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Emission inventory of PM_{10} in Dhanbad/Jharia coalfield (JCF), India: an intricate coal mining sector

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Abstract

Open-cast coal mining and its associate activities are responsible for the generation of atmospheric particulate pollutants. An emission inventory technique has been employed to identify and quantify the sources of PM_{10} in Dhanbad/Jharia coalfield (JCF), India. Inventory of natural (mine fire) and anthropogenic (mining and non-mining) was considered to create actual database in the study area. It is a unique approach for a complex coal mining zone associated with mine fire in India. The multiple emission sources such as anthropogenic (open coal mining, industrial and local) and natural (coal mine fire) are responsible for the complexity in the study area. Gridding systems of 129 grids (2 km × 2 km each) were developed to build up a detailed database of sources/activities throughout the study area. The total 9409 kg/day emission load of PM_{10} was estimated during study period. Between all the sources, emission from the open-cast coal mining (19.97%), thermal power plant (18%), vehicles (16%), the paved/unpaved road (14%), domestic fuel burning (12%), open coal burning and mine fire (6%) and garbage burning (5%) were generated a significant amount of PM_{10} throughout the study area. Globally, this study could be guideline to identify and quantify the emission sources in the critically polluted coal mining complex for the developing and developed countries.

Keywords PM_{10} · Open-cast coal mines · Emission inventory · Sources inventory · Jharia coalfield

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1 Introduction

Particulate matter such as PM_{10} has emerged concern today in the field of atmospheric pollution research for its adverse impact on human and the social environment (Gautam et al. 2012; Patra et al. 2016; Roy et al. 2017, 2019a, b, c). Open-cast coal mining and its associate activities were notified as a most common source of atmospheric particulate pollution (Roy et al. 2015, 2016; Gautam et al. 2014). "Coal capital of India" Dhanbad/Jharia coalfield (JCF), located in Dhanbad and Bokaro district (23° 38′ N–23° 48′ N and 86° 11′ E–86° 27′ E), is one of the largest coalfields in India. The Central Pollution Control Board (CPCB) declared this area as critically polluted due to negative impacts of multiple pollution source emission (CPCB 2009). The increasing trend of particulate matter pollution levels in mining complex like JCF is a big threat for the people and living organisms. An emission inventory (EI) technique has been employed to identify the sources to suggest mitigation strategies (USEPA 1998). EI technique describes and identifies polluters of anthropogenic and natural sources. It also provides necessary information for air pollution dispersion modelling studies (Snyder et al. 2013). EI also provides information about the atmosphere trace compounds release rates, with spatial and temporal resolution. It is essential to determine the atmospheric transport and change (Shorshani et al. 2015; Zhang et al. 2014).

The emission factor (EF), an integral part of EI, is a value that relates the quantity of pollutants dispersed into the air and an associated activity. This factor can be determined as the amount of pollutants divided by a unit weight, volume, distance and duration of the activity releasing the pollutants (e.g., grams of particulate emitted per kilogram of coal burnt).

Emission characteristic and EI of a critically polluted coal complex with multiple pollution sources are a new trend in India (Ghose and Banerjee 2002; Gargava et al. 2014; Chen et al. 2016). Multiple sources like thermal power stations (CTPS), open-cast coal mines, residential area and commercial area at the city, vehicular emissions, etc., were taken into consideration in this study. Very few researches are available in these aspects. It is a unique approach for a complex coal mining zone associated with coal mine fire in India. Multiplicity and complexity of sources were created due to the presence of natural and anthropogenic sources in JCF.

2 Materials and methods

Emission inventory (EI) is a tool to identify the sources of pollution. This could be helpful to reduce the pollution levels at source. In the present study, the emission data have been developed using grid systems. For the detailed investigation, entire study area (36 km × 26 km) was divided into 129 grids of 2 km × 2 km. The grid map of the study area is shown in Fig. 1. The equation to calculate the emission is given as

$$E = A \times \mathrm{EF} \times \left(1 - \frac{\mathrm{ER}}{100}\right) \quad (1)$$

where 'ER' is emission reduction efficiency (%); 'E' is emissions; and 'EF' is the emission factor (CPCB 2010). 'A' is activity rate. The activity data were collected through the field survey.

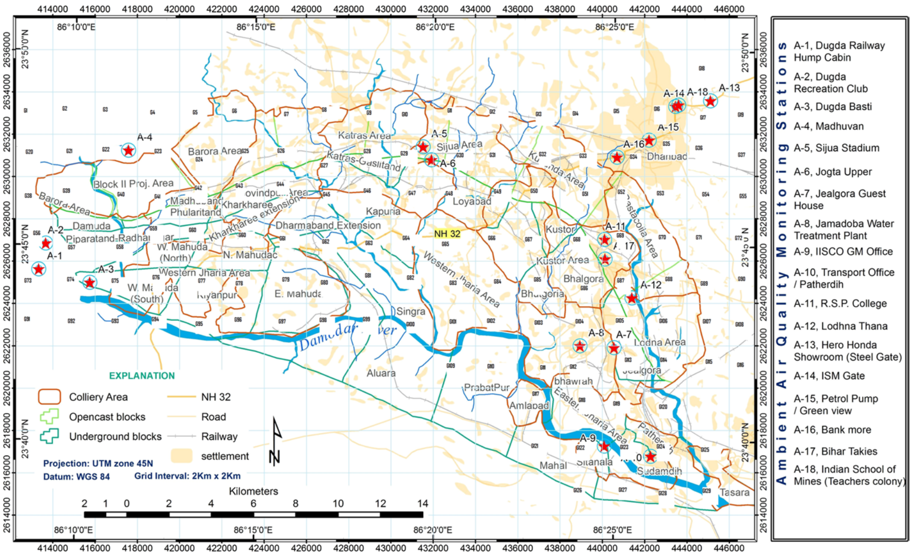


Fig. 1 Grid map of the study area

2.1 Population density and grid population

The parameters such as land-use pattern, population density and grid-wise population data have direct relation with the total emission (E). These parameters are most important for EI study. For the detail investigation, questionnaire format was prepared as per the "source apportionment study" carried out in Delhi by CPCB (2010). The land-use pattern of the JCF is given in Fig. 2. The population density and grid-wise population are estimated as per Eqs. (2) and (3).

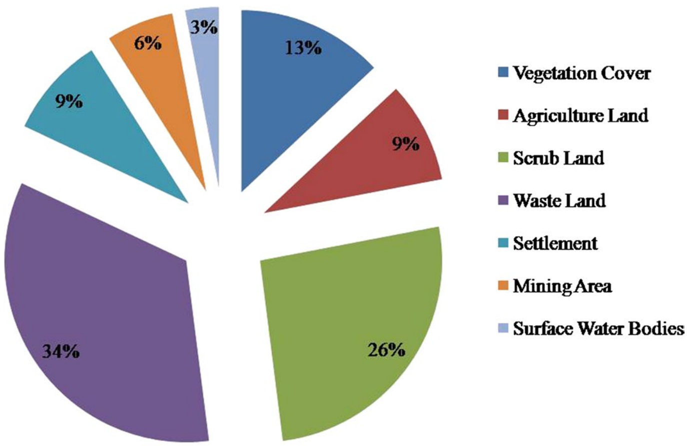


Fig. 2 Land-use pattern of Jharia coalfield (Singh et al. 2013)

$$\mathrm{PD} = \frac{P}{A} \tag{2}$$

$$\mathrm{GP} = \sum_{i=1}^{N} A_i \times \mathrm{PD} \tag{3}$$

where PD = population density (person/km^2), P = population in each ward (person), and A = ward area (km^2), GP = grid population, A_i = intersected ward area, and N = no. of wards lying in that (ith) grid (CPCB 2010).

2.2 Emission factor

Emission inventory of different types of sources at JCF was carried out with the help of EF data. Choosing appropriate EF is an important part to develop EI. In this study, the EF values for various fuels were used to calculate total emission from industrial, residential and power sector. The EFs values were taken from the different source as per the suitability to Indian conditions (Table ST1). These experiments were conducted by certified agencies of Indian government; non-government agencies authorized by the government and various autonomous agencies (Venkataraman et al. 2006; CPCB 2010; US EPA 1978).

Pollution sources from vehicles are heterogeneous due to the presence of the technological mix of fuel type used such as diesel or gasoline or natural gas, usage of engine, technology and type, i.e., BS-II or BS-III, Bharat Statge (BS-I), 4-stroke or 2-stroke, etc. EFs of two-to-four wheelers were taken from various project reports conducted by CPCB and Indian Clean Air Programmed (ICAP) (CPCB 2010; ARAI 2007). In the present study, the above-mentioned EFs were used for the current scenario. These EFs are shown in Table ST2. Emission factors for all area sources apart from coal mining are given in Table ST3. Thirteen traffic junctions were selected throughout the study area as a vehicular monitoring station. Emission factor data of different types of vehicles are as per CPCB database and are given in Table ST4.

2.3 Emission sources

In this study, coal mining and other activities, hotels and restaurants, domestic fuel burning, open burning, paved road dust, demolition/ construction /alteration activities, the bakery, generator sets (DG sets) used in industrial and commercial purpose are identified as area sources (Sahu et al. 2012). The coal mines in JCF are under the supervision of Bharat Coking Coal Limited (BCCL). JCF is composed of 17 clusters containing 88 collieries out of which 39 collieries were in production stage during October, 2011 to June, 2012. Production data of all active collieries during the study period were collected from BCCL office in Dhanbad. Out of 39 collieries, 11 active open-cast collieries are situated near the study area. The huge amount of dust is generated during its various operations. Mining and its associated activities like coal extraction, overburden excavation, coal and topsoil transportation, piling and unloading, stock piling /loading and size reduction etc. are the primary sources of particulate matter in surrounding the region. The detail about the emission factors for each activity is given in Supplementary Table ST5. The emission rate has been calculated as per Eq. (1). The ER value was taken as 72% of total PM_{10} emission levels (Huertas et al. 2012). Calculated emission rate data of PM_{10} from different collieries are given in Table ST6.

2.3.1 Open coal and garbage burning

The open coal burning which is generally observed in JCF can be classified into biomass and refuse burning. In refuse burning, the solid waste generation depends upon the regional locality types, i.e. more garbage generation in areas having more commercial activities. Field surveys were conducted in the study area to calculate the garbage generation and collection. Open coal burning, the survey was conducted simultaneously in the mining areas of JCF. Additionally, neighbourhood locals gather coal from the mines through the unlawful procedure and burn it in an open space to expel contaminations.

Additionally, the emission from garbage burning is directly related with the amount generated per day. Generation garbage was calculated from the activity data (kg/person/day) and the number of population in a particular grid (CPCB 2010). On the basis of the database, the assumptions made and emissions for various pollutants were calculated. The activity data can be expressed in kg of combustible garbage/person/day. The activity data are expressed as kg /person/day. The emissions of various pollutants were calculated for all the grids of the study area. The calculation is based on Eq. (1).

2.3.2 Unpaved and paved road emissions

It was observed that dust emissions from the unpaved and paved roads depend on the 'silt loading' factor and weight of vehicles travelling on the road. The silt loading (sL) is the mass of the silt-size material per unit area of the travel surface. The quantity of dust generates by vehicles movement on a paved road can be estimated by the following equation:

$$E = k\left(\frac{sL}{2}\right)^{0.65}\left(\frac{W}{3}\right)^{1.5} \tag{4}$$

where 'E' is the emission rate of PMs; 'sL' is silt load (g/m^2); 'W' is the average weight of the vehicle (Tons); 'k' is constant (the function of particle size) in g VKT-1 (Vehicle Kilometer Travel) (e.g. $k = 4.6$ for PM_{10}) (CPCB 2010).

2.3.3 Domestic and commercial fuel combustions

Details of the hotels and restaurants including fuel consumption data of coal, LPG and wood and other activities were collected from all the grids. The majority of these activities were observed in the business regions and some in institutional, industrial and private zones too. Extremely restricted overviews were additionally led in the mining zone. The data were collected separately for restaurants. For each fuel type (LPG, coal and wood), fuel consumption was estimated for each grid. The emissions with respect to different contaminations from these exercises were assessed from each fuel type and were summarized. The calculation is made by using Eq. (1), where 'ER' is efficiency reduction (zero). 'EFs' is emission factor (as per CPCB guidelines).

Estimations of outflow for family unit exercises depended on the demographic data of the location. The classifications were made as low, medium and high (based on average annual income) for a particular grid. The kinds of fuel utilized for family cooking in the city are LPG, wood, coal and kerosene. On the basis of the survey, it was assumed that higher and middle economic group people used LPG or kerosene and the poor economic groups in the city used kerosene, wood and coal (in different fractions) at the same localities. Emission of PM_{10} was estimated from the activity data without any emission reduction. The subtleties of the bread kitchens were gathered from the State Pollution Control Board, Jharkhand, India. There were eight bakeries in the study area. The limit of the bread kitchen and day-by-day fuel utilization was taken according to CPCB source profile information. Significant stacks with prominent heights were absent in these small industries. Coal is the significant fuel source utilized in these industries in Dhanbad. The fuel consumption for individual bakery was estimated by multiplying the amount of fuel required per unit of production with the capacity of the bakery. The unit of the action information is kg of fuel/day devoured for every bread kitchen. Emissions from the bakery with respect to various pollutants are estimated using Eq. (1).

2.3.4 Development activities and DG set emissions

A detailed survey was carried out for the collection of data related to demolition and construction works in the location. The survey of various structures, streets and flyovers under development were reviewed in the study region. The under-construction area was estimated from the survey information. The emission is calculated using Eq. (1). The activity data are expressed in m^2, i.e., area of these activities.

Because of the electricity crisis in Dhanbad, DG sets are utilized as an alternative source of electricity in industries, shopping malls and in the residential area. The survey data showed minimum 6 h per day power outage in Dhanbad. That is the reason for considering the DG sets emissions as a most important emission sources in this area. Every grid was surveyed to quantify the power consumption for DG sets. The intensive survey concluded that people in the residential area used battery-operated inverters more commonly than the DG sets in emergency. Fuel admissions for these exercises are for the most part diesel. Diesel is commonly used as a fuel intake. The estimation is based on Eq. (1), where 'ER' is efficiency reduction (zero). The values of EFs were taken from the CPCB database.

3 Results and discussion

Grid-wise survey identified eleven major polluting sources in JCF/Dhanbad city. Emission load from area, point and line sources for each grid is given in Supplementary Table ST7. These predominating emission sources can be subdivided into three categories, i.e., point, area and line sources. The industries having the stack height more than 40 m have been considered as medium-to-large-scale industries. Chandrapura Thermal Power Station (CTPS) which is 4 km from the western parts of JCF was considered as a polluting source within the all point sources present in the study area. As a result, emission of PM_{10} from CTPS was estimated 1693 kg/day. A same result was reported by Das (2011). Another side, roadway air emissions were identified as most prominent line source in this study. The counting of vehicles was monitored from 8 a.m. to 8 p.m. with an interval of every 1 h at 13 different junctions of Dhanbad. The concentration of 2W (Two Wheelers), 3W (Three Wheelers), 4W (Four Wheelers) and HDV (Heavy Duty Vehicles) is given in Tables 1, 2, 3 and 4.

Vehicle estimation is one of the important parts of the emission inventory study of the city area. Among the 13 junctions, maximum amount of 2W were observed at Bank

Table 1 Hourly distributions of two wheelers (2W) at junctions

Area	Hours												Total
	8.00–9.00	9.00–10.00	10.00–11.00	1.00–12.00	12.00–13.00	13.00–14.00	14.00–15.00	15.00–16.00	16.00–17.00	17.00–18.00	18.00–19.00	19.00–20.00	
Dugdha More	62	211	245	292	283	223	230	262	356	323	210	71	2768
Madhuban More	120	214	334	361	422	329	215	319	381	352	145	52	3244
Sijua More	236	457	539	521	489	458	536	478	592	581	231	112	5230
Jealgora More	120	215	245	282	287	221	230	264	346	323	205	123	2861
Jamadoba More	120	216	338	363	425	334	217	231	341	332	135	142	3194
IISCO More	236	457	539	521	489	458	536	478	592	581	231	112	5230
Patherdih More	120	214	334	361	422	329	215	319	381	352	145	52	3244
R.S.P College More	253	485	564	551	589	558	636	578	692	581	431	212	6130
Steelgate	123	238	355	351	412	380	235	369	521	492	435	272	4183
I.S.M Gate	128	228	325	345	421	368	229	361	514	452	415	282	4068
Green View More	316	389	452	489	523	693	642	529	512	678	390	378	5991
Bank More	246	467	619	621	789	658	536	478	612	781	431	312	6550
Bihar Talkies	236	457	539	521	489	458	536	478	592	581	231	112	5230

Table 2 Hourly distributions of three wheelers (3W) at junctions

Area	Hours												Total
	8.00–9.00	9.00–10.00	10.00–11.00	1.00–12.00	12.00–13.00	13.00–14.00	14.00–15.00	15.00–16.00	16.00–17.00	17.00–18.00	18.00–19.00	19.00–20.00	
Dugdha More	40	180	220	254	238	196	206	225	310	247	169	25	2310
Madhuban More	40	120	180	167	143	90	87	123	132	145	89	25	1341
Sijua More	136	157	239	321	289	158	136	278	292	331	131	112	2580
Jealgora More	80	114	150	155	130	80	60	140	153	112	97	52	1323
Jamadoba More	50	69	125	136	114	98	85	148	137	119	94	41	1216
IISCO More	70	112	143	152	128	117	105	134	129	141	103	73	1407
Patherdih More	80	114	150	155	130	80	60	140	153	112	97	52	1323
R.S.P College More	134	154	232	241	269	158	138	278	292	301	131	82	2410
Steelgate	80	157	239	321	289	258	236	278	292	331	131	112	2724
I.S.M Gate	71	143	253	325	281	278	226	268	282	323	139	122	2711
Green View More	81	149	259	327	291	268	246	258	292	329	149	126	2775
Bank More	236	457	539	521	489	458	536	478	592	581	231	112	5230
Bihar Talkies	134	154	232	241	269	158	138	278	292	301	131	82	2410

Table 3 Hourly distributions of four wheelers (4W) at junctions

Area	Hours												Total
	8.00–9.00	9.00–10.00	10.00–11.00	1.00–12.00	12.00–13.00	13.00–14.00	14.00–15.00	15.00–16.00	16.00–17.00	17.00–18.00	18.00–19.00	19.00–20.00	
Dugdha More	20	42	45	60	66	57	31	70	65	40	34	10	540
Madhuban More	40	120	180	167	143	90	87	123	132	145	89	25	1341
Sijua More	76	137	139	221	189	138	116	178	192	231	131	84	1832
Jealgora More	80	114	150	155	130	80	60	140	153	112	97	52	1323
Jamadoba More	50	69	125	136	114	98	85	148	137	119	94	41	1216
IISCO More	70	112	143	152	128	117	105	134	129	141	103	73	1407
Patherdih More	80	114	150	155	130	80	60	140	153	112	97	52	1323
R.S.P College More	94	154	232	241	269	158	138	278	292	301	131	82	2370
Steelgate	80	157	239	321	289	258	236	278	292	331	131	112	2724
I.S.M Gate	71	143	253	325	281	278	226	268	282	323	139	122	2711
Green View More	81	149	259	327	291	268	246	258	292	329	149	126	2775
Bank More	111	351	431	421	482	338	336	368	482	481	289	112	4202
Bihar Talkies	84	154	232	241	269	158	138	278	292	301	131	82	2360

Table 4 Hourly distributions of buss/trucks at junctions

Area	Hours												Total
	8.00–9.00	9.00–10.00	10.00–11.00	1.00–12.00	12.00–13.00	13.00–14.00	14.00–15.00	15.00–16.00	16.00–17.00	17.00–18.00	18.00–19.00	19.00–20.00	
Dugdha More	31	42	46	49	82	80	60	102	115	52	41	80	780
Madhuban More	40	120	180	167	143	90	87	123	132	145	89	126	1442
Sijua More	80	114	150	155	130	80	60	140	153	112	97	114	1385
Jealgora More	84	115	150	155	125	80	90	134	153	117	97	123	1423
Jamadoba More	50	79	125	116	114	98	85	146	127	129	94	121	1284
IISCO More	62	112	145	154	135	147	118	134	129	140	103	173	1552
Patherdih More	60	114	120	141	133	105	60	120	141	132	104	122	1352
R.S.P College More	91	154	232	221	219	138	148	278	252	211	131	82	2157
Steelgate	10	9	11	8	10	12	5	8	10	9	7	6	105
I.S.M Gate	10	9	11	8	10	12	5	8	10	9	7	6	105
Green View More	10	9	11	8	10	12	5	8	10	9	7	6	105
Bank More	10	9	11	8	10	12	5	8	10	9	7	6	105
Bihar Talkies	12	19	21	18	20	22	15	18	20	19	17	16	217

Table 5 Emissions rate of PM_{10} from various vehicle types

Pollutant	Emission kg/day				Total
	2W	3W auto and tempos	4W cars and jeeps	Buses and trucks (HDV)	
PM_{10}	91	618	392	407	1508

Table 6 Contribution of emissions from area sources

Source	PM_{10} emissions of pollutants (kg/day)	Emission by percentage
Open-cast coal mines	1878	38
Hotel and restaurants	282	06
Garbage burning	470	10
Barren land waste burning	376	08
Emission from DG set	188	04
Open coal burning	565	11
Domestic fuels	1129	23

More (6550) followed by R.S.P. College (6130), Green view More (5991), Bihar Takies (5230) and IISCO More (5230). It was also observed that 2W concentration was found the maximum at morning 10–12 noon and evening 4–6 throughout all the junctions due to office and college timings. As per 3W study at the junctions, it was observed that hourly in an average 150–200 vehicles were passed through the junctions. The sharp change of 3W concentration was found in Bank More, Dhanbad, and it was also recorded maximum concentration of 3W (112–592) with the average of 300 per hours followed by Green view More (81–329), I.S.M. Gate and Steel Gate (80–292). Concentration of 4W also found higher during 10 a.m. to 11 a.m. and 4 p.m. to 6 p.m. It was found the maximum at Bank More (4202) followed by Green view More (2775), Steel Gate (2724), ISM Gate (2711), etc. On the other side, the maximum number of Buss/ Trucks was counted at R.S.P. College (2157) followed by IISCO More (1552) and Jealgora More (1423). A very less significant concentration of Buss/ Trucks was recorded at Steel Gate, I.S.M. Gate, Green view More, Bank More, Bihar Takies due to no entry stop in this road during 8 a.m. to 10 p.m. Estimated emissions of PM_{10} from vehicular sources are given in Table 5. It was estimated that vehicular emission contributed 1508 kg/day in the study area which is 16% of the total emission of PM_{10} in the study area. In the total emission, 2W, 3W, 4W, buses and truck (HDV) contributed 91 kg/day, 618 kg/day, 392 kg/day and 407 kg/day, chronologically. The effects of 3W are more significant in the study area.

Contributions from area sources are presented in Table 6 and Fig. 3. Estimated emissions of all sources in the study area are presented in Table 7 and Fig. 4. The area sources were contributed 76% of the total emission of total PM_{10} (9409 kg/day) in the study area. This source is subdivided into four categories such as open-cast coal mining, hotel and restaurant, domestic sector and open coal burning/mine fire. Among these, open-cast coal burning contributed 48% of the total contribution of area sources. Another side, the domestic sector, open-cast coal burning/mine fire and hotels/restaurants were contributed 32%, 14% and 06%, respectively. In the case of the domestic sector, kerosene, wood, LPG and coal contributed 3%, 24%, 20% and 53%. In open burning sources, open coal burning/mine

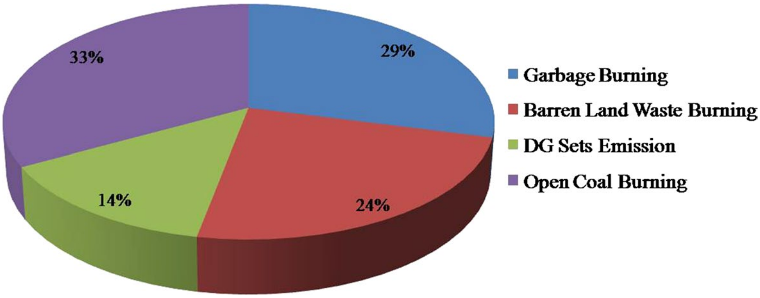
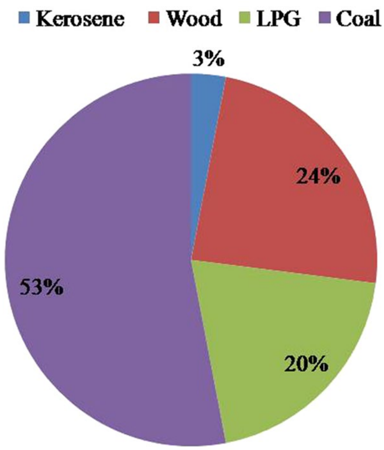


Fig. 3 Emission profile of PM_{10} from different open burning sources

Table 7 Estimated emission rate of all possible sources

SL. no	Sources	PM_{10}	
		kg/day	%
1	Hotel and restaurant	282	3
2	Garbage burning	470	5
3	DG sets	188	2
4	Barren land waste burning	376	4
5	Open coal burning and mine fire	565	6
6	Domestic fuels	1129	12
7	Industries (area sources)	1878	19.97
8	Industries (point sources)	1693	18
9	Vehicular sources	1508	16
10	Paved and non-paved road dust	1317	14
11	Construction and demolition	3	0.03

Fig. 4 Emission profile of PM_{10} from domestic sources



fire, garbage burning, barren land waste burning and DG set emission contributed PM_{10}, 33%, 29%, 24% and 14%, respectively.

Within the all area sources, the maximum contribution of PM_{10} was recorded for open-cast coal mining followed by the domestic sector, open coal burning/ mine fire and hotel and restaurant emissions. In all together, industrial (area), open-cast coal mining contributed (about 20%) maximum PM_{10} followed by the industrial point sources (CTPS) (18%), vehicular emission (16%), paved and non-paved emission (14%) and domestic fuel burning (12%) were contributed significant amount of PM_{10} in the study area.

4 Conclusions

Emission inventory in a critically polluted coal mining area is a most sensitive part of this study. Emissions from open-cast coal mining and thermal power station are found to be the main sources of PM_{10} at the study area. Besides this, a large amount of PM_{10} is released from vehicular, paved & non-paved road dust emission, fossil fuel combustion and biomass burning. Apart from the above sources, open coal burning, garbage burning, barren land waste burning etc. also contributed to the study area. The total PM_{10} emission load in the study area was estimated at 9409 kg/day. Among the all possible sources, open-cast coal mining (19.97%), thermal power plant (18%), vehicles (16%), paved and unpaved road (14%), domestic fuel burning (12%), open coal burning and mine fire (6%) and garbage burning (5%) were the major contributors throughout the study area during the study period. Apart from the mining activities, other multiple sources played a significant role in atmospheric particulate emission in the study area. Again, a composite emission abatement including most of the sources will be required to obtain the desired air quality. This work may be a guideline for the further research and policy makers while planning air pollution-related mitigative measures.

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