tonnes/year for $PM_{2.5}$, and 881 tonnes/year for NO_X. HCVs and LCVs contributed around 49% and 47% of the PM emissions, respectively, of which 77% of HCV emissions and 50% of LCV emissions were emitted from vehicles aged >10 years. HCVs (including buses) and LCVs constituted only 4% and 11% of the total number of vehicles plying in Pakur, respectively, but contributed 49% and 47% of the PM load from transportation. Two-wheelers and diesel autos contributed about 3% and 1.4% of the PM emissions, respectively, whereas diesel cars and petrol cars contributed about 0.4% and 0.1%, respectively. Overall, 34% of the two-wheeler PM emissions were attributed to vehicles aged >10 years. $PM_{2.5}$ emissions from different vehicle types are shown in Figure 47.

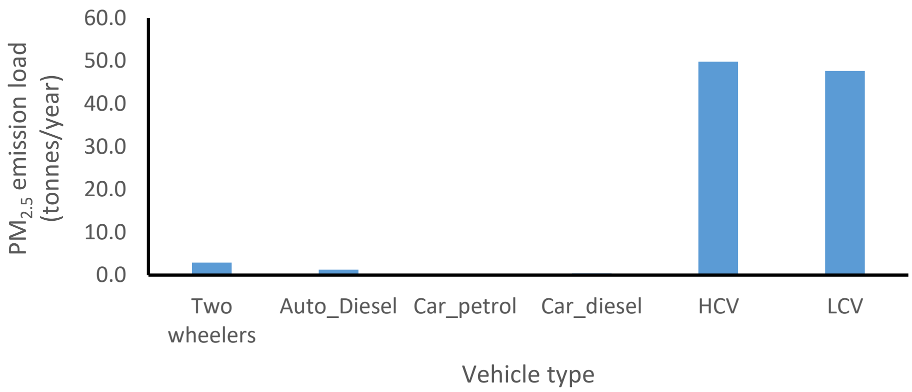

Figure 47: Contribution of tailpipe emissions to the $PM_{2.5}$ emission load in Pakur

Transport emissions were distributed based on the population density and fraction of road networks. The total length of national highways, state highways, and major roads in the airshed was found to be 20, 4.8, and 23 km, respectively. Vehicular emission was high on major and arterial roads in the town because of the high heterogeneous traffic volume. The emission on these roads was contributed by the movement of mixed traffic (including HCVs). Emission from these roads attributed to only 26% of the transport PM share. The major share of the transport PM emissions was contributed by national highways that passed through the town (mainly emitted from HCVs and LCVs) and major roads located outside the town. National Highway 114A contributed 43% and major roads outside the town contributed 27% of the transport PM emissions (Figure 48).

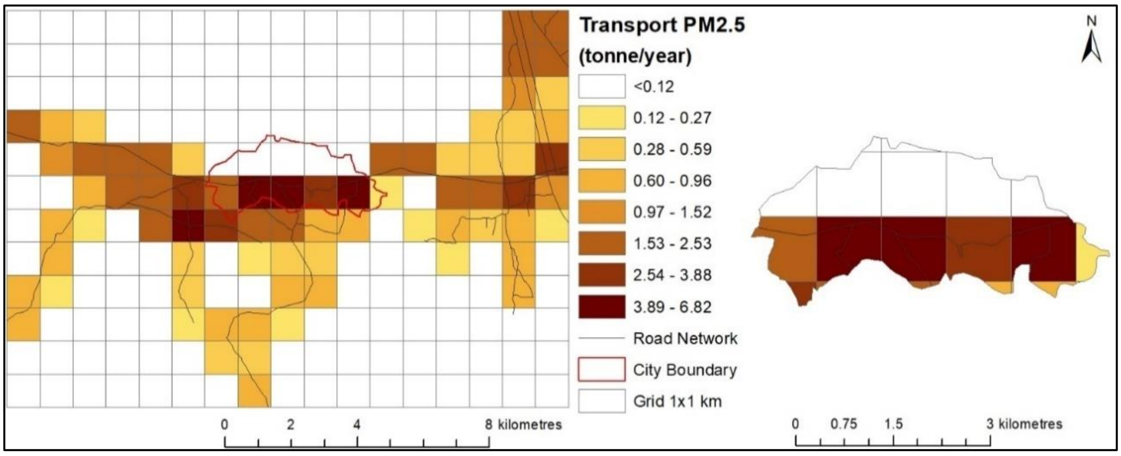

Figure 48: Spatial distribution of $PM_{2.5}$ emissions from the transport sector in Pakur

Resuspension of dust:

In addition to tailpipe emissions, vehicular movement and bad road infrastructure are responsible for the resuspension of dust. For the estimation of road dust, road type data were also considered in addition to road network data. The EF for road dust varies with the road type (paved or unpaved), vehicle share, and climatic conditions. The emission from resuspension of dust was estimated to be 145 tonnes/year for PM_{10} and 36 tonnes/year for $PM_{2.5}$. Around 26% of the PM emissions from road dust was contributed by arterial and major roads in the town, and the major share of the road dust PM emissions was contributed by roads located outside the town (Figure 49).

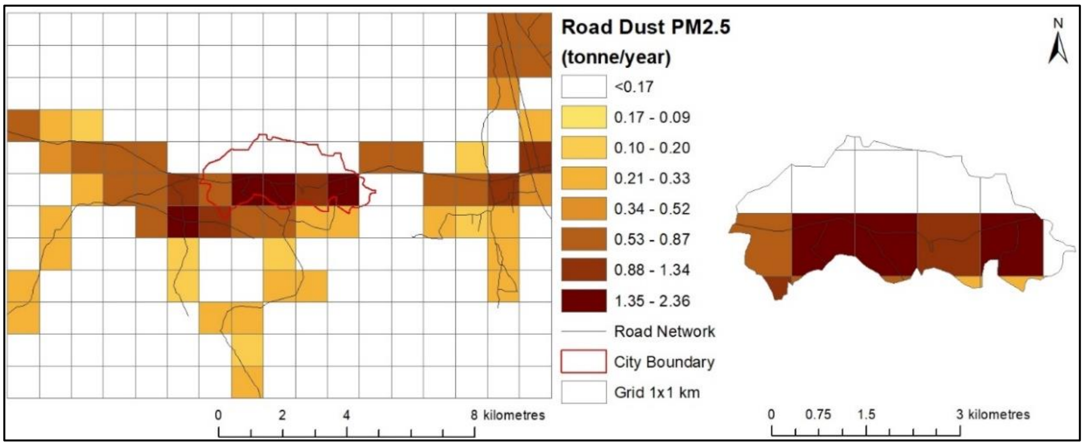

Figure 49: Spatial distribution of $PM_{2.5}$ emissions from road dust in Pakur

Industrial emissions:

In terms of industrial pollution, Pakur's airshed has both stack and fugitive emission sources. Few stone mining and stone-based industries such as stone crushers operated in the vicinity of the town and were responsible for a significant amount of fugitive emissions. The major pollutant from fugitive emissions was particulate matter, especially PM_{10} and $PM_{2.5}$. No stack-based industries were identified in the airshed.

Stone mining and stone crushers were mostly located in the southern part of the Pakur airshed. Few stone mines and stone crushers operated in the northern side of the airshed. Overall, 30 stone mines were identified in the airshed, with an area of 1036 acres and production of 6.7 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from stone mining in the airshed were estimated to be 335 and 33.5 tonnes/year, respectively. Emissions were highly concentrated in areas such as Basmata, Piparjoria, Rajbandh, Chotapara Urf Harispara, and Ramchandrapur (Figure 50).

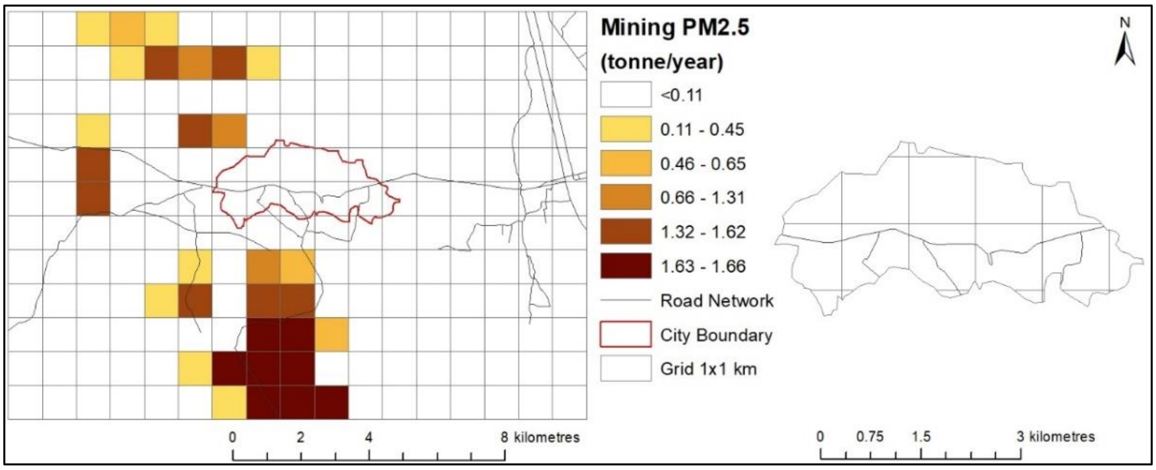

Figure 50: Spatial distribution of $PM_{2.5}$ emissions from mining in Pakur

In total, 151 stone crushers were identified in the airshed and were located in the airshed other than the town area. The total production of stone crushers in the Pakur airshed was around 2.95 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from stone crushers in the airshed were estimated to be 3.5 and 1.7 tonnes/year, respectively. Similar to stone mining, emissions from stone crushers were highly concentrated near the stone mining sites (Figure 51).

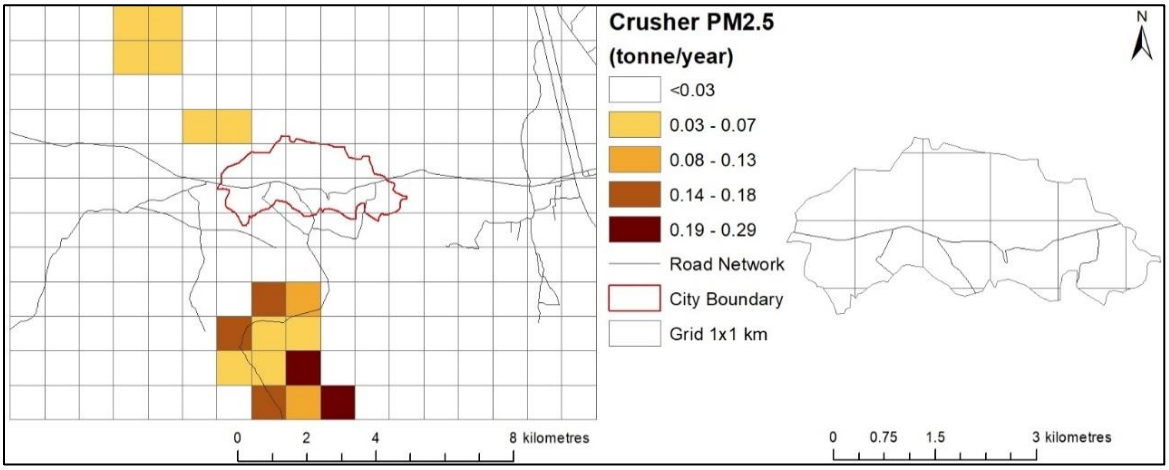

Figure 51: Spatial distribution of $PM_{2.5}$ emissions from stone crushers in Pakur

Open burning:

The per capita generation of waste in Pakur was 266 g/day, and the total waste generated in the town was 12.2 TPD. It was estimated that around 445 tonnes of solid wastes generated are being burned every year in the airshed.

For space heating, emissions were calculated based on the proportion of households using different solid fuels for heating. Nearly 70% of households in Pakur used wood as the primary fuel for space heating during winter, followed by coal (30%; Census, 2011). Consumption data (wood = 1 kg/household/day; coal = 1 kg/household/day) were obtained from the field survey. The 4-month winter period was considered for the estimation. Total consumption of biomass and coal in the airshed was estimated to be 8645 and 1514 tonnes/year, respectively.

The total emission from open burning was calculated to be 92 tonnes/year for PM_{10}, 74 tonnes/year for $PM_{2.5}$, 15 tonnes/year for NOx, and 9.7 tonnes/year for SO_2. The emissions were distributed in the airshed based on the population density. High emitting grids (Nimtita, Jaladipur, Bhasaipaikar, Kismat Kadamsai, Sitapahari, and Mahadeb Nagar) were mostly located outside the town (Figure 52).

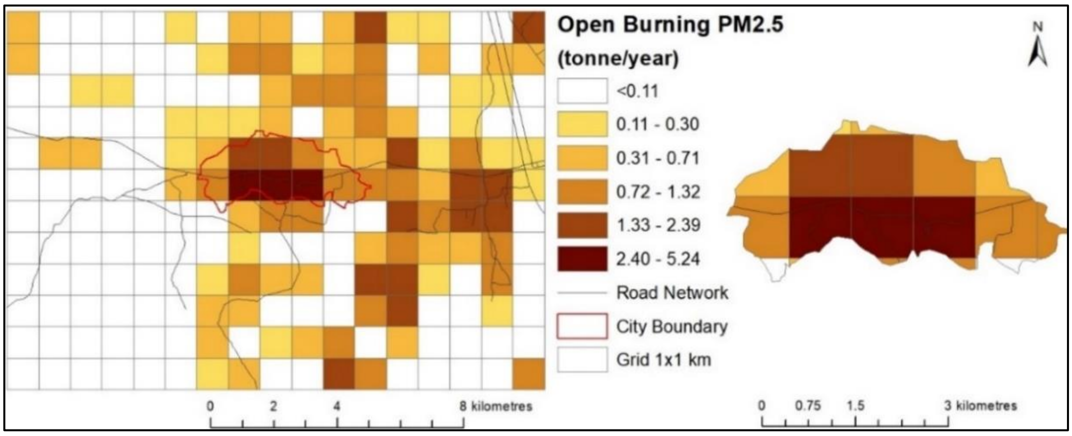

Figure 52: Spatial distribution of $PM_{2.5}$ emissions from open burning in Pakur

Construction and demolition:

The emissions were estimated based on the rise in built-up areas in a time frame and duration of that construction activity. During 2019–2020, we identified around 4.93 acres rise in the built-up area in the airshed. The emission from the construction sites was estimated to be 6.2 tonnes/year for PM_{10} and 1.02 tonnes/year for $PM_{2.5}$. The emissions were distributed in the airshed based on satellite imagery. The construction activities were scattered across the airshed, mostly located outside the town, and the scale of construction activities was mainly residential (Figure 53).

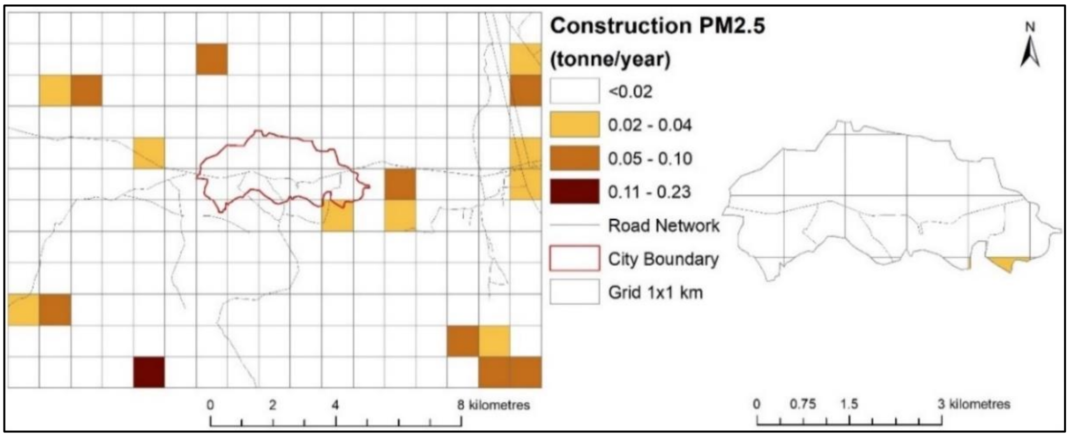

Figure 53: Spatial distribution of $PM_{2.5}$ emissions from construction in Pakur

Total emission load:

For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 876, 392, 74, and 927 tonnes/year, respectively, whereas those in the town area were 117, 71, 10, and 317 tonnes/year, respectively. The sectoral contribution of $PM_{2.5}$ emissions in Pakur town and its airshed is shown in Figure 54. Total emissions over the airshed indicated that the domestic sector was the major contributor to $PM_{2.5}$ emissions, followed by transportation, open burning, road dust, and mining. Contributions from brick kilns, stone crushers, construction, and eateries were minor. Within the town, transport was the major contributor, followed by open burning, domestic sector, and road dust. Mining, domestic sector, and transport were the major contributors to PM_{10}, SO_2, and NOx emissions, respectively, over the airshed.

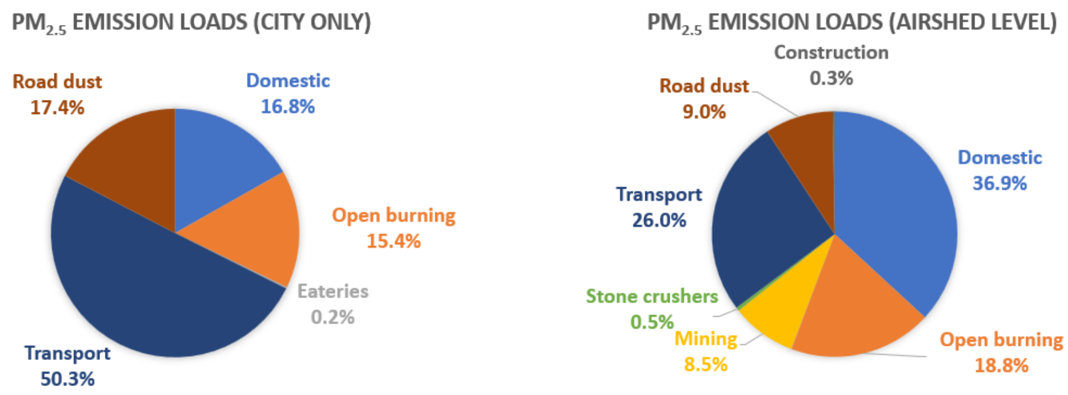

Figure 54: Sectoral contribution of $PM_{2.5}$ emissions at the a) town level and b) airshed level in Pakur

Figure 55 presents the spatial distribution of $PM_{2.5}$ emissions in Pakur airshed. High emitting grids in the town (Bhagatpara, Tulsi Nagar, Kalkapur, Rajpara, and Harindanga Nagar) and those outside the town (Chandpur, Antardwipa, and Gauripur) were attributed to transport, domestic sector, road dust, and open burning. The sector-wise spatial distribution of $PM_{2.5}$, SO_2, and NO_X emissions in Pakur airshed is provided in the Annexure (Figure A40–Figure A58).

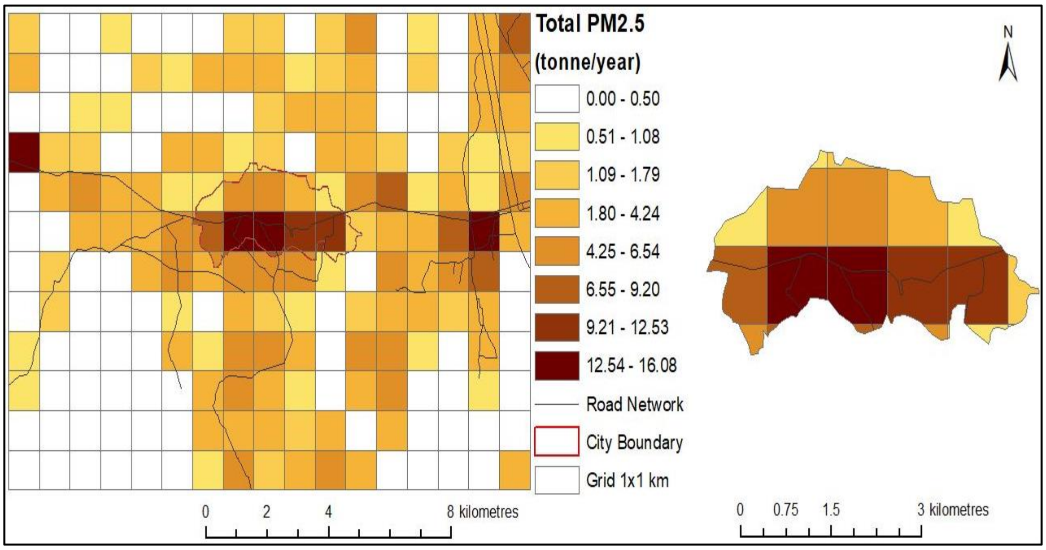

Figure 55: Spatial distribution of total $PM_{2.5}$ emissions in Pakur

4.2.4. Chaibasa

Sectoral emission estimation

Fugitive dust emissions from mining activities and stone crushing activities, use of biomass and coal in brick kilns, and vehicle exhaust of heavy-duty trucks were the major emission sources in the town and its vicinity, besides traditional sources such as domestic cooking and heating, passenger vehicles, road dust, commercial cooking, and solid waste burning.

Domestic sector:

The domestic survey was conducted in selected slums inward Gitilpi and Meritola in Chaibasa town. The survey revealed that 55% of slum households used wood, 36% used mixed fuel (wood and LPG), and 9% used LPG for cooking (Table 23). The average frequency of cooking in slums was twice a day.

Although about 45% of slum households had LPG connections, 87% of these households used wood along with LPG for cooking. The average consumption of energy for cooking in a slum household in Chaibasa town was 59.4 GJ.

Table 23: Average fuel consumption for cooking in a slum household in Chaibasa town

Household fuel preference	Percentage Share (%)	Fuel consumption	
		Wood (W) (kg/month)	LPG (L) (cylinders/month)
W	55	350	
L	9		1
Mixed (W+L)	39	70	1

The total consumption of LPG and biomass in Chaibasa town was estimated to be 2326 and 6837 tonnes/year, respectively. For the airshed other than the town area, the consumption of domestic fuels was determined based on the PPAC (2016) and NFHS (2019) as well as Census (2011) district statistics, considering the airshed other than the town area possessed nearly the same socioeconomic level as that of the district. The proportion of households using domestic fuels and their consumption in the airshed other than the town area are presented in Table 28. The total consumption of LPG, biomass, coal, dung cake, and kerosene in the airshed other than the town area was estimated to be 51.9, 6614, 23.7, 3.4, and 0.2 tonnes/year, respectively.

For the town area, emissions from the domestic sector were estimated to be 59.2 tonnes/year for PM_{10}, 47.2 tonnes/year for $PM_{2.5}$, 16 tonnes/year for NOx, and 1.37 tonnes/year for SO_2. For the airshed area, emissions from the domestic sector were estimated to be 115.7 tonnes/year for PM_{10}, 92.5 tonnes/year for $PM_{2.5}$, 25.5 tonnes/year for NOx, and 2.8 tonnes/year for SO_2. The total emission (from the airshed area) was spatially distributed over the airshed based on the population density. It was evident that emissions from the domestic sector were more concentrated within the town. Domestic emissions contributed about 51% of the total emissions (all pollutants) in the town, which were mainly emitted from slum areas (with prevalent wood use). In the town vicinity, higher emissions were attributed to high population density coupled with a large number of households using solid fuel for cooking (83%). Diliyamarcha, Lupunggutu, and Sentola areas had the highest emissions (Figure 56). Accessibility of biomass from forest areas in the vicinity and low economic status prevent people from using clean fuel.

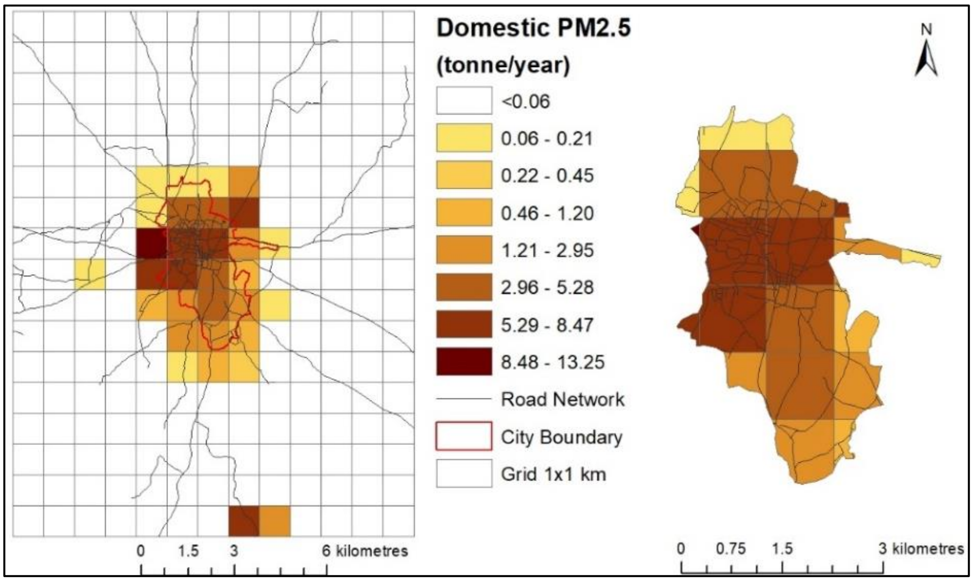

Figure 56: Spatial distribution of $PM_{2.5}$ emissions from the domestic sector in Chaibasa

Commercial cooking:

The field survey was performed at selected restaurants located in different parts of the town. We found that fuel use in restaurants varied by size and daily customer footfall. We divided the surveyed restaurants into three categories (small, medium, and large restaurants; Figure 57). The percentage of restaurants using solid and clean fuels and their average fuel consumption are presented in Table 24. Restaurants predominantly used LPG as the main fuel along with wood, kerosene, and coal as the concurrent fuel. All three categories of restaurants used solid fuels for cooking. Easy accessibility of wood in the vicinity of the town at a lower cost drove the restaurants to use wood beside LPG. We also found that some speciality restaurants used coal for preparing barbeque and tandoori food items. However, these restaurants did not possess any filters in their vents to capture PM emissions. The average specific energy consumed in a year in large restaurants using solid fuels (411 GJ) was more than 1.4 times higher than that in small (350 GJ) and medium restaurants (305 GJ).

The survey also revealed that small and medium restaurants (97% of the surveyed restaurants) used invertors during power cuts, whereas large restaurants predominantly used diesel generators (98% of the surveyed restaurants) with an average diesel consumption of 22 L/month.

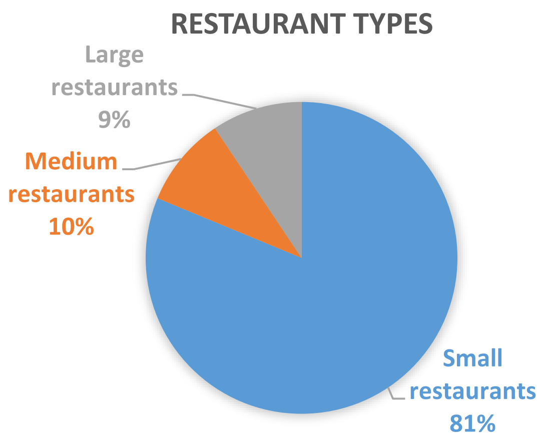

Figure 57: Share of restaurant types in Chaibasa

Table 24: Percentage of restaurants using solid and clean fuel and their average fuel consumption

Fuel used in restaurants	Percentage (%)	Fuel consumption				Annual specific energy consumption (GJ)
		Coal (C) (kg/month)	Wood (W) (kg/month)	LPG (L) (19 kg cylinder/month)	Kerosene (K) (L/month)	
Small restaurants (footfall < 100)						
W+K+L	14		60	4	20	392
C+L	18	30		4		310
L	68			5		51.3
Medium restaurants (footfall = 100–500)						
W+L	100		40	7		305
Large restaurants (footfall > 500)						
W+K+L	100		60	6	18	412

Data on the number of restaurants and their locations were obtained using Google API and then geo-located on the grids. About 60 restaurants were identified in the airshed. The total consumption of coal, biomass, LPG, and kerosene in restaurants in Chaibasa town was estimated to be 65.4, 258.7, 75.3, and 5.4 tonnes/year, respectively. The emission from eateries was estimated to be 2.9 tonnes/year for PM_{10}, 2.3 tonnes/year for $PM_{2.5}$, 0.68 tonnes/year for NOx, and 0.42 tonnes/year for SO_2.

The spatial distribution of emissions from eateries was based on the number and type of eateries in each grid. It was evident that emissions from the eateries sector were more concentrated within the town. Emissions from eateries were greater in the areas with more commercial activities, such as Sentola, Tungri, and Tambo (Figure 58). The high consumption of coal and wood in eateries contributed up to 98% of the total pollutant emissions. Overall, small restaurants (footfall < 100) using solid fuels emitted 1.6 times more than medium restaurants. Cooks were the potential receptors who were constantly exposed to $PM_{2.5}$ emissions, and their exposure should be curtailed.

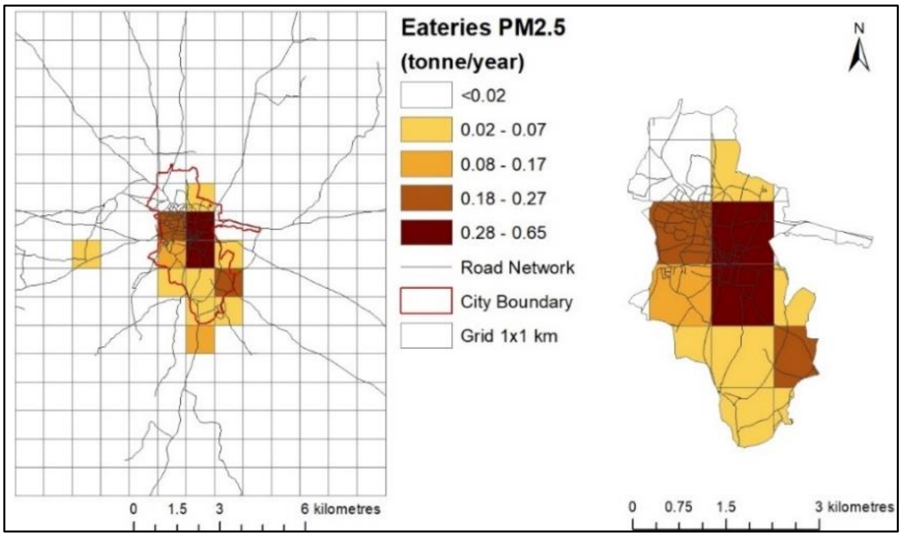

Figure 58: Spatial distribution of $PM_{2.5}$ emissions from eateries in Chaibasa

Transport emissions:

The transportation survey was performed at petrol bunks to determine the vintage and VKT of vehicles. In total, 832 vehicles were surveyed at six petrol bunks. From this survey, we determined the share of age of vehicles plying in Chaibasa and share of four-wheelers and three-wheelers on the basis of fuel type (petrol or diesel). Figure 59 and Figure 60 present the vintage and VKT of the vehicles plying in Chaibasa, respectively. The survey results revealed that 38% of the vehicles plying in Chaibasa were aged less than 5 years, 35% were aged between 5 and 10 years, and 26% were aged more than 10 years. The survey did not capture HCVs, as HCVs were restricted inside the town during the daytime (survey was performed during the day).

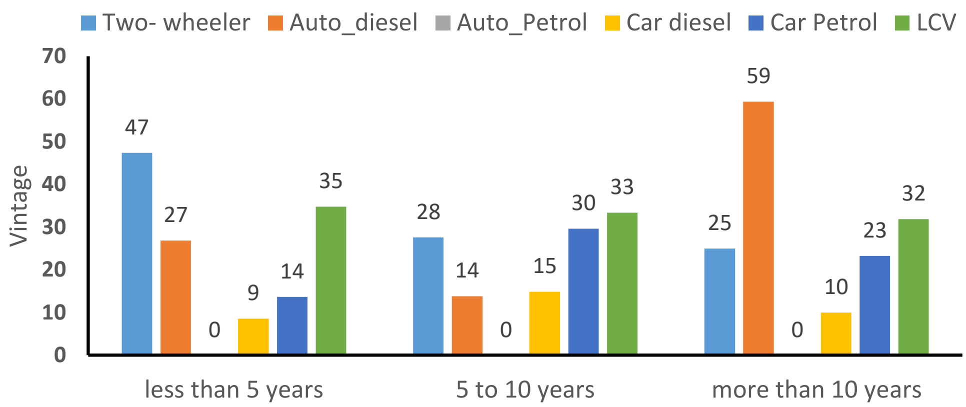

Figure 59: Vintage of vehicles plying in Chaibasa

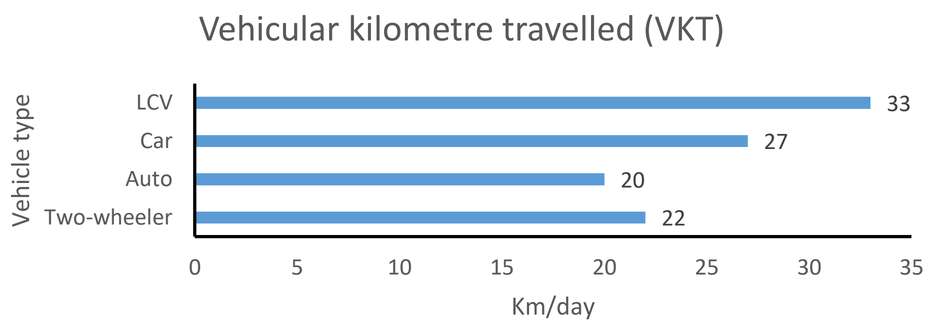

Figure 60: VKT of vehicles plying in Chaibasa

Tailpipe emissions: In most Indian cities, transportation is one of the biggest contributors to air pollution. Transport growth is largely influenced by demographic growth as well as economic growth. Like other cities, increase in population and economic activities led to an increase in vehicular population in the town, with an average annual vehicular growth rate of 17%. The year-wise cumulative vehicle registration in Chaibasa is shown in Figure 61.

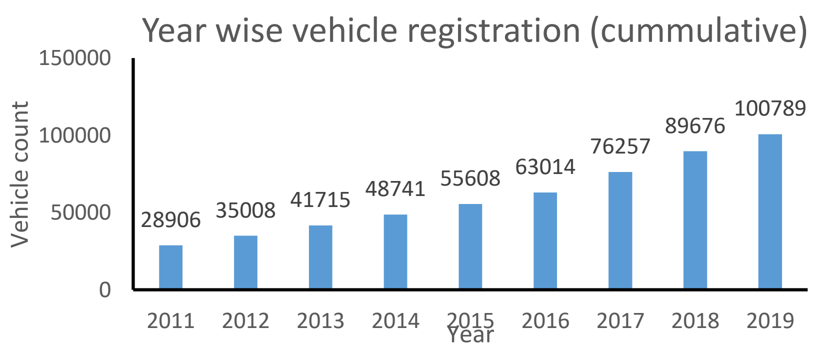

Figure 61: Year-wise vehicle registration in Chaibasa

Tailpipe emissions were estimated based on the VKT data obtained from the transportation survey and vehicle statistics obtained from the transport department and VAHAN database. For calculating emissions from HCVs, VKT was assumed to be 86 km. The share of types of vehicles plying on road in Chaibasa is shown in Figure 62.

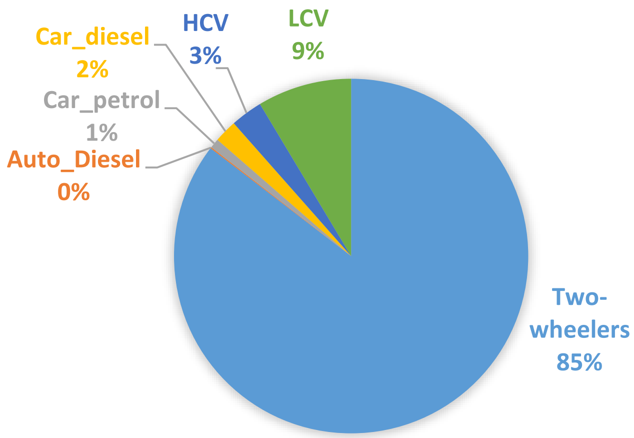

Figure 62: Share of types of vehicles plying in Chaibasa

Tailpipe emissions were estimated to be 226 tonnes/year for PM_{10}, 205 tonnes/year for $PM_{2.5}$, and 1846 tonnes/year for NOx. HCVs and LCVs contributed around 72% and 22% of PM emissions, respectively, of which 87% of HCV emissions and 50% of LCV emissions were emitted from vehicles aged >10 years. HCVs (including buses) constituted only 3% of the total number of vehicles plying in Chaibasa but contributed 72% of the PM emission load from transportation. Two-wheelers and diesel autos contributed about 5% and 0.1% of the PM emissions, respectively, whereas diesel cars and petrol cars contributed about 1% and 0.1% of the PM emissions, respectively. About 63% of the two-wheeler PM emissions were attributed to vehicles aged >10 years. $PM_{2.5}$ emissions from different vehicle types are shown in Figure 63.

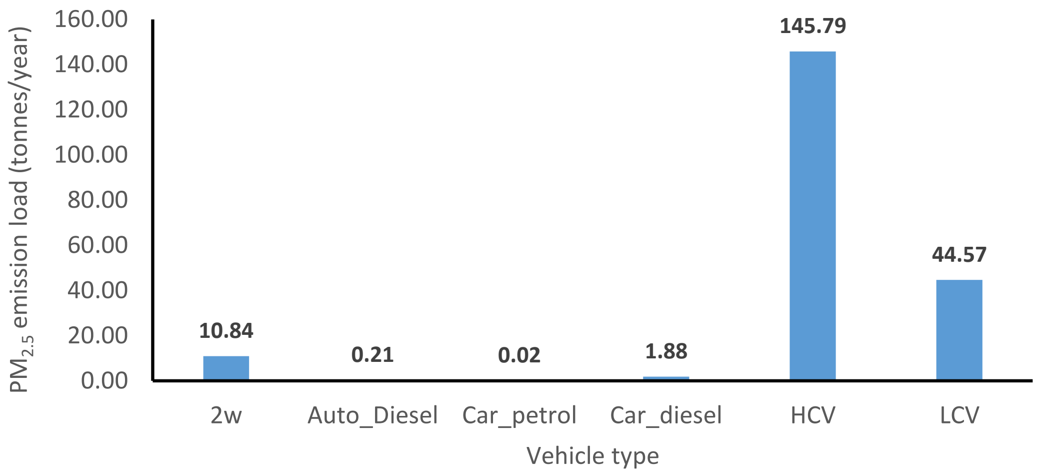

Figure 63: Contribution of tailpipe emissions to $PM_{2.5}$ emission load in Chaibasa

Transport emissions were distributed based on the population density and fraction of road networks. The total length of national highways, state highways, and major roads in the airshed was found to be 33, 82, and 45 km, respectively. Vehicular emission was high on main and arterial roads in the town because of the high heterogeneous traffic volume. The emission on these roads was contributed by the movement of mixed traffic (including HCVs). Emission from these roads attributed to only 38% of the transport PM share. The major share of the transport PM emissions was contributed by national highways located within the town and its vicinity, mainly emitted from HCVs. National Highways 20, 220, and 43 together contributed 45% of the transport PM emissions (Figure 64).

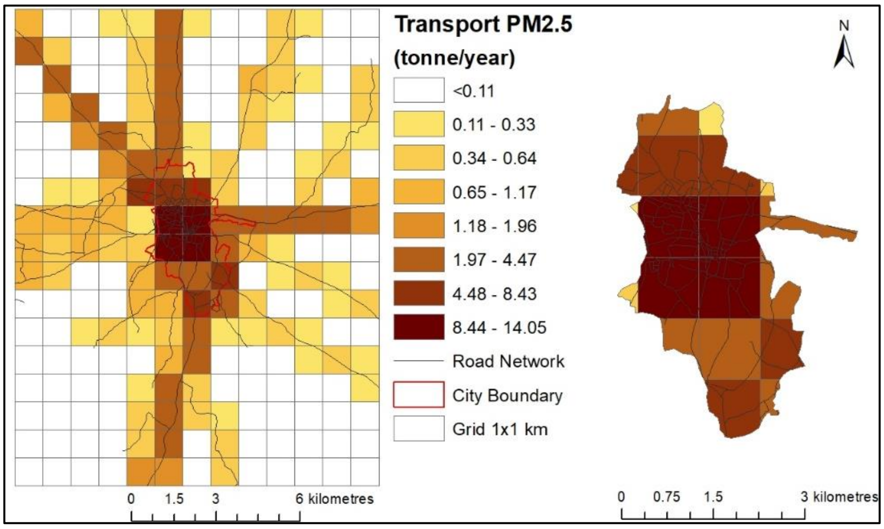

Figure 64: Spatial distribution of $PM_{2.5}$ emissions from the transport sector in Chaibasa

Resuspension of dust: In addition to tailpipe emissions, vehicular movement and bad road infrastructure are responsible for the resuspension of dust. For the estimation of road dust, road type data were also considered in addition to road network data. The EF for road dust varies with the road type (paved or unpaved), vehicle share, and climatic conditions. The emission from resuspension of dust was estimated to be 247 tonnes/year for PM_{10} and 60 tonnes/year for $PM_{2.5}$. Around 38% of the PM emissions from road dust were contributed by arterial and main roads in the town, and the major share of the road dust PM emissions was contributed by national highways located within and outside the town limits (Figure 65).

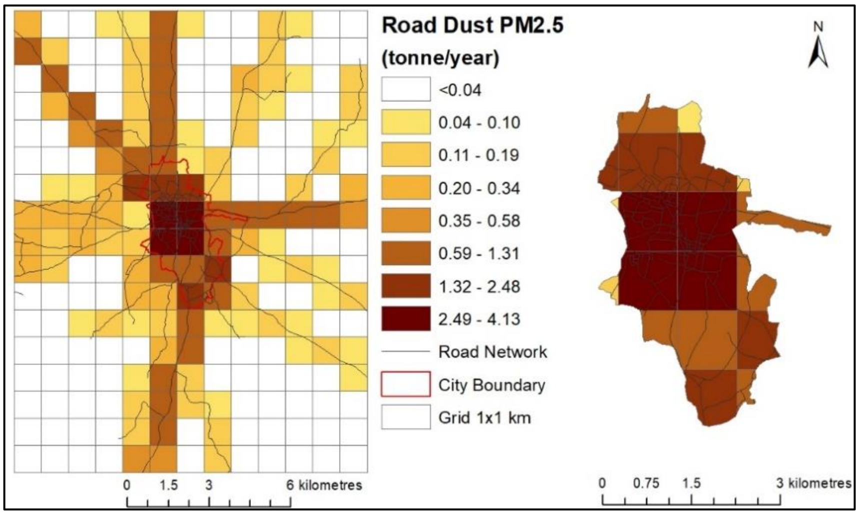

Figure 65: Spatial distribution of $PM_{2.5}$ emissions from road dust in Chaibasa

Industrial emissions:

In terms of industrial pollution, Chaibasa's airshed had both stack and fugitive emission sources. Few stone mining and stone-based industries such as stone crushers operated in the vicinity of the town and were responsible for a significant amount of fugitive emissions. Few stack-based industries, such as brick kilns, were also identified in the study domain.

Stone mining was observed in the southern parts of the Chaibasa airshed (Figure 66). Two stone mines were identified in the airshed, with an area of 1 acre and production of 0.020 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from stone mining in the airshed were estimated to be 0.84 and 0.08 tonnes/year, respectively.

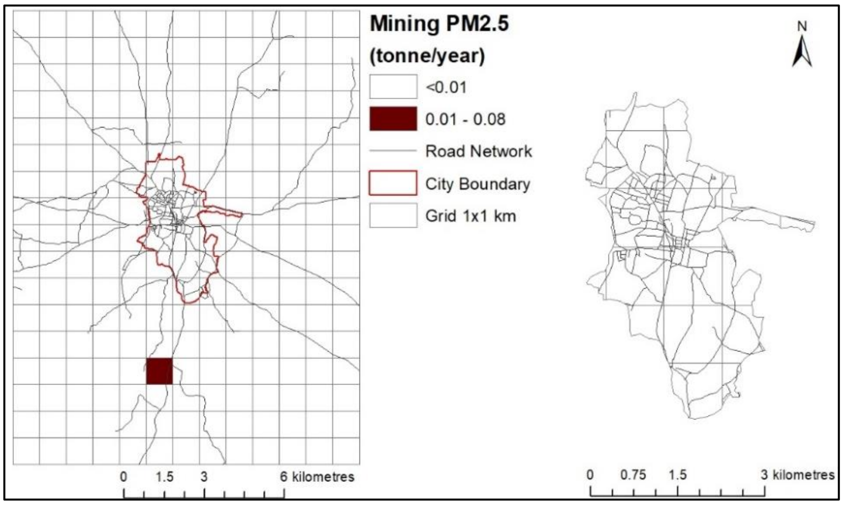

Figure 66: Spatial distribution of $PM_{2.5}$ emissions from stone mining in Chaibasa

Ten stone crushers were identified in the airshed and were mainly found in the airshed area other than the town area (Figure 67). The total production of stone crushers in the Chaibasa airshed was around 0.19 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from stone crushers in the airshed were estimated to be 0.24 and 0.12 tonnes/year, respectively.

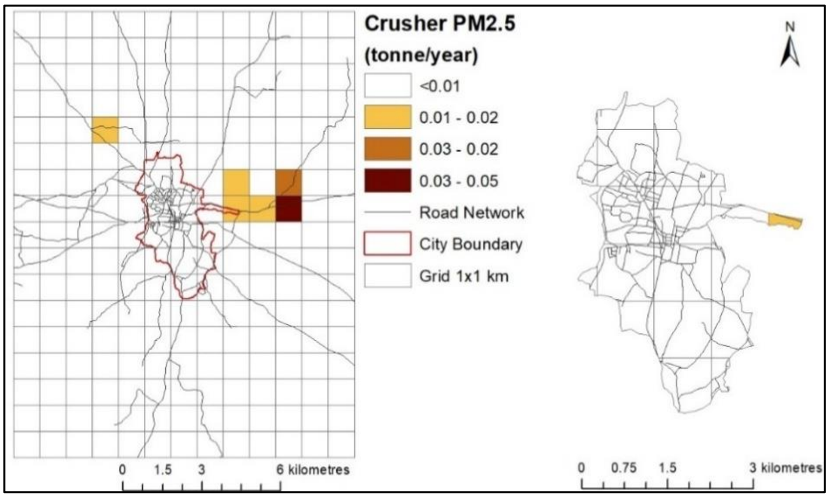

Figure 67: Spatial distribution of $PM_{2.5}$ emissions from stone crushers in Chaibasa

Brick kilns were mostly located in the south-western and north-eastern regions of the airshed (Figure 68). Emissions from brick kilns were uncontrolled. The emission estimation was based on production of the units. The total production of brick kilns in the airshed was estimated to be around 0.042 million tonnes/year. Total thermal energy produced by coal and wood consumed by the brick kilns was estimated to be 19 TJ/year. The emission from brick kilns was estimated to be 36.1 tonnes/year for PM_{10}, 7.56 tonnes/year for $PM_{2.5}$, and 27.7 tonnes/year for SO_2.

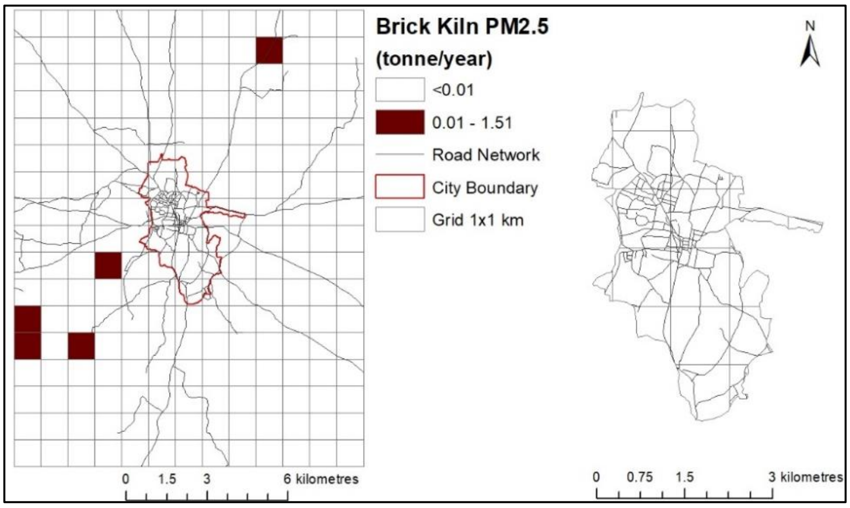

Figure 68: Spatial distribution of $PM_{2.5}$ emissions from brick kilns in Chaibasa

Open burning:

The per capita generation of waste in Chaibasa was 260 g/day, and the total waste generated in the town was 18 TPD. It was estimated that around 660 tonnes of solid wastes generated are being burned every year in the airshed.

For space heating, emissions were calculated based on the proportion of households using different solid fuels for heating. Nearly 98% of the households in Chaibasa used wood as the primary fuel for space heating during winter, followed by coal (2%; Census, 2011). Consumption data (wood = 1 kg/household/day; coal = 1 kg/household/day) were obtained from the field survey. The 4-month winter period was considered for the estimation. Total consumption of biomass and coal in the airshed was estimated to be 2416 and 40 tonnes/year, respectively.

The total emission from open burning was calculated to be 22 tonnes/year for PM_{10}, 18 tonnes/year for $PM_{2.5}$, 4 tonnes/year for NOx, and 1 tonnes/year for SO_2. The emissions were distributed in the airshed based on the population density. The hotspots were located at Sentola, Kalyanpur Guttu Sai, and Tungri (Figure 69). About 98% of the open burning emissions were contributed by the burning activities occurring within the town. Regular door-to-door collection of waste and proper auditing of the waste collection mechanism will reduce garbage burning to a large extent.

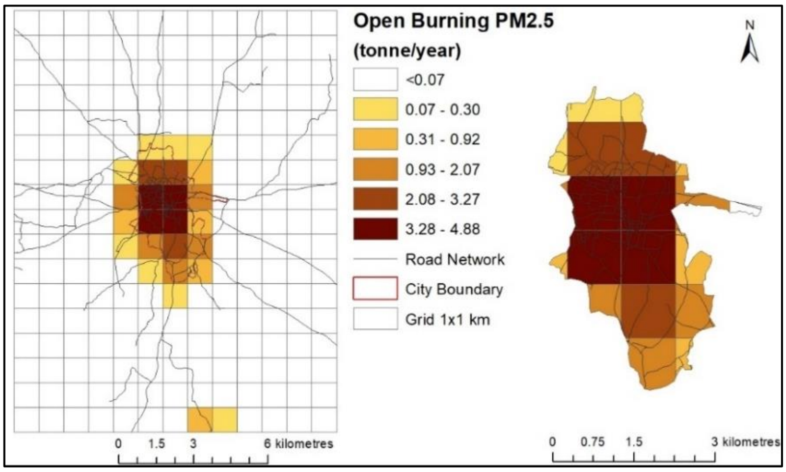

Figure 69: Spatial distribution of $PM_{2.5}$ emissions from open burning in Chaibasa

Construction and demolition:

The emissions were estimated based on the rise in built-up areas in a time frame and duration of that construction activity. During 2019–2020, we identified around 0.76 and 4.9 acres rise in the built-up area in the town and airshed, respectively. The emissions from construction sites were estimated to be 6.1 tonnes/year for PM_{10} and 1.1 tonnes/year for $PM_{2.5}$. The emissions were distributed in the airshed based on satellite imagery. The construction activities were scattered across the airshed with few sites inside the town, and the scale of construction activities was mostly residential (Figure 70). The construction activities within the town accounted only for 3% of the total PM emissions from construction.

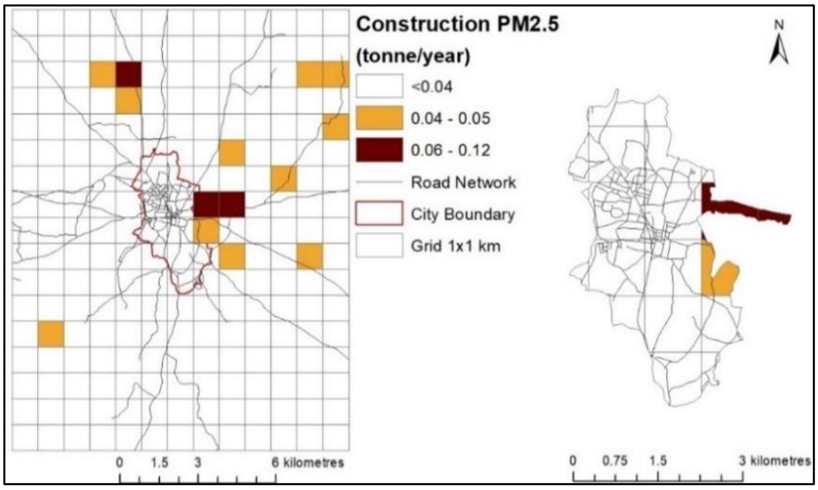

Figure 70: Spatial distribution of $PM_{2.5}$ emissions from construction in Chaibasa

Total emission load:

For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 654, 383, 31, and 1876 tonnes/year, respectively, whereas those in the town area were 334, 206, 2, and 1039 tonnes/year, respectively. The sectoral contribution of $PM_{2.5}$ emissions in Chaibasa town and its airshed is shown in Figure 71.

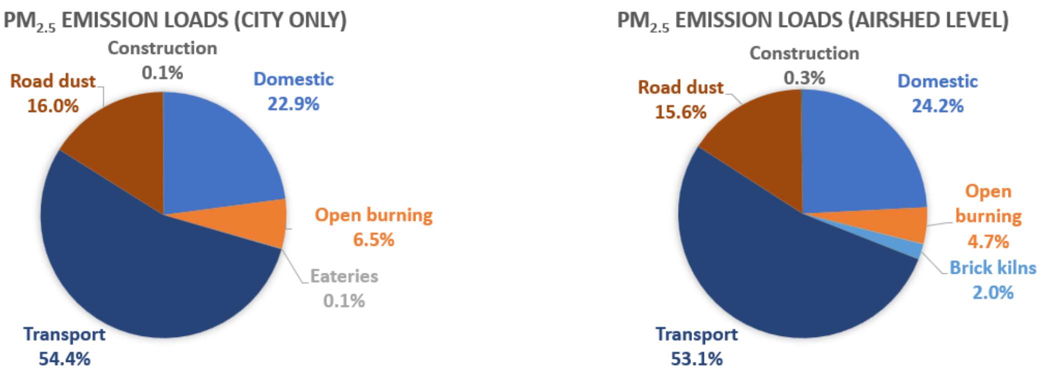

Figure 71: Sectoral contribution of $PM_{2.5}$ emissions at the a) city level and b) airshed level in Chaibasa

The total $PM_{2.5}$ emission within the town indicated that transportation was the major contributor, followed by domestic, open burning, and road dust. Over the airshed, transport was the major contributor, followed by domestic, road dust, open burning, and brick kilns. Contributions from construction, eateries, and stone crushers were minor. Road dust, brick kilns, and transport were the largest contributors to $PM_{2.5}$, SO_2, and NOx emissions, respectively. The spatial distribution of $PM_{2.5}$ emissions is presented in Figure 72. The spatial distribution of PM_{10}, SO_2, and NO_x emissions in the Chaibasa airshed is provided in the Annexure (Figure A59–Figure A78).

The high emitting grids in the town (Sentola, Kalyanpur Guttu Sai, and Tungri) were mainly attributed to sources such as transport, road dust, domestic, and open burning, whereas those over the airshed (Diliyamarcha, Lupunggutu, and Asura) were mainly attributed to the domestic sector.

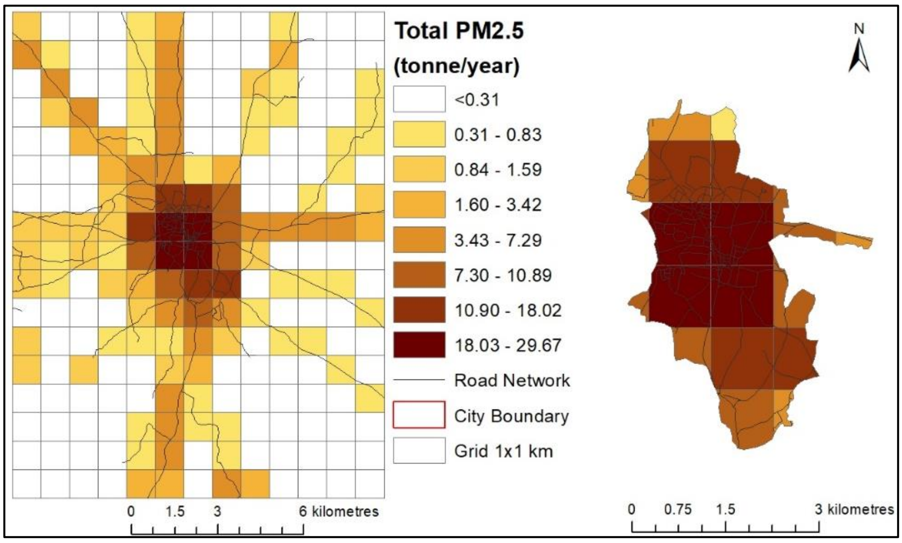

Figure 72: Spatial distribution of total $PM_{2.5}$ emissions in Chaibasa

4.2.5. Hazaribagh

Sectoral emission estimation

Domestic sector

The domestic survey was conducted in selected slums inward Korrah, Okni, and Matwari in Hazaribagh city. The survey revealed that 52% of slum households used coal and 48% used LPG for cooking. The average frequency of cooking in slums was twice a day. The average fuel consumption for cooking in a slum household is presented in Table 25.

The easy availability of solid fuel (coal) is a major barrier preventing LPG penetration in slums. The average consumption of energy for cooking in a slum household in Hazaribagh city was found to be 14 GJ.

Table 25: Average fuel consumption for cooking in a slum household in Hazaribagh city

Fuel Preference	Percentage (%)	Average fuel consumption	
		(C) (kg/month)	(L) (cylinders/month)
Coal (C)	52	60	
LPG (L)	48		1

The total consumption of LPG and coal in Hazaribagh city was estimated to be 5019 and 1329 tonnes/year, respectively. For the airshed other than the city area, the consumption of domestic fuels was determined based on the survey data and NFHS (2019) as well as Census (2011) district statistics, considering the airshed other than the city area possessed nearly the same socioeconomic level as that of the district. The proportion of households using domestic fuels and their consumption in the airshed other than the city area are presented in Table 25. The total consumption of LPG, biomass, coal, dung cake, and kerosene in the airshed was estimated to be 7364, 21425, 6230, 1767, and 1.2 tonnes/year, respectively.

For the city area, emissions from the domestic sector were estimated to be 16 tonnes/year for PM_{10}, 12.3 tonnes/year for $PM_{2.5}$, 15.7 tonnes/year for NOx, and 6.8 tonnes/year for SO_2. For the airshed area, emissions from the domestic sector were estimated to be 277 tonnes/year for PM_{10}, 224 tonnes/year for $PM_{2.5}$, 61 tonnes/year for NOx, and 37 tonnes/year for SO_2. The total emission (from the airshed area) was spatially distributed over the airshed based on the population density. It was evident that emissions from the domestic sector were more concentrated in the outskirts of the city (Sultana, Katkamdag, Barasi, Dandai, and Mandu) (Figure 73).

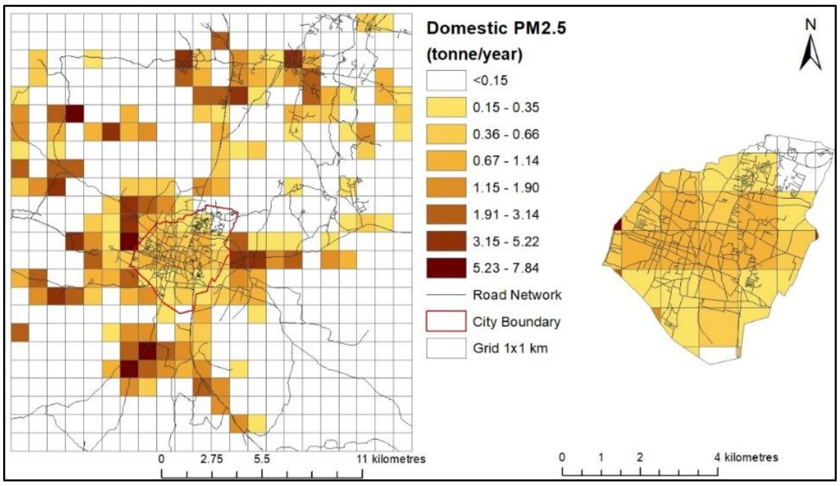

Figure 73: Spatial distribution of total $PM_{2.5}$ emissions in Hazaribagh

The main reason for the higher emissions was the high population density coupled with a large number of households using solid fuel for cooking (63%). Accessibility of biomass from dense forest areas in the vicinity, accessibility of coal from mines, and low economic status prevent people from using clean fuel. In the city, domestic emissions contributed only about 7% of the total emissions for all pollutants, which were mainly emitted from slum areas (with prevalent coal use).

Commercial cooking:

The field survey was performed at selected restaurants located in different parts of the city. We found that fuel use in restaurants varied by size and daily customer footfall. We divided the surveyed restaurants into three categories (small, medium, and large restaurants; Figure 74). The percentage of restaurants using solid and clean fuels and their average fuel consumption are presented in Table 26.

Small restaurants predominantly used coal as the main fuel, whereas LPG usage was found to be dominant in medium and large restaurants. Easy availability of coal in the vicinity of the city at a lower cost hinders small restaurants from adopting LPG. Moreover, these restaurants do not possess any filters in their vents to capture PM emissions. The type of coal used in these restaurants is sub-bituminous (ash content: 40% and sulphur content: 0.5%), which emits significant SO_2 and PM emissions. The average specific energy consumed in a year in small restaurants using coal was 1.1 times higher than that in medium and large restaurants.

The survey also revealed that 90% of small restaurants used invertors during power cuts, whereas medium and large restaurants predominantly used diesel generators (98% of the surveyed restaurants) with an average diesel consumption of 20 L/month.

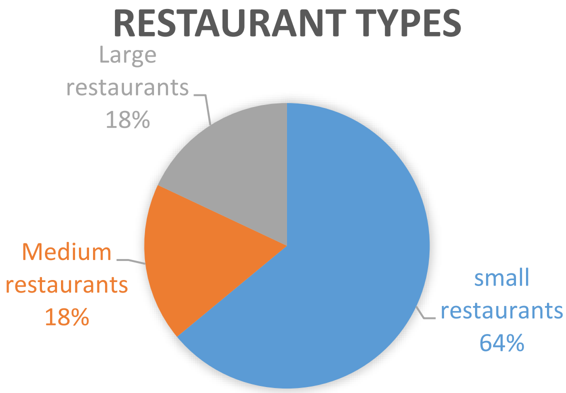

Figure 74: Share of restaurant types in Hazaribagh

Table 26: Percentage of restaurants using solid and clean fuel and their average fuel consumption

	Percentage (%)	Average fuel consumption		Annual specific energy consumption (GJ)
		Coal (kg/month)	LPG (19 kg cylinder/month)	
Small restaurants (daily footfall < 100)				
Restaurants using coal	50	400		100.32
Restaurants using LPG	50		5	57
Medium restaurants (daily footfall > 100 and < 500)				
Restaurants using LPG	100		8	91.2
Large restaurants (daily footfall > 500)				
Restaurants using LPG	100		8	91.2

Commercial places ranged from provisional stores to high-end hotels. Fuel consumption in these areas was dependent on the type of establishment. Among these establishments, eateries used the largest amount of fuel (for cooking). Along with LPG, coal was used in eateries for preparing specialised food items (e.g., tandoori food items). Unlike major cities, Tier-3 cities like Hazaribagh predominantly used solid fuels as the main fuel for cooking in small restaurants owing to their abundant availability.

Data on the number of restaurants and their locations were obtained using Google API and then geo-located on the grids. The total consumption of coal and LPG in eateries in Hazaribagh city was estimated to be 238 and 158 tonnes/year, respectively. The emissions from eateries were estimated to be 2.5 tonnes/year for PM_{10}, 2 tonnes/year for $PM_{2.5}$, 0.6 tonnes/year for NOx, and 1.2 tonnes/year for SO_2.

The spatial distribution of emissions from eateries was based on the number and type of eateries in each grid. It was evident that emissions from the eateries sector were more concentrated within the city. Emissions from eateries were greater in the areas with more commercial activities, such as Kasai Mohallah, BTC Chowk, Matwari Chowk, Ompuri, Gandhi Maidan, and Babugaon Chowk (Figure 75). The consumption of coal in eateries was about 60% of the total fuel consumption and contributed to 97% of the total pollutant emissions. Overall, small restaurants (footfall < 100) emitted more than double the average emissions from medium and large restaurants.

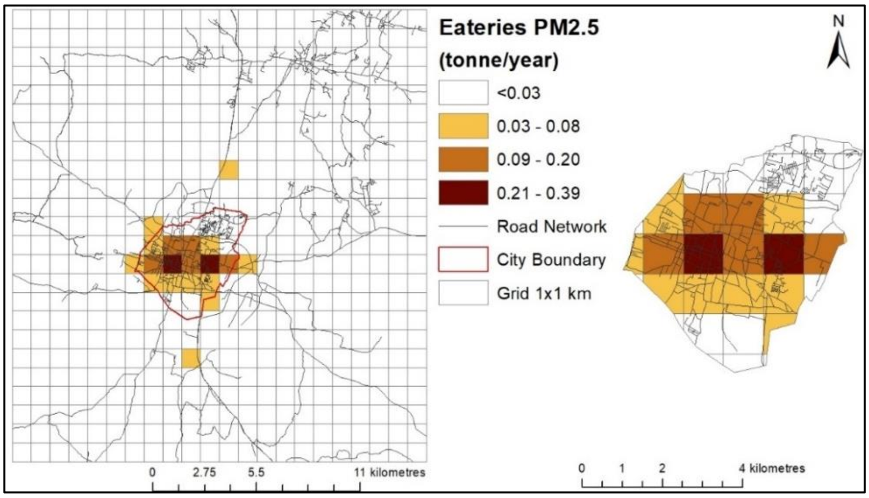

Figure 75: Spatial distribution of $PM_{2.5}$ emissions from eateries in Hazaribagh

Transport emissions:

The transportation survey was performed at petrol bunks to determine the vintage and VKT of vehicles. In total, 1,569 vehicles were surveyed at six petrol bunks. From this survey, we determined the vintage of vehicles plying in Hazaribagh (Figure 76) and share of four-wheelers and three-wheelers on the basis of fuel type (petrol or diesel). Figure 77 present the vintage and VKT of the vehicles plying in Hazaribagh, respectively.

The survey results revealed that 40% of the vehicles plying in Hazaribagh were aged less than 5 years, 41% were aged between 5 and 10 years, and 19% were aged more than 10 years. The survey did not capture HCVs, as HCVs were restricted inside the city during the daytime (survey was performed during the day).

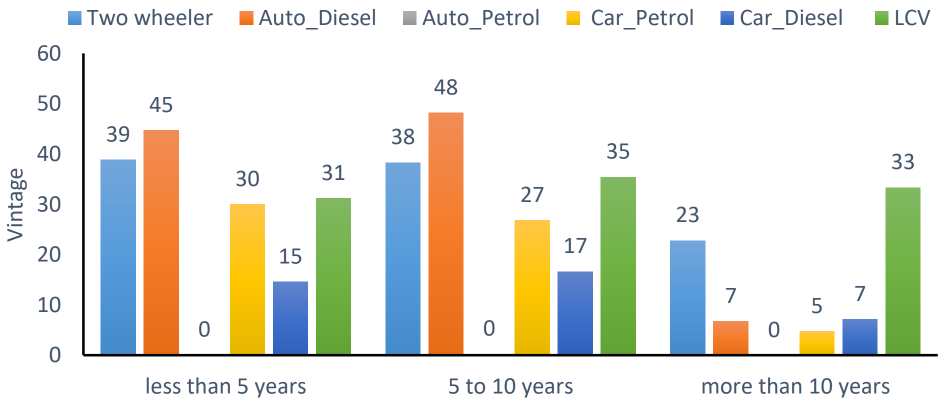

Figure 76: Vintage of vehicles plying in Hazaribagh

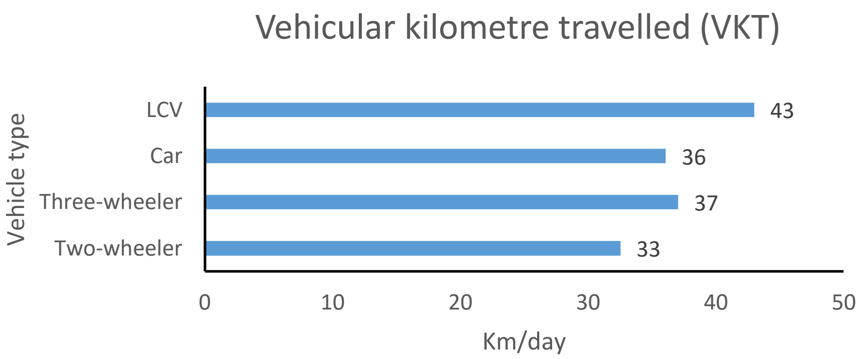

Figure 77: VKT of vehicles plying in Hazaribagh

Tailpipe emissions: In most Indian cities, transportation is one of the biggest contributors to air pollution. Transport growth is largely influenced by demographic growth as well as economic growth. Like other cities, increase in population and economic activities led to an increase in vehicular population in the city, with an average annual vehicular growth rate of 15%. The year-wise cumulative vehicle registration in Hazaribagh is shown in Figure 78.

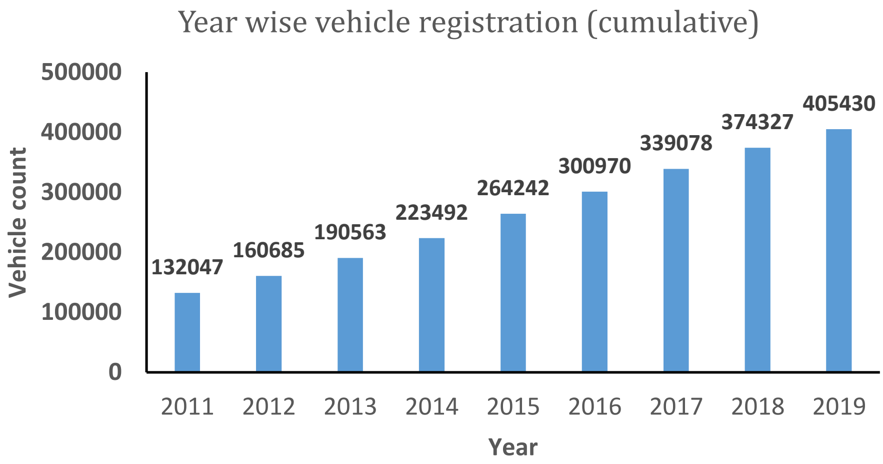

Figure 78: Year wise vehicle registration in Hazaribagh

Tailpipe emissions were estimated based on the VKT data obtained from the transportation survey and vehicle statistics obtained from the transport department and VAHAN database. For calculating emissions from HCVs, VKT was assumed to be 86 km. The share of vehicle types plying on road in Hazaribagh is shown in Figure 79.

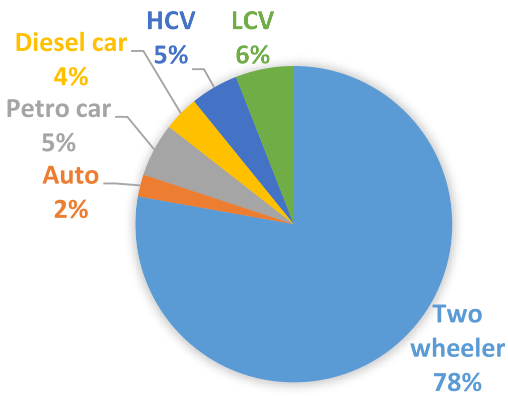

Figure 79: Vehicle type share in Hazaribagh

Tailpipe emissions were estimated to be 591 tonnes/year for PM_{10}, 531 tonnes/year for $PM_{2.5}$, and 6707 tonnes/year for NOx. HCVs and LCVs contributed around 73% and 17% of the PM emissions, respectively, of which 56% of HCV emissions and 14% of LCV emissions were emitted from vehicles aged >10 years. HCVs (including buses) constituted only 5% of the total number of vehicles plying in Hazaribagh but contributed 72% of the total PM emission load from transportation. Two-wheelers and diesel autos contributed about 7% and 1.5% of the PM emissions, respectively, whereas diesel cars and petrol cars contributed about 1.4% and 0.1% of the PM emissions, respectively. About 56% of the two-wheeler PM emissions were emitted from vehicles aged >10 years. $PM_{2.5}$ emissions from different vehicle types are shown in Figure 80.

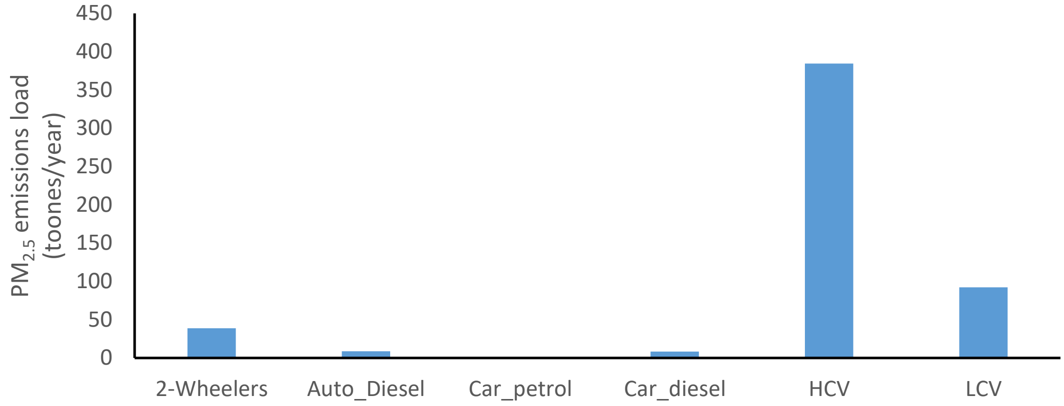

Figure 80: Contribution of tailpipe emissions to $PM_{2.5}$ emission load in Hazaribagh

Transport emissions were distributed based on the population density and fraction of road networks. The total length of national highways, state highways, and major roads in the airshed was identified to be 43, 15, and 80 km, respectively. Vehicular emission was found to be high on main and arterial roads in the city because of the high heterogeneous traffic volume. The emission on these roads was contributed by the movement of mixed traffic (including HCVs). Emission from these roads was only 30% of the transport PM share. The major share of the transport PM emissions was contributed by state and national highways located outside the city, mainly emitted from HCVs. National Highway 20 and State Highway 7 contributed 43% and 13% of the transport PM emissions (Figure 81).

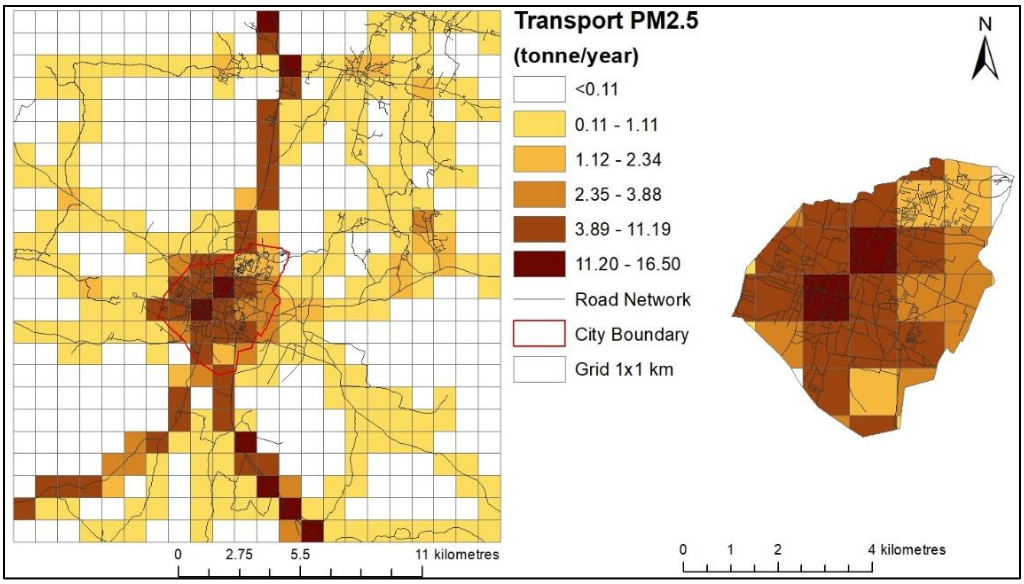

Figure 81: Spatial distribution of $PM_{2.5}$ emissions from the transport sector in Hazaribagh

Resuspension of dust:

In addition to tailpipe emissions, vehicular movement and bad road infrastructure are responsible for the resuspension of dust. For the estimation of road dust, road type data were also considered in addition to road network data. The EF for road dust varies with the road type (paved or unpaved), vehicle share, and climatic conditions. The emission from resuspension of dust was estimated to be 949 tonnes/year for PM_{10} and 229 tonnes/year for $PM_{2.5}$. Around 30% of the PM emissions from road dust were contributed by arterial and main roads in the city, and the major share of the road dust PM emissions was contributed by roads located outside the city (Figure 82).

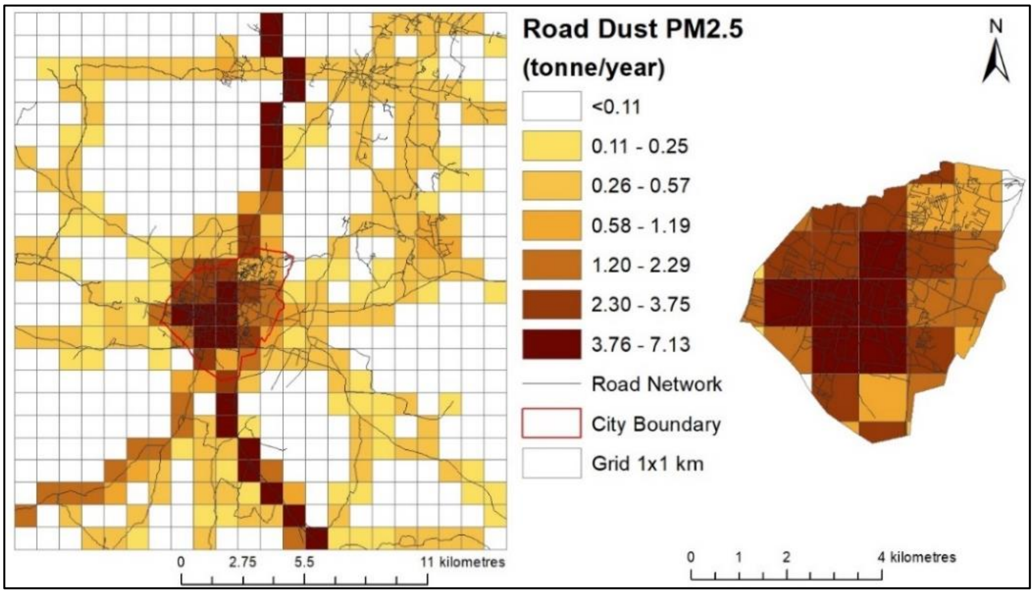

Figure 82: Spatial distribution of $PM_{2.5}$ emissions from road dust in Hazaribagh

Industrial emissions:

In terms of industrial pollution, Hazaribagh's airshed has both stack and fugitive emission sources. Stone mining and stone-based industries such as stone crushers operate in the vicinity of the city and were responsible for a significant amount of fugitive emissions. The major pollutant from fugitive emissions was particulate matter, especially PM_{10} and $PM_{2.5}$.

Although Hazaribagh is one of the industrialised districts of Jharkhand, very few stack-based industries such as food processing, sponge iron, brick kilns, cement, and rice mills were located in the study domain; however, these industries significantly contributed to stack-based emissions. The major pollutants through stack emissions other than PM were SO_2 and NO_X, emitted from stacks of the various industries due to combustion of different fuels.

Stone mining and stone crushers were scattered in the northern part of the Hazaribagh airshed. In total, 14 stone mines were identified in the airshed, with an area of 169 acres and production of 2.67 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from stone mining in the airshed were estimated to be 133.4 and 13.4 tonnes/year, respectively. Emissions from stone mining were highly concentrated in areas such as Tilaidih, Sijhua, Dumraun, Saram, and Tepsa (Figure 83).

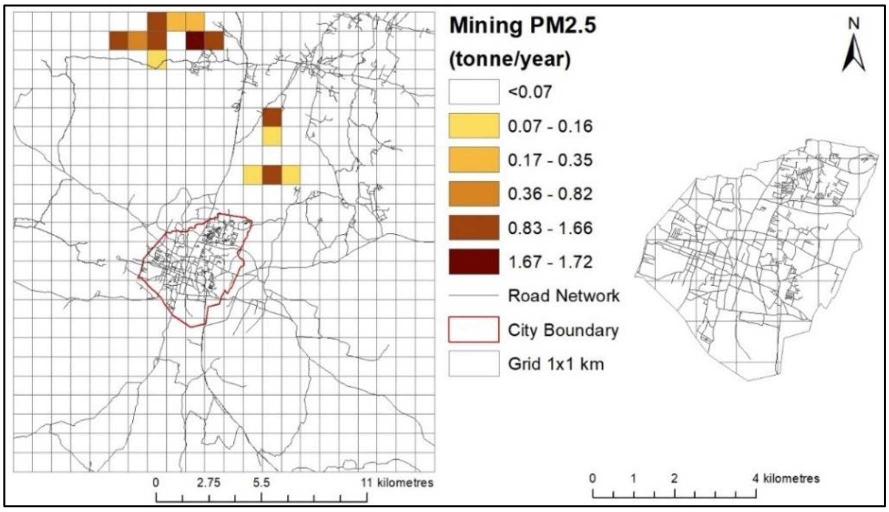

Figure 83: Spatial distribution of $PM_{2.5}$ emissions from mining in Hazaribagh

We identified 240 stone crushers in the airshed, which were mainly located in the airshed area other than the city area. Figure 84 presents the spatial distribution of emissions from stone crushers.

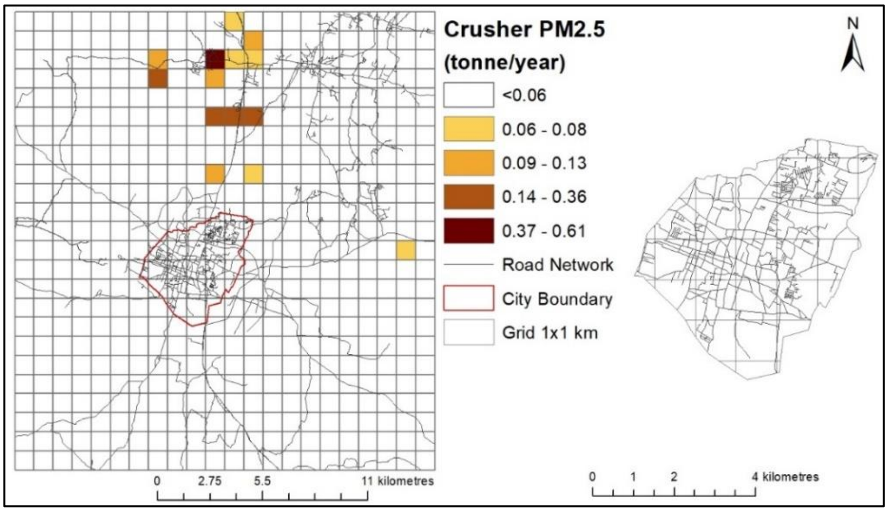

Figure 84: Spatial distribution of $PM_{2.5}$ emissions from stone crushers in Hazaribagh

The total production of stone crushers in the Hazaribagh airshed was around 4.76 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from the stone crushers in the airshed were estimated to be 5.64 and 2.8 tonnes/year, respectively. Similar to stone mining, emissions from stone crushers were highly concentrated near the stone mining sites (Bonga and Dumraun).

Dust suppression is the most common technique used to control particulate emissions in stone mining and crushing activities. Water wetting arrangements for drilling and hauling activities, capturing and venting control devices and wet-dust suppression arrangements for crushing, and screening and conveying activities can significantly reduce PM emissions. Treatment with surface agents, soil stabilisation, and pavement of roads for hauling operations can also curtail PM emissions. These control technologies should be strictly enforced by authorities and regularly monitored by installing air quality sensors.

The total energy consumption of the stack-based industries based on their fuel usage is shown in Figure 85.

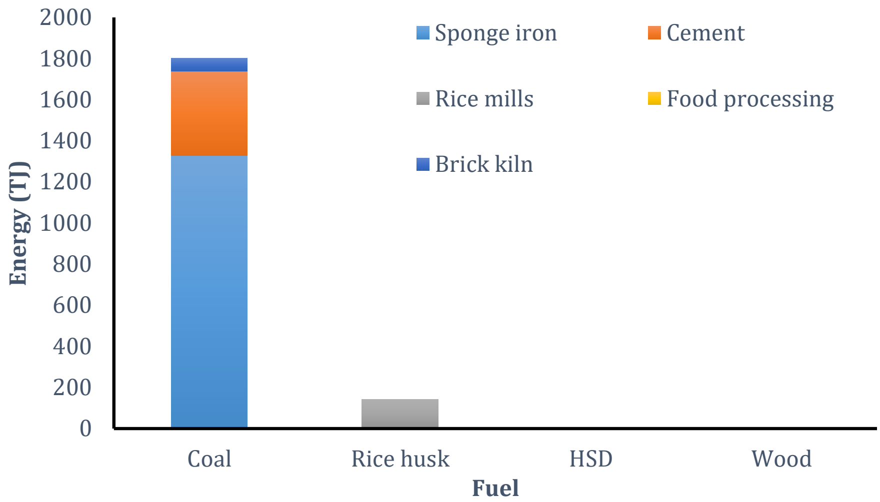

Figure 85: Total energy consumption of the industries based on their fuel usage in Hazaribagh

Emissions from sponge iron and cement plant (highly energy intensive) were estimated with a control efficiency of 95% for PM and 50% for SO_2 and NO_X, whereas rice mills, brick kilns, and food processing emissions were uncontrolled. The emission estimation was either based on production of the units or fuel consumed in the units. The total production of brick kilns in the airshed was estimated to be around 0.042 million tonnes/year.

The stack-based industrial emissions were estimated to be 366 tonnes/year for PM_{10}, 104 tonnes/year for $PM_{2.5}$, 209 tonnes/year for NO_x, and 585 tonnes/year for SO_2. Industry-wise $PM_{2.5}$ emissions are shown in Figure 86. Although energy consumption in the sponge iron plant was very high, emissions from this plant were lower than those from the cement plant. Besides combustion emissions from cement plants, processes such as grinding and crushing of raw materials and grinding of clinkers produced also contributed to the PM emissions. In contrast, SO_2 emissions from the sponge iron plant were higher than those from the cement plant owing to a high consumption of coal. However, both of these industries emitted significant PM and SO_2 emissions. The sponge iron plant and cement plants were located in the southern part of the airshed (Dembu, Marhand, and Morangi)

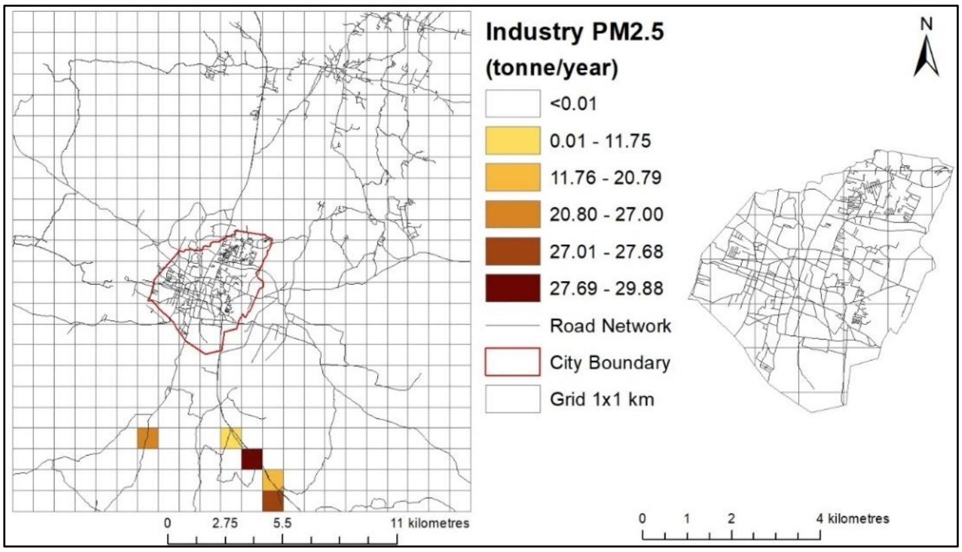

Figure 86: Spatial distribution of $PM_{2.5}$ emissions from industries in Hazaribagh

Despite being medium energy-intensive industries, rice mills and brick kilns also emit significant pollutant emissions. Rice mills use rice-husk fired steam boilers for rice processing or captive power generation. The inefficiency of the boilers and use of rice husk as a fuel induce the release of significant PM emissions during combustion. Rice mills should focus on partially replacing biomass or solid fuel usage in boilers with gas or high-speed diesel (HSD). Rice mills were located in the southern region of the airshed (Figure 86). Brick kilns were mostly located in the southwest and southern region of the airshed (Tumba, Hupad, Marhand, and Nawada; Figure 87).

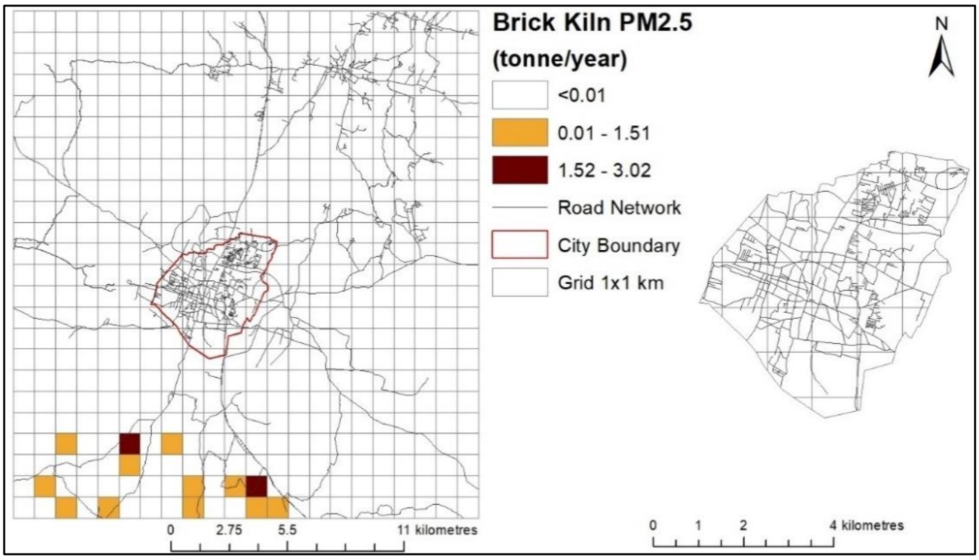

Figure 87: Spatial distribution of $PM_{2.5}$ emissions from brick kilns in Hazaribagh

Industry-wise emission contribution is depicted in Figure 88. As evident, the cement industry was the largest contributor to $PM_{2.5}$ emissions, followed by sponge iron industries and rice mills. The contribution of the food processing industry to $PM_{2.5}$ emissions was negligible.

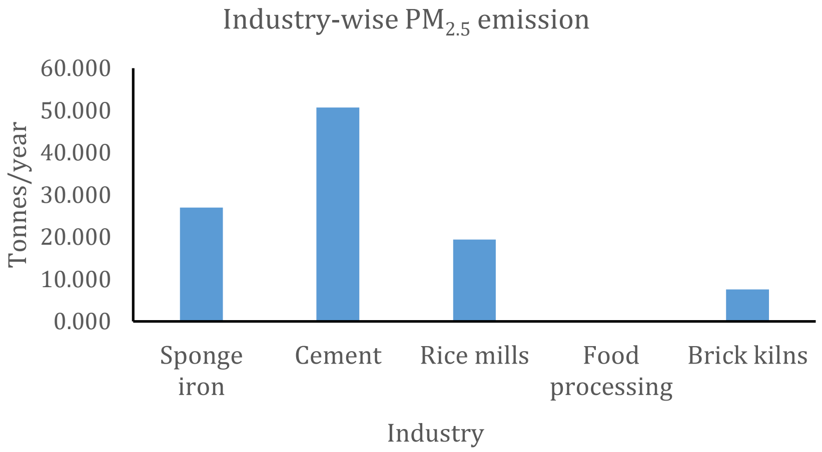

Figure 88: Industry-wise contribution to $PM_{2.5}$ emissions in Hazaribagh

Open burning:

The amount of waste burned was estimated based on the quantity of waste generated, collection efficiency, and quantity of waste processed. The per capita generation of waste in Hazaribagh was 415 g/day, and the total waste generated in the city was 59 TPD. It was estimated that around 2155 tonnes of solid wastes generated are being burned every year in the airshed.

For space heating, emissions were calculated based on the proportion of households using different solid fuels for heating. Nearly 70% of the households in Hazaribagh used biomass as the primary fuel for space heating during winter, followed by coal (30%; Census, 2011). Consumption data (biomass = 1 kg/household/day; coal = 1 kg/household/day) were obtained from the field survey. The 4-month winter period was considered for the estimation. Total consumption of biomass and coal in the airshed was estimated to be 10864 and 2232 tonnes/year, respectively.

The total emission from open burning was calculated to be 125 tonnes/year for PM_{10}, 101 tonnes/year for $PM_{2.5}$, 22 tonnes/year for NOx, and 14 tonnes/year for SO_2. The emissions were distributed in the airshed based on the population density. High emitting grids (Okni No.II, Ramnagar, Jabra, Kasai Mohallah, and Mangura) were mostly concentrated within the city (Figure 89). The main reason for the higher emissions was the high population density coupled with a large number of households using solid fuel for heating during winter.

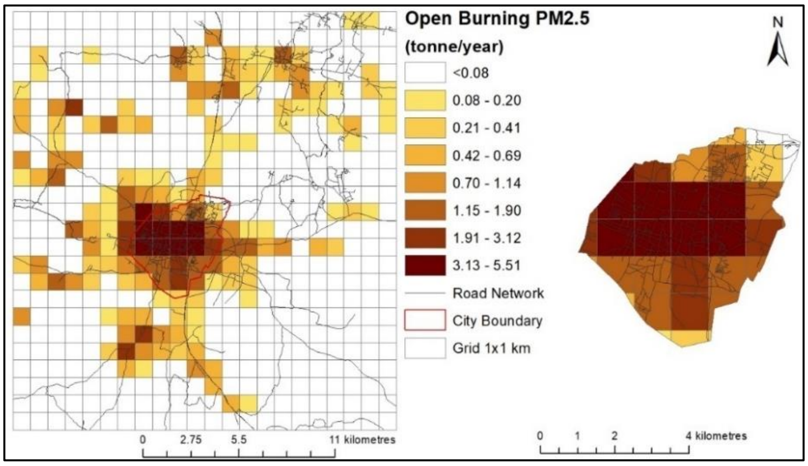

Figure 89: Spatial distribution of $PM_{2.5}$ emissions from open burning in Hazaribagh

Construction and demolition:

The emissions were estimated based on the rise in built-up areas in a time frame and duration of that construction activity. During 2019–2020, we identified around 0.14 and 4.4 acres rise in the built-up area in the city and airshed, respectively. The emissions from construction sites were estimated to be 5.5 tonnes/year for PM_{10} and 0.9 tonnes/year for $PM_{2.5}$. The emissions were distributed in the airshed based on satellite imagery. The construction activities were scattered across the airshed with few sites inside the city, and the scale of construction activities was mostly residential (Figure 90). The construction activities within the city accounted only for 3% of the total PM emissions from construction.

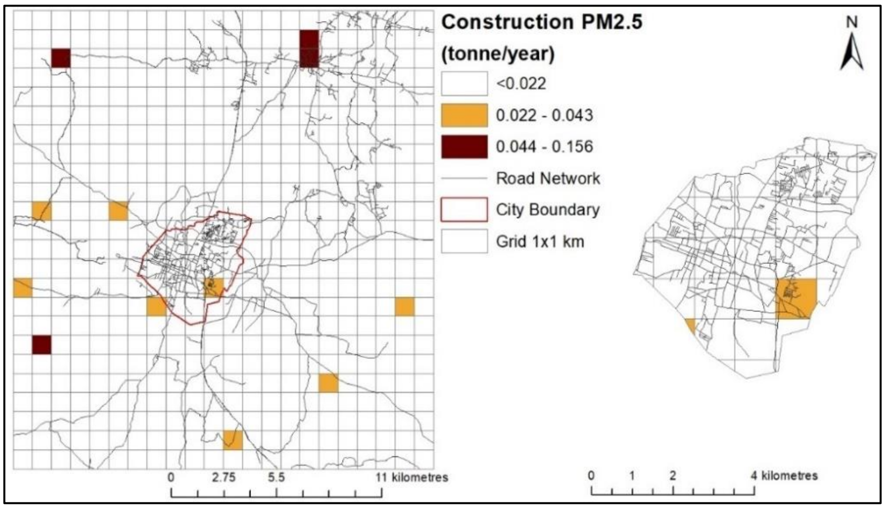

Figure 90: Spatial distribution of $PM_{2.5}$ emissions from construction in Hazaribagh

Total emission load:

For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 2583, 1245, 699, and 7000 tonnes/year, respectively, whereas those in the city area were 533, 283, 2133, and 15 tonnes/year, respectively. The sectoral contribution of $PM_{2.5}$ emissions in Hazaribagh city and its airshed is shown in Figure 91. Total $PM_{2.5}$ emissions indicated that transport, road dust, open burning, and domestic were the major contributors within the city. Contributions of eateries and construction activities were minor. Road dust, transport, industries, and domestic were the major contributors over the airshed, followed by minor contributions from open burning, mining, brick kilns, construction, eateries, and crushers within the city as well as over the airshed. Road dust, industries, and transport were major contributors to PM_{10}, SO_2, and NOx emissions, respectively.

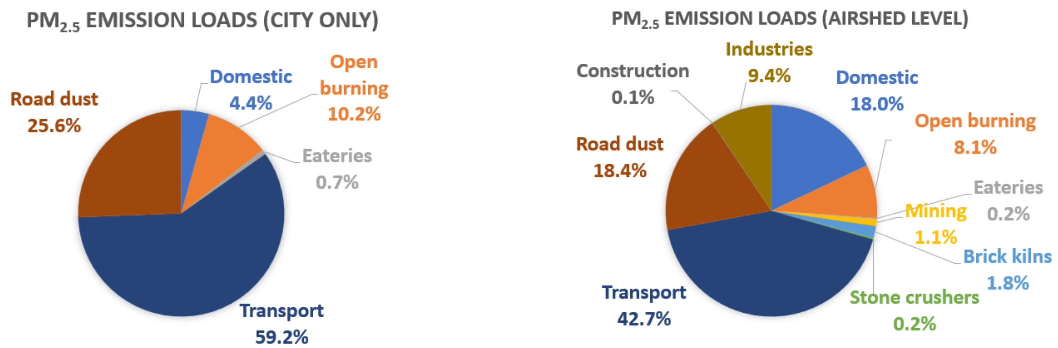

Figure 91: Sectoral contribution of $PM_{2.5}$ emissions at the a) city level and b) airshed level in Hazaribagh

Figure 92 presents the spatial distribution of $PM_{2.5}$ emission load in Hazaribagh airshed. The high emitting grids in the city (Kasai Mohallah, BTC chowk, Matwari chowk, Ompuri, Gandhi Maidan, Sultana, Katkamdag, Barasi, Dandai, and Mandu) were mostly attributed to sources such as transport, domestic, open burning, and road dust, whereas those outside the city (Dembu, Tumba, Hupad, Marhand, Nawada, and Morangi) were contributed by transport, industries, domestic, road dust, and open burning. The sector-wise spatial distribution of $PM_{2.5}$, SO_2, and NO_X emissions in Hazaribagh airshed is provided in the Annexure (Figure A79–Figure A100).

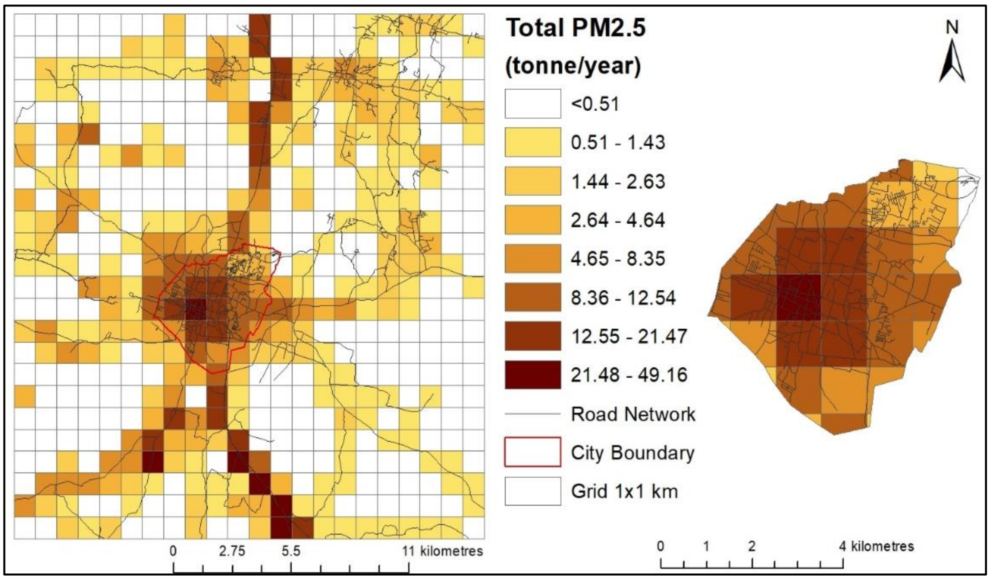

Figure 92: Spatial distribution of total $PM_{2.5}$ emissions in Hazaribagh

4.2.6. Ramgarh

Sectoral emission estimation

Domestic sector:

Since slum data were not available for the town, domestic survey in slums was not conducted. Estimation for both town as well as airshed was based on the PPAC (2016) state statistics and district NFHS (2019) and Census (2011) statistics. The proportion of households using domestic fuels and their consumption in the town and airshed areas are presented in Table 27. The total consumption of LPG, biomass, coal, dung cake, and kerosene in the town was estimated to be 1224, 1184, 9564, 304, and 2.1 tonnes/year, respectively. The total consumption of LPG, biomass, coal, dung cake and kerosene in the airshed was estimated to be 5914, 5,720, 46,211, 1468, and 10.4 tonnes/year, respectively.

Table 27: Percentage of households using domestic fuels and their consumption in the town and airshed areas

Type of fuel	%	Average fuel consumption (PPAC, 2016)				
		LPG (cylinder/month)	Biomass (kg/month)	Coal (kg/month)	Dung cake (kg/month)	Kerosene (kg/month)
LPG (NFHS, 2019)	33.2	1				
Biomass (Census, 2011)	3.8		150			
Coal (Census, 2011)	61.4			29		
Dung cake (Census, 2011)	1.3				132	
Kerosene (Census, 2011)	0.3					4

For the town area, emissions from the domestic sector were estimated to be 113.8 tonnes/year for PM_{10}, 89.6 tonnes/year for $PM_{2.5}$, 18.3 tonnes/year for NOx, and 49.5 tonnes/year for SO_2. For the airshed area, emissions from the domestic sector were estimated to be 550 tonnes/year for PM_{10}, 433.2 tonnes/year for $PM_{2.5}$, 88.3 tonnes/year for NOx, and 238.9 tonnes/year for SO_2. The total emission (from the airshed area) was spatially distributed over the airshed based on the population density. It was evident that emissions from the domestic sector were more concentrated outside the town. The airshed other than the town area contributed about 80% of the total domestic emissions (all pollutants). Higher emissions could be attributed to the high population density coupled with a large number of households using solid fuel for cooking (67.5%). Accessibility of coal from mines in the vicinity and low economic status prevent people from using clean fuel. Bhurkunda, Gegda, Suddi, Piri, and Chitarpur were the major locations contributing to domestic emissions in the airshed other than the city area. Goriaribag and Chowk areas were the major sites within the town (Figure 93).

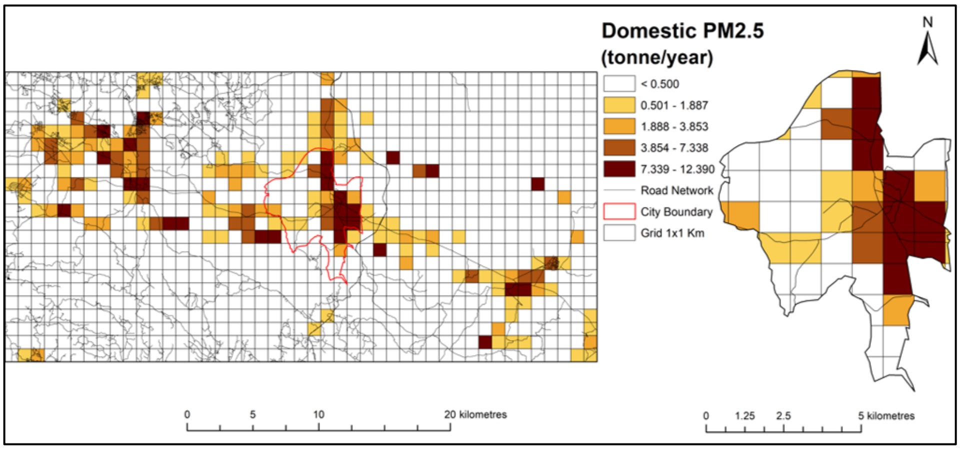

Figure 93: Spatial distribution of $PM_{2.5}$ emissions from the domestic sector in Ramgarh

Commercial cooking:

The field survey was performed at selected restaurants located in different parts of the town. We found that fuel use in restaurants varied by size and daily customer footfall. We divided the surveyed restaurants into two categories (small and medium restaurants; Figure 94). The percentage of restaurants using solid and clean fuels and their average fuel consumption are presented in Table 28. Both small and medium restaurants predominantly used solid fuels (wood and coal) for cooking. We found that coal was the dominant fuel used in majority of the restaurants. Easy accessibility of coal in the vicinity of the town at a lower cost drove the restaurants to use coal beside wood and LPG. We also found that some speciality restaurants used coal for making barbeque and tandoori food items. The average specific energy consumed in a year in medium restaurants using solid fuels (227 GJ) was more than 2.6 times higher than that in small restaurants (86 GJ).

The survey also revealed that small and medium restaurants (73% of the surveyed restaurants) used invertors during power cuts, whereas 27% of restaurants did not possess any power backup.

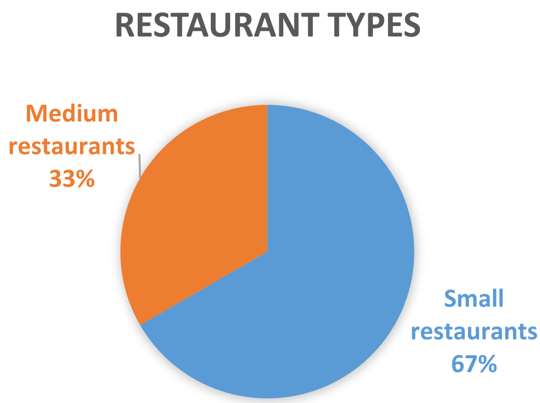

Figure 94: Share of restaurant types in Ramgarh

Table 28: Percentage of restaurants using solid and clean fuel and their average fuel consumption

Fuel used in restaurants	Percentage (%)	Fuel consumption			Annual specific energy consumption (GJ)
		Coal (C) (kg/ month)	Wood (W) (kg/ month)	LPG (L) (19 kg cylinder/ month)	
Small restaurants (footfall < 100)					
Mixed fuel (C+W)	19	300	50		98.16
C	65	250			73.8
L	16			4	41.04
Medium restaurants (footfall = 100–500)					
C	33	900			265.7
Mixed fuel (C+L)	58	500		6	209.16
Large restaurants (footfall > 500)					
Mixed fuel (C+W)	9	600	150		205.9

Data on the number of restaurants and their locations were obtained using Google API and then geo-located on the grids. About 145 restaurants were identified in the airshed. The total consumption of LPG, coal, and wood in restaurants in Ramgarh airshed was estimated to be 62, 564, and 19 tonnes/year, respectively. The emission from eateries was estimated to be 5.7 tonnes/year for PM_{10}, 4.4 tonnes/year for $PM_{2.5}$, 0.9 tonnes/year for NOx, and 2.8 tonnes/year for SO_2.

The spatial distribution of emissions from eateries was based on the number and type of eateries in each grid. It was evident that emissions from the eateries sector were more concentrated within the town. Emissions from eateries were greater in the areas with more commercial activities, such as Subhash Chowk, Bijulia, and MES colony (Figure 95). The high consumption of coal and wood in eateries contributed up to 98% of the total pollutant emissions. Overall, medium restaurants using solid fuels emitted 1.3 times more than small restaurants.

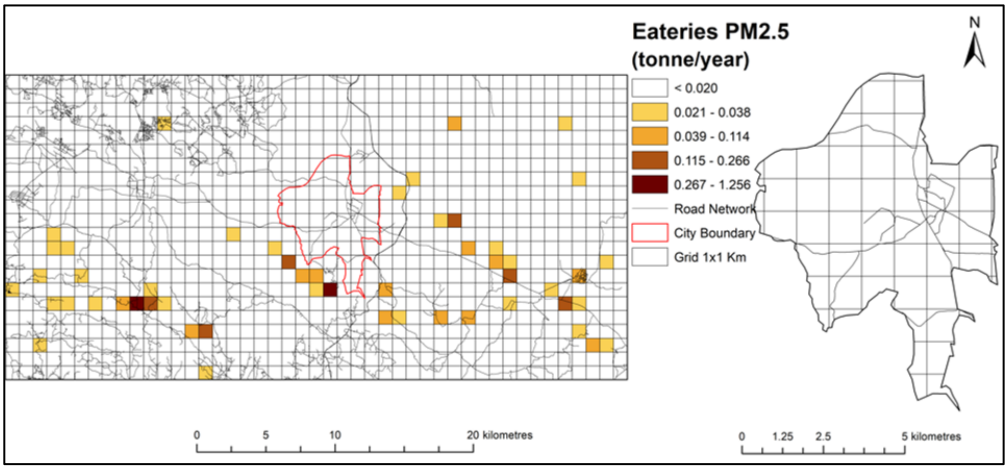

Figure 95: Spatial distribution of $PM_{2.5}$ emissions from eateries in Ramgarh

Transport emissions

The transportation survey was performed at petrol bunks to determine the vintage and VKT of vehicles. In total, 1106 vehicles were surveyed at six petrol bunks. From this survey, we determined the share of age of vehicles plying in Ramgarh and share of four-wheelers and three-wheelers on the basis of fuel type (petrol or diesel). Figure 96 and Figure 97 present the vintage and VKT of the vehicles plying in Ramgarh. The survey results revealed that 37% of the vehicles plying in Ramgarh were aged less than 5 years, 40% were aged between 5 and 10 years, and 22% were aged more than 10 years. The survey did not capture HCVs, as HCVs were restricted inside the town during the daytime (survey was conducted during the day). Further, most of the vehicles aged >10 years were from Ramgarh and Ranchi, as the Ramgarh RTO came into existence after 2007.

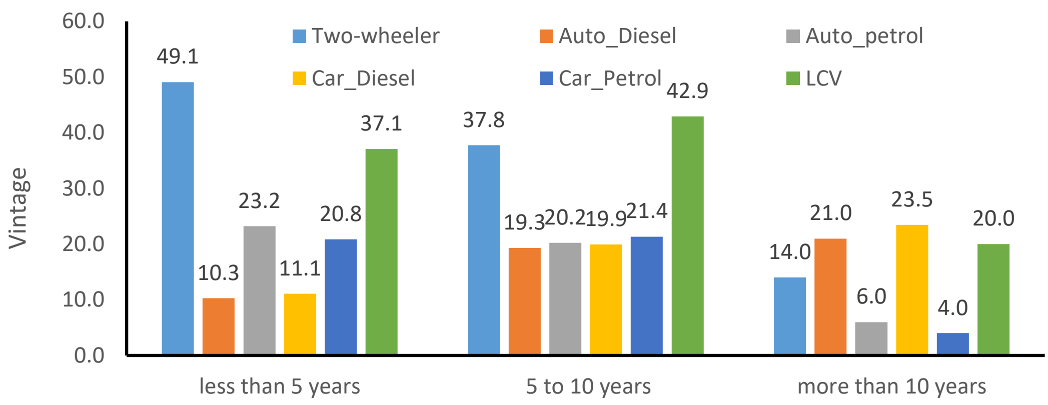

Figure 96: Vintage of vehicles plying in Ramgarh

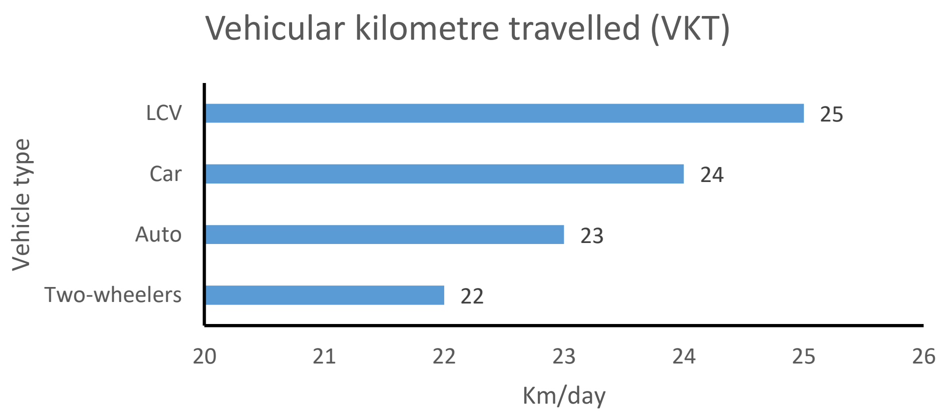

Figure 97: VKT of vehicles plying in Ramgarh

Tailpipe emissions*:* In most Indian cities, transportation is one of the biggest contributors to air pollution. Transport growth is largely influenced by demographic growth as well as economic growth. Like other cities, increase in population and economic activities led to an increase in vehicular population in the town, with an average annual vehicular growth rate of 46%. The year-wise cumulative vehicle registration in Ramgarh is shown in Figure 98.

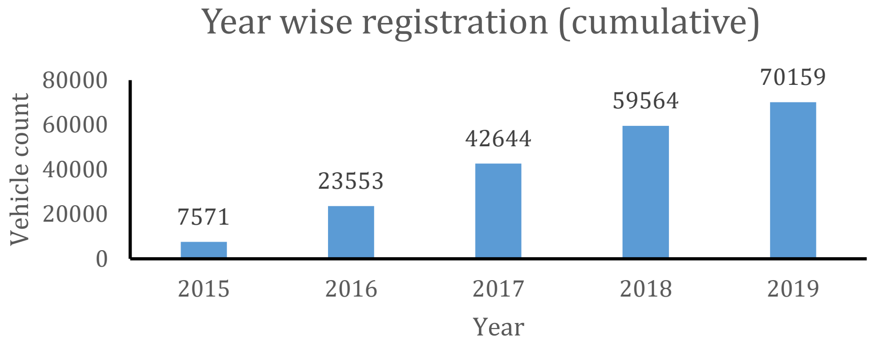

Figure 98: Year-wise vehicle registration in Ramgarh

Tailpipe emissions were estimated based on the VKT data obtained from the transportation survey and vehicle statistics obtained from the transport department and VAHAN database. The Ramgarh transport department came into existence after 2007; hence, data before 2010 were unavailable. The growth rate of transport in Ranchi was considered to project vehicle statistics before 2010 for Ramgarh. The share of vehicle types plying on road in Ramgarh is shown in Figure 99.

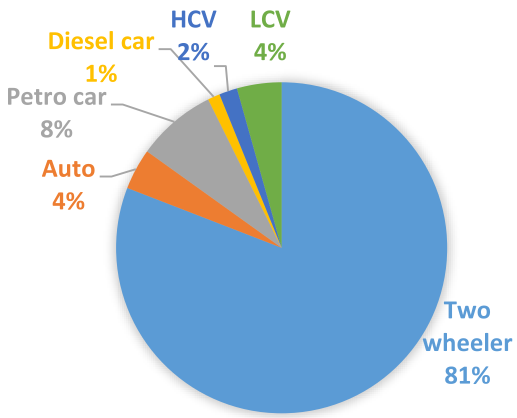

Figure 99: Share of vehicles plying in Ramgarh

Tailpipe emissions were estimated to be 153 tonnes/year for PM_{10}, 140 tonnes/year for $PM_{2.5}$, and 1235 tonnes/year for NOx. HCVs and LCVs contributed around 53% and 35% of the PM emissions, respectively, of which 76% of HCV emissions and 57% of LCV emissions were emitted from vehicles aged >10 years. HCVs (including buses) constituted only 2% of the total number of vehicles plying in Ramgarh but contributed 76% of the PM emission load from transportation. Two-wheelers and diesel autos contributed about 7% and 4.6% of the PM emissions, respectively, whereas diesel cars and petrol cars contributed about 1% and 0.2% of the PM emissions, respectively. About 50% of the two-wheeler PM emissions were emitted from vehicles aged >10 years. $PM_{2.5}$ emissions from different vehicle types are shown in Figure 100.

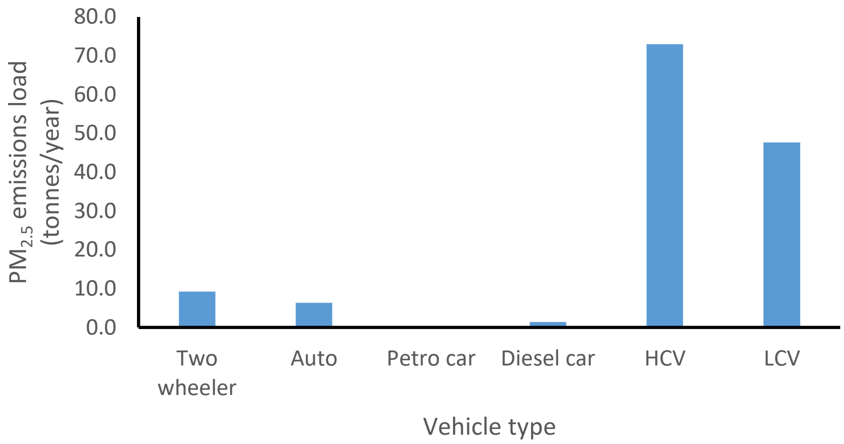

Figure 100: $PM_{2.5}$ emission load across vehicle types in Ramgarh

Transport emissions were distributed based on the population density and fraction of road networks. The total length of national highways, state highways, and major roads in the airshed was identified to be 76, 52, and 52 km, respectively. Vehicular emission was found to be high on main roads in the town because of the high heterogeneous traffic volume. The emissions on these roads were contributed by the movement of mixed traffic (including HCVs). Emissions from these roads attributed to only 14% of the transport PM emission share. The major share of the transport PM emissions was contributed by state and national highways located outside the town, mainly emitted from HCVs and LCVs. National Highway 20 and Chitarpur State Highway contributed 40% and 11% of the transport PM emissions (Figure 101).

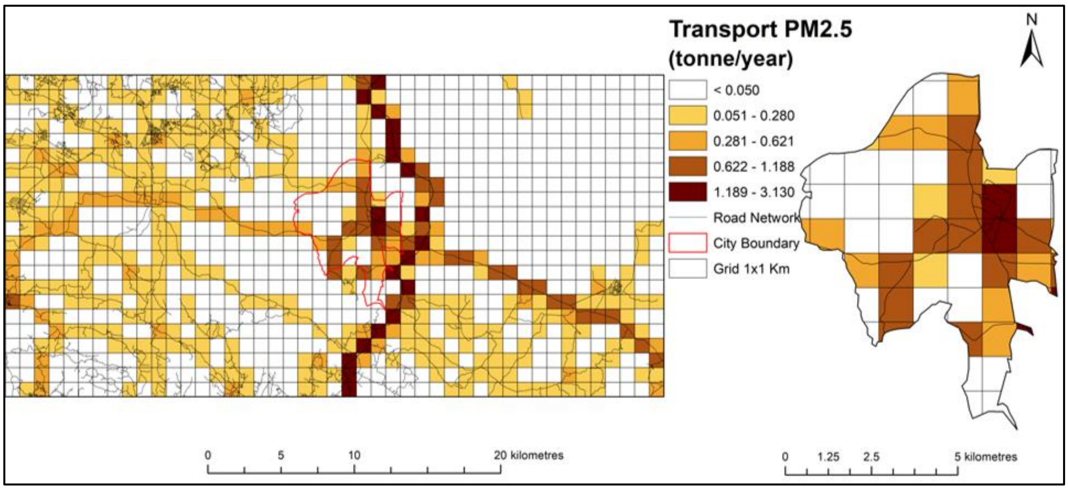

Figure 101: Spatial distribution of $PM_{2.5}$ emissions from the transport sector in Ramgarh

Resuspension of dust: Along with tailpipe emissions, vehicular movement is responsible for the resuspension of dust. For the estimation of road dust, road type data were also considered in addition to road network data. The EF for road dust varies with the road type (paved or unpaved), vehicle share, and climatic conditions. The emission from resuspension of dust was estimated to be 159 tonnes/year for PM_{10} and 39 tonnes/year for $PM_{2.5}$. Around 14% of the PM emissions from road dust were contributed by main roads in the town, and the major share of the road dust PM emissions was contributed by roads located outside the town (Figure 102).

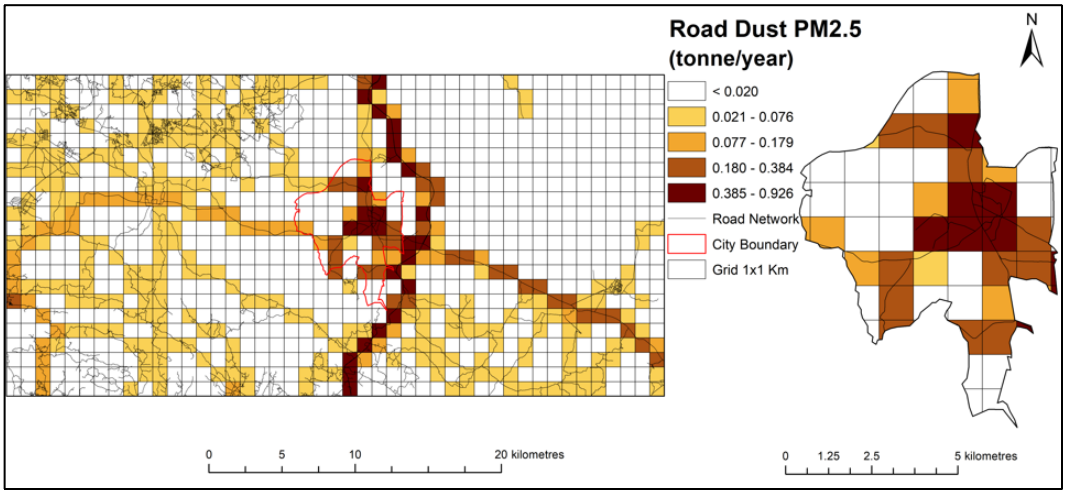

Figure 102: Spatial distribution of $PM_{2.5}$ emissions from resuspension of dust in Ramgarh

Industrial emissions

Coal mines were mostly located in the north-west part of the airshed, whereas stone mines were scattered in the southern and eastern parts of the airshed. Stone crushers were mostly located in the southern and western parts of the airshed. In total, 10 coal mines were identified in the airshed, with an area of 1384 acres and production of 8.42 million tonnes/year. Further, 29 stone mines were identified in the airshed, with an area of 136 acres and production of 2.7 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from coal mining in the airshed were estimated to be 421 and 42 tonnes/year, respectively. The PM_{10} and $PM_{2.5}$ emissions from stone mining in the airshed were estimated to be 135 and 13.5 tonnes/year, respectively. Coal blocks in Garsula, Kurkuta, Gidi, Religara, and Dari emitted significant fugitive dust emissions in the airshed (Figure 103). Chuttupalu and Piska were the major sites with high emissions from stone mining (Figure 103).

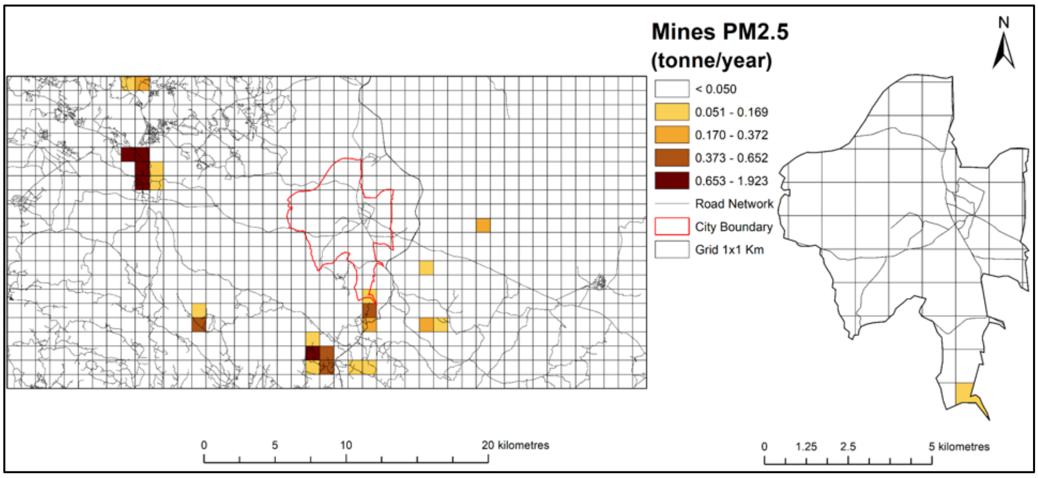

Figure 103: Spatial distribution of $PM_{2.5}$ emissions from mining in Ramgarh

Eighty stone crushers were identified in the airshed and were mainly located in the airshed area other than the town area. The total production of stone crushers in Ramgarh airshed was around 1.6 million tonnes/year. The PM_{10} and $PM_{2.5}$ emissions from stone crushers in the airshed were estimated to be 1.88 and 0.94 tonnes/year, respectively. Chuttupalu, Piska, and Jidu were the major locations with high emissions from stone crushers (Figure 104).

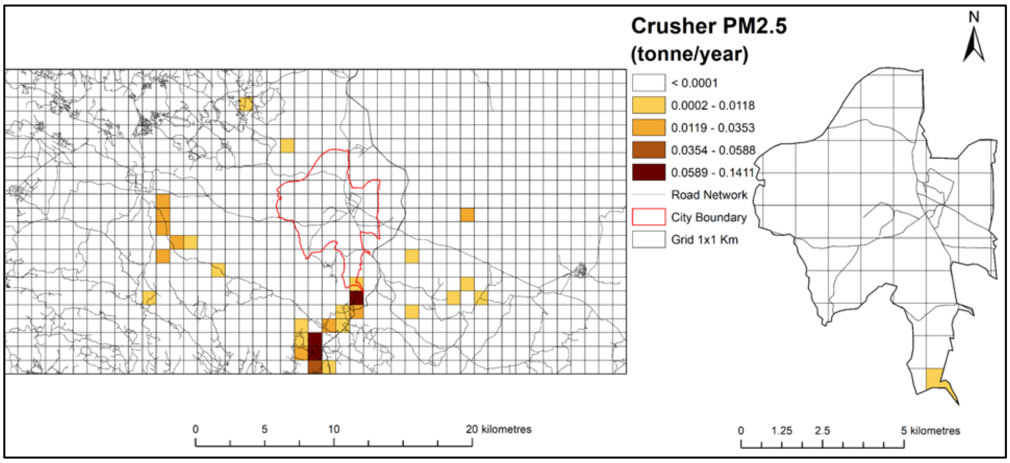

Figure 104: Spatial distribution of $PM_{2.5}$ emissions from stone crushers in Ramgarh

The total energy consumption of the stack-based industries based on their fuel usage is shown in Figure 105.

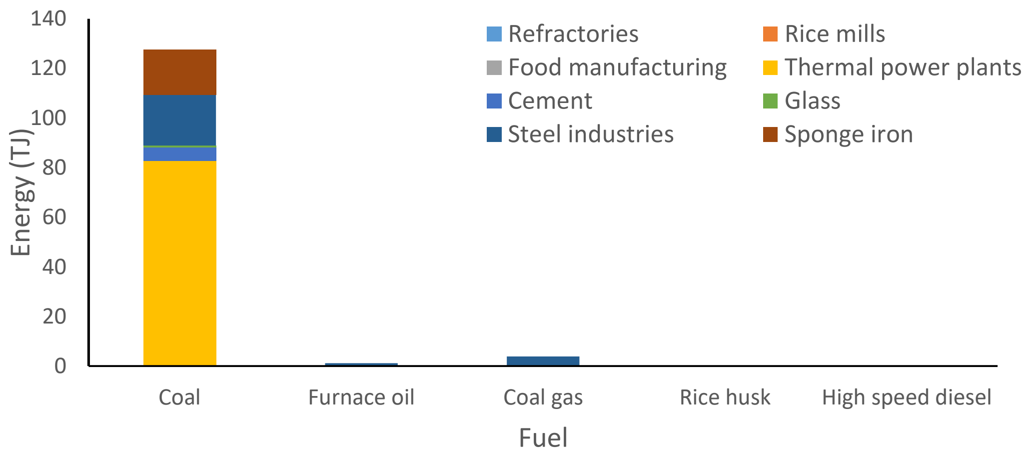

Figure 105: Total energy consumption of the industries based on their fuel usage

Emissions from sponge iron, glass, iron and steel, and cement plant (high energy intensive) were estimated with a control efficiency of 95% for PM emissions and 50% for SO_2 and NO_X emissions, whereas rice mills, brick kilns, refractories, and food processing emissions were uncontrolled. Emissions from thermal power plants were estimated with a control efficiency of 98% for PM emissions and 50% for SO_2 and NOx emissions. The emission estimation was either based on production of the units or fuel consumed in the units.

The stack-based industrial emission was estimated to be 12887 tonnes/year for PM_{10}, 3438 tonnes/year for $PM_{2.5}$, 17870 tonnes/year for NO_x, and 16801 tonnes/year for SO_2. High pollutant emissions were observed from thermal power plants, followed by iron and steel industries. These industries used a high proportion of coal in their energy mix. Besides combustion emissions from kilns in iron and steel industry, melting furnaces and rolling mills also contributed significantly to PM and NOx emissions. Highest SO_2 emissions were observed from thermal power plants.

Energy consumption of sponge iron plants was higher than that of cement plants, but their PM emissions were relatively lower. Besides combustion emissions from cement plants, processes such as grinding and crushing of raw materials and grinding of clinkers produced also contributed to the PM emissions. However, both of these industries emitted significant PM and SO_2 emissions. The rate of conversion of SO_2 to particulate sulphate is high (between 1% and 3% per hour); hence, SO_2 and PM treatments are equally important. Glass manufacturing is another energyintense industry that consumes a high amount of coal in the energy mix and generates considerable emissions.

Despite being medium energy-intensive industries, rice mills, refractories, and brick kilns also emitted significant pollutant emissions. Rice mills use rice-husk fired steam boilers for rice processing or even a driving force for power generation. The inefficiency of the boilers and use of rice husk as a fuel induce the release of significant PM emissions during combustion. Rice mills should focus on partially replacing biomass or solid fuel usage in boilers with gas or HSD. Fugitive emissions and emissions from rice husk-fired boilers can be effectively controlled using bag-filters; however, most mills have adopted cyclones as a control technology. Authorities should strictly enforce the use of bag filters in rice mills. Refractories use coal in their kilns to melt and deform the metallurgy or ceramic materials. Refractories should focus on the replacement of coal with clean fuels such as natural gas. Agarda, SAIL, IFICO, Bangada, Patratu, and Kamta were the major industrial sites with high emissions from industries (Figure 106).

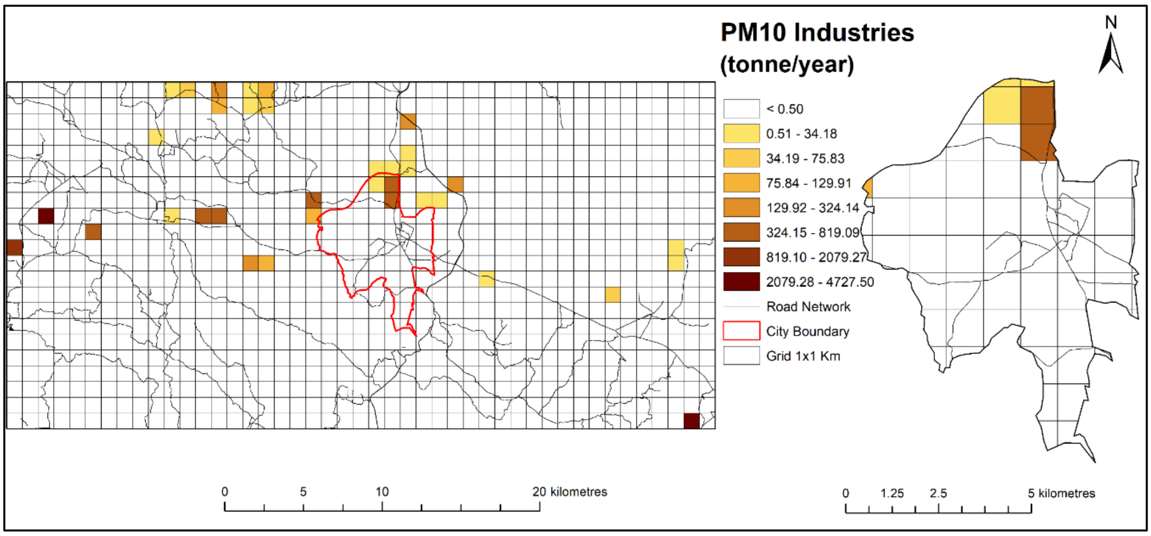

Figure 106: Spatial distribution of $PM_{2.5}$ emissions from industries in Ramgarh

Brick kilns were mostly located in the eastern and southwestern regions of the airshed. Brick kilns are commonly located around the towns and cities, which are high demand centres for bricks. The fixed-chimney bull's trench kiln emits significant PM emissions, including black carbon, SO_2, and NO_x. It has been ranked as the most contaminating technology for brick production, resulting in numerous adverse environmental impacts, such as climate change, deforestation, and land use impacts, as well as health effects such as cardiorespiratory diseases. Kaitha, Gobardarha, Piri, and Masmohana were the major sites with high emissions from brick kilns in the airshed (Figure 107).

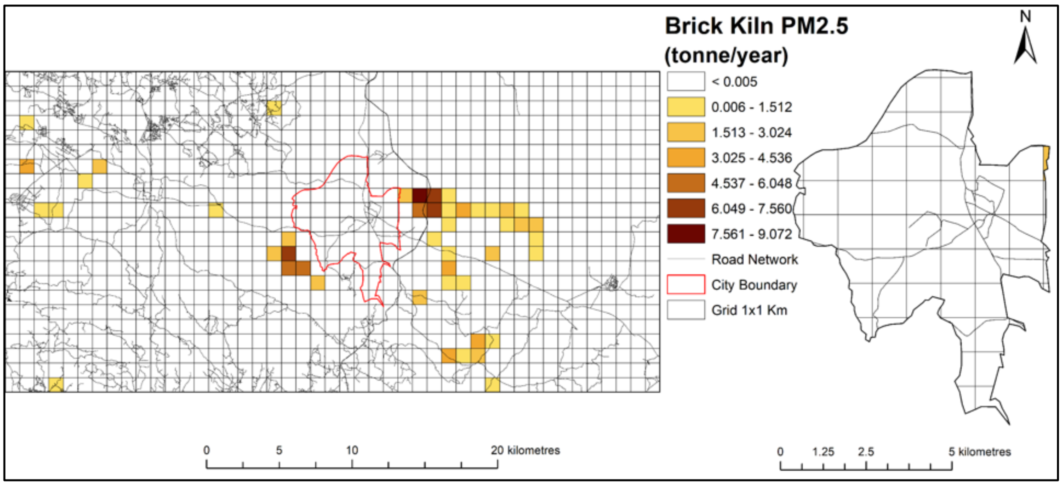

Figure 107: Spatial distribution of $PM_{2.5}$ emissions from brick kilns in Ramgarh

Figure 108 presents the $PM_{2.5}$ emissions from various industries present in the Ramgarh airshed. Thermal power plants contributed around 1276 tonnes/year, followed by iron and steel plants (1011 tonnes/year) and cement industries (691 tonnes/year). Iron plants, brick kilns, refractories were the other air polluting industries in the region.

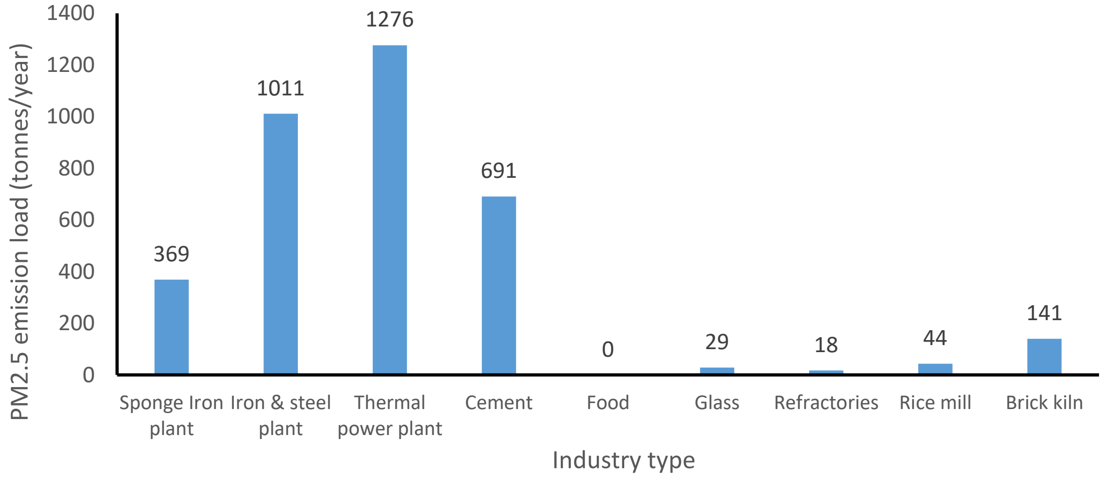

Figure 108: Industry-wise contribution to $PM_{2.5}$ emissions in Ramgarh

Open burning:

The per capita generation of waste in Ramgarh was 474 g/day, and the total waste generated in the town was 51 TPD. The collection efficiency in the town was 33%. It was estimated that around 1254 tonnes of solid wastes generated are being burned every year in the airshed.

For space heating, emissions were calculated based on the proportion of households using different solid fuels for heating. Nearly 78% of the households in Ramgarh used coal as the primary fuel for space heating during winter, followed by wood (22%; Census, 2011). Consumption data (wood = 1 kg/household/day; coal = 1 kg/household/day) were obtained from the field survey. The 4-month winter period was considered for the estimation. Total consumption of biomass and coal in the airshed was estimated to be 7369 and 9820 tonnes/year, respectively.

The total emission from open burning was calculated to be 160 tonnes/year for PM_{10}, 129 tonnes/year for $PM_{2.5}$, 26.7 tonnes/year for NOx, and 44.2 tonnes/year for SO_2. The emissions were distributed in the airshed based on the population density. Bhurkunda, Goriyabag, Block Chowk, Gegda, Suddi, Piri, and Chitarpur were the areas with high emissions from open burning (Figure 109).

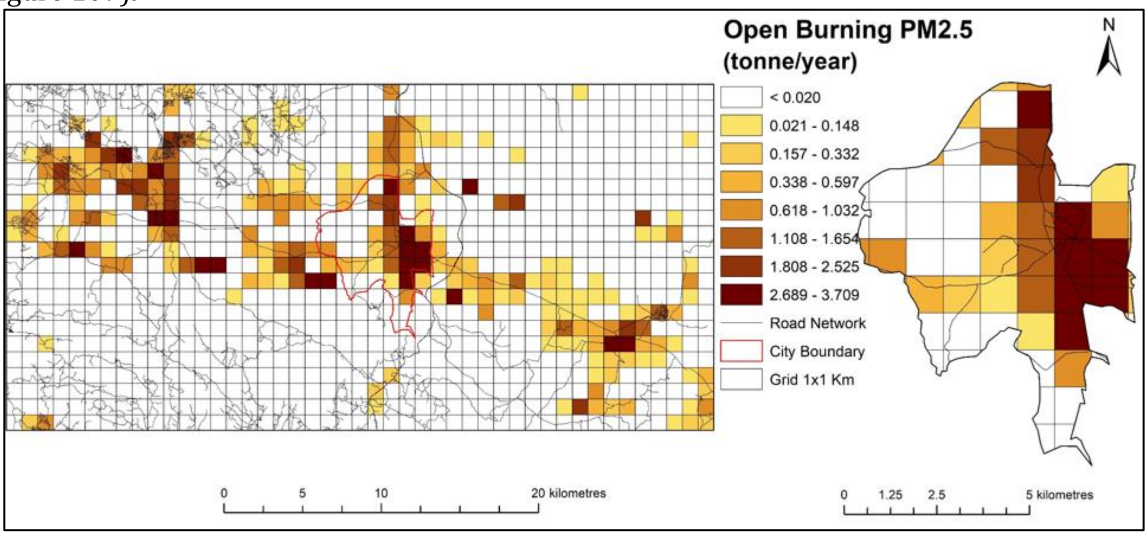

Figure 109: Spatial distribution of $PM_{2.5}$ emissions from open burning in Ramgarh

Construction and demolition:

The emissions were estimated based on the rise in built-up areas in a time frame and duration of that construction activity. During 2019–2020, we identified around 0.8 and 3.4 acres rise in the built-up area in the town and airshed, respectively. The emissions from construction sites were estimated to be 4.27 tonnes/year for PM_{10} and 0.71 tonnes/year for $PM_{2.5}$. The emissions were distributed in the airshed based on satellite imagery. The construction activities were scattered across the airshed with few sites inside the town, and the scale of construction activities was mostly residential (Figure 110). The construction activities within the town accounted only for 23% of the total PM emissions from construction.

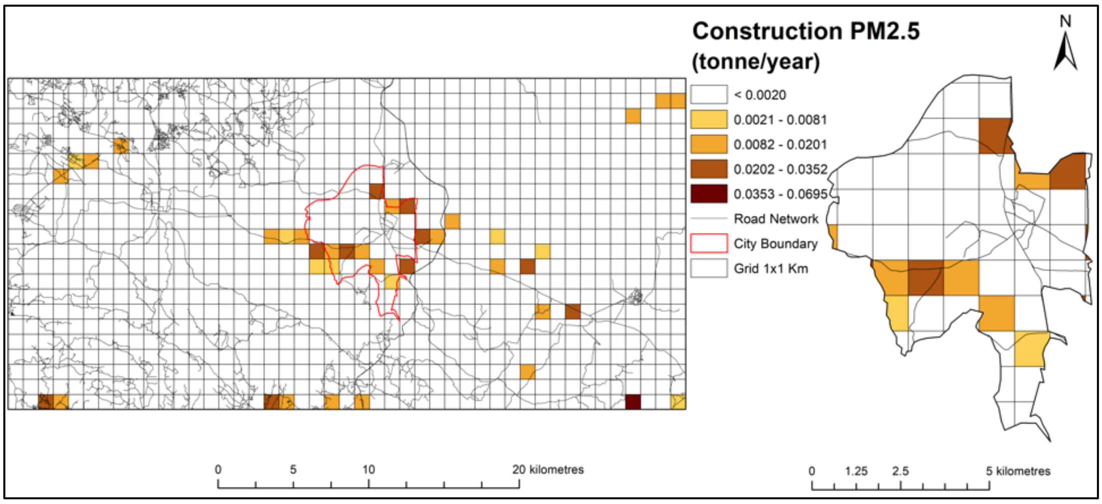

Figure 110: Spatial distribution of $PM_{2.5}$ emissions from construction activities in Ramgarh

Total emissions:

For the base year 2019, PM_{10}, $PM_{2.5}$, SO_2, and NO_X emissions in the airshed area were estimated to be 14426, 4192, 17087, and 13778 tonnes/year, respectively, whereas those in the city area were 1424, 801, 1041, and 396 tonnes/year, respectively. The sectoral contribution of $PM_{2.5}$ emissions in Ramgarh city and its airshed is shown in Figure 111 and Figure 112, respectively. The total $PM_{2.5}$ emissions within the city indicated that industries were the major contributors to $PM_{2.5}$ emissions, followed by domestic sector, transportation, open burning, mining, and road dust. In contrast, industries were the major contributors over the airshed, followed by domestic, open burning, transport, and road dust. Contributions from stone crushers and construction were minor within the city as well as over the airshed. Industries were the major contributors for all pollutants. Excluding the industries within the town, the domestic sector was the major contributor, followed by open burning, transport, and road dust.

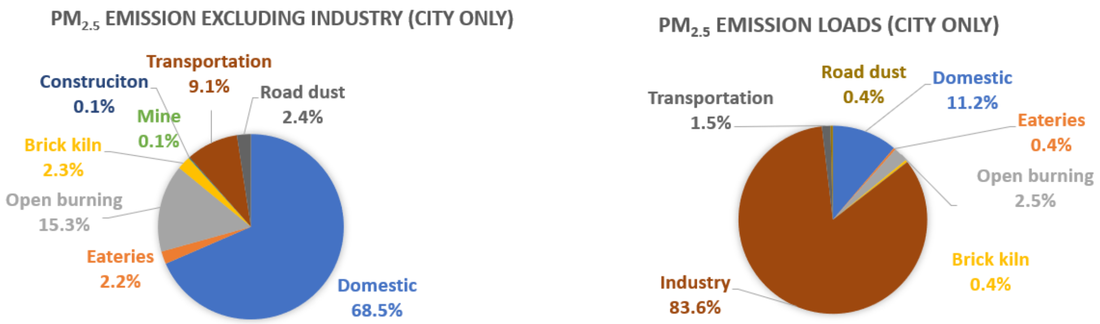

Figure 111: Sectoral contribution of $PM_{2.5}$ emissions in Ramgarh a) excluding and b) including industries

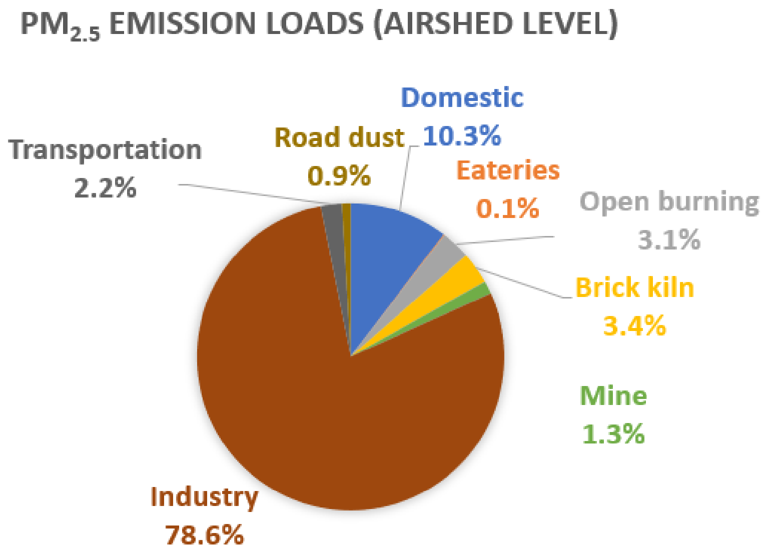

Figure 112: Sectoral contribution of $PM_{2.5}$ emissions at the airshed level in Ramgarh

Figure 113 presents the spatial distribution of $PM_{2.5}$ emission load in Ramgarh airshed. The high emitting grids (Argada, Patratu, Chaingara, and Kamta) were mainly attributed to industrial sources over the airshed as well as the town. The sector-wise spatial distribution of $PM_{2.5}$, SO_2, and NO_X emissions in Ramgarh airshed is provided in the Annexure (Figure A101–Figure A120).

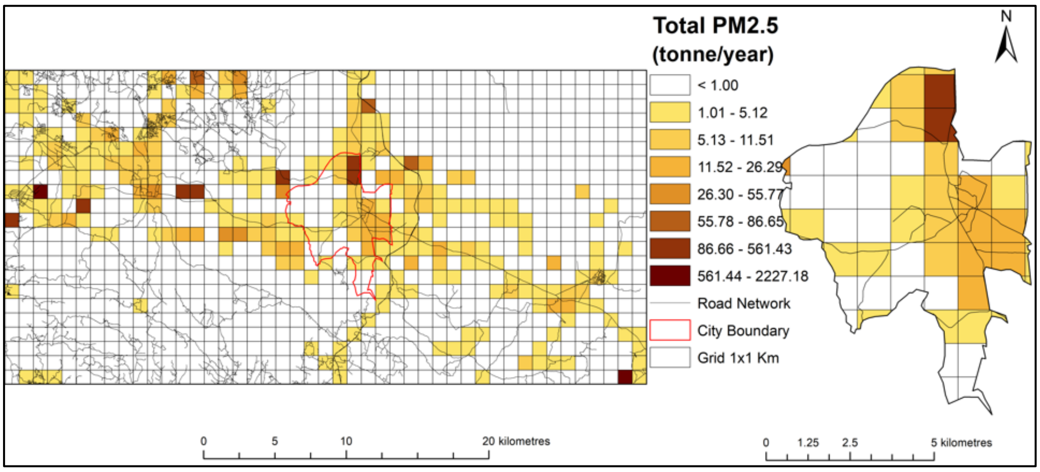

Figure 113: Spatial distribution of total $PM_{2.5}$ emissions in Ramgarh

5. Way forward

Holistic approaches are warranted to reduce emissions in the study cities. Of note, these cities do not have the required population for establishing a full-fledged public transportation system. Most of these cities have a rudimentary mass transport system with inter-city buses, point-to-point auto-rickshaws, and cars (six seater and more) serving as within-city transport. Fuel shift in these modes of transportation (CNG buses and cars and electric auto rickshaws) will significantly reduce emissions. As a large portion of transport emissions are generated from HCVs, new roads bypassing the city area need to be constructed.

The major polluting industries need to be shifted from the city areas. In addition, these industries need to adopt cleaner technologies for air pollution mitigation. The authorities should encourage energy-intensive industries to replace energy-intensive fuels and promote the utilisation of clean energy. Coal used in cement plants for burning kilns should be replaced by clean energy sources, such as natural gas. Coal usage in sponge iron and iron and steel plants can be minimised by partially replacing coal with a coal-based gasifier, which increases the energy efficiency of the plant and reduces coal consumption. The use of pet-coke in these industries should be completely banned. Furthermore, end-of-pipe treatment technologies used in cement and iron and steel industries should maintain a control efficiency greater than 98% for PM and 90% for SO_2 to meet the Indian PM and SO_2 norms. The end-of-pipe treatment technologies in thermal power plants should maintain a control efficiency greater than 99.5% for PM and 90% for SO_2 to meet the Indian PM and SO_2 norms. In addition, these industries should focus on more advanced end-of-pipe treatment technologies, such as low-nitrogen combustion technologies, denitrification devices, and high-efficiency desulphurisation devices to remove pollutants.

Dust suppression is the most common technique used to control particulate emissions in stone mining and crushing activities. Water wetting arrangements for drilling and hauling activities, capturing and venting control devices and wet-dust suppression arrangements for crushing, and screening and conveying activities can significantly reduce PM emissions. Treatment with surface agents, soil stabilisation, and pavement of roads for hauling operations can also curtail PM emissions. Authorities should strictly enforce the use of these control technologies in mining and crushing units and should regularly monitor these units by installing air quality sensors.

The government should focus on converting traditional brick kilns to the zig-zag technology. Traditional bricks kilns do not ensure a uniform distribution of temperature in the firing zone, and hence, only 60%–70% of the bricks are properly fired. The zig-zag technology ensures a more uniform distribution of temperature, and hence, 80%–90% of the bricks are properly fired. The zig-zag technology increases the energy efficiency of the kiln and enables the production of good-quality bricks. Moreover, this technology can save up to 10% energy and reduce suspended PM, $PM_{2.5}$, and SO_2 emissions by 70%, 27%, and 52%, respectively. Strengthening the monitoring infrastructure in brick kiln clusters by installing sensors will help in the effective management of pollution levels.

Use of solid fuels for cooking results in direct exposure to pollutants (specifically $PM_{2.5}$). This aggravates health problems (such as asthma, chronic obstructive pulmonary disorder, heart disorders, and bronchial problems) among vulnerable sections of the society. Access to LPG will help reduce the use of solid fuels for cooking and thus prevent harmful exposure. However, for many people, economic condition can be a major hurdle in the continuous use of LPG cylinders. Although government schemes such as the Pradhan Mantri Ujjwala Yojana have helped low-income families obtain LPG connections, many households do not refill cylinders after the subsidy expires. Authorities should prioritise LPG connections not only within the town but also in its vicinity, which will help reduce emissions from the domestic sector.

Considering the emissions from wood burning are responsible for 83% of the overall emissions from eateries, the government should consider restricting the sale of wood in the towns. Further, small-scale restaurants should be encouraged to adopt alternative methods of cooking, and use of cleaner fuels should be made mandatory for all restaurant types.

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Annexure

Grid-Wise Emissions: Sahibganj

PM_{10}- Sahibganj

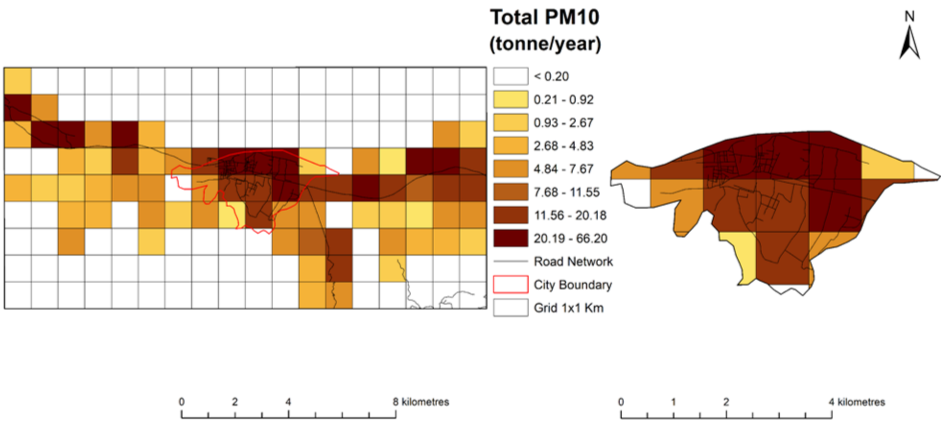

Figure A1 Spatial distribution of total PM_{10} emissions in Sahibganj

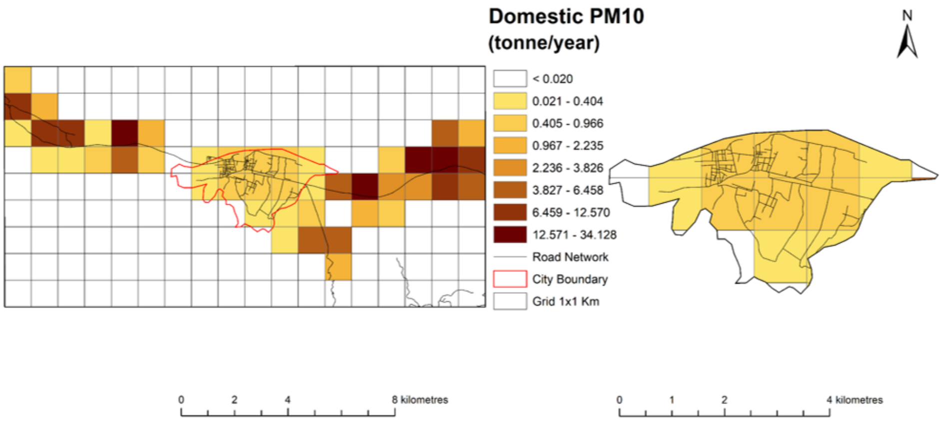

Figure A2 Spatial distribution of PM_{10} emissions from the domestic sector in Sahibganj

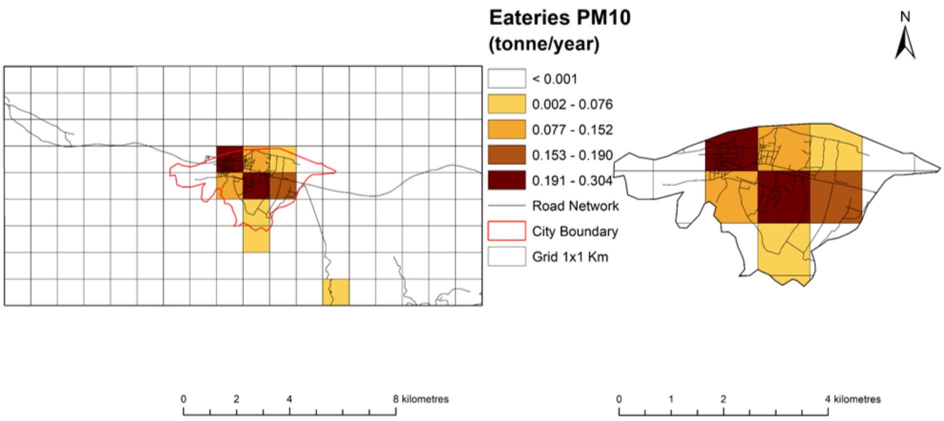

Figure A3 Spatial distribution of PM_{10} emissions from eateries in Sahibganj

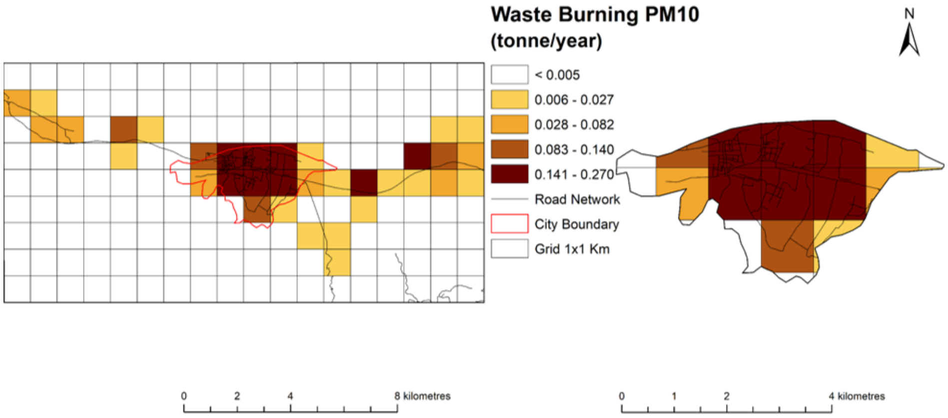

Figure A4 Spatial distribution of PM_{10} emissions from waste burning in Sahibganj

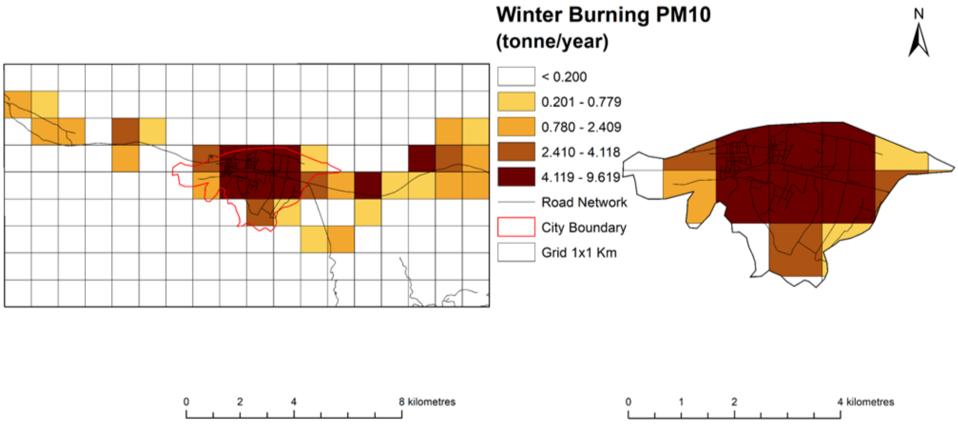

Figure A5 Spatial distribution of PM_{10} emissions from winter burning in Sahibganj

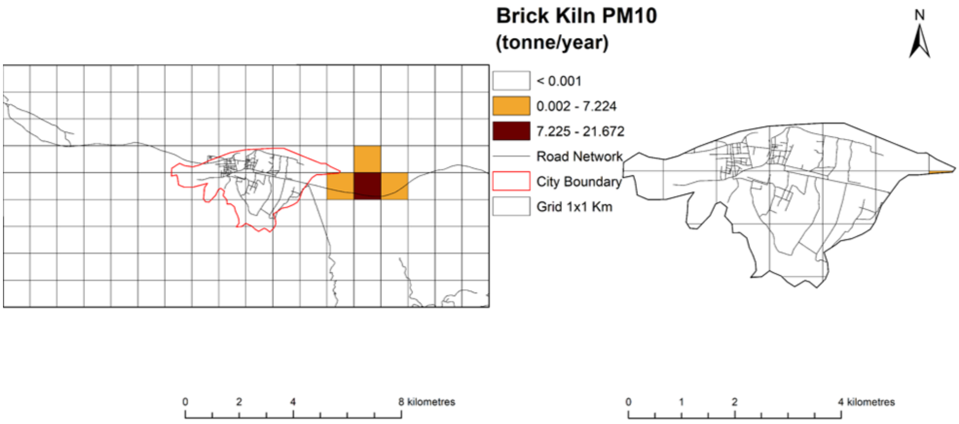

Figure A6 Spatial distribution of PM_{10} emissions from brick kilns in Sahibganj

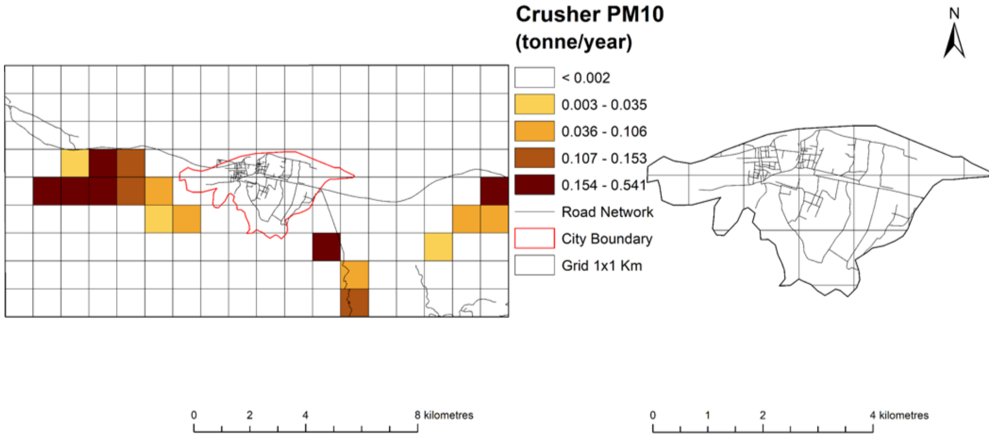

Figure A7 Spatial distribution of PM_{10} emissions from stone crushers in Sahibganj

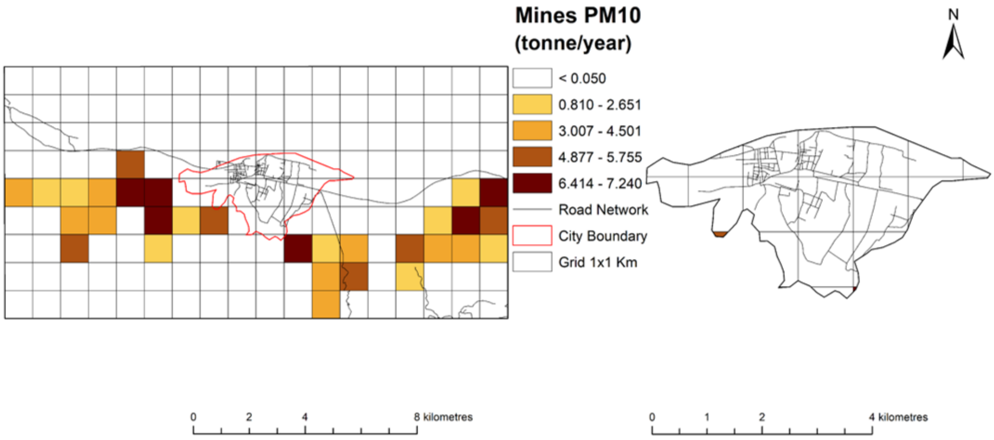

Figure A8 Spatial distribution of PM_{10} emissions from mines in Sahibganj

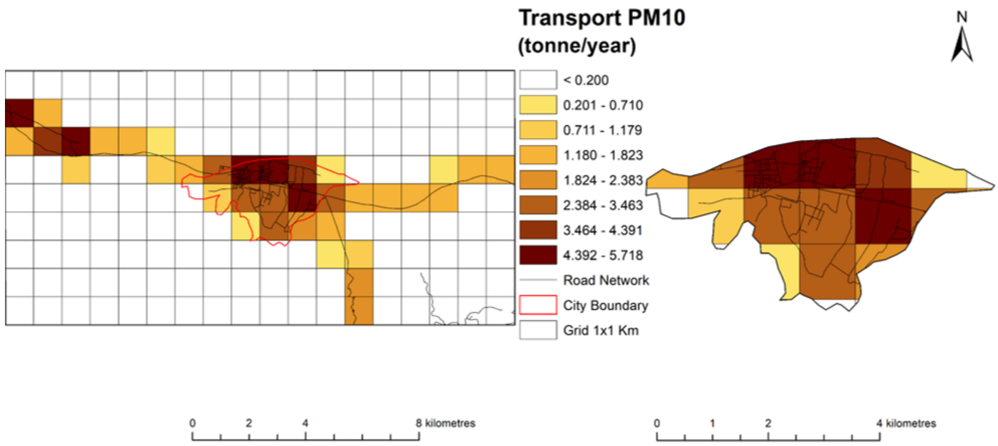

Figure A9 Spatial distribution of PM_{10} emissions from transport in Sahibganj

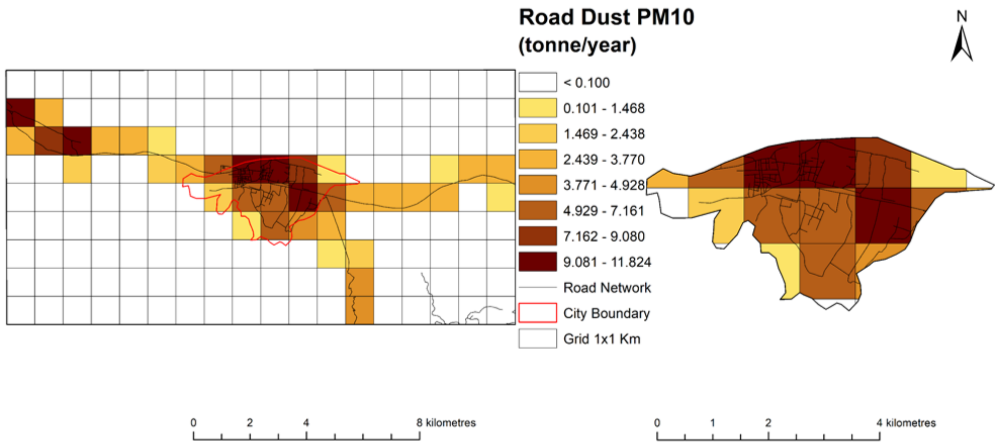

Figure A9 Spatial distribution of PM_{10} emissions from road dust in Sahibganj

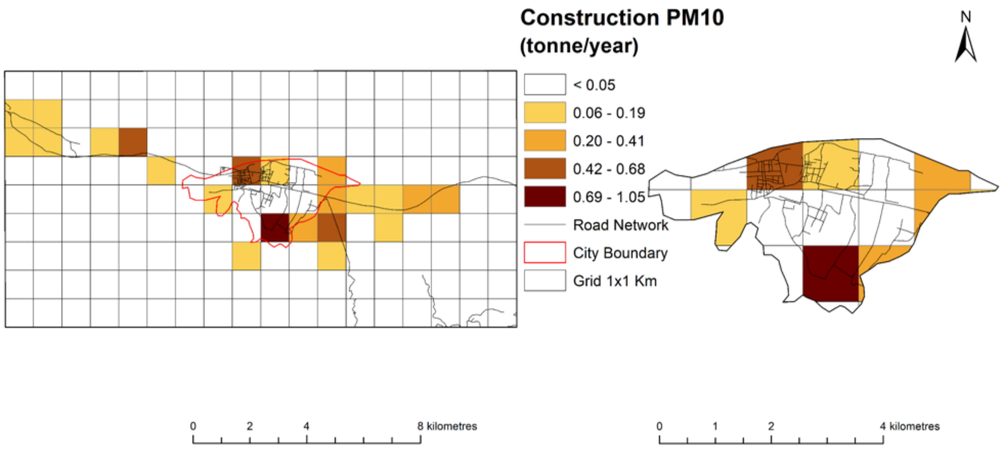

Figure A10 Spatial distribution of PM_{10} emissions from construction in Sahibganj

SO2- Sahibganj

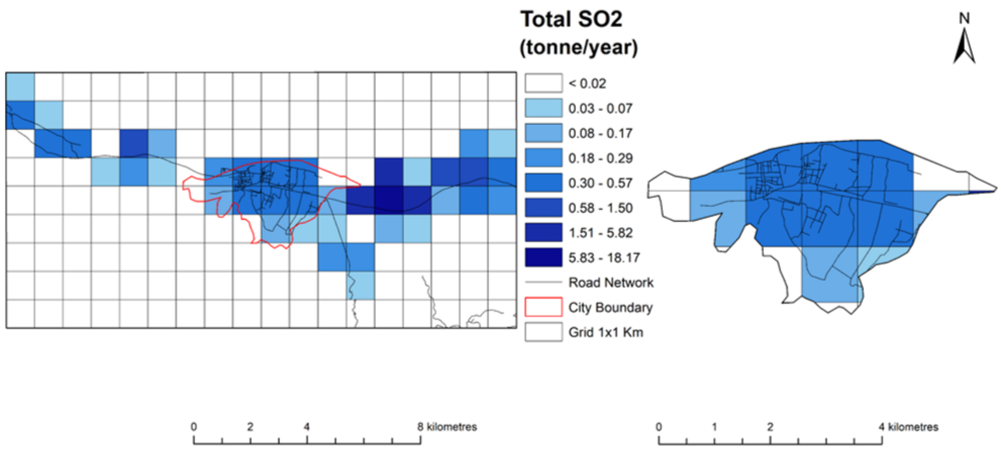

Figure A11 Spatial distribution of total SO_2 emissions in Sahibganj

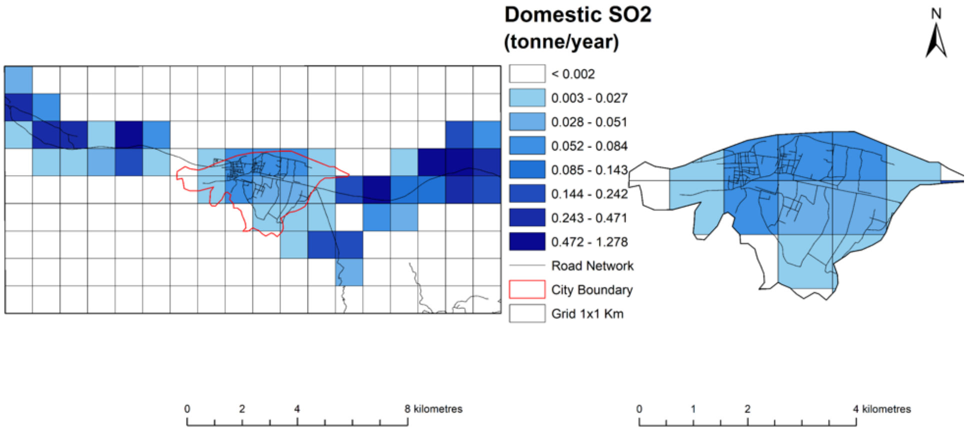

Figure A12 Spatial distribution of SO_2 emissions from the domestic sector in Sahibganj

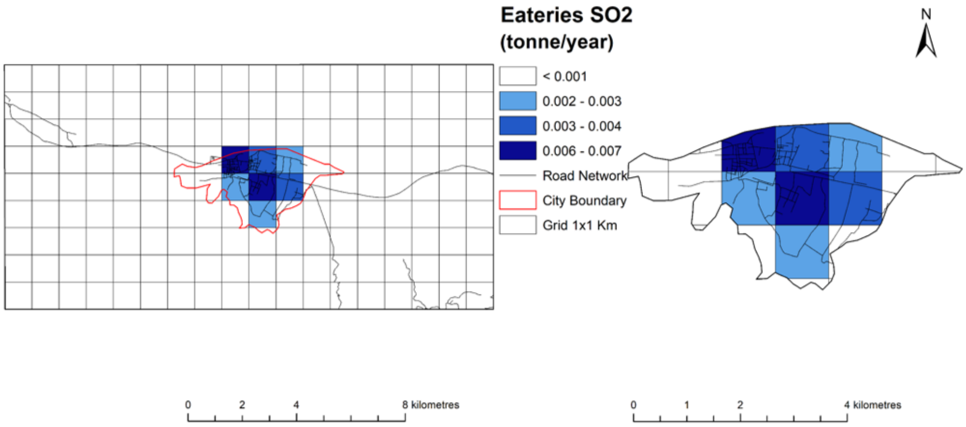

Figure A13 Spatial distribution of SO_2 emissions from eateries in Sahibganj

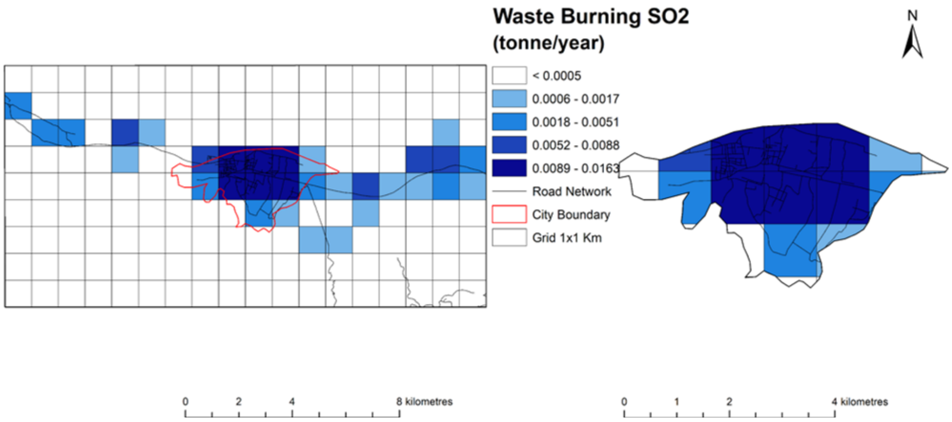

Figure A14 Spatial distribution of SO_2 emissions from waste burning in Sahibganj

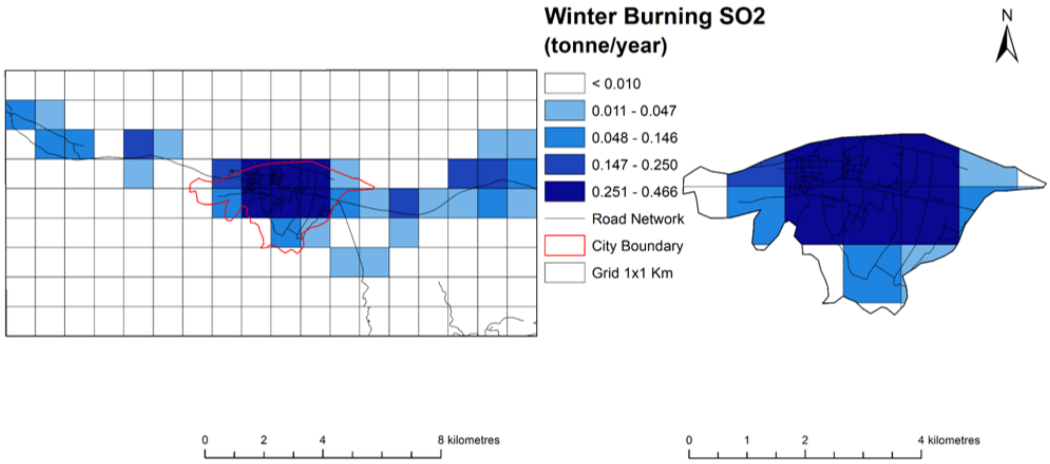

Figure A15 Spatial distribution of SO_2 emissions from winter burning in Sahibganj

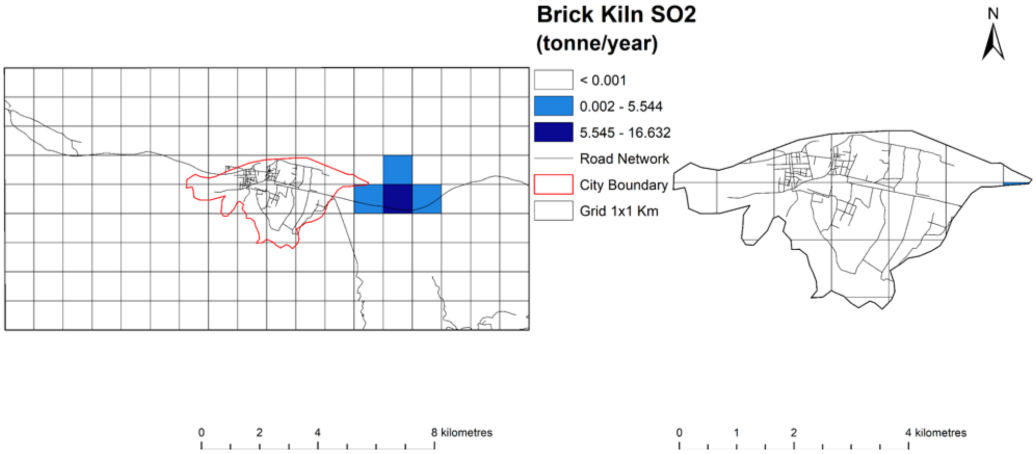

Figure A16 Spatial distribution of SO_2 emissions from brick kilns in Sahibganj

NOx- Sahibganj

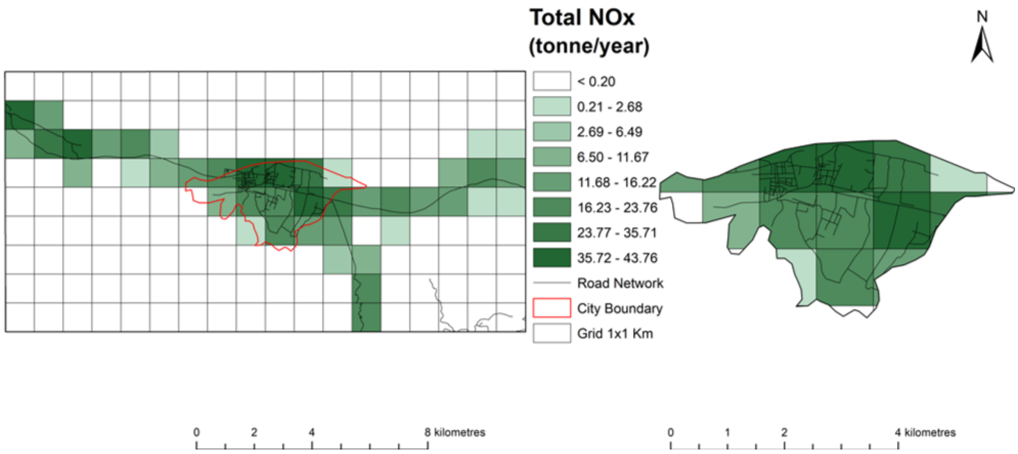

Figure A17 Spatial distribution of total NO_x emissions in Sahibganj

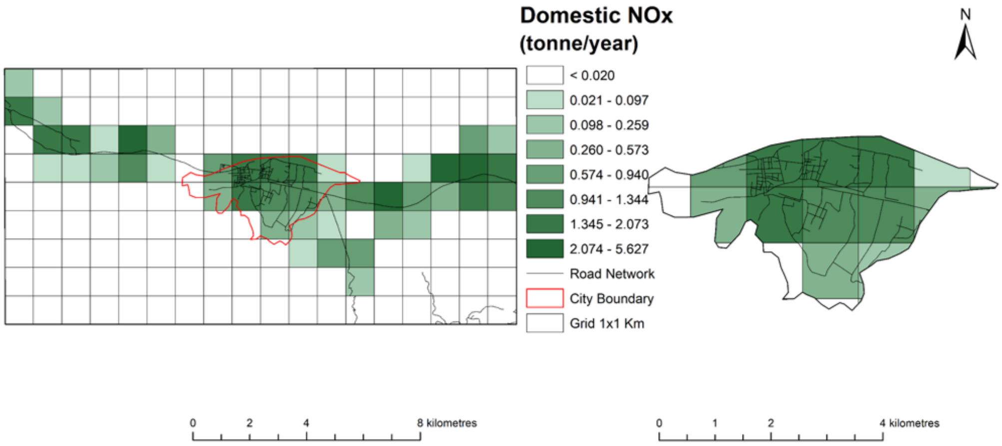

Figure A18 Spatial distribution of NO_x emissions from the domestic sector in Sahibganj

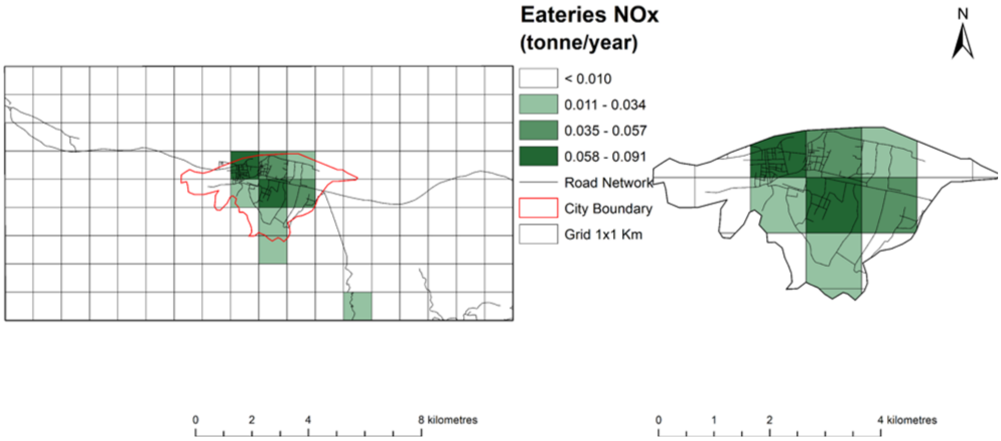

Figure A19 Spatial distribution of NO_x emissions from eateries in Sahibganj

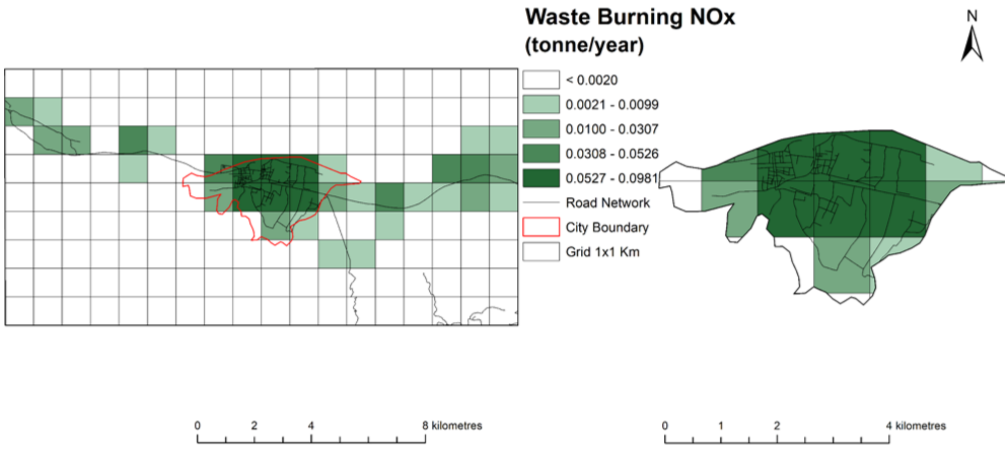

Figure A20 Spatial distribution of NO_x emissions from waste burning in Sahibganj

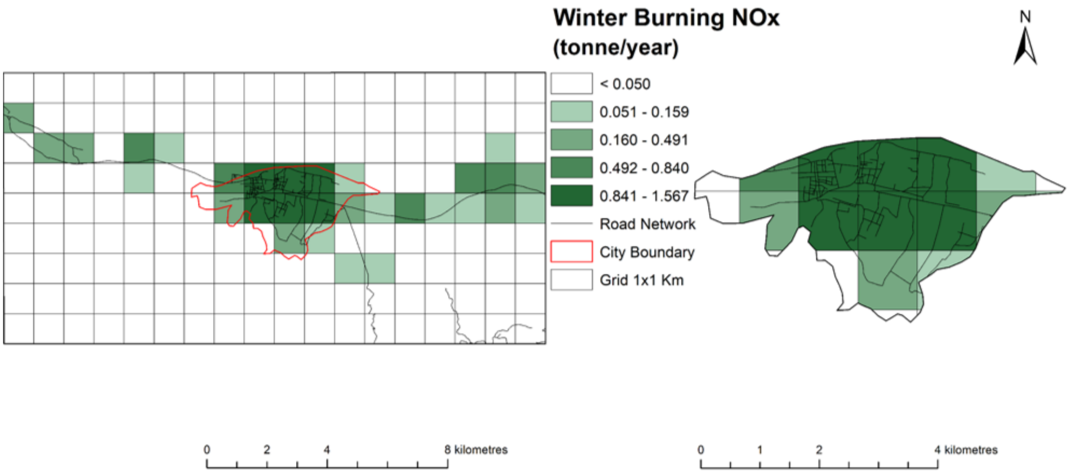

Figure A21 Spatial distribution of NO_x emissions from winter burning in Sahibganj

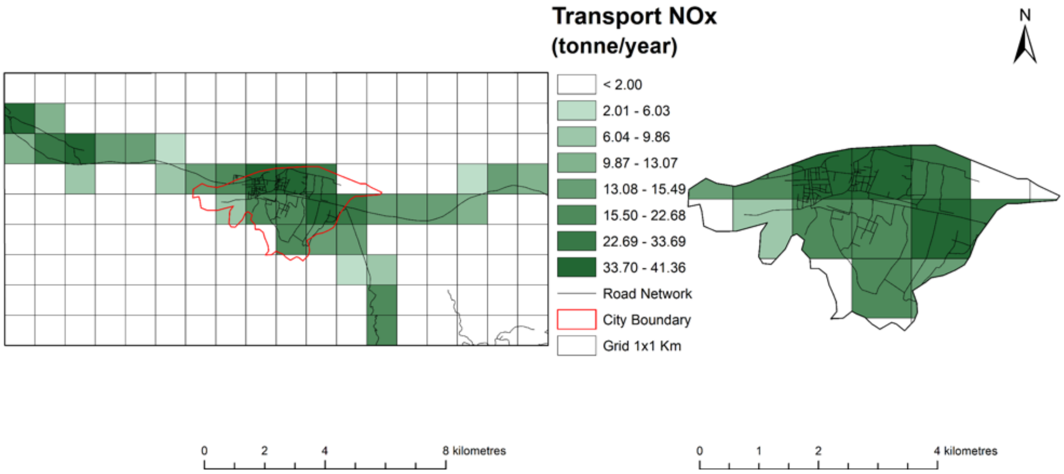

Figure A22 Spatial distribution of NO_x emissions from the transport sector in Sahibganj

Grid-wise emissions: Dumka

PM$_{10}$- Dumka

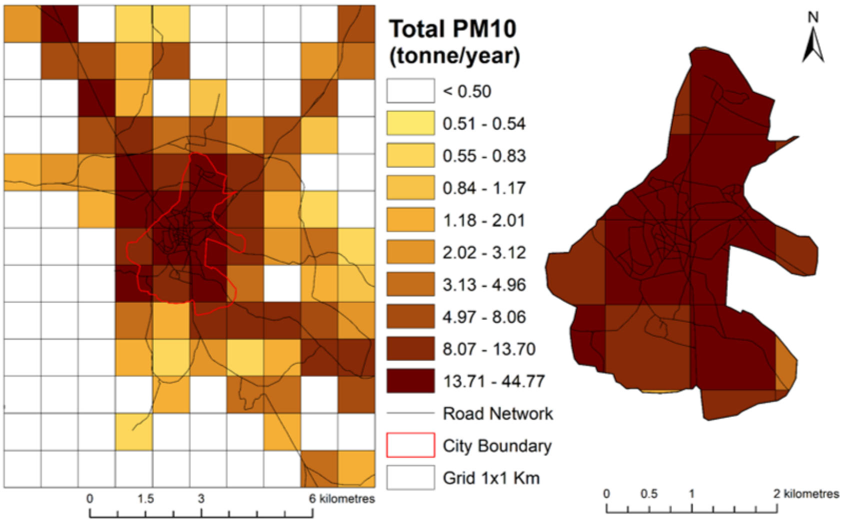

Figure A23 Spatial distribution of total PM$_{10}$ emissions in Dumka

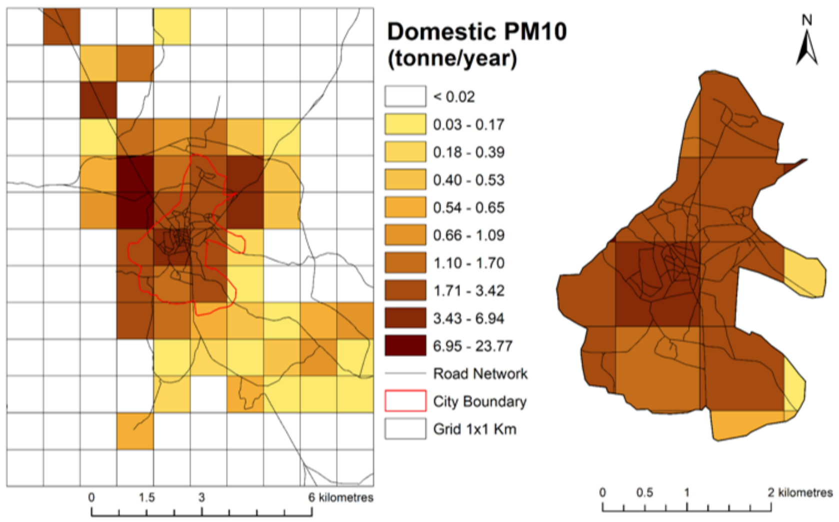

Figure A24 Spatial distribution of PM$_{10}$ emissions from the domestic sector in Dumka

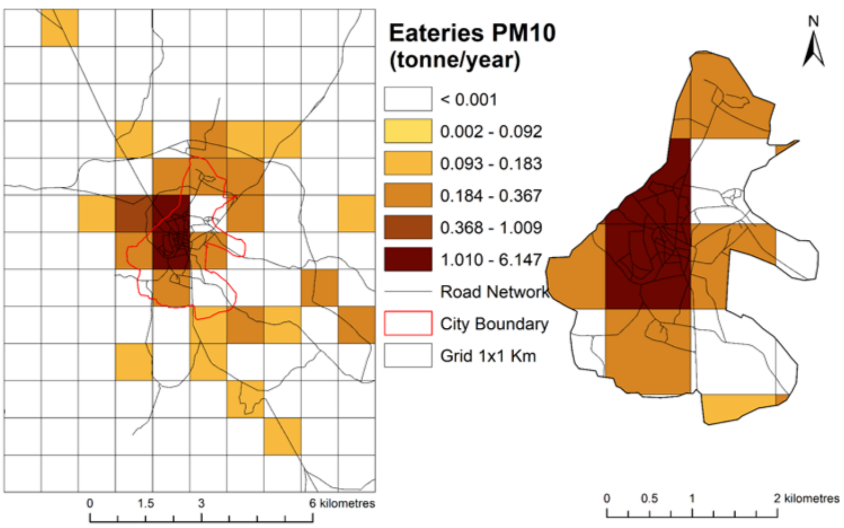

Figure A25 Spatial distribution of PM$_{10}$ emissions from eateries in Dumka

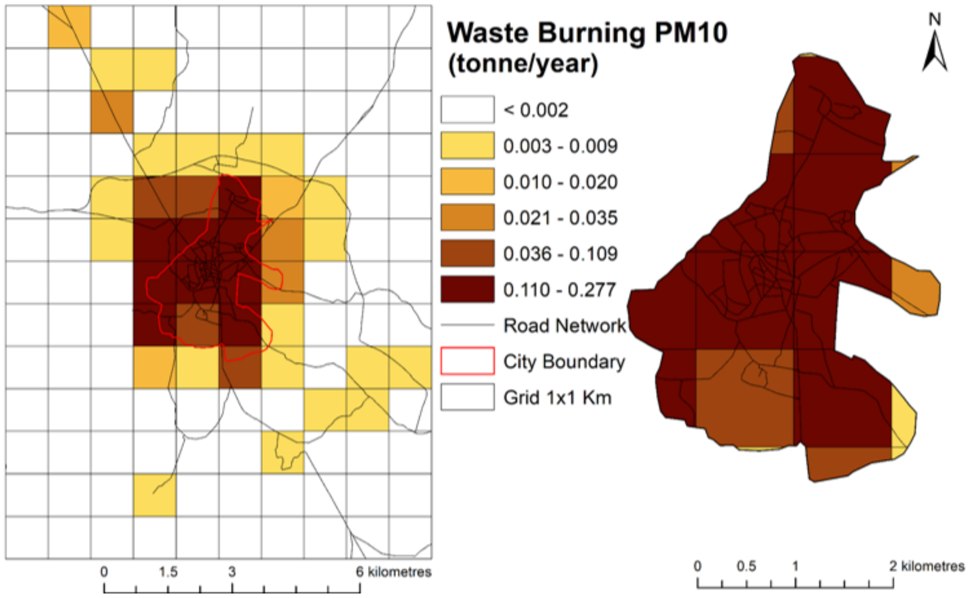

Figure A25 Spatial distribution of PM_{10} emissions from waste burning in Dumka

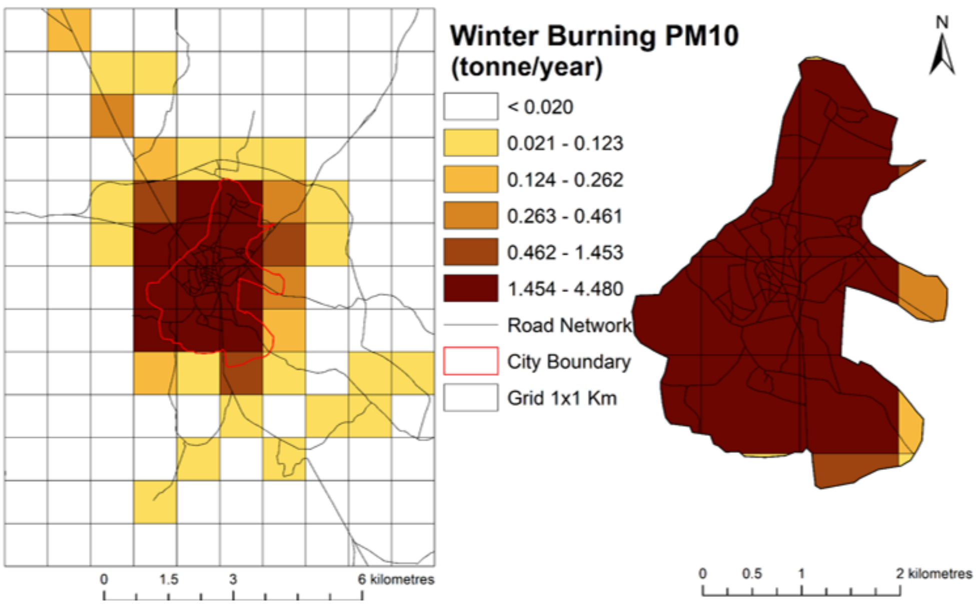

Figure A26 Spatial distribution of PM_{10} emissions from winter burning in Dumka

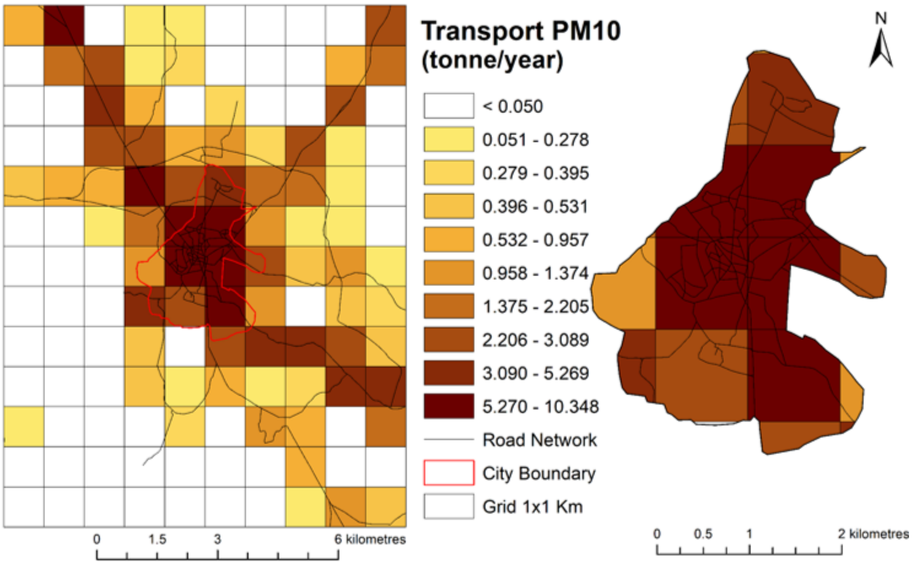

Figure A27 Spatial distribution of PM_{10} emissions from transport in Dumka

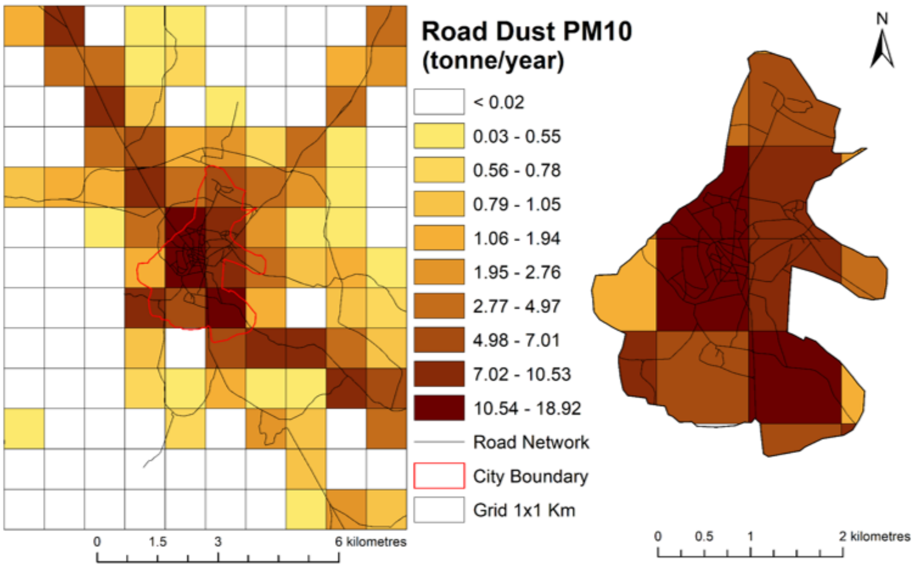

Figure A28 Spatial distribution of PM_{10} emissions from road dust in Dumka

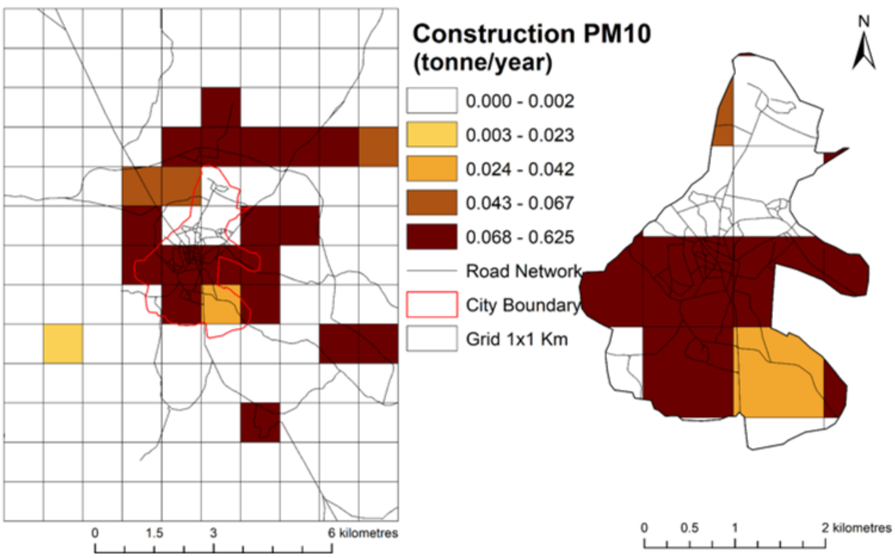

Figure A29 Spatial distribution of PM_{10} emissions from construction in Dumka

SO_2- Dumka

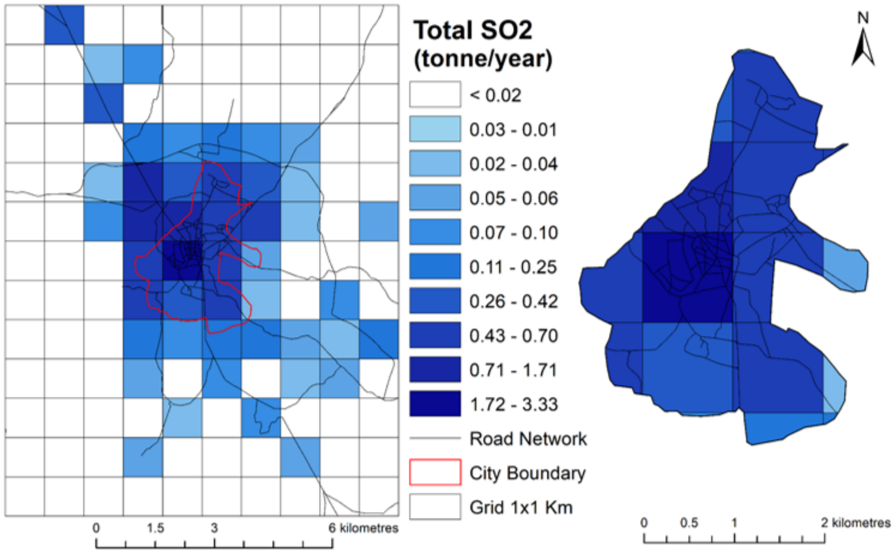

Figure A30 Spatial distribution of total SO_2 emissions in Dumka

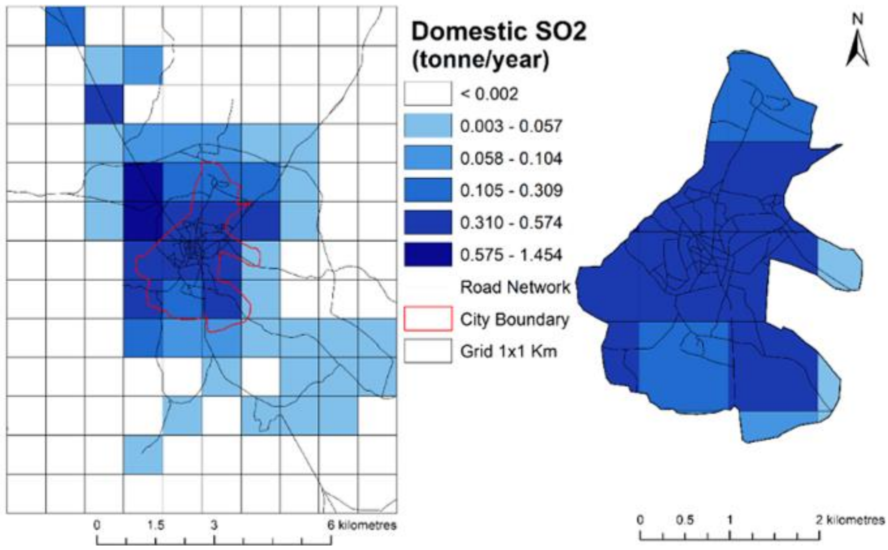

Figure A31 Spatial distribution of SO_2 emissions from the domestic sector in Dumka

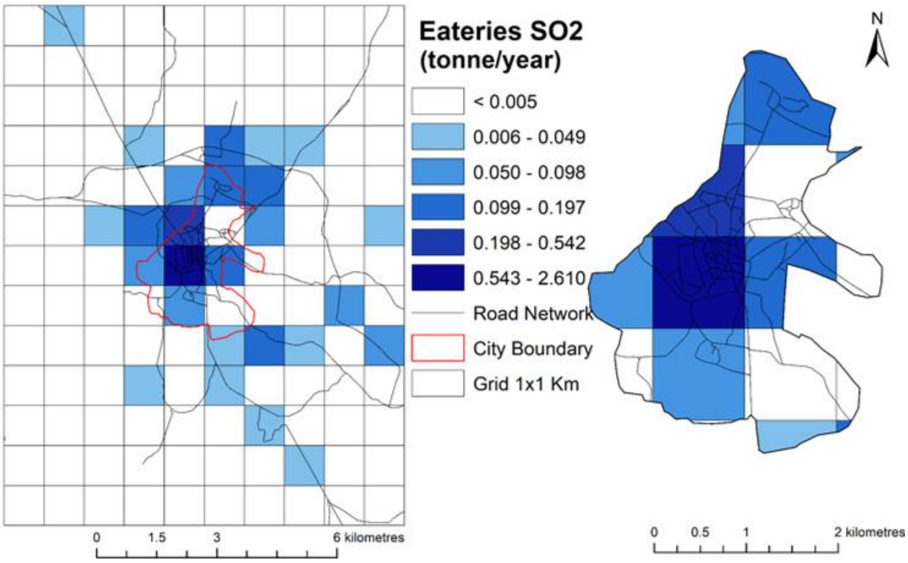

Figure A32 Spatial distribution of SO_2 emissions from eateries in Dumka

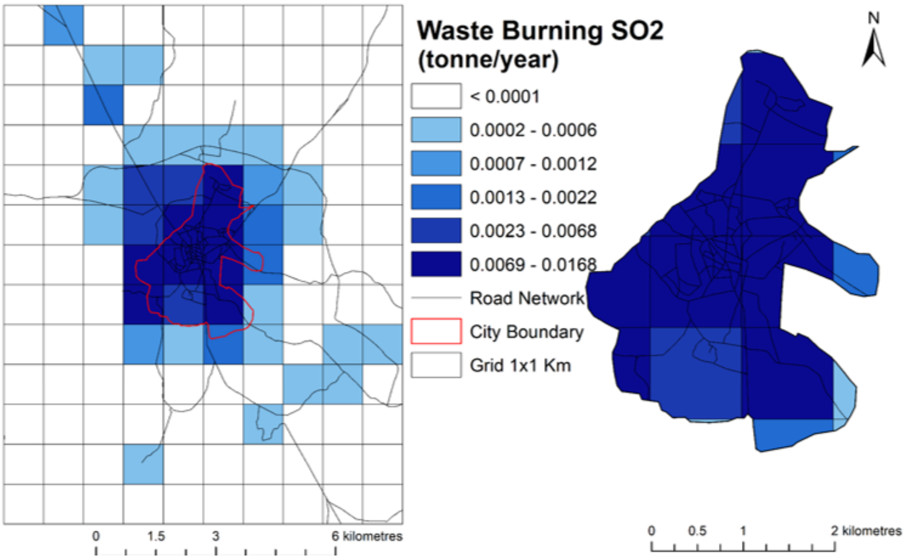

Figure A33 Spatial distribution of SO_2 emissions from waste burning in Dumka

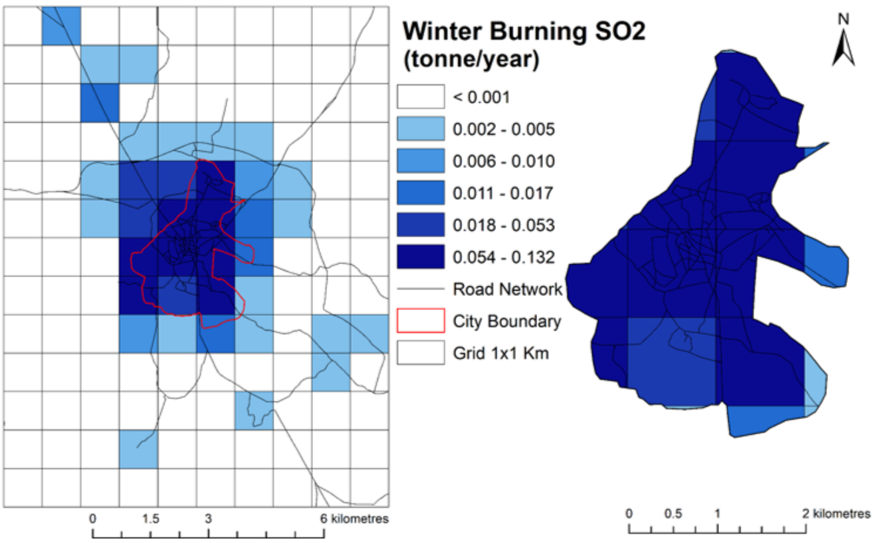

Figure A34 Spatial distribution of SO_2 emissions from winter burning in Dumka

NO_x emissions - Dumka

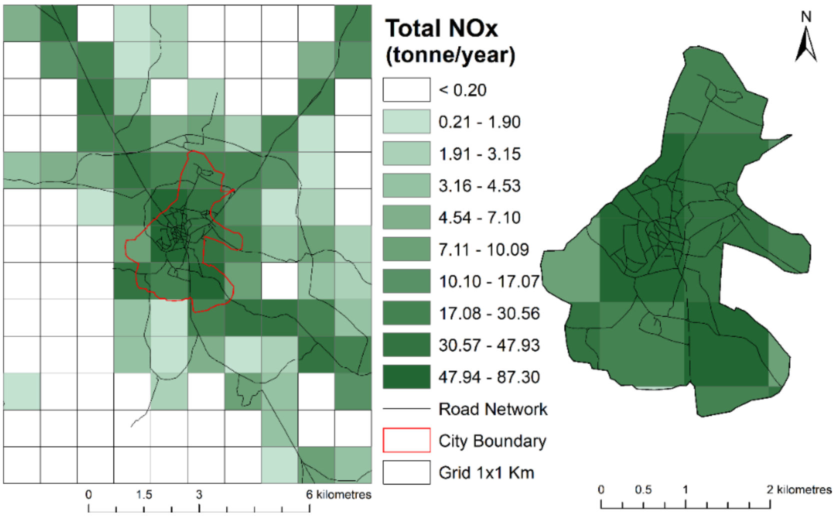

Figure A35 Spatial distribution of total NO_x emissions in Dumka

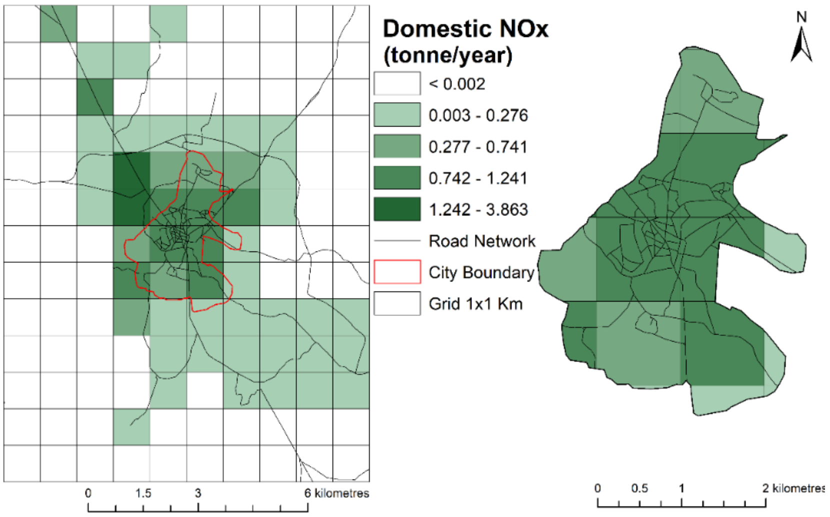

Figure A36 Spatial distribution of NO_x emissions from the domestic sector in Dumka

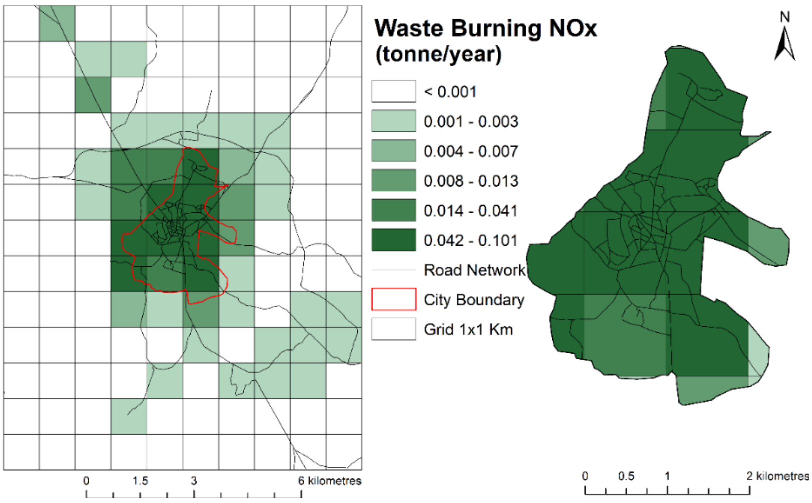

Figure A37 Spatial distribution of NO_x emissions from waste burning in Dumka

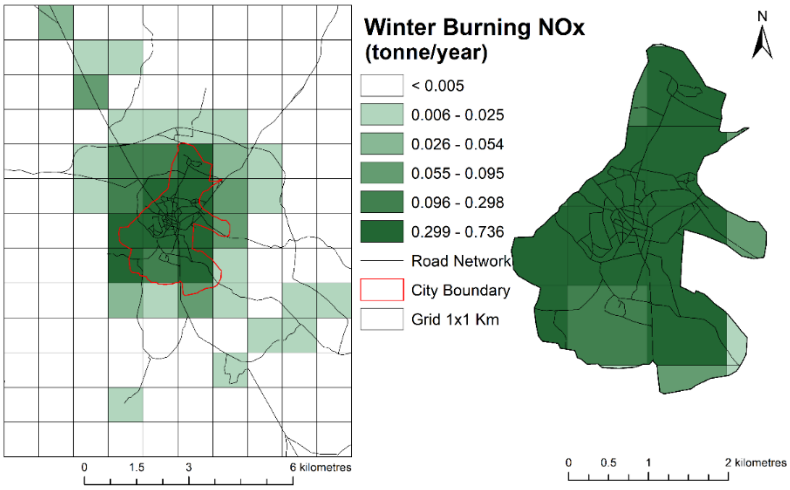

Figure A38 Spatial distribution of NO_x emissions from winter burning in Dumka

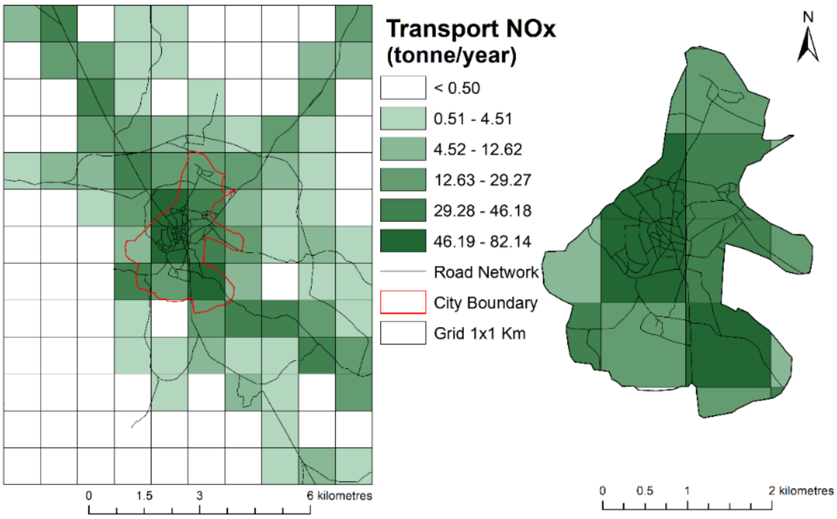

Figure A39 Spatial distribution of NO_x emissions from the transport sector in Dumka

Grid-wise emissions: Pakur

PM_{10}- Pakur

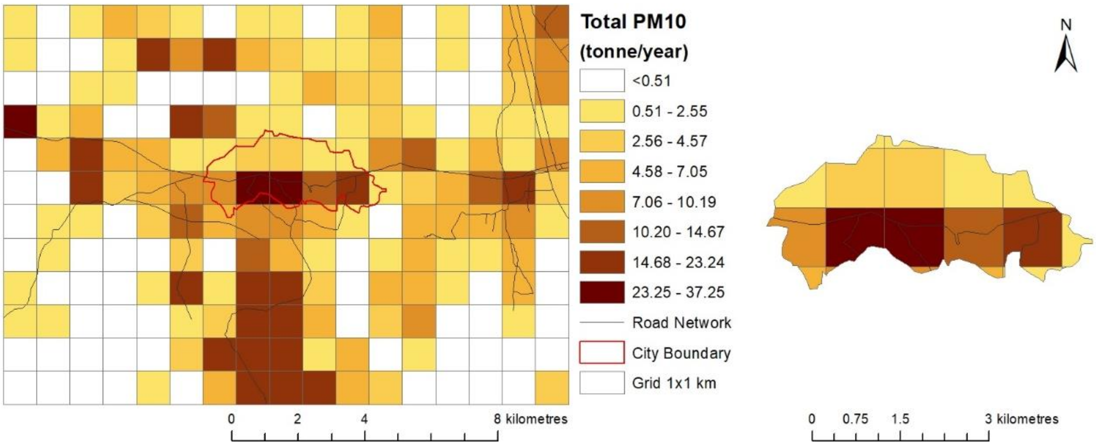

Figure A40 Spatial distribution of total PM_{10} emissions in Pakur

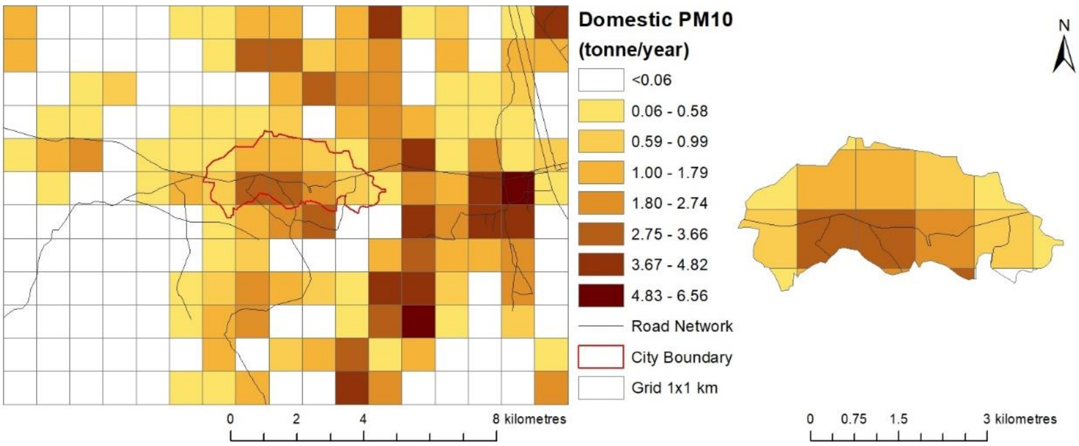

Figure A41 Spatial distribution of PM_{10} from the domestic sector in Pakur

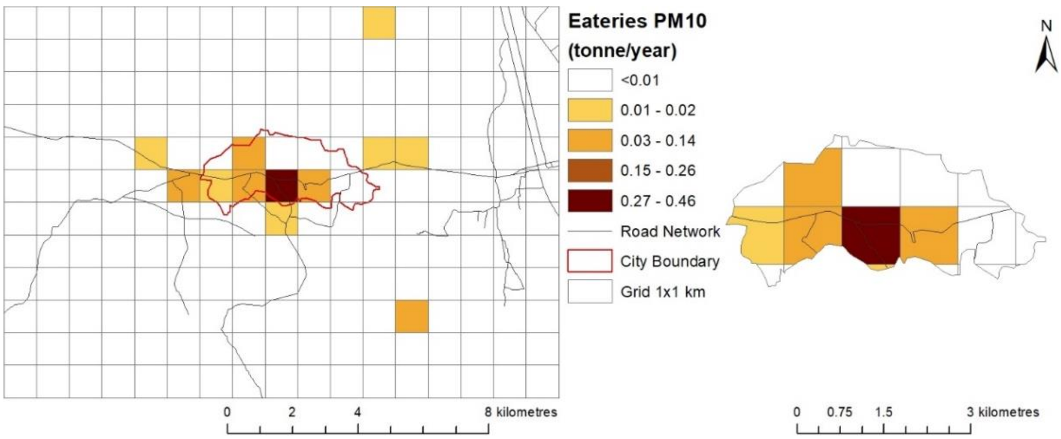

Figure A42 Spatial distribution of PM_{10} from eateries in Pakur

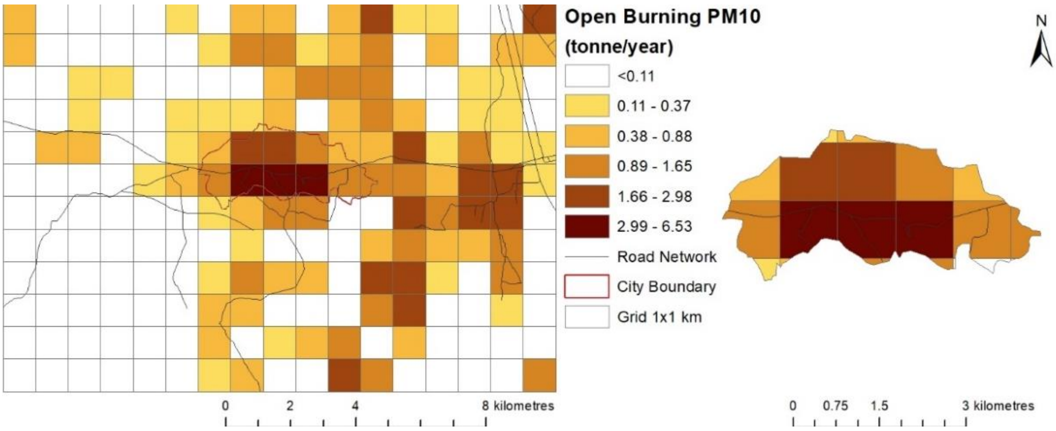

Figure A43 Spatial distribution of PM_{10} from open burning in Pakur

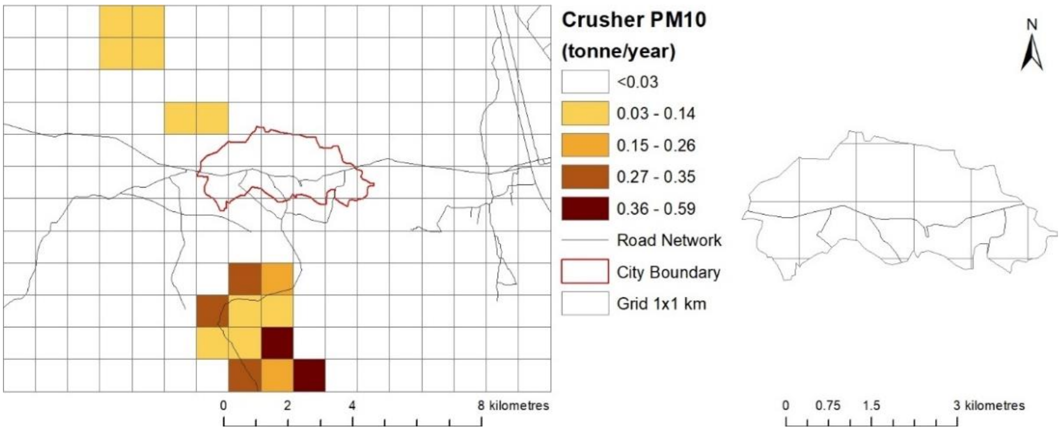

Figure A44 Spatial distribution of PM_{10} from stone crushers in Pakur

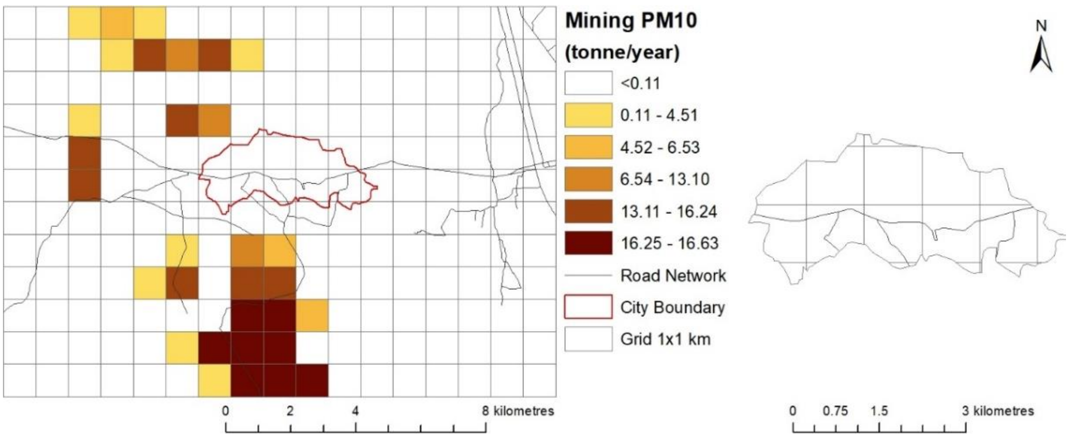

Figure A45 Spatial distribution of PM_{10} from mining in Pakur

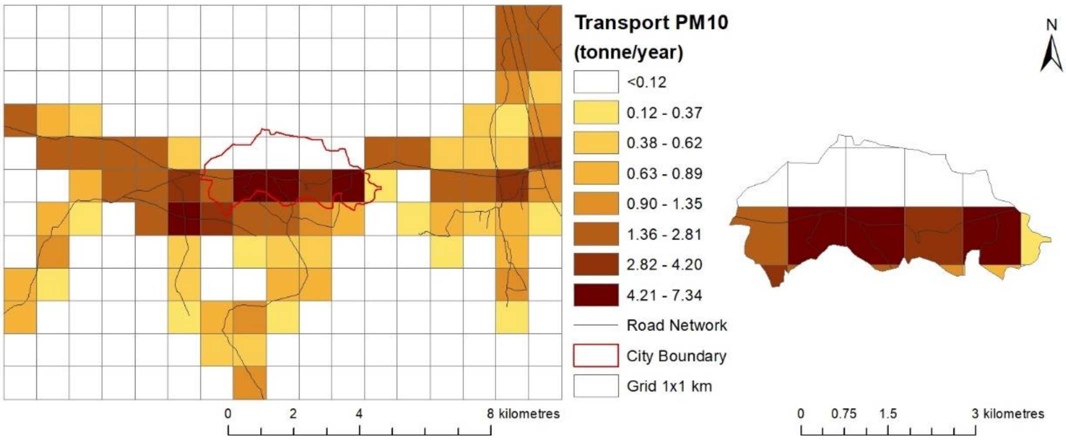

Figure A46 Spatial distribution of PM_{10} from transport in Pakur

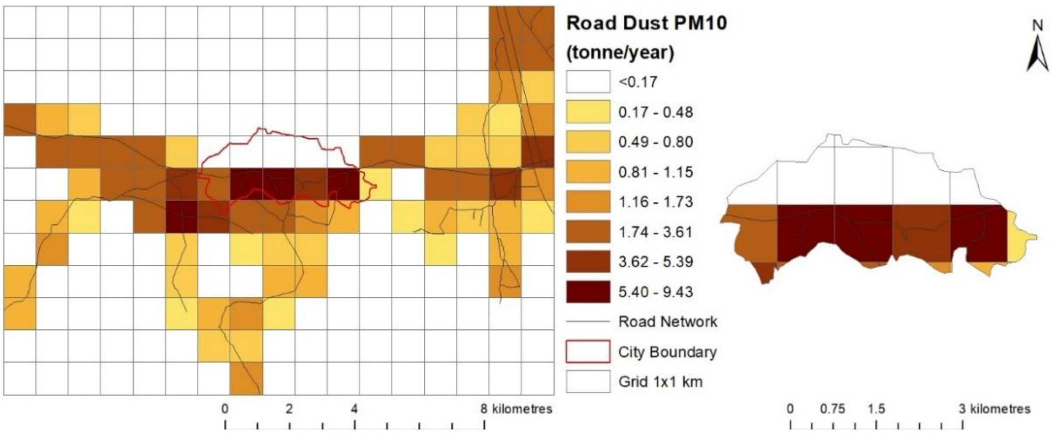

Figure A47 Spatial distribution of PM_{10} from road dust in Pakur

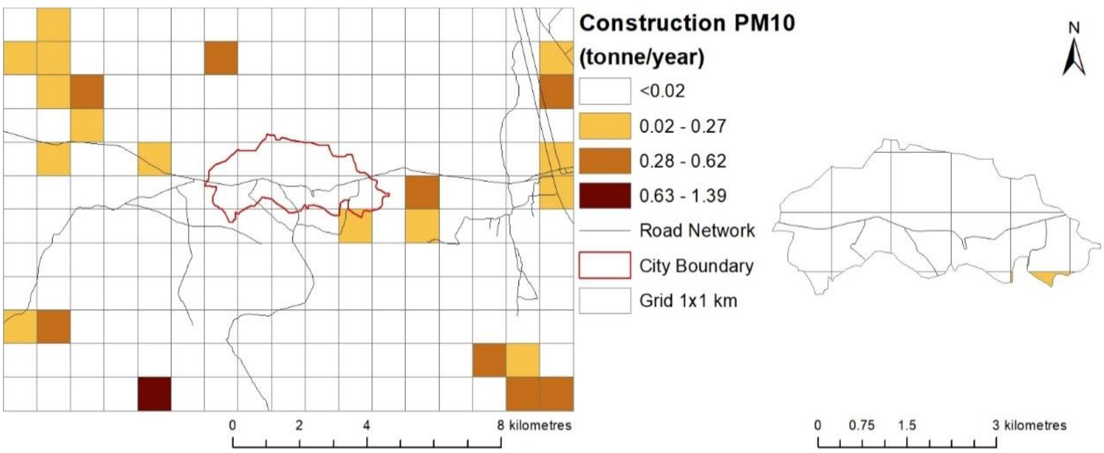

Figure A48 Spatial distribution of PM_{10} from construction in Pakur

SO_2- Pakur

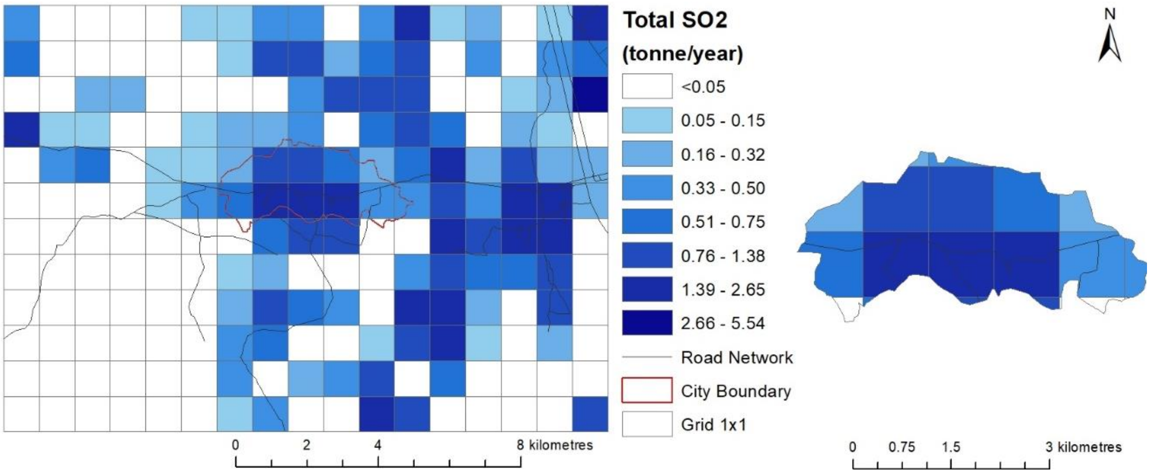

Figure A49 Spatial distribution of total SO_2 emissions in Pakur

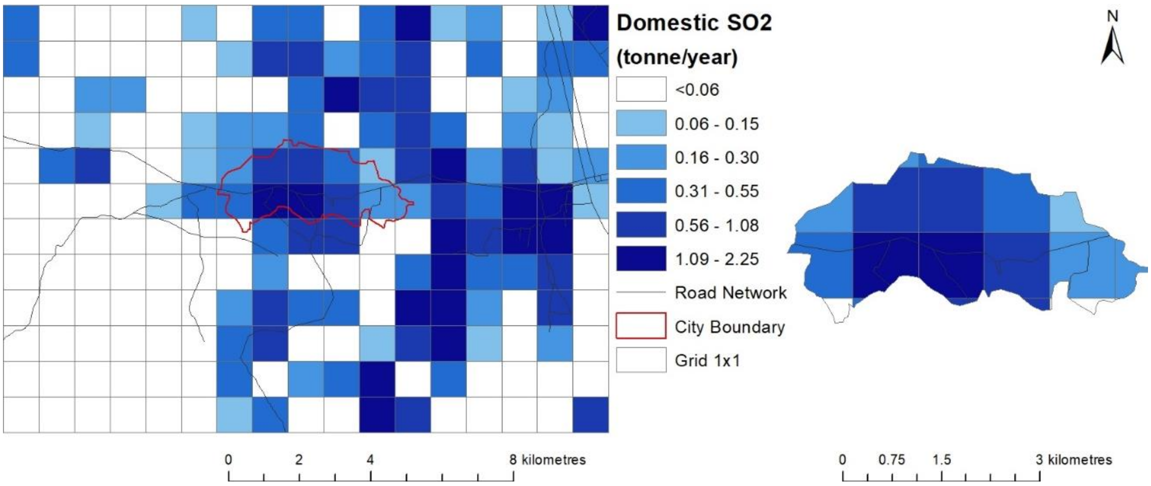

Figure A50 Spatial distribution of SO_2 emissions from the domestic sector in Pakur

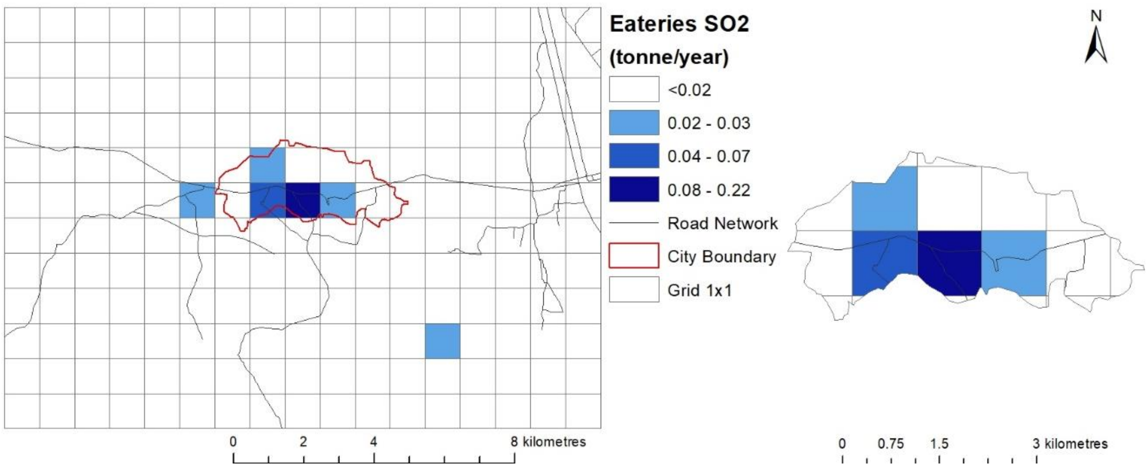

Figure A51 Spatial distribution of SO_2 emissions from eateries in Pakur

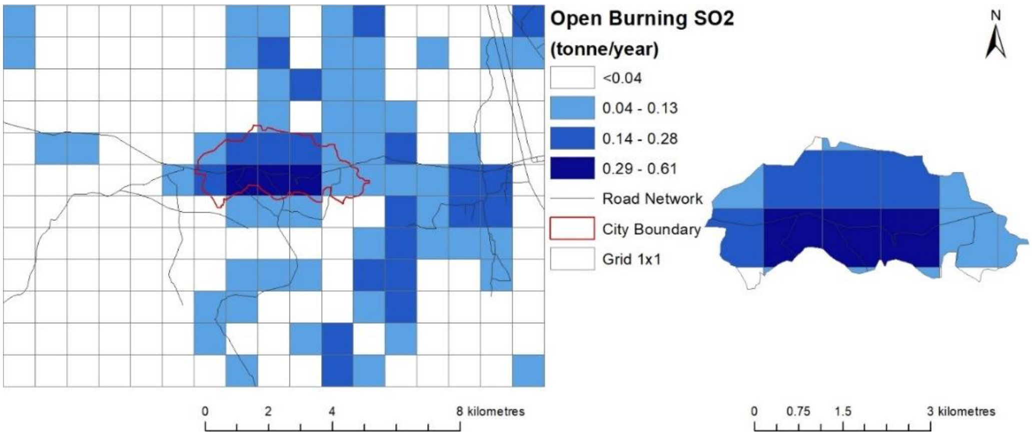

Figure A52 Spatial distribution of SO_2 emissions from open burning in Pakur

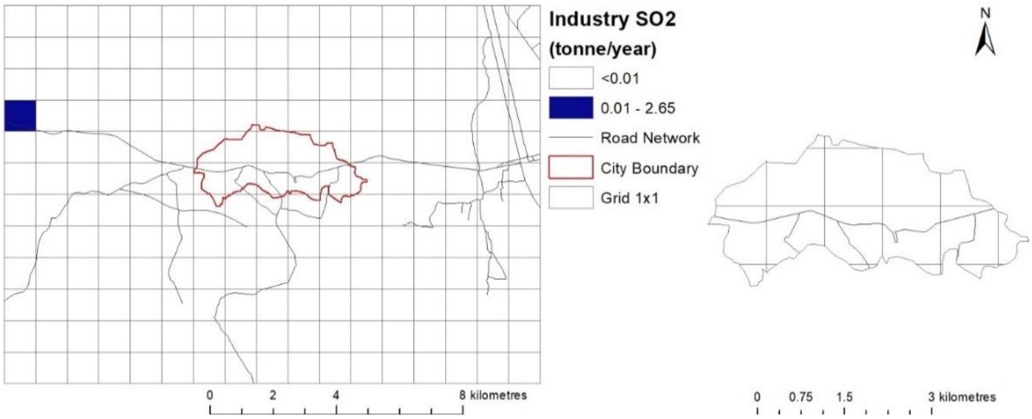

Figure A53 Spatial distribution of SO_2 emissions from industry in Pakur

NO_x- Pakur

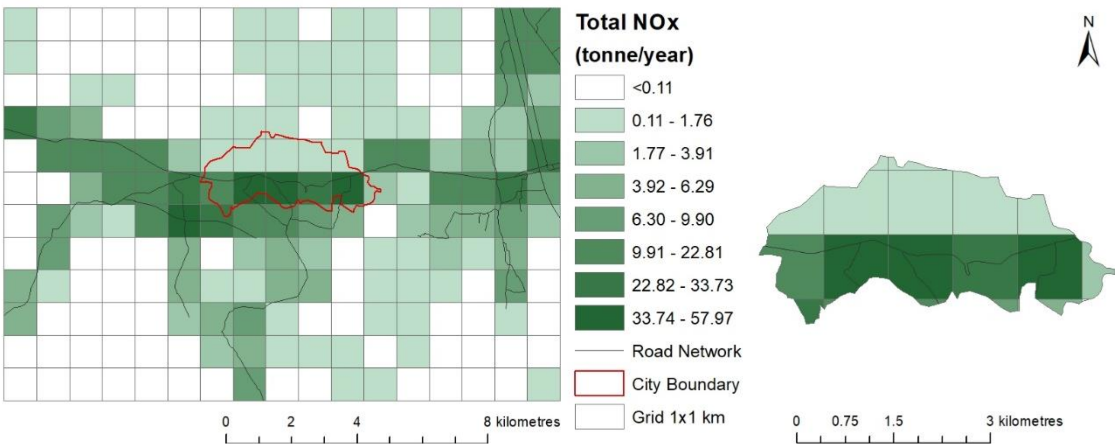

Figure A54 Spatial distribution of total NO_x emissions in Pakur

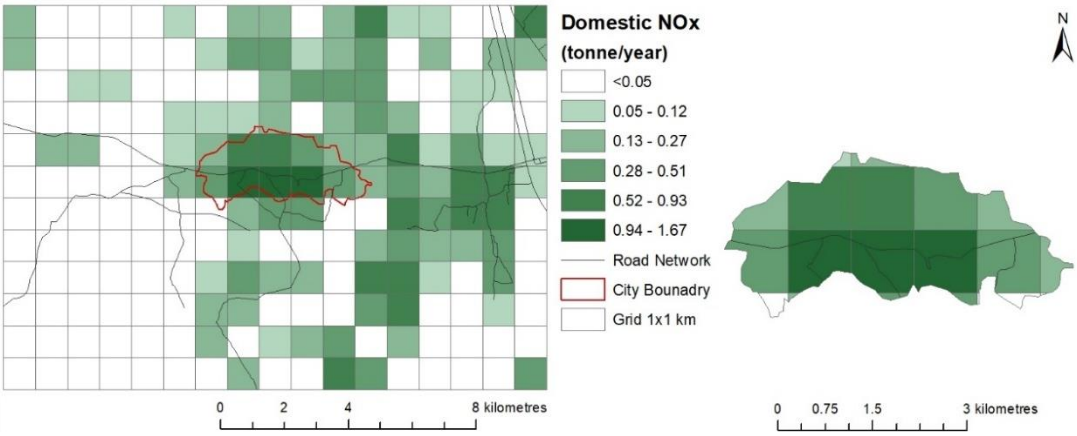

Figure A55 Spatial distribution of NO_x emissions from the domestic sector in Pakur

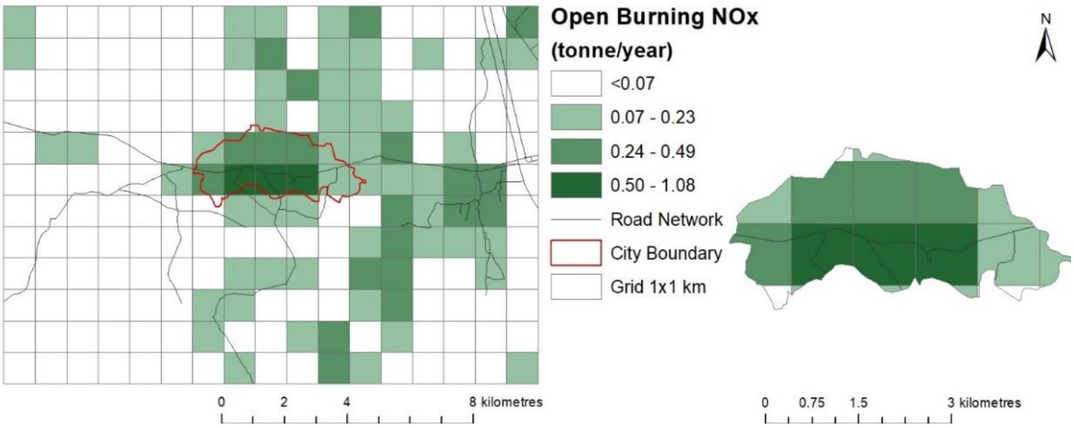

Figure A56 Spatial distribution of NO_x emissions from open burning in Pakur

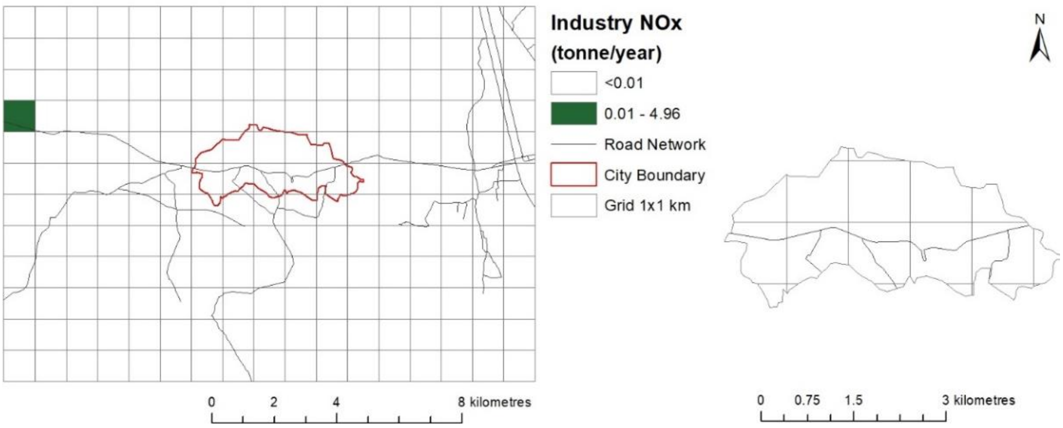

Figure A57 Spatial distribution of NO_x emissions from industry in Pakur

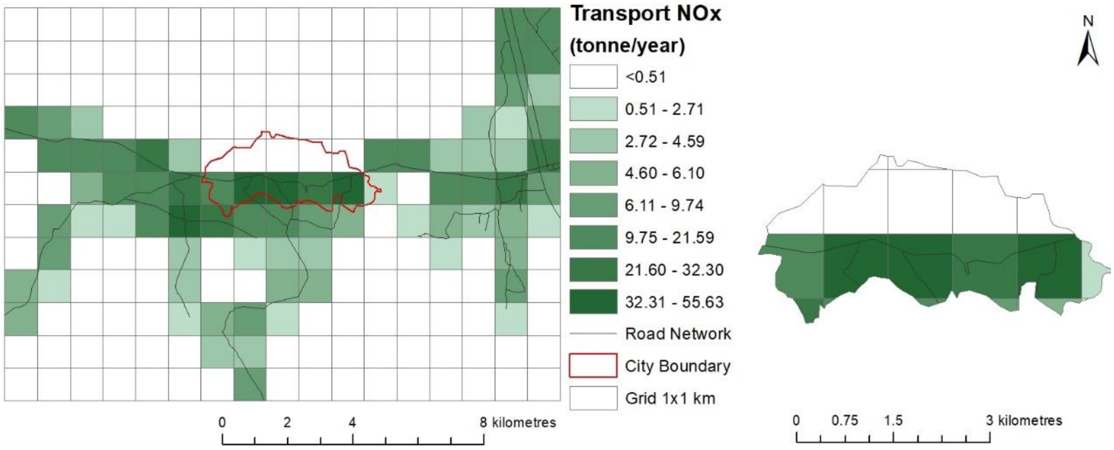

Figure A58 Spatial distribution of NO_x emissions from the transport sector in Pakur

Grid-wise emissions: Chaibasa

PM_{10}- Chaibasa

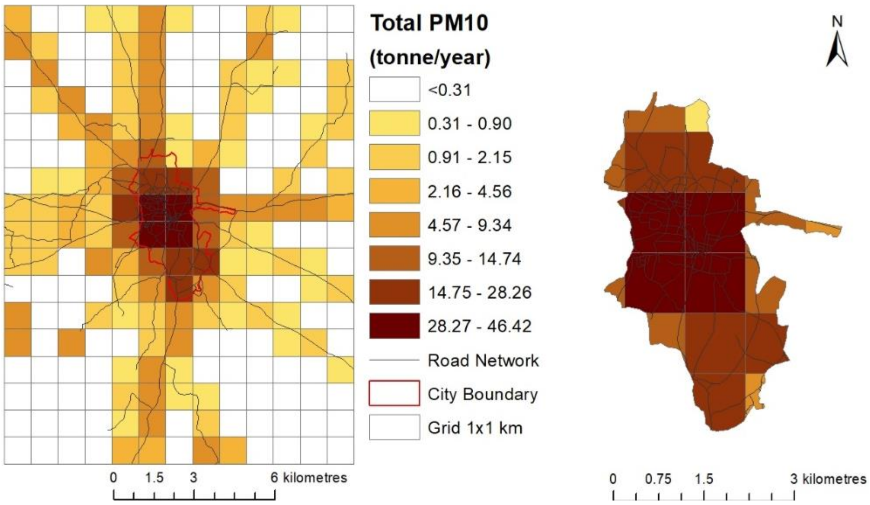

Figure A59 Spatial distribution of total PM_{10} emissions in Chaibasa

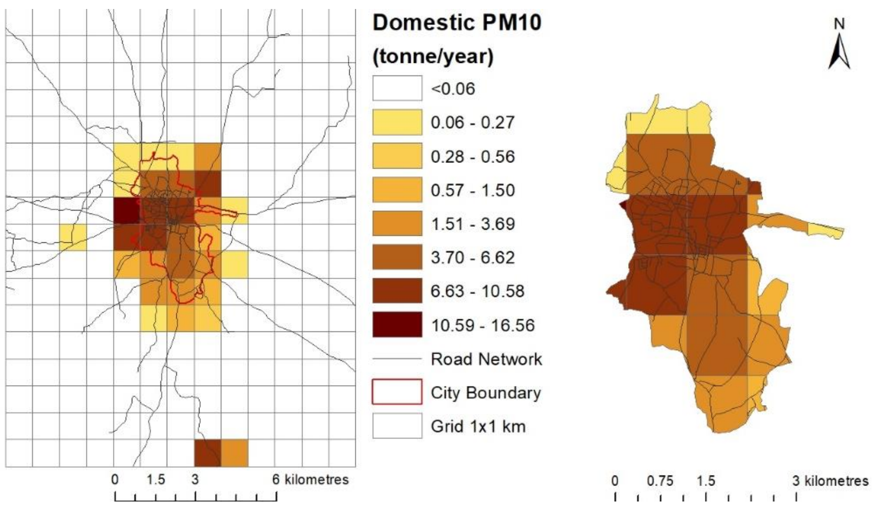

Figure A60 Spatial distribution of PM_{10} emissions from the domestic sector in Chaibasa

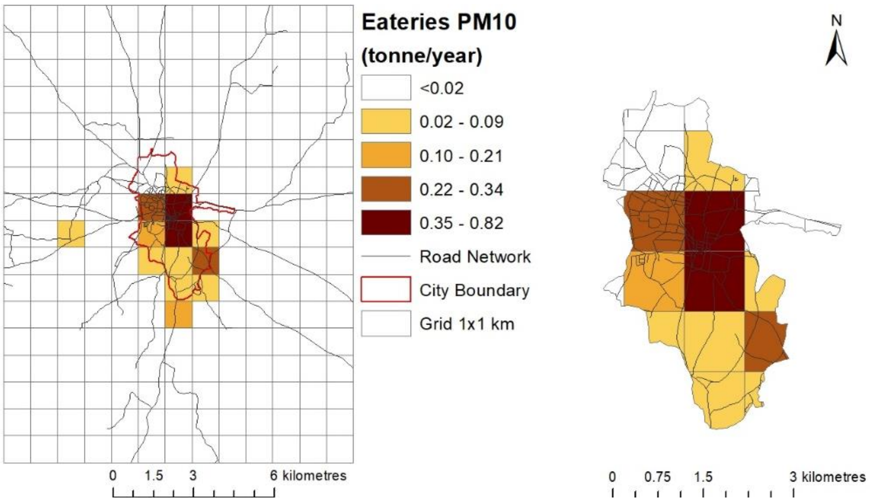

Figure A61 Spatial distribution of PM_{10} emissions from eateries in Chaibasa

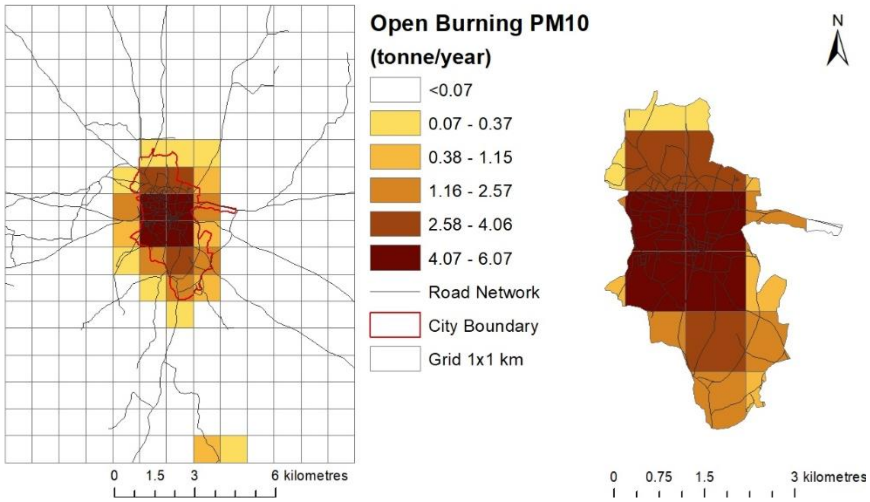

Figure A62 Spatial distribution of PM_{10} emissions from open burning in Chaibasa

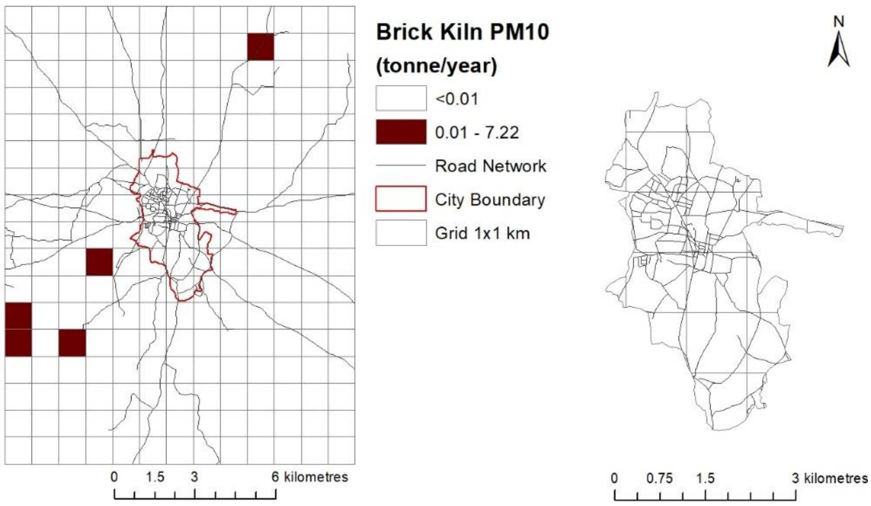

Figure A63 Spatial distribution of PM_{10} emissions from brick kilns in Chaibasa

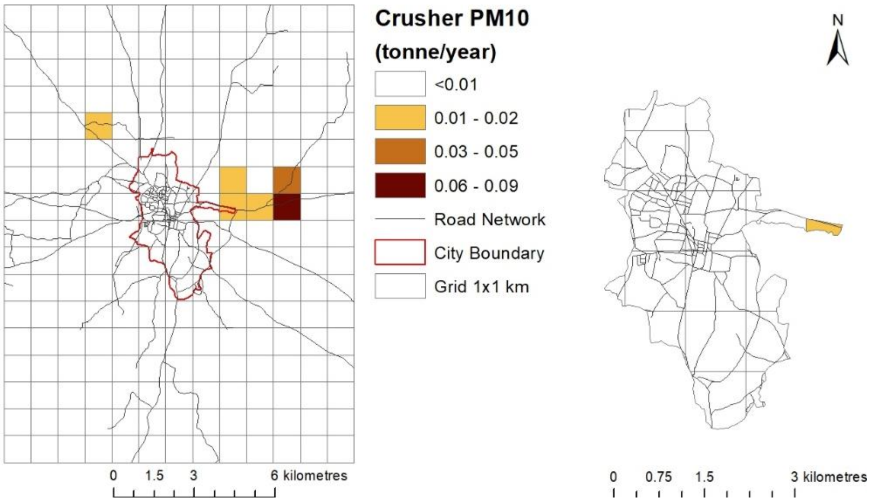

Figure A64 Spatial distribution of PM_{10} emissions from stone crushers in Chaibasa

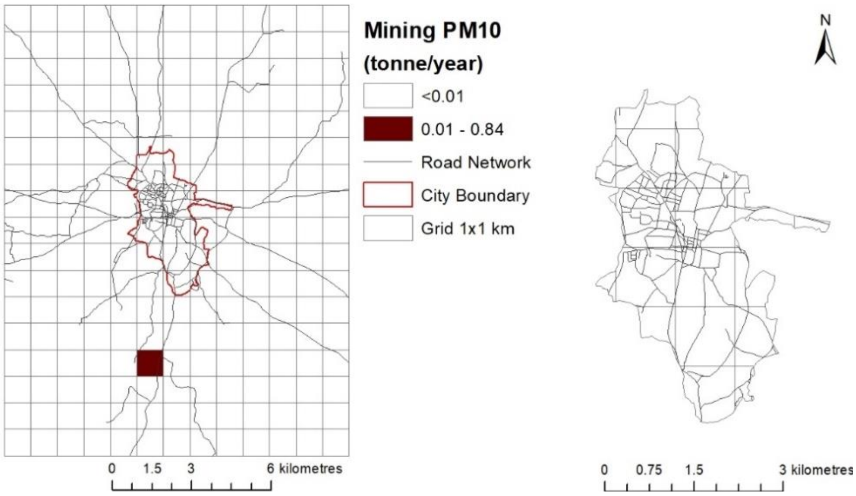

Figure A65 Spatial distribution of PM_{10} emissions from mining in Chaibasa

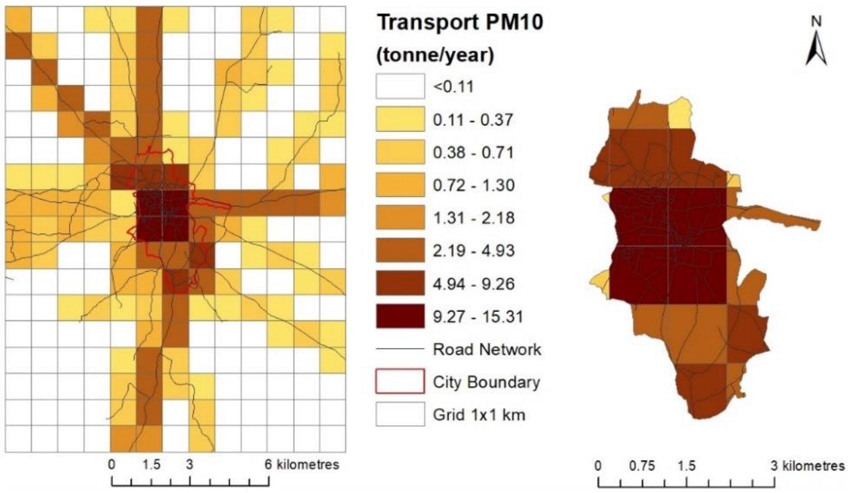

Figure A66 Spatial distribution of PM_{10} emissions from transport in Chaibasa

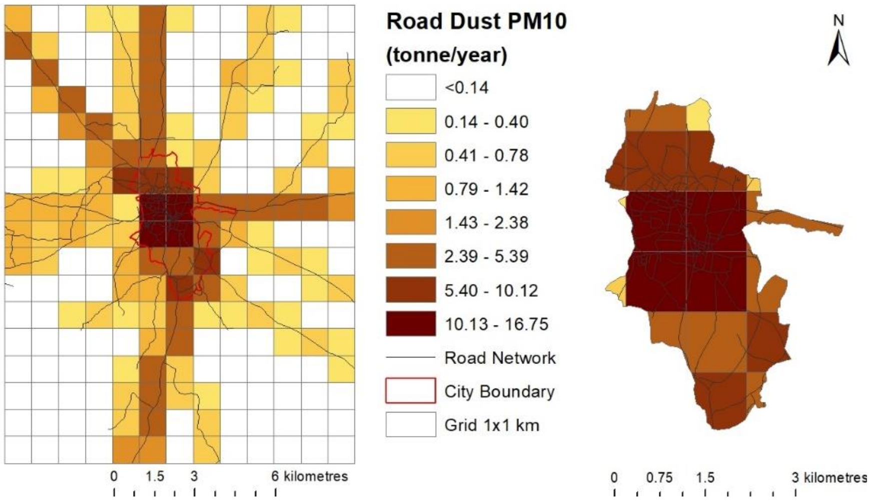

Figure A67 Spatial distribution of PM_{10} emissions from road dust in Chaibasa

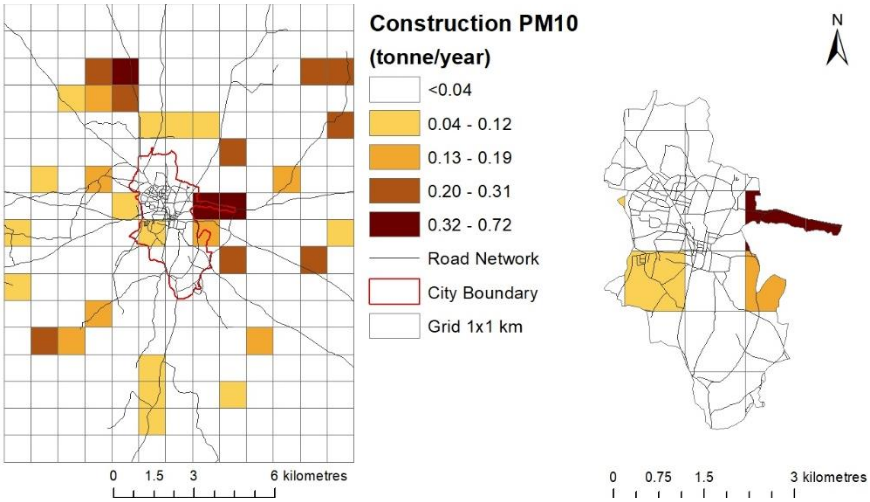

Figure A68 Spatial distribution of PM_{10} emissions from construction in Chaibasa

SO_2 - Chaibasa

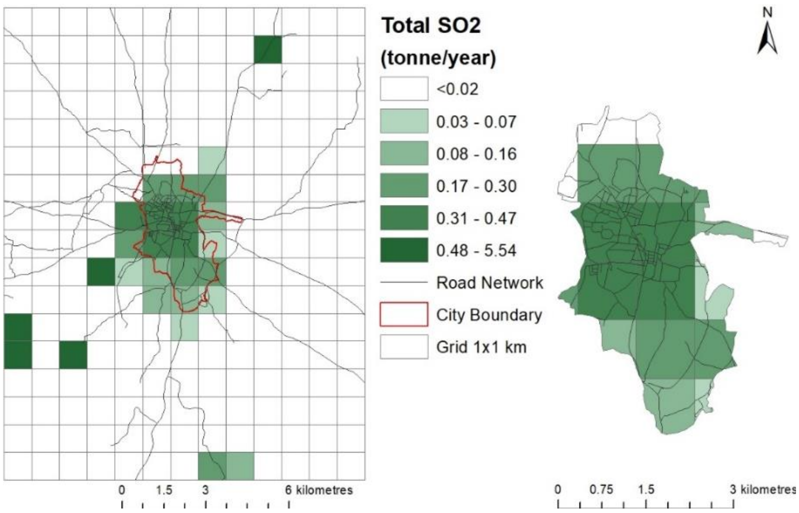

Figure A69 Spatial distribution of total SO_2 emissions in Chaibasa

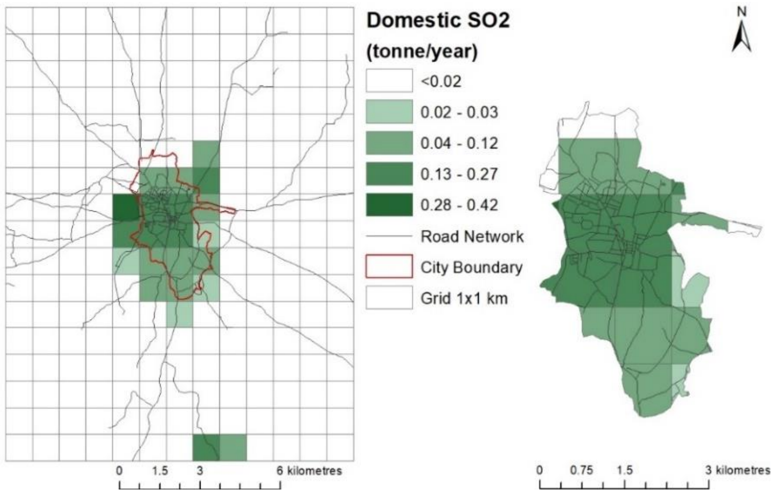

Figure A70 Spatial distribution of SO_2 emissions from the domestic sector in Chaibasa

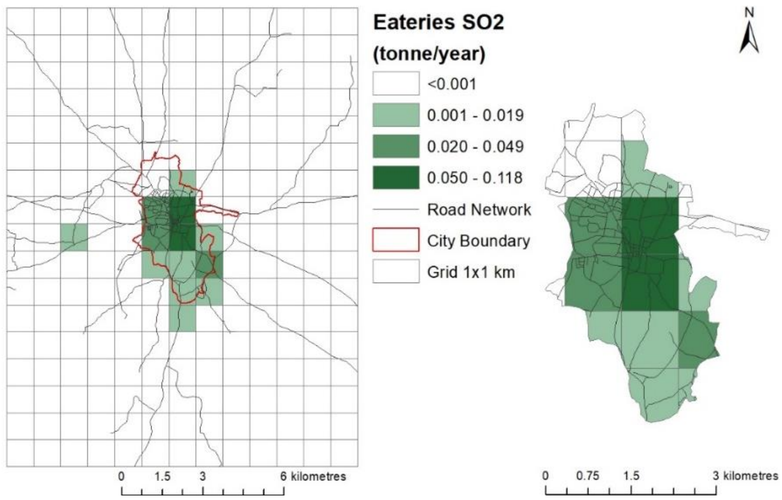

Figure A71 Spatial distribution of SO_2 emissions from eateries in Chaibasa

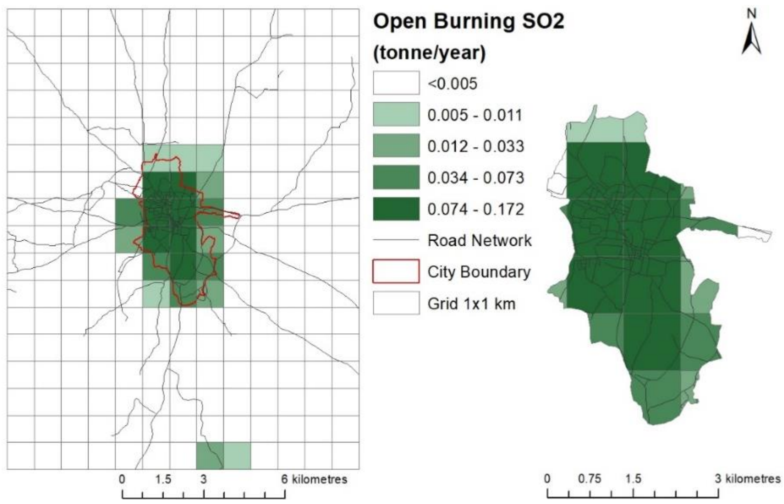

Figure A72 Spatial distribution of SO_2 emissions from open burning in Chaibasa

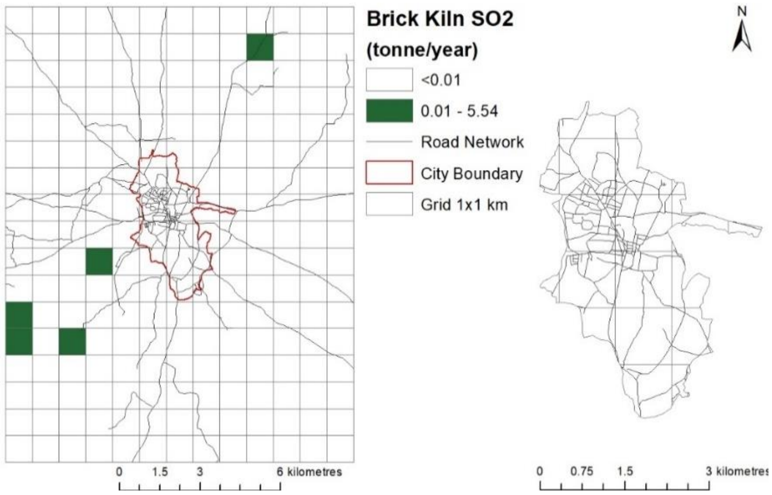

Figure A73 Spatial distribution of SO_2 emissions from brick kilns in Chaibasa

NO_x - Chaibasa

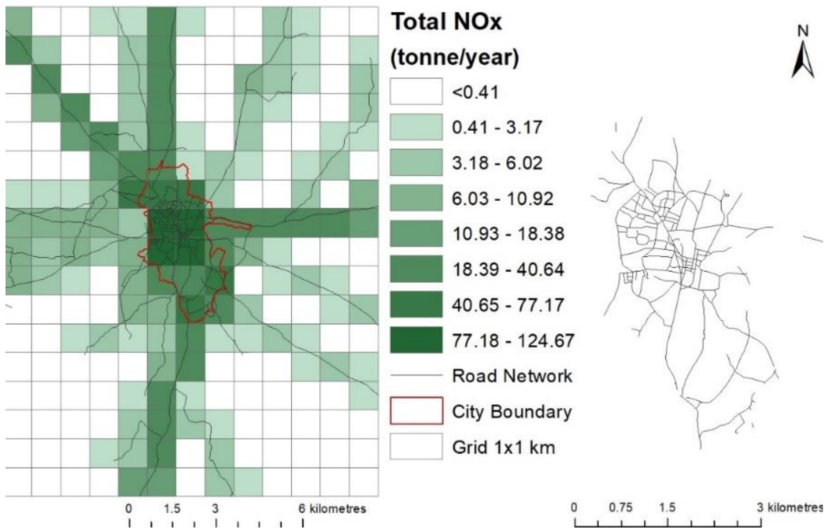

Figure A74 Spatial distribution of total NO_x emissions in Chaibasa

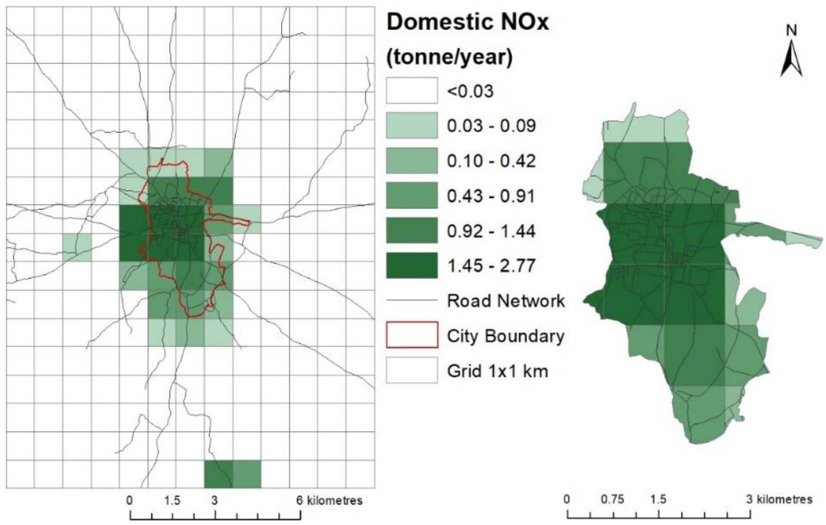

Figure A75 Spatial distribution of NO_x emissions from the domestic sector in Chaibasa

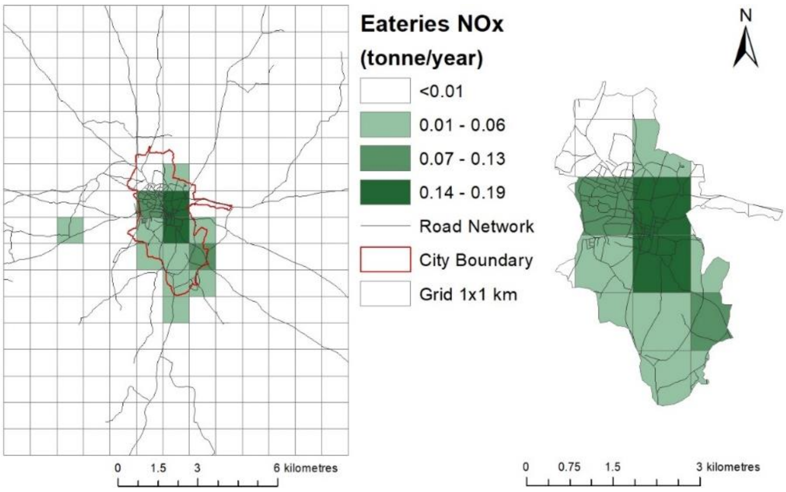

Figure A76 Spatial distribution of NO_x emissions from eateries in Chaibasa

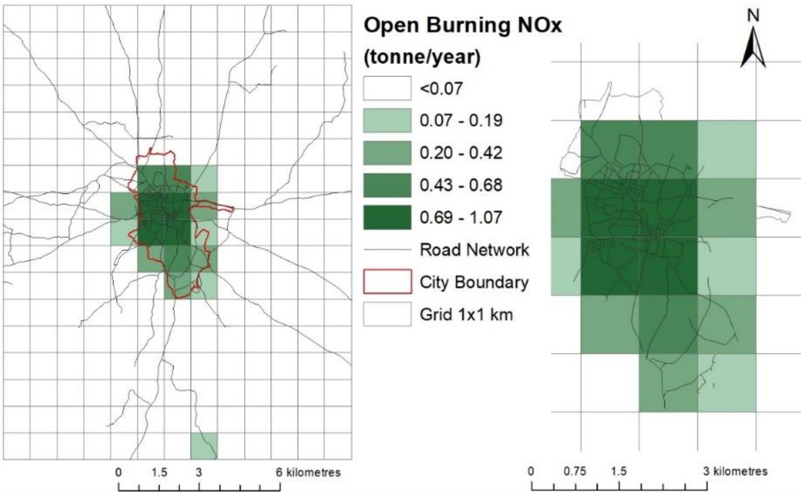

Figure A77 Spatial distribution of NO_x emissions from open burning in Chaibasa

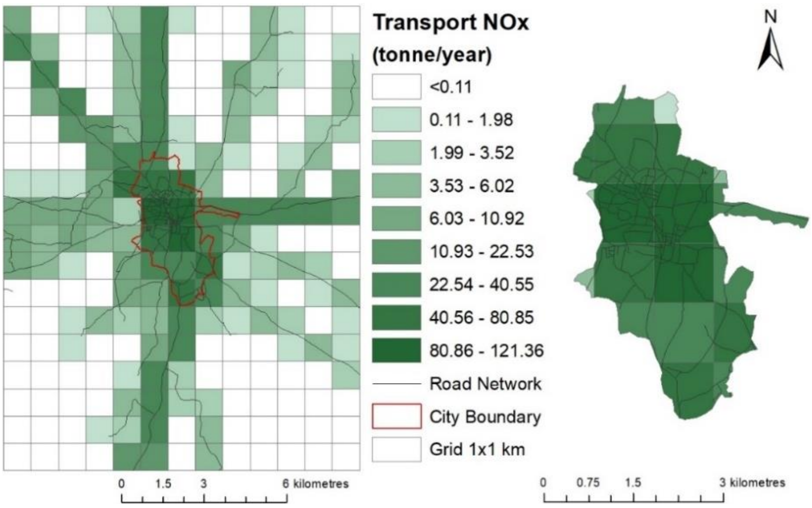

Figure A78 Spatial distribution of NO_x emissions from transport in Chaibasa

Grid-wise emissions: Hazaribagh

PM_{10} - Hazaribagh

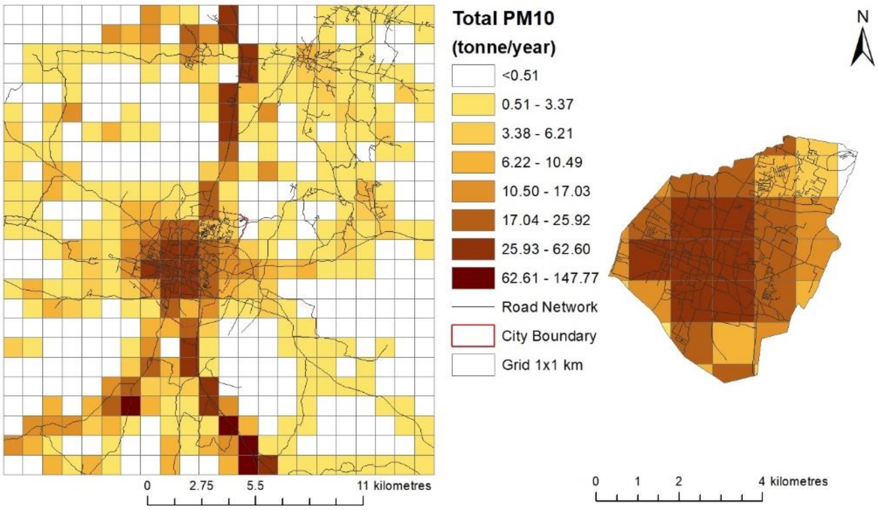

Figure A79 Spatial distribution of total PM_{10} emissions in Hazaribagh

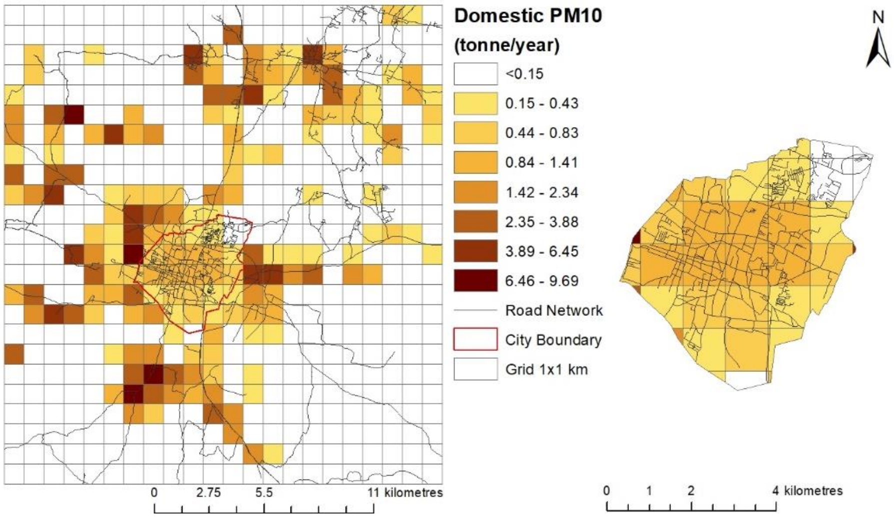

Figure A80 Spatial distribution of PM_{10} emissions from the domestic sector in Hazaribagh

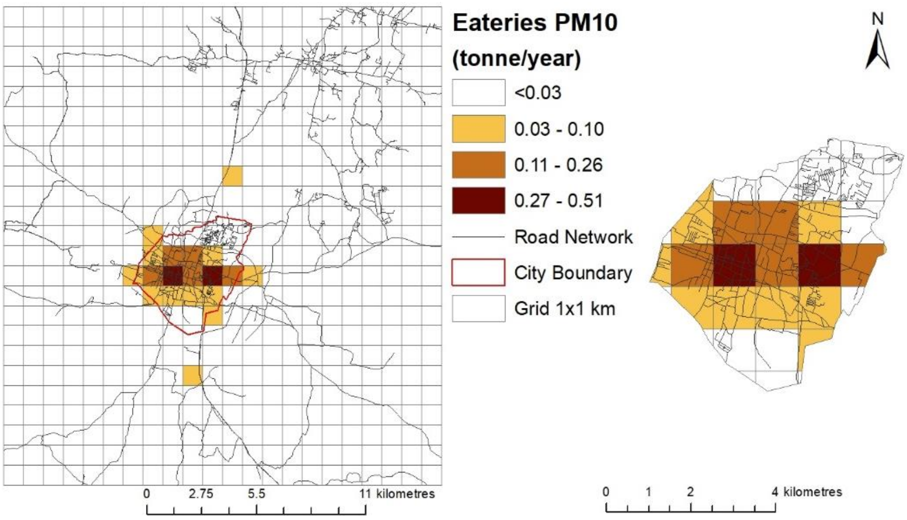

Figure A81 Spatial distribution of PM_{10} emissions from eateries in Hazaribagh

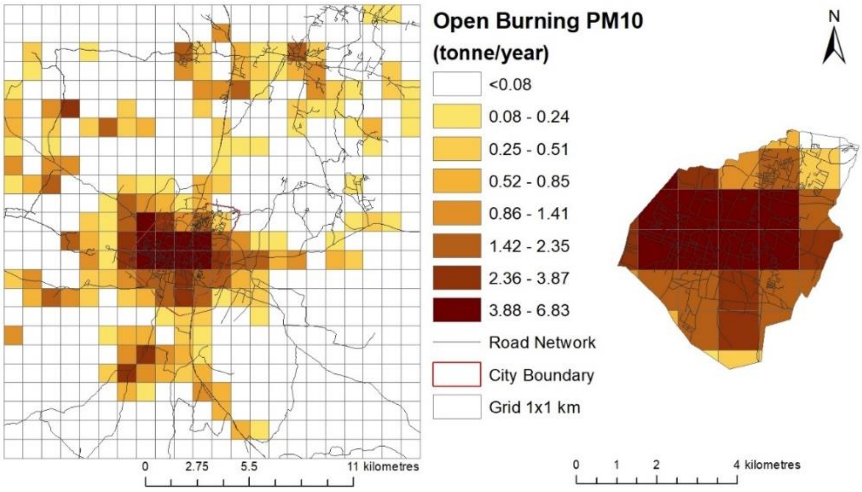

Figure A82 Spatial distribution of PM_{10} emissions from open burning in Hazaribagh

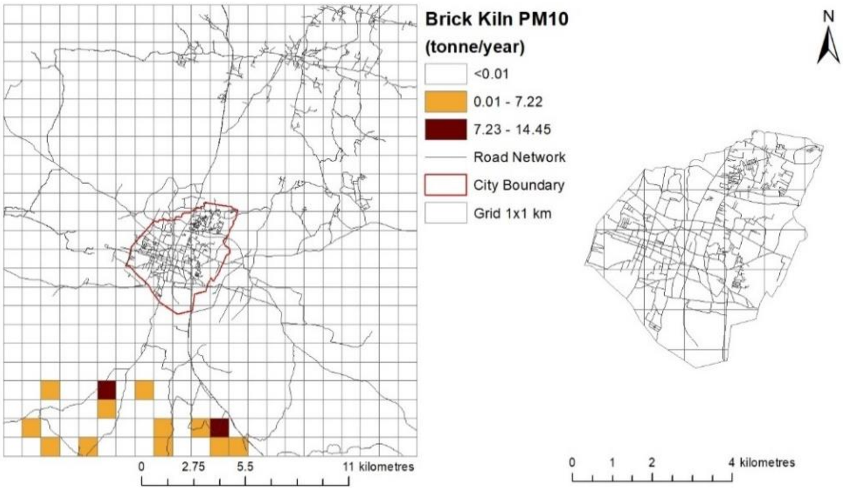

Figure A83 Spatial distribution of PM_{10} emissions from brick kilns in Hazaribagh

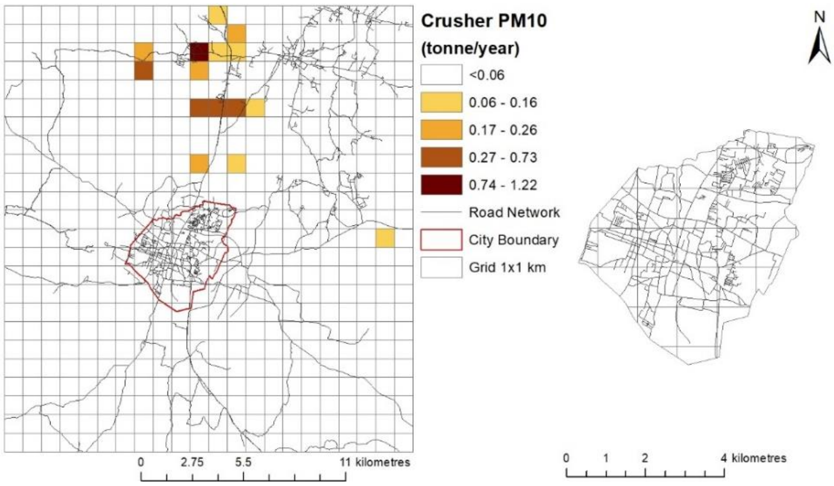

Figure A84 Spatial distribution of PM_{10} emissions from stone crushers in Hazaribagh

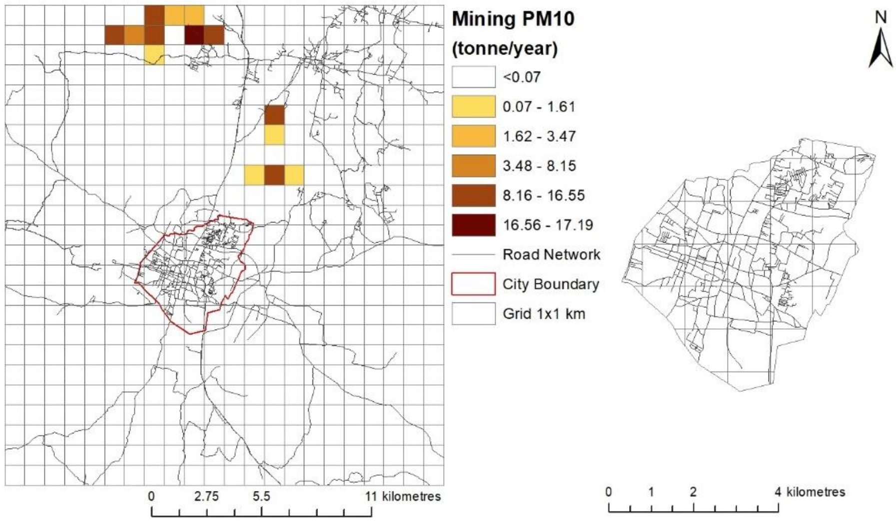

Figure A85 Spatial distribution of PM_{10} emissions from mining in Hazaribagh

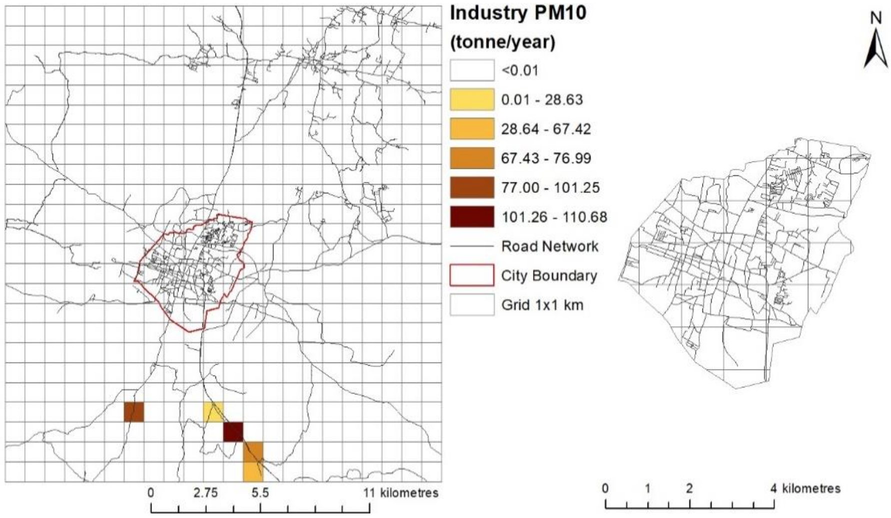

Figure A86 Spatial distribution of PM_{10} emissions from industries in Hazaribagh

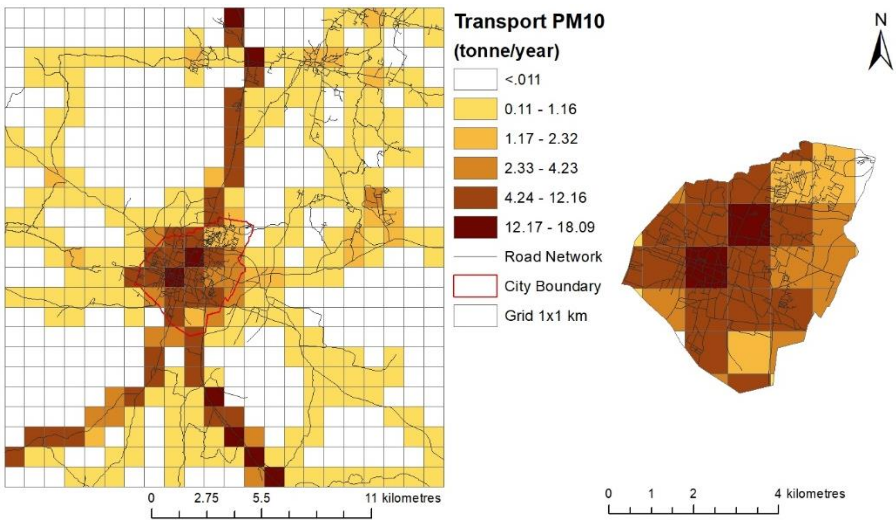

Figure A87 Spatial distribution of PM_{10} emissions from transport in Hazaribagh

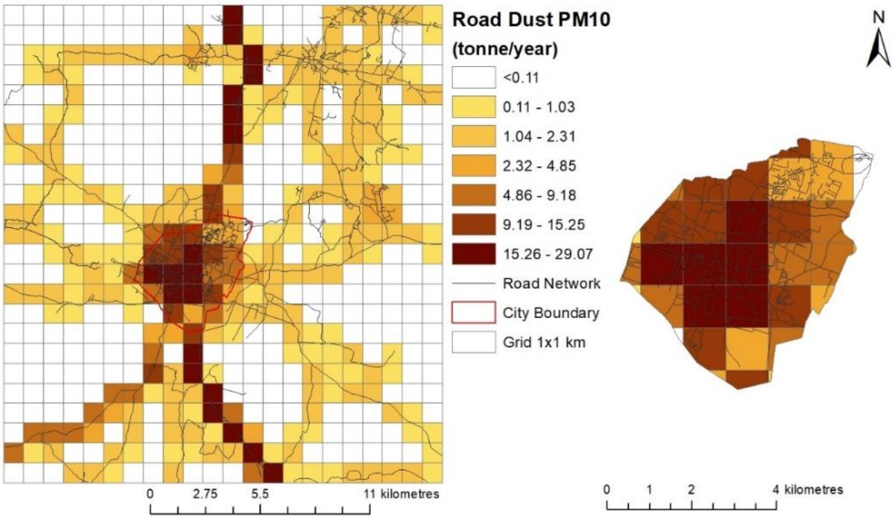

Figure A88 Spatial distribution of PM_{10} emissions from road dust in Hazaribagh

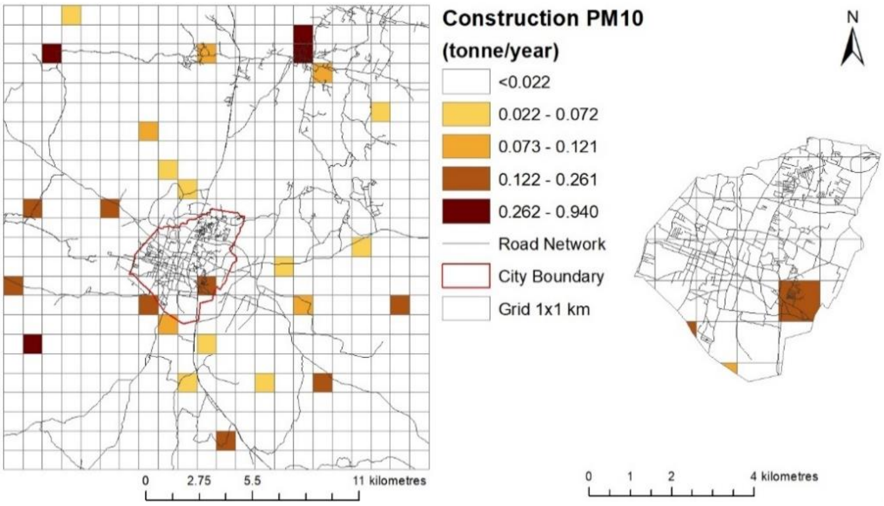

Figure A89 Spatial distribution of PM_{10} emissions from construction in Hazaribagh

SO_2 emissions -Hazaribagh

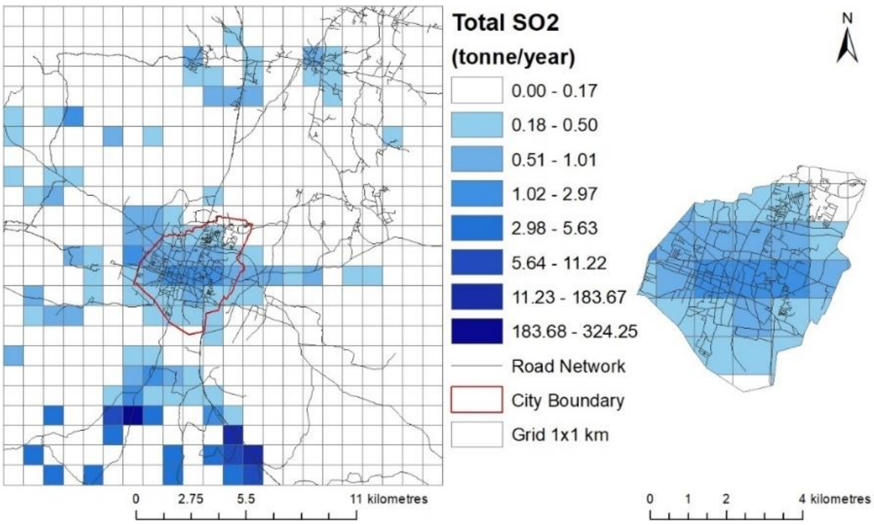

Figure A90 Spatial distribution of total SO_2 emissions in Hazaribagh

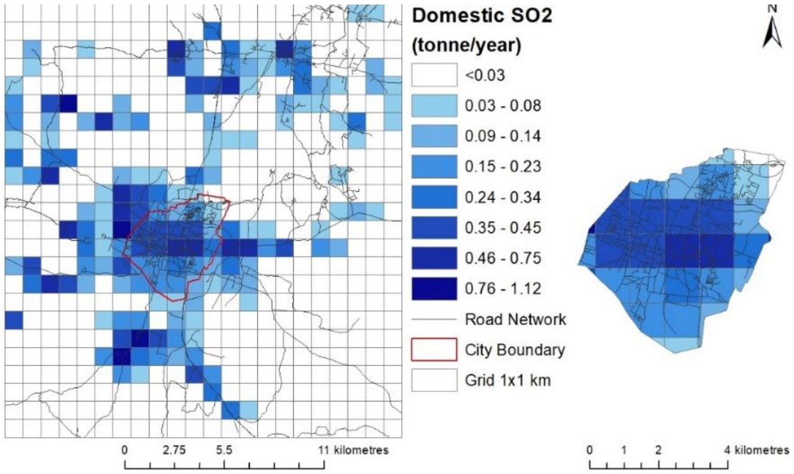

Figure A91 Spatial distribution of SO_2 emissions from the domestic sector in Hazaribagh

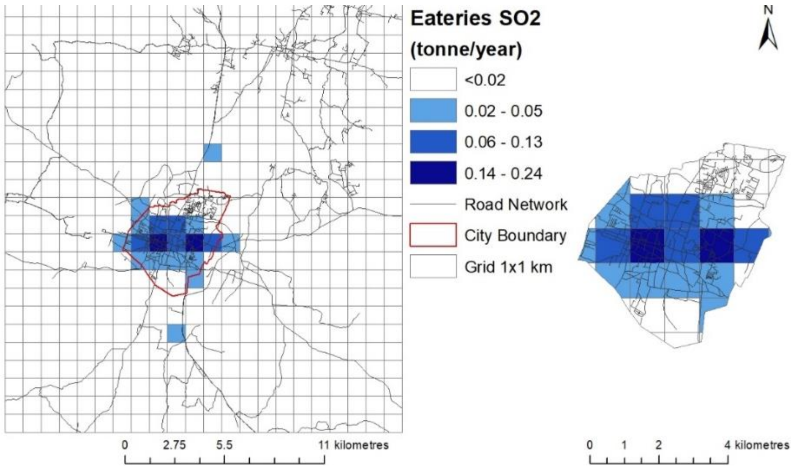

Figure A92 Spatial distribution of SO_2 emissions from eateries in Hazaribagh

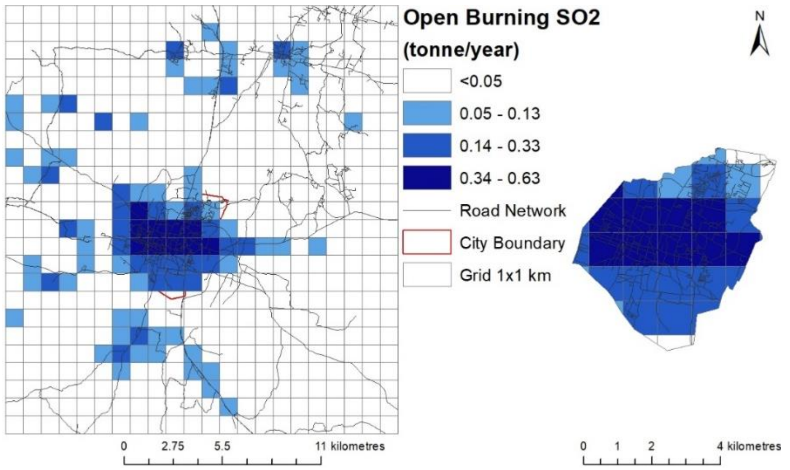

Figure A93 Spatial distribution of SO_2 emissions from open burning in Hazaribagh

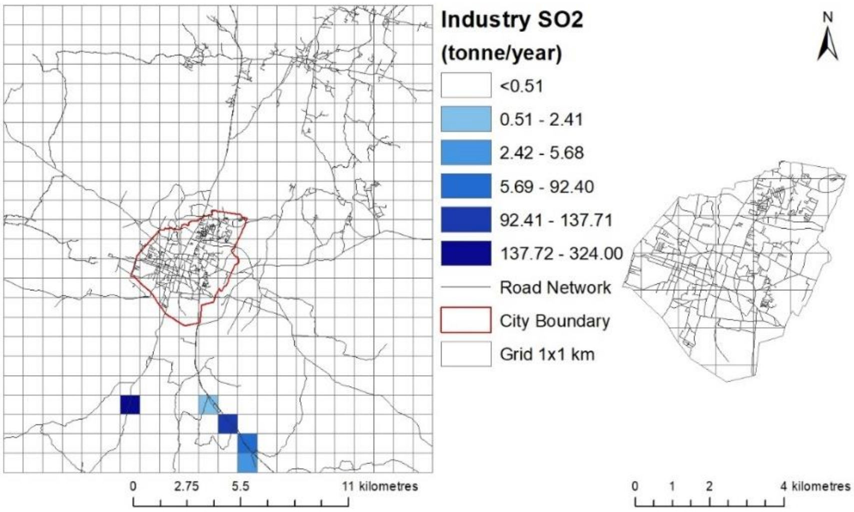

Figure A94 Spatial distribution of SO_2 emissions from industry in Hazaribagh

NO_x emissions – Hazaribagh

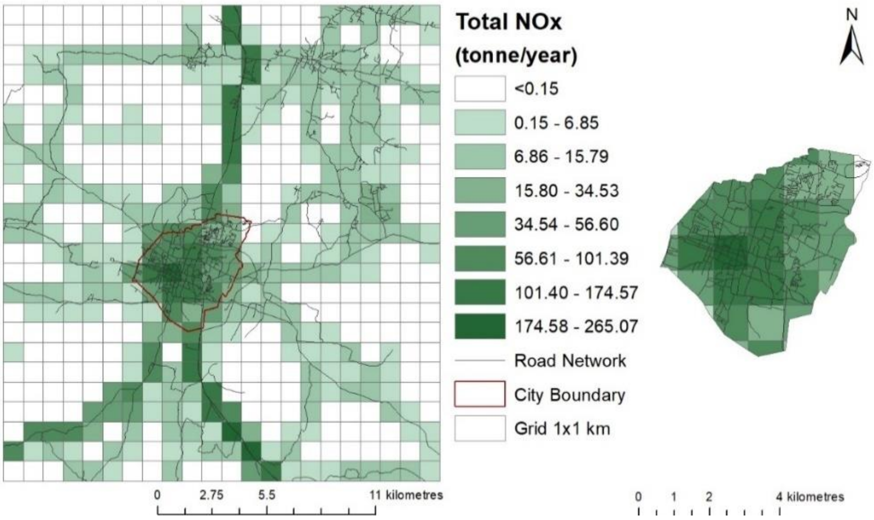

Figure A95 Spatial distribution of total NO_x emissions in Hazaribagh

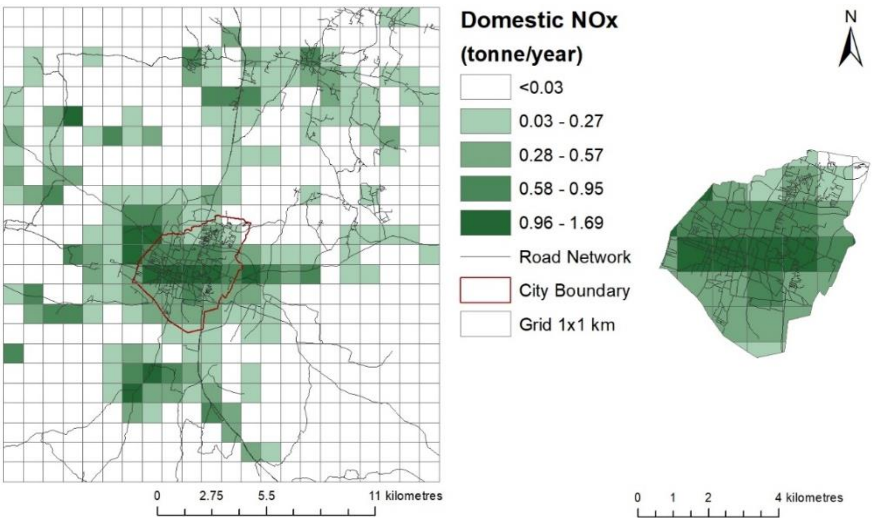

Figure A96 Spatial distribution of NO_x emissions from the domestic sector in Hazaribagh

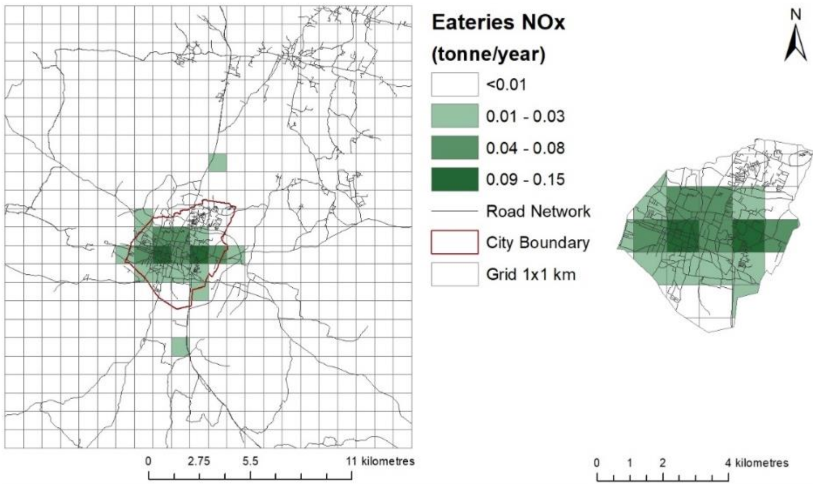

Figure A97 Spatial distribution of NO_x emissions from eateries in Hazaribagh

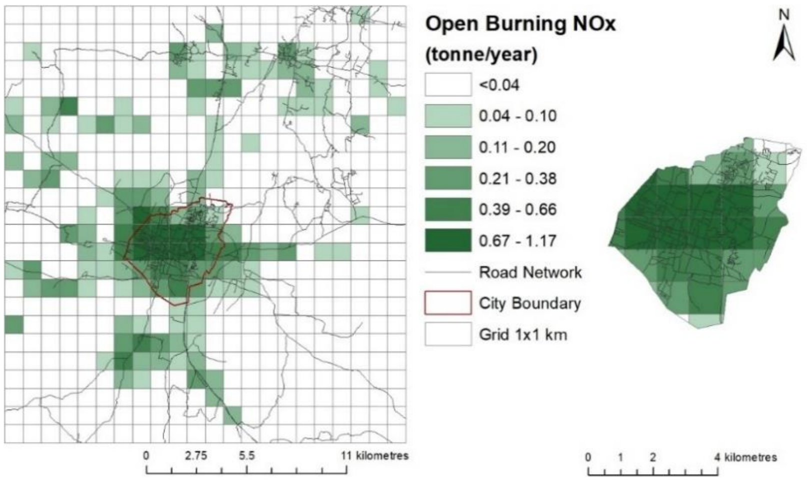

Figure A98 Spatial distribution of NO_x emissions from open burning in Hazaribagh

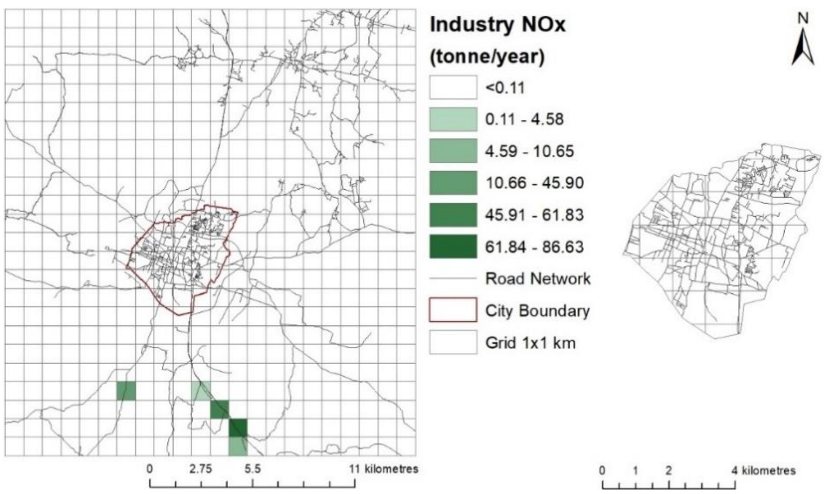

Figure A99 Spatial distribution of NO_x emissions from industry in Hazaribagh

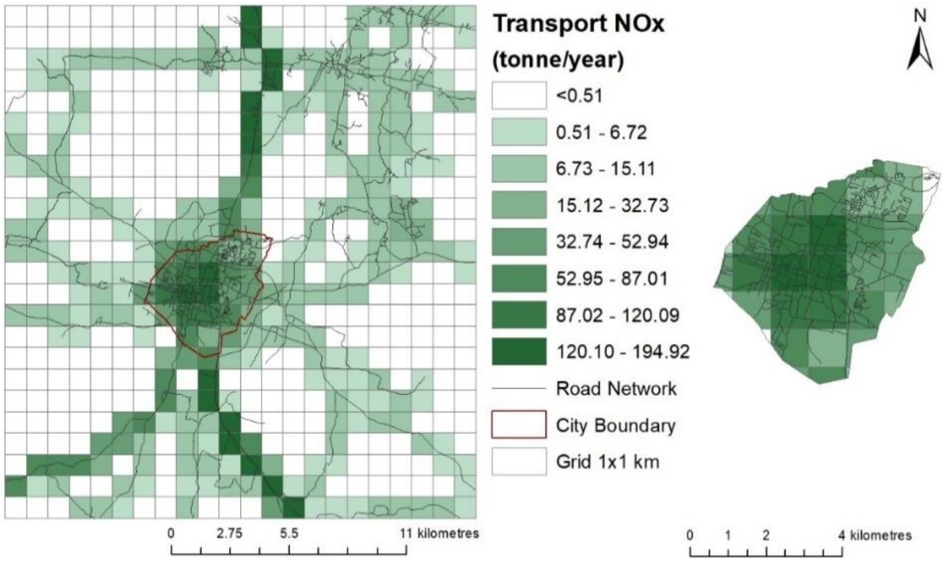

Figure A100 Spatial distribution of NO_x emissions from the transport sector in Hazaribagh

Grid-wise emissions: Ramgarh

PM_{10} emissions - Ramgarh

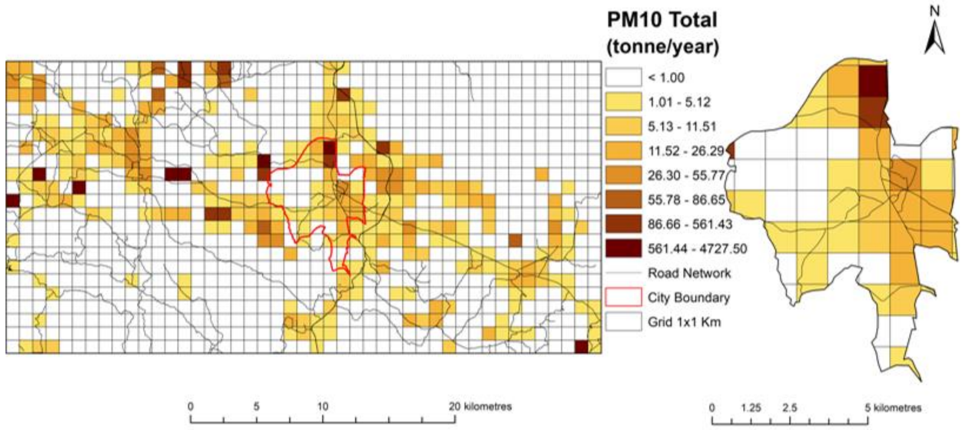

Figure A101 Spatial distribution of total PM_{10} emissions in Ramgarh

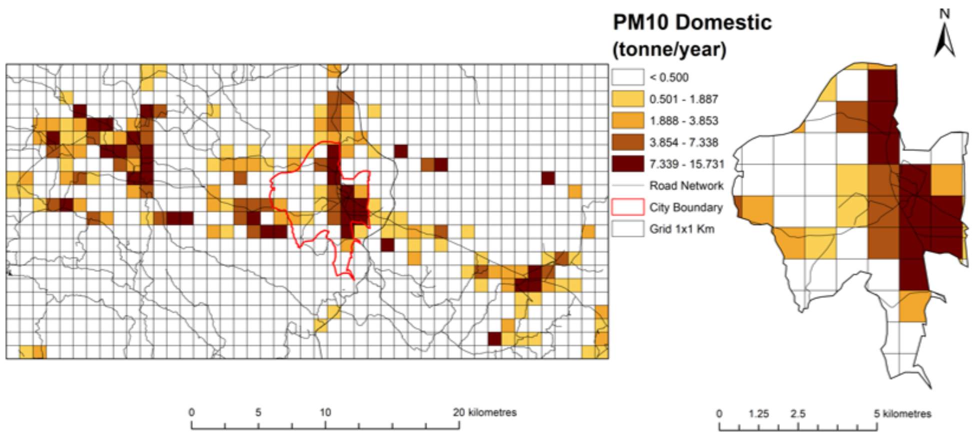

Figure A102 Spatial distribution of PM_{10} emissions from the domestic sector in Ramgarh

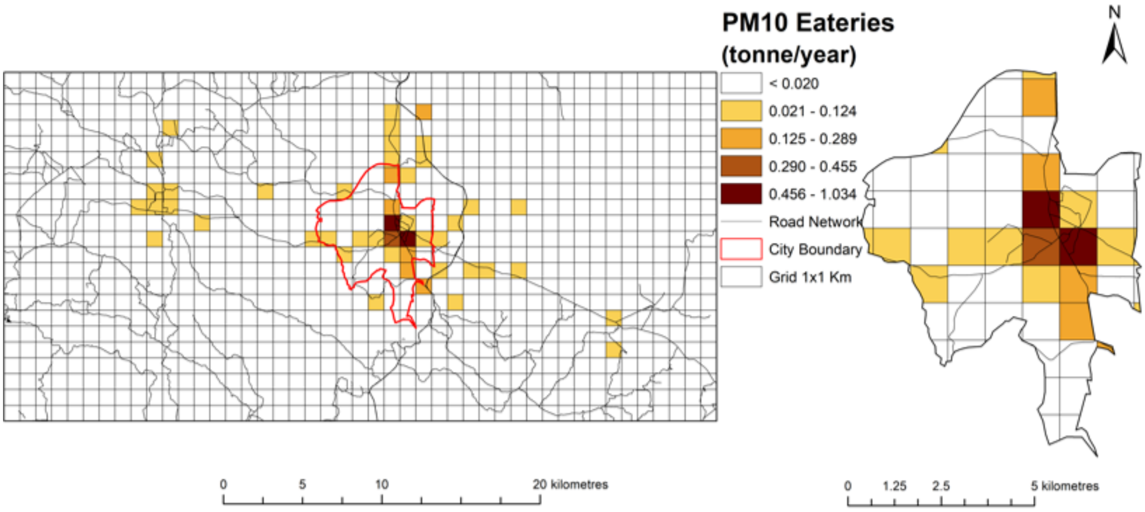

Figure A102 Spatial distribution of PM_{10} emissions from eateries in Ramgarh

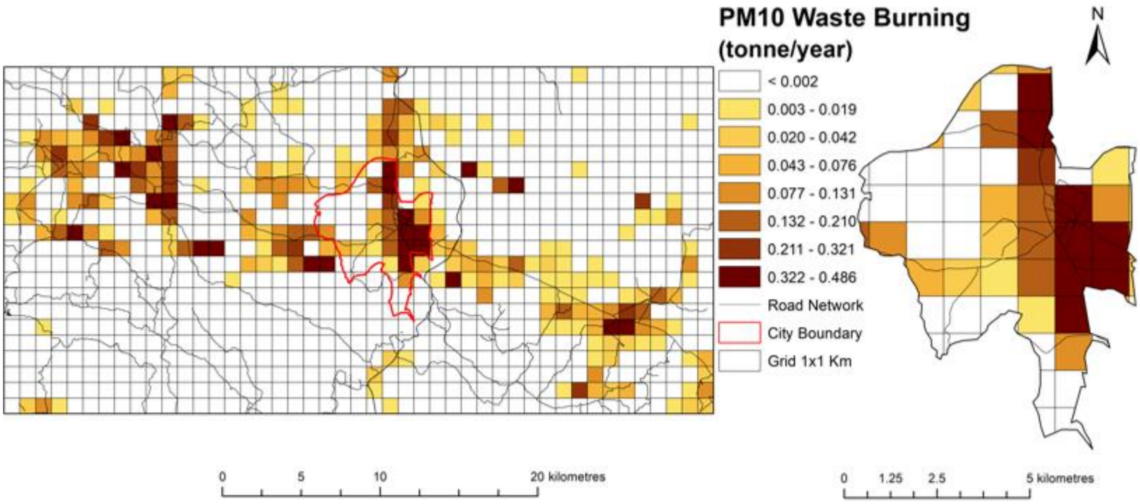

Figure A103 Spatial distribution of PM_{10} emissions from open burning in Ramgarh

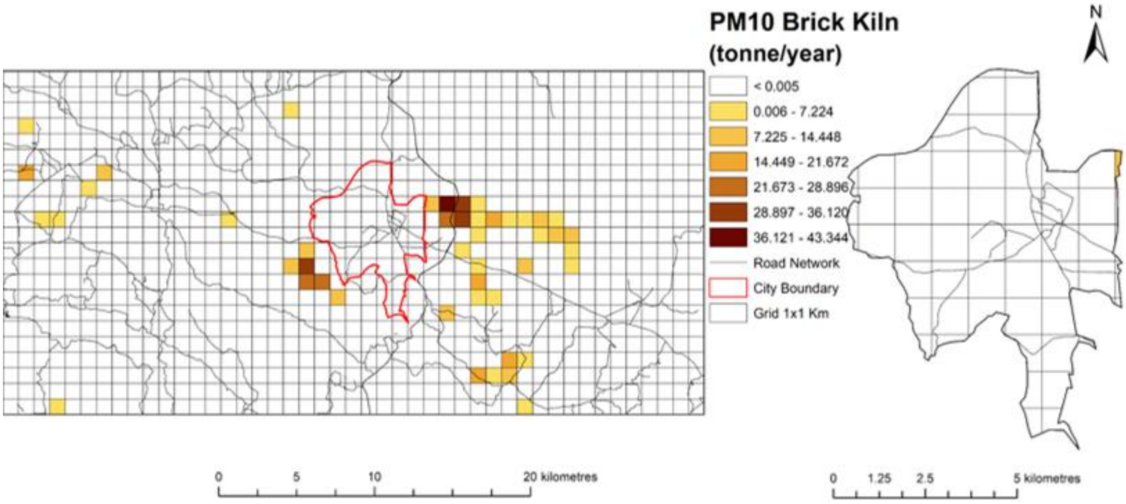

Figure A104 Spatial distribution of PM_{10} emissions from brick kilns in Ramgarh

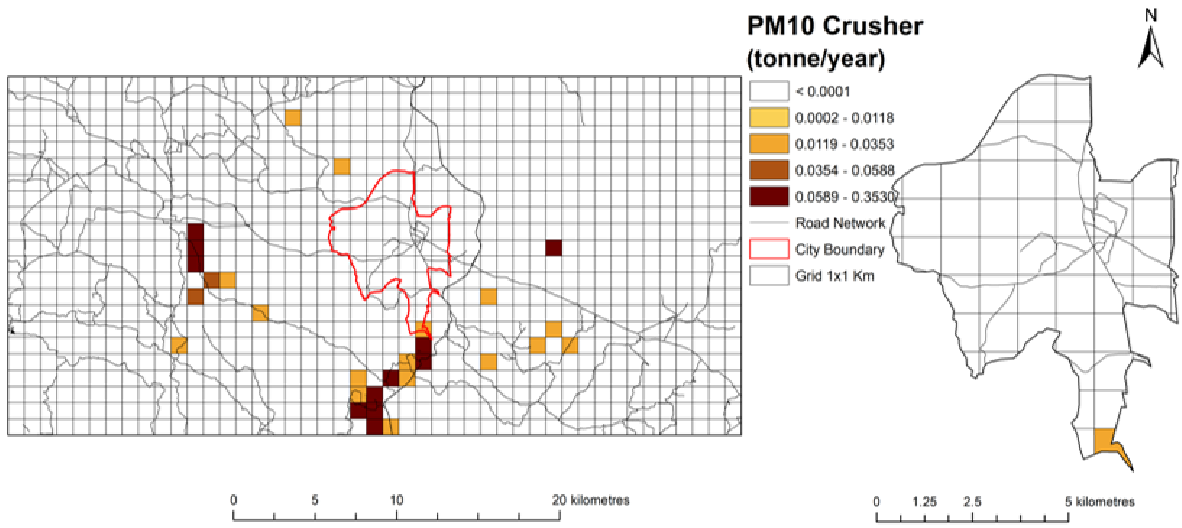

Figure A105 Spatial distribution of PM_{10} emissions from stone crushers in Ramgarh

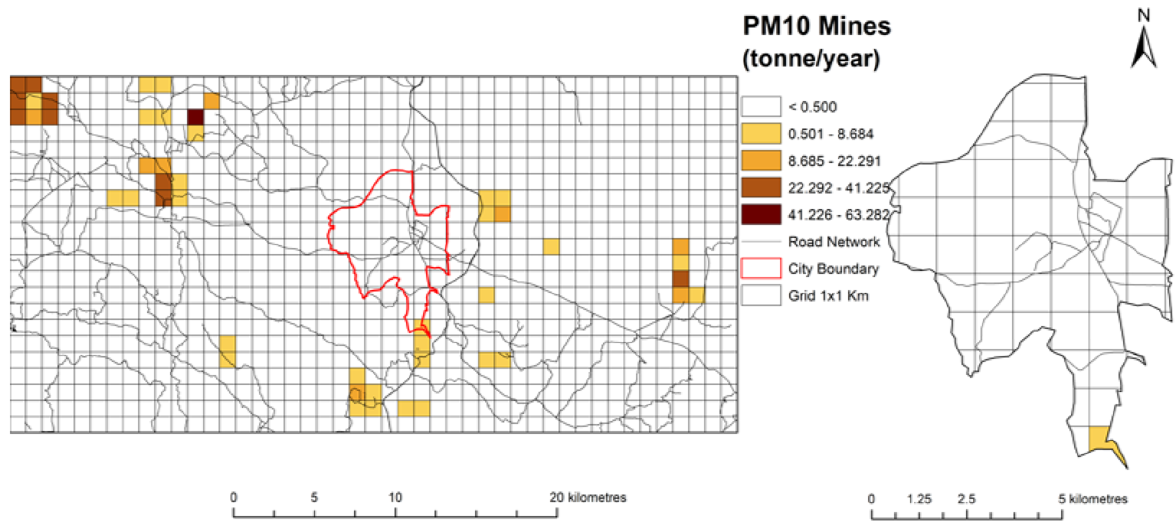

Figure A106 Spatial distribution of PM_{10} emissions from mining in Ramgarh

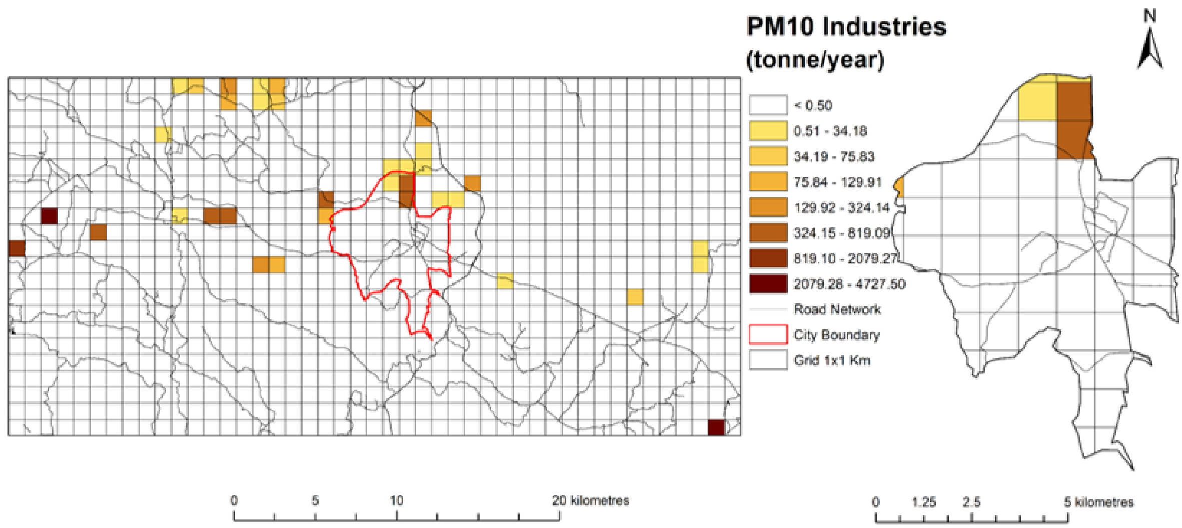

Figure A107 Spatial distribution of PM_{10} emissions from industries in Ramgarh

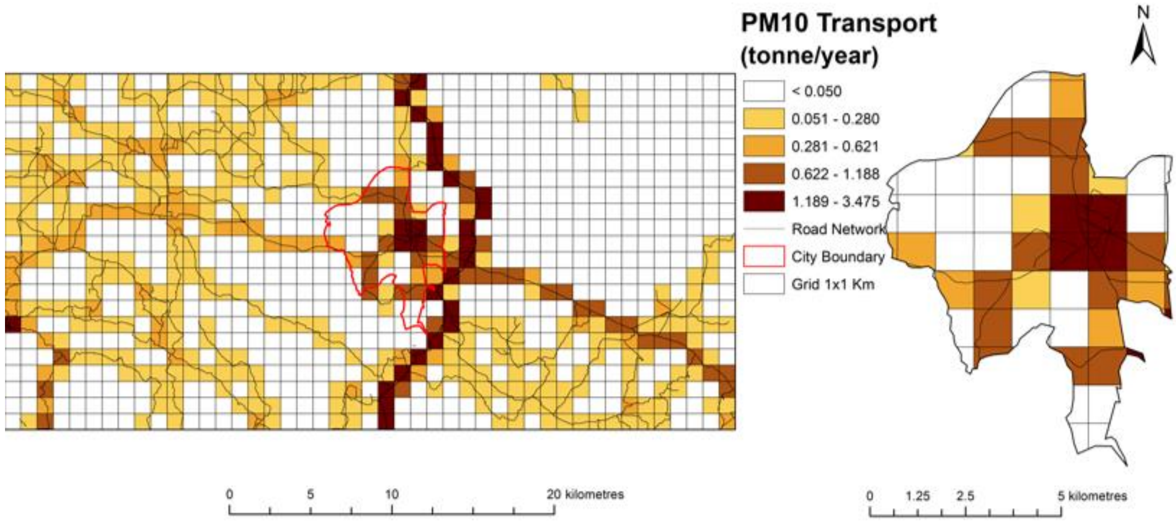

Figure A108 Spatial distribution of PM_{10} emissions from transport in Ramgarh

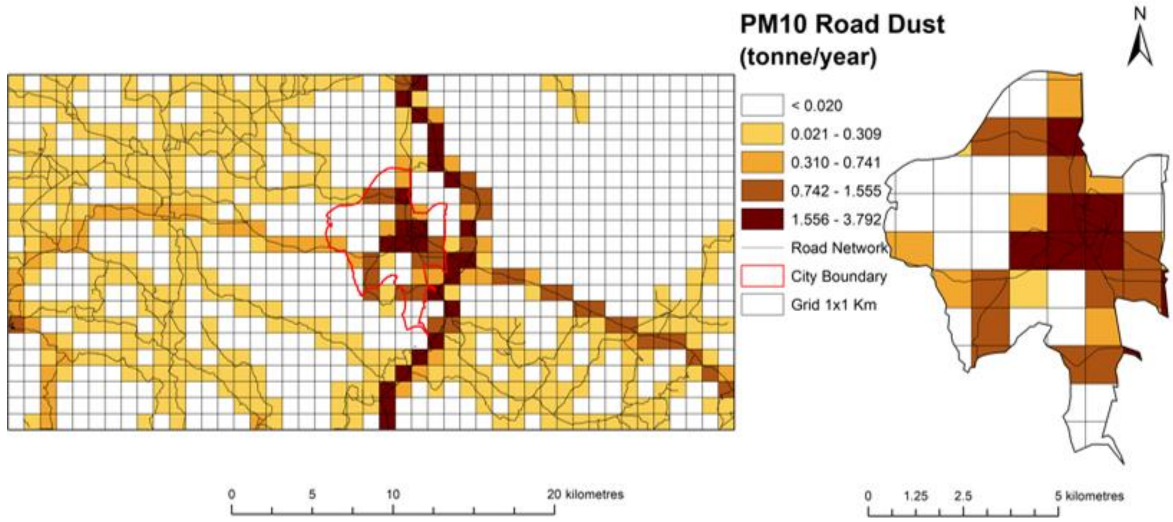

Figure A109 Spatial distribution of PM_{10} emissions from road dust in Ramgarh

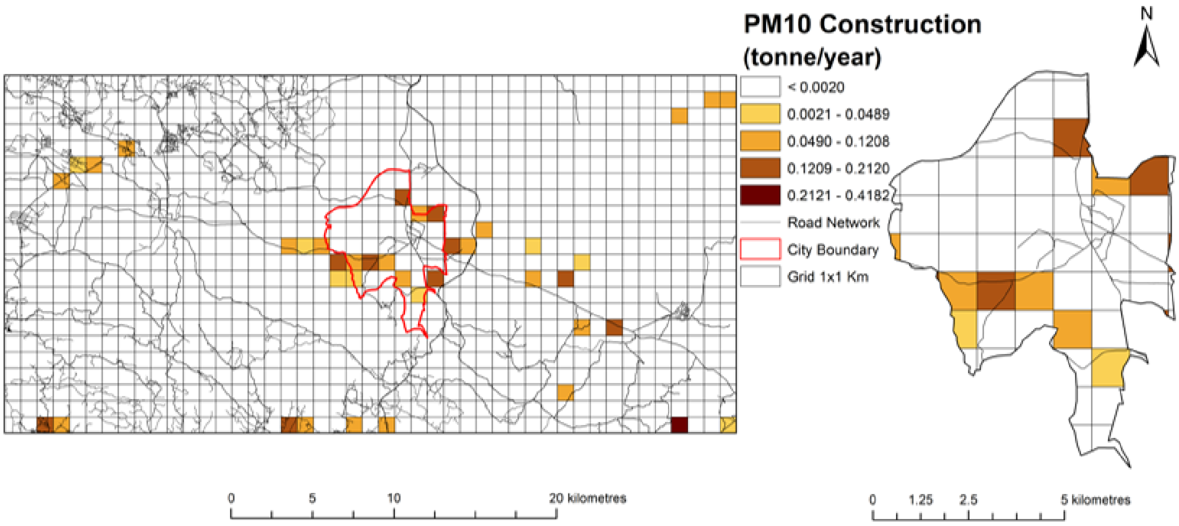

Figure A110 Spatial distribution of PM_{10} emissions from construction in Ramgarh

SO_2 emissions - Ramgarh

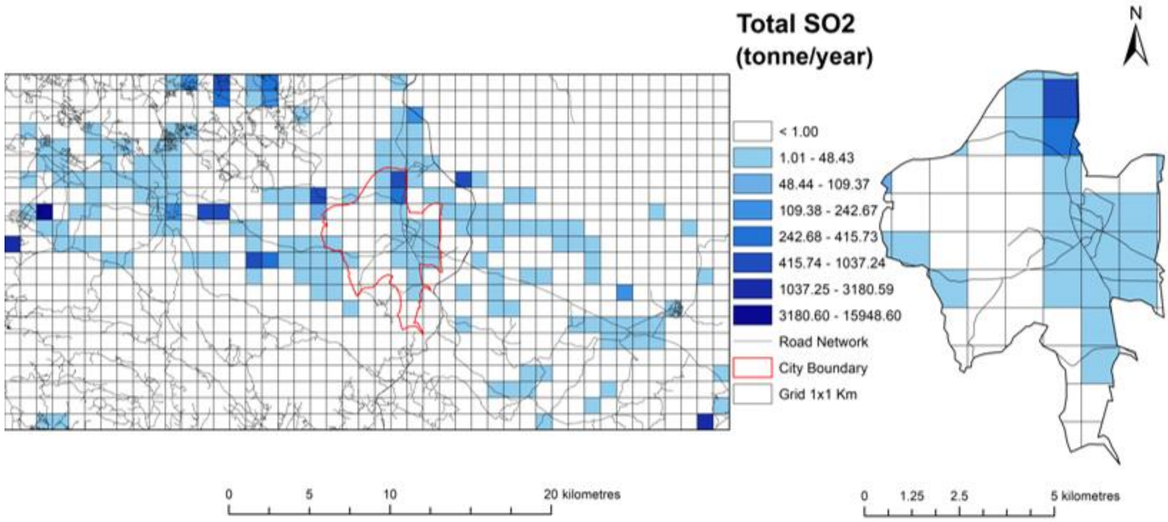

Figure A111 Spatial distribution of total SO_2 emissions in Ramgarh

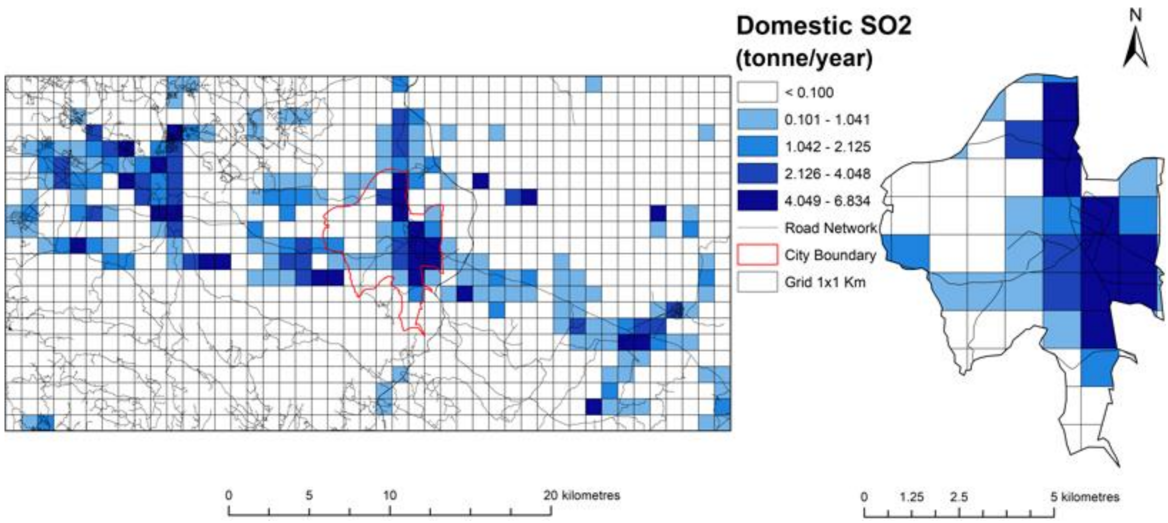

Figure A112 Spatial distribution of SO_2 emissions from the domestic sector in Ramgarh

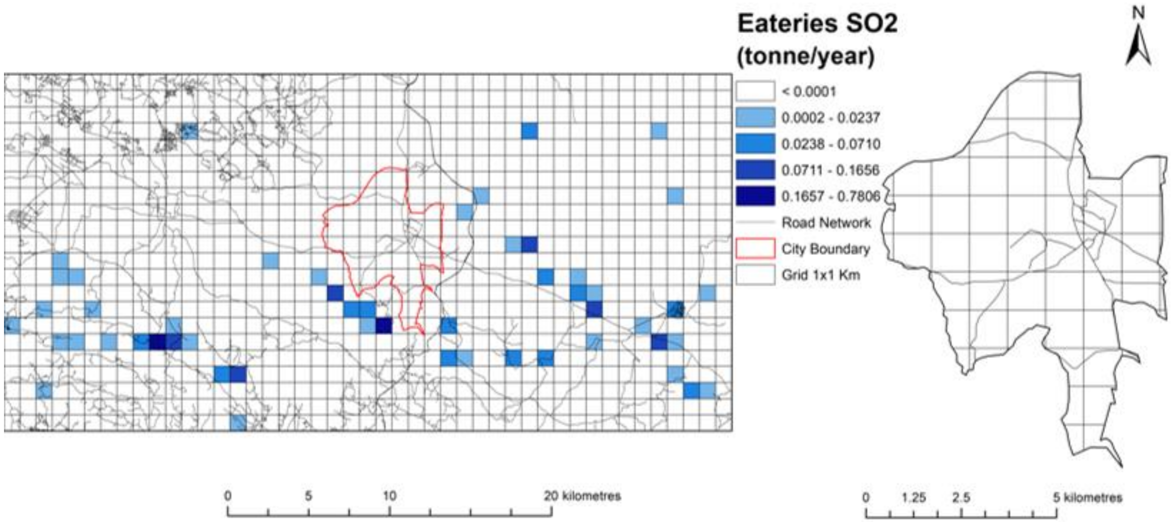

Figure A113 Spatial distribution of SO_2 emissions from eateries in Ramgarh

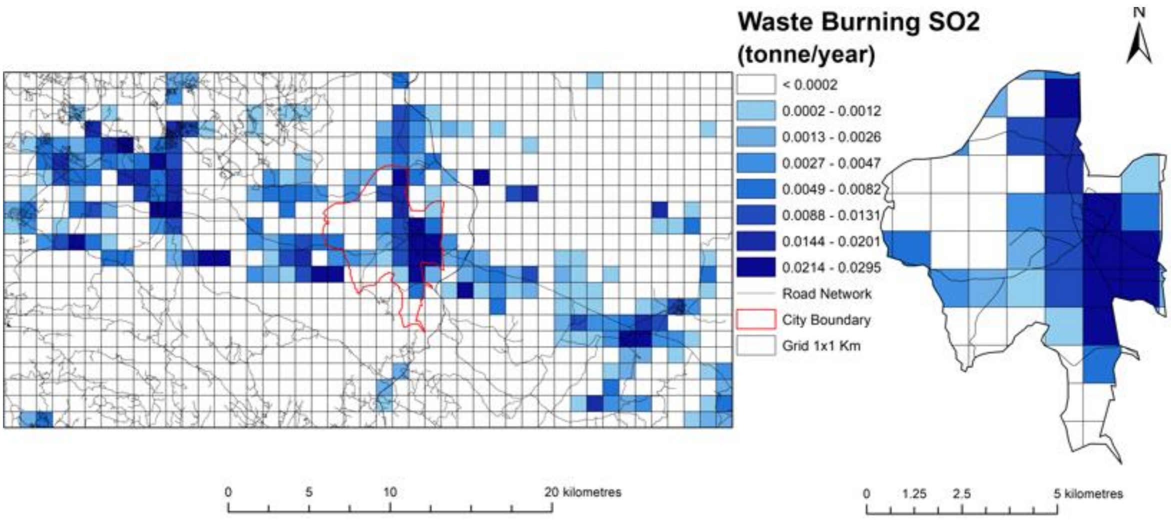

Figure A114 Spatial distribution of SO_2 emissions from waste burning in Ramgarh

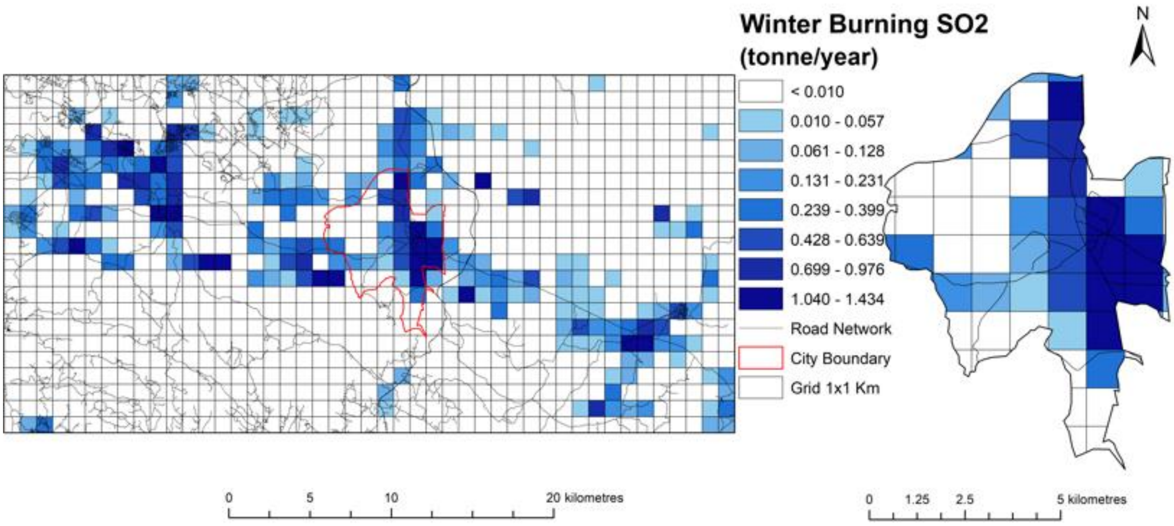

Figure A115 Spatial distribution of SO_2 emissions from winter burning in Ramgarh

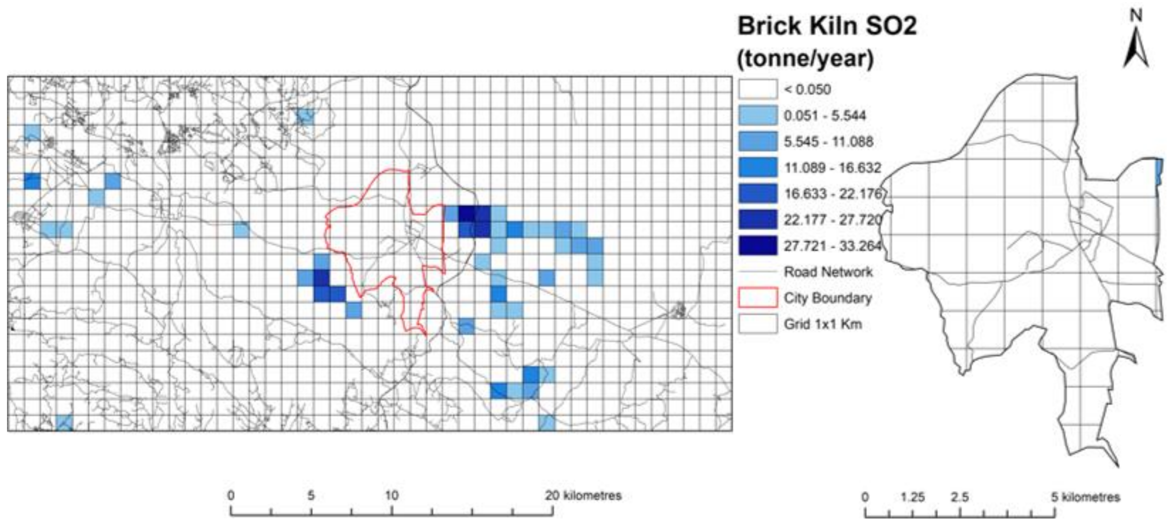

Figure A116 Spatial distribution of SO_2 emissions from brick kilns in Ramgarh

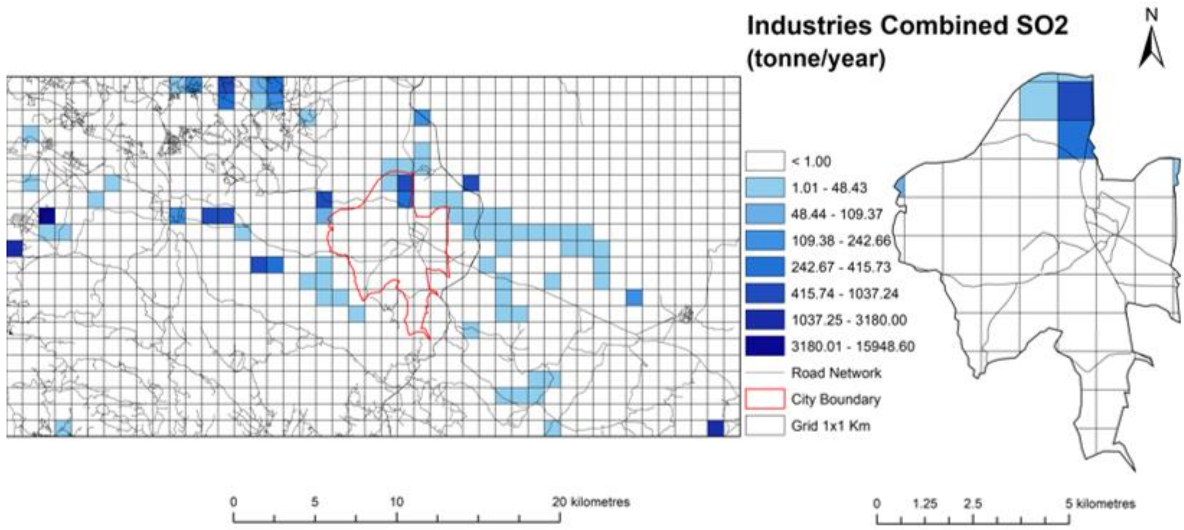

Figure A117 Spatial distribution of SO_2 emissions from industries in Ramgarh

NO_x emissions - Ramgarh

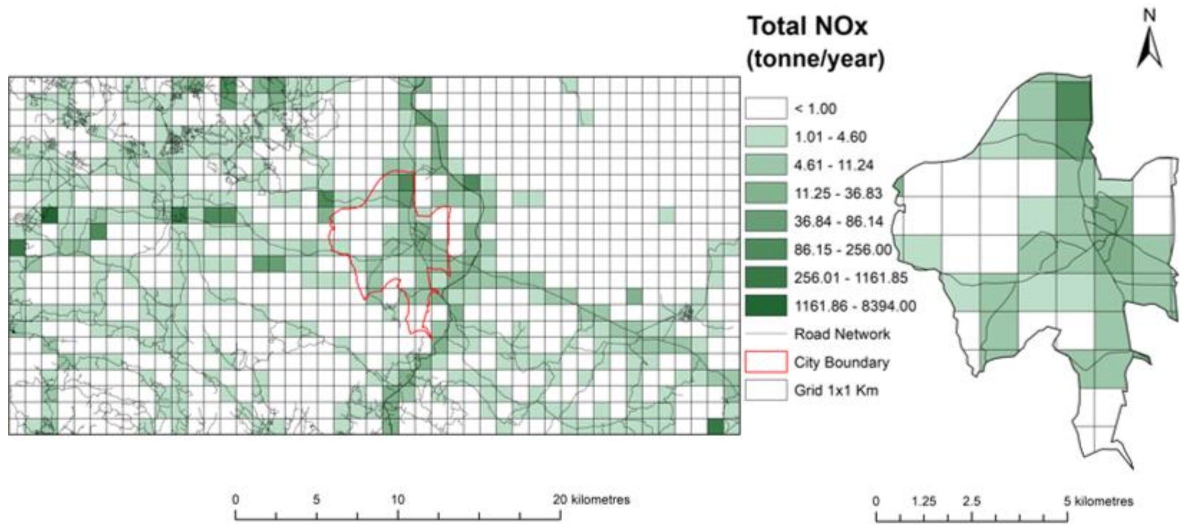

Figure A118 Spatial distribution of NO_x emissions in Ramgarh

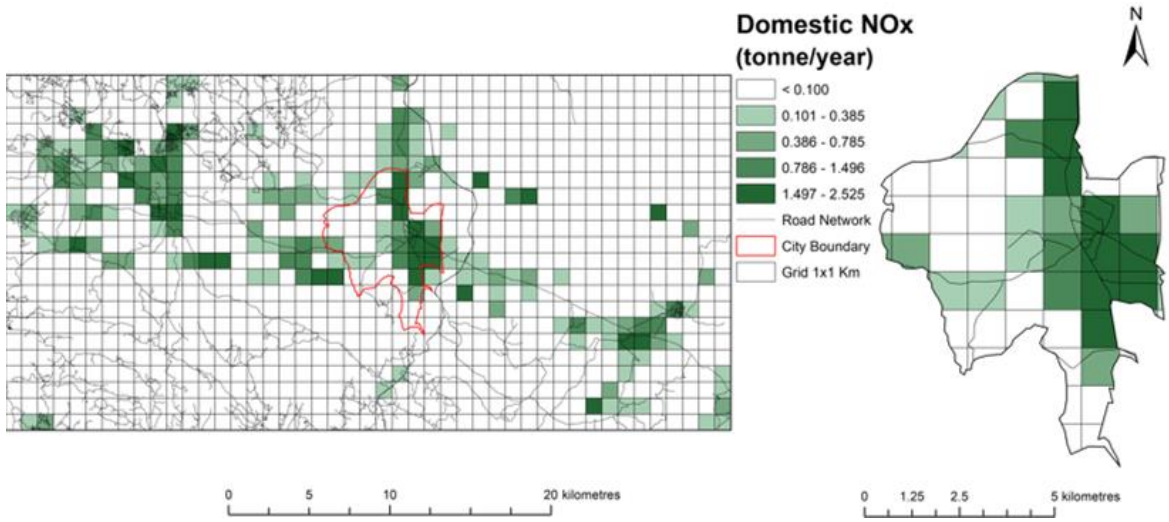

Figure A119 Spatial distribution of NO_x emissions from the domestic sector in Ramgarh

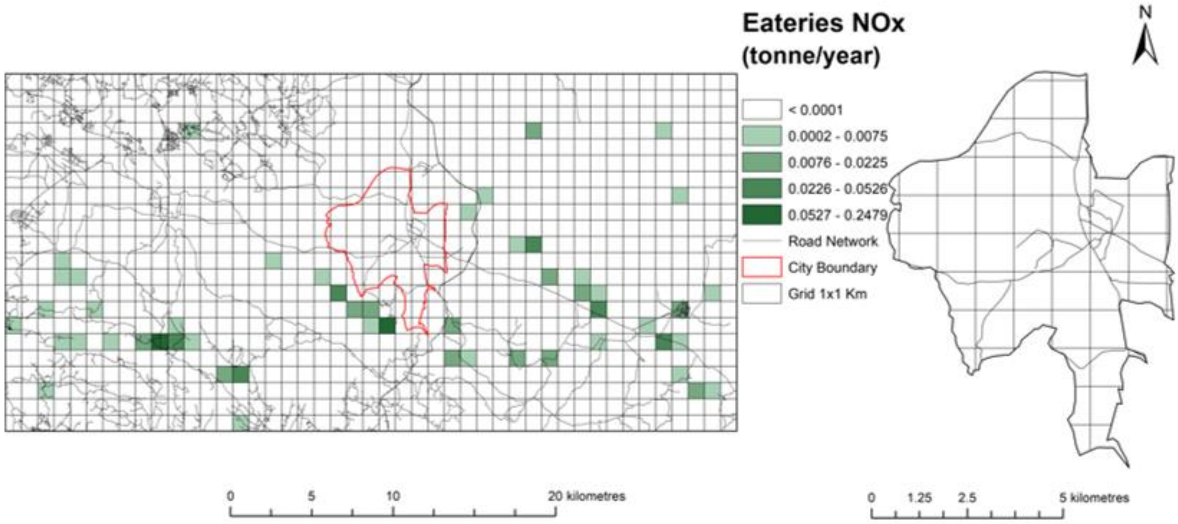

Figure A120 Spatial distribution of NO_x emissions from eateries in Ramgarh

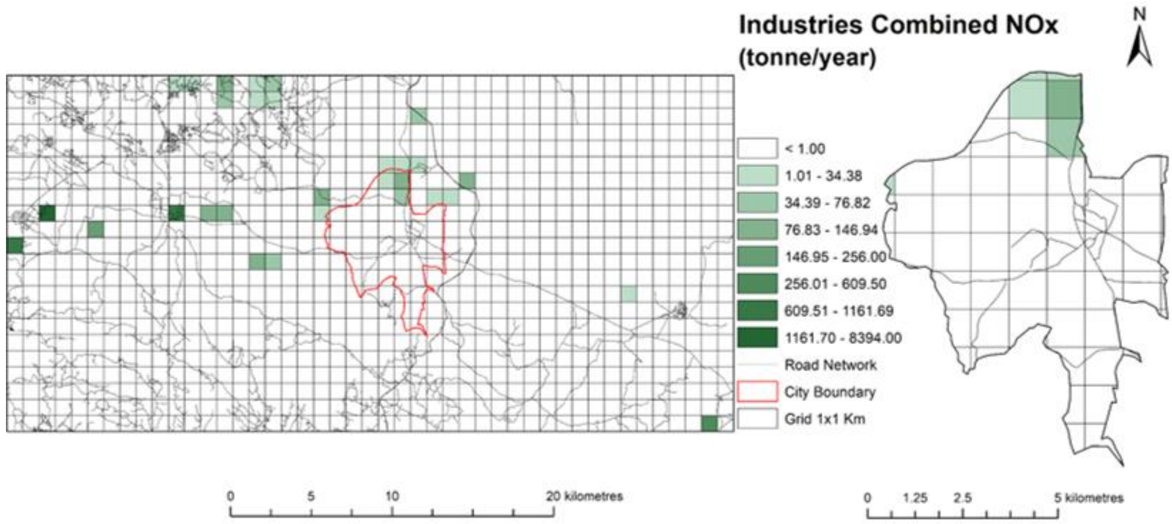

Figure A121 Spatial distribution of NO_x emissions from industries in Ramgarh

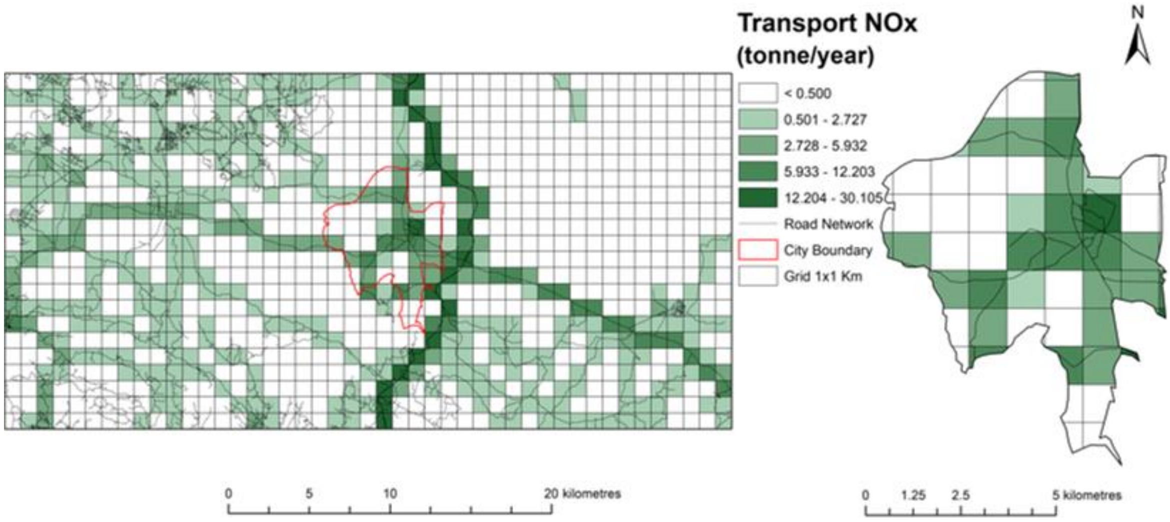

Figure A122 Spatial distribution of NO_x emissions from the transport sector in Ramgarh

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