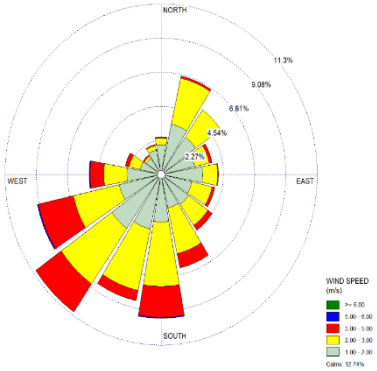
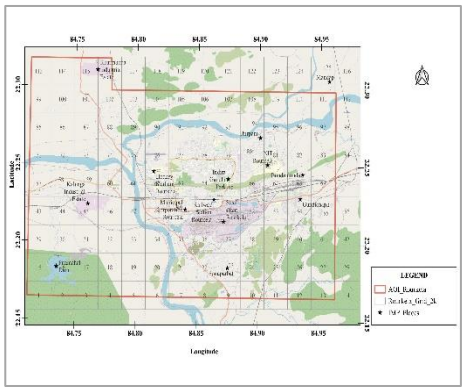
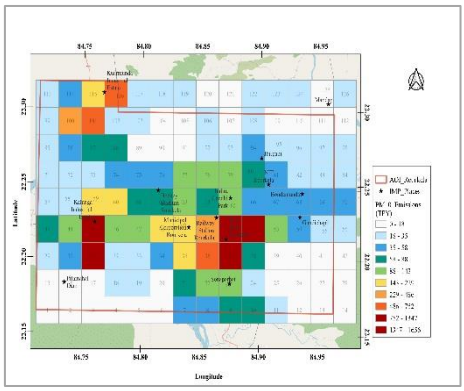
Report No.: ARAI/ERL/OSPCB_PKG_II/ROU/2024-25/Final_Report

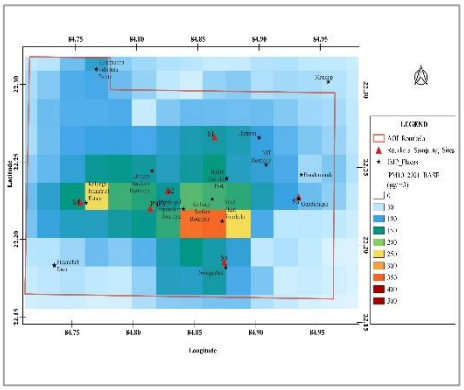
FINAL REPORT

Emission Inventory and Source Apportionment Study of Rourkela Region in Odisha









Submitted to

State Pollution Control Board, Odisha
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State Pollution Control Board, Odisha (OSPCB)

Submitted by

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ARAI
Progress through Research

Environment Research Laboratory
The Automotive Research Association of India (ARAI), Pune

December 2024

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Disclaimer

This report is the outcome of the project "Emission Inventory and Source Apportionment Study of Rourkela Region in Odisha" sponsored by State Pollution Control Board, Odisha (OSPCB). The information in this report has been generated by The Automotive Research Association of India (ARAI), Pune, India, as per the scope of work in the above-referred project. The inferences, analysis and projections made in this report are based on the data gathered physically at the identified locations in Rourkela during the project duration. Due care has been taken to validate the authenticity and correctness of the information.

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Hersbach, H. et al., (2018) was downloaded from the Copernicus Climate Change Service (2023). The results contain modified Copernicus Climate Change Service information 2020. Neither the European Commission nor ECMWF is responsible for any use that may be made of the Copernicus information or data it contains.

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Abbreviations

AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model
AQI: Air Quality Index
ARAI: Automotive Research Association of India
BAU: Business-as-usual
RMC: Rourkela Municipal Corporation
BRTS: Bus rapid transit system
BS-X: Bharat Stage (I to VI)
CAAQM: Continuous Ambient Air Quality Monitoring Station
CM: Crustal materials
CO: Carbon Monoxide
CPCB: Central Pollution Control Board
DG: Diesel Generators
EC: Elemental carbon
EF: Emission factors
EV: Electric Vehicle
FCBTK: Fixed chimney bull trench kiln
GCP: Good construction practices
GIS: Geographic Information System
GoI: Government of India
MoEFCC: Ministry of Environment, Forest and Climate Change
OSPCB: State Pollution Control Board, Odisha
MRTS: Mass rapid transit system
TPY: Tonnes Per Year
VKT: Vehicle Kilometres Travelled
MSL: Mean Sea Level
MSW: Municipal Solid Waste
NCAP: National Clean Air Project
NFC: No further control
NGO: Non-Governmental organisation
NMT: Non-motorised transport
NOx: Nitrogen Oxides
NMVOCs: Non-Methane Volatile Organic Compounds
NAAQS: National Ambient Air Quality Standards
OC: Organic carbon
PM: Particulate Matter
PM10: Particulate Matter having aerodynamic diameter less than or equal to 10 microns
PM2.5: Particulate Matter having aerodynamic diameter less than or equal to 2.5 microns
QA: Quality assurance
QC: Quality control
SC-I: Scenario I
SC-II: Scenario II
sL: Silt Loading
SNA: Sulphate, Nitrate and Ammonium
SO2: Sulfur Dioxide
SS: Sea salts
TE: Trace elements
USEPA: United States Environmental Protection Agency
ZIF: Zone of influence

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Executive Summary

Air pollution has become a serious problem recently and it is considered as a major challenge for pollution and health regulatory agencies around the world. The Central Pollution Control Board (CPCB), New Delhi has identified 131 cities in India where the prescribed annual National Ambient Air Quality Standards (NAAQS) are violated. In this regard, Ministry of Environment, Forest and Climate Change (MoEFCC) have launched National Clean Air Program (NCAP) in 2019 which aims to reduce the national level $PM_{2.5}$ and PM_{10} concentrations by 20-30% by year 2024, taking 2017 as the base year for the comparison of concentration.

In recent years, with rapid economic development and population growth, several cities in Odisha have also witnessed an increase in air pollution and are getting reflected in the non-attainment cities. Six cities including Angul, Balasore, Bhubaneswar, Cuttack, Rourkela, Talcher in Odisha state have also been identified by CPCB in the above list due to routine violation of NAAQS mainly in terms of PM_{10}. There can be significant difference in the contribution of sources at the regional scales and hence the regional/city-scale clean air action plans must be dynamic and evolve, based on the available scientific evidence, including the information available through source apportionment studies (MoEFCC, 2019). Emission inventory and source apportionment study, which is primarily based on measurements and tracking down the sources through receptor modelling, helps in identifying the sources and extent of their contribution.

To address the air pollution issues of the Rourkela region, State Pollution Control Board, Odisha (OSPCB) has entrusted The Automotive Research Association of India (ARAI), Pune to carry out a detailed study on "Emission Inventory and Source Apportionment Study of Rourkela Region in Odisha". The main aim of this study is to identify and characterize various emission sources in Rourkela region of Odisha and help the regulatory agencies in prioritizing the actions for improving the air quality. The major objectives of the study are:

- To carry out particulate matter (PM_{10} & $PM_{2.5}$) source apportionment using receptor modelling approach for Rourkela region.
- To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Rourkela region.

This study has six major components 1. air quality sampling and chemical analysis, 2. receptor modelling, 3. emission inventory, 4. dispersion modelling, 5. evaluation of control scenarios and air quality benefits and 6. Air quality action plan. The highlights of these components are presented below:

Air quality sampling and chemical analysis

Based on the reconnaissance surveys and inputs from OSPCB five sampling locations were identified for this study which represent various land-use patterns, and included 1 background site, 2 residential sites, 1 mixed land use site and 1 industrial site. These sites are located in different parts of Rourkela region and can provide an integrated insight into the characteristics of $PM_{2.5}$ and PM_{10} over Rourkela region. Table ES-1 and Fig. ES-1 provides details of the monitoring locations.

Table ES-1 Geographic information of the selected sampling sites in Rourkela region

Code	Location	Latitude	Longitude	Category
S1	Hamirpur Highschool, Sector 19, Hamirpur, Rourkela, Odisha 769005	22° 16' 6.38" N	84° 51' 52.31" E	Background
S2	IDCO Office, Chhend Colony, Rourkela, Odisha 769004	22° 14' 0.64" N	84° 49' 35.83" E	Mixed
S3	College of Arts, Science and Commerce, Gundichapli, Rourkela, Odisha 770036	22° 13' 49.40" N	84° 56' 0.82" E	Residential (LIG and MIG)
S4	Jay Matadi Plastics, Kalunga Industrial Estate, Kalunga, Rourkela - 769004.	22° 13' 32.09" N	84° 45' 32.96" E	Industrial
S5	IDL Outpost, Naudera Village, Sonaparbat, Rourkela, Odisha 769016	22° 11' 16.48" N	84° 52' 24.78" E	Residential (MIG and HIG)

The ambient $PM_{2.5}$ and PM_{10} samples were collected in the study area, during two critical seasons i.e. winter (January 2 to 21, 2022) and summer (March 17 to April 5, 2022). It is important to note that, the summer season sampling could not be conducted in summer season of 2021 due to the COVID-19 lockdown/movement restrictions.

The ambient $PM_{2.5}$ and PM_{10} samples were collected using multi-channel speciation samplers for 24 hours at a flow rate of 16.7 LPM. Teflon filters were used for measurement of gravimetric mass, elemental concentrations, and water-soluble ions while the quartz-fiber filters were analysed for carbonaceous materials. The Teflon filters were subjected to analysis of elements using Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRF) method while the water-soluble inorganic ionic components were determined using ion chromatography method. Similarly, the quartz filter samples were used for the analysis of organic carbon (OC) and elemental carbon (EC) using a Thermal/Optical Carbon Analyzer (DRI Model 2001A; Desert Research Institute, USA) following IMPROVE_A protocol (Chow et al. 2007).

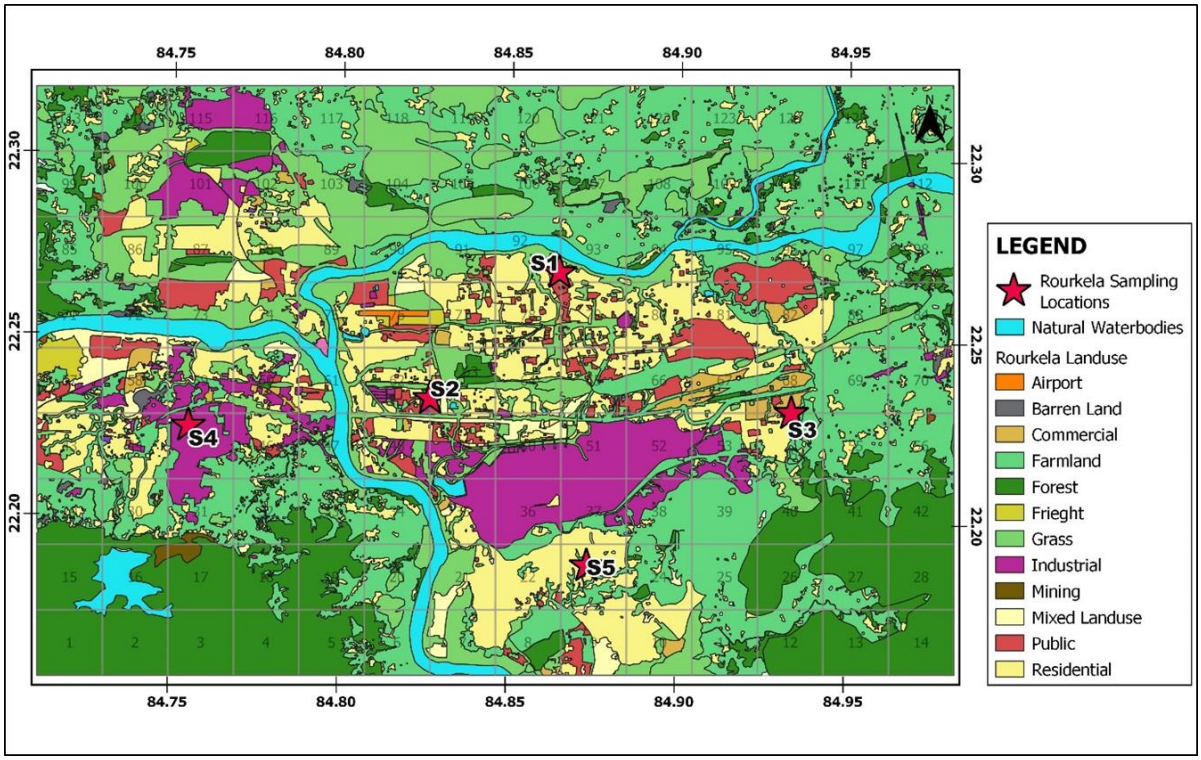


Figure ES-1 Rourkela region map showing different land-use classes. The red stars show the location of five sampling sites selected for source apportionment study

The winter-season mean $PM_{2.5}$ and PM_{10} mass concentrations over all sites were 60.3 and 155.3 µg/m^3, respectively. The highest seasonal mean $PM_{2.5}$ concentrations were observed at S3 i.e. Jay Matadi Plastics Ltd., Kalunga (120.4 µg/m^3) while the lowest were recorded at S2 i.e. IDCO Office (28.8 µg/m^3). Similarly, the highest seasonal mean PM_{10} concentrations

were also observed at S3 i.e. Jay Matadi Plastics Ltd., Kalunga (547.1 µg/m^3) while the lowest were recorded at S2 i.e. IDCO Office (50.1 µg/m^3). The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.46, varying from 0.20 to 0.58, which in turn indicates a mix of dusty and combustion sources.

The summer-season mean $PM_{2.5}$ and PM_{10} mass concentrations over all sites were 105.1 and 363.6 µg/m^3, respectively. The highest seasonal mean $PM_{2.5}$ concentrations were observed at S3 i.e. Jay Matadi Plastics Ltd., Kalunga (192.0 µg/m^3) while the lowest were recorded at S2 i.e. IDCO Office (34.6 µg/m^3). Similarly, the highest seasonal mean PM_{10} concentrations were also observed at S3 i.e. Jay Matadi Plastics Ltd., Kalunga (1151.3 µg/m^3) while the lowest were recorded at S2 i.e. IDCO Office (84.6 µg/m^3). The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.39, varying from 0.16 to 0.58, which in turn indicates dominance of dusty sources.

Based on the chemical speciation analysis, the PM chemical components were grouped into six categories i.e. organic matter (OM), elemental carbon (EC), sulphate, nitrate and ammonium ions (together referred to as SNA), chloride ions, crustal materials (CM) and other trace elements (TE). The reconstructed PM mass is then calculated and compared with observed gravimetric mass. The reconstructed mass was significantly related to gravimetric mass in both winter and summer seasons. The squared correlation coefficient, R^2 is found to be 0.63 (winter) and 0.77 (summer) for $PM_{2.5}$ whereas it is found to be 0.82 (winter) and 0.98 (summer) for PM_{10}, respectively. During the winter season, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM> SNA > CM > EC > TE > SS in PM_{10}. Similarly, during the summer season, the fractions of major chemical compositions followed the order of OM > EC > SNA > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM > CM > EC > SNA > TE > SS in PM_{10}. Additionally, chemical ratios such as OC/EC, Cl-/Na+, K+/OC, K+/EC, NO3-/SO4^{--} and degree of neutralization (DON) were also used as indicators to qualitatively assess the contributions from air polluting sources.

Receptor modelling

The data generated from chemical analysis along with source profiles is then used for receptor modelling assessment. In the present study, the US EPA-Chemical Mass Balance Model (CMB V8.2; Coulter 2004) is used to apportion the sources of $PM_{2.5}$ and PM_{10} particles in Rourkela region. The CMB model uses ambient pollutant concentrations, their chemical composition, and the chemical composition of sources i.e. source profiles, to estimate the relative contribution of each source to ambient concentrations at a given location.

Source contributions to fine and coarse particulate matter i.e. $PM_{2.5}$ and PM_{10} were calculated with the CMB model for the individual daily samples for five sampling sites in Rourkela region. Five pollution sources were apportioned using the average concentration data including i) transport (TRAN), ii) road and construction dust (DUST), iii) biomass burning (BCOM), iv) industry and thermal powerplants and fugitive dust (INDU) and v) secondary aerosols (SECY). The residual/un-apportioned mass is considered to be originating from the unidentified sources (UNID). The results from individual sites are averaged to calculate the regional mean source contributions and are explained below.

Overall, the winter-time $PM_{2.5}$ mass at Rourkela (Fig. ES2(A)) are found to be dominated by dust sector with highest contribution of 33.7%. The other sources of $PM_{2.5}$ at Rourkela are identified as secondary aerosols (17.2%), solid waste and biomass combustion (14.5%), transport (12.4%), and industry (10.4%). Similarly, the winter-time PM_{10} mass at Rourkela is found to be dominated by dust (42.9%), followed by industries (20.6%), secondary aerosols (15.4%), transport (12.4%), and solid waste and biomass combustion (8.7%). Additionally, about 11.9% and 7.0% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

The summer-time $PM_{2.5}$ mass at Rourkela (Fig. ES2(B)) is found to be dominated by dust with highest contribution of 45.1%. The other summer-time sources of $PM_{2.5}$ at Rourkela region are identified as secondary aerosols (12.7%), transport (12.5%), industry (12.2%), secondary aerosols (12.0%), and solid waste and biomass combustion (6.5%). Similarly, the summer-time PM_{10} mass at Rourkela is also found to be dominated by dust (48.9%), followed by industry (23.0%), secondary aerosols (12.0%), transport (5.0%), and solid waste and biomass combustion (3.1%). Additionally, about 10.7% and 8.0% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

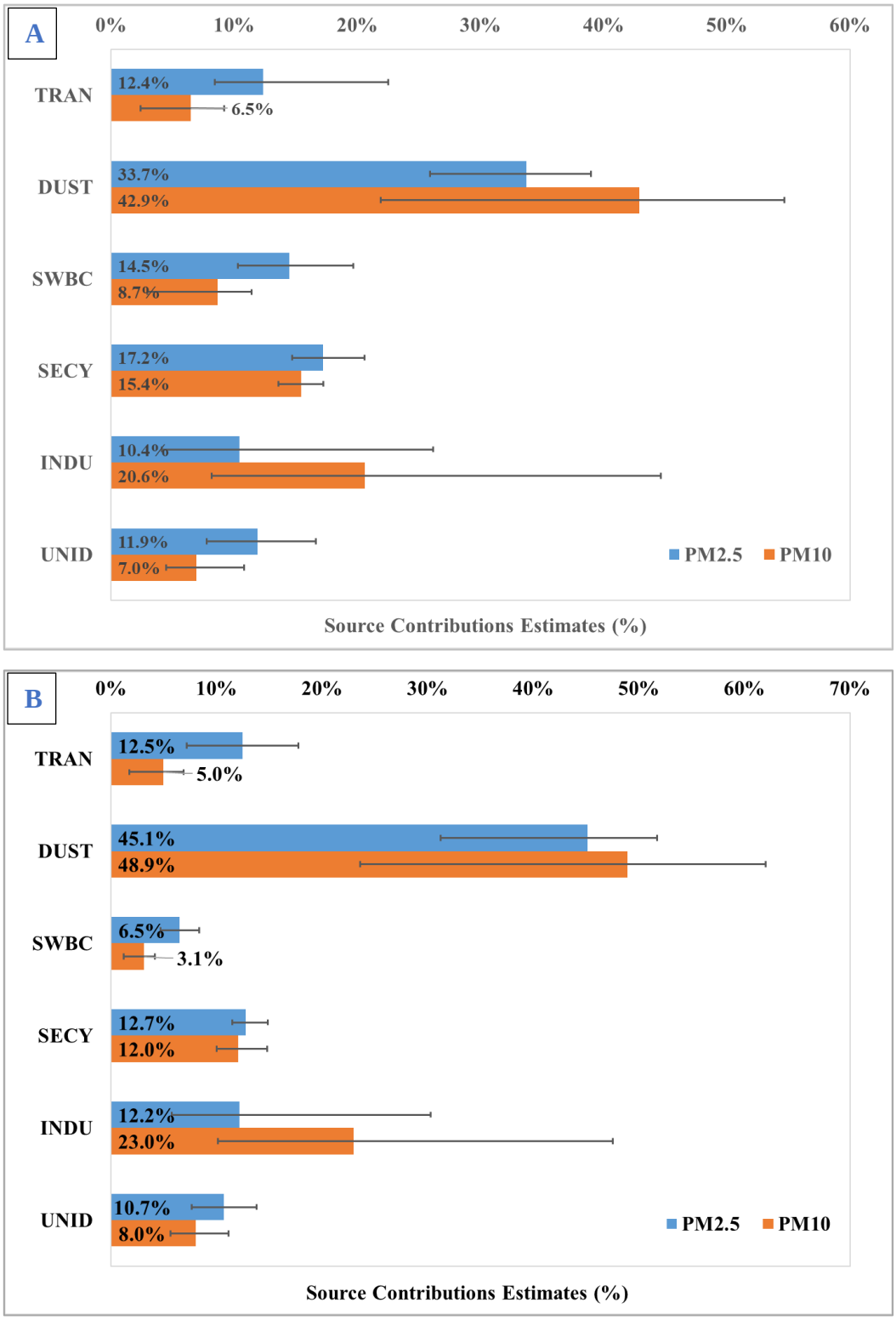


Figure ES-2 City-level source contribution estimates (SCE) for** Rourkela region **using CMB receptor model during winter (A) and summer (B) seasons

(Note-The horizontal blue and orange coloured bars represent the mean SCE percentage in $PM_{2.5}$ and PM_{10}, respectively while the error bars represent the range of estimated SCE among five sampling sites.)

Emission Inventory

The development of emission inventory for Rourkela region involved quantification of emission loads originating from sectors including: Transport, Re-suspended road dust, Industries and captive thermal powerplants, Fugitive dust, Open Waste Burning, Residential, Diesel generators, Hotels, Restaurants and Bakeries, Crematoria, Brick kilns, and Construction activities. The air pollutants considered in this study includes: particulate matter having aerodynamic diameter less than or equal to 10 microns (PM_{10}), particulate matter having aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). The spatial resolution of emission inventory is: 2 x 2 km^2 over the study area while the temporal resolution is monthly.

The emission inventory development started with data collection activity. Two types of data collection approaches are used in this study i.e. primary and secondary data collection. The first approach i.e. primary data collection involves field surveys at identified locations for residential, commercial, and industrial fuel consumption, parking lot surveys to understand details of vehicle fleet, classified vehicle surveys to understand traffic count for various vehicle types. The second approach i.e. secondary data collection involves extracting relevant data from published reports, research papers, and government department website. The emission inventory development followed a bottom-up approach for estimation of emissions using activity rates for each sector and the measured emission factors (EFs) in India wherever possible. The bottom-up approach uses source-specific and category-specific data at the most refined spatial level to estimate emissions. The emissions estimated for individual sources are summed up to obtain a regional emissions inventory.

The overall baseline emission inventory (Year 2021) for the Rourkela region is presented in Table ES-2, while the pollutant wise contribution is shown in Fig. ES-3. The Rourkela regional spatial distribution of the pollutants is provided in Fig. ES-4. The total PM_{10} emission load in the Rourkela region is estimated to be 16,986.1 tonnes per year. The top four contributors to PM_{10} emissions are industry (56.1%), followed by resuspended road dust (22.5%), fugitive (11.5%) and transport (3.4%). Similarly, $PM_{2.5}$ emission load in the Rourkela region is estimated to be 6,666.8 tonnes per year. The top four contributors to $PM_{2.5}$ emissions are industry (65.8%), resuspended road dust (13.9%), transport (8.2%), and residential (4.2%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable Daily and seasonal emissions could be highly variable.

Table ES-2 Geographic information of the selected sampling sites in Rourkela region

SECTOR	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOC
INDU	9527.42 ± 1964.56	4384.76 ± 904.14	35658.99 ± 3986.67	28512.16 ± 5879.21	96194.31 ± 19835.27	--
TRAN	574.36 ± 150.77	545.64 ± 143.23	11.01 ± 2.17	4139.7 ± 2186.18	9518.31 ± 5026.62	6871.72 ± 3628.95
RDST	3823.46 ± 854.93	925.03 ± 206.84	NA	NA	NA	NA
WAST	175.77 ± 94.65	163.22 ± 87.89	11.2 ± 6.03	25.11 ± 13.52	841.21 ± 452.99	182.05 ± 98.04
CONS	261.23 ± 53.87	65.31 ± 13.47	NA	NA	NA	NA
DSGN	24.33 ± 12.41	21.27 ± 10.85	22.69 ± 5.07	343.97 ± 175.39	74.28 ± 37.88	491.38 ± 250.56
RESI	420.51 ± 214.42	280.45 ± 143	131.9 ± 18.65	186.86 ± 95.28	3952.98 ± 2015.63	1466.9 ± 747.97
BRIC	161.74 ± 87.1	46.31 ± 24.94	98.8 ± 53.2	0.01 ± 0.01	643.72 ± 346.64	18.51 ± 9.97
HRBE	43.96 ± 23.67	31.99 ± 17.23	1.25 ± 0.28	6.53 ± 3.52	291.28 ± 156.85	20.68 ± 11.14
CREM	21.1 ± 10.76	10.38 ± 5.29	0.46 ± 0.06	2.85 ± 1.45	106.09 ± 54.09	59.2 ± 30.19
FUGT	1952.08 ± 995.37	192.31 ± 98.06	NA	NA	NA	NA
TOTAL	16985.98 ± 4462.5	6666.67 ± 1654.93	35936.29 ± 4072.15	33217.28 ± 8354.58	111622.36 ± 27926.02	9110.54 ± 4776.84

NA: indicates the emissions quantification is not applicable for a particular sector. The value after ± indicates uncertainty in emission estimates (tonnes).

The gaseous pollutants, included in the study were SO_2, NO_X, CO and NMVOC. The SO_2, NO_X, CO and NMVOC emission loads for year 2021 in the study domain are estimated to be 35,936.3, 33,217.3, 1,11,621.4, and 9,110.5 tonnes per year, respectively.

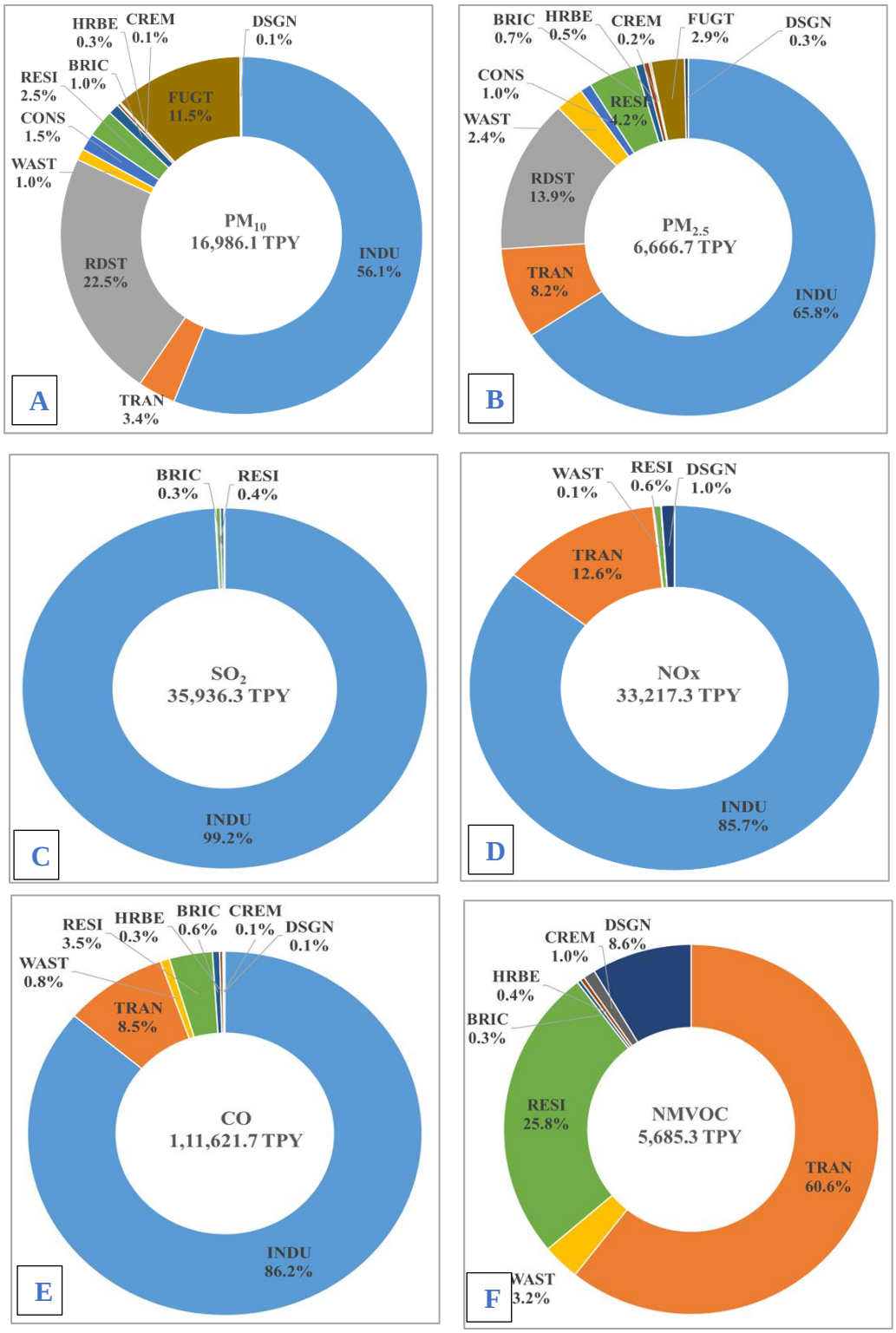
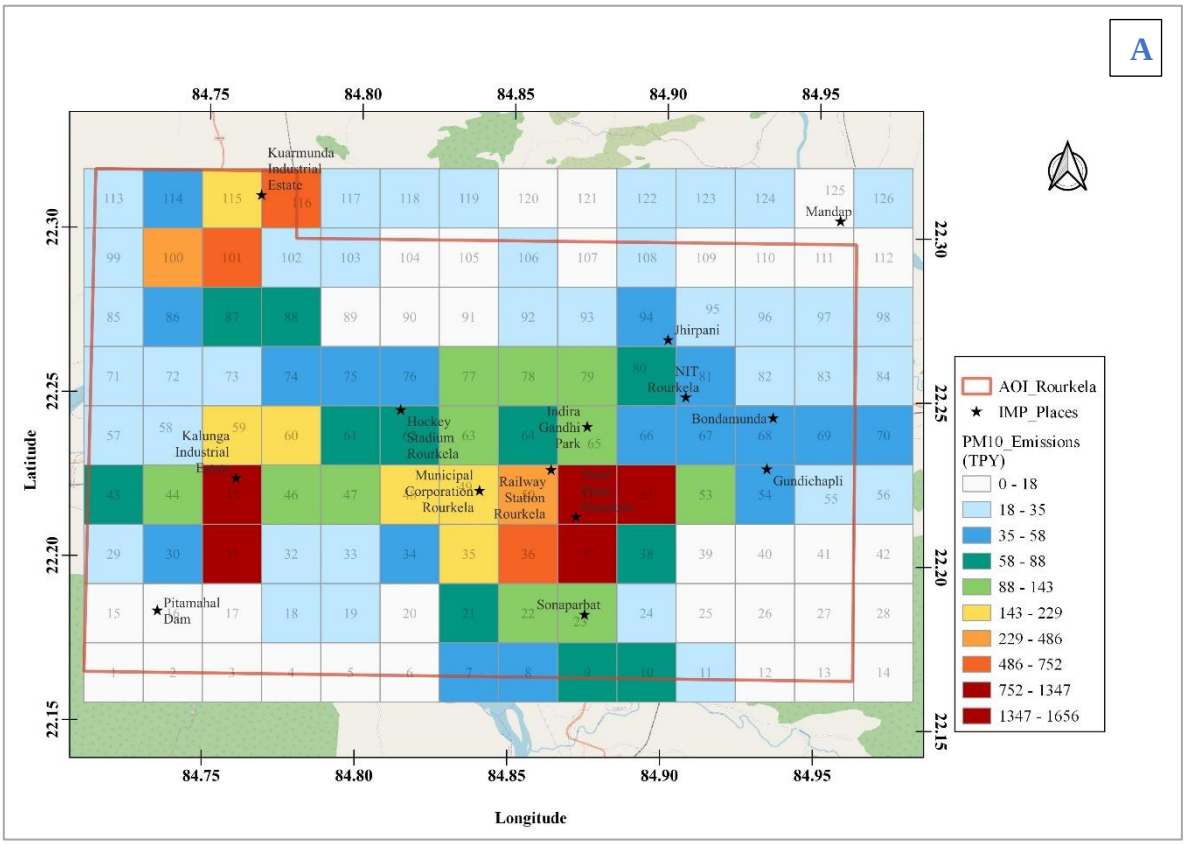


Figure ES-3 Sector-wise contribution to air pollutant emissions of A) PM_{10}, B) $PM_{2.5}$, C) SO_2, D) NOX, E) CO and F) NMVOC in Rourkela region in 2021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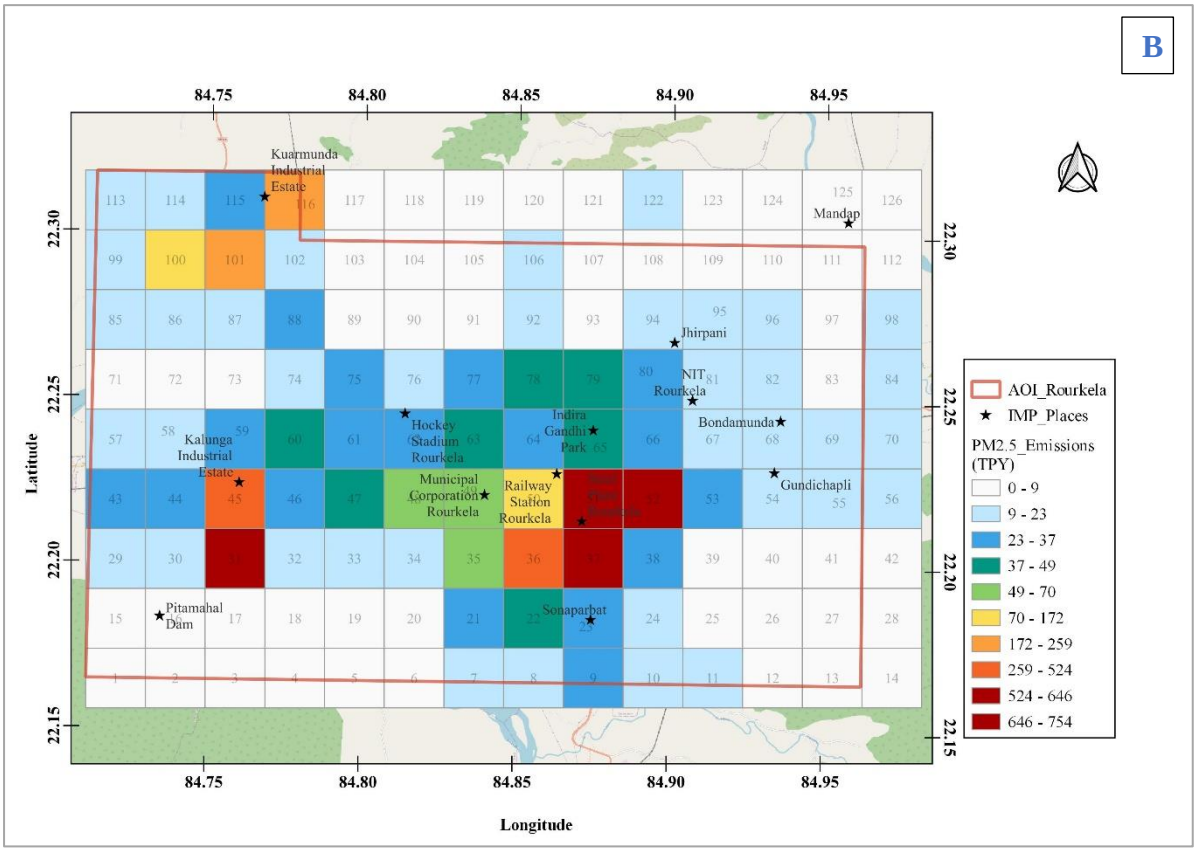
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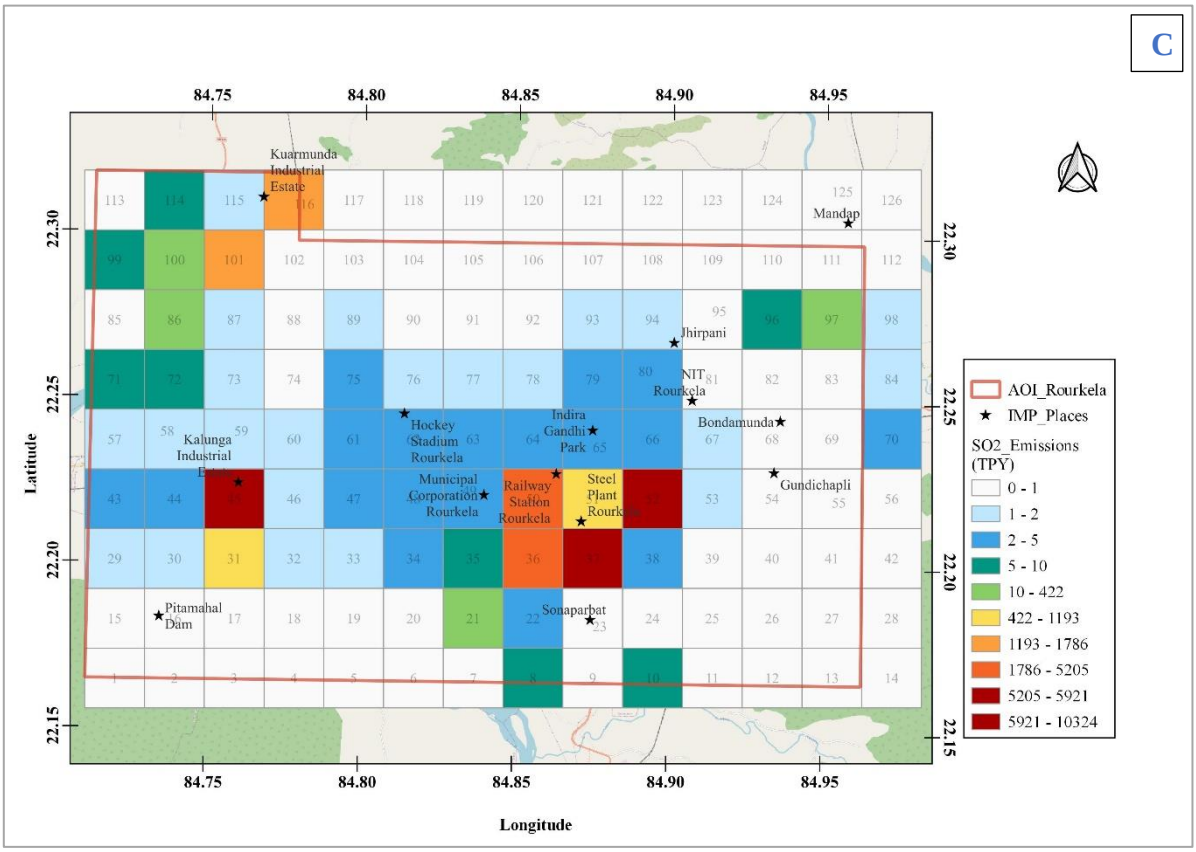
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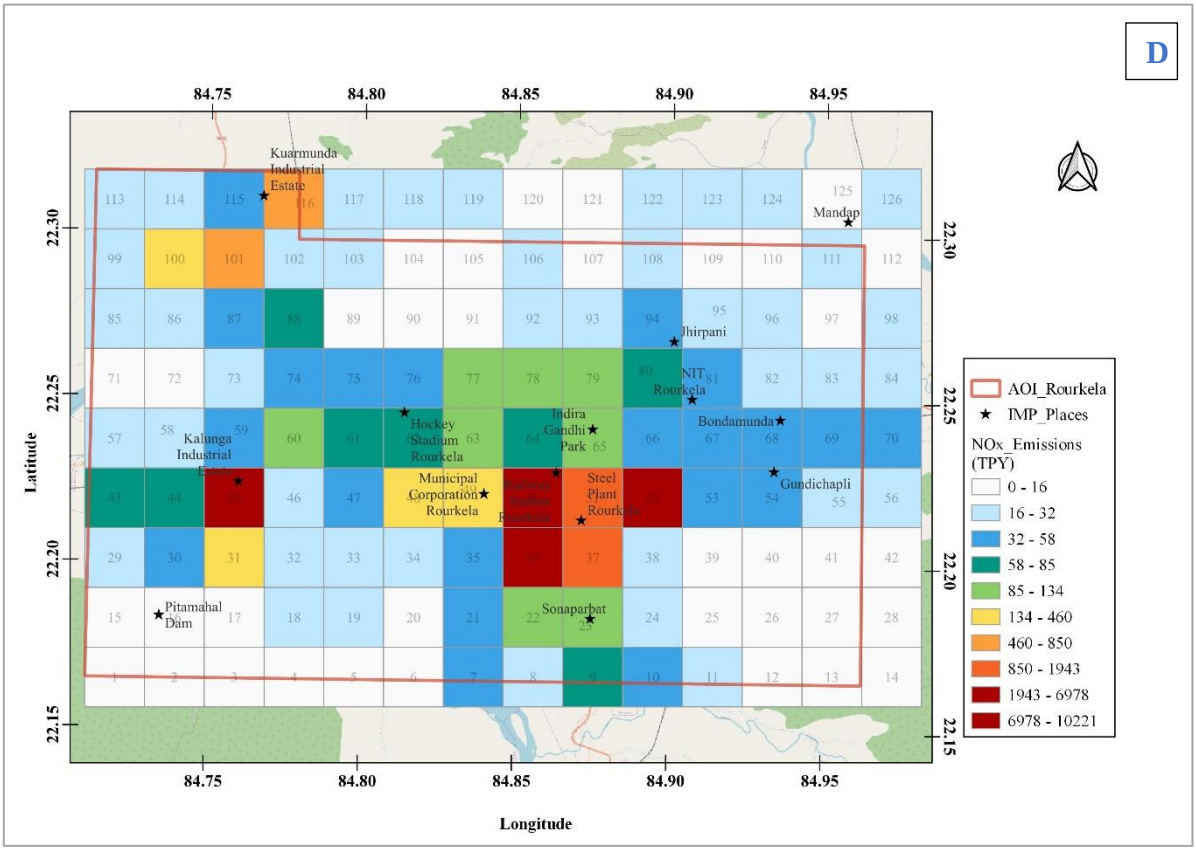
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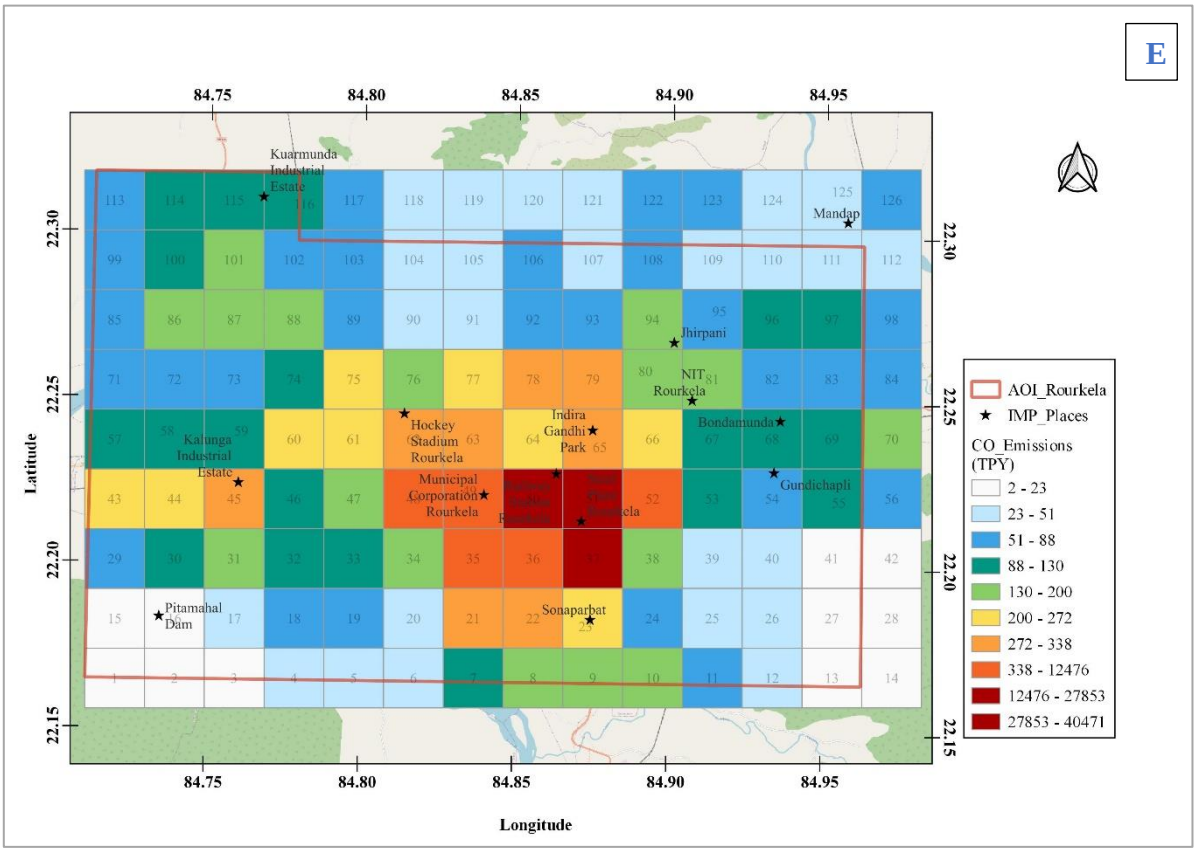


Figure ES-4 Spatial distribution of air pollutant emissions A) PM_{10}, B) $PM_{2.5}$, C) SO_2, D) NO_X, and E) CO (tonnes per year) in Rourkela region in 2021.

Dispersion Modelling

In this study the AERMOD model is used to estimate the pollutant concentrations under different emission scenarios. AERMOD is configured to consider the local meteorology, emissions and terrain information to simulate the air pollutant concentrations at specified receptors in the study domain. The emissions from different sectors are modelled as area sources having dimensions 2 x 2 km^2, except industries and thermal powerplants, crematoria and brick kilns. The stack emissions of industries, thermal powerplants, and crematoria are modelled as point sources while clamp type brick kilns are modelled as volume sources.

The gridded receptors are placed at the vertex of each grid cell used in the emission inventorization, forming a network of 150 gridded receptors (refer Fig. ES-7). Additionally, six discrete receptors are also configured at Pansposh Chowk CAAQM station (operated by OSPCB and in this study used for model validation purpose) and five ARAI sampling sites locations. The height of each receptor is set to 1.5 m above ground level i.e. average breathing level for humans. Further, the lowest daily concentration of a pollutants reported, in a particular

month, at Pansposh Chowk CAAQM station are used to derive the daily background concentration to reflect the regional-scale contributions from distant sources.

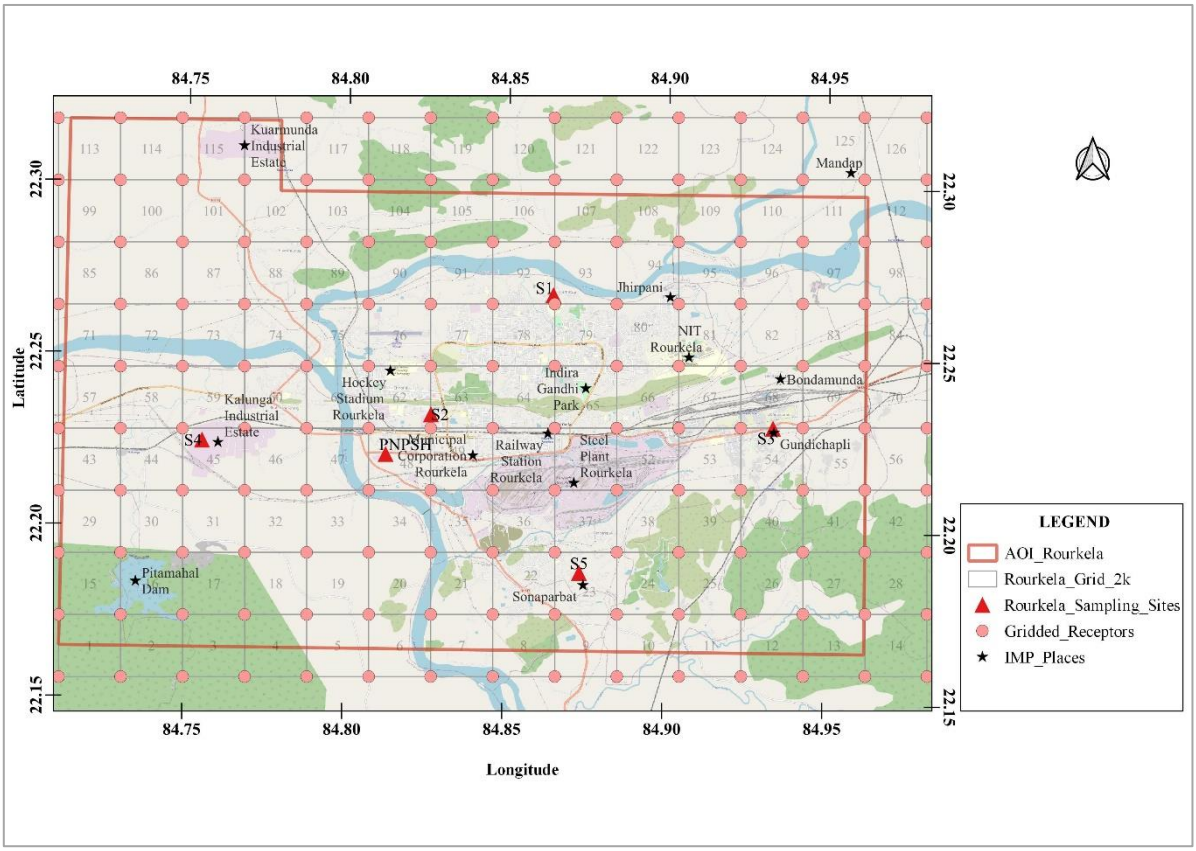
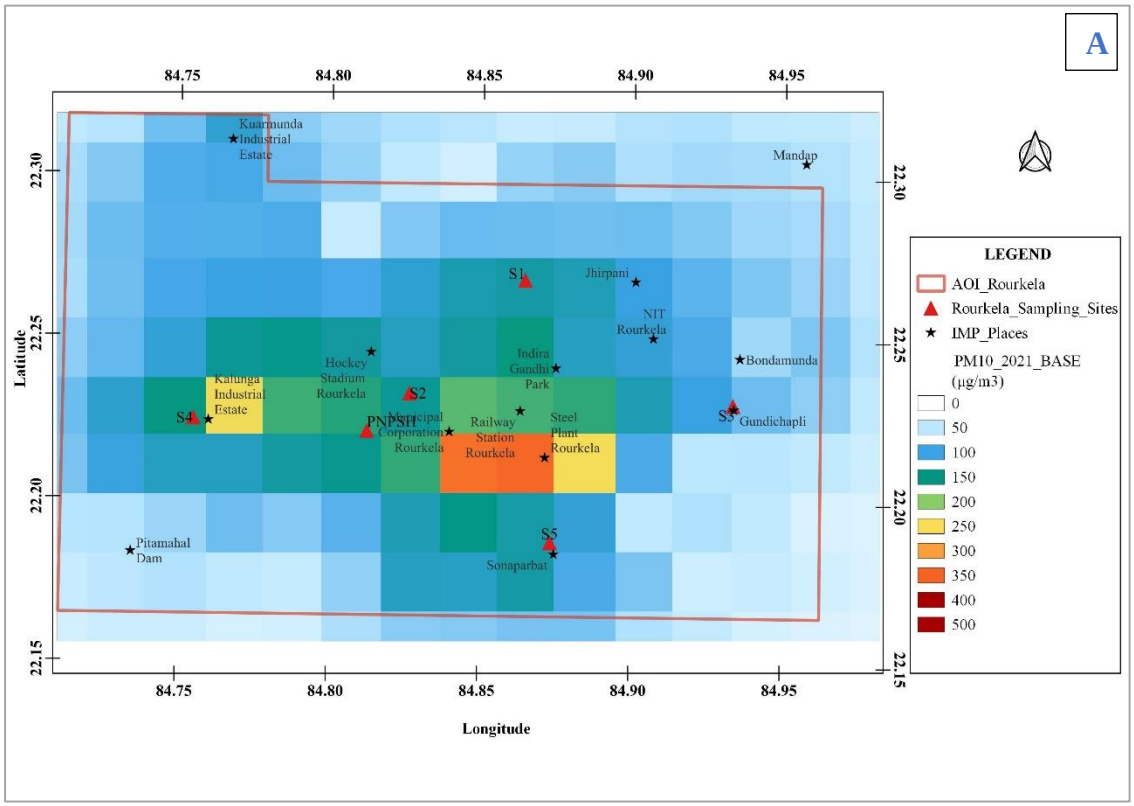


Figure ES-5 Map showing AERMOD modelling domain overlaid by gridded and discrete receptors configured in this study.

In order to validate the dispersion modelling set-up, the AERMOD simulated daily averaged concentrations of pollutants including $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO are compared against observations at CAAQM observations at Pansposh Chowk for year 2022. The model performance is evaluated using six statistical measures including: mean, pearson correlation coefficient (R), Mean Bias (MB), Factor of two (FAC2) envelope and Mean Fractional bias (MFB) and Mean Fractional Error (MFE). Based on the statistical analysis, the AERMOD model has been found to estimate the pollutant concentrations in Rourkela region, with a reasonable accuracy. Fig. ES-8 shows the spatial distribution of AERMOD simulated PM_{10} and $PM_{2.5}$ concentrations during baseline year, respectively.



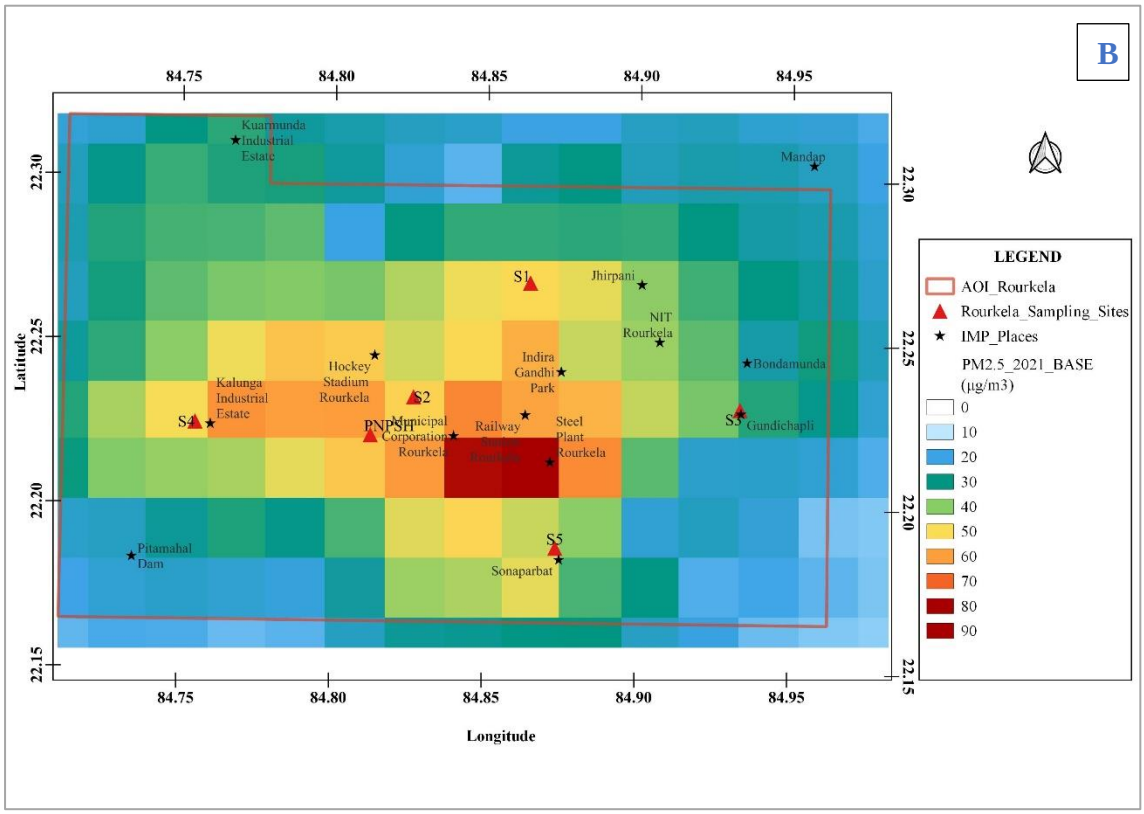


Figure ES-6 Map showing spatial distribution of PM_{10} (A) and $PM_{2.5}$ (B) annual average concentrations ($\mu g/m^3$) over Rourkela region for year 2022

Future projections and air quality benefits

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 2021. Four hypothetical emission scenarios viz. i) No further control (NFC), ii) Business-as-usual (BAU), iii) Scenario – I (SC-I) and iv) Scenario – II (SC-II); are developed for Rourkela region to include various existing and planned control interventions in each sector. These scenarios can be defined as given below:

i) **No further control (NFC):** No further control (NFC) scenario assume that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 but the control measures would be similar to present/current levels.

ii) **Business-as-usual (BAU):** Business-as-usual (BAU) scenarios consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the planned control measures would be implemented.

iii) **Scenario – I (SC-I):** Scenario – I (SC-I) consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the planned control measures would be implemented more aggressively compared to BAU scenarios.

iv) **Scenario – II (SC-II):** Scenario – II (SC-II) consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the planned control measures would be implemented to the highest aggressive levels, possible.

These scenarios consider changes in technology and fuels which mainly include: adoption of Best Available Techniques (BAT) in iron steel and sponge iron industries to reduce stack as well as fugitive emissions, faster electric vehicles (EV) adoption, increase in penetration of natural gas based vehicles, roll-out of ethanol blende gasoline fuel (E20), reduction in silt loading on road surfaces, promotion and improvements in non-motorized transport (NMT) & public transport, usage of clean fuel for cooking, improved waste collection efficiency, continuous supply of grid electricity, adoption of Zig-Zag type brick kilns and various other control measures. The four emission scenarios defined above can be further categorized as mid-term (2026) and long term (2031). The details on sector-wise considerations and assumptions are provided in Chapter 5 of the report. Table ES-2 summarizes the estimated emissions (tonnes per year) of selected pollutants under four scenarios in Rourkela region for years 2021, 2026 and 2031.

Table ES-3 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Rourkela region for years 2021, 2026 and 2031

Year	Scenario	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
2021	BASE	16,986	6,667	35,936	33,217	1,11,622
2026	NFC	17,387	6,482	36,036	32,174	94,447
	BAU	13,002	5,082	33,830	30,418	88,755
	SC_I	11,930	4,683	31,621	28,653	83,014
	SC_II	10,125	3,960	27,197	25,136	72,124
2031	NFC	17,619	6,683	36,123	31,491	95,002
	BAU	12,125	4,730	31,700	27,784	82,751
	SC_I	9,381	3,753	23,163	21,703	67,184
	SC_II	5,493	2,319	14,146	14,234	44,018

The NFC scenario projections in Rourkela region indicate a potential increase in PM_{10} emissions to 17,387 tonnes per year in 2026 i.e. an increase of 2.4% w.r.t. baseline year 2021 and to 17,619 tonnes per year in 2031 i.e. an increase of 3.7% w.r.t. baseline year 2021. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to reach to 6482 (-2.8%) and 6,683 tonnes per year (i.e. 0.2%) in 2026 and 2031, respectively. The BAU projections in Rourkela indicate a potential decrease of PM_{10} emissions to 13,002 tonnes per year in 2026 i.e. a decrease of 25.2 % w.r.t. NFC_2026 and to 12,125 tonnes per year in 2031 i.e. a decrease of 31.2% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 5,082 (-21.6%%) and 4730 tonnes per year (i.e. -29.2%) in 2026 and 2031, respectively.

The SC-I projections in Rourkela region indicate a potential decrease of PM_{10} emissions to 11,930 tonnes per year in 2026 i.e. a decrease of 31.4% w.r.t. NFC 2026 and to 9,381 tonnes per year in 2031 i.e. a decrease of 46.8% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 4,683 (27.8%) and 3,753 tonnes per year (i.e. 43.8%) in 2026 and 2031, respectively. The SC-II projections in Rourkela region indicate a potential decrease of PM_{10} emissions to 10,125 tonnes per year in 2026 i.e. a decrease of 41.8% w.r.t. NFC 2026 and to 5,493 tonnes per year in 2031 i.e. a decrease of 68.8% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 3,960 (i.e. 38.9%) and 2,319 tonnes per year (i.e. 65.3%) in 2026 and 2031, respectively.

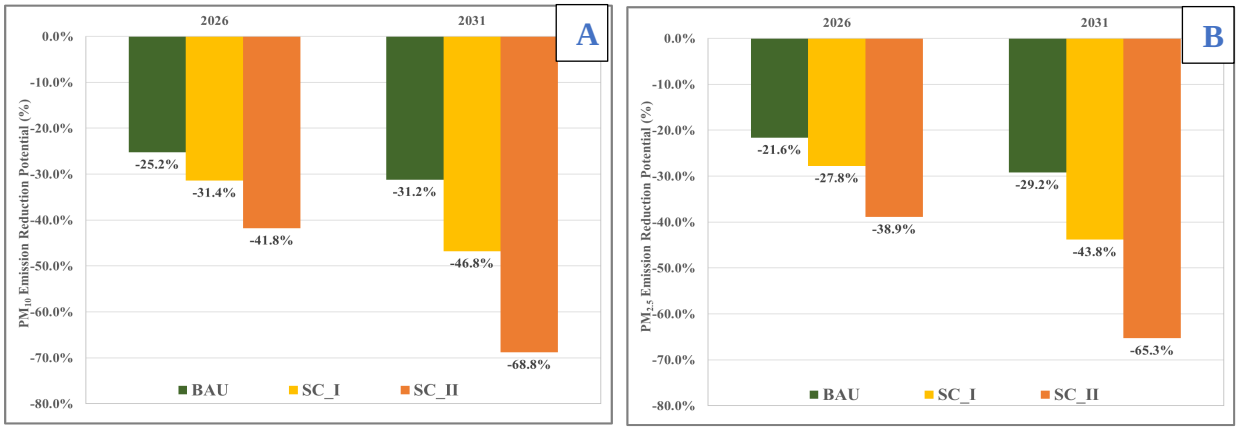


Figure ES-7 Estimated PM_{10} and $PM_{2.5}$ emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

Air quality benefits of four designed scenarios were assessed for years 2026 and 2031 using AERMOD simulated seasonal average pollutant concentrations in Rourkela region. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2026 and 2031 due to changes in technology and fuels such as adoption of Best Available Techniques (BAT) in iron steel and sponge iron industries to reduce stack as well as fugitive emissions, faster EV adoption, increased penetration of BS VI vehicles, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, improvement in NMT & public transport, usage of clean fuel for cooking, improved waste collection efficiency, adoption of Zig-Zag type brick kilns and various other control strategies considered in different scenarios.

With implementation of control measures considered in different scenarios, the ambient PM_{10} concentrations are estimated to reduce 7.2%, 13.3%, and 23.0% in 2026 and 12.2%, 26.0%, 44.1% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively, compared to corresponding NFC scenarios. In case of $PM_{2.5}$, with implementation of control measures considered in different scenarios, an estimated reduction of 6.3%, 11.5%, and 19.8% in 2026 and 10.1%, 21.5%, 35.0% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively compared to corresponding NFC scenarios.

This study also extracted location -specific air quality benefits due to implementation of different scenarios in 2026 and 2031. Six representative locations, i.e. Panposh Chowk CAAQMS and five ARAI sampling locations, were selected to understand the impact of controls measures on air quality. Tables ES-3 presents the Percentage change in predicted

ambient air quality concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at Panposh Chowk CAAQMS location in Rourkela.

Table ES-4 Percentage change in predicted ambient air quality concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at Panposh Chowk CAAQMS location

Year/Scenario	2026			2031		
Pollutant	**BAU**	**SC-I**	**SC-II**	**BAU**	**SC-I**	**SC-II**
PM_{10}	-8.2%	-15.7%	-27.4%	-13.2%	-29.5%	-51.3%
$PM_{2.5}$	-8.5%	-15.4%	-26.7%	-12.8%	-28.4%	-46.9%
SO_2	-6.9%	-13.6%	-28.2%	-23.8%	-48.1%	-62.6%
NO_2	-2.3%	-3.6%	-6.2%	-1.3%	-6.5%	-13.4%
CO	-4.3%	-8.4%	-15.6%	-9.1%	-20.3%	-35.5%

The air quality benefits are also translated to improvement in Air quality index (AQI). AQI is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (Ott, 1978). It is important to note that, the AQI values are calculated using the AERMOD estimated pollutant concentrations, only. The air quality situation can gradually improve with implementation of proposed scenarios. The combined proportion of Good and Satisfactory AQI classes are estimated to be substantially higher compared to the corresponding do-nothing or NFC scenario. For example, the combined proportion of Good and Satisfactory AQI classes in NFC is 34% in both 2026 and 2031. This combined proportion of Good and Satisfactory AQI classes improves to 37% and 41% in 2026 and 2031, respectively under BAU scenario, to 41% and 51% in 2026 and 2031, respectively under SC-I, to 50% and 71% in 2026 and 2031, respectively under SC-II scenario.

It is important to note that, the AQI changes presented here are location specific and a similar improvement is expected in other locations of Rourkela region as well. These findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level $PM_{2.5}$ and PM_{10} concentrations by 20-30% by the year 2024, as compared to 2017 i.e. base year.

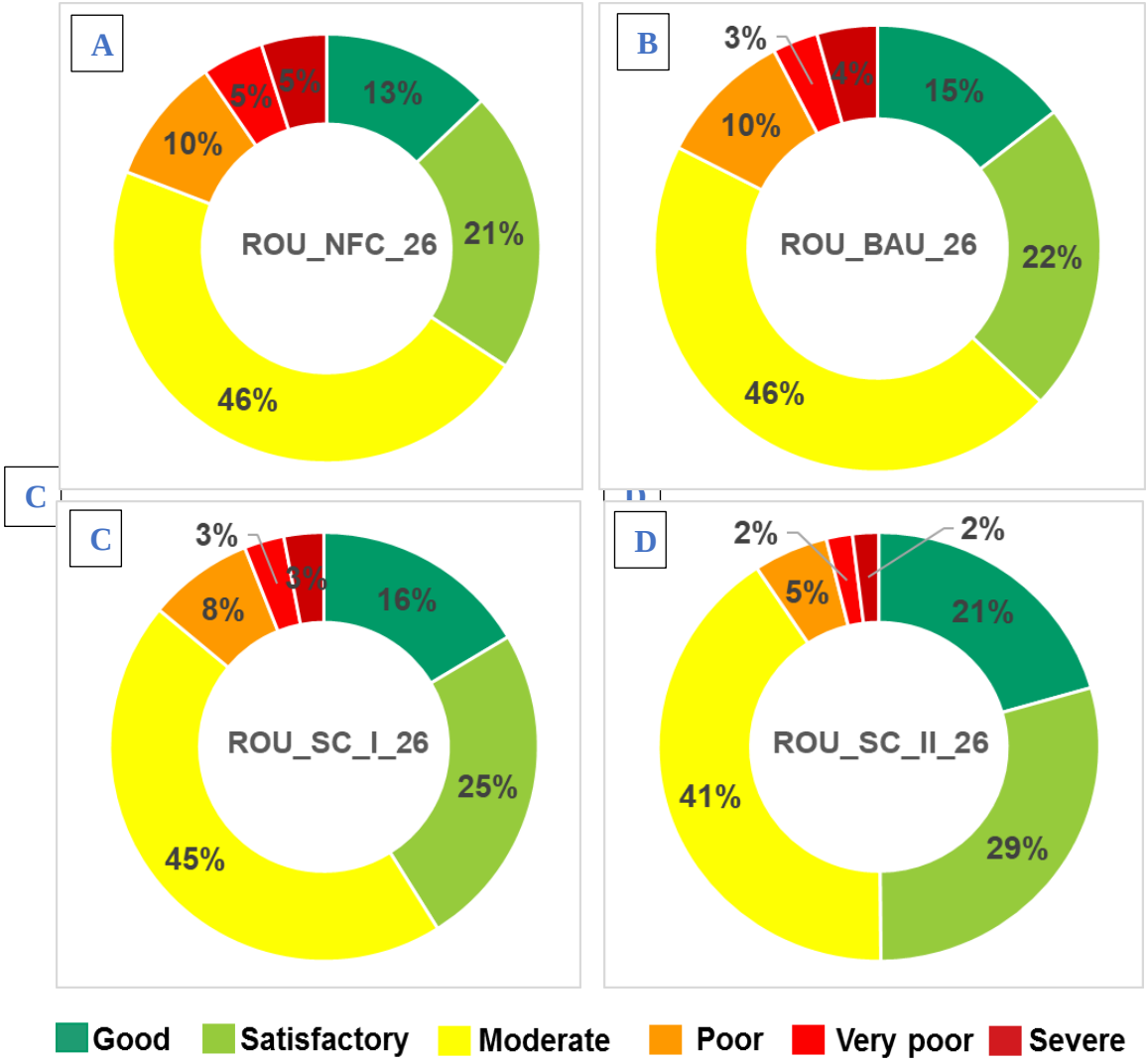


Figure ES-8 Distribution of six AQI categories at Panposh Chowk CAAQMS location in Rourkela for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2026

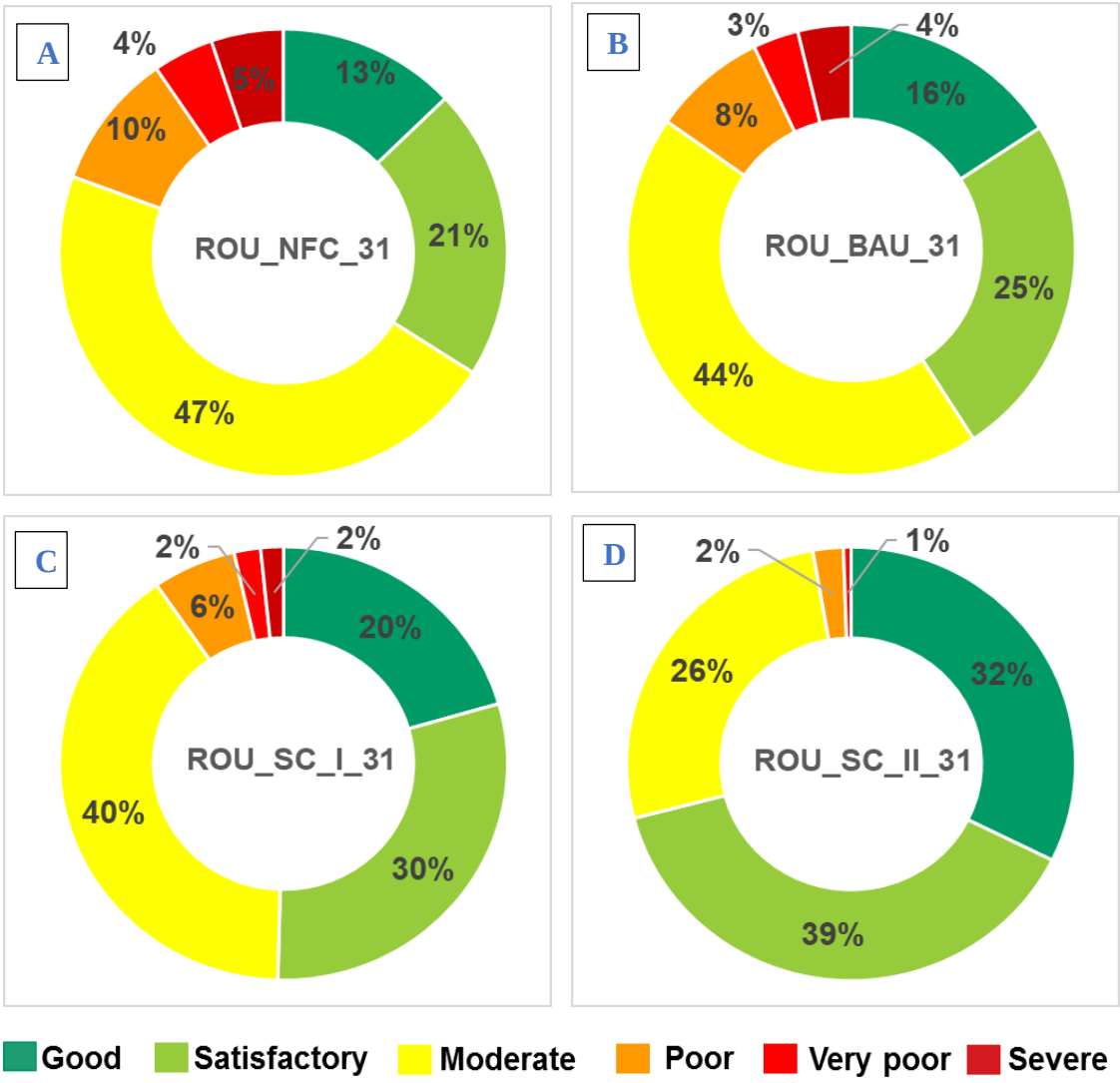


Figure ES-9 Distribution of six AQI categories at Panposh Chowk CAAQMS location in Rourkela for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2031

Air Action Plan

Table ES-4 presents the proposed air quality action plan for Rourkela region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

Table ES-4 Proposed Air quality action plan for Rourkela Region

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Transport	**A) Management**		
	TR1. Congestion Management: Identify the hotspot locations of traffic congestion. Introduce traffic actuated signals at such locations. Consider the one-way routes during peak hours at these locations. Also, regulate eateries along the kerb side, especially small ones to avoid traffic congestions.	RTO, Rourkela	Immediate
	TR2. Parking Policy: Formulate vehicle parking policy and ensure its effective implementation. Provide parallel parking system along the major roads of the town. Enforce strict action and penalty for vehicles parked in non-parking areas.	RMC / RTO, Rourkela	6 months
	TR3. Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses).	RMC	3 years
	TR4. Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	RMC	1 -2 years
	TR5. Declare NO-vehicle zones in hot-spots, university / school premises.	RMC / University / School	6 months
	TR6. Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO, Rourkela	Immediate
	TR7. Examine existing framework for removing broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.	RMC	6 months

	B) Technology		
	TR8. Improve and strengthen PUC program. (SMS based system to alerts, Linking of PUC centres with remote server and elimination of manual intervention in PUC testing, Fitness and calibration audits of PUC centres adopted with defined team for verification, Integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, Linking of PUC certificates with annual vehicle insurance, etc.)	RTO, Rourkela	1 year
	TR9. Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Rourkela / Oil Companies/ GAIL / State Government	3 years
	TR10. The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	RMC, Government Offices	3 years
	TR11. Encouraging EV adoption for personal and commercial vehicles through incentivisation or tax relaxation.	State Government, RTO	3 years
Road Dust	RD1. End-to-end paving of roads along with black-topping and maintaining potholes free roads.	PWD / RMC	Immediate / Continuous
	RD2. Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / RMC	Immediate / Continuous
	RD3. Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / RMC	Immediate / Continuous
	RD4. Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	RMC	Immediate / Continuous
	RD5. Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	RMC	6 months
	RD6. All the canals/nallah's side roads should be concrete / brick lined.	RMC	1 year
	RD7. Regular cleaning of roads and water spraying to suppress the dust. Remove road dust/silt regularly by using mechanical sweepers.	RMC	Immediate / Continuous

	RD8. Identify road stretches with high dust generation and use Foggers to supress the dust.	RMC	6 months
	RD9. Greening of traffic corridors, open areas, gardens, community places, schools and housing societies	RMC	1 year
Industries	All potential industries to be implemented with Continuous Emission Monitoring System (CEMS). Ensure regular calibration and working of this system and its online reporting is required.	OSPCB	1 year
	Assess the number of industrial units that are non-compliant and prepare unit/plant wise action plan for time bound compliance.	OSPCB	Immediate and Continuous
	Intensive polluting industries to be restricted from operations within urban zone. Restriction of any new red category industry to open within urban zone.	OSPCB	Immediate
	Strict compliance to be followed on industrial open waste burning.	OSPCB	Immediate
	Control of Fugitive Emissions: • Use of hoods and enclosure for all process equipment, • Scrap management programme for the prevention or minimization of waste and other feed materials. • Use of covered or enclosed conveyors and transfer points • Enclosures for emission controls of the charging and tapping operations. • Minimising the number of flanges by welding piping connections wherever possible and using appropriate sealing for flanges and valves • Use of larger oven chambers and regulation of pressure within oven chambers	OSPCB	Immediate
	Adoption of Cleaner Fuels: • Cleaner fuel implementation to be encouraged and incentivized. • Discourage the fuels with high sulphur content. • A favourable taxation and pricing policy for mass adoption.	OSPCB	1 year

	Ensuring installation/Up-gradation and operation of air pollution control devices in industries	OSPCB	6 months
	Disposal of all non-hazardous wastes into the designated dumping sites	OSPCB	Continuous
	Industry shall prepare plant wise inventory of vents and ensure that it is routed to vapour recovery system followed by flare system, wherever applicable.	OSPCB	6 months
	Regeneration frequency of Adsorption / absorption system / Activated carbon bed should be clearly defined as per the trend data of previous cycles and should be documented.	OSPCB	6 months
	Industry should include a special training module regarding "fugitive emissions and its health impacts on individual and surrounding communities" for its staff, operating personnel & Drivers to spread awareness about risk/hazard associated with spills and leaks of various chemicals.	OSPCB	Continuous
	Bank guarantee should be taken for the compliance of conditions imposed in CTO/CTE for control of Environmental Pollution from industries.	OSPCB	6 months
	Industrial units to install water spraying system of internal roads and washing of tyres of vehicles	OSPCB	6 months
	Development of mobile facility/van for continuous ambient air quality monitoring for different localities.		
	Coke Ovens: • Coal fired boilers to be converted to oil/gas fired driers, preferably with coal bed methane (CBM) • Switch to coke dry quenching system (CDQ) • Increasing carbonization chamber height • High pressure ammonia liquor aspiration • Wet oxidative desulphurization of coke oven gas • Stationary land-based pushing emission control	OSPCB	
	Iron and Steel Industry: • Use of desulphurized coal • Use of pulverized coal injection method	OSPCB	1 years

	• Installation of coke dry quenching (CDQ) • Installation of top gas recovery Turbine (TRT) • Introduction of coal dust injection (CDI) • Introduction of coal dust injection (CDI); waste heat recovery in Sinter Plant; waste heat recovery at blast furnace stove • Use of by-product fuel for power generation • Waste heat recovery in Sinter Plant; Waste heat recovery at blast furnace stove • Switch to Direct Reduction Electric Arc Furnace from basic oxygen furnace		
	Thermal Power Plants • Implementation of new thermal power plant standards in all power plants by an early date. The power plants need to comply with the new emission standards. • Check status of compliance and prepare a transition plan for each plant to meet the new standards. This should apply to all state owned, private and captive power plants: • Plants found not meeting set emission reduction targets to be penalized. • Prepare plan for full utilization of flyash, and also carry out monitoring, sprinkling of water (recycled water) especially during summer months to curtail wind-blown ash. • Progressively close the older and more polluting thermal power plants and to move to cleaner natural gas • Installation of Flue Gas Desulfurization (FGD) units to reduce the SO_2 emissions. (Efficiency 50 to 99.8% based on age of plant, sulfur content in coal etc)	OSPCB	2 years

	• Prepare a roadmap for cleaner plants and Incentivize their operation by giving them the priority over other polluting plants.		
Open Waste Burning	Improving door to door waste collection efficiency to 100%.	RMC	1 year
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	RMC	Immediate
	Non-recyclable waste with a calorific value of 1,500 kcal or more must not be disposed of into landfills and must be used solely to generate energy	OSPCB, RMC	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	RMC	Immediate / Continuous
	Encouraging the reduce, recycle and reuse policy for waste in city	RMC / State Government	Immediate / Continuous
	Organic waste conversion (OWC) units can be installed in the city at a decentralized scale especially in more prominent societies and colonies based on the MSW characteristics of the area.	RMC	1 year
	Effective management of landfill sites through increasing the recycling rate, installing waste to energy conversion plants, restricting illegal waste dumping, proper disposal of hazardous waste, as per Hazardous waste management rule 2016, to prevent greenhouse gas emissions from site	RMC	1 year
	Reduce the VKT of waste collection vehicles with route optimisation technique.	RMC	6 months
Construction	Adoption of Good Construction Practices (GCP) to minimize the waste generation. Promote recycling of materials. Encourage the use of environmentally friendly material. Ensure compliance check for GCP regularly	RMC / OSPCB	Immediate
	Strict enforcement of CPCB guidelines for construction activity such as use of green screens, side covering of digging sites, etc.	RMC / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	RMC / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	RMC	Immediate

	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	RMC / OSPCB	Immediate
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	RMC / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	RMC / Site Developer	3 months
	Develop and implement dust control measures such as site covering, fugitive emission control, installing air pollution controlling devices for all types of construction activities i.e. buildings and infrastructure.	RMC	1 year
	C&D waste should be sent to construction and demolition processing facility only. Strict action against non-compliance of the same on any individual or developers.	RMC	Immediate
	Mandatory use of RMC plants at large construction sites and preparation of guidelines for dust control measures for operation of RMC plants.	RMC / OSPCB	1 Year
DG sets	Ensure uninterrupted electric supply to avoid the use of DG sets, especially in commercial and industrial zones.	State Electricity Board	1 Year
	Curtail use of DG Sets in social events by providing temporary electric connections	RMC / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	RMC	6 months
	Develop the city into a Renewable Energy Hub with a focus on creation of RE Equipment Manufacturing Eco-system as per Odisha Renewable energy policy	RMC / State Government	5 years
	Leverage rooftop solar programme to reduce dependence on DG sets.	BMC	1 year
	Installation of Retrofitted Emission Control Devices (RECD) to diesel generators as per CPCB guidelines	OSPCB	1 year

Residential	Ensure easy availability of affordable cleaner cooking fuels (LPG/ PNG/biogas) for all to achieve 100% LPG adoption.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP/BP, etc.)	1-3 years
	Expanding coverage of LPG under Pradhan Mantri Ujjwala Yojana (PMUY).	State / Central Government	1-2 years
	Introduce schemes for providing subsidized LPG connections as well as providing means of finance to small tea vendors/hawkers who are using kerosene stoves in order to reduce emissions from burning of kerosene	State / Central Government	1-2 years
	Introduction of improved *Chullahs* (low emission *Chullahs*) in rural areas	RMC, NGOs	1 year
	Encouraging use of electricity for domestic cooking. (for example: Induction cooktops)	Department of Food, Civil Supplies and Consumer Affairs	2 year
	Provide centralized solar based hot water in slum areas to avoid solid fuel usage for water heating purposes	RMC	1 year
Hotel, restaurant and bakeries	Coal and wood-based cooking in restaurants to be shifted to electricity and LPG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1-2 years
	Promoting mini LPG cylinders to small open eateries.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
Brick kilns	Ensure the compliance checking routinely. Provide design specifications for improved kilns.	RMC / OSPCB	Immediate
	Enforce restrictions for the operations of brick kilns in urban zone. Zig-Zag technology to be encouraged and promoted. Ensure the mass adoption of Zig-Zag or improved technology	RMC / OSPCB	1-3 years
	Closure of unauthorized brick kilns, if any.	OSPCB	Immediate
Crematoria	Convert all existing traditional crematoria (wood based) to electric. Installing new electric crematoria as per requirement.	RMC	1 year
	Launch Public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicle, lane discipline, etc.	RMC, OSPCB, NGOs	Immediate

Public Awareness	Encourage the use of public transport for daily commute.	RMC, OSPCB, NGOs	Immediate
	Education program to create awareness among citizens through various mass media tools, such as local newspapers, local news channels on TV or radio, street plays, social media platforms, citizen engagement events, recording announcements through waste collection vehicle, organizing awareness seminars at the community level	RMC, OSPCB, NGOs	Immediate
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	RMC	1 year
CAAQMS	Increase the number of air quality monitoring stations	OSPCB	1 -2 year

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Chapter 1: Introduction

1.1. Background

Air pollution has become a serious problem in recent years with $PM_{2.5}$ i.e. particles with aerodynamic diameter less than or equal to 2.5 µm, accounting for about 4.9 million deaths worldwide and ~1.2 million deaths in India in the year 2017 (HEI, 2019) and it is considered as a major challenge for air pollution and health regulatory agencies around the world. Similarly, PM_{10} i.e. particles with aerodynamic diameter less than or equal to 10 µm, has also been shown to affect health in the short-term while long-term effects are yet to be confirmed (Katzman et al., 2010). The particulate matter is considered dangerous, primarily due to its fine size; but its chemical composition makes it even more hazardous for humans (Pope III et al., 2002, 2006). Particulate matter often consists of carbon, sulfate and nitrate compounds, but also may include other substances such as heavy Elements (WB and IHME, 2016), mineral dust and sea salt. The chemical composition of PM offers valuable information to identify the contributions of specific sources and to understand aerosol properties and processes that could affect health, climate, and atmospheric conditions.

The Central Pollution Control Board (CPCB), New Delhi has identified 131 cities in India where the prescribed annual National Ambient Air Quality Standards (NAAQS) are violated. Considering the health impacts associated with PM, the Indian planning and regulatory agencies have also aligned their roadmap towards effectively addressing the $PM_{2.5}$ pollution. India's National Clean Air Program (NCAP) launched by Ministry of Environment, Forest and Climate Change (MoEFCC) in 2019 aims to reduce the national level $PM_{2.5}$ and PM_{10} concentrations by 20-30% by year 2024, taking 2017 as the base year for the comparison of concentration. The overall objective of the India's NCAP is comprehensive mitigation actions for prevention, control and abatement of air pollution besides augmenting the air quality monitoring network across the country and strengthening the awareness and capacity building activities (MoEFCC, 2020).

NCAP has identified 16 key components in order to achieve national level $PM_{2.5}$ and PM_{10} targets. It is proposed to extend emission inventory and source apportionment of particulate matter to non-attainment cities in India and plan actions for controlling and reducing air pollution based on such scientific studies. A cost-effective approach for improving air quality in such cities involve (i) identification of emission sources; (ii) assessment of extent of contribution of these sources on ambient environment; (iii) prioritizing the sources that need to

be tackled; (iv) evaluating various options for controlling the sources with regard to feasibility and economic viability; and (v) formulation and implementation of most appropriate action plans (MoEFCC, 2020).

Figure 1 Key components of India's National Clean Air Program (NCAP; Source: MoEFCC, 2020)

Six cities including Angul, Balasore, Bhubneshwar, Cuttack, Rourkela, Talcher in Odisha state have also been identified by CPCB in the above list due to routine violation of NAAQS mainly in terms of PM_{10}. State Pollution Control Board, Odisha (OSPCB) has entrusted The Automotive Research Association of India (ARAI), Pune to carry out a detailed study on "Emission Inventory and Source Apportionment Study of Rourkela Region in Odisha".

1.2. Brief Description of the City

Rourkela is located in the Sundargarh district of the Indian state of Odisha. It is known for its steel industry, with the Rourkela Steel Plant being one of the largest steel plants in India. The Rourkela region has a diverse population and a rich cultural heritage, with influences from various communities and traditions. Rourkela is also surrounded by lush greenery and natural beauty, making it an attractive destination for both industrial and eco-tourism. Additionally, the city has educational institutions, healthcare facilities, and recreational areas, making it a well-rounded urban center in eastern India.

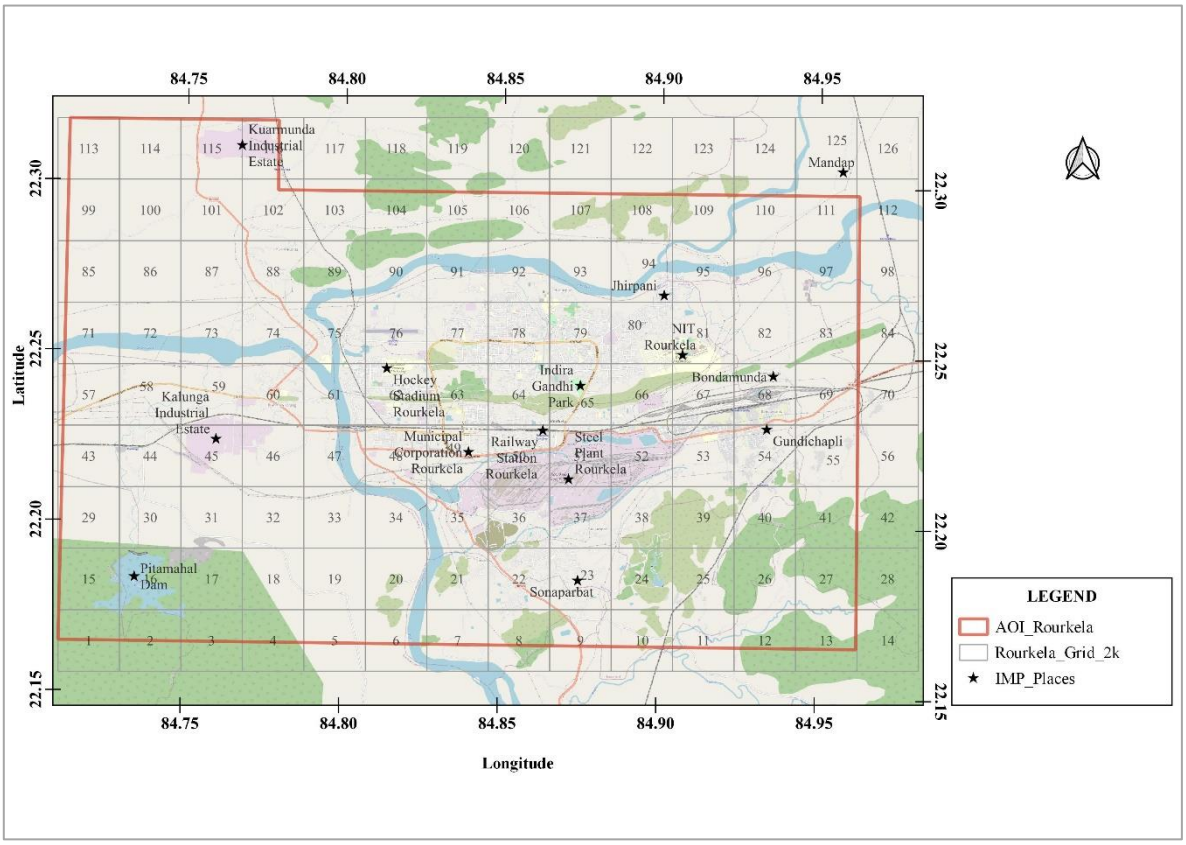

Figure 2 Map showing location of Rourkela (Left inset) and a zoomed view of grids overlaid on Rourkela region map

1.2.1. Geography

Rourkela is the industrial capital of Odisha and is popularly known as the engineering heartland of India. Rourkela is geographically located at 22.12 0N latitude and 84.54 0E longitude in the Sundergarh district of Odisha at an average elevation of about 219 m above mean sea level (MSL). The city is surrounded by a range of hills and encircled by Koel and Sankha rivers which meet at Vedvyas, Rourkela and flow as a single river called Brahmani. It

is important to note that, the study area for this study extends beyond the municipal limits of Rourkela city (53.3 km2) and covers an area of 395.85 km2. Fig. 2, shows the study area divided into grids of size 2 x 2 km2 for the emission inventory purpose.

1.2.2. Weather and Climate

Rourkela region exhibits a tropical climate and receives abundant rainfall during Southwest monsoon (June – September). The average annual temperature in this region is ~25.9 0C and the highest and lowest temperatures are generally observed in the months of May and January, respectively. Rourkela region receives an annual average rainfall of about 1389 mm, with highest rainfall in the month of July.

1.2.3. Demography

According to Census of India 2011, the total population of Rourkela city was 2,72,721 and number of households were 61,717. These figures have now increased to a total population of 3,09,689 and 69,609 households (RMC, 2021). Fig. 3 shows the trend in population of Rourkela city.

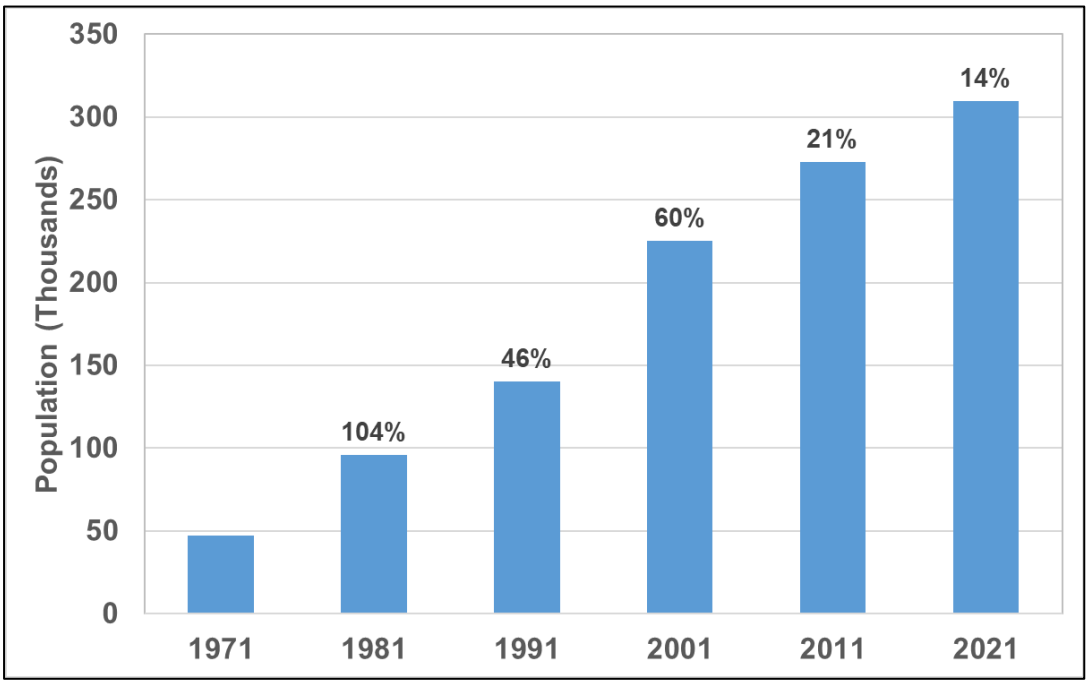

Figure 3 Time-series showing historic population of the Rourkela city since 1971.

The numbers on the top of each bar represent the decadal growth rate (%) in population. (Source: Census of India)

As discussed previously, the study area extends beyond municipal limits and geo-located population details are not available for this region. Hence, first we derived the gridded population of the study area for year 2011, using population dataset prepared by Balk et al. (2020). The gridded population for year 2021 is estimated considering several factors such as current and proposed land use, land cover, population density, growth directions, and scope for future development. The total population of the study area is estimated to be 7,21,654 for year 2021. Fig. 4 shows the gridded population of the study area for year 2021.

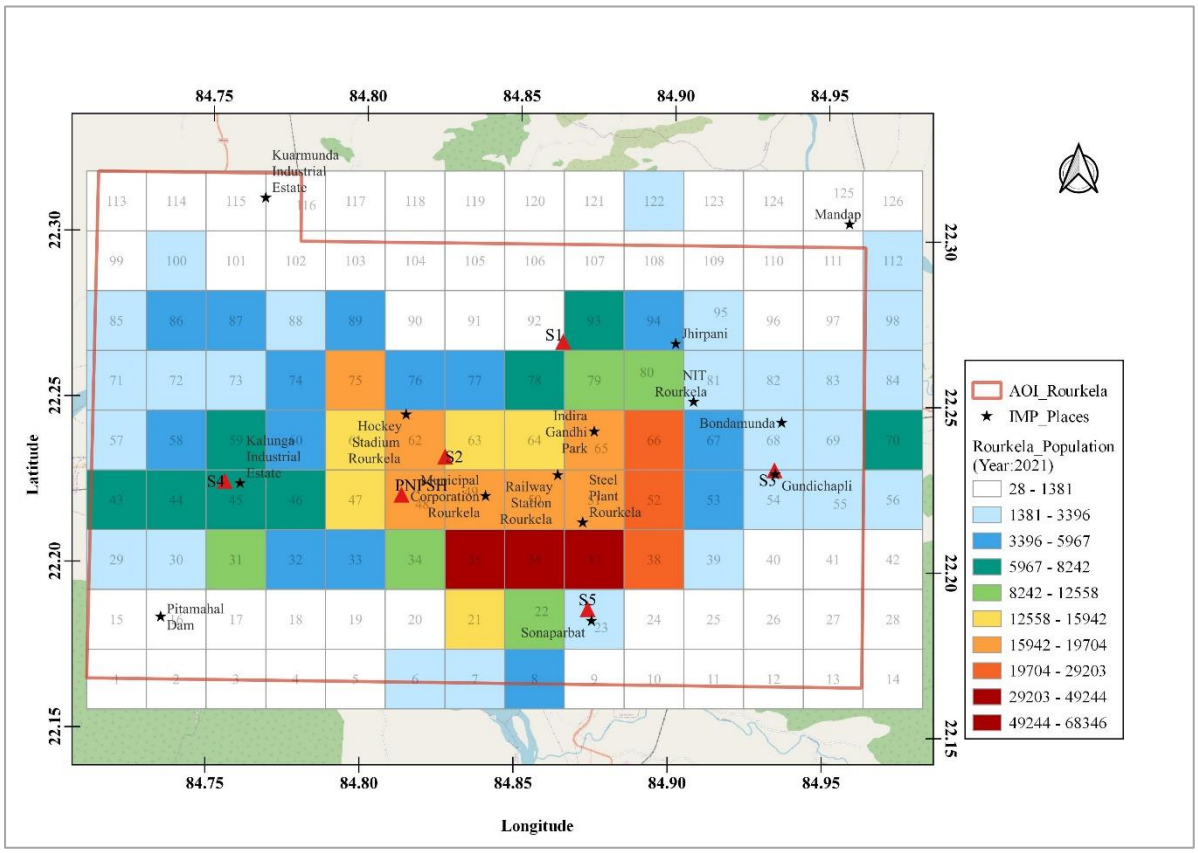

Figure 4: The estimated gridded population of the study area for year 2021.

1.3. Objectives of the Project

The main aim of this study is to identify and characterize various emission sources in Rourkela region in Odisha and help the regulatory agencies in prioritizing the actions for improving the air quality. The objectives of the study are:

i) To carry out particulate matter (PM_{10} & $PM_{2.5}$) source apportionment using receptor modelling approach for Rourkela region.

ii) To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Rourkela region.

1.4. Scope of Work

1.1. Sampling of Particulate Matter (PM_{10} & $PM_{2.5}$) using speciation samplers at identified sites (5 locations in Rourkela region). Sampling (24 hrs) for minimum 15 days at each location in 2 critical seasons i.e. winter and summer. Additionally, sampling for SO_2, NO2, Benzene, Toulene and Xylene will be carried out identified locations during winter season only.

1.2. Analysis of collected Particulate Matter (PM_{10} & $PM_{2.5}$) samples for ions, elements, carbon fractions (organic and elemental carbon) and molecular markers (PAHs, alkanes, hopanes).

1.3. To carry out PM_{10} & $PM_{2.5}$ source apportionment study through receptor modelling using CMB8.2 model.

1.4. To conduct data collection surveys and calculate baseline emission loads of air pollutants including: PM_{10}, $PM_{2.5}$, SO_2, NOx, CO and NMVOCs originating from various sources for Rourkela region for year 2021.

1.5. To project the baseline emission loads using growth rate method for future years (2026 and 2031) and plan control actions in consultation with stakeholders.

1.6. To generate the spatial distribution of PM_{10} & $PM_{2.5}$ concentrations using AERMOD dispersion model.

1.7. To prepare a comprehensive action plan for reducing, control and abatement of PM_{10} & $PM_{2.5}$.

1.8. To prepare a rapid source apportionment study report, based on monitoring carried out in one season.

1.9. To provide adequate training to the OSPCB officials on source apportionment and emission inventory study

1.10. To submit the final detailed study report after carrying out monitoring for two seasons i.e. summer and winter, emission inventory, dispersion modelling, receptor modelling with complete data analysis and data validation

1.5. Integrated framework for source apportionment study

This section discusses the overall framework designed to carry out the present study. In general, two fundamental scientific approaches are used to identify and quantify the sources of

particulate matter: (A) bottom-up or dispersion model-based approach (Fig. 5) and (B) top-down or receptor model-based approach (Fig. 6).

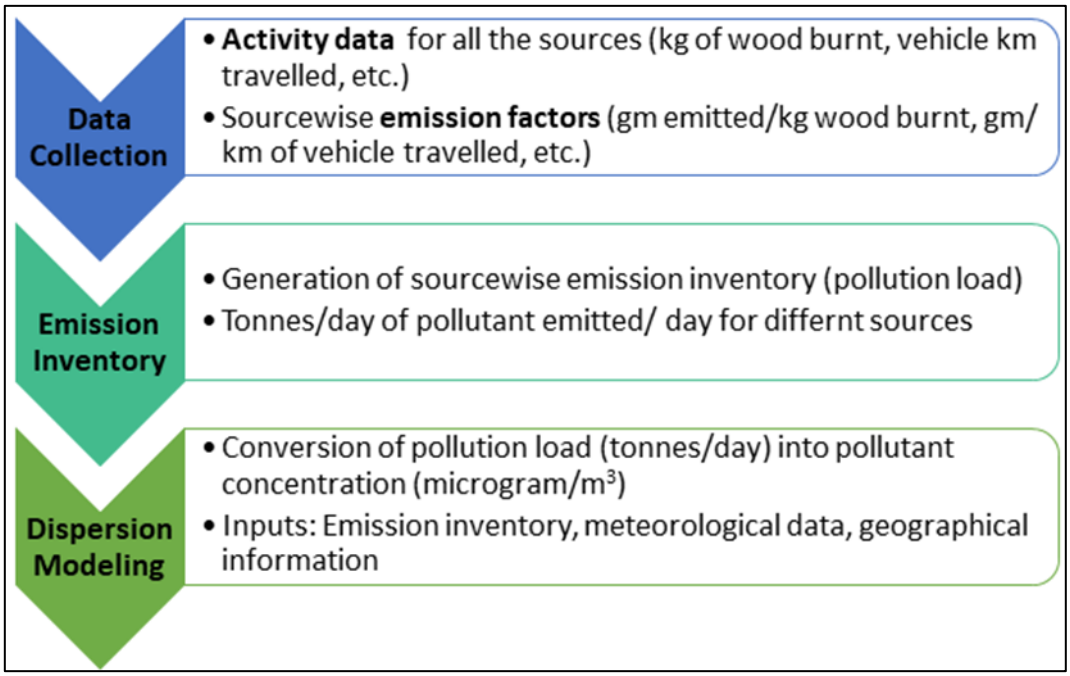

Figure 5 Bottom-up approach for Particulate Matter Source Apportionment

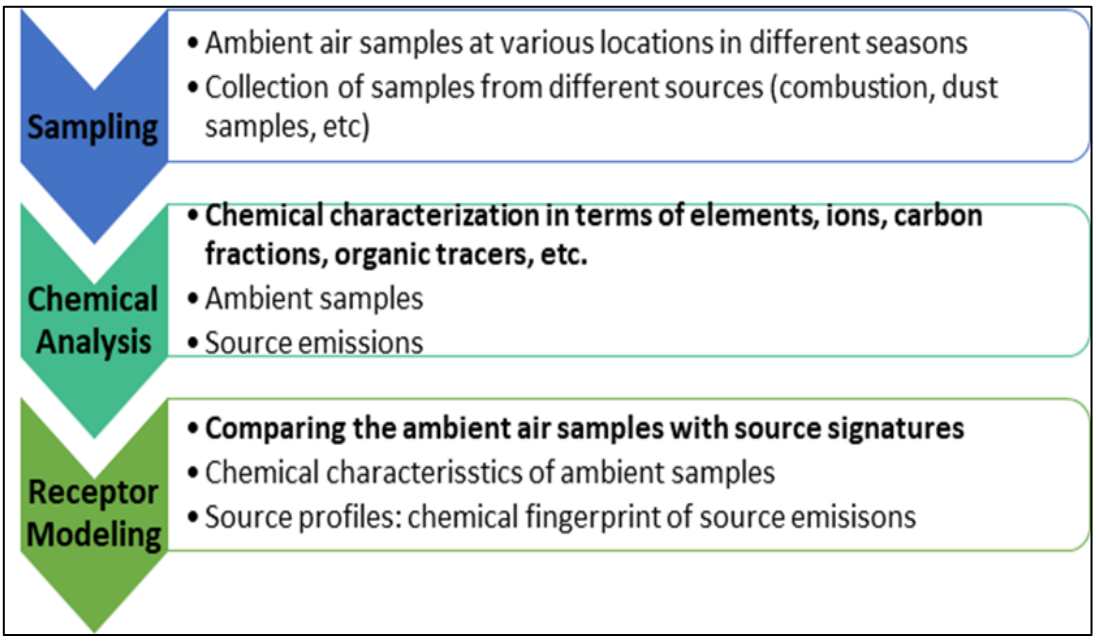

Figure 6 Top-down approach for Particulate Matter Source Apportionment

The bottom-up approach includes identification of air pollution sources and their emission strengths using activity data and available emission factors (Fig. 5). These emissions are then used as input to dispersion models such as AERMOD, WRF-Chem etc. along with

meteorological parameters and land use characteristics to predict pollutant concentrations over space and time. The top-down approach on the other hand include sampling air at identified receptor locations and deducing the potential air pollution sources by correlating common physical and chemical characteristics between the sources and collected samples (Fig. 6). These two approaches and their inter-relations are described in a step-wise manner in the following sections.

Fig. 7 illustrates the details of the integrated approach, combining the two approaches described above, adopted for Emission Inventory and Source Apportionment study of Rourkela region in Odisha.

1.6. Organization of the Report

This report is organized into six chapters and a brief description of each chapter is given below:

Chapter 1 presents the background of the study, brief description of the region, including geography, demography, weather and climate. The objectives, scope of the work and the integrated approach to this study are also briefly described in this chapter.

Chapter 2 of this report presents the air quality status w.r.t. sampling and chemical characterization of particulate matter (PM_{10} and $PM_{2.5}$) at five sampling sites for two critical seasons, i.e., winter and summer. This chapter also describes the details of site selection, PM sampling, instrumentation used in laboratory analysis, quality assurance and quality control (QA/QC) protocol, source apportionment using receptor model i.e. CMB. This chapter also discusses the site-wise, seasonal chemical composition of PM_{10} and $PM_{2.5}$ and results of receptor modelling based source apportionment. The contribution of various sources at identified receptor sites and the region are also presented.

Chapter 3 initially describes the sector-wise methodology adopted for developing an emission inventory of pollutants at the regional level, followed by results of emission inventory for various pollutants. This chapter also discusses the spatio-temporal variations in the emissions inventory.

Chapter 4 presents the methodology adopted for dispersion modelling of air pollutants during the summer and winter seasons. This chapter further describes the analysis of dispersion modelling outputs in terms of model validation, seasonal changes and spatial distribution over the study domain.

Chapter 5 describes the various emission control scenarios designed for Rourkela region in future years i.e. 2026 and 2031 and analyses their impact in terms of emissions, air quality concentrations and AQI.

Chapter 6 presents a comprehensive, sector-wise action plan for effective the prevention, control and abatement of air pollution based on the findings of this study.

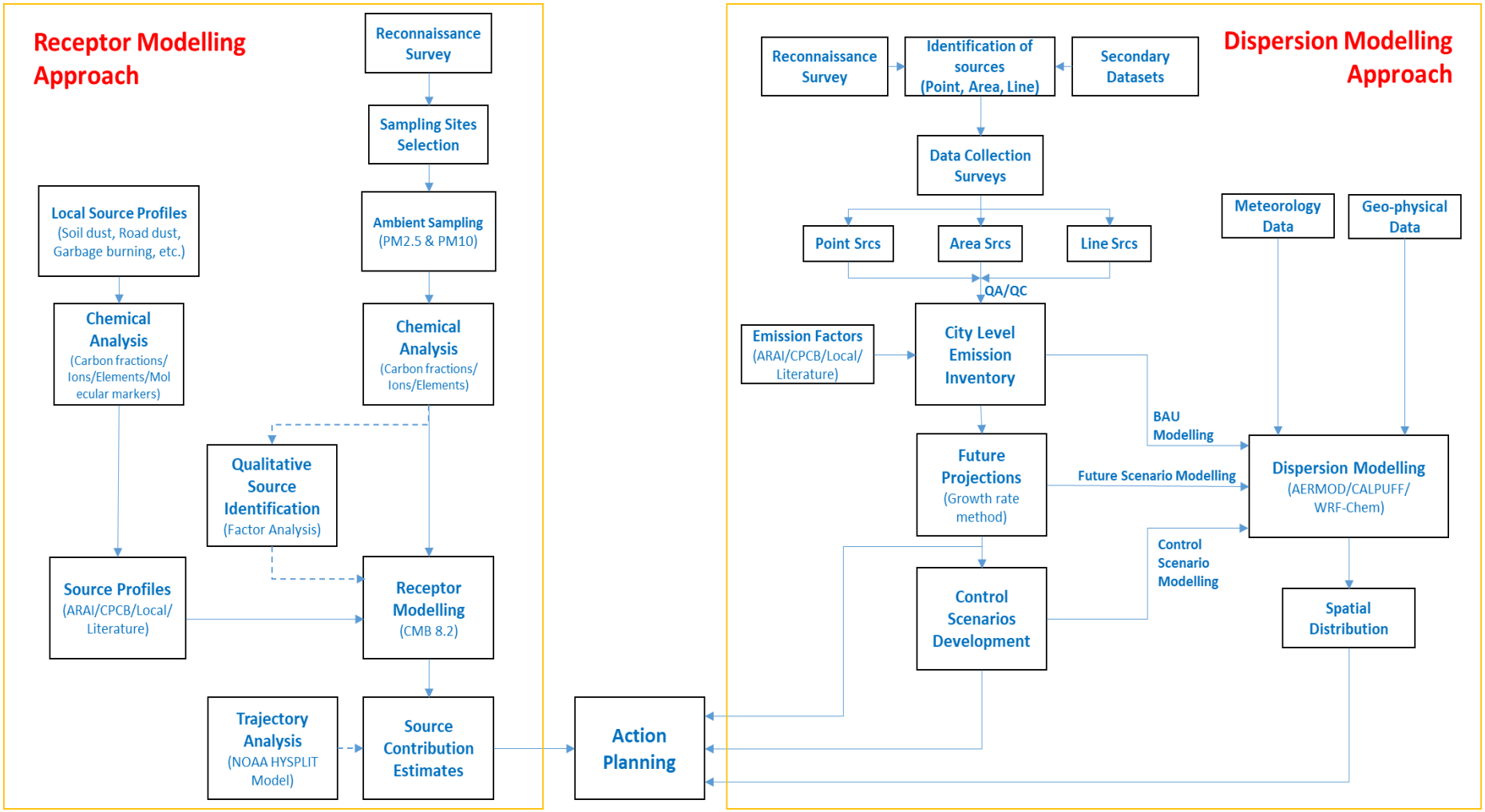

Figure 7 Framework for integrated emission inventory and source apportionment study of Rourkela region in Odisha

Chapter 2: Air Quality Monitoring, Chemical Analysis & Receptor Modelling

2.1. Introduction

The main objective of ambient air quality monitoring was to generate the baseline data of ambient concentrations of PM_{10} and $PM_{2.5}$ and to identify the major sources contributing to it. Monitoring was conducted in two critical seasons i.e. winter and summer, to capture the seasonal variations. A comprehensive exercise to monitor air quality was carried out during winter season i.e. January 2 to 21, 2022 and summer season i.e. March 17 to April 5, 2022 at 5 representative locations, having different land-use patterns and sources of activity.

2.2. Methodology

2.2.1. Sampling sites selection

Based on the preliminary survey and inputs from State Pollution Control Board, Odisha (OSPCB) five sampling locations are identified for this study in Rourkela region. Figure 8 and Table 1 respectively show the geographic distribution and details of the sampling sites, which include 1 background site, 2 residential sites, 1 mixed land use site and 1 industrial site. These sites are located in different parts of study domain and can provide an integrated insight into the characteristic of $PM_{2.5}$ and PM_{10} over Rourkela region. For example, the residential sites, such as those at IDL Outpost (S5) and Bondamunda (S3), are surrounded by typical residential areas with middle-to-high income and low-income group households, respectively. The background site such as Hamirpur (S1), is located in natural habitat, which are far away from anthropogenic emissions and are less influenced by human activities. The other two sites i.e. IDCO Office (S2) and Kalunga (S4) typically represent mixed land use and industrial sites, respectively.

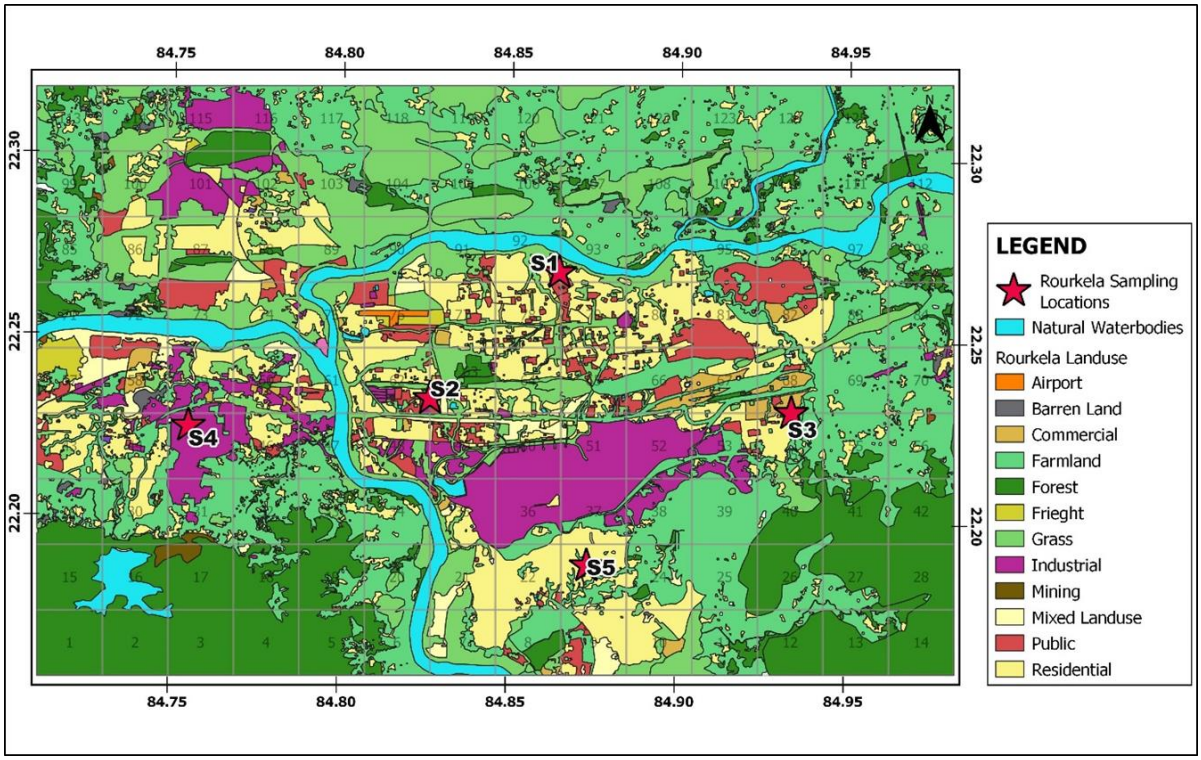

Figure 8 Rourkela region map showing different land-use classes. The red stars show the location of five sampling sites selected for source apportionment study

Table 5 Geographic information of the selected sampling sites in Rourkela region

Code	Location	Latitude	Longitude	Category
S1	Hamirpur Highschool, Sector 19, Hamirpur, Rourkela, Odisha 769005	22° 16' 6.38" N	84° 51' 52.31" E	Background
S2	IDCO Office, Chhend Colony, Rourkela, Odisha 769004	22° 14' 0.64" N	84° 49' 35.83" E	Mixed
S3	College of Arts, Science and Commerce, Gundichapli, Rourkela, Odisha 770036	22° 13' 49.40" N	84° 56' 0.82" E	Residential (LIG and MIG)
S4	Jay Matadi Plastics, Kalunga Industrial Estate, Kalunga, Rourkela - 769004.	22° 13' 32.09" N	84° 45' 32.96" E	Industrial
S5	IDL Outpost, Naudera Village, Sonaparbat, Rourkela, Odisha 769016	22° 11' 16.48" N	84° 52' 24.78" E	Residential (MIG and HIG)

2.2.2. Sampling schedule

The ambient $PM_{2.5}$ and PM_{10} samples were collected in the study area, during two critical seasons i.e. winter and summer. As shown in Fig. 9, the winter season sampling was conducted at identified locations from January 2 to 21, 2022 while summer season sampling was conducted from March 17 to April 5, 2022. The summer season sampling could not be conducted in 2021 due to the COVID-19 lockdown. There were restrictions on movement of people as well polluting sources activities were also well below normal. Hence, it was decided to conduct summer season sampling in 2022, upon normalization of activities and movement of people.

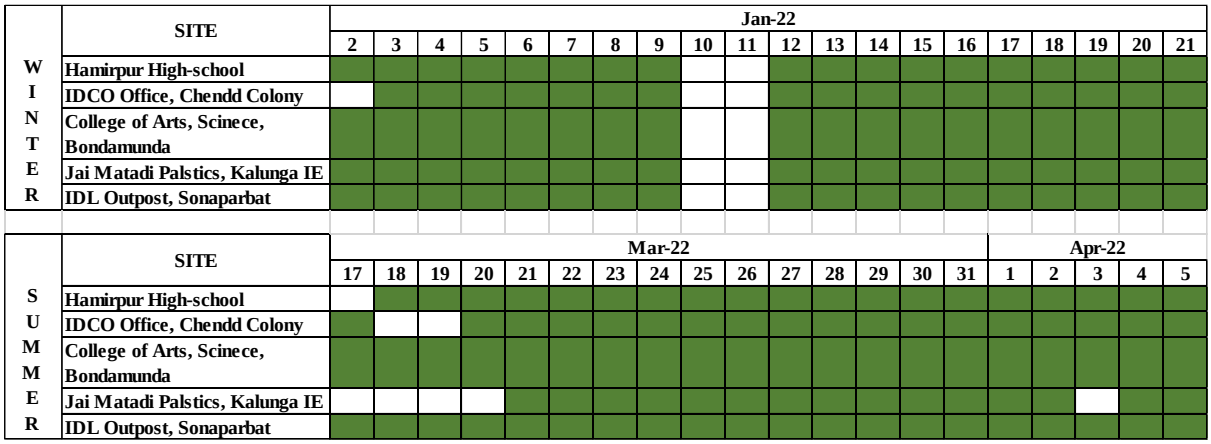

Figure 9 The sampling schedule for collection of PM samples during winter and summer seasons in Rourkela region

2.2.3. Sampling and gravimetric analysis

$PM_{2.5}$ and PM_{10} samples were collected using multi-channel speciation samplers for 24 hours at a flow rate of 16.7 LPM during both the winter and summer seasons. Samples were simultaneously collected on 47 mm diameter polytetrafluoroethylene (PTFE) membrane filters (Whatman make; GE Healthcare Life Sciences, India) and quartz fiber filters (Tissuequartz™ 2500QAT-UP; Pall Corporation, USA) for both $PM_{2.5}$ and PM_{10}. Teflon filters were used for measurement of gravimetric mass, elemental concentrations, and water-soluble ions while the quartz-fiber filters were analyzed for carbonaceous materials. Each filter paper was visually inspected for damage, if any, before and after sampling. The filter papers were conditioned before and after sampling in desiccators to attain equilibration under the controlled temperature (20 – 30 ^{0}C) and relative humidity (20 – 35%) for 24 hours. Additionally, the quartz-fiber filter papers were pre-baked at 900 ^{0}C for 3 hours in an oven to remove any deposited organic

compounds. The conditioned filters were transferred to individual cassettes to avoid the contamination of filters on the way and cassettes were then stored at ~4 ^{0}C to minimize the evaporation of volatile compounds. Filters were handled only using tweezers coated with Teflon tape to reduce the possibility of contamination. As discussed earlier, Teflon filter papers were weighed before and after sampling for the determination of collected particulate mass using a Mettler Toledo electronic microbalance (Model: XP2U).

2.2.4. Chemical analysis of PM

The chemical speciation analysis of PM samples collected on filter papers can be divided into the three most common categories i.e. elements, ions (sulphates, nitrates, ammonium, and others), and carbon fractions for identifying the sources of pollutants in Rourkela region. The details of the instrumental techniques utilized for analysing PM are given below.

2.2.5. Elemental/Organic Carbon

Two classes of carbon are commonly measured in aerosol samples collected on quartz fibre filters: 1) organic, volatilized, or non-light absorbing carbon and 2) elemental or light-absorbing carbon.

'Organic carbon' and 'elemental carbon' generally refer to particles that appear black and are also called 'soot', 'graphitic carbon', or 'black carbon'. Various methods include thermal/optical reflectance (TOR), thermal/optical transmission (TOT), and thermal manganese oxidation (TMO) methods for organic and elemental carbon. TOR method of analysis was used for carbon fractions. DRI Model 2015 (Series 2) Multi-Wavelength Thermal/Optical Carbon Analyzer was used for the carbon-measurement study. Pre-baked filters were used for carrying out blank analysis.

2.2.6. Elements

The energy dispersive X-ray fluorescence (ED-XRF) technique was used for the quantification of elements present in $PM_{2.5}$ and PM_{10} collected on Teflon paper. It is a non-destructive technique of inorganic speciation analysis; XRF does not require sample preparation or long operator time after it is loaded into the analyzer. Filters remain intact after analysis and were used for analysis of ions.

2.2.7. Ions

Ionic species are those that are soluble in water. Anions and cations were analyzed using an ion chromatograph with conductivity detector. In $PM_{2.5}$ and PM_{10} samples, ions that are analysed on an ion chromatograph are grouped under anions such as fluoride, chloride,

bromide, nitrite, nitrate, sulphate and under cations such as sodium, ammonium, potassium, calcium, and magnesium. Sample preparation was done by using the ultrasonication method. Milli-Q grade water, freshly produced from the Gradient A10 Millipore system and having resistivity of 18 M-Ohm, was used for sample preparation and analysis. Laboratory blank, field blank, and samples were always filtered through 0.2-micron nylon membrane filters to avoid background matrix interference.

2.3. Quality Assurance/Quality Control

Quality assurance (QA)/quality control (QC) is an essential part of any monitoring system. It is a programme of activities that ensures that the measurements meet the defined and appropriate standards of quality, with a stated level of confidence. Each sample to be sent to the field for monitoring was prepared carefully by following the QA/QC system. A unique sample ID was given to each sample collected for future reference and database generation.

The Instrumex make dual channel speciation samplers were used for particulate sampling during both the seasons. The field staff, handling the sample kit, were trained for specific tasks like the handling of filters and cartridges. Proper training was provided to the field staff and supervisors for conducting intermediate performance checks. The details of QA/QC audits performed are presented in Annexure-F.

2.4. Chemical Mass Reconstruction

The chemical mass reconstruction is carried out following the methodology adopted by Bawase et al., 2021 and Chow et al., 2015. The PM chemical components were grouped into six categories i.e. organic matter (OM), elemental carbon (EC), sulphate, nitrate and ammonium ions (together referred to as SNA), seas salts (SS), crustal materials (CM) and other trace elements (TE) and reconstructed PM mass is calculated as follows (Eq. 1):

$$\mathbf{PM_{Chem} = OM + EC + SNA + SS + CM + TE} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{Eq.(1)}$$

Organic Mass (OM) was obtained by multiplying the measured concentration of organic carbon (OC) by a factor of 1.6 ± 0.2, to account for the ageing effect of urban aerosols (Turpin and Lim, 2001). It is to be noted, that this approach may introduce some uncertainties in the overall estimations of OM to the total mass.

In this study, secondary ions are expressed as sums of sulphate, nitrate and ammonium ions while the sea salts are expressed as sum of sodium and chloride ions.

The crustal mass was obtained using IMPROVE formula (Malm et al. 1994, Eq. 2). This formula estimates crustal mass on the basis of elemental oxides such as Al_2O_3, SiO_2, CaO, TiO_2, and Fe_2O_3.

$$\mathbf{CM = 2.2 * Al + 2.49 * Si + 1.63 * Ca + 1.94 * Ti + 2.42 * Fe \ldots\ldots\ldots\ldots\ldots Eq.(2)}$$

The trace element mass is the sum of 14 different elemental species and is expressed as (Eq. 3):

$$\mathbf{TE = K + V + Cr + Mn + Co + Ni + Cu + Zn + As + Se + Rb + Sr + Mo + Pd + Cd + Sn + Te + Cs + Ba + La + Pb \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.(3)}$$

The chemical reconstruction method explained above was applied to all 5 sites over Rourkela city and reconstructed PM mass (PM_{Chem}) was compared against the corresponding observed gravimetric mass (PM_{Grav}).

2.5. Receptor Modelling: Chemical Mass Balance (CMB) Model

In the present study, the US EPA-Chemical Mass Balance Model (CMB V8.2; Coulter 2004) is used to apportion the sources of $PM_{2.5}$ and PM_{10} particles in Rourkela region. This model uses an effective variance least-squares algorithm to apportion the ambient data to selected source profiles (Gordon 1980; Hidy and Venkataraman 1996; Watson 1984; Watson, et al. 1984). The basic principle of the CMB model could be expressed by Equation (4), which represents the relationship between the ambient concentrations of the chemical species at a receptor site and those emitted from the source.

$$C_i = \sum_{j=1}^{P} F_{ij} \text{ x } S_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ (4)$$

In this equation, Ci is the ambient concentrations of the species i measured at the receptor site, P is the number of contributing sources, Fij is the fraction of the emissions of the species i

starting from the source j, and Sj indicates the ambient contribution of the source j (Srivastava and Jain, 2007).

The CMB model uses ambient pollutant concentrations, their chemical composition, and the chemical composition of sources i.e. source profiles, to estimate the relative contribution of each source to ambient concentrations at a given location. The CMB model also considers the known uncertainties in the ambient measurements and the source profiles.

As discussed above, source profiles are one of the essential requirements of receptor modelling using CMB. The source profiles in a given region depends upon sources, process operating conditions, geology, and geographic seasonality (Patil et al., 2013) and hence the choice of appropriate source profiles is very crucial in source identification and apportionment. India specific source profiles for a number of vehicular and non-vehicular sources were generated by CPCB source apportionment study (CPCB, 2010) and the same have been used in this study. A detailed description of the source profiles can be found in references CPCB (2010) and Patil et al. (2013).

The CMB model was run for each site for each day of sampling. The performance of the CMB model was examined using parameters such as squared correlation coefficient (R^2), measured fitting species concentration (χ^2), model computed per cent mass, and ratio of residual to uncertainty (R/U ratio). The daily source contributions obtained from the CMB model are averaged over the sampling period in each season to get the seasonal source contributions for each site.

2.6. Results and discussions

2.6.1. Winter season

2.6.1.1. PM mass concentrations

Fig. 10, presents the distribution of daily $PM_{2.5}$ and PM_{10} concentrations observed at five sampling locations in Rourkela region during the winter season i.e. Jan 2 – 21, 2022. The mean $PM_{2.5}$ and PM_{10} mass concentrations during the entire sampling period over all sites were 60.3 and 155.3 µg/m^3, respectively. The mean $PM_{2.5}$ concentrations exhibited a 4-fold range and ranged from a minimum of 28.8 µg/m^3 (at IDCO Office i.e. S2) to a maximum of 120.4 µg/m^3 (at Kalunga IE i.e. S3). Similarly, the mean PM_{10} concentrations exhibited a 10-fold range and ranged from 50.1 µg/m^3 (at IDCO Office i.e. S2) to 547.1 µg/m^3 (at Kalunga IE i.e. S4). The

National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 µg/m^3 for $PM_{2.5}$ and PM_{10}, respectively. The winter-time $PM_{2.5}$ concentrations were observed to exceed the daily NAAQS limit at all sites (16.7 to 76.5%) with minimum exceedance at S5, i.e. IDL Outpost, Sonaparabat (16.7%). The daily averaged PM_{10} concentrations exceeded the NAAQS limit at all sites (33-100%) with minimum exceedance at S5, i.e. IDL Outpost, Sonaparabat (33%) whereas maximum PM_{10} exceedance was observed at S4 i.e. Jai Matadi Plastics Ltd., Kalunga (100%).

2.6.1.2. Spatial variability

The highest seasonal mean $PM_{2.5}$ concentrations were observed at S4 i.e. Jai Matadi Plastics Ltd., Kalunga (84.2 µg/m^3) while the lowest were recorded at S5, i.e. IDL Outpost, Sonaparabat (49.0 µg/m^3). These two locations also reported the highest and lowest variability in $PM_{2.5}$ concentrations, respectively. For example, $PM_{2.5}$ concentrations ranged from 55.7 to 120.4 at S4 i.e. Jai Matadi Plastics Ltd., Kalunga while it ranged from 32.2 to 68.6 at S5, i.e. IDL Outpost, Sonaparabat.

The highest seasonal mean PM_{10} concentrations were observed at S4 i.e. Jai Matadi Plastics Ltd., Kalunga (339.9 µg/m^3) while the lowest were recorded at S1 i.e. Hamirpur Highschool (93.6 µg/m^3). The PM_{10} concentrations showed highest variability at S4 i.e. Jai Matadi Plastics Ltd., Kalunga ranging from a minimum of 137.4 to a maximum of 547.1 µg/m^3 while it ranged between 38.9 and 131.9 µg/m^3 at S1 i.e. Hamirpur Highschool.

These concentration levels can be attributed to air polluting activities around each site. For example, S4 i.e. Jai Matadi Plastics Ltd., Kalunga is located in the heart of Kalunga Industrial estate which has number of Sponge Iron Industries. In addition to Industrial stack emissions and fugitive emissions, road dust re-suspension due to movement of heavy vehicles in the region can be one of the major reasons for highest particulate levels.

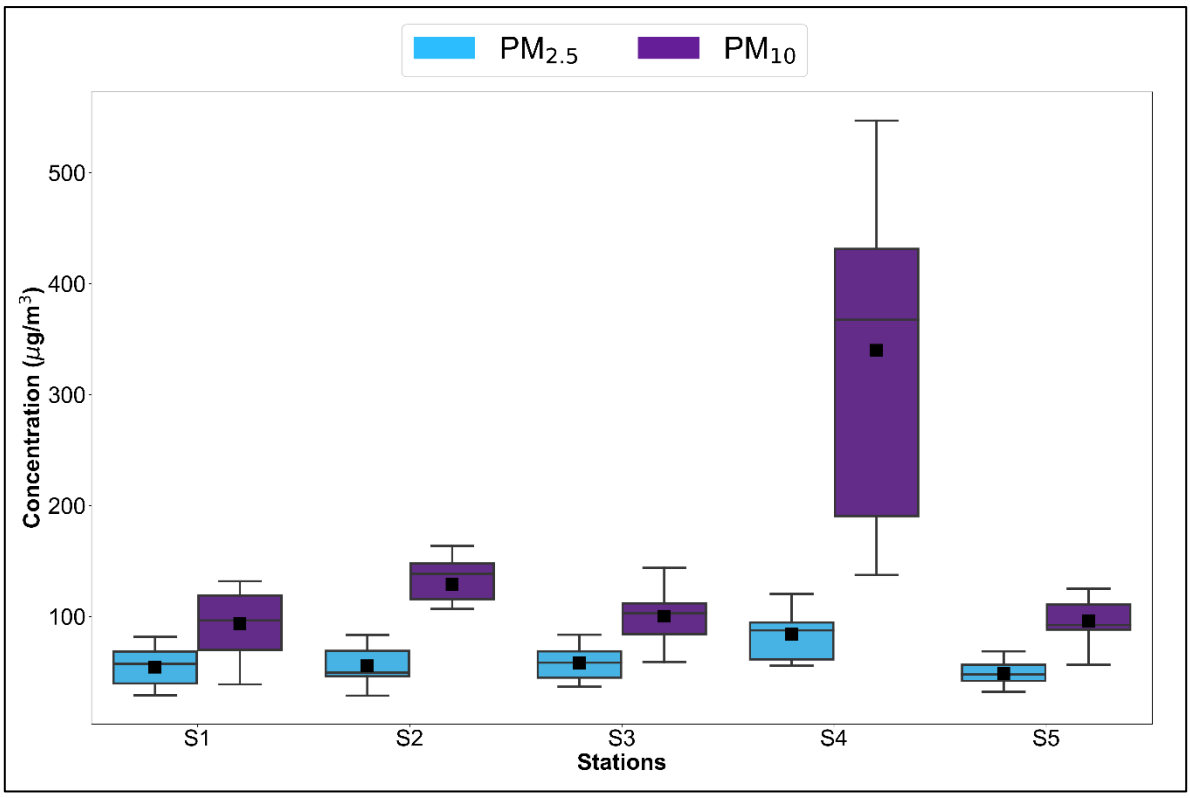

Figure 10 Boxplot showing distribution of daily $PM_{2.5}$ ***(blue colored boxes) and*** PM_{10} ***(violet colored boxes) concentrations observed at five sampling sites in Rourkela region during the winter season sampling period (Jan 2 – 21, 2022).***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.1.3. Temporal variability

Fig. 11 shows daily time-series of $PM_{2.5}$ and PM_{10} observed at five selected sampling locations in Rourkela region during the winter season sampling period. Only valid samples between Jan 2 - 21, 2022 are considered for this analysis. Overall, the PM concentrations showed an increasing trend from January 2 to 21 at all sites with a typical low concentrations period between January 13-15 followed by high pollution episode during January 18-20, 2022. This could be attributed to the meteorological phenomena over Rourkela region during the winter season.

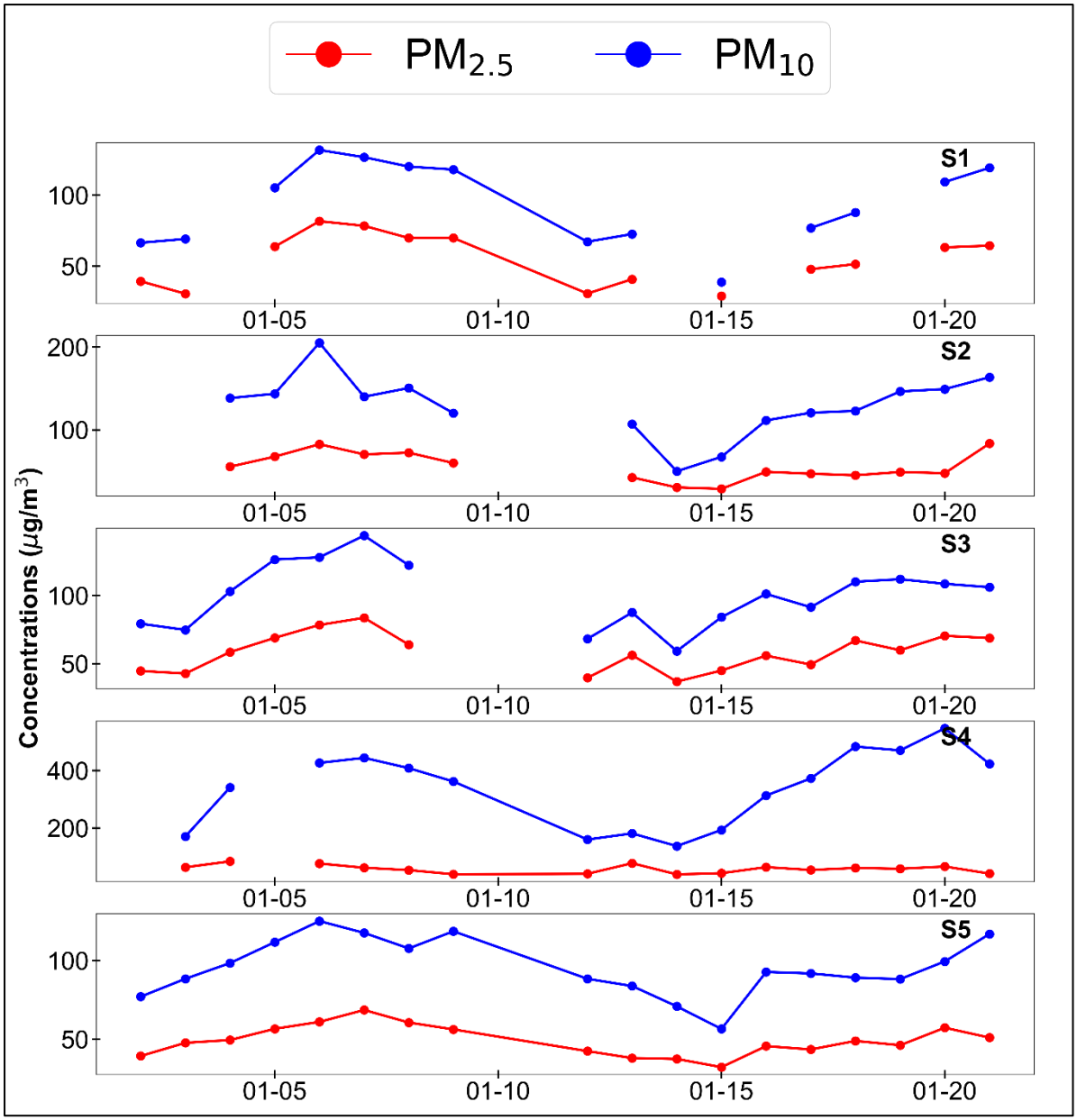

Figure 11 Daily time-series of $PM_{2.5}$ ***(red) and*** PM_{10} ***(blue) concentrations observed at five sites in Rourkela region during the winter season sampling (Jan 2-21, 2022)***

2.6.1.4. $PM_{2.5}$ to PM_{10} ratios

Fig. 12 shows distribution of daily $PM_{2.5}$ to PM_{10} ratios observed at five selected sites during the winter season sampling. The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.46, varying from 0.20 to 0.58. The highest winter season mean $PM_{2.5}$ to PM_{10} ratio was observed at S1 i.e. Hamirpur Highschool (0.58) while the lowest was observed at S4 i.e. Jai Matadi Plastics Ltd., Kalunga (0.20). This variability in fine and coarse mode particles may be attributed to variability in PM chemical composition, which is in turn affected by various sources and meteorological conditions.

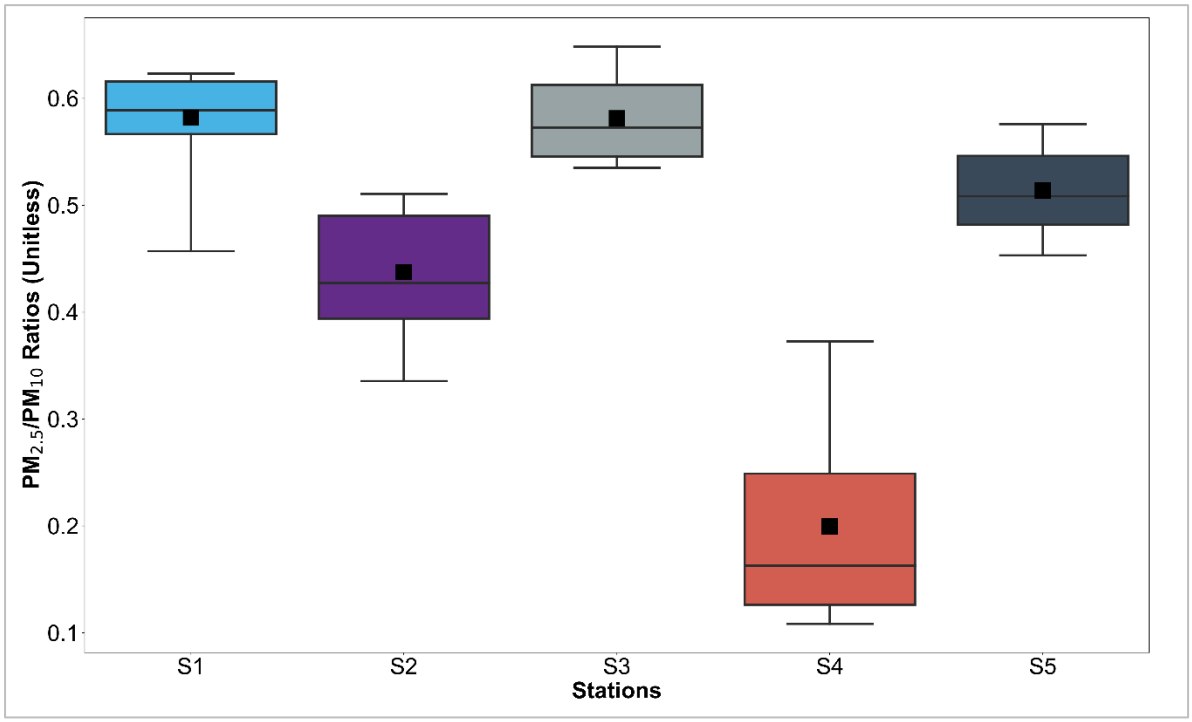

Figure 12 Boxplot showing distribution of $PM_{2.5}$ *to* PM_{10} *ratios at five selected sites in Rourkela region during the winter season (Jan 2-21, 2022)*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5. Chemical composition of $PM_{2.5}$ and PM_{10}

2.6.1.5.1. Site 1: Hamirpur Highschool, Hamirpur

Fig. 13 shows the frequency distribution of different species observed in $PM_{2.5}$ and PM_{10} at Hamirpur Highschool site (S1) in Rourkela region during the winter season. OC, EC, SO4-- and NH4+ in $PM_{2.5}$ and OC, EC, SO4--, NO3- and NH4+ in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

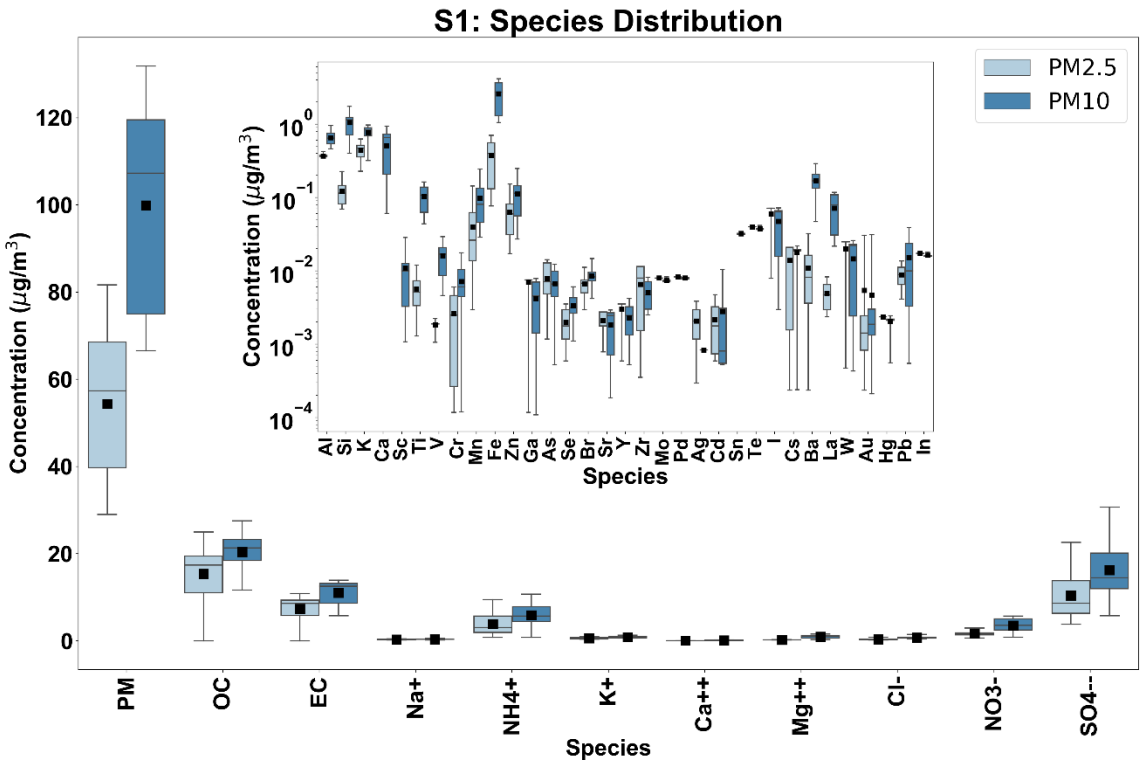

Figure 13 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at Hamirpur Highschool site (S1) in Rourkela region during the winter season*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5.2. Site 2: IDCO Office (S2)

Fig. 14 shows the frequency distribution of different species observed in $PM_{2.5}$ and PM_{10} at IDCO Office (S2) during winter season (January 2-21, 2022). OC, EC, SO4--, and NH4+ in $PM_{2.5}$ and OC, EC, SO4--, NO3- and Fe in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

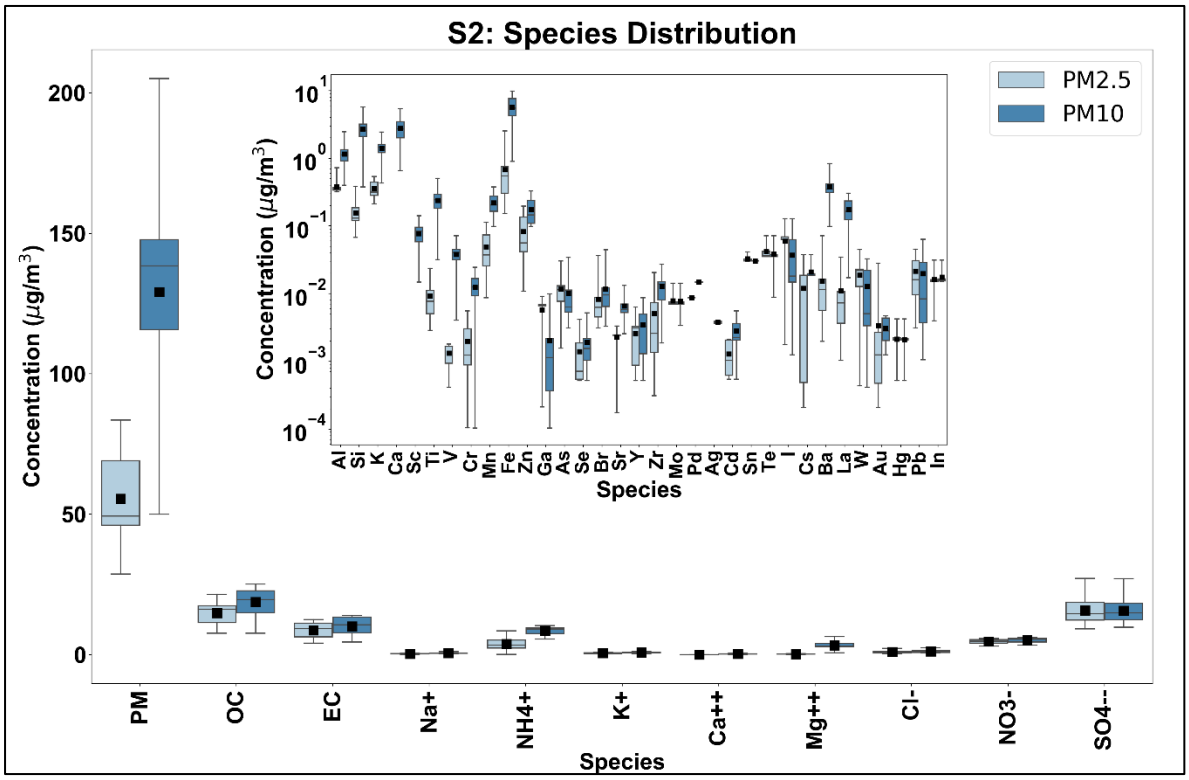

Figure 14 Box plots showing distribution of different species observed in $PM_{2.5}$ ***and*** PM_{10} ***at*** IDCO Office (S2) ***in Rourkela region during the winter season***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5.3. Site 3: College of Arts, Science & Technology, Bondamunda (S3)

Fig. 15 shows the frequency distribution of different species observed in $PM_{2.5}$ and PM_{10} at College of Arts, Science & Technology, Bondamunda (S3) in Rourkela region during the winter season. OC, EC, SO_4^{--}, and NO_3^- are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3 in both $PM_{2.5}$ and PM_{10}, respectively. Trace elements concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

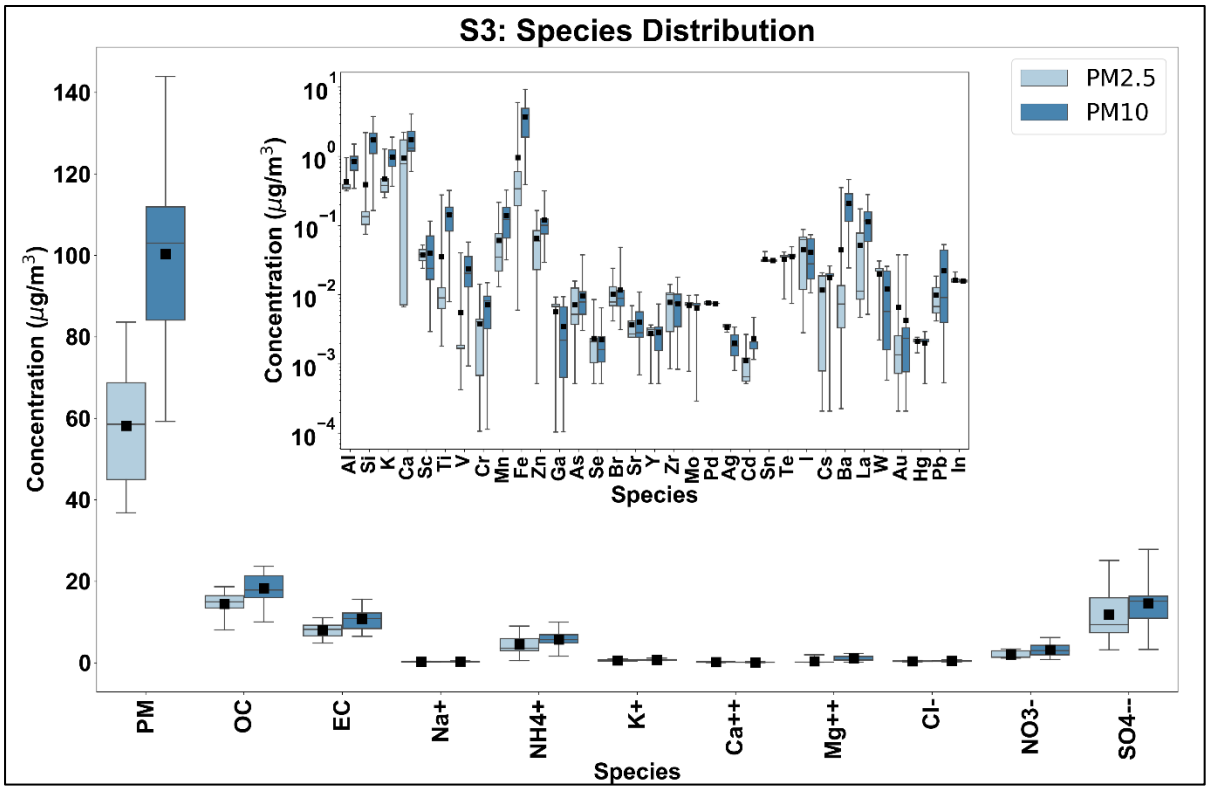

Figure 15 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at College of Arts, Science & Technology, Bondamunda site (S3) in Rourkela region during the winter season*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5.4. Site 4: Jay Matadi Plastics Ltd, Kalunga (S4)

Fig. 16 shows the frequency distribution of different species observed in $PM_{2.5}$ and PM_{10} at Jay Matadi Plastics Ltd, Kalunga (S4) in Rourkela region during the winter season. OC, EC, and SO4-- in $PM_{2.5}$ and OC, EC, SO4--, Si, Ca and Fe in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

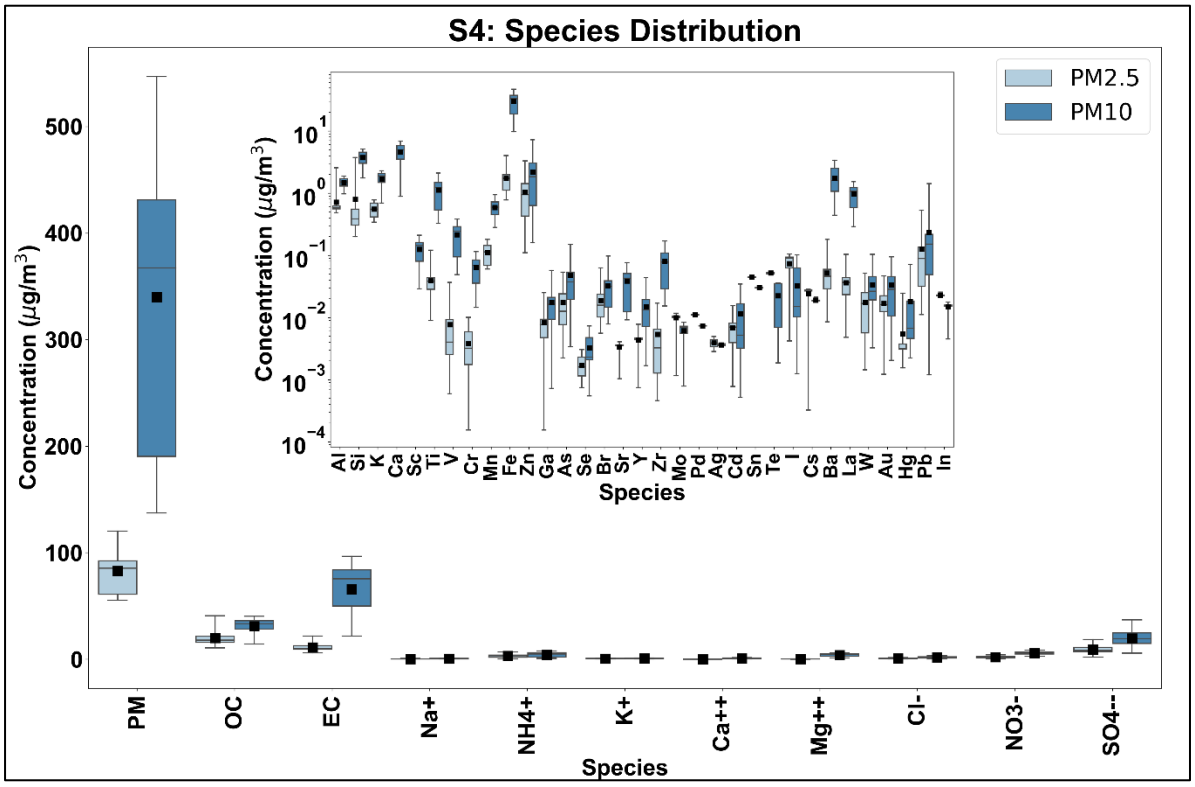

Figure 16 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at Jay Matadi Plastics Ltd, Kalunga (S4) in Rourkela region during the winter season*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.1.5.5. Site 5: IDL Outpost, Sonaparabat (S5)

Fig. 17 shows the frequency distribution of different species observed in $PM_{2.5}$ and PM_{10} IDL Outpost, Sonaparabat (S5) in Rourkela region during the winter season. OC, EC, SO4--, and NH4+ in $PM_{2.5}$ and OC, EC, SO4--, NO3, NH4+ and Fe in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

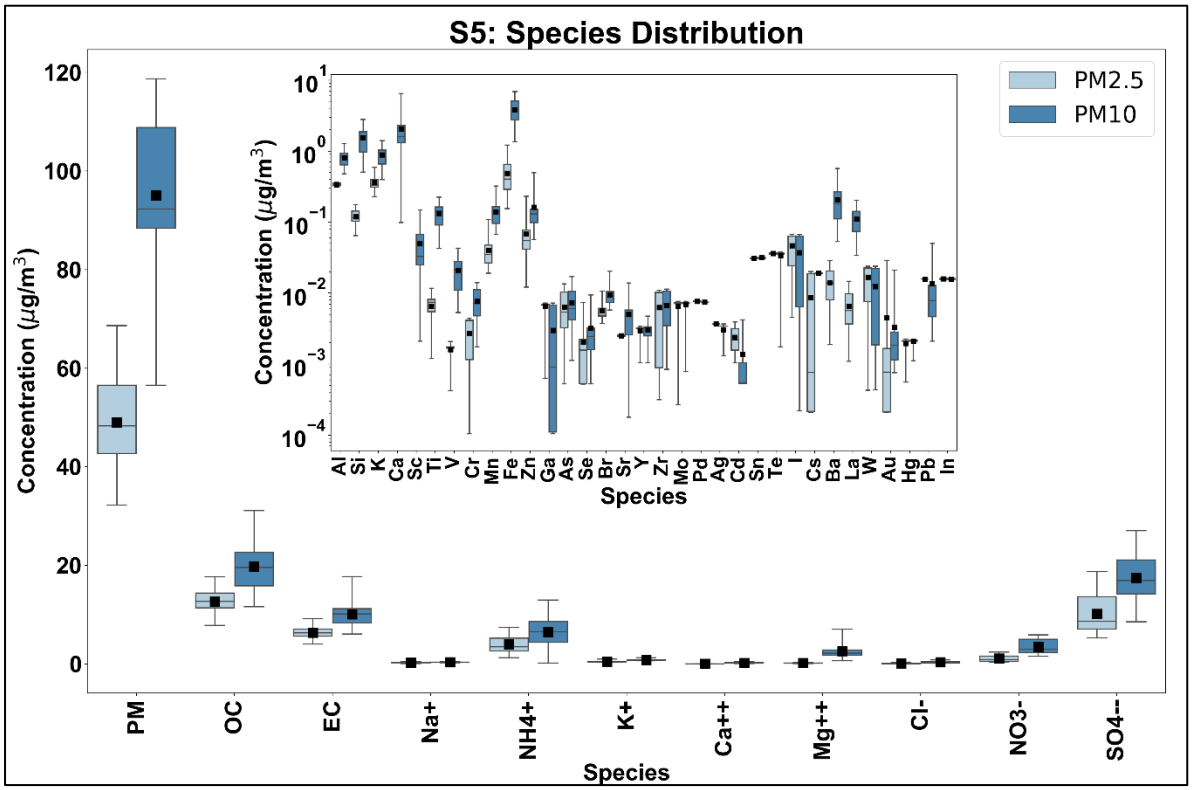

Figure 17 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at IDL Outpost, Sonaparabat (S5) in Rourkela region during the winter season*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles (lower and upper edges of the box), and minimum and maximum (lower and upper horizontal whiskers) concentrations

2.6.2. Summer season

2.6.2.1. PM mass concentrations

Fig. 18, presents the distribution of daily $PM_{2.5}$ and PM_{10} concentrations observed at five sampling locations in Rourkela region during the summer season i.e. Mar 17 – Apr 5, 2022. The mean $PM_{2.5}$ and PM_{10} mass concentrations during the entire sampling period over all sites were 105.1 and 363.6 µg/m^3, respectively. The mean $PM_{2.5}$ concentrations exhibited a 5-fold range and ranged from a minimum of 34.6 µg/m^3 (S2 i.e. IDCO Office) to a maximum of 192.0 µg/m^3 (at S4 i.e. Jay Matadi Plastics Ltd, Kalunga). Similarly, the mean PM_{10} concentrations exhibited a 13-fold range and ranged from 84.6 µg/m^3 (S2 i.e. IDCO Office) to 1151.3 µg/m^3 (S4 i.e. Jay Matadi Plastics Ltd, Kalunga). The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 µg/m^3 for $PM_{2.5}$ and PM_{10}, respectively. The summer-time $PM_{2.5}$ concentrations were observed to exceed the daily NAAQS limit at all sites (83 to 94%) with minimum exceedance at S2 i.e. IDCO Office (83%) and maximum at S4 i.e. Jay Matadi Plastics Ltd, Kalunga (94%). The daily averaged PM_{10} concentrations exceeded the NAAQS limit at all sites (93-100%) with minimum exceedance at S2 i.e. IDCO Office (93%) whereas all other sites exceeded the PM_{10} limits by 100%.

2.6.2.2. Spatial variability

The highest seasonal mean $PM_{2.5}$ concentrations were observed at S4 i.e. Jay Matadi Plastics Ltd, Kalunga (120.3 µg/m^3) while the lowest was recorded at S2 i.e. IDCO Office (96.1 µg/m^3). These two locations also reported the significant variability in $PM_{2.5}$ concentrations, respectively. For example, daily $PM_{2.5}$ concentrations ranged from 58.3 to 192.0 µg/m^3 at S4 i.e. Jay Matadi Plastics Ltd, Kalunga while it ranged from 34.6 to 150.6 µg/m^3 at S2 i.e. IDCO Office. This could be attributed to activities around the S4 i.e. Jay Matadi Plastics Ltd, Kalunga including, sponge iron industries, fugitive emissions, heavy duty traffic, and road dust re-suspension. S2 i.e. IDCO Office on the other hand, is a city location and is relatively unaffected by the industrial emissions.

The highest seasonal mean PM_{10} concentrations were observed at S4 i.e. Jay Matadi Plastics Ltd, Kalunga (850.3 µg/m^3) while the lowest were recorded at S5 i.e. IDL Outpost, Sonaparabat

(217.2 µg/m^3). The PM_{10} concentrations showed highest variability at S4 i.e. Jay Matadi Plastics Ltd, Kalunga ranging from a minimum of 420.4 to a maximum of 1151.3 µg/m^3. This could be attributed to stack emissions, fugitive emissions, road dust re-suspension due to movement of heavy vehicles in the region as well as summer time meteorological conditions (low RH and higher wind speed).

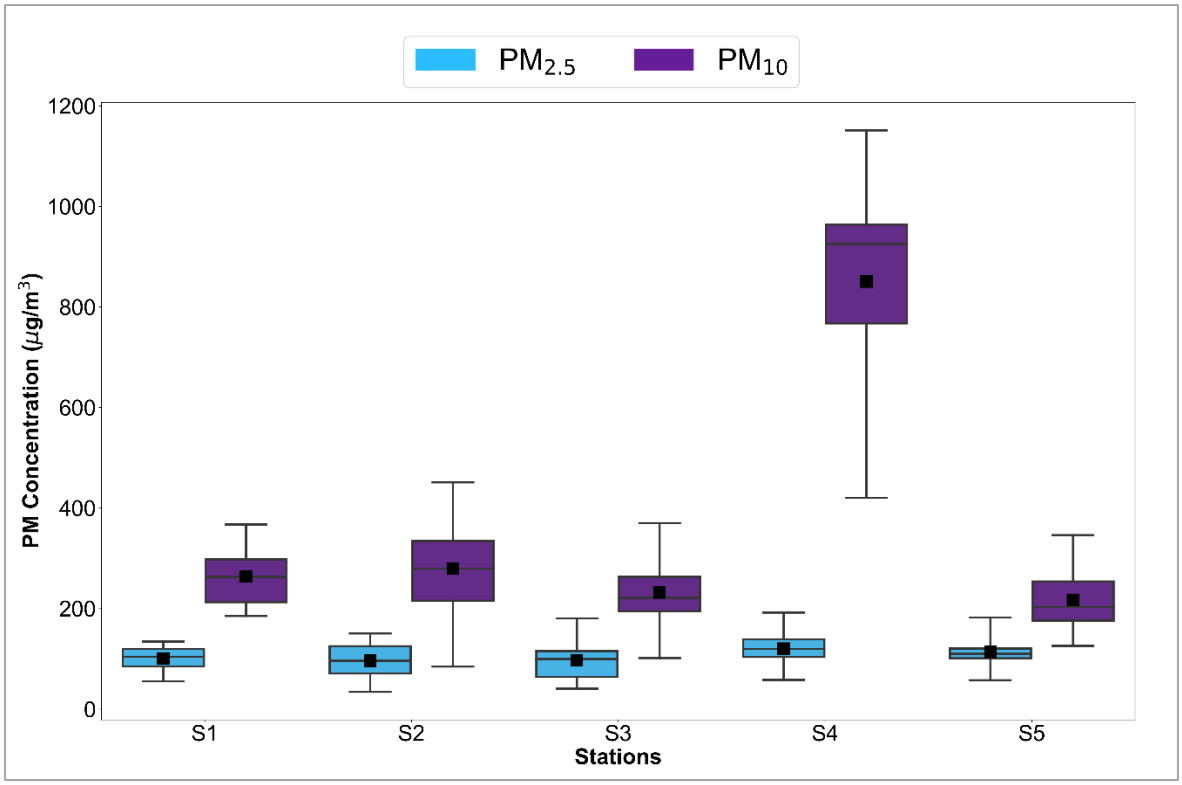

Figure 18 Boxplot showing distribution of daily $PM_{2.5}$ ***(blue colored boxes) and*** PM_{10} ***(violet colored boxes) concentrations observed at five sampling sites in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.3. Temporal variability

Fig. 19 shows the daily time-series of $PM_{2.5}$ and PM_{10} observed at five selected sampling locations in Rourkela region during the summer season sampling period. Only valid samples between Mar 17 - Apr 5, 2022, 2022 are considered for this analysis. Overall, the PM concentrations did not exhibit any trend and were more or less similar during summer season sampling campaign.

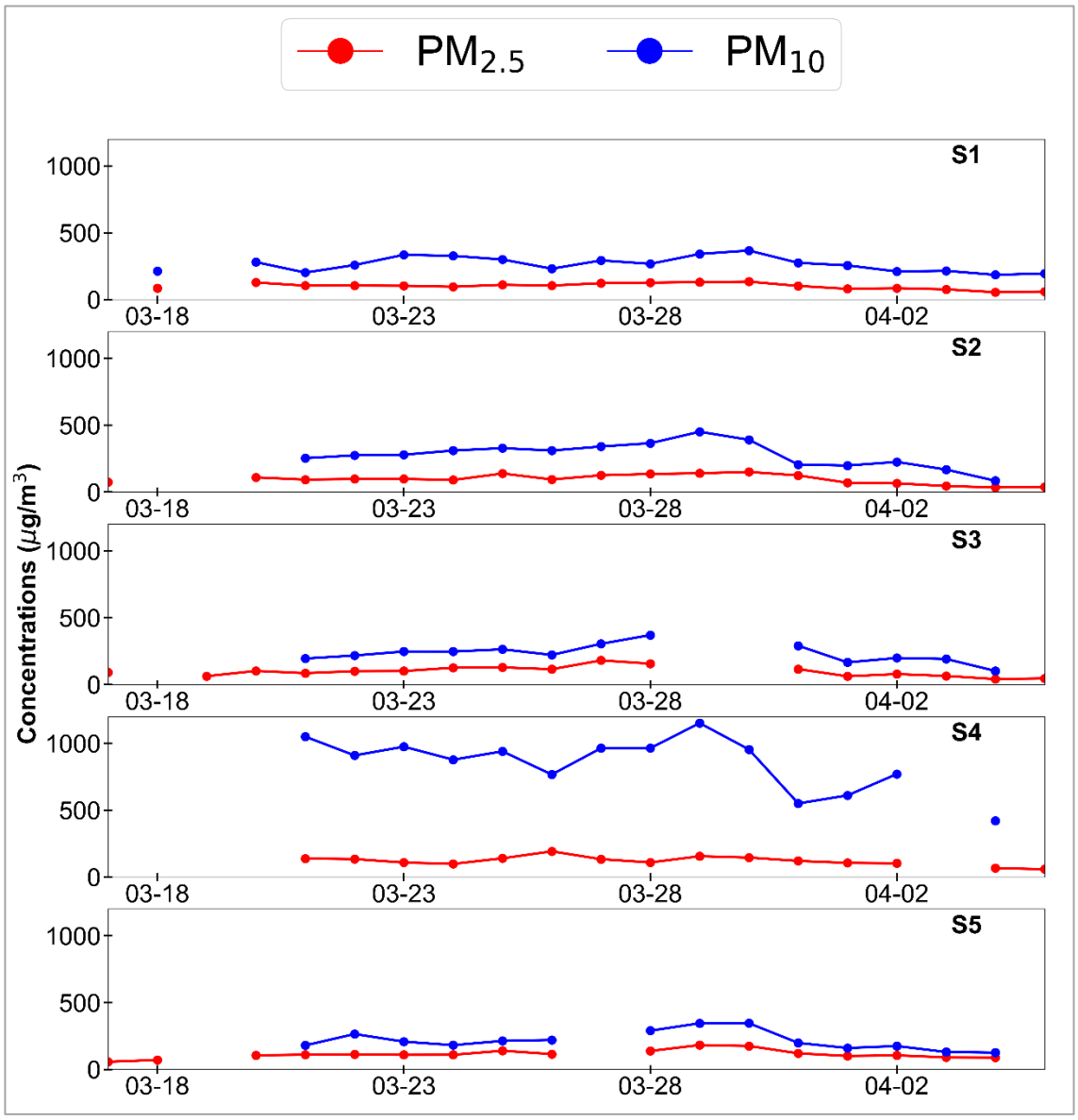

Figure 19 Daily time-series of $PM_{2.5}$ *(red) and* PM_{10} *(blue) concentrations observed at five sites in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)*

2.6.2.4. $PM_{2.5}$ to PM_{10} ratios

Fig. 20 shows distribution of daily $PM_{2.5}$ to PM_{10} ratios observed at five selected sites during the summer season sampling period (Mar 17 - Apr 5, 2022). The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.39, varying from 0.16 to 0.58. The highest summer season mean $PM_{2.5}$ to PM_{10} ratio was observed at S5 i.e. IDL Outpost, Sonaparabat (0.58) while the lowest was observed at S4 i.e. Jay Matadi Plastics Ltd, Kalungasite (0.16). This variability in fine and coarse mode particles may be attributed to variability in PM chemical composition, which is in turn affected by various sources and meteorological conditions.

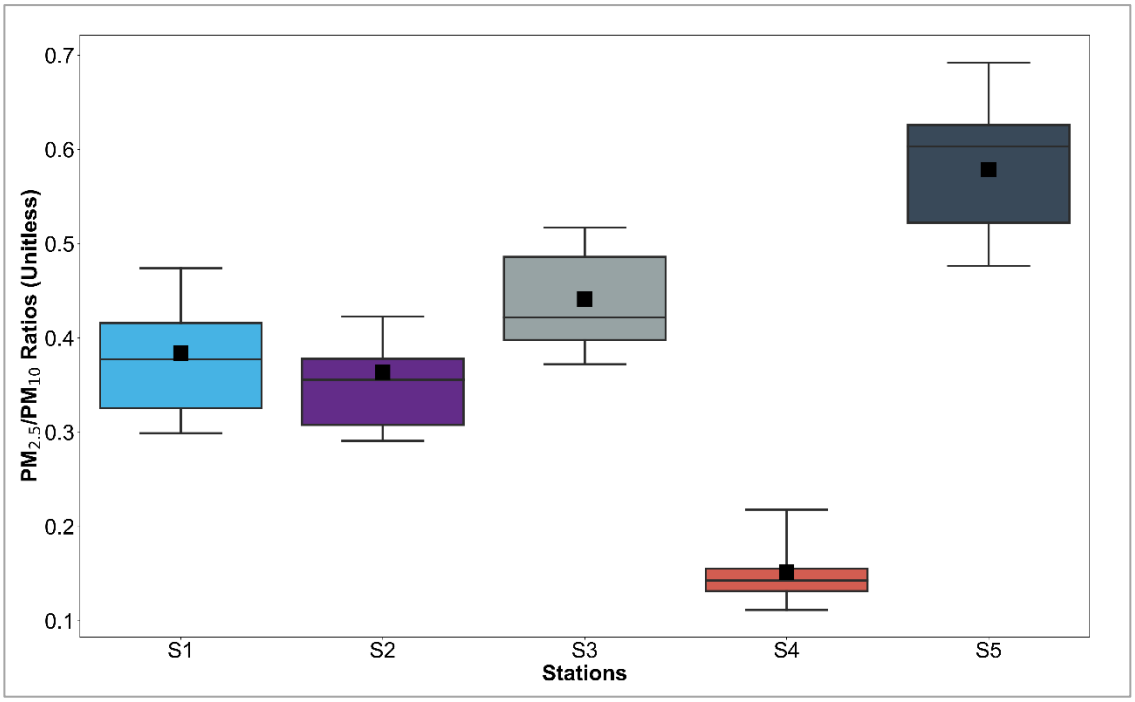

Figure 20 Boxplot showing distribution of $PM_{2.5}$ ***to*** PM_{10} ***ratios at five selected sites in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.5. Chemical composition of $PM_{2.5}$ and PM_{10}

2.6.2.5.1. Site 1: Hamirpur Highschool

Fig. 21 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S1 i.e. Hamirpur Highschool site in Rourkela region during the summer season (Mar 17 - Apr 5, 2022). OC and EC in $PM_{2.5}$ and OC, EC, Fe and SO_4^{--} PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

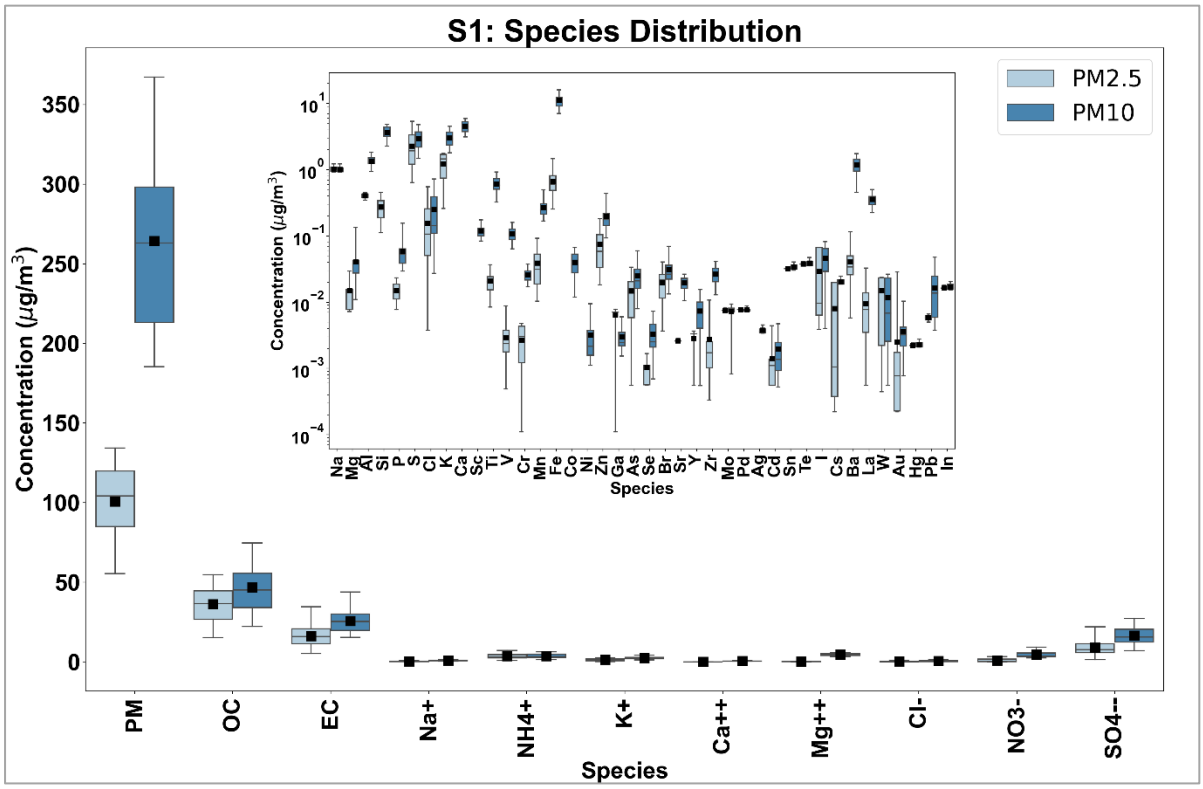

Figure 21 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at S1 i.e. Hamirpur Highschool in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022).*

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.5.2. Site 2: IDCO Office

Fig. 22 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S2 i.e. IDCO Office site in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022). OC, EC, and SO_4^{--} in $PM_{2.5}$ and OC, EC, Ca, Si, Fe, NO_3^- and SO_4^{--} in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

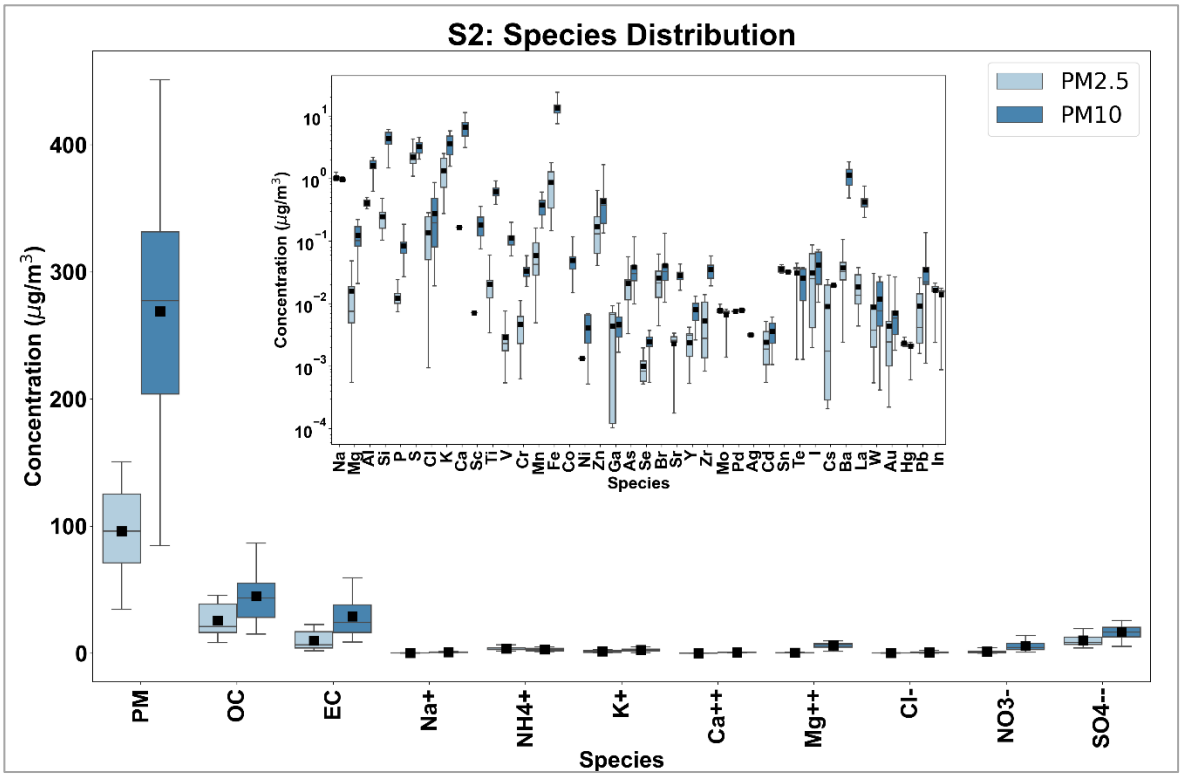

Figure 22 Box plots showing distribution of different species observed in $PM_{2.5}$ ***and*** PM_{10} ***at S2 i.e. IDCO Office in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.5.3. Site 3: College of Arts, Science & Technology, Bondamunda

Fig. 23 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S3 i.e. College of Arts, Science & Technology, Bondamunda in Rourkela region during the summer season (Mar 17 - Apr 5, 2022). OC, EC, and SO_4^{--} in $PM_{2.5}$ while OC, EC, Ca, Fe, Mg^{++}, NO_3^-, and SO_4^{--}, in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

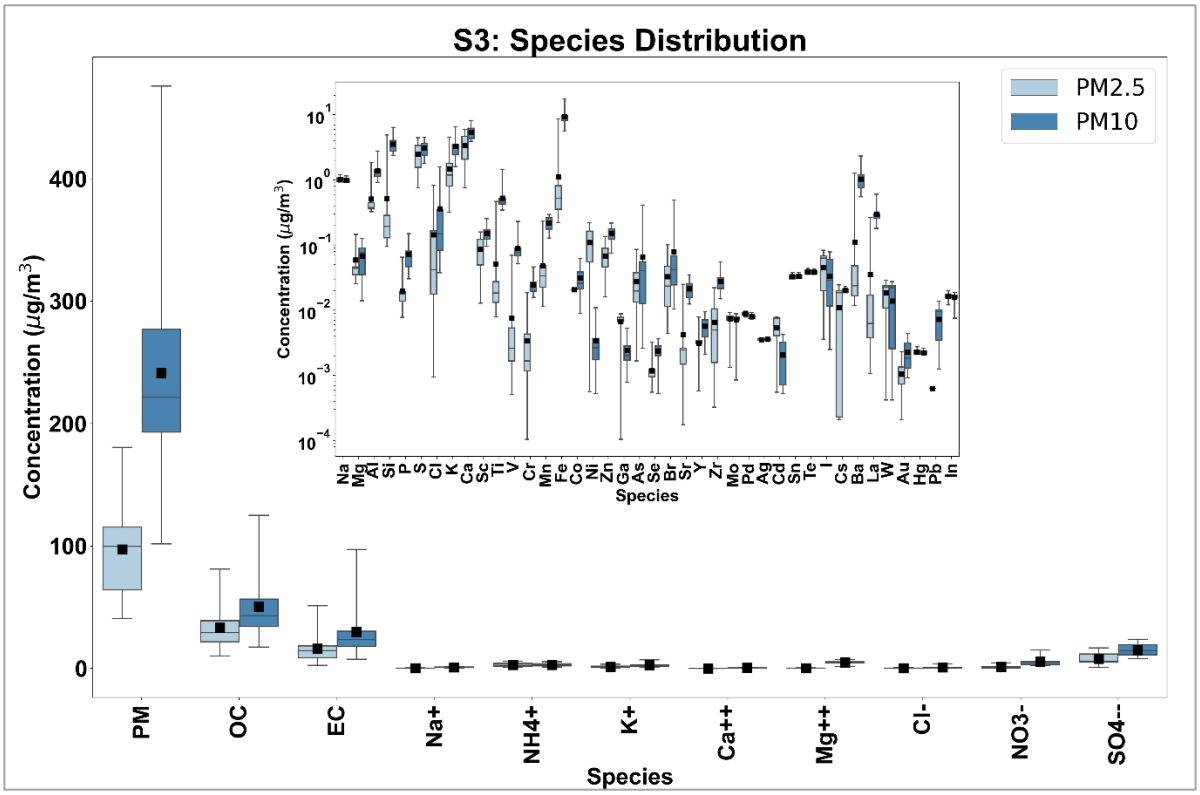

Figure 23 Box plots showing distribution of different species observed in $PM_{2.5}$ ***and*** PM_{10} ***at S3 i.e. College of Arts, Science & Technology, Bondamunda in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.5.4. Site 4: Jay Matadi Plastics Ltd, Kalunga

Fig. 24 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S4 i.e. Jay Matadi Plastics Ltd, Kalunga in Rourkela region during the summer season (Mar 17 - Apr 5, 2022). OC and EC in $PM_{2.5}$ and OC, EC, Si, Ca, Fe, Zn, Mg^{++}, NO_3^- and SO_4^{--}in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

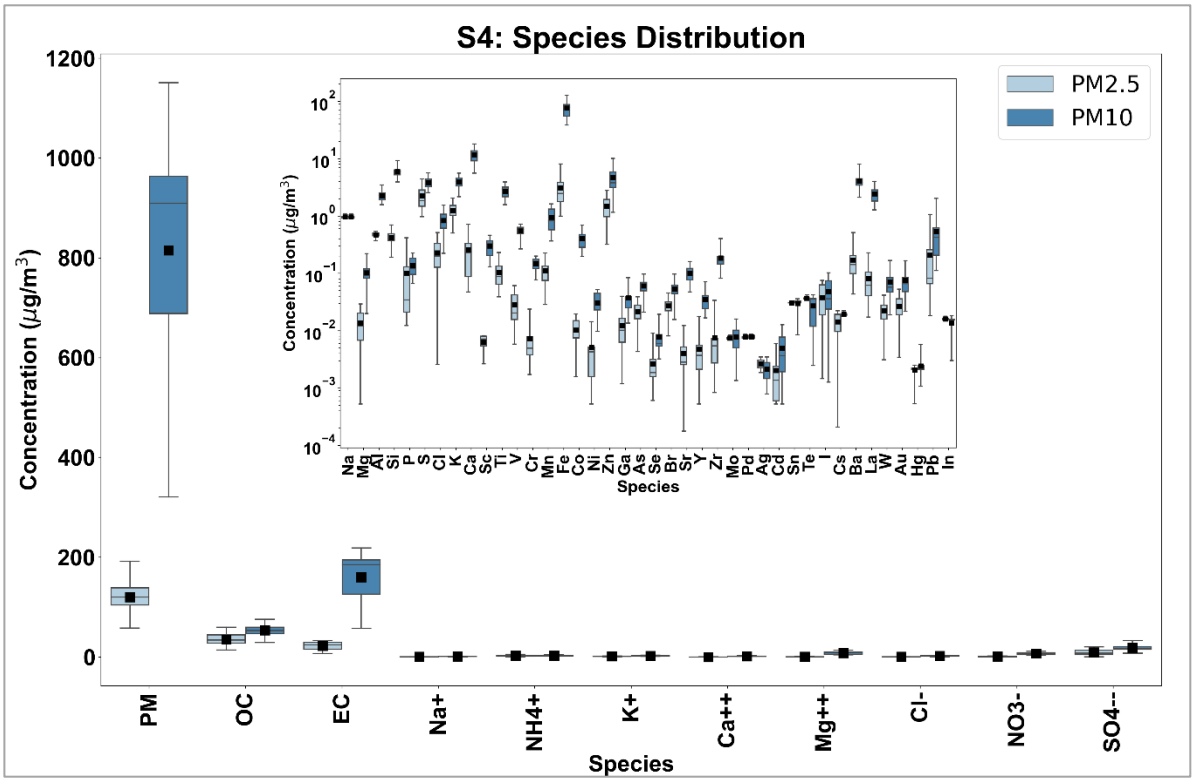

Figure 24 Box plots showing distribution of different species observed in $PM_{2.5}$ ***and*** PM_{10} ***at S4 i.e. Jay Matadi Plastics Ltd, Kalunga in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.6.2.5.5. Site 5: IDL Outpost, Sonaparabat

Fig. 25 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S5 i.e. IDL Outpost, Sonaparabat in Rourkela region during the summer season (Mar 17 - Apr 5, 2022). OC, EC, and SO_4^{--} in $PM_{2.5}$ and OC, EC, Ca, Fe, and SO_4^{--}, in PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

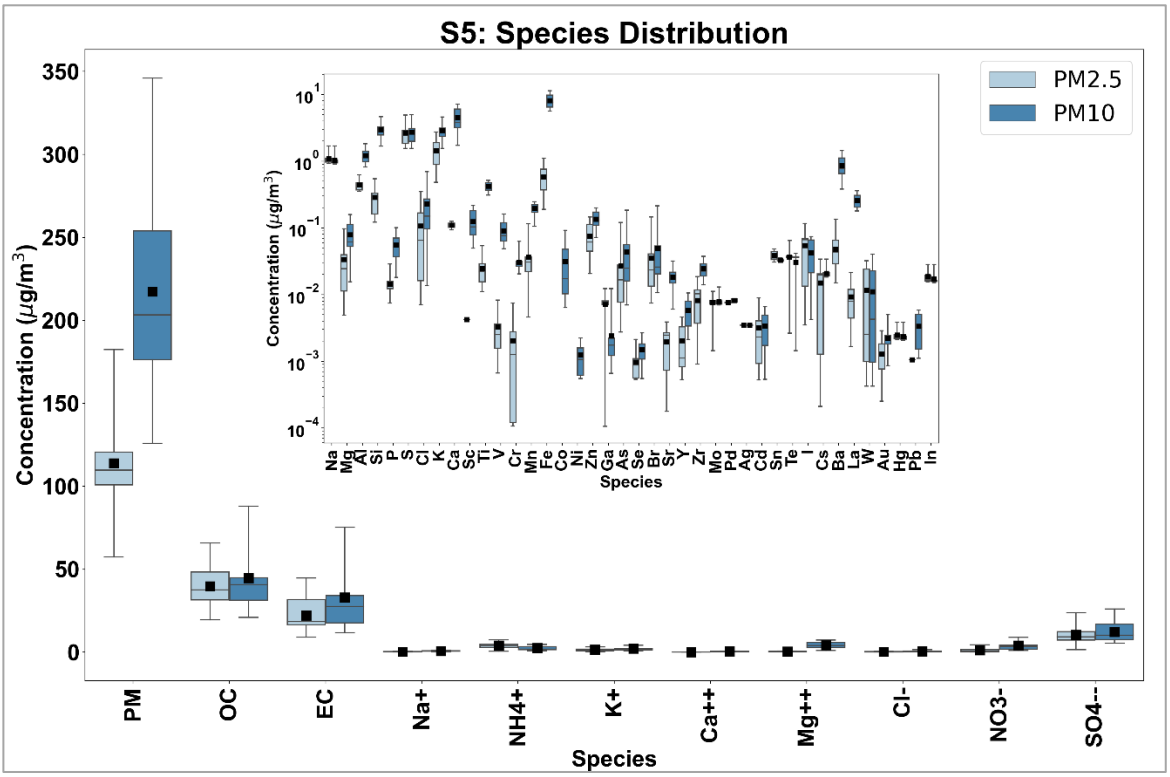

Figure 25 Box plots showing distribution of different species observed in $PM_{2.5}$ ***and*** PM_{10} ***at S5 i.e. IDL Outpost, Sonaparabat in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)***

Note: Each box represents: average (black square), median (central horizontal line), 25th and 75th percentiles concentrations (lower and upper edges of the box), while lower and upper horizontal whiskers represent range

2.7. Mass reconstruction of Particulate Matter ($PM_{2.5}$ and PM_{10})

2.7.1. Validation of mass reconstruction methodology

As discussed in section 2.6.1.1, $PM_{2.5}$ and PM_{10} mass concentrations were reconstructed. Fig. 26 and 27 shows the scatter plots of the 24-hour averaged reconstructed and gravimetric mass concentrations for the winter and summer season sampling duration, respectively. The reconstructed mass was significantly related to gravimetric mass in both winter and summer seasons. The squared correlation coefficient, R^2 is found to be 0.63 (winter) and 0.77 (summer) for $PM_{2.5}$ whereas it is found to be 0.82 (winter) and 0.98 (summer) for PM_{10}, respectively. These correlation coefficients are consistent with other published literature, with average values varying from 0.73 to 0.96 (Chow et al. 2015; Huang et al. 2014; 2017). In general, the PM_{Chem} concentrations are less than those of PM_{Grav} and the difference is defined as unknown. The unknown mass could be attributed to: i) the water retained in the sampling membrane and particulate matter, ii) volatilization of organic matter and the decomposition of ammonium nitrate that may occur during the period between weighing and chemical measurements (Huang et al. 2017) and iii) uncertainties associated with conversion factors used in the estimation of metal oxides and OC to OM conversion (Cheung et al. 2011).

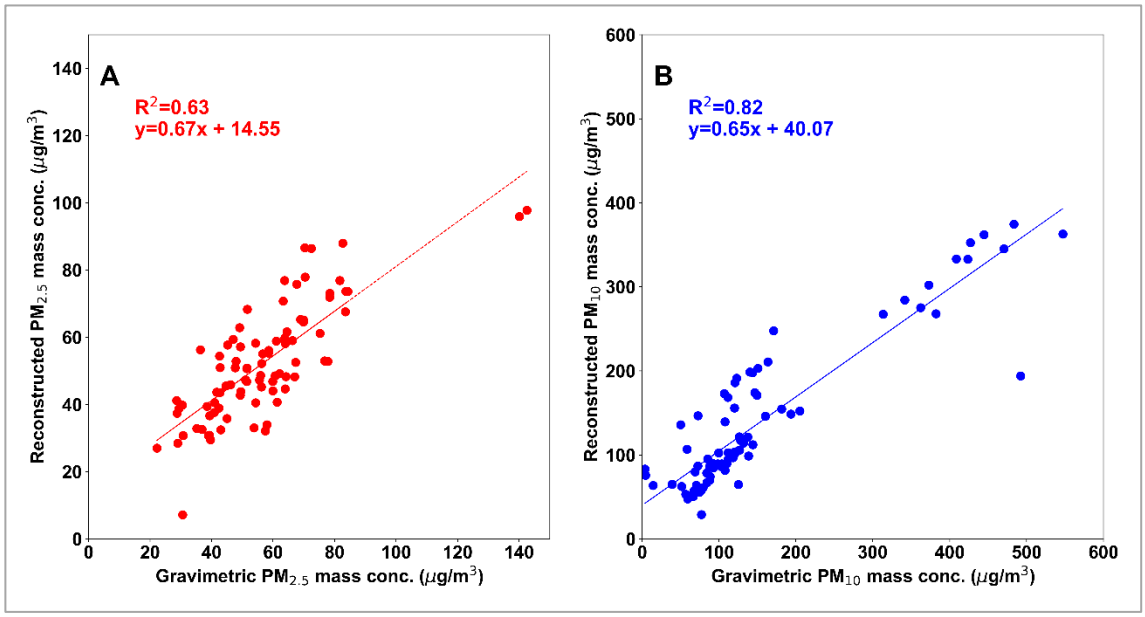

Figure 26 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) $PM_{2.5}$ *and (B)* PM_{10} *in Rourkela region during the winter season sampling period (Jan 2-21, 2022)*

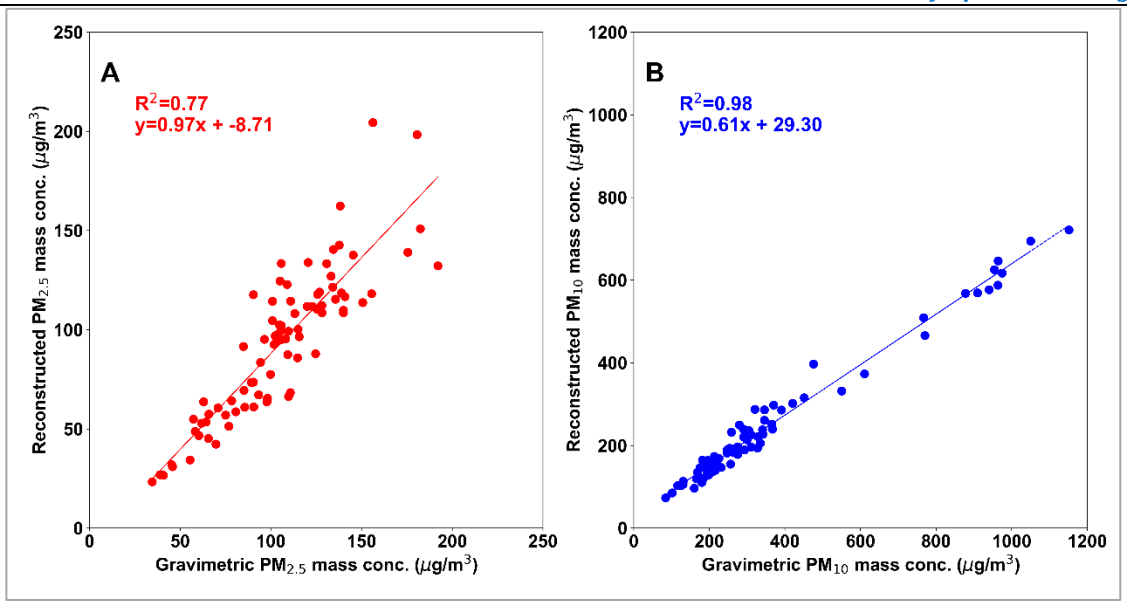

Figure 27 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) $PM_{2.5}$ *and (B)* PM_{10} *in Rourkela region during the summer season sampling period (Mar 17 - Apr 5, 2022)*

2.7.2. Winter Season: Reconstructed chemical mass

Fig. 28 to 32 and 33 to 37 presents the reconstructed chemical compositions of $PM_{2.5}$ and PM_{10} during the winter season at five sampling locations in Rourkela region, respectively. Overall, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM> SNA > CM > EC > TE > SS in PM_{10}.

The Organic mass (OM) was the most abundant component in $PM_{2.5}$ during the winter season, with seasonal mean contribution of 34.9 to 46.3% in $PM_{2.5}$ and 20.7 to 40.0% in PM_{10}. The seasonal mean OM concentrations among the five sites in the winter season ranged from 20.2 to 24.5 µg/m3 in $PM_{2.5}$ while it ranged from 28.1 to 115.8 µg/m3 in PM_{10}.

Secondary inorganic aerosols, represented as SNA, are the second major component observed in $PM_{2.5}$ and PM_{10} fractions during the winter season in Rourkela region. The seasonal mean contributions from SNA varied from 17.1 to 40.9% in $PM_{2.5}$ while it varied from 8.5 to 63.7% in PM_{10}. The seasonal mean SNA concentrations among the five sites ranged from 10.1 to 22.2 µg/m^3 in $PM_{2.5}$ whereas it ranged from 22.7 to 92.3 µg/m^3 in PM_{10}. The relative contributions indicate significant share of SNA in $PM_{2.5}$ during the winter season and can be mainly attributed to gas to particle conversion between SO_2 and sulfate particles.

Crustal Mass (CM) is the most important contributor to coarse fraction i.e. PM_{10} during winter season, besides OM and SNA. The seasonal mean contributions from CM varied from 3.5 to 9.4% in $PM_{2.5}$ while it varied from 12.2 to 28.1% in PM_{10}. The seasonal mean CM concentrations in PM_{10} varied from a minimum of 9.3 to 98.0 µg/m^3 in PM_{10}. In contrast, the CM concentrations in fine fraction i.e. $PM_{2.5}$ were relatively lower and ranged from 1.8 to 5.6 µg/m^3.

The seasonal mean contributions from EC ranged between 12.2 and 16.0% in $PM_{2.5}$ while it ranged between 4.8 and 13.2% in PM_{10}. The seasonal mean elemental carbon (EC) concentrations during winter season varied from 6.4 to 8.7 µg/m^3 in $PM_{2.5}$ whereas it ranged from 9.0 to 16.8 µg/m^3 in PM_{10}.

Trace elements (TE) also form an important part of the reconstructed mass in coarse fraction i.e. PM_{10} during the winter season, with contributions ranging from 1.7 to 2.4%. The seasonal

mean TE concentrations ranged from 0.6 to 1.6 µg/m^3 and 1.3 to 8.3 µg/m^3 in $PM_{2.5}$ and PM_{10}, respectively.

The Sea salt (SS) represented by a sum of Na+ and Cl- ions, are the minor contributors to $PM_{2.5}$ and PM_{10} masses during the winter season over Rourkela, with contributions ranging from 0.7 to 2.5%. The seasonal mean SS ranged from 0.4 to 1.4 µg/m^3 in $PM_{2.5}$ while it ranged from 0.7 to 2.5 µg/m^3 in PM_{10}.

The residual mass i.e. difference between the gravimetric and reconstructed mass, is defined as unidentified mass.

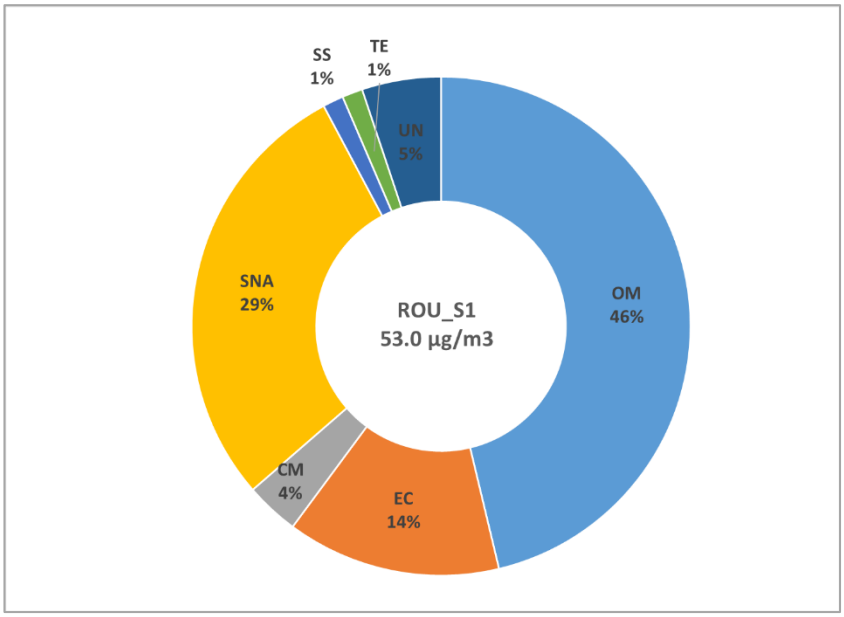

Figure 28: The reconstructed mass of $PM_{2.5}$ ***at S1 i.e. Hamirpur Highschool in Rourkela region during the winter season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

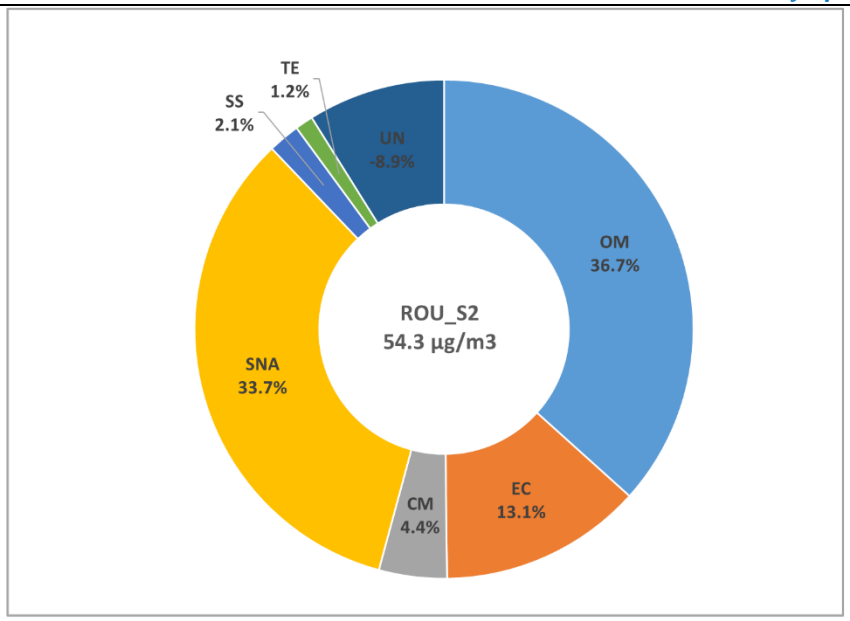

Figure 29: The reconstructed mass of $PM_{2.5}$ ***at S2 i.e. IDCO Office in Rourkela region during the winter season***

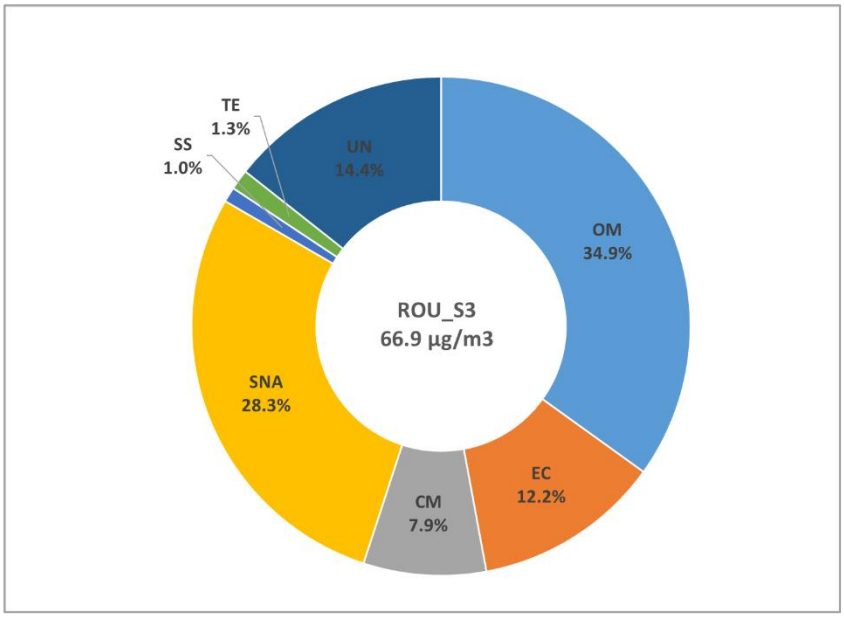

Figure 30: The reconstructed mass of $PM_{2.5}$ ***at S3 i.e. College of Arts, Science & Technology, Bondamunda in Rourkela region during the winter season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

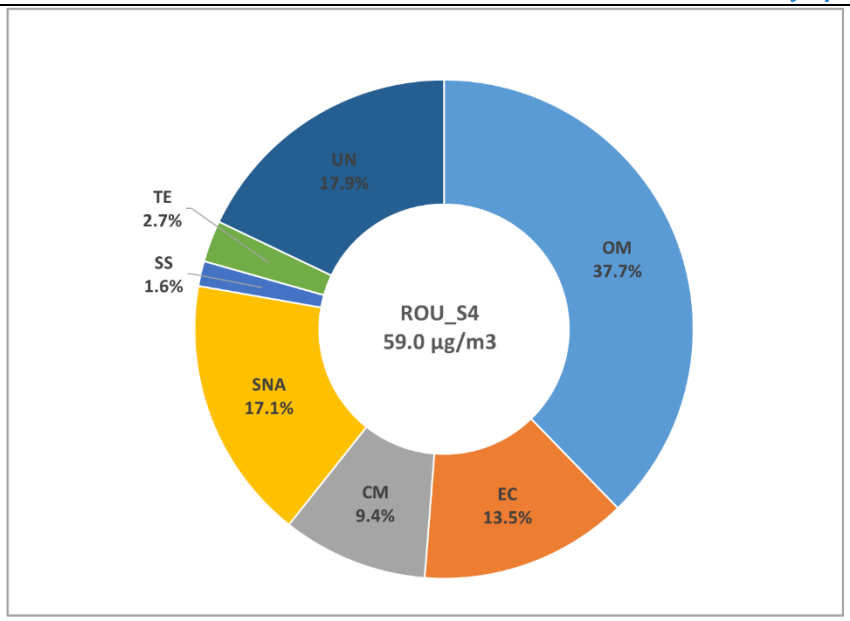

Figure 31: The reconstructed mass of $PM_{2.5}$ *at S4 i.e. Jay Matadi Plastics Ltd, Kalunga in Rourkela region during the winter season*

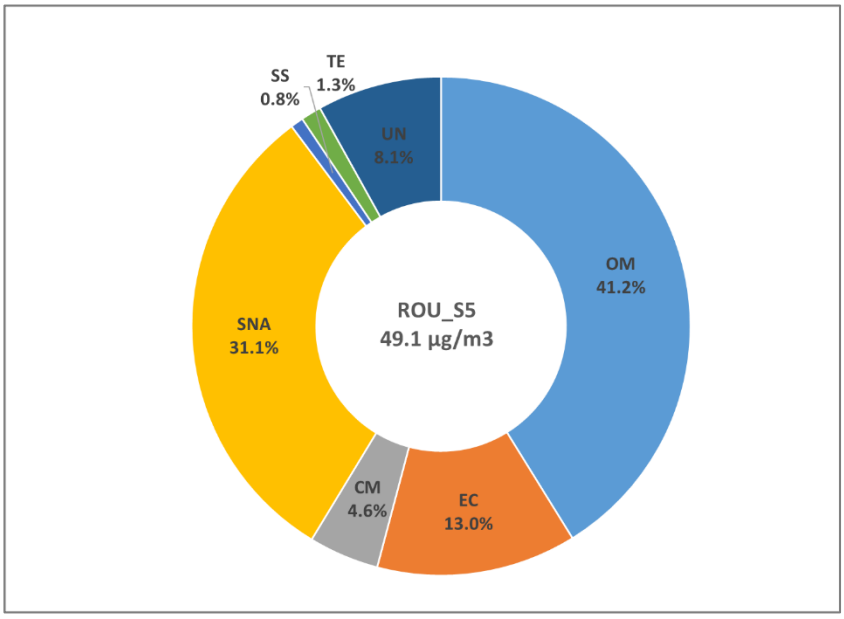

Figure 32: The reconstructed mass of $PM_{2.5}$ *at S5 i.e. IDL Outpost, Sonaparabat in Rourkela region during the winter season*

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

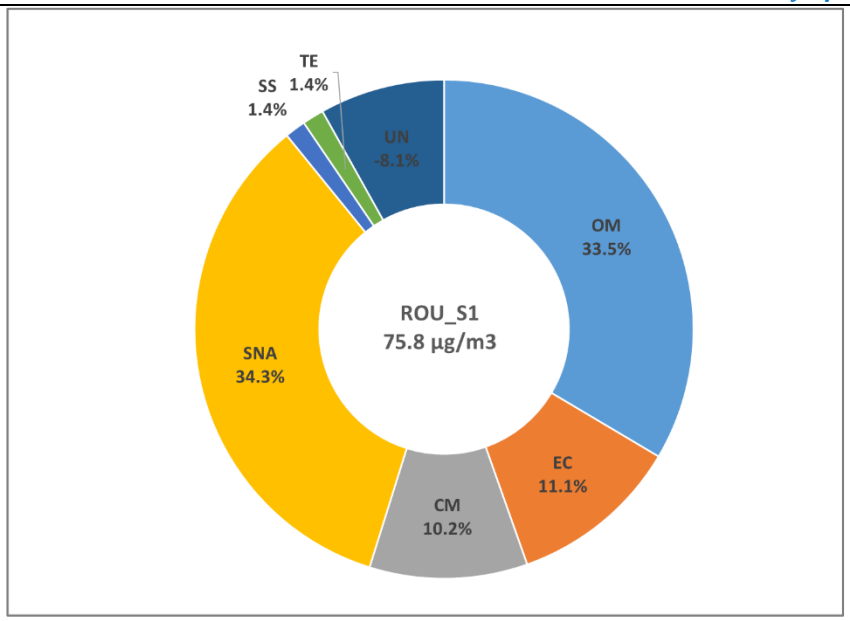

Figure 33: The reconstructed mass of PM_{10} ***at S1 i.e. Hamirpur Highschool in Rourkela region during the winter season.***

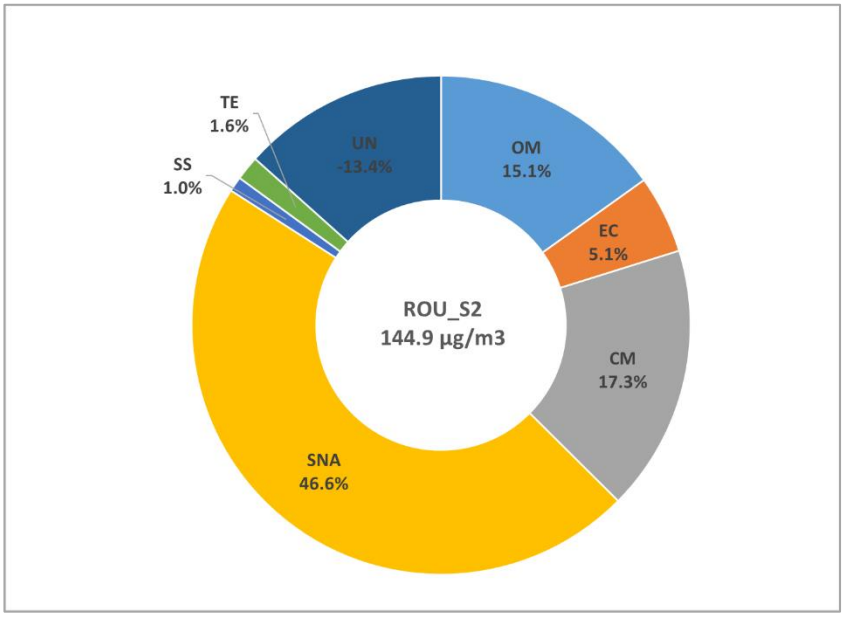

Figure 34: The reconstructed mass of PM_{10} ***at S2 i.e. IDCO Office in Rourkela region during the winter season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

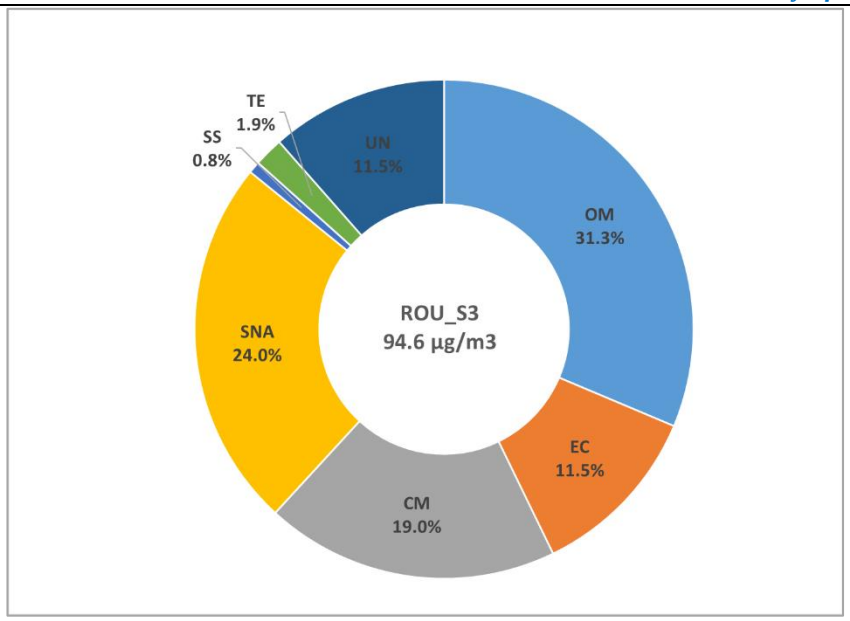

Figure 35: The reconstructed mass of PM_{10} ***at S3 i.e. College of Arts, Science & Technology, Bondamunda in Rourkela region during the winter season***

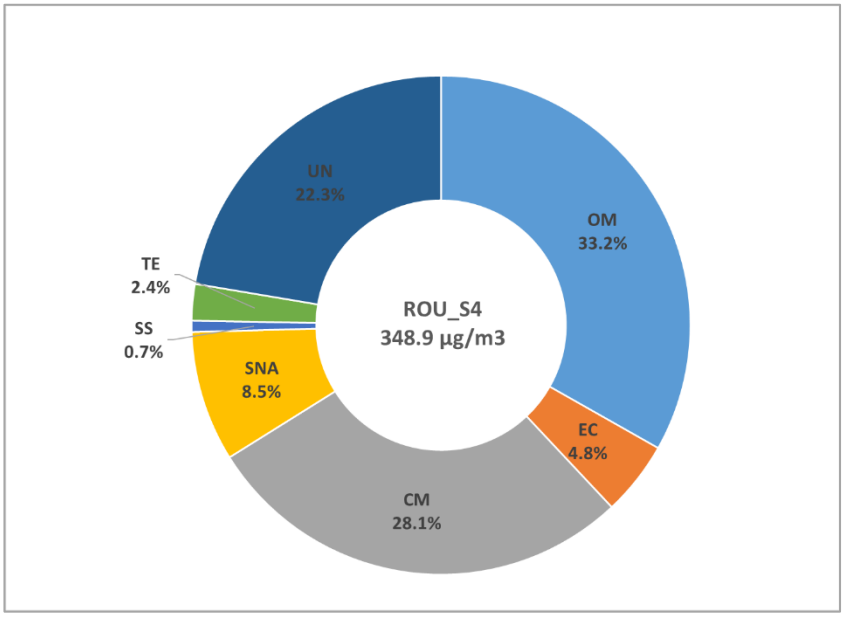

Figure 36: The reconstructed mass of PM_{10} ***at S4 i.e. Jay Matadi Plastics Ltd, Kalunga in Rourkela region during the winter season.***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

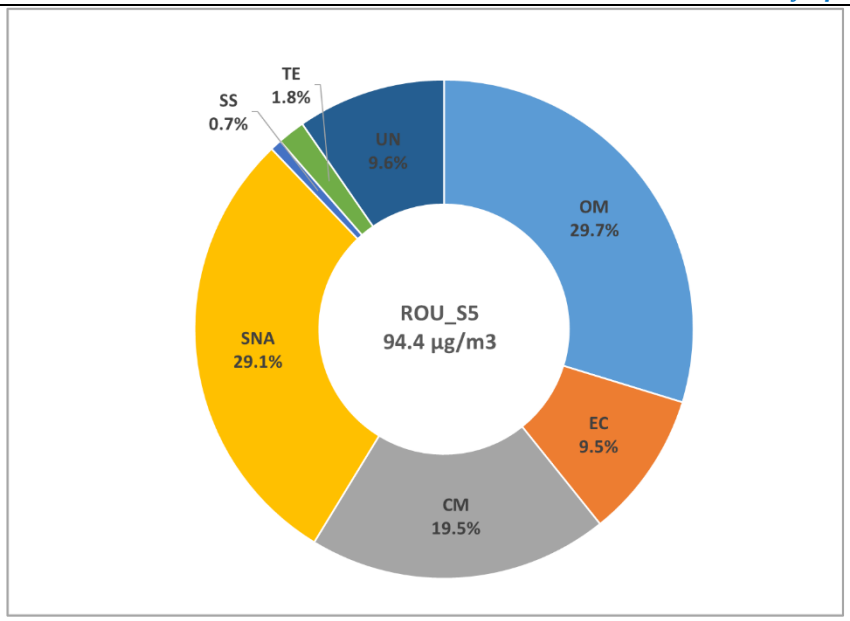

Figure 37: The reconstructed mass of PM_{10} ***at S5 i.e. IDL Outpost, Sonaparabat in Rourkela region during the winter season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

2.7.3. Summer Season: Reconstructed chemical mass

Fig. 38 to 42 and 43 to 47 presents the reconstructed chemical compositions of $PM_{2.5}$ and PM_{10} during the summer season at five sampling locations in Rourkela region, respectively. Overall, the fractions of major chemical compositions followed the order of OM > EC > SNA > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM > CM > EC > SNA > TE > SS in PM_{10}.

The Organic mass (OM) was the most abundant component in both $PM_{2.5}$ and PM_{10} during the summer season, with seasonal mean contribution of 43.2 to 57.6% in $PM_{2.5}$ and 10.6 to 33.4%. The seasonal mean OM concentrations in the summer season ranged from 41.2 to 63.5 μg/m^3 in $PM_{2.5}$ while it ranged from 71.5 to 86.1 μg/m^3 in PM_{10}.

Crustal Mass (CM) is the most important contributor to coarse fraction i.e. PM_{10} during summer season. The seasonal mean contributions from CM varied from 2.8 to 8.4% in $PM_{2.5}$ while it varied from 17.4 to 28.1% in PM_{10}. The seasonal mean CM concentrations in PM_{10} varied from a minimum of 37.8 to 229.4 μg/m^3 in PM_{10}. In contrast, the CM concentrations in fine fraction i.e. $PM_{2.5}$ were relatively lower and ranged from 3.1 to 10.1 μg/m^3.

Secondary inorganic aerosols, represented as SNA, is the third and fourth major component observed in $PM_{2.5}$ and PM_{10} fractions during the summer season in Rourkela region, respectively. The seasonal mean contributions from SNA varied from 10.9 to 15.6% in $PM_{2.5}$ while it varied from 3.5 to 9.8% in PM_{10}. The seasonal mean SNA concentrations ranged from 11.9 to 15.6 μg/m^3 in $PM_{2.5}$ whereas it ranged from 18.7 to 28.3 μg/m^3 in PM_{10}. The relative contributions indicate significant share of SNA in $PM_{2.5}$ during the summer season.

The seasonal mean contributions from EC ranged between 10.4 and 19.4% in $PM_{2.5}$ while it ranged between 9.8 and 19.6% in PM_{10}. The daily averaged elemental carbon (EC) concentrations during summer season varied from 10.0 to 22.4 μg/m^3 in $PM_{2.5}$ whereas it ranged from 25.8 to 160.1 μg/m^3 in PM_{10}.

Trace elements (TE) form an important part of the reconstructed mass in coarse fraction i.e. PM_{10} during the summer season, with contributions ranging from 2.1 to 2.4%. The seasonal mean TE concentrations ranged from 1.6 to 3.6 μg/m^3 and 4.7 to 18.1 μg/m^3 in $PM_{2.5}$ and PM_{10}, respectively.

The Sea salt (SS) represented by a sum of Na+ and Cl- ions, are the minor contributors to $PM_{2.5}$ and PM_{10} masses during the summer season over Rourkela region, with contributions ranging from 0.4 to 0.7%. The seasonal mean SS ranged from 0.5 to 0.9 µg/m^3 in $PM_{2.5}$ while it ranged from 1.3 to 3.2 µg/m^3 in PM_{10}.

The residual mass i.e. difference between the gravimetric and reconstructed mass, is defined as unidentified mass.

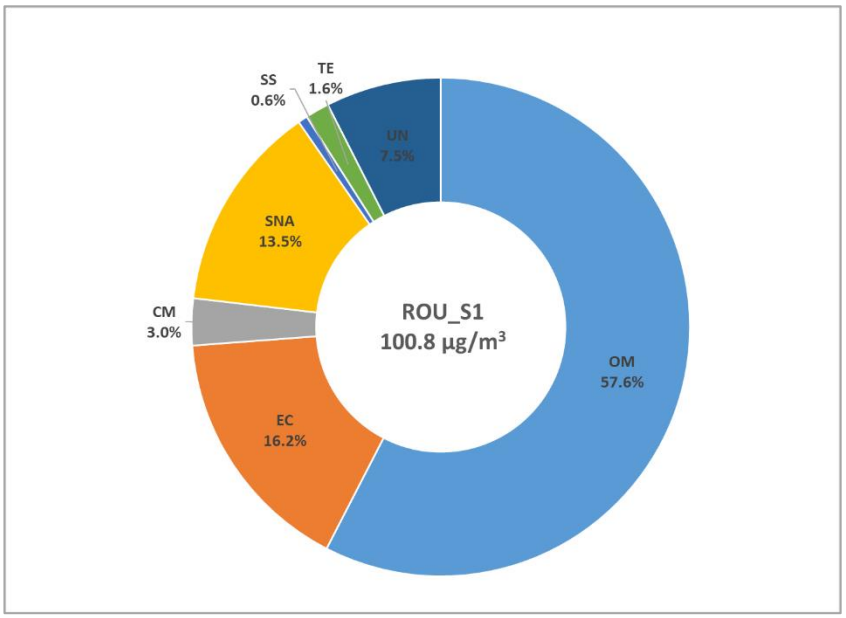

Figure 38: The reconstructed mass of $PM_{2.5}$ ***at S1 i.e. Hamirpur Highschool in Rourkela region during the summer season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

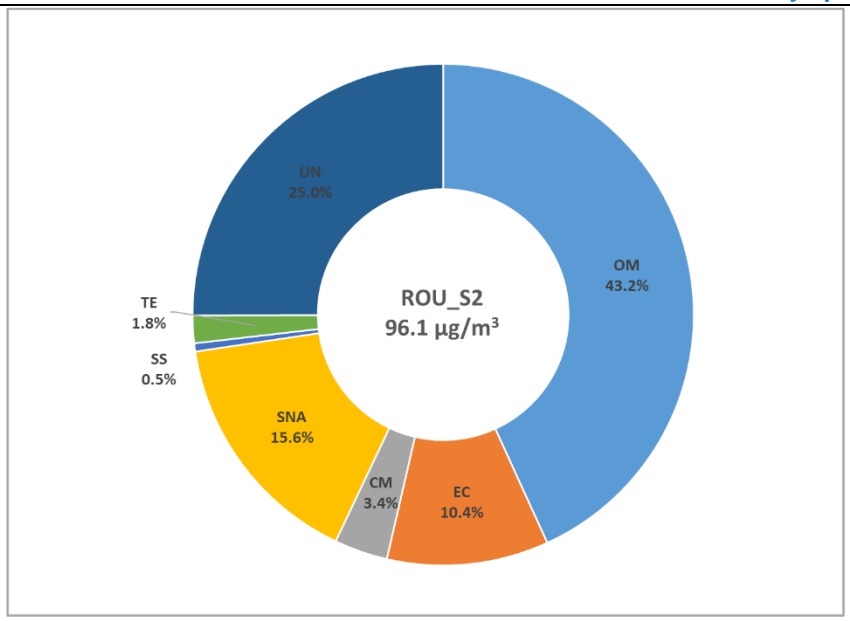

Figure 39: The reconstructed mass of $PM_{2.5}$ ***at S2 i.e. IDCO Office in Rourkela region during the summer season***

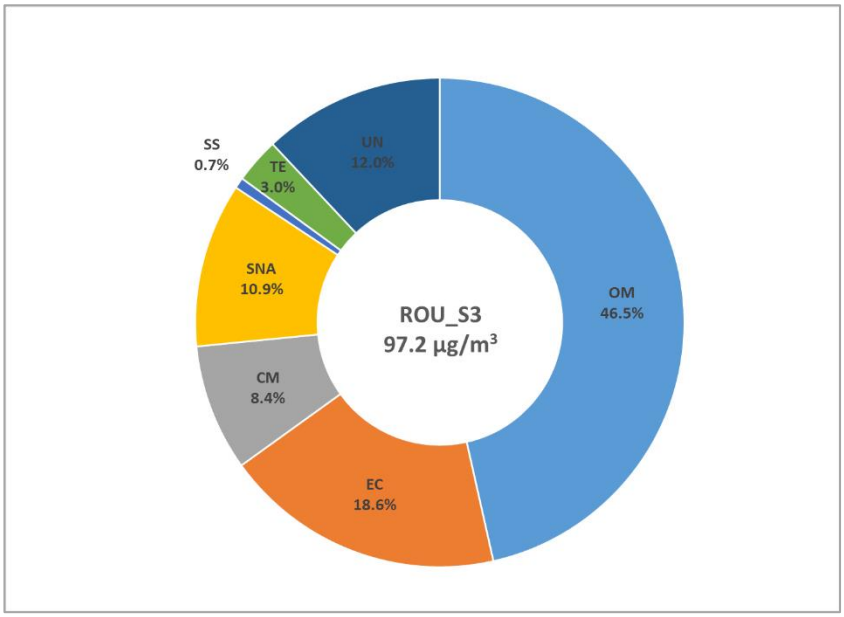

Figure 40: The reconstructed mass of $PM_{2.5}$ ***at S3 i.e. College of Arts, Science & Technology, Bondamunda in Rourkela region during the summer season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

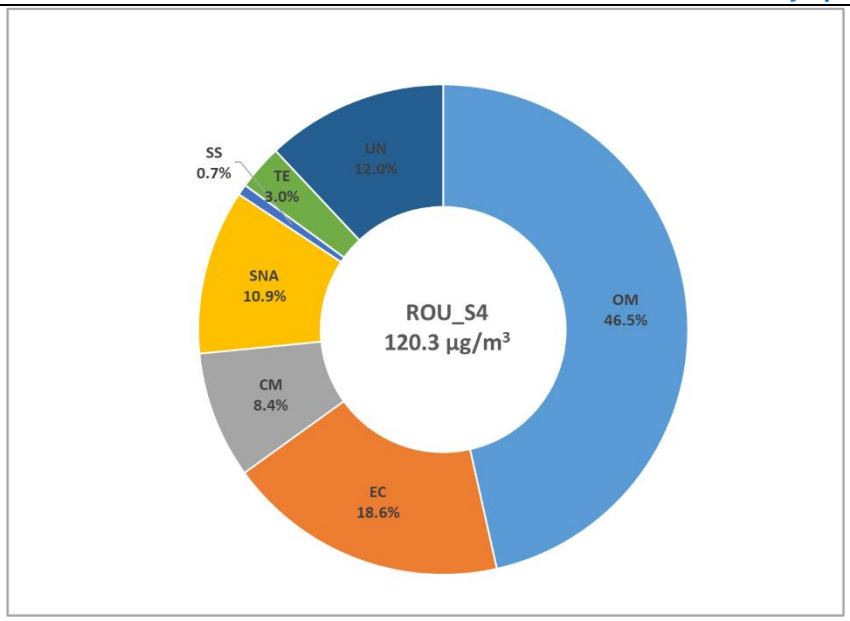

Figure 41: The reconstructed mass of $PM_{2.5}$ *at S4 i.e. Jay Matadi Plastics Ltd, Kalunga in Rourkela region during the summer season*

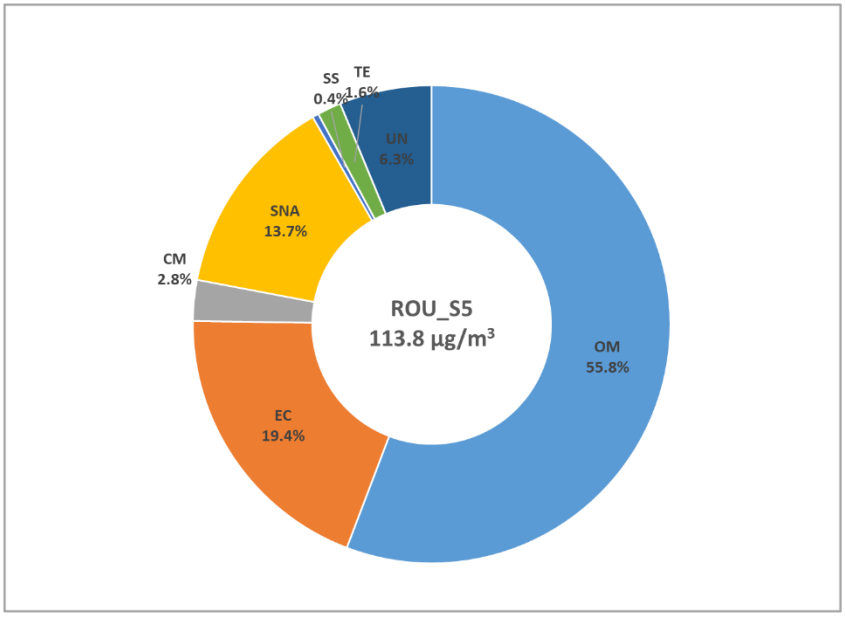

Figure 42: The reconstructed mass of $PM_{2.5}$ *at S5 i.e. IDL Outpost, Sonaparabat in Rourkela region during the summer season*

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

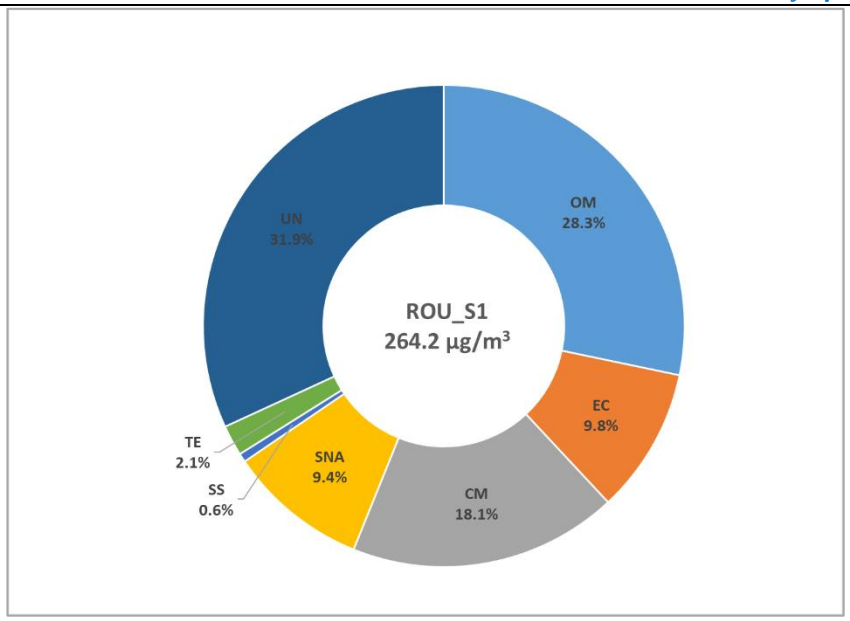

Figure 43: The reconstructed mass of PM_{10} ***at S1 i.e. Hamirpur Highschool in Rourkela region during the summer season.***

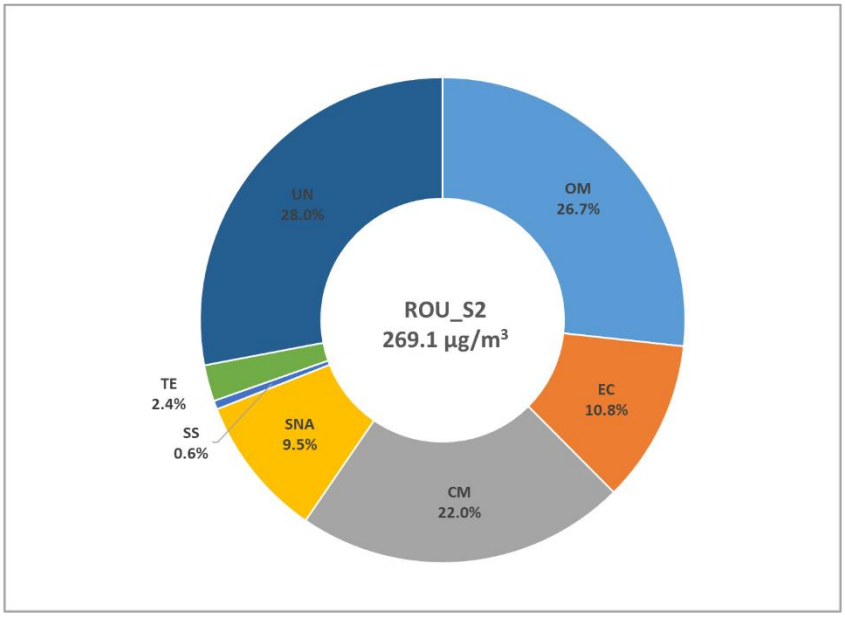

Figure 44: The reconstructed mass of PM_{10} ***at S2 i.e. IDCO Office in Rourkela region during the summer season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

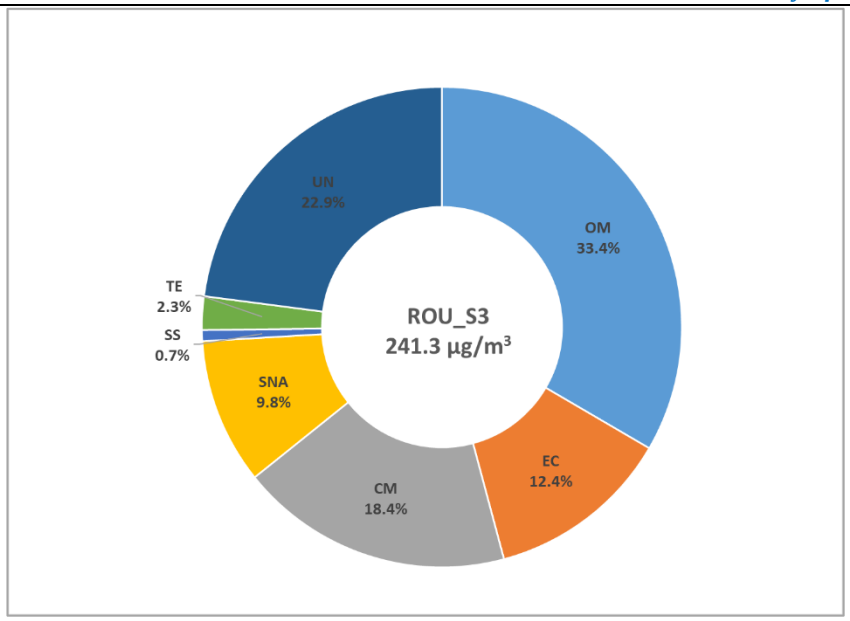

Figure 45: The reconstructed mass of PM_{10} ***at S3 i.e. College of Arts, Science & Technology, Bondamunda in Rourkela region during the summer season***

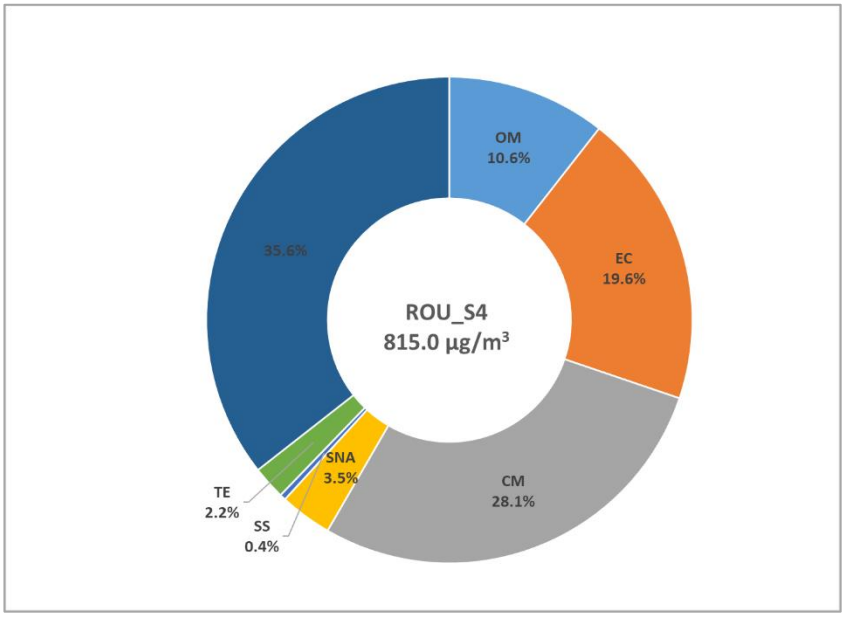

Figure 46: The reconstructed mass of PM_{10} ***at S4 i.e. Jay Matadi Plastics Ltd, Kalunga in Rourkela region during the summer season.***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

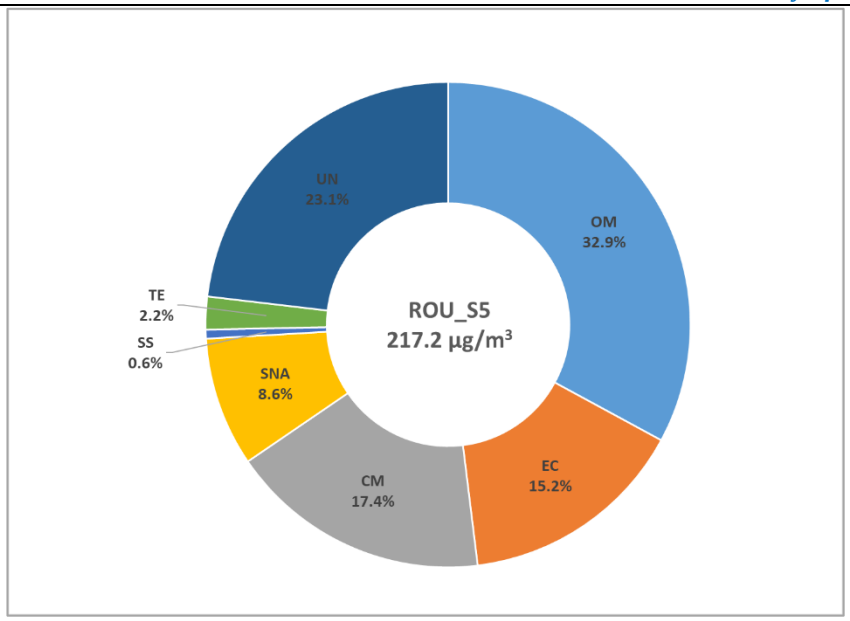

Figure 47: The reconstructed mass of PM_{10} ***at S5 i.e. IDL Outpost, Sonaparabat in Rourkela region during the summer season***

Legend represents – OM: Organic Matter, EC: Elemental Carbon, CM: Crustal Material, SNA: Sulfate, Nitrate, Ammonium ions, SS: Sea salts, TE: Trace Elements and UN: Unidentified.

2.8. Chemical Ratios Analysis in $PM_{2.5}$ and PM_{10}

The chemical ratios of OC/EC, Cl^-/Na^+, K^+/OC, K^+/EC, NO_3^-/SO_4^{--} and degree of neutralization (DON) have been used as indicators to qualitatively assess the contributions from air polluting sources in the region and these ratios were calculated for our study sites. Fig. 48 and 49 shows the chemical ratios i.e. i) OC to EC ratio, ii) Cl^- to Na^+ ratio, iii) K^+ to OC ratio, iv) K^+ to EC, v) NO_3^- to SO_4^{--} ratio, and vi) degree of neutralization (DON) in $PM_{2.5}$ and PM_{10} observed at five sampling locations in Rourkela region during the winter and summer seasons, respectively. Table 2 provides summary of average chemical ratios.

The OC/EC ratio indicate the origins of carbonaceous fraction (Salameh et al. 2014) and is commonly used to assess the impacts of fossil fuel emissions and aging, and the formation of secondary organic aerosols (Niu et al. 2016). The average OC/EC ratio in the present study is less than 2, indicates that carbonaceous fraction is originated from primary sources during the both winter and summer seasons. A good correlation ($R > 0.8$) is observed between OC and EC in both $PM_{2.5}$ and PM_{10} at sampling sites implies their primary source signature (Srinivas and Sarin, 2014). A relatively lower OC/EC ratio at S4 i.e. Jay Matadi Plastics Ltd., Kalunga, suggests dominance of fossil fuel burning in nearby industries (Ram and Sarin, 2011).

Soluble potassium (K^+) concentrations were used to determine the possibility of contribution from biomass burning. Fossil fuel combustion seems to produce very little potassium and exhibit K^+/OC and K^+/EC ratios close to zero while other combustion sources such as biomass combustion and Savannah burning are characterized by K^+/OC ratios ranging from 0.08 to 0.10 (Echalar et al. 1998) and from 0.04 to 0.13 (Andreae and Merlet 2001), respectively. Similarly, K^+/EC ratios for biomass burning are reported to vary from 0.20 to 0.69 (Andreae 1983; Ram and Sarin 2010). The winter season K^+/OC ratios ranged from 0.03 to 0.05 in $PM_{2.5}$ and PM_{10}. Similarly, K^+/EC ratios ranged from 0.02 to 0.09 in $PM_{2.5}$ and PM_{10}. The summer season K^+/OC ratios ranged from 0.04 to 0.06 $PM_{2.5}$ and PM_{10}. Similarly, K^+/EC ratios ranged from 0.02 to 0.19 in $PM_{2.5}$ and PM_{10}. These ratios suggest possibility of biomass burning in the region.

The NO_3^-/SO_4^{--} ratio has been used by researchers to assess the relative contributions from stationary versus mobile sources of PM (Arimoto et al. 1996). The winter-time NO_3^-/SO_4^{--} ratios varied from 0.13 to 0.32 in $PM_{2.5}$ whereas it varied from 0.22 to 0.35 PM_{10}. Similarly, summer-time NO_3^-/SO_4^{--} ratios varied from 0.12 to 0.16 in $PM_{2.5}$ whereas it varied from 0.35 to 0.44 in PM_{10}. Ratios less than unity indicates the dominance of stationary sources over mobile sources in Rourkela region.

The average Cl^-/Na^+ ratio of seawater is 1.8 and in general a ratio greater than 10, indicates anthropogenic origin of Cl^- ions. In the present study, the winter season mean Cl^-/Na^+ ratio ranged from 0.44 to 2.87 in $PM_{2.5}$ whereas it ranged from 1.06 to 3.0 in PM_{10}. The summer season mean Cl^-/Na^+ ratio ranged from 0.58 to 1.28 in $PM_{2.5}$ whereas it ranged from 0.76 to 1.90 in PM_{10}. The ratios less than 10 at all sites, indicate the natural origin of Cl^- ions such as marine aerosols.

Additionally, to understand the neutralization reactions in detail, Degree of Neutralization (DON) suggested by Adams et al. (1999) is calculated (refer Eq. 4) for daily $PM_{2.5}$ and PM_{10} samples. In Eq. 5, $[NH_4^+]$, $[SO_4^{--}]$ and $[NO_3^-]$ represents the molar concentrations of ammonium, sulfate and nitrate ions, respectively observed over 24-h sampling. A DON < 1 indicates an ammonium deficiency; DON = 1 indicates complete neutralization whereas DON > 1 indicates the presence of surplus ammonium in the atmosphere. It is important to note that, DON is a daily averaged value calculated from integrated 24-h filter-based samples, there are likely to be diurnal variations in the actual acidity of sulfate and nitrate particles.

$$\mathbf{DON} = \frac{[\mathbf{NH_4^+}]}{\mathbf{2[SO_4^{--}] + [NO_3^-]}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{Eq.}\ (\mathbf{5})$$

In winter season, the average DON values ranged from 0.28 to 0.49 in $PM_{2.5}$ and 0.24 to 0.67 in PM_{10} at five sampling locations in Rourkela region. It shows the ammonium deficiency at all sites during the winter season, which in turn implies the acidic nature of sulfate and nitrate particles. This could be explained by the persistent weak solar radiations, cold temperatures, and an obvious decoupling of high organic aerosol concentrations with acid particles, which in turn implies that the observed winter-time organics may be primary in nature. In addition to the primary organic particle emissions, there is possibility of condensation of semi-volatile organic gases onto aerosols under the cold temperatures (Chu et al., 2004).

In summer season, the average DON values ranged from 0.9 to 1.18 in $PM_{2.5}$ and 0.32 to 2.1 in PM_{10} at five sampling locations in Rourkela region. It shows the presence of excess ammonium during the summer season, which in turn implies the basic nature of sulfate and nitrate particles.

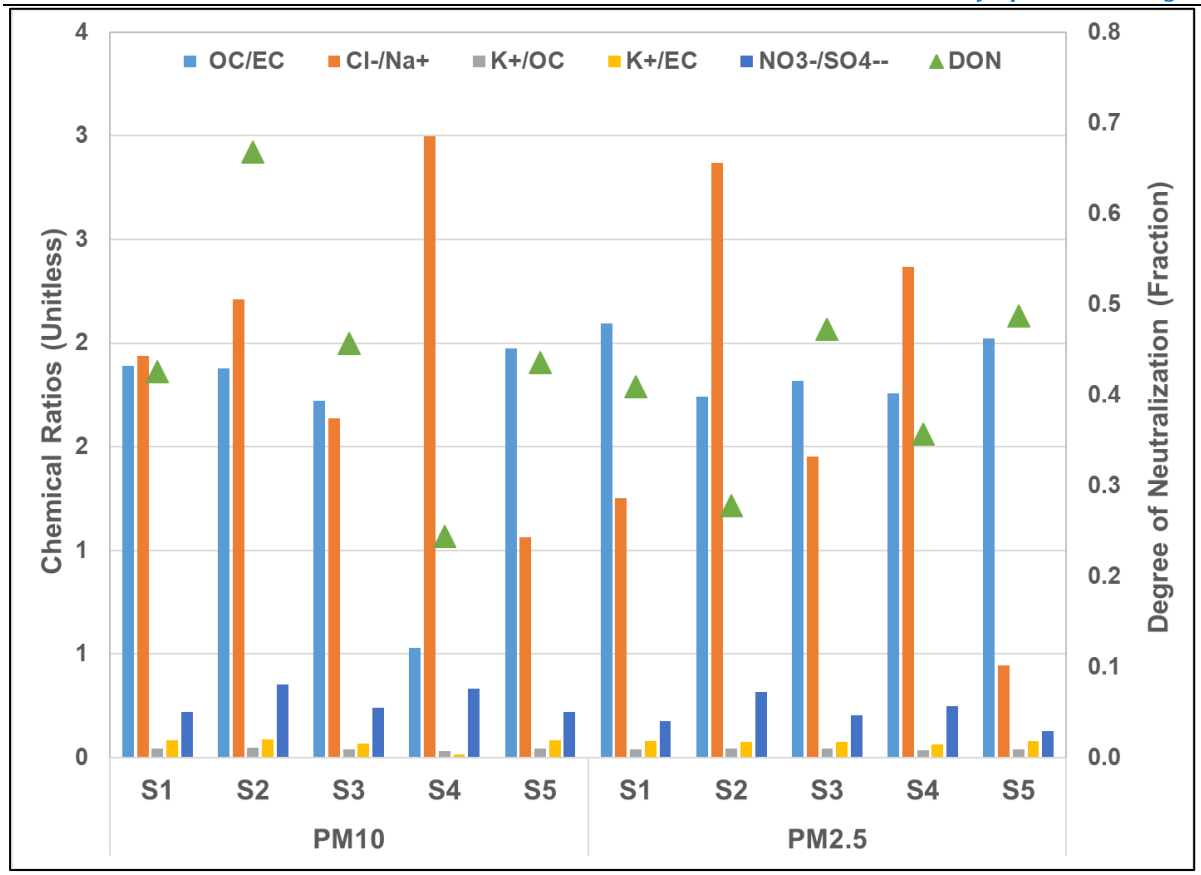

Figure 48: Chemical ratios i.e. OC to EC ratio, Cl^- to Na^+ ratio, K^+ to OC ratio, K^+ to EC, NO_3^- to SO_4^{--} ratio, and degree of neutralization (DON) observed at five sampling locations during the winter season in Rourkela region.

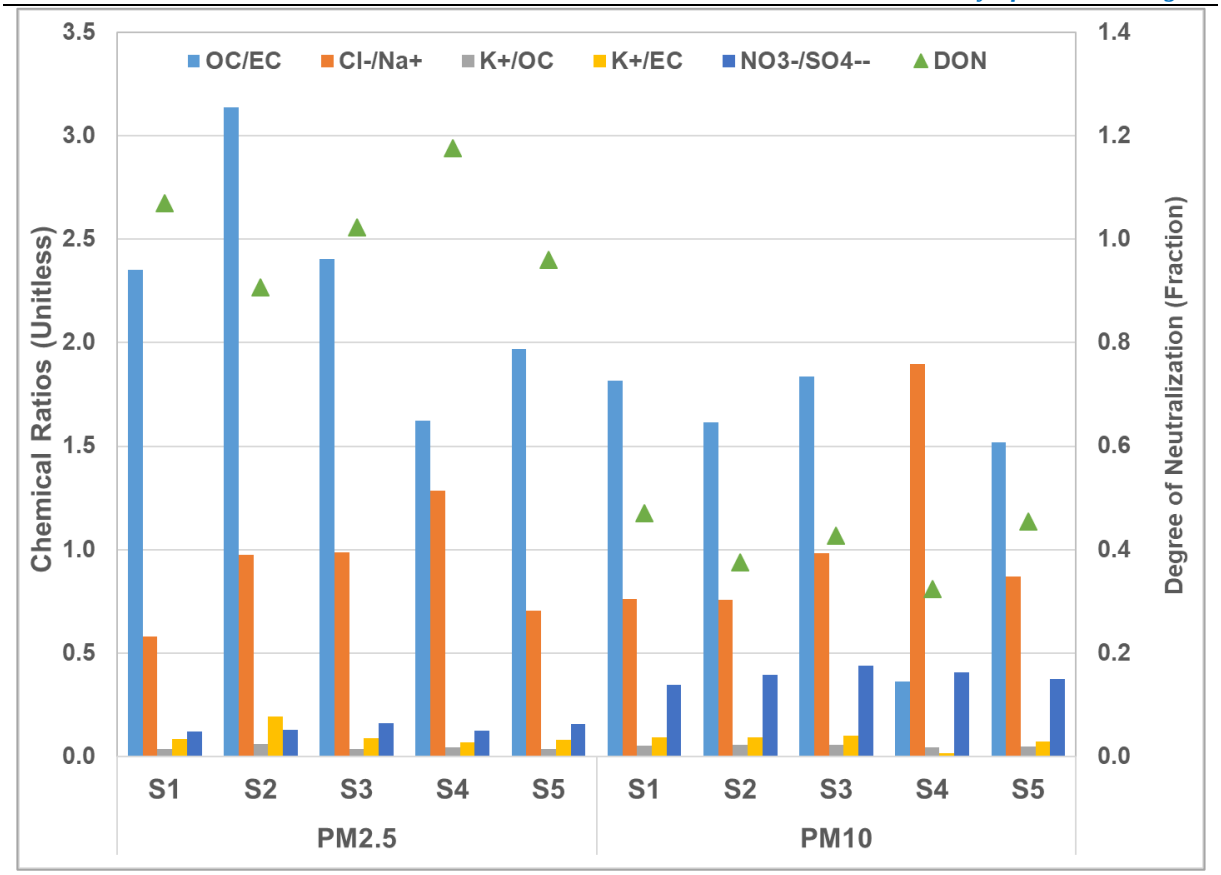

Figure 49: Chemical ratios i.e. OC to EC ratio, Cl^- to Na^+ ratio, K^+ to OC ratio, K^+ to EC, NO_3^- to SO_4^{--} ratio, and degree of neutralization (DON) observed at five sampling locations during the summer season in Rourkela region.

Table 6 Summary of different chemical ratios observed at five sampling locations during the winter and summer seasons in Rourkela region

Fraction	Site	OC/EC	Cl^-/Na^+	K^+/OC	K^+/EC	NO_3^-/SO_4^{--}	DON
Winter $PM_{2.5}$	S1	2.09	1.25	0.04	0.08	0.18	0.41
	S2	1.74	2.87	0.04	0.08	0.32	0.28
	S3	1.82	1.45	0.04	0.08	0.21	0.47
	S4	1.76	2.37	0.04	0.06	0.25	0.36
	S5	2.02	0.44	0.04	0.08	0.13	0.49
Winter PM_{10}	S1	1.89	1.94	0.04	0.08	0.22	0.43
	S2	1.88	2.21	0.05	0.09	0.35	0.67
	S3	1.72	1.64	0.04	0.07	0.24	0.46
	S4	0.53	3	0.03	0.02	0.33	0.24
	S5	1.97	1.06	0.04	0.09	0.22	0.44
Summer $PM_{2.5}$	S1	2.4	0.58	0.04	0.09	0.12	1.07
	S2	3.1	0.98	0.06	0.19	0.13	0.91
	S3	2.4	0.99	0.04	0.09	0.16	1.02
	S4	1.6	1.28	0.04	0.07	0.12	1.18
	S5	2.0	0.71	0.04	0.08	0.16	0.96
Summer PM_{10}	S1	1.8	0.76	0.05	0.09	0.35	0.47
	S2	1.6	0.76	0.06	0.09	0.40	0.38
	S3	1.8	0.98	0.06	0.10	0.44	0.43
	S4	0.4	1.90	0.04	0.02	0.41	0.32
	S5	1.5	0.87	0.05	0.07	0.38	0.46

2.9. Source apportionment of $PM_{2.5}$ and PM_{10}

Source contributions to fine and coarse particulate matter i.e. $PM_{2.5}$ and PM_{10} were calculated with the CMB model for the individual daily samples for five sampling sites in Rourkela region. Five pollution sources were apportioned using the average concentration data including i) transport (TRAN), ii) road and construction dust (DUST), iii) biomass burning (BCOM), iv) industry and thermal powerplants and fugitive dust (INDU) and v) secondary aerosols (SECY). The residual/un-apportioned mass is considered to be originating from the unidentified sources (UNID).

2.9.1. WINTER SEASON

2.9.1.1. Site 1: Hamirpur Highschool

Fig. 50 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S1 i.e. Hamirpur Highschool during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 53.0 µg/m^3 and 75.8 µg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 37.3%. The other sources of $PM_{2.5}$ at this site were identified as secondary aerosols (20.6%), biomass and solid waste combustion (14.4%), transport (9.8%), and industry (4.4%). The winter-time PM_{10} concentrations at this site were also dominated by dust (52.4%), followed by, secondary aerosols (14.5%), biomass and solid waste combustion (11.0%), transport (8.8%), and industry (8.0%). About 13.5% and 5.3% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

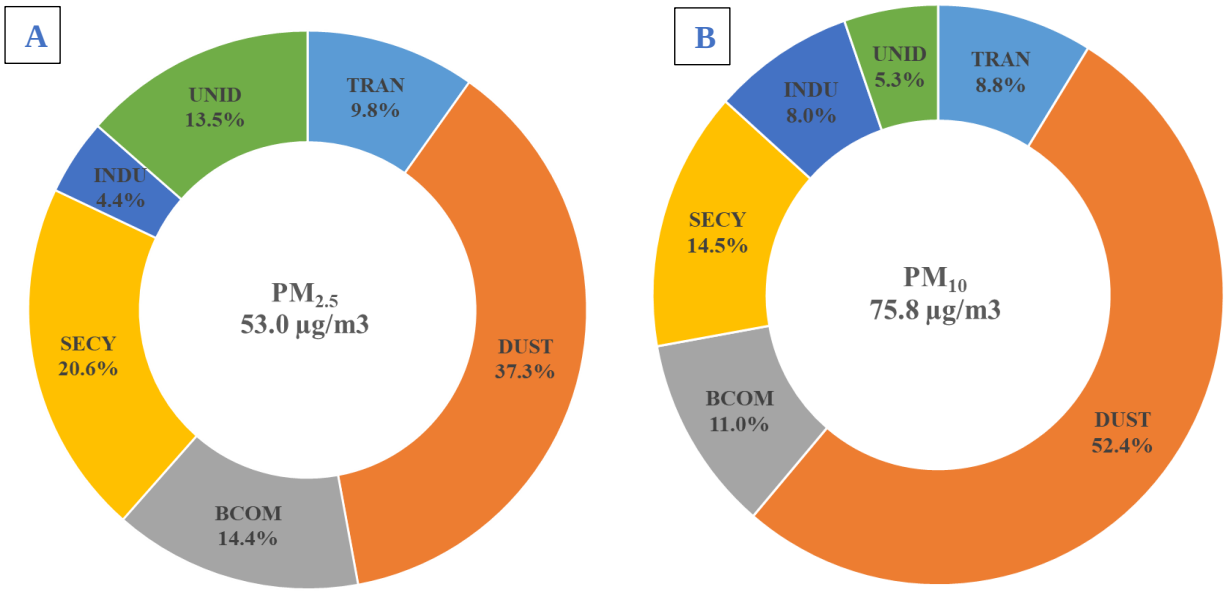

Figure 50 Sectoral source contributions to $PM_{2.5}$ ***(A) and*** PM_{10} ***(B) at S1 i.e. Hamirpur Highschool during the winter season in Rourkela region***

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.1.2. Site 2: IDCO Office

Fig. 51 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S2 i.e. IDCO Office during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 54.3 µg/m^3 and 144.9 µg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 35.1%. The other sources of $PM_{2.5}$ at this site were identified as transport (22.5%), biomass and solid waste combustion (15.8%), secondary aerosols (14.7%), and industry (4.1%). The winter-time PM_{10} concentrations at this site were also dominated by dust (51.8%), followed by secondary aerosols (16.0%), transport (8.5%), biomass and solid waste combustion (7.8%), and industry (8.2%). About 7.8% and 7.6% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

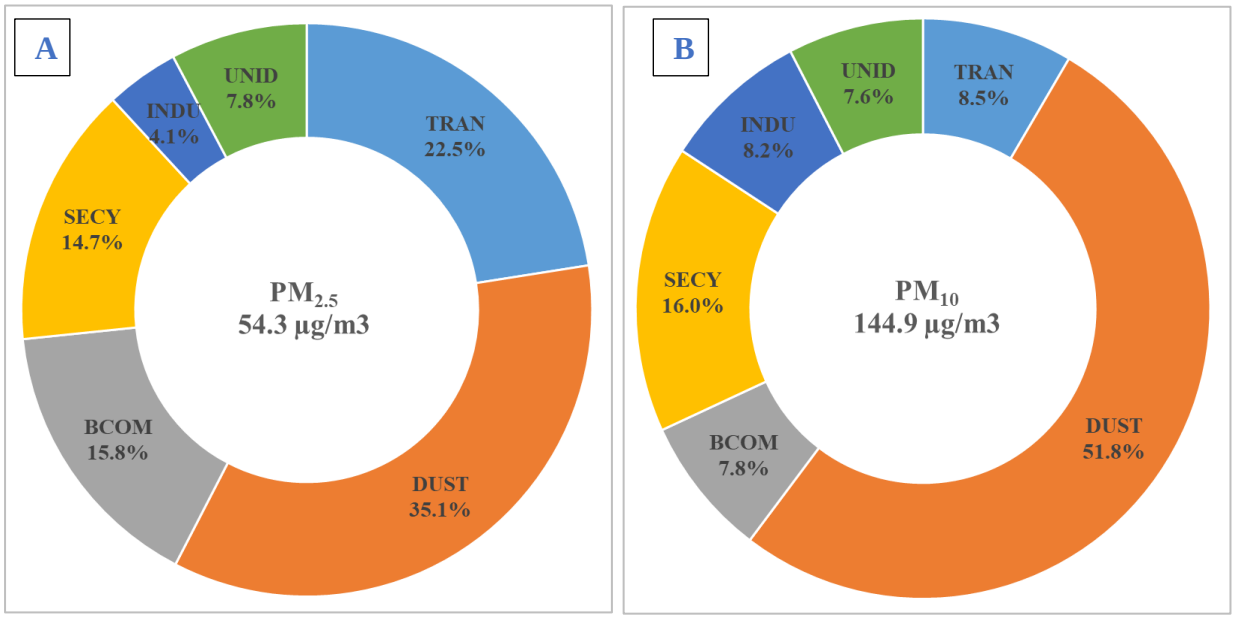

Figure 51 Sectoral source contributions to $PM_{2.5}$ ***(A) and*** PM_{10} ***(B) at S2 i.e. IDCO Office during winter season***

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.1.3. Site 3: College of Arts, Science & Technology, Bondamunda

Fig. 52 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S3 i.e. College of Arts, Science & Technology, Bondamunda during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 66.9 µg/m^3 and 94.6 µg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 38.9%. The other sources of $PM_{2.5}$ at this site were identified as secondary aerosols (19.3%), biomass and solid waste combustion (12.2%), transport (8.4%), and industry (4.6%). The winter-time PM_{10} concentrations at this site were also dominated by dust (48.5%), followed by secondary aerosols (15.1%), industry (12.5%), biomass and solid waste combustion (7.8%), and transport (6.7%). About 16.6% and 6.3% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

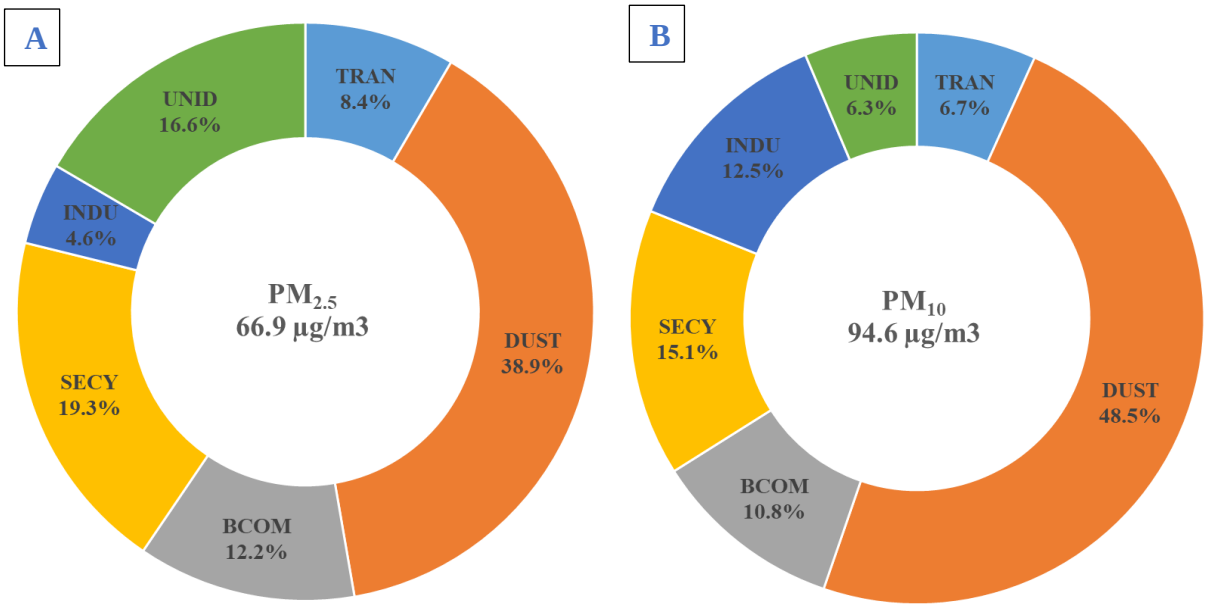

Figure 52 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S3 i.e. College of Arts, Science & Technology, Bondamunda during winter season*

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.1.4. Site 4: Jay Matadi Plastics Ltd., Kalunga

Fig. 53 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S4 i.e. Jay Matadi Plastics Ltd., Kalunga site during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 59.0 µg/m^3 and 348.9 µg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by industrial sources with highest contribution of 26.2%. The other sources of $PM_{2.5}$ at this site were identified as dust (25.9%), secondary aerosols (15.4%), transport (11.1%), and biomass and solid waste combustion (10.3%). The winter-time PM_{10} concentrations at this site were also dominated by industries (44.6%), followed by dust (21.9%), secondary aerosols (17.3%), biomass and solid waste combustion (3.0%), and transport (2.4%). About 11.0% and 10.8% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

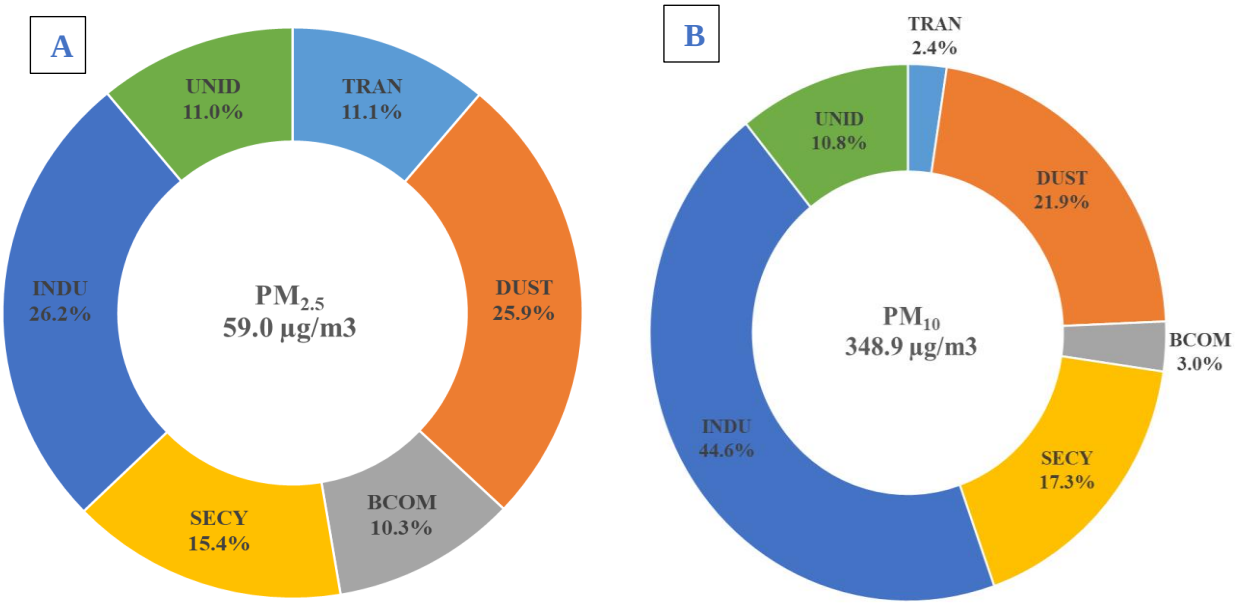

Figure 53 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S4 i.e. Jay Matadi Plastics Ltd., Kalunga during winter season*

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.1.5. Site 5: IDL Outpost, Sonaparabat

Fig. 54 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S5 i.e. IDL Outpost, Sonaparabat during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 49.1µg/m^3 and 94.4 µg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 31.3%. The other sources of $PM_{2.5}$ at this site were identified as solid waste and biomass combustion (19.6%), secondary aerosols (16.0%), industry (12.7%) and transport (10.0%). The winter time PM_{10} concentrations at this site were also dominated by dust (37.1%), followed by industry (29.2%), secondary aerosols (13.5%), solid waste and biomass combustion (10.2%) and transport (5.5%). About 10.5% and 4.5% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

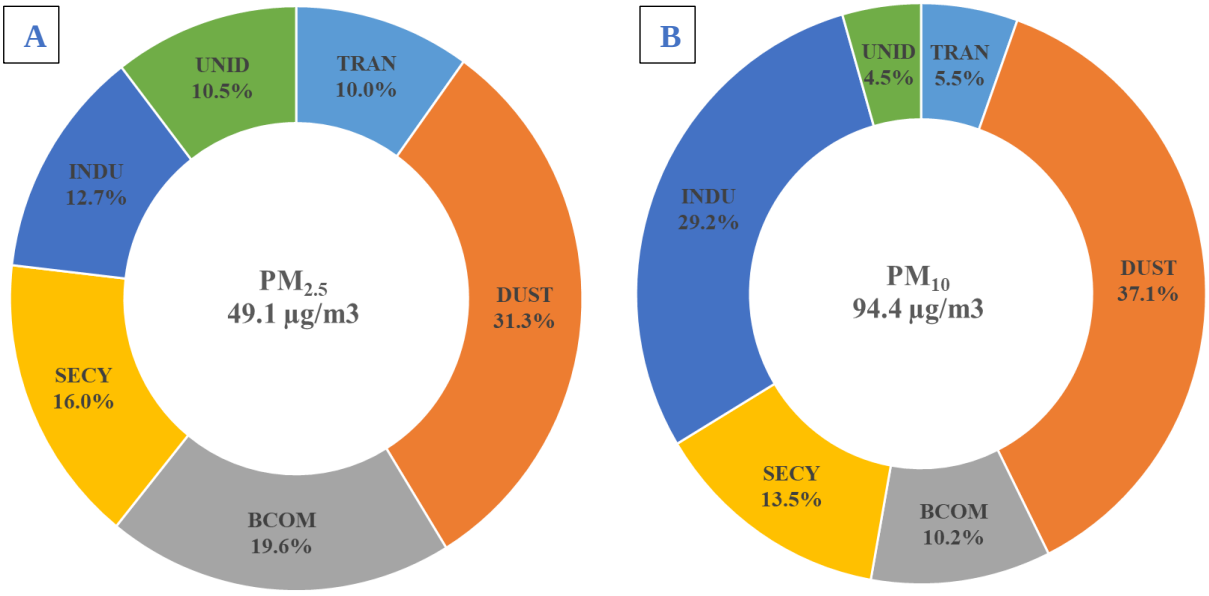

Figure 54 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S5 i.e. IDL Outpost, Sonaparabat during winter season*

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.2. SUMMMER SEASON

2.9.2.1. Site 1: Hamirpur Highschool

Fig. 55 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S1 i.e. Hamirpur Highschool during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 100.8 µg/m^3 and 264.2 µg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 49.8%. The other sources of $PM_{2.5}$ at this site were identified as transport (17.8%), secondary aerosols (12.1%), biomass and solid waste combustion (6.9%), and industry (5.8%). The summer-time PM_{10} concentrations at this site were also dominated by dust (62.0%), followed by, secondary aerosols (12.3%), industry (10.2%), transport (6.9%), biomass and solid waste combustion (2.9%), and. About 7.7% and 5.7% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

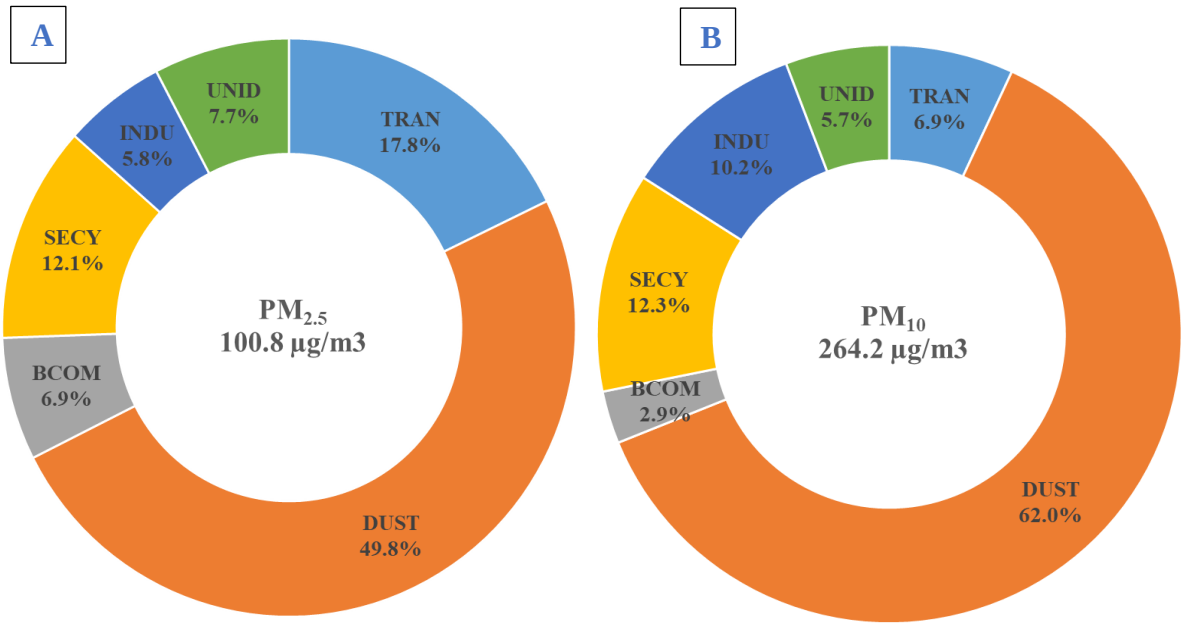

Figure 55 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S1 i.e. Hamirpur Highschool during the summer season in Rourkela region*

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.2.2. Site 2: IDCO Office

Fig. 56 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S2 i.e. IDCO Office during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 96.1 µg/m^3 and 269.1 µg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 46.2%. The other sources of $PM_{2.5}$ at this site were identified as transport (15.8%), secondary aerosols (13.6%), biomass and solid waste combustion (8.4%), and industry (6.3%). The summer-time PM_{10} concentrations at this site were also dominated by dust (56.2%), followed by industry (13.6%), secondary aerosols (12.7%), transport (6.1%), and biomass and solid waste combustion (3.5%). About 9.7% and 7.9% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

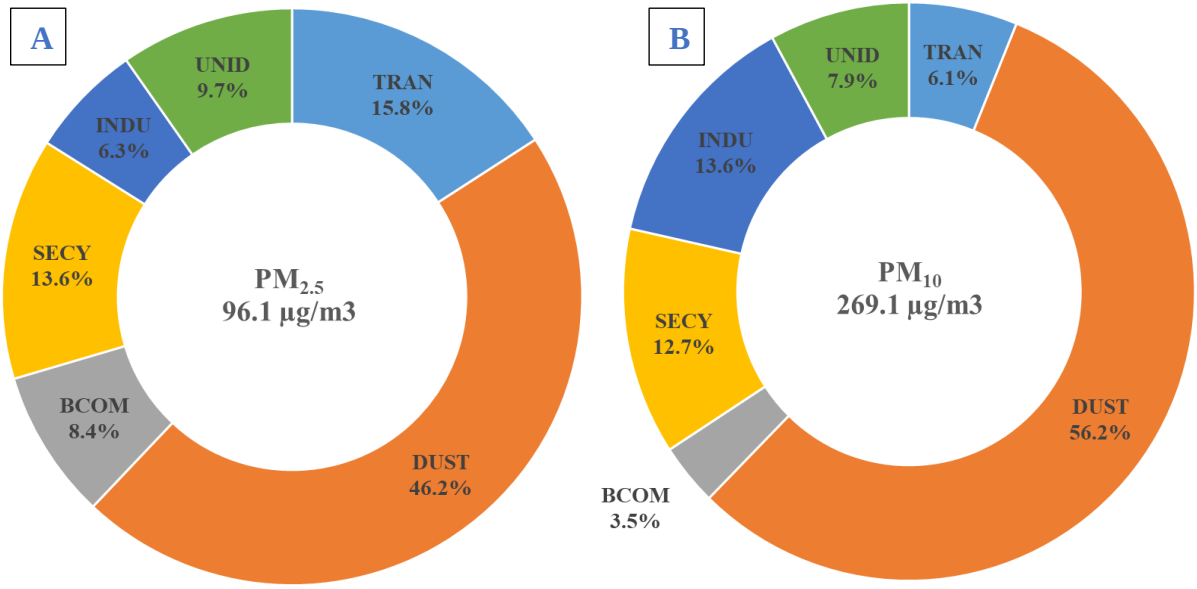

Figure 56 Sectoral source contributions to $PM_{2.5}$ ***(A) and*** PM_{10} ***(B) at S2 i.e. IDCO Office during summer season***

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.2.3. Site 3: College of Arts, Science & Technology, Bondamunda

Fig. 57 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S3 i.e. College of Arts, Science & Technology, Bondamunda during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 97.2 µg/m^3 and 241.3 µg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 51.8%. The other sources of $PM_{2.5}$ at this site were identified as transport (12.1%), secondary aerosols (11.5%), industry (5.8%) and biomass and solid waste combustion (5.1%). The summer-time PM_{10} concentrations at this site were also dominated by dust (53.1%), followed by industry (17.9%), secondary aerosols (10.4%), transport (5.1%) and biomass and solid waste combustion (3.9%). About 13.8% and 9.6% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

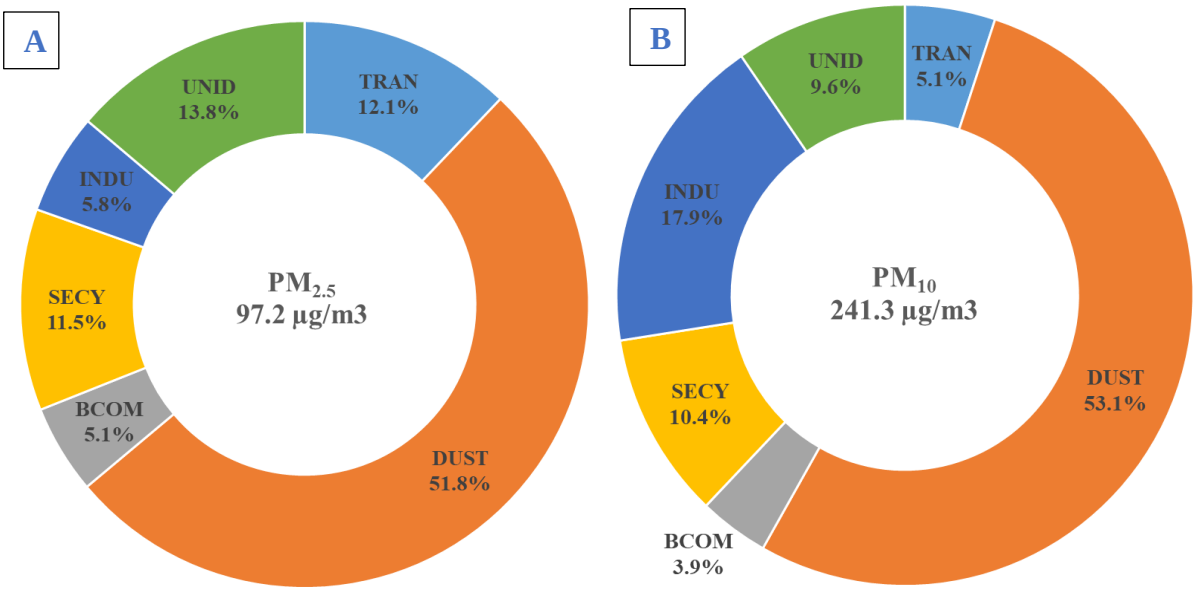

Figure 57 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S3 i.e. College of Arts, Science & Technology, Bondamunda during summer season*

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.2.4. Site 4: Jay Matadi Plastics Ltd., Kalunga

Fig. 58 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S4 i.e. Jay Matadi Plastics Ltd., Kalunga site during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 120.3 µg/m^3 and 815.0 µg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 31.4%. The other sources of $PM_{2.5}$ at this site were identified as industry (30.4%), secondary aerosols (15.0%), transport (7.2%), and biomass and solid waste combustion (4.7%). The summer-time PM_{10} concentrations at this site were also dominated by industries (47.5%), followed by dust (23.6%), secondary aerosols (14.8%), transport (1.7%), biomass and solid waste combustion (1.2%). About 11.3% and 11.1% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

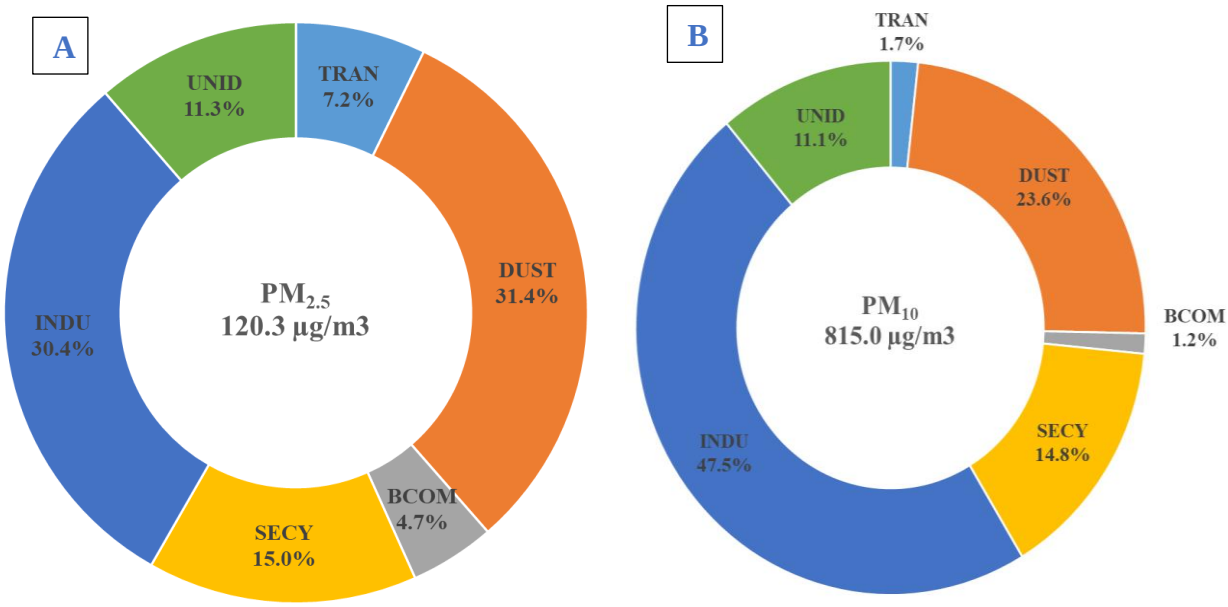

Figure 58 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S4 i.e. Jay Matadi Plastics Ltd., Kalunga during summer season*

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.2.5. Site 5: IDL Outpost, Sonaparabat

Fig. 59 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S5 i.e. IDL Outpost, Sonaparabat during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 113.8 µg/m^3 and 217.2 µg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 47.1%. The other sources of $PM_{2.5}$ at this site were identified as industry (12.7%), secondary aerosols (11.8%), transport (9.5%), and solid waste and biomass combustion (7.6%). The summer time PM_{10} concentrations at this site were also dominated by dust (49.5%), followed by industry (25.7%), secondary aerosols (10.0%), transport (5.1%) and solid waste and biomass combustion (4.1%). About 11.1% and 5.6% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

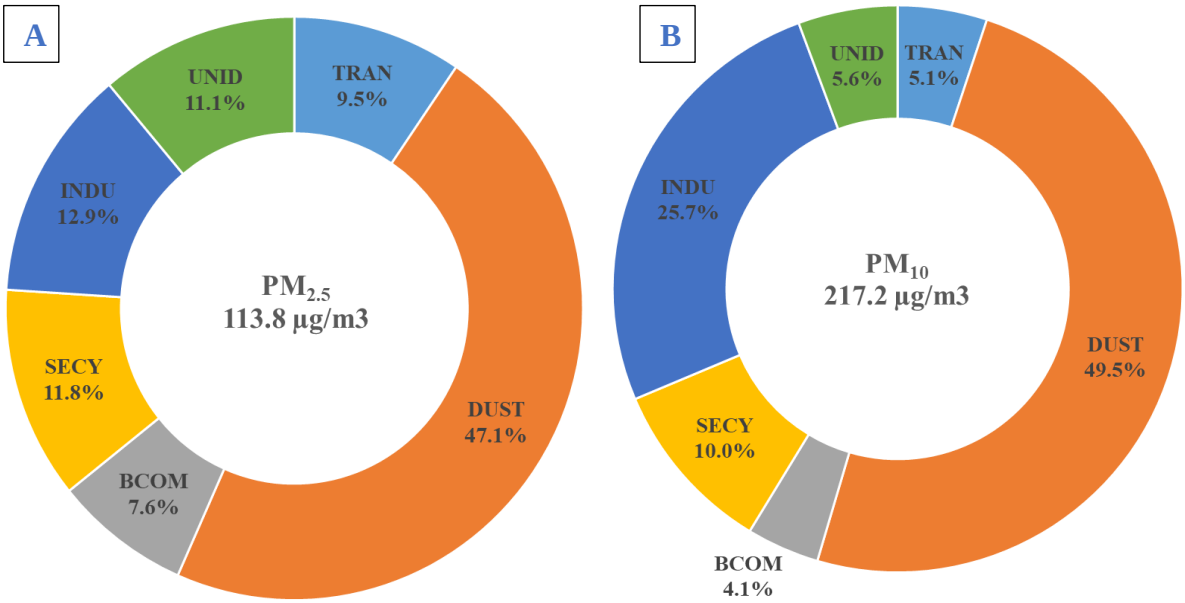

Figure 59 Sectoral source contributions to $PM_{2.5}$ ***(A) and*** PM_{10} ***(B) at S5 i.e. IDL Outpost, Sonaparabat during summer season***

Legend represents – TRAN: Transport, DUST: natural + re-suspended + construction dust, BCOM: Biomass and solid waste combustion, SECY: Secondary aerosols, INDU: Industrial stack emissions + industrial fugitive dust + DG sets, and UNID: Unidentified.

2.9.3. City-level source contribution analysis

The city-level average source contributions were determined, using the site-wise source contribution estimates obtained in the previous section. Fig. 60 and 61 presents the average source contributions to ambient $PM_{2.5}$ and PM_{10} at Rourkela during winter and summer seasons, respectively.

Overall, the winter-time $PM_{2.5}$ mass at Rourkela (Fig. 60) are found to be dominated by dust sector with highest contribution of 33.7%. The other sources of $PM_{2.5}$ at Rourkela are identified as secondary aerosols (17.2%), solid waste and biomass combustion (14.5%), transport (12.4%), and industry (10.4%). Similarly, the winter-time PM_{10} mass at Rourkela is found to be dominated by dust (42.9%), followed by industries (20.6%), secondary aerosols (15.4%), transport (12.4%), and solid waste and biomass combustion (8.7%). Additionally, about 11.9% and 7.0% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

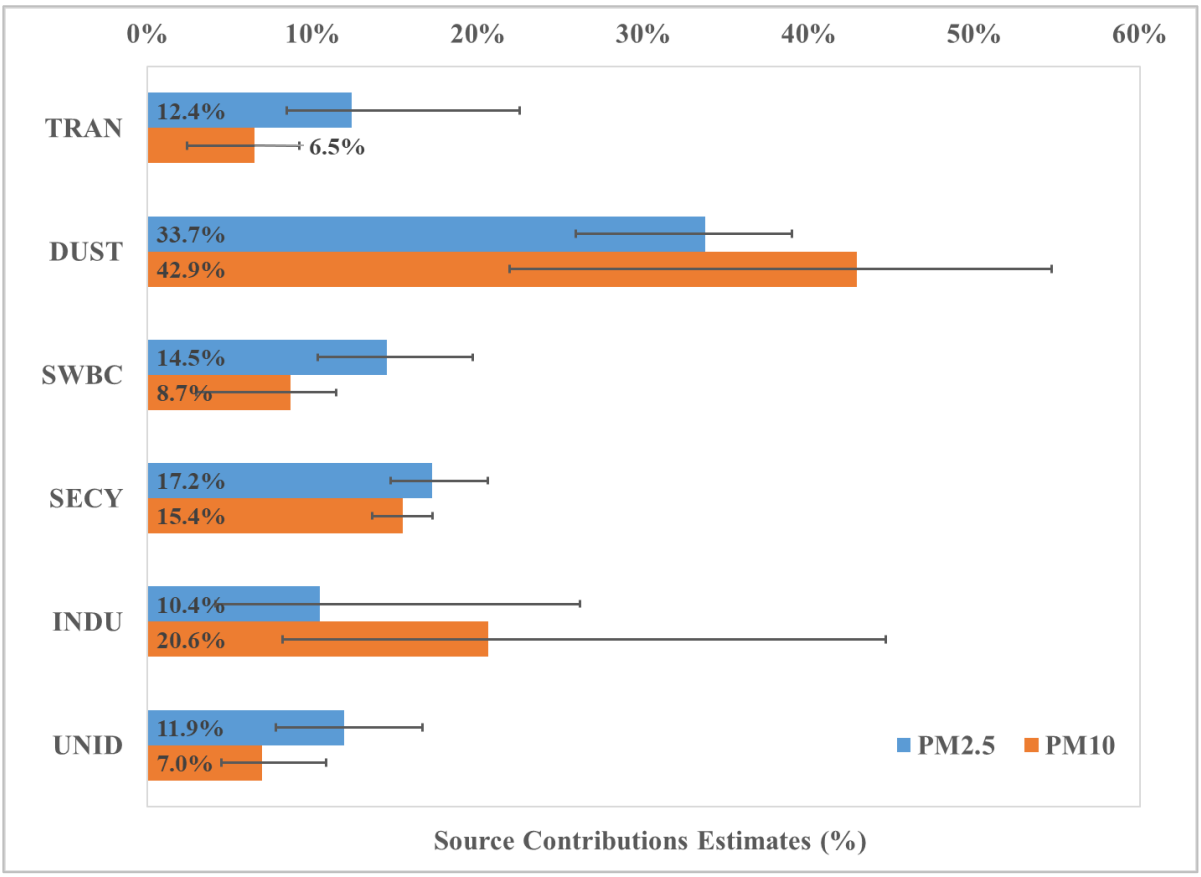

Figure 60 City-level source contribution estimates (SCE) for Rourkela region using CMB receptor model during winter season

The summer-time $PM_{2.5}$ mass at Rourkela (Fig. 61) is found to be dominated by dust with highest contribution of 45.1%. The other summer-time sources of $PM_{2.5}$ at Rourkela region are identified as secondary aerosols (12.7%), transport (12.5%), industry (12.2%), secondary aerosols (12.0%), and solid waste and biomass combustion (6.5%). Similarly, the summer-time PM_{10} mass at Rourkela is also found to be dominated by dust (48.9%), followed by industry (23.0%), secondary aerosols (12.0%), transport (5.0%), and solid waste and biomass combustion (3.1%). Additionally, about 10.7% and 8.0% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

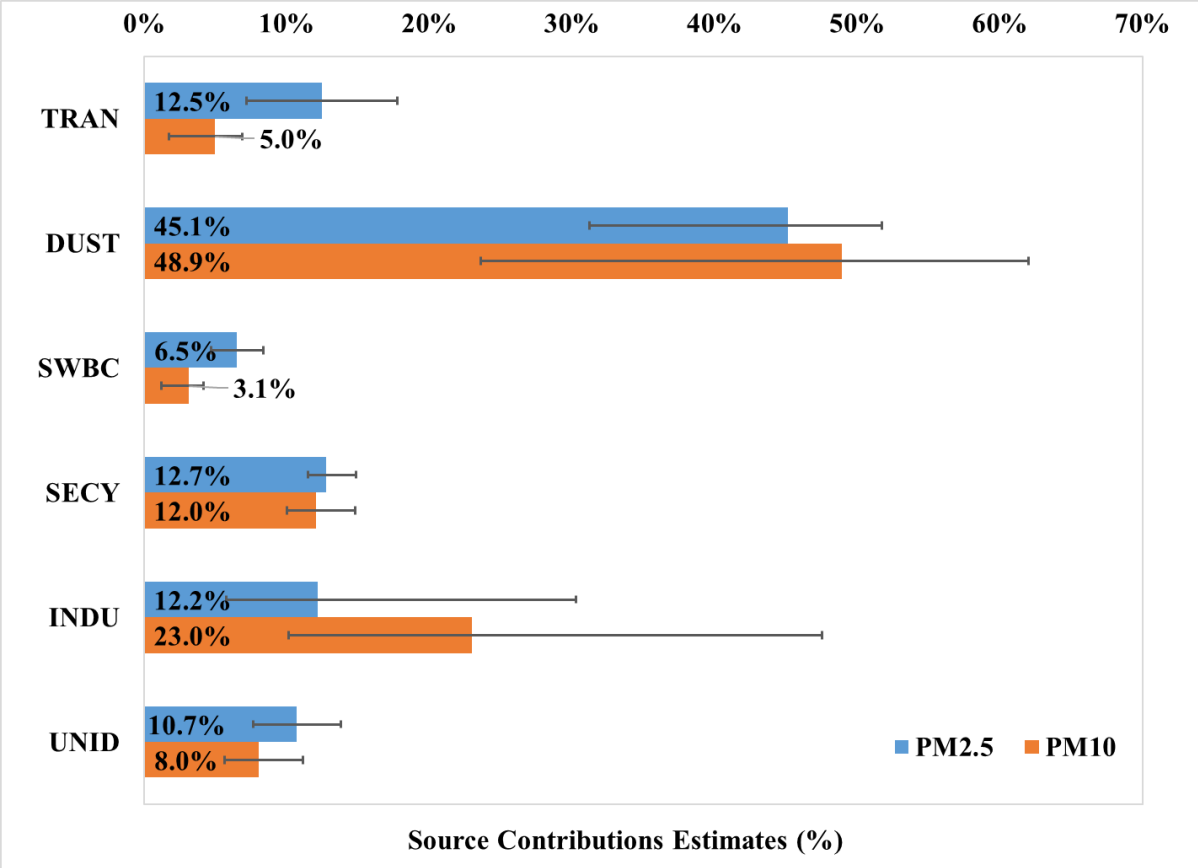

Figure 61 City-level source contribution estimates (SCE) for Rourkela region using CMB receptor model during summer season (April 23 – May 11, 2022)

(Note: The horizontal blue and orange coloured bars in Fig 60 and 61 represent the mean SCE percentage in $PM_{2.5}$ and PM_{10}, respectively while the error bars represent the range of estimated SCE among five sampling sites.)

Chapter 3: Emission Inventory

3.1. Introduction

An emission inventory (EI) is a comprehensive listing by source of air pollutant in a geographic area during a specific time period. Emission inventories are one of the fundamental components of Air Quality Management Plans to measure progress/changes over time to achieve cleaner air and to determine compliance with environmental regulations (Shrestha et al., 2013).

Air pollutant emission inventory is a crucial input for pollutant emission control and air quality management (Xu et al., 2020). Further, emission inventories are an essential input to mathematical models that estimate air quality (EPA, 2022). Emission inventory and dispersion models, together provide guidance for decision-makers by supplying information on pollutant emission sources and their characteristics. Emission inventories and air quality modelling are two significant components of air quality management in urban areas.

3.2. Objectives and Scope of Work

The main objective of this study is development of baseline emission inventory (Year: 2021) of air pollutant loads originating from eleven sectors in Rourkela region. The scope of this study includes:

- Quantification of emission loads originating from sectors including: Transport, Re-suspended road dust, Open Waste Burning, Residential, Industries, Diesel generators, Hotels, Restaurants and Bakeries, Crematoria, Brick kilns, Fugitive emissions and Construction activities in Rourkela region.
- Air pollutants considered in this research includes: particulate matter having aerodynamic diameter less than or equal to 10 microns (PM_{10}), particulate matter having aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs).
- The spatial resolution of emission inventory is: 2 x 2 km^2 over the study area
- The temporal resolution of emission inventory is monthly.

3.3. Approach to the EI development

Figure 62 shows the methodology adopted in development of emission inventory for Rourkela region. The first phase of the emission inventory development involves research on previous emission inventories in the region, reconnaissance surveys, collection of secondary datasets. Based on this data analysis, air pollution sources in the study domain were identified. Once the air polluting sources in the study domain are identified, the primary data collection surveys were taken up for different sectors.

There are several estimation methods to calculate emissions. This study uses the most widely used approach based on emission factor and activity rate. A literature review was carried out for selection of emission factors. Emission factors for vehicular sector were adopted from Automotive Research Association of India (ARAI, 2010, 2018), while for other sectors India specific and local emission factors have been used as far as possible.

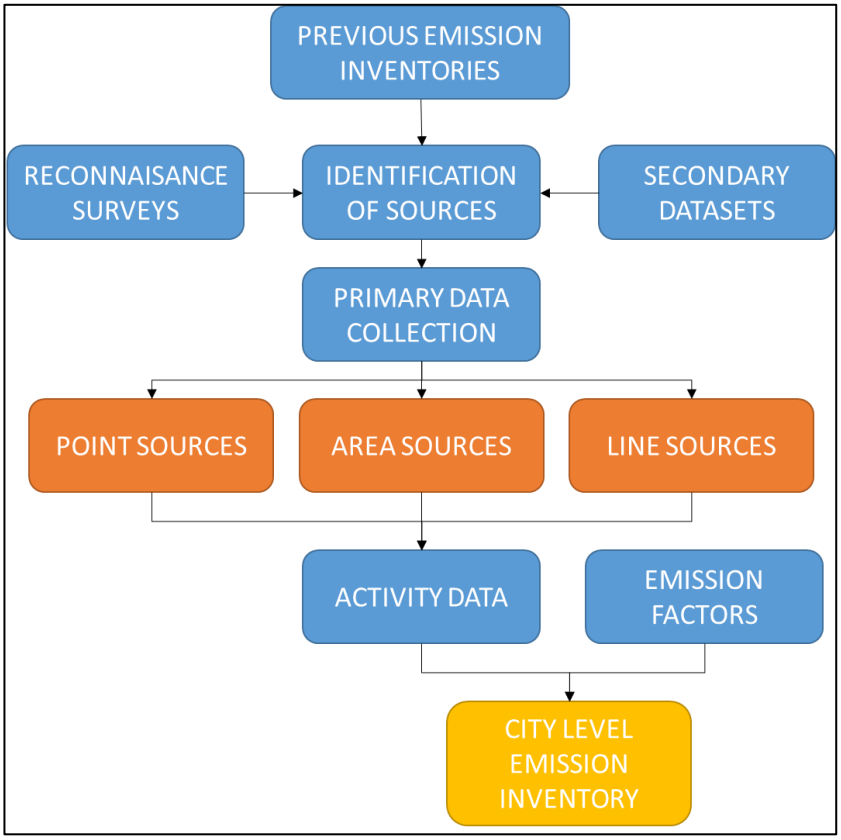

Figure 62: Approach adopted for emission inventory development at city level

The study area was divided into high resolution grid cells at 2 X 2 km^2 grids over entire city using GIS tools. Emission inventory has been prepared for the study area and thereafter allocated to high resolution grid cells. Fig. 63 presents the gridded study domain (2 x 2 km^2).

The methodologies followed for estimation of emissions from different sectors are described in subsequent sections.

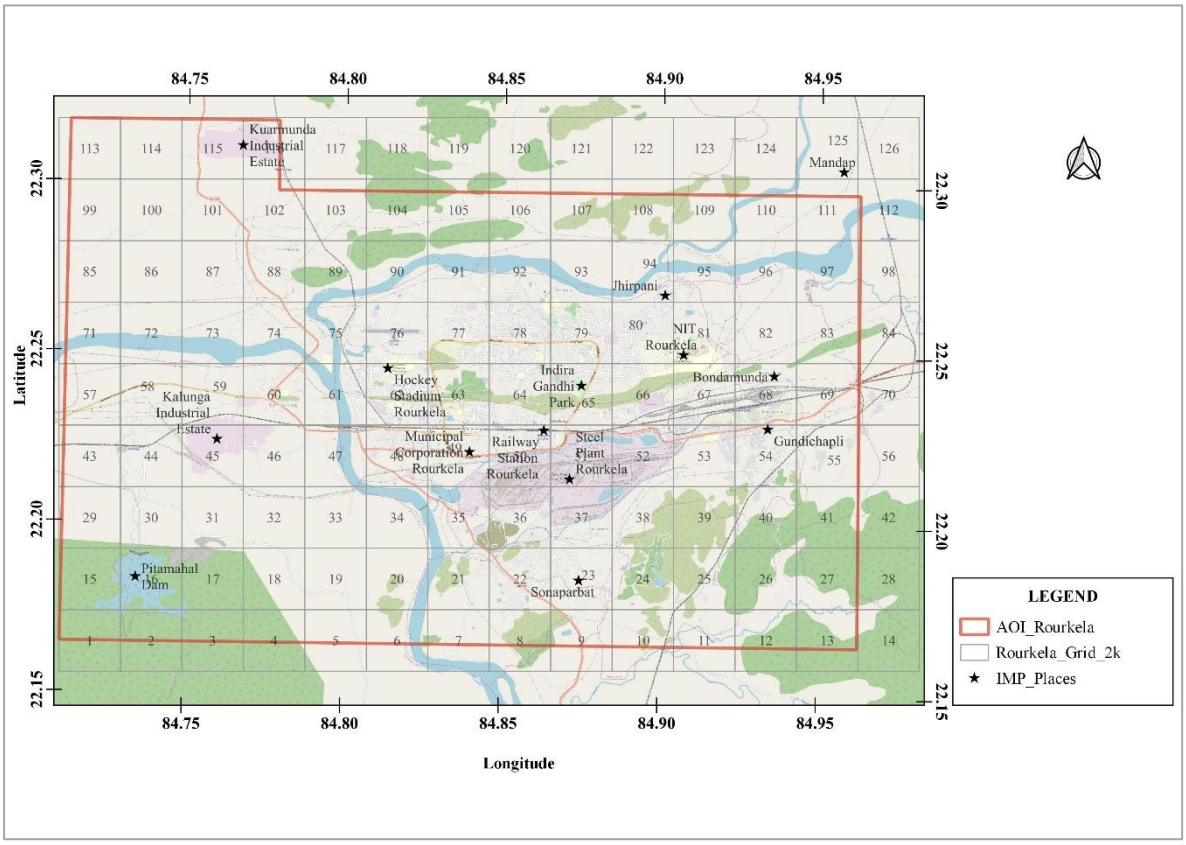

Figure 63: Map showing study area overlaid with emission inventory grids with horizontal spacing of 2 x 2 km^2

3.4. Methodology

The methodology follows a bottom-up estimation of emissions using activity rates for each sector and the measured emission factors (EFs) in India wherever possible. The bottom-up approach uses source-specific and category-specific data at the most refined spatial level to estimate emissions. The emissions estimated for individual sources are summed up to obtain a city-level inventory. The sector-specific activity rate is uniquely estimated across each sub-sector using available primary and secondary data such as fuel consumption, daily vehicle kilometres travelled, registered number of vehicles, and production capacities. The approach also incorporates latest process technologies and control measures for particulates and other species in Industrial and vehicular sectors.

The widely used emission estimation method based on activity rate and emission factor is used. This method estimates the rate at which a pollutant is released to the atmosphere as a result of certain processes (Shrestha et al., 2013). Table 3 shows the different air pollution

sources inventorised for study domain. Emission calculation can be expressed by using the following equation (6):

$$\mathbf{E = A \times EF \times \frac{(100 - CE)}{100}} \ldots\ldots\ldots\ldots\ldots..(6)$$

where,

E = Emission load

A = Activity rate

EF = Emission factor

CE = Overall control efficiency (%).

Table 3: Different air pollution sources inventorised in this study for Rourkela region

Source Type	Sources Included
Point Sources	Industries, Thermal and Captive Powerplants, Crematoria, Brick kilns
Area Sources	Fugitive dust, Residential, Hotels, restaurants and bakeries, Construction, Diesel generators, Open waste burning
Line Sources	Transport, Re-suspended road dust

Details of primary and secondary data collection surveys are provided in sectoral manner in subsequent sections. Air pollution sources were categorized into three main types i.e. point, area and line sources and details of sectors included in each type are provided in Table 1. Area sources are sources of pollution that emit a substance from a specific area. These include small pollution sources such as residential, hotels, restaurants and bakeries, construction sites, etc. Although emissions from individual area sources are relatively small per unit, collectively their emissions can be of concern, particularly where large numbers of sources are located in heavily populated areas. Line sources mainly include both on-road vehicles such as two wheelers, cars, trucks and buses (Shrestha et al., 2013).

3.4.1. Primary and secondary data collection

The data collection is a pre-requisite for development of the regional emission inventory. Two types of data collection approaches are used in this study i.e. primary and secondary data collection. The first approach i.e. primary data collection involves field surveys at identified locations for residential, commercial, and industrial fuel consumption, parking lot surveys to understand details of vehicle fleet, classified vehicle surveys to understand traffic count for various vehicle types. The second approach i.e. secondary data collection involves extracting relevant data from published reports, research papers, and government department website. Table 4 and 5 summarizes the primary and secondary data collection used in this study.

Table 4: Summary of primary data collection surveys carried out in this study

Sr. No.	Sector	Primary Data Collection Surveys
1.	Transport	• Classified vehicle counts • Parking lot / Fuel station surveys
2.	Re-suspended road dust	• On -road dust sampling to determine the silt loading rates
3.	Residential	• Fuel consumption surveys
4.	Hotels, Restaurants. Bakeries and Open eateries	• Fuel consumption surveys
5	Diesel Generators	• Fuel consumption surveys

Table 5 Summary of secondary data sources used in this study

Sr. No.	Sector	Secondary Data Sources
1.	Transport	• VAHAN database • MoRTH Annual Reports • Road network from Openstreetmap and Google Inc.
2.	Construction	• Google Earth Inc.
3.	Hotels, Restaurants. Bakeries and Open eateries	• Numbers, types, and locations of facilities through online food delivery portals

4.	Open waste burning	• Solid waste generation, processing and disposal statistics from Rourkela Swachha Bharat Sarvekshan, 2018
5.	DG Sets	• Numbers, types, and locations of facilities through open street map, wherever applicable.
6.	Brick Kilns	• Google Earth Inc.
7.	Industry	• OSPCB database
8.	Residential	• National Family Health Survey (NFHS) 2019-2021

3.4.2. Transport

The transport sector emissions are calculated using data generated from primary surveys for on-road vehicle counts, parking lot surveys, and data available in public domain from different government departments at state and local level. The vehicular exhaust emissions are calculated using equation (7):

$$\textbf{Trasnport Emissions} = \textbf{VKT x EF}_{EX} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where, EF_{EX} is the emission factor (g/km) for a particular category of vehicle of particular vintage, fuel and engine technology and VKT is Vehicle Kilometers Travelled, by same category of vehicle, in a day. As illustrated in Eq. 1, the emission factor (EF) is an important input required for quantifying the vehicular emissions at city level. The vehicular emissions factors developed by Automotive Research Association of India (ARAI) for in-use Indian vehicles (ARAI, 2010; 2018) are used in this study.

3.4.2.1. Road network digitization

Road network in the study area was digitized using Google Earth application (Fig. 64). Roads in Rourkela region are classified into six categories viz. i) highways, ii) major roads, iii) intermediate roads, iv) minor roads v) residential roads and vi) industrial roads. After complete digitization, road lengths were calculated for each link in the network using GIS software. Category-wise gridded road lengths were also computed using GIS software.

3.4.2.2. Reconnaissance survey

A Reconnaissance survey was conducted in the Rourkela region to select the locations for traffic count and parking lot surveys. Reconnaissance surveys helped in understanding the

traffic movement in the city, major traffic locations, type of vehicles, etc. Total 10 survey locations were identified in the Rourkela region to perform the classified vehicle count surveys and 5 areas/localities were selected for Parking lot surveys.

3.4.2.3. Traffic counts and vehicle fleet characteristics

Estimation of reasonably accurate vehicular emissions requires a good characterisation of the in-service vehicle fleet. Important characteristics of vehicle fleet include information on vehicle type, size, fuel type, age and emission control technologies. The historic vehicle registration data provides preliminary information vehicle type, size and fuel-type. The vehicle fleet in Rourkela region was categorised into six categories: 2-wheelers (motorcycles, scooters and mopeds), autos, passenger cars both private and commercial, light commercial vehicles (LCV) such as delivery vans, heavy duty vehicles (HDV) such as trucks and lorries and buses and coaches. Fig. 65 depicts the vehicle categories used in this study.

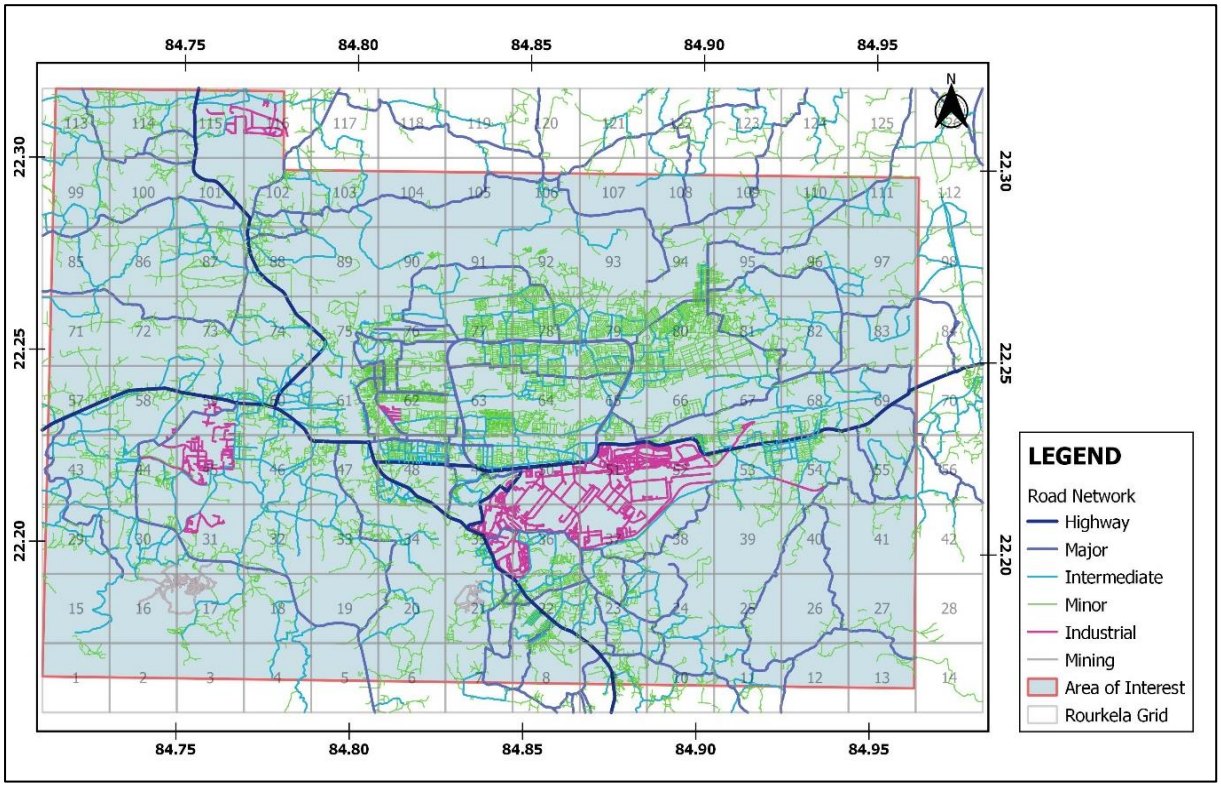

Figure 64: Map showing road network in Rourkela region and surrounding areas digitized using OpenStreetMap and Google Earth Applications

Traffic count surveys were carried out to obtain the information of on-road vehicles plying in the city, such as total number of vehicles, variation of vehicles on different road categories (major, minor and arterial), transit vehicles, temporal variations, etc. Traffic count

surveys were conducted by manual counting by teams of surveyors. At each of the selected location, category-wise traffic count data is collected in single direction. The vehicles are counted during the peak hours i.e. 08:00 to 13:00 hours and 15:00 to 18:00 hours on selected weekdays and weekend during the month of January- March, 2022. Parking lot surveys were also carried out to understand the distribution of existing vehicular fleet as per model, vintage, technology, fuel mix, average daily distance travelled, occupancy, and mileage. Parking lot surveys are carried out in 5 areas/localities around the selected sampling sites (S1-S5) in Rourkela region during January- March, 2022. Table 6 and 7 shows the details of locations of vehicle count surveys and parking lot surveys respectively.

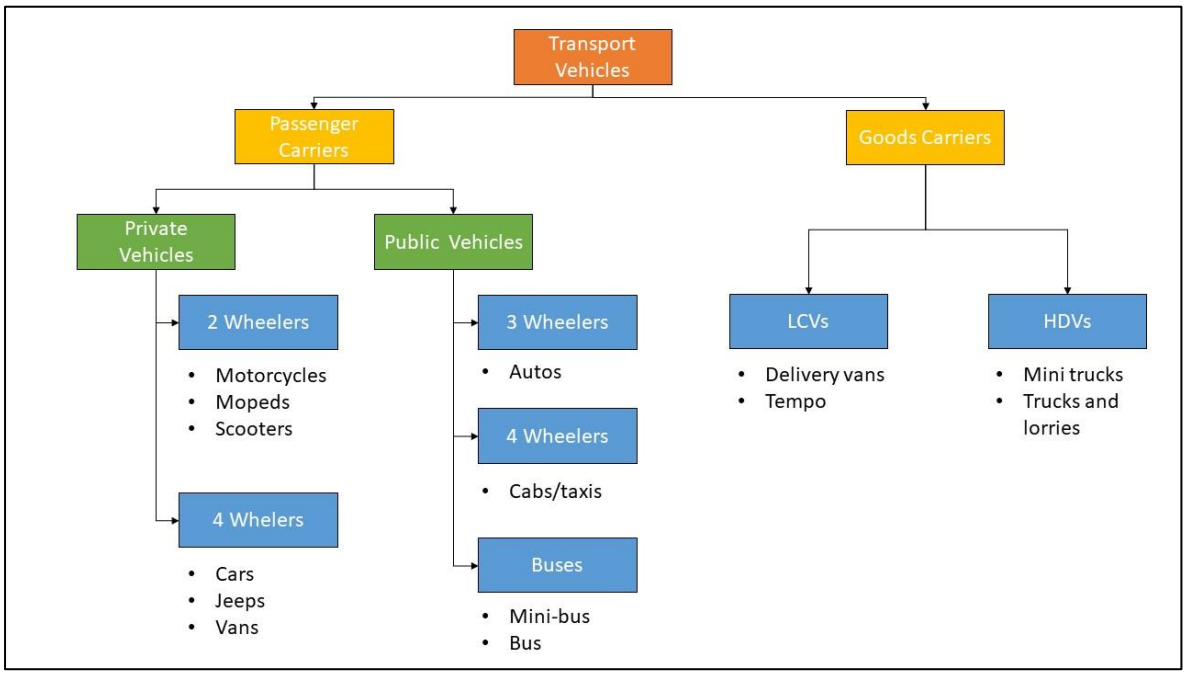

Figure 65: Vehicle categories used in this study

Each vehicle category is further differentiated in up to four fuel or engine types respectively: Gasoline, Diesel, Natural Gas, and battery-operated or electric vehicles. In addition, vehicular emission calculations require the vehicle fleet by age, as mass emission factors are significantly different for each vehicle type and control technology. Based on approach adopted by Baidya and Borken-Kleefeld (2009), the in-service vehicles were calculated using Survival function which models the vehicle's finite service life. The survival rate, which is a fraction of vehicles survived in the fleet after a certain age, was calculated for each vehicle category considered in Rourkela region.

The data generated through road network mapping, vehicle count surveys, parking lot surveys, and vehicle registration analysis was used to calculate the vehicle kilometers travelled (VKT) by different vehicle types on each road type.

Emission factors (EF) are essential input required to calculate the emissions originating from transport sector. Emissions measured on vehicle using chassis dynamometers are expressed in grams of pollutant per unit of distance travelled (g/km). Vehicular emissions are dependent on the large range of variables such as vehicle technology, age, condition, road profiles, driving habits, emission control regulatory levels, fuel and payload (Bawase et al., 2021). For this study, EFs developed by ARAI during 2010 and 2018 are used to calculate the total on-road vehicular emissions. It is important to note that, as BS-VI vehicles were recently introduced in i.e. year 2020, the mass emission factors for in-service vehicles in India are not available. Hence, the emission factors for such vehicles were derived using BS-VI emission limits.

Table 6: Locations of vehicle count surveys in Rourkela region

Station No.	Road Name	Longitude	Latitude	Road Type
VC1	Ring Road, Bank Street, Sector 6, Rourkela, Odisha 7690	22.2540	84.8643	Major
VC2	Near Sai baba temple, Sector 16, Rourkela, Odisha 770039	22.2642	84.8569	Inter
VC3	Sector 16, Rourkela, Odisha 770039	22.2668	84.8523	Minor
VC4	Jail Rd, Chhend Colony, Rourkela, Odisha 769004	22.2337	84.8260	Inter
VC5	Chhend Colony, Rourkela, Odisha 769004	22.2309	84.8248	Minor
VC6	Gundichapli, Rourkela, Odisha 770036	22.2312	84.9340	Major
VC7	Sector - D, Rourkela, Odisha 770036	22.2298	84.9314	Inter
VC8	Kalunga, Rourkela, Odisha 770031	22.2276	84.7657	Inter
VC9	I.D.L Colony, Rourkela, Odisha 769011	22.1882	84.8729	Inter
VC10	I.D.L Colony, Rourkela, Odisha 769011	22.1917	84.8721	Minor

Table 7 Locations of Parking Lot Surveys in Rourkela region

Location No.	Area Name

P1	Hamirpur
P2	Chhend Colony
P3	Bondamunda
P4	Kalunga
P5	IDL Colony

Figure 66 shows the yearly and cumulative vehicle registrations in Rourkela RTO office starting year 2000 till 2021. The total cumulative vehicle registrations reached 4 lakhs till 2021. The yearly registration showed a significant decline in vehicle registrations during year 2020- and 2021, mainly due to the COVID-19 pandemic.

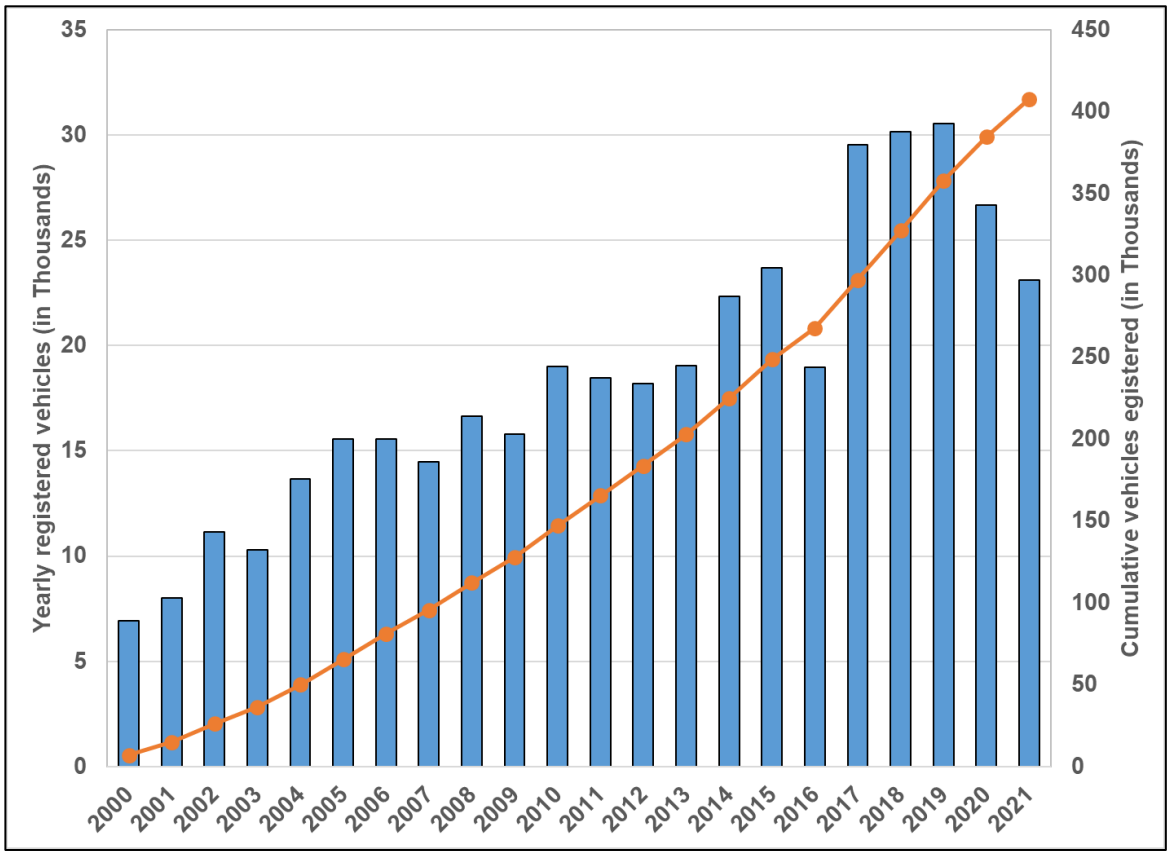

Figure 66: The number of vehicles registered by year (blue bars) and cumulative (orange line) in Rourkela from 2000 to 2021.

Fig. 67 presents the classified vehicle count observed at different types of roads in Rourkela region. Major roads such as Ring Road (VC1), exhibited highest vehicular population in a day, followed by intermediate roads and minor roads. Further, it is interesting to note that the observed vehicle population remains similar on both weekdays and weekend on the ring

road whereas other roads exhibit a significant contrast in vehicular population. This can be attributed to regular traffic during office hours on weekdays.

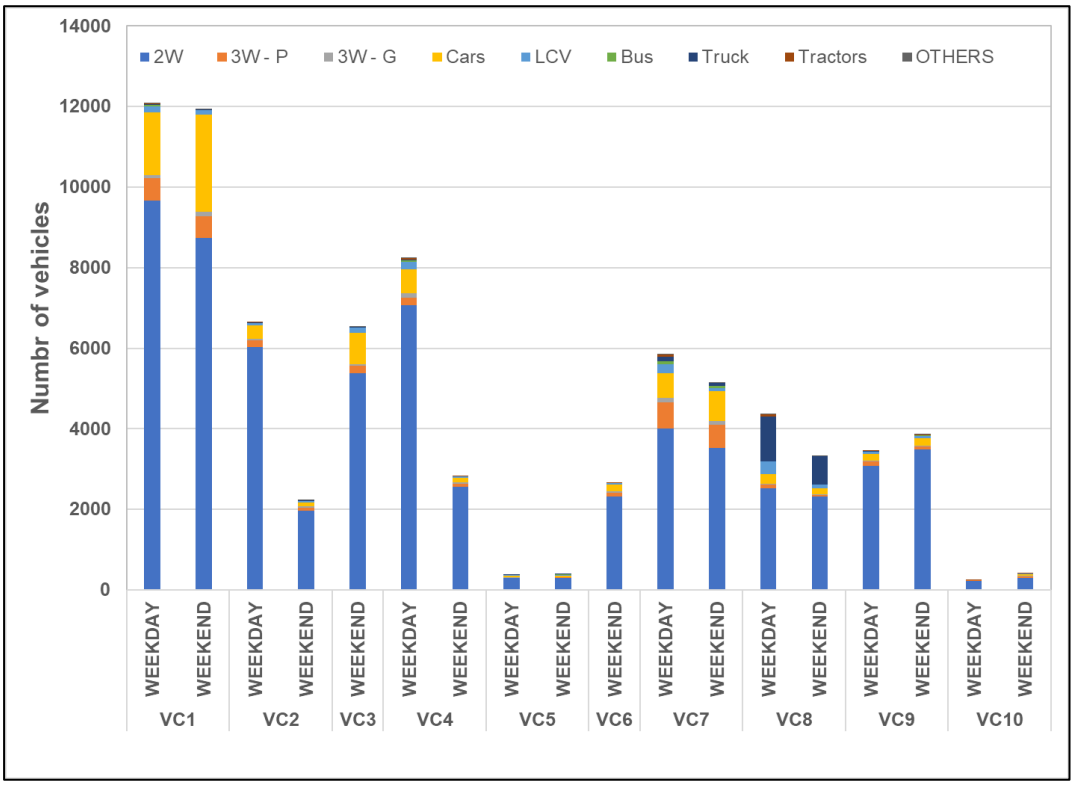

Figure 67: Classified vehicle counts observed at selected locations in Rourkela region during the primary surveys.

Fig. 68 depicts the observed percentage distribution of vehicles according to Bharat standards in Rourkela region. A total of 512 vehicles were surveyed in the Rourkela region during the primary surveys. The BS-III category vehicles are observed to be maximum (50.0%) followed by BS-IV (31.4%), BS-VI (8.8%), BS-II (6.6%), BS-I (2.5%) and pre-BS (0.6%).

Fig. 69 shows the estimated daily vehicle kilometres travelled by each category of vehicles in the Rourkela region. The daily VKT is estimated to be 1.93 Cr km and is dominated by two wheelers (80.0%) followed by private cars (6.8%), and passenger three wheelers (4.8%). Other vehicle categories together constitute about 8% of the daily VKT in Rourkela region.

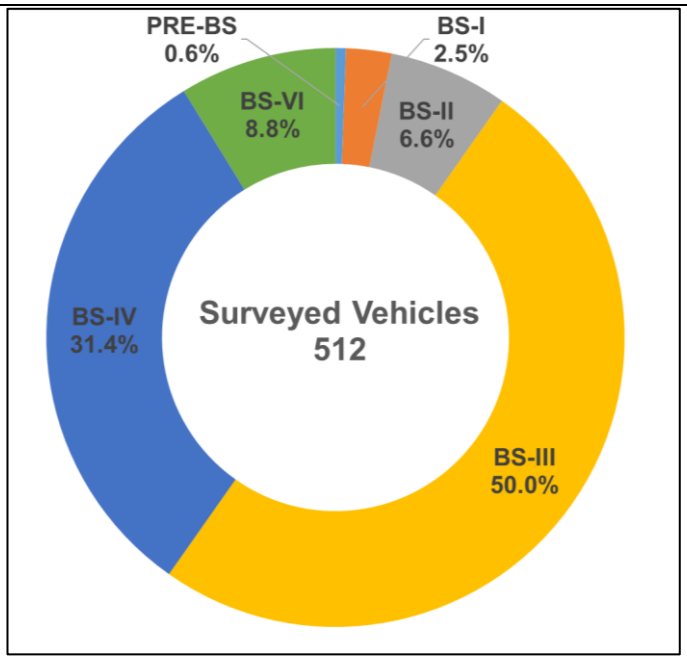

Figure 68: Distribution of vehicles as per different Baharat standards in Rourkela region obtained through parking lot surveys.

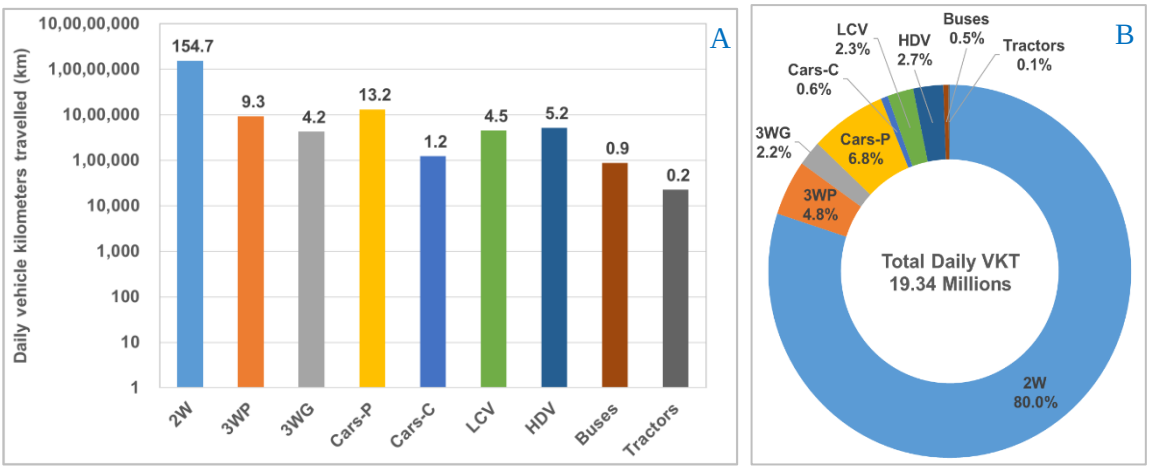

Figure 69: Daily vehicle kilometres travelled (A) and percent distribution (B) by different category of vehicles in Rourkela region.

In 30 (a), the numbers of top of each bar represent daily VKT in lakh and y-axis scale is expressed as a logarithmic scale.

3.4.3. Road Dust

Emissions from paved road dust re-suspension due to movement of vehicles were calculated using US EPA (AP-42) method. These dust emissions due to movement of vehicles varies with the silt loading on the road surface and also the average weight of the vehicles plying on the road. The term silt loading (sL) refers to the mass of the silt-size material (equal to or less than 75 µm in physical diameter) per unit area of the road surface. Silt loading values are calculated based road dust sample collection at previously listed vehicle counting locations. Particulate matter emissions from re-suspension of road dust due to movement of vehicles on paved roads were calculated using Eq. 8:

$$\textbf{Emissions load} = \textbf{VKT x EF}_{RD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where, VKT is Vehicle Kilometer Travelled (km/day) and EF is paved road dust emission factor and calculated using Eq. 9:

$$\mathbf{EF}_{RD} = \mathbf{k\ x\ w^{1.02}\ x\ (sL)^{0.91} x} \left(1 - \frac{P}{4N}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where,

EF = particulate emission factor (having units matching the units of k)

k = constant (function of particle size) in g/VKT, value of k for PM_{10} and $PM_{2.5}$ is 0.62 and 0.15, respectively.

sL = road surface silt loading in g/m2

w = average weight of the vehicles (in tons) travelling on the road

P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period,

N = number of days in the averaging period (e.g., 365 for annual).

The road dust samples were collected from selected locations to determine the silt loading rates for different category of roads in Rourkela region. The gross vehicle weights for different classes are obtained from vehicle specifications sheets through online surveys. Number of rainy days in a year were obtained from climatology data (IMD, 2015). The paved road emission factors for $PM_{2.5}$ and PM_{10} are listed in Table 8. These emission factors are then multiplied by gridded VKT values obtained earlier for calculation of vehicular emissions to obtain total road dust emissions.

Table 8: Road dust re-suspension emission factors (in g/km) used in this study

PM Fraction	AREA TYPE	HIGHWAY	MAJOR	INTER	MINOR	RESI
$PM_{2.5}$	URBAN	0.45	0.45	1.23	0.36	0.54
$PM_{2.5}$	FOREST	0.49	0.49	1.35	0.39	0.59
$PM_{2.5}$	INDUSTRIAL	0.78	0.78	2.15	0.63	0.95
$PM_{2.5}$	RURAL	0.56	0.56	1.53	0.45	0.68
PM_{10}	URBAN	1.85	1.85	5.07	1.48	2.23
PM_{10}	FOREST	2.04	2.04	5.58	1.63	2.46
PM_{10}	INDUSTRIAL	3.24	3.24	8.88	2.59	3.91
PM_{10}	RURAL	2.32	2.32	6.34	1.85	2.79

3.4.4. Open Waste Burning

The basic equation (10) followed to estimate the emissions of different pollutants from the open burning of solid waste is:

$$E_p = W_b \text{ x } EF_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where, E_p the emission of a particular pollutant from the burning of the refuse material, W_b is the quantity of waste materials burnt in an area, and EF_p is the emission factor of the particular pollutant (p) from the burning of the waste material.

In this study, the MSW burnt for the sake of disposal at the household level or on the street (W_b) is quantified using methodology adopted by Sharma et al. (2019). The MSW generated in the study domain is calculated using per capita MSW generation rate of 500 gm (ENVIS, 2021). MSW burnt refers to the non-inert fraction of the uncollected MSW left behind after collection (MSW_C), recycling (MSW_R), and secondary use as fodder, fertilizer, and fuel (MSW_F). f_i in eq. 11 stands for the inert fraction of the waste (ash and dust), which is estimated to be about 11.73% for Rourkela region (Swachh Bharat Mission 2018 Survey). Additionally, it is assumed that out of the uncollected waste, 60% of the total waste available to be burned that is actually burned. (IPCC, 2006; Wiedinmyer, 2014).

$$W_b = (MSW_P - MSW_C - MSW_R - MSW_F) \text{ x } (1 - f_i) \text{ x } 0.6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

The waste burnt daily is dependent upon the population, per capita waste generation, waste collection efficiency and fraction of uncollected waste burnt. The details on waste

generation and waste collection are obtained from statistics available in public domain. The emission factors of various pollutants considered in present study are illustrated in Table 9.

Table 9: Emission factors (g/kg) for open waste burning

Pollutants	EF (g/kg)	References
PM_{10}	14	Sharma et al., 2019
$PM_{2.5}$	13	
SO_2	0.892	
NO_X	2	
CO	67	
NMVOCs	14.5	TERI, 2016

3.4.5. Residential

The basic equation (12) employed for emission estimation from the residential sector is:

$$E_p = \sum_{f=1}^{6} Pop_f \text{ x } C_f \text{ x } EF_{f,p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

where, E_p is the emissions of a particular pollutant (p) from the residential sector, Pop_f is the population of the study region using a particular fuel (f), C_f is the per capita consumption of a particular fuel (f), and $EF_{f,p}$ is the Emission factor in (g/kg) of the particular pollutant (p) of the particular fuel type (f). Six major fuels are used in the residential households for cooking and lighting purposes– a) Fuel wood, b) dung cake, c) crop residue, d) coal, e) kerosene and f) LPG and were included in the estimation of emissions.

The latest census data for Rourkela region is available for year 2011 but Rourkela region has undergone huge transformation in the last decade and old data cannot be used. Hence, the gridded population of the study area (Refer Fig. 70) was estimated using suitable population projection techniques and assumptions.

The percentage of population using different fuels and daily average fuel consumption is derived from the primary surveys conducted in Rourkela region as a part of this study. The emission factors for residential sector used in this study are summarized in Table 10.

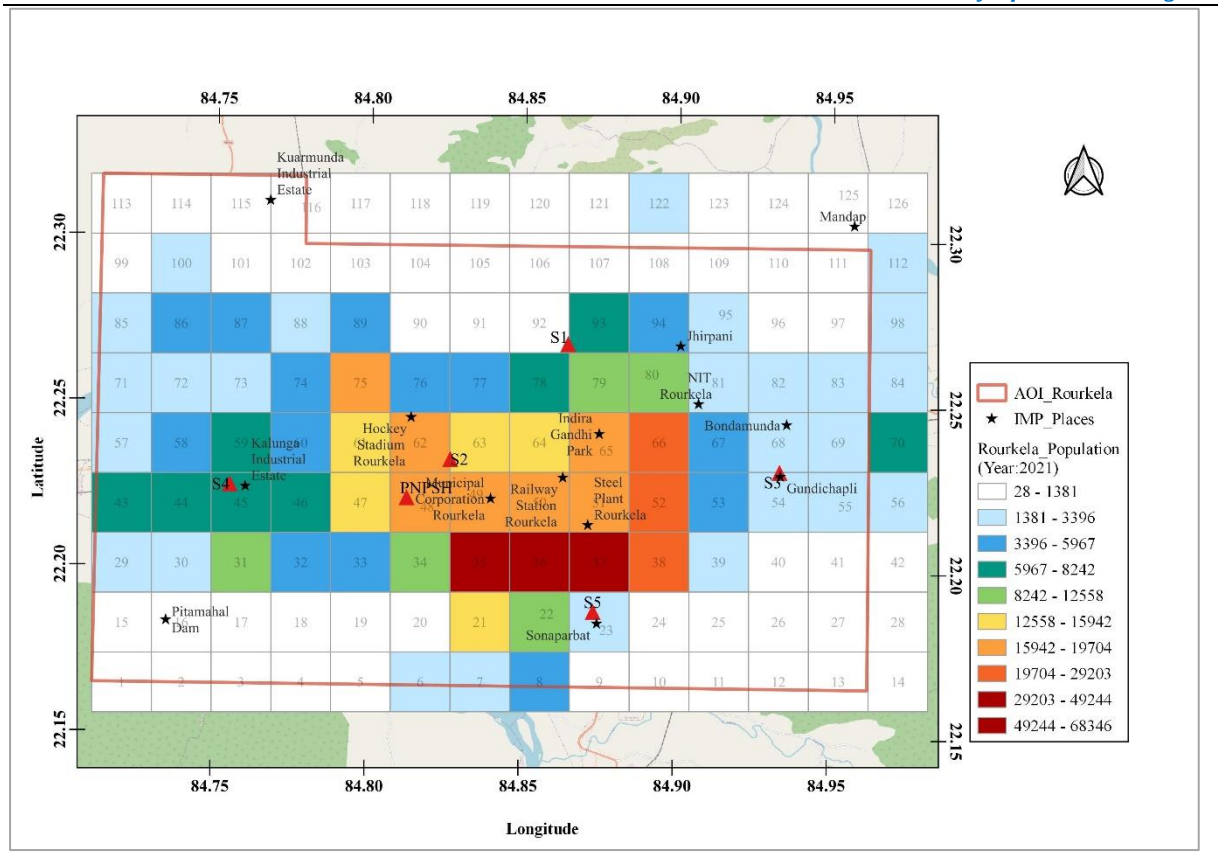

Figure 70 Map showing the estimated gridded population of the study area in year 2021

Table 10: Emission factors (g/kg) of different pollutants from different fuel types used in the residential sector

Fuel type	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOC
Fuel wood	6.8	4.6	0.8	1.7	66.5	15.9
Crop residue	8.6	5.7	0.7	1.8	64	8.5
Dung cake	10.5	4.4	0.6	1	78.6	24.1
Coal	8.3	4	15.3	2.16	59.5	10.5
Kerosene	3.6	3	0.4	1.3	43	17
LPG	0.4	0.4	0.4	2.9	2	19

#EFs adopted from Datta and Sharma (2014)

3.4.6. Industries

Rourkela is a major industrial town and is known as "Engineering Heartland of India". The major industries in Rourkela are Iron & Steel plants, Cement Industry, Sponge and Power Industry, Detonators, Chemical Plants etc. The major industries in Rourkela region are located in three important zones i.e. Rourkela city, Kalunga Industrial Estate and Kaurmunda Industrial Estate. In Rourkela city there are only two major industries i.e. Rourkela Steel Plant and Rourkela Captive Power Plant (2 x 60 MW). For the steel plant, raw materials like coal, haematite, limestone, dolomite etc. are available within a short radius of the plant itself. Besides these, bulk of raw materials comes from its own captive mines. The other two zones i.e. Kalunga and Kaurmunda Industrial Estate, are dominated by Sponge Iron and Steel Industries. Figure 71 shows the locations of these industrial areas in study area.

For the Rourkela steel plant, raw materials like coal, haematite, limestone, dolomite etc. are available within a short radius of the plant itself. Besides these, bulk of raw materials comes from its own captive mines. The main air polluting industries include the Rourkela steel plant, sponge iron industries, NTPC SAIL Power Company limited. Generally, coal is the dominant fuel used by these industries (OSPCB, 2019).

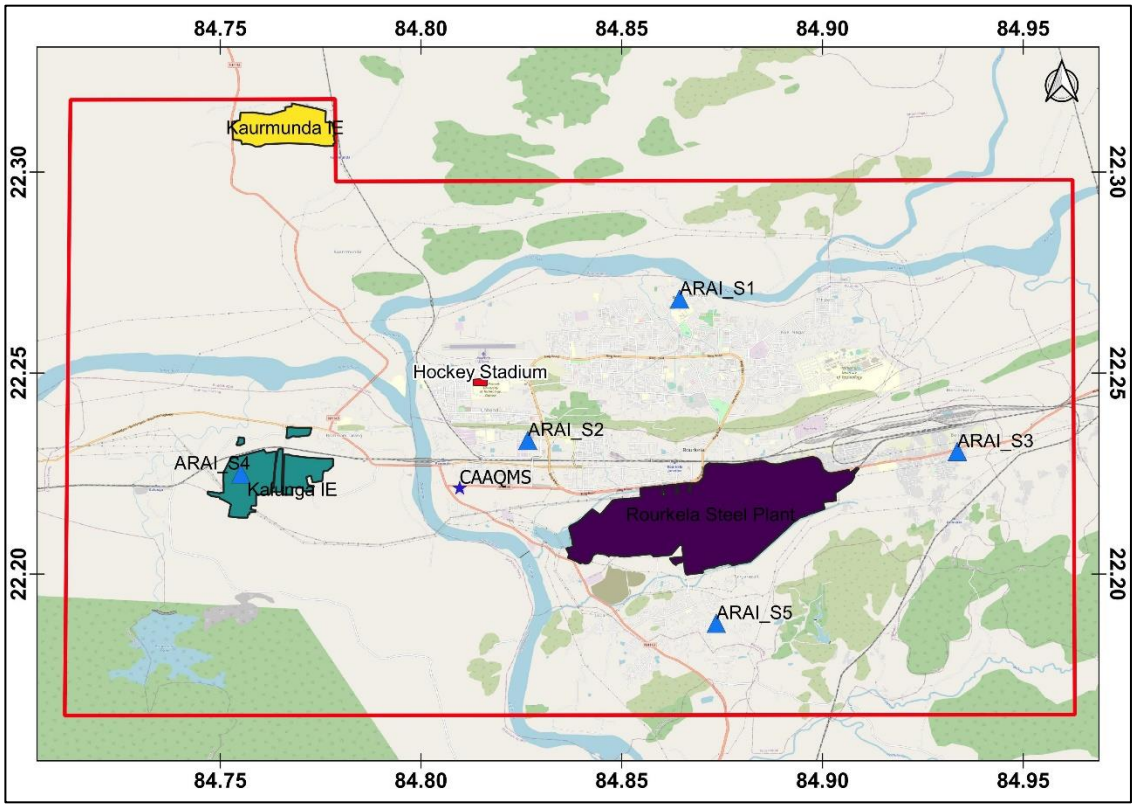

Figure 71: Map showing major industrial areas i.e. Rourkela steel plant, Kalunga and Kaurmunda industrial areas in the study area.

The emissions from major industries in Rourkela region are quantified based on previously measured stack emissions and recent fuel usage data. The stack emissions monitoring data for all large point sources are obtained from Rourkela regional office of State pollution control board, Odisha (OSPCB). This included data on manufacturing process, stack dimensions, installed control equipment and stack emissions of pollutants (PM, NO2, and SO_2). As CO and NMVOC emissions from industrial stacks are not routinely monitored, these emissions are estimated based on the production capacity.

3.4.7. Fugitive dust

In addition to industrial process emission sources described previously, industrial fugitive dust sources also contribute to the atmospheric particulate burden. These fugitive dust sources mainly include raw material handling outside of buildings, vehicle movement on paved and unpaved roads, and wind erosion from storage piles and exposed terrain. The fugitive dust emissions are calculated based on material handling data provided by regional office – OSPCB.

3.4.8. Diesel Generators

The industrial diesel generators are commonly used in the case of power failures and are considered as an important source of air pollution. The primary data such as installed capacity, fuel consumption, frequency and time of usage, and locations is obtained from regional office of OSPCB. The emission factors suggested by CPCB (2011) are used to quantify the emissions originating from industrial diesel generators. The emission factors used for computing emissions from diesel-based generators are presented in Table 11.

Table 11 Emission factors (kg/kWh) for different pollutants used for diesel generators

Activity	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOC
Diesel generator	0.00133	0.001197	0.00124	0.0188	0.00406	0.026857

3.4.9. Hotels, Restaurants and Bakeries

Emissions from this sector are mainly generated due to coal and wood used in tandoors and/or barbeques. The common fuels used by restaurants/hotels in Rourkela region are and LPG, coal and wood. The equation (13) used for calculating emissions by this sector:

$$E_p = C_f \text{ x } EF_{f,p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Where, E_p is the emission of a particular pollutant (p), C_f is the Fuel consumption by the hotel/ restaurant and EF is Emission factor for the pollutant (p) generated by the use of fuel (f).

Primary surveys were conducted in different localities of Rourkela region to understand the fuel usage pattern in hotels, restaurants, bakeries ad open eateries. The locations of hotels, restaurants, bakeries are obtained from online food delivery portals. Fig. 72 shows the locations of hotels, restaurants, bakeries in Rourkela region. The data collected fuel consumption in restaurants and open eateries is used to quantify the emissions for year 2021. The emissions factors are used from the CPCB (2011, refer Table 12). It is also assumed that no control devices are installed in the restaurants to control the emissions.

Table 12 Emission factors (g/kg) for the Hotels/Restaurants (Source: CPCB, 2011)

Fuel	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOCs
Coal	14	8.4	13.3	3.99	24.92	9
LPG	2.1	2.1	0.4	1.8	0.252	10.5
Wood	17.3	12.1	0.2	1.3	126.3	0.01

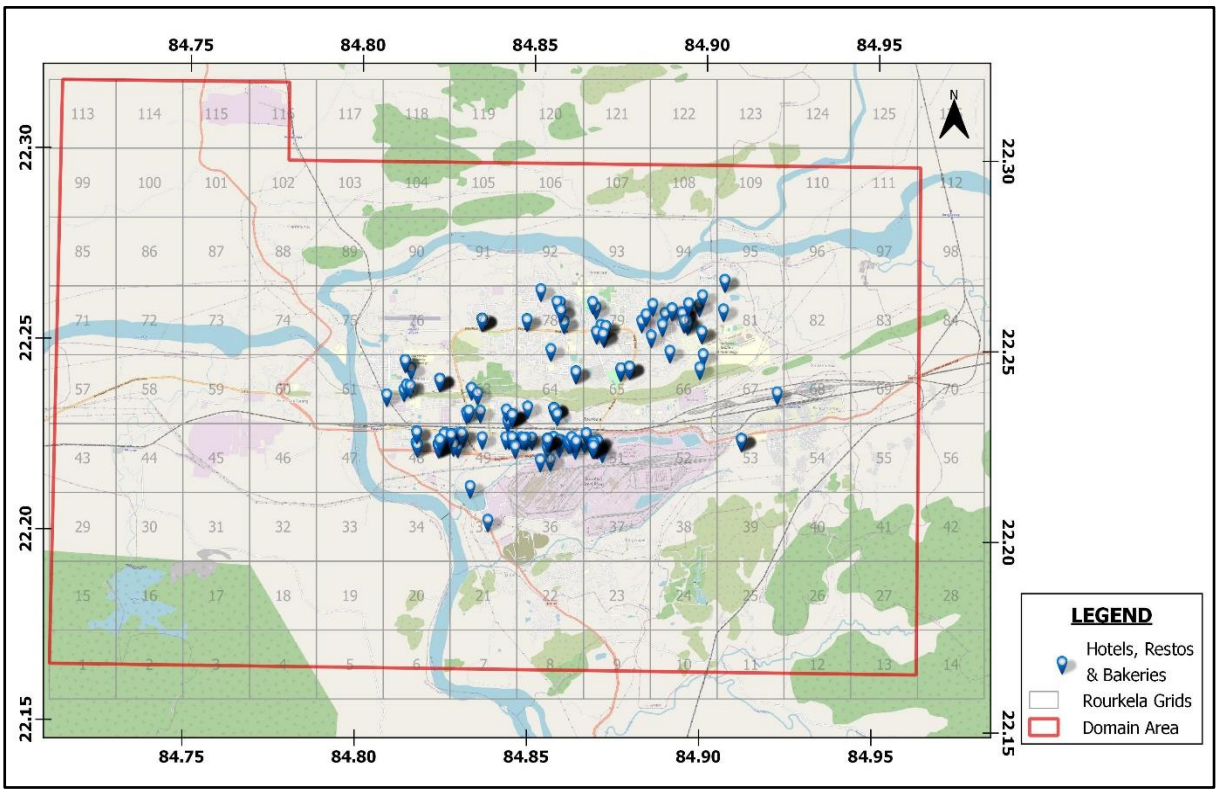

Figure 72: Map showing locations of hotels, restaurants and bakeries based on data obtained from online food delivery portals.

3.4.10. Crematoria

Cremating the bodies of dead people is an ancient ritual and practice in India. The total emissions from cremation calculated using Eq. 14.

$$E_p = F_b \text{ x } EF_{f,p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where, E_p is the emission of a particular pollutant p, F_b is the amount of fuel used per body in the crematoria, $EF_{f,p}$ is Emission factor for pollutant p. The locations of crematoria are marked and average number of dead bodies cremated each month is calculated based on crude death rate of Rourkela district.

In addition to number of dead bodies cremated, the data also include type of fuel used viz. wood, electricity, gas, and cow dung cakes. The emission factors for wood burning at crematoria are taken from Akagi et al. (2011) and Sharma et al. (2016) and listed below in Table 13. The emissions are quantified using equation 14.

Table 13: Emission Factors for crematoria

Fuel	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOCs
Wood (g/body)	5550.0	2730.0	120.0	750.0	27900.0	15,570.0
Electricity (g/body)	3.60	2.25	3.60	26.1	18.0	171.0

3.4.11. Brick Kilns

Brick kilns are an important source of air pollution, especially in the peripheral areas of the urban centres. This study used latest available satellite imagery to locate and identify the operational brick kilns over the study domain. The study domain has 31 number of brick kilns. Most of the brick kilns are of Fixed Chimney Bull's Trench Kiln (FCBTK) whereas a few are of traditional clamp type brick kilns. Fig. 73 shows the locations of brick kilns in the study area. The data on production capacity, operation pattern, fuel usage was generated based on personal interactions with the kiln operators.

The production-based approach is used to estimate the brick kilns emissions. In this method, emissions are estimated based on tonnes of bricks produced annually. The emission factors are provided in Table 14. The total emissions from brick kilns calculated using Eq. 15

$$E_P = W_b \text{ x } EF \ldots\ldots\ldots\ldots (15)$$

Where, E_p Stands for emissions of particular pollutant, W_b is weight of annual production of bricks and EF_p is the emission factor for a particular pollutant.

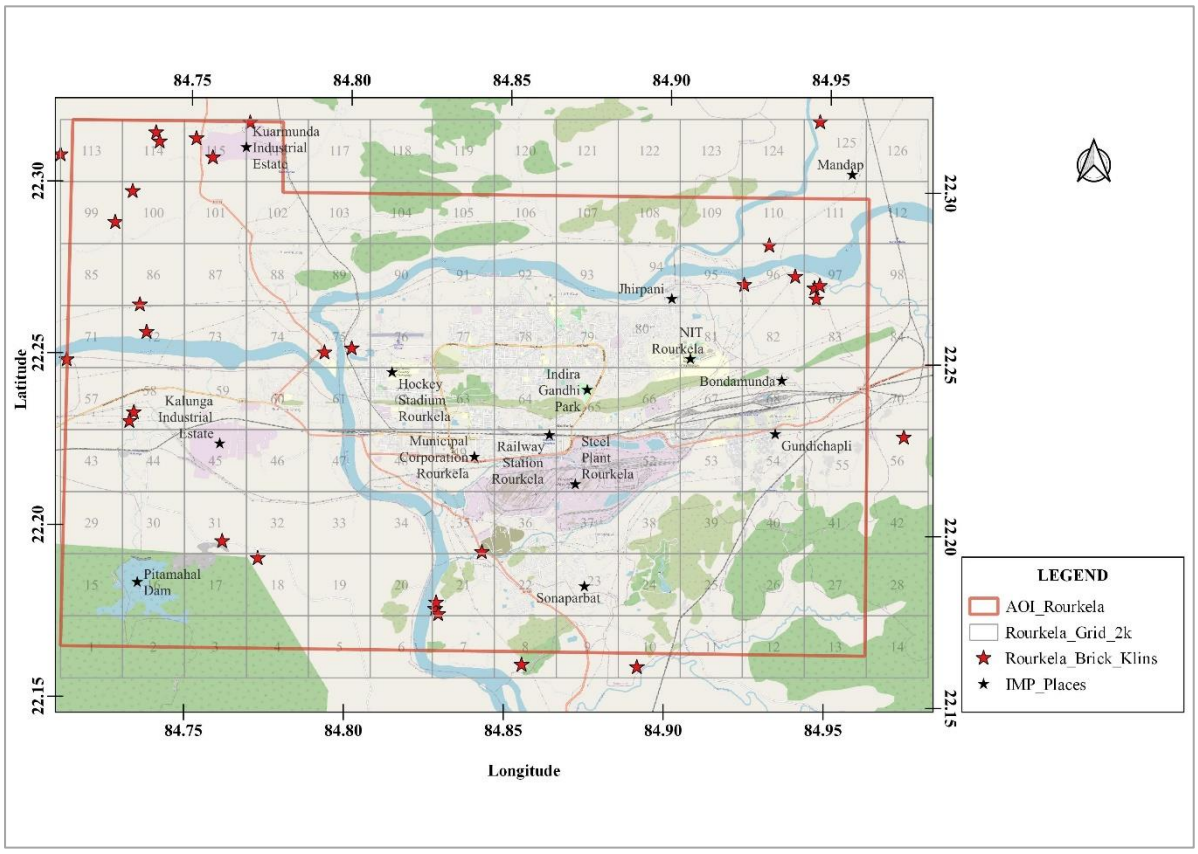

Figure 73 Map showing locations of brick kilns in the study domain identified using satellite imagery

Table 14 Emission Factors (g/kg) for different technology brick kilns

Technology	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOC
FCBTK	0.875	0.18	0.59	0.00005	2.94	0.1
Clamp	1.3	1	0.3	0.00015	10	0.15
Zig-zag	0.26	0.13	0.32	0.00004	1.47	0.1

3.4.12. Construction

The PM emissions from construction sector are estimated on the basis of total area under construction in the study area for the specified baseline year. The construction area is determined using the satellite imaging on Google Earth. To determine the newly constructed areas in each grid, satellite images in two different time frames (i.e. December, 2021 vs January, 2021) are visually/manually compared. The newly constructed buildings were marked using

polygon tool in Google earth application. Fig. 74 shows the map of construction locations identified using the satellite imagery. The emissions are obtained by using equation 17.

$$\mathbf{E = A_s \ x \ EF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{Eq.(17)}$$

Where, E is Total PM Emissions; A_s is total construction area and EF is Emission Factors (USEPA). The emissions from construction activities will be estimated using PM emission factor of 1.2 tons/acre/month of activity provided by EPA. As per a recent study by The Energy & Resources Institute (TERI, 2016) in Surat, PM_{10} and $PM_{2.5}$ emissions from construction areas are approximately 25% and 6% of the total PM mass.

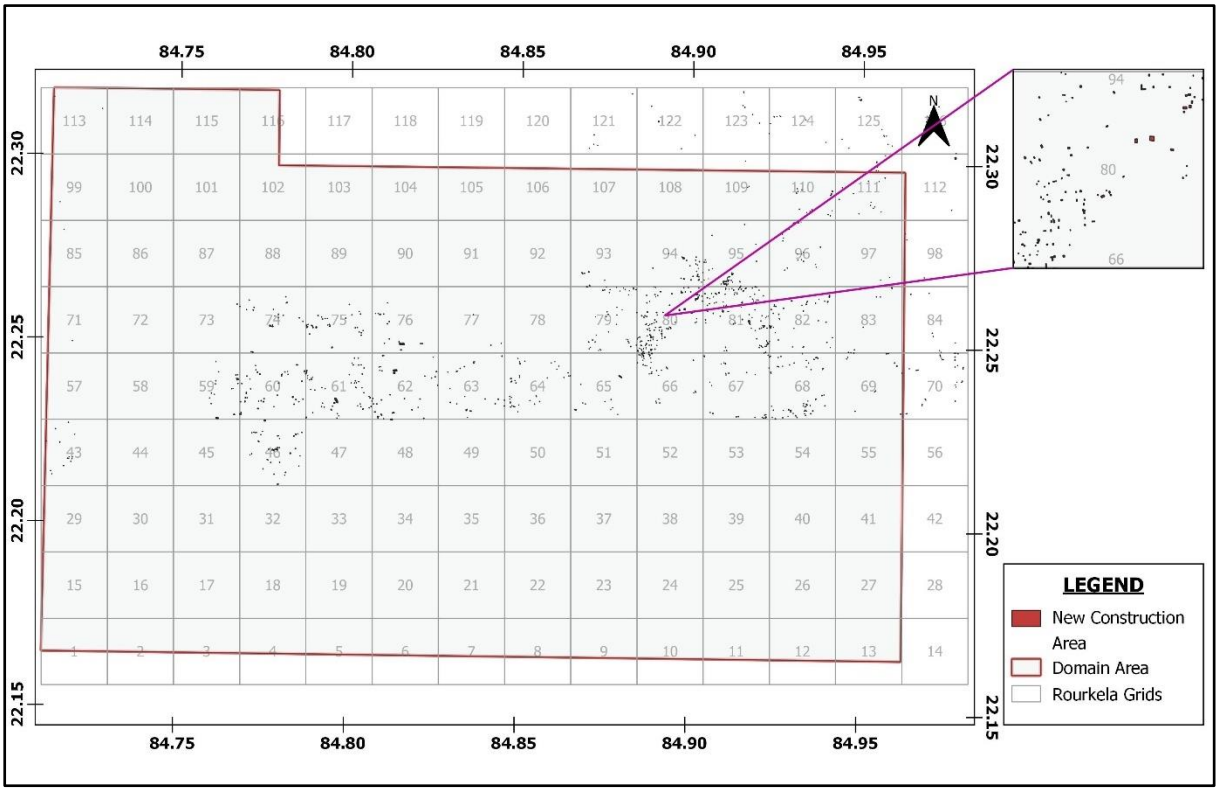

Figure 74 Map showing construction areas identified using the satellite imagery in Rourkela region. The inset view shows zoomed in view of new construction activities in grid no. 80 of the study domain

3.5. Uncertainty in Emission Estimates

In this study, the uncertainties are quantified using uncertainty aggregation method prescribed by EMEP and IPCC (2006). Uncertainty aggregation method is used to propagate the uncertainty introduced by activity data (AD) and emission factors (EFs) to any combination/aggregation of sources. Analyses are conducted for the emission baseline year 2022 for pollutants including PM10, PM2.5, SO2, NOx, and CO.

Primarily, the uncertainty in emission estimates is a function of the uncertainty of input data i.e. activity and emission factors, used to compile the inventory. The uncertainty in the AD (u_{AD}) collected from authorities, local administration and primary surveys is mainly of a statistical nature, stemming from incompleteness, representativeness of sampling, the imputation of missing data, and extrapolation (Rypdal and Winiwarter, 2001; Olivier, 2002; IPCC, 2006; Solazzo et al., 2021). The urban level statistics and data are believed to be comparatively more reliable and robust than the rural and other areas. Hence, the sector-wise activity data uncertainties for urban or city areas and other areas are calculated, separately.

The uncertainty in the EF (u_{EF}) has many sources – for example, the degree of representativeness of the limited number of observations underlying the EF, including the under-representativity of operating conditions, the inaccuracy of assumptions and/or of source aggregation, bias, variability, and/or random errors (IPCC, 2006; Solazzo et al., 2021).

As per method prescribed by IPCC (IPCC, 2006), the emission uncertainty (u_E) is the sum of the squares of the uncertainty of activity data (u_{AD}) and the uncertainty of emission factors (u_{EF}; Eq. (18)). It is assumed that uncertainties of different source categories are uncorrelated (e.g. industries and waste burning).

$$u_E = \sqrt{u_{AD}^2 + u_{EF}^2} \ldots\ldots\ldots\ldots Eq.(18)$$

The uncertainty estimates are provided along with baseline emission inventory estimates in section 3.7.

3.6. Exclusion of sectors in emission inventory

As described previously, this study has considered __ source sectors in development of emission inventory for the Bhubaneswar-Cuttack region. Although, the sectors listed above represent regional emissions in Bhubaneswar-Cuttack region adequately; there are certain sectors which are not considered in this study. This section presents a brief discussion on excluded sectors/sources of air pollution in the present emission inventory.

3.6.1. Agricultural burning and forest fires

Agricultural burning and forest fires are considered as an important source of air pollution in the regional context of many Indian cities. A preliminary analysis of satellite derived fire counts and Fire Radiative Power (FRP) is conducted over the study domain for the baseline year 2022. The analysis was conducted using VIIRS Soumi NPP fire data, downloaded from NASA's Fire Information for Resource Management System (FIRMS; https://firms.modaps.eosdis.nasa.gov/). The downloaded data in shapefile format was pre-processed to remove any false fire counts observed over Industrial stacks in the Bhubaneswar-Cuttack region. Annexure G-6 depicts the time series plot of daily fire counts observed during year 2022 over Bhubaneswar-Cuttack study domain. As shown in Annexure G-6, the daily fire incidents/counts over study domain are very low, reaching maximum upto 10, during summer months. These fire incidents are mainly observed over the forest areas located on the western part and isolated places on the outskirts of the study domain. Considering insignificant numbers and intensity of fire incidents over study domain, the emissions from such activities are excluded from the regional inventory.

3.6.2. Rail transport

The emissions from Railway operations are not considered in this study. During the initial discussion with stakeholders and literature review, it was learned that railway operations in the region are mainly electricity-based and may not constitute to local/regional emissions.

3.7. Sectorial Emission Inventory

3.7.1. Transport

Figure 75 shows the emissions of pollutants originating from transport sector in Rourkela region. It can be seen that CO is the maximum contributing pollutant with emissions of 9518.3 tonnes per year, followed by NMVOCs (3446.8 tonnes per year), NO_X (4205.5 tonnes per year). Transport sector contribution to city level PM_{10} and $PM_{2.5}$ was found to be 574.5 and 545.8 tonnes per year, respectively. It is important to note that, the vehicular exhaust PM emissions predominantly consist of fine particles i.e. particles having aerodynamic diameter less than or equal to 2.5 µm (Ketzel et al., 2007). Following the approach suggested by Sharma and Dikshit (2016), PM vehicular exhaust emission factors are used directly for quantifying PM_{10} while $PM_{2.5}$ fraction is assumed to be 90% of PM_{10} emissions. The core area of the city accounts for one-third emissions of city level air pollutants, owing to dense road network, population and higher on-road activities.

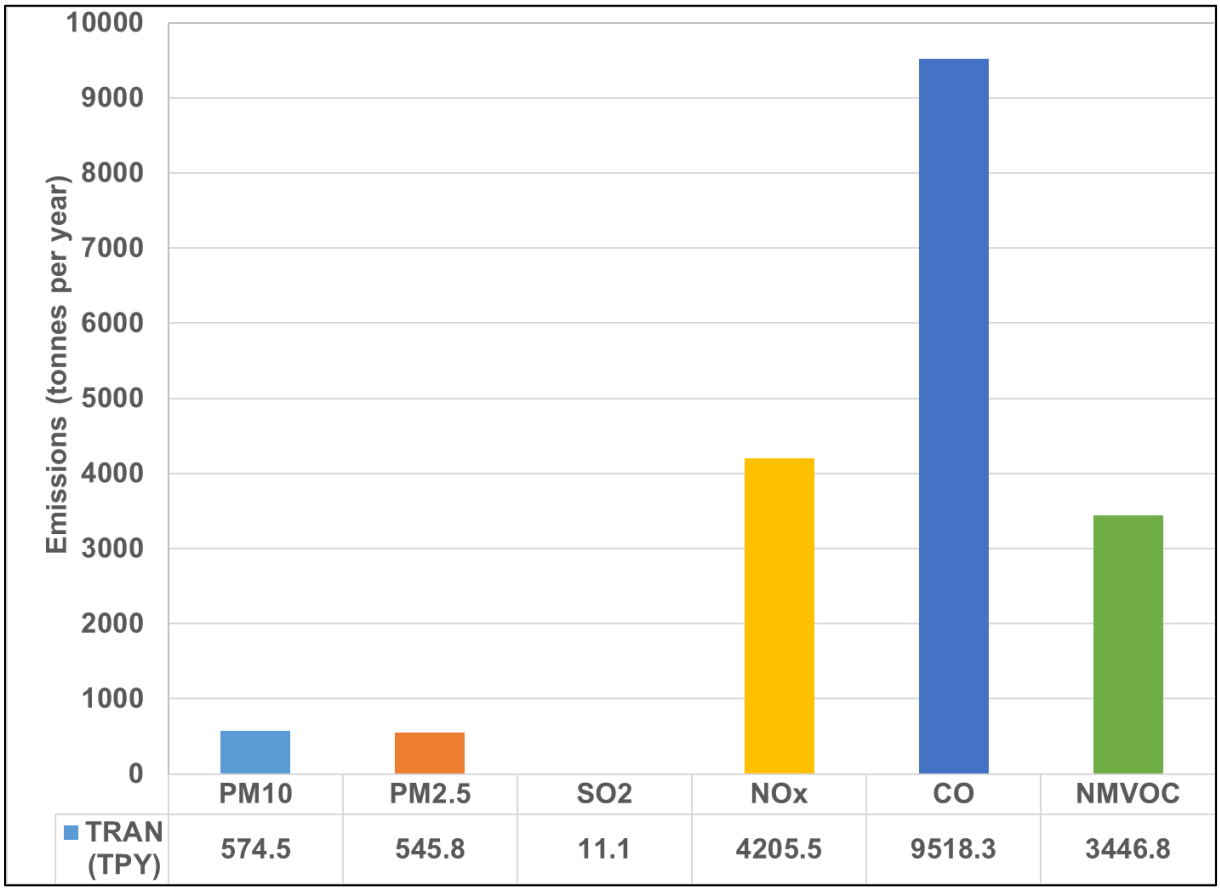

Figure 75: Emission loads (tonnes per year) of pollutants originating from the transport in Rourkela region

3.7.2. Road dust resuspension

The emissions generated due to road dust re-suspension in Rourkela region are depicted in Fig. 76. The road dust contributes only to particulate matter and not the gaseous pollutants. The road dust primarily contributes to the coarse fraction of PM i.e. PM_{10} and emissions are estimated to be 3823.4 tonnes per year in city and 925.0 tonnes per year in the core area. $PM_{2.5}$ emissions from road dust re-suspension are about four times lower than PM_{10} emissions

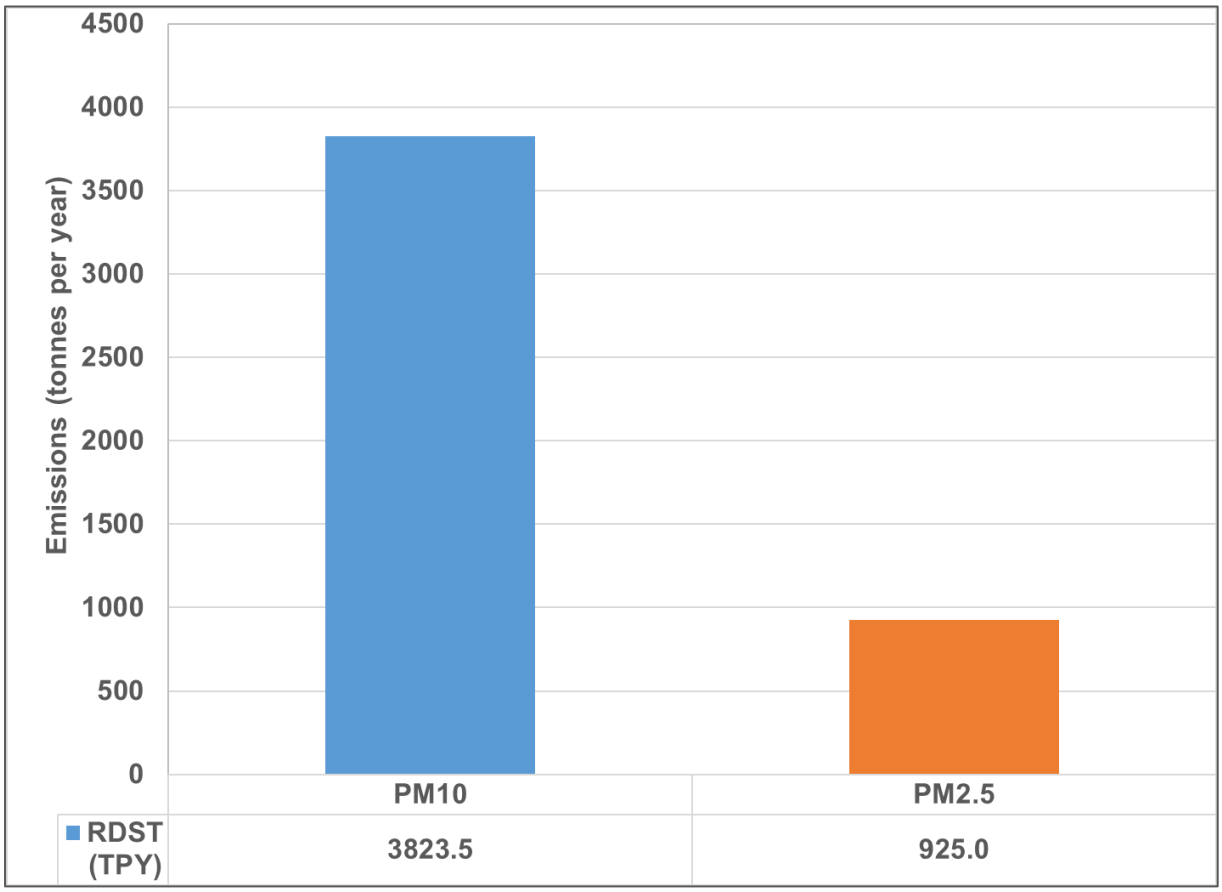

Figure 76: Emission load (tonnes per year) of pollutants originating from the road dust resuspension sector in Rourkela region

(Note: Emission loads for pollutants other than PM_{10} and $PM_{2.5}$ are "NOT APPLICABLE")

3.7.3. Open waste burning

Figure 77 presents the emissions of air pollutants originating from open waste burning in Rourkela region. It is observed that, due to incomplete combustion of the waste a large amount of CO would be introduced into the atmosphere (841.2 tonnes per year) followed by NMVOCs (182.1 tonnes per year), PM_{10} (175.8 tonnes per year) $PM_{2.5}$ (163.2 tonnes per year), NO_X (25.1 tonnes per year) and SO_2 (11.2 tonnes per year).

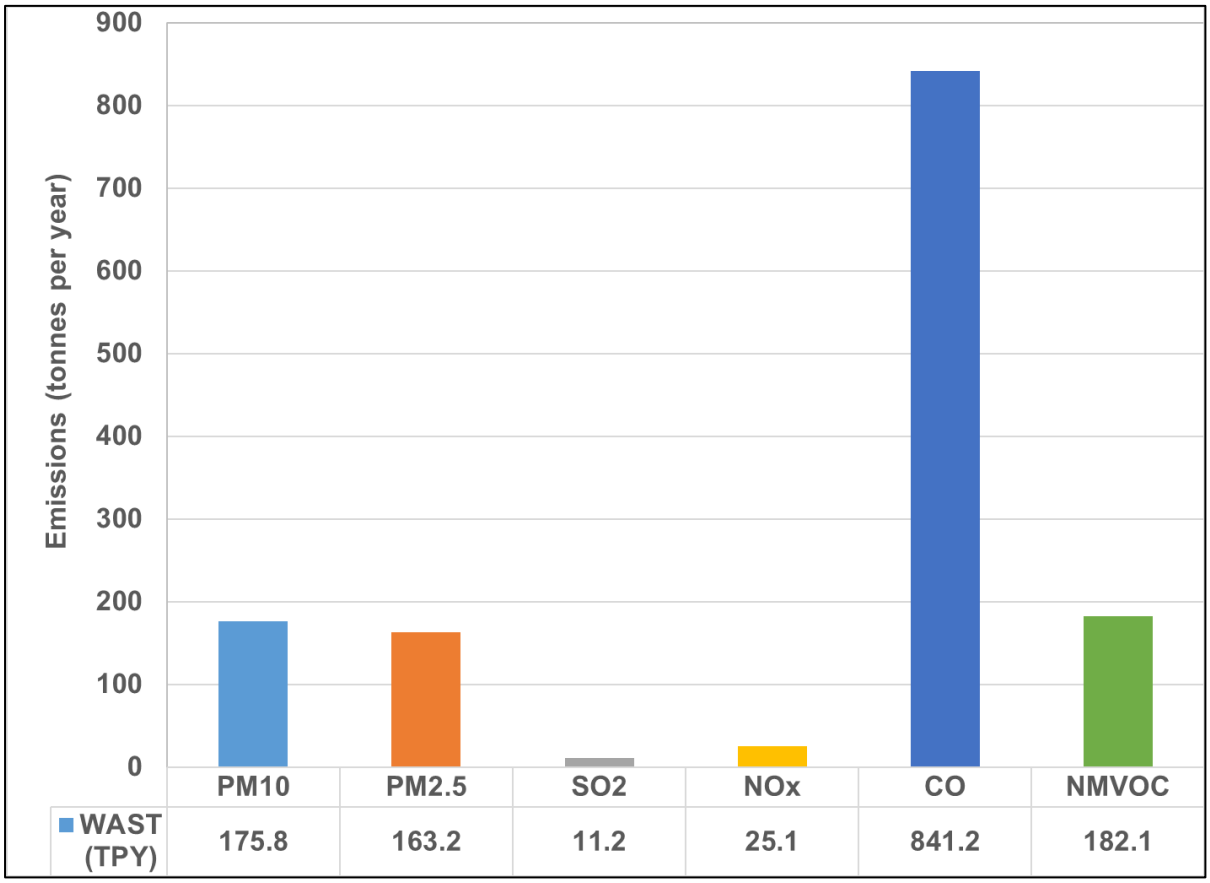

Figure 77 Emission load (tonnes per year) of pollutants originating from the open waste burning sector in Rourkela region

3.7.4. Residential

Figure 78 depicts the emission loads originating from residential sector in Rourkela region and core area. CO is found to be the major pollutant from residential sector with annual emissions of 3953.0 tonnes per year, followed by NMVOCs (1466.9 tonnes per year), PM_{10} (420.5 tonnes per year), $PM_{2.5}$ (280.4 tonnes per year), NO_X (186.9 tonnes per year) and SO_2 (131.9 tonnes per year).

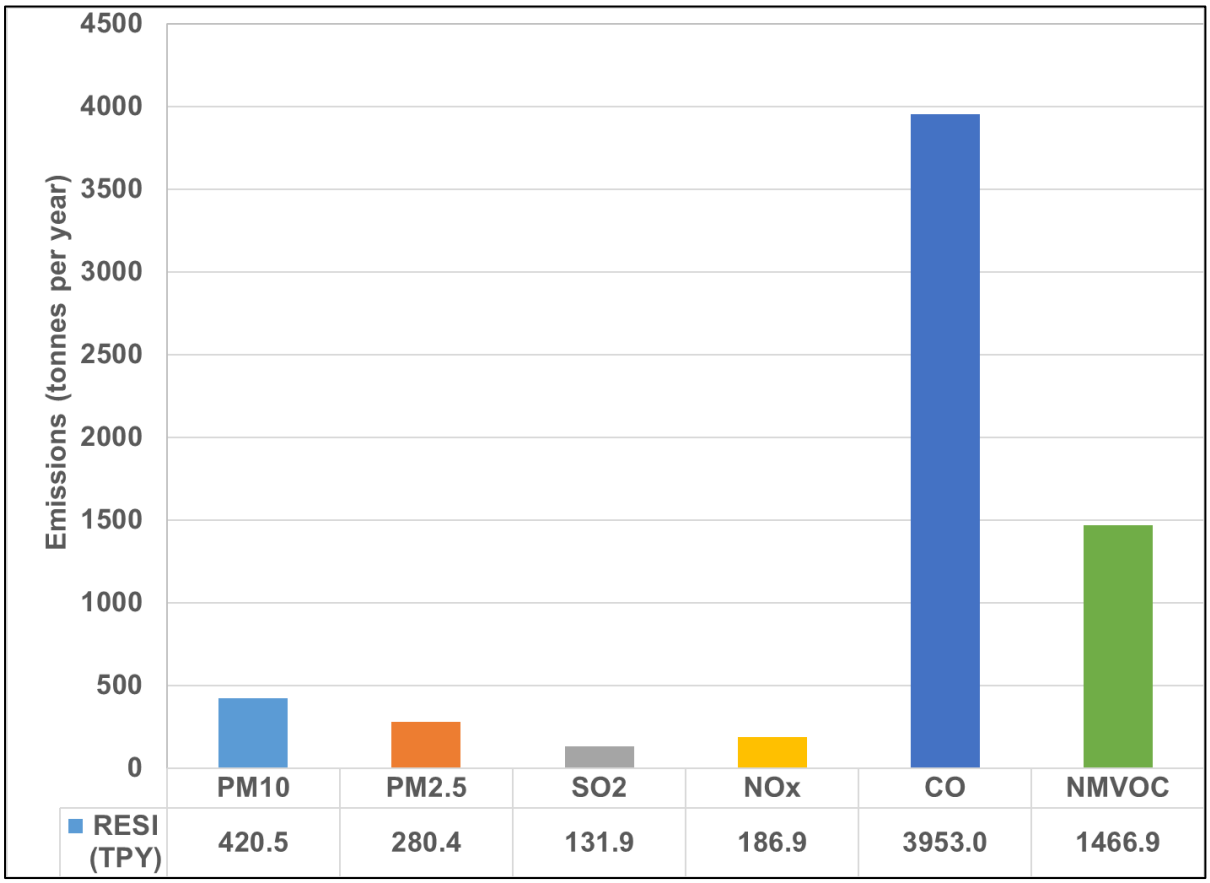

Figure 78: Emissions load (tonnes/year) of pollutants originating from residential sector in Rourkela region

3.7.5. Industries and thermal powerplants

The stack emissions originating from industries are shown in Figure 79. CO is the major contributor (96164.3 tonnes per year) in Rourkela region. Followed by SO_2 (35659.0 tonnes per year), NO_X (28512.2 tonnes per year), PM_{10} (9527.4 tonnes per year) and $PM_{2.5}$ (4384.8 tonnes per year).

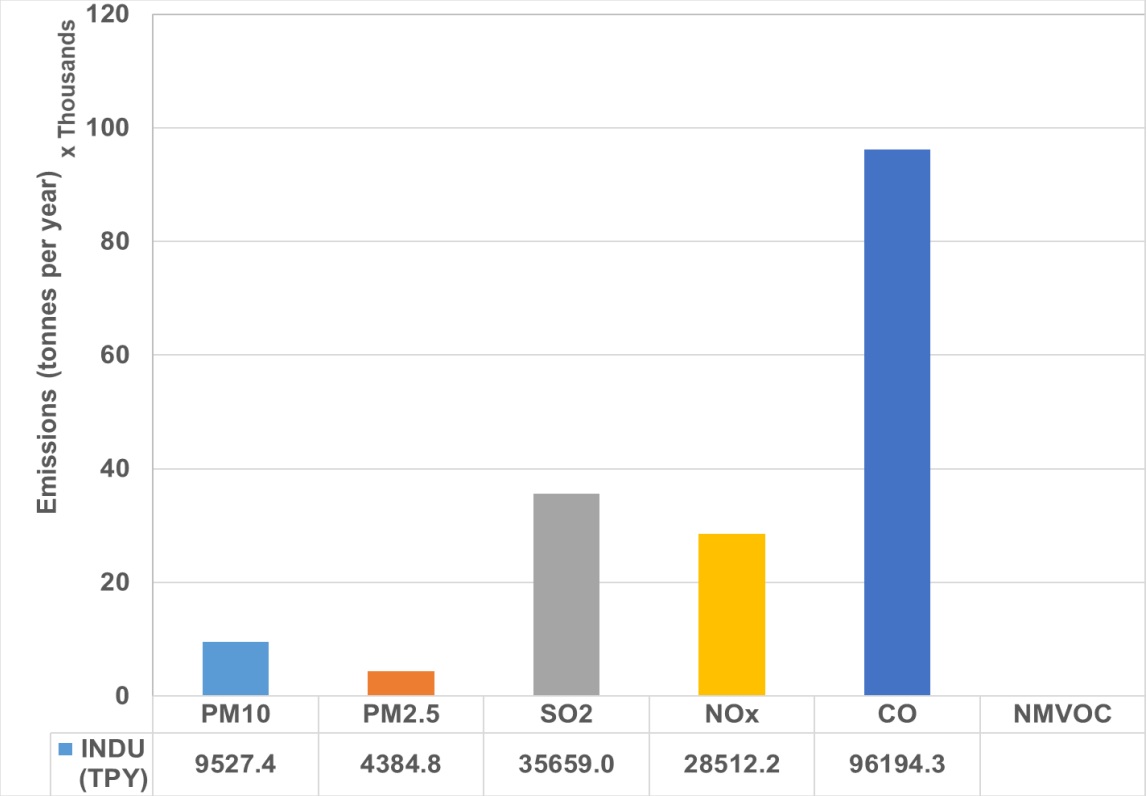

Figure 79: Emissions load (tonnes per year) of pollutants originating from industrial and thermal powerplant sectors in Rourkela region

Rourkela steel plant and NTPC SAIL Powerplant are major emitters in city limits whereas Sponge Iron units located in Kalunga and are major emitters outside city limits. Fig. 80, depicts relative contributions (%) of different industrial units/areas to total industrial stack PM Emissions load (tonnes per year) in Rourkela region. In terms of PM_{10}, Kalunga industrial estate is the top contributor with share of 42.5%, followed by SAIL Steel plant (SAIL, 23.8%), Kaurmunda industrial estate (KAUR, 22.7%) and NTPC powerplant (NTPC, 11.0%). On the other hand, $PM_{2.5}$ stack emissions are dominated by SAIL Steel plant (SAIL, 34.4%), followed by Kalunga industrial estate (KALN, 32.3%), Kaurmunda industrial estate (KAUR, 17.2%) and NTPC powerplant (NTPC, 16.0%).

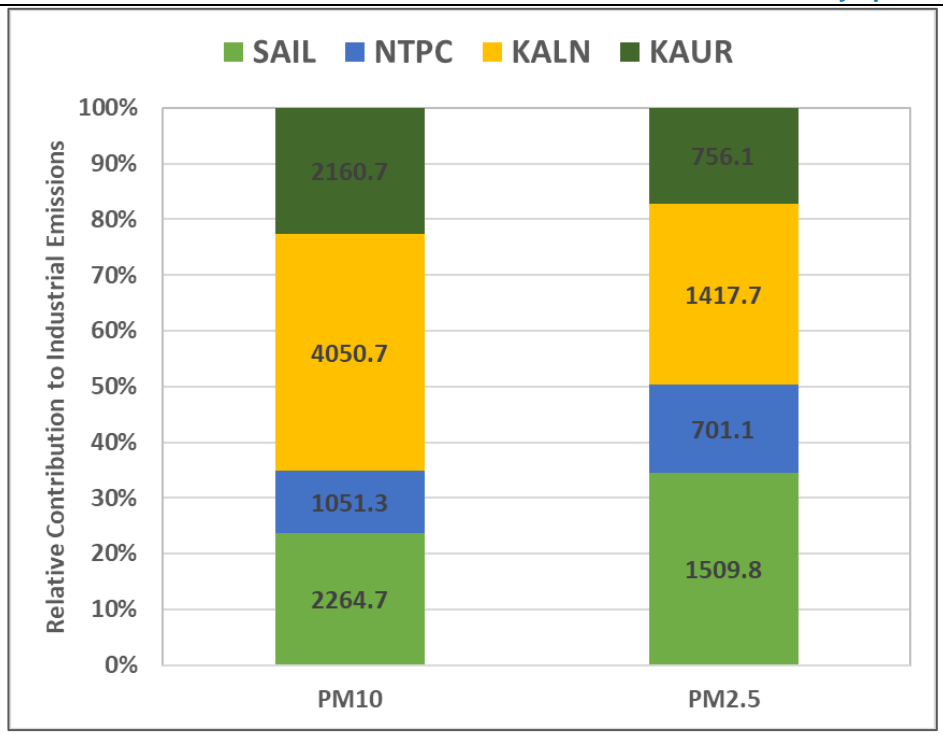

Figure 80: Relative contributions (%) of different industrial units/areas to total industrial stack PM Emissions load (tonnes per year) in Rourkela region.

Note: The numbers inside each bar represent industrial stack PM Emissions load in tonnes per year

3.1.1. Fugitive Emissions

In addition to industrial process emissions, fugitive dust also contributes a significant share of particulate emission load. Further, unlike stack emissions, these emissions are generally released close to surface, thereby increasing their relative contributions to ambient particulate matter. Figure 81 shows the fugitive emissions load originating from different industrial operations in Rourkela region. PM_{10} was estimated to be 2050.4 tonnes per year, followed by $PM_{2.5}$ (205.0 tonnes per year).

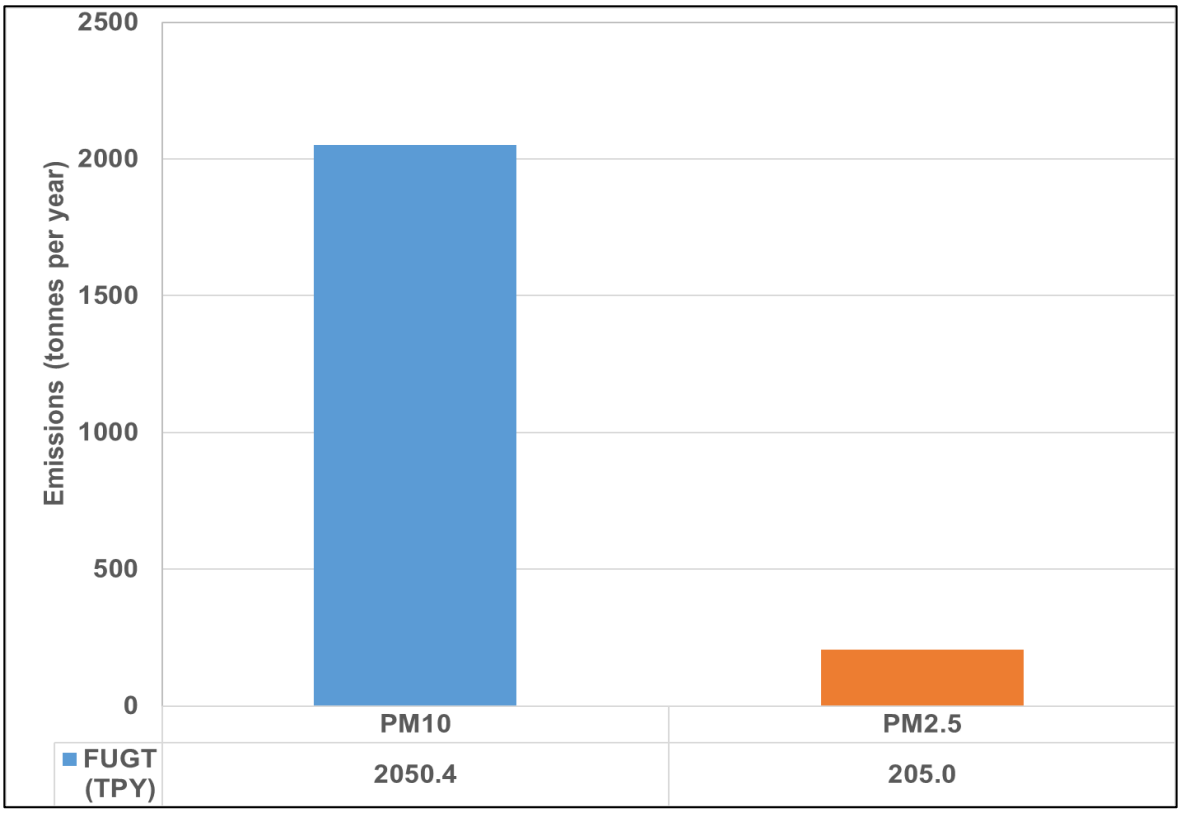

Figure 81: Emissions load (tonnes per year) of pollutants originating from fugitive operations in Rourkela region

3.1.2. Industrial diesel generators

Figure 82 shows emissions of pollutants originating from diesel generators usage. NMVOC is the major contributor (491.4 tonnes per year) in Rourkela region. Followed by NOX (344.0 tonnes per year), CO (74.3 tonnes per year), PM_{10} (24.3 tonnes per year), SO_2 (22.7 tonnes per year) and $PM_{2.5}$ (21.3 tonnes per year).

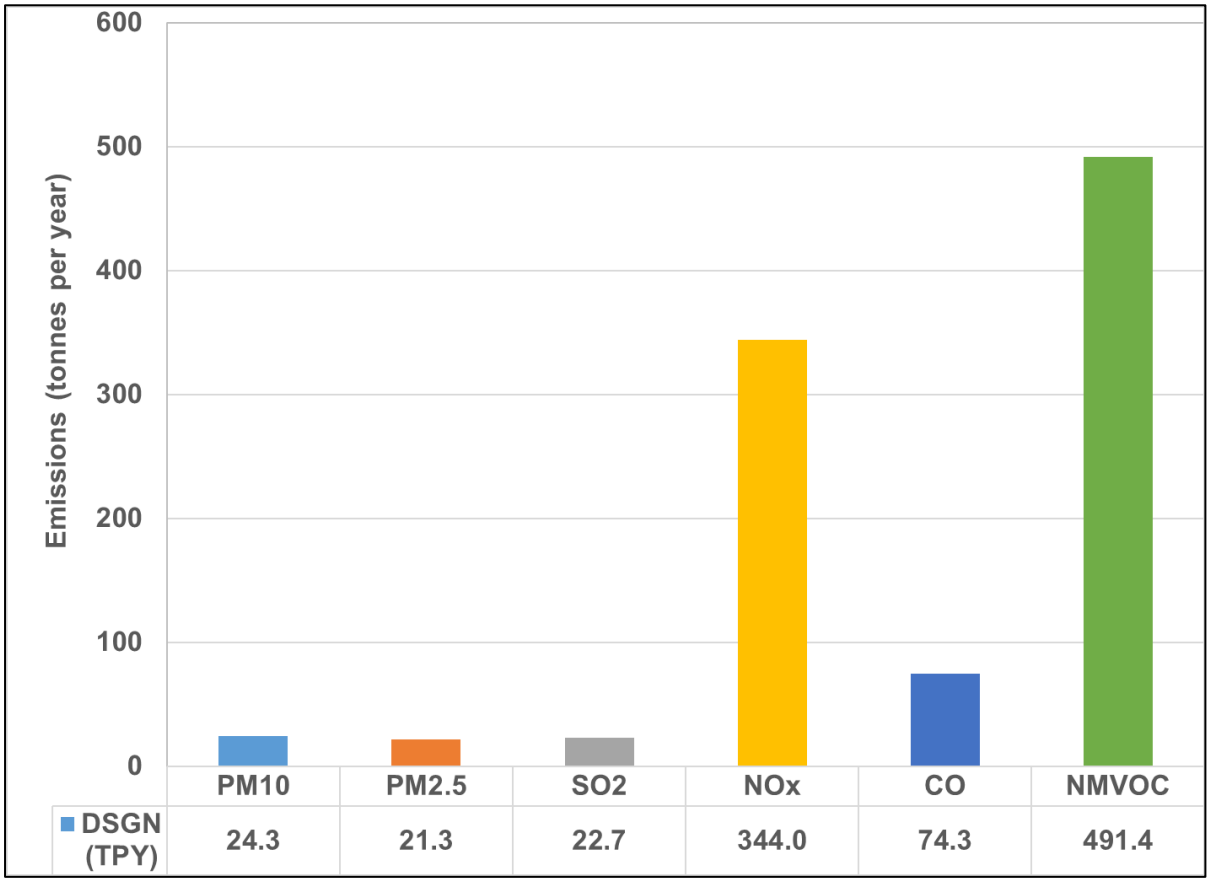

Figure 82 Emissions load (tonnes per year) of pollutants originating from diesel generators usage in Rourkela region

3.1.3. Hotels, restaurants and bakeries

Figure 83 presents the emissions load contributed by Hotels, Restaurants and Bakeries in Rourkela region. CO has been found to be the major contributor 291.3 tonnes per year, followed by, PM_{10} (44.0 tonnes per year), $PM_{2.5}$ (32.0 tonnes per year), NMVOC (20.7 tonnes per year) and NO_x (6.5 tonnes per year). SO_2 was found to be the lowest contributing pollutant in this sector with emissions of 1.2 tonnes per year. This is primarily because of the type of fuel used in hotels and restaurants. Restaurants generally prefer use of LPG for general purposes and coal/wood for tandoor like applications, which in turn leads to lower NO_X but higher CO emissions.

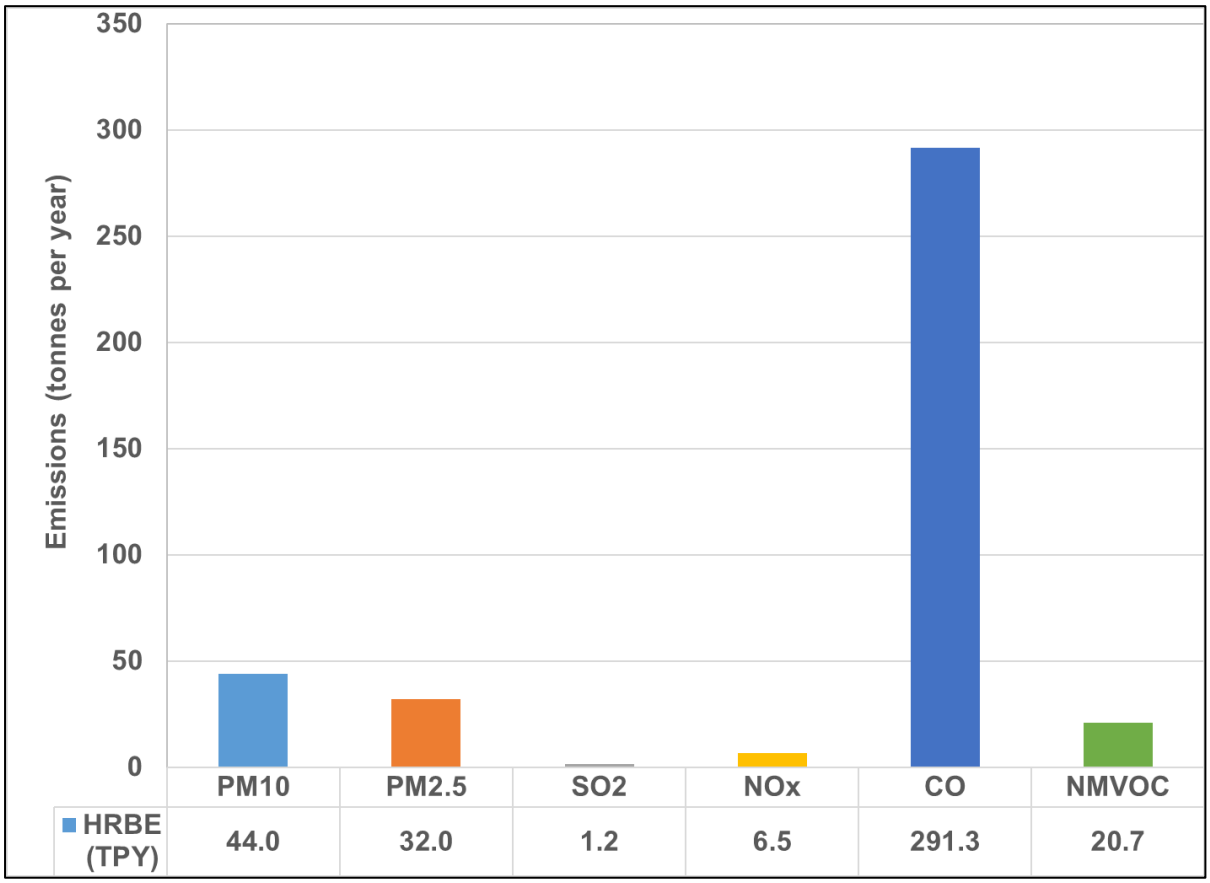

Figure 83: Emissions load (tonnes per year) of pollutants originating from hotels, restaurants and bakeries in Rourkela region

3.1.4. Crematoria

Figure 84 shows the emissions of pollutants originating from crematoria in Rourkela region. CO is the maximum contributor with emissions of 105.6 tonnes per year, followed by NMVOCs (58.9 tonnes per year), PM_{10} (21.0 tonnes per year) and $PM_{2.5}$ (10.3 tonnes per year). NO_X was found to contribute 2.8 tonnes per year of emissions, while SO_2 was found to be the lowest among all pollutants with 0.5 tonnes per year of emissions.

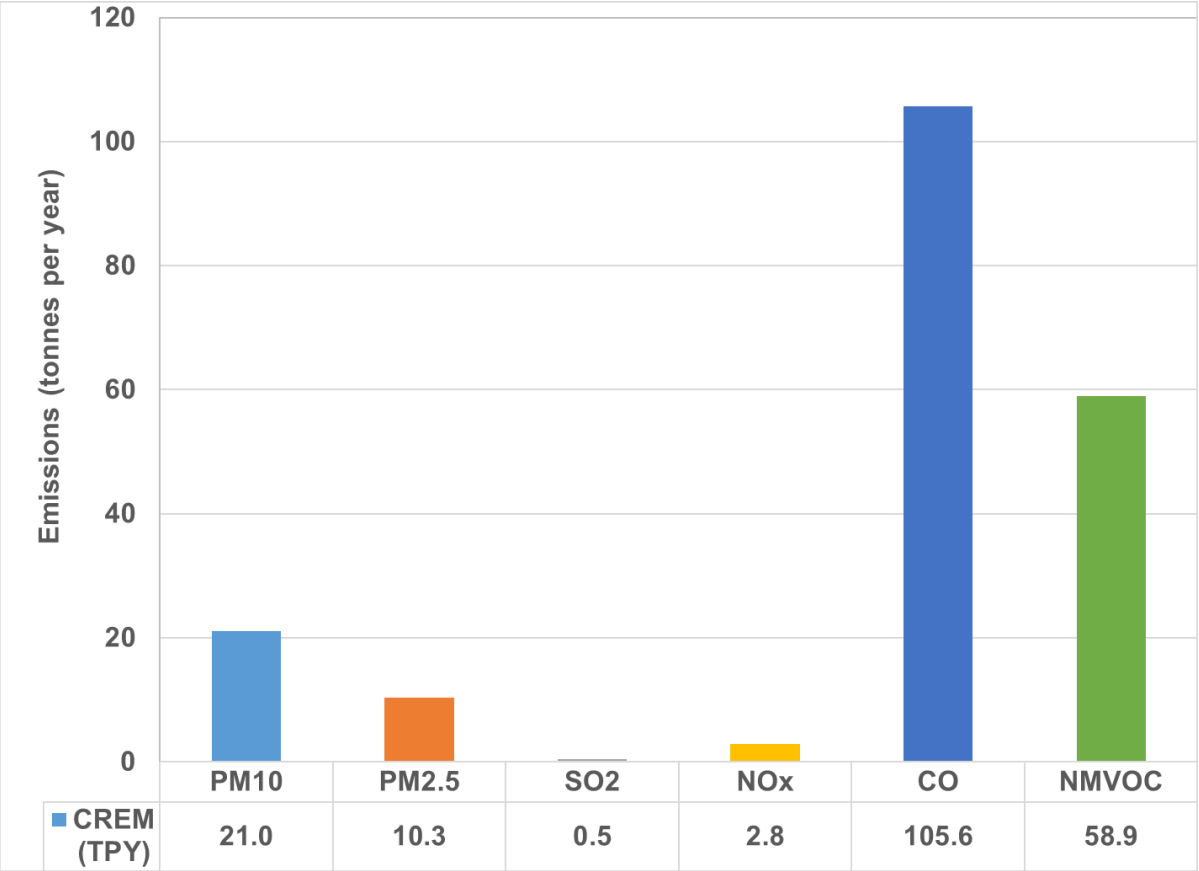

Figure 84 Emissions loads (tonnes per year) of pollutants originating from crematoria in Rourkela region

3.1.5. Brick Kilns

Figure 85 shows the emissions of pollutants originating from brick kilns in Rourkela region. CO is the maximum contributor with emissions of 643.7 tonnes per year, followed by PM_{10} (161.7 tonnes per year), SO_2 (98.8 tonnes per year), $PM_{2.5}$ (46.3 tonnes per year) and NMVOC (18.5 tonnes per year). NO_X was found to be lowest contributor with emission of 0.01 tonnes per year.

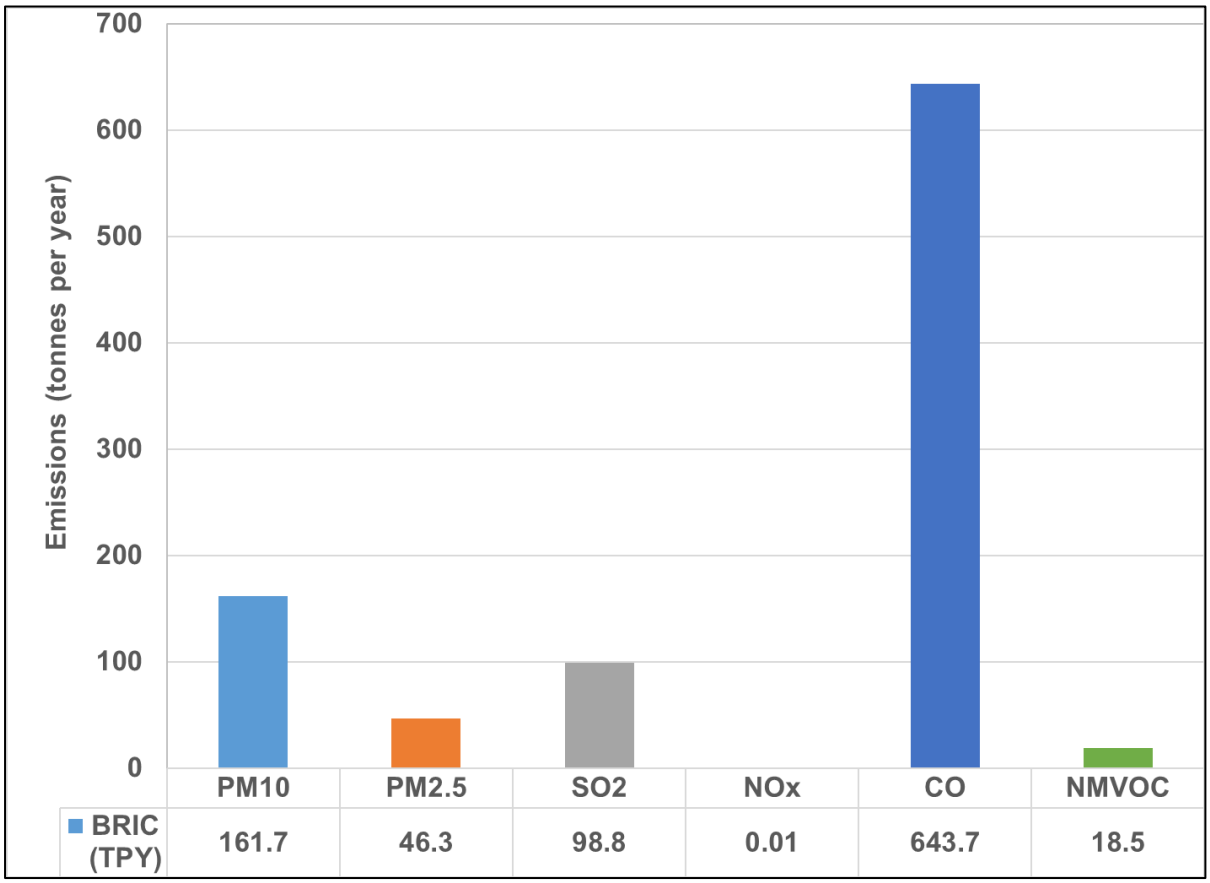

Figure 85 Emissions loads (tonnes per year) of pollutants originating from brick kilns in Rourkela region

3.1.6. Construction

Figure 86 shows the PM_{10} and $PM_{2.5}$ emissions originating from construction activities in Rourkela region. Construction sector is estimated to contribute about 261.2 tonnes per year of PM_{10} and 65.3 tonnes per year of $PM_{2.5}$.

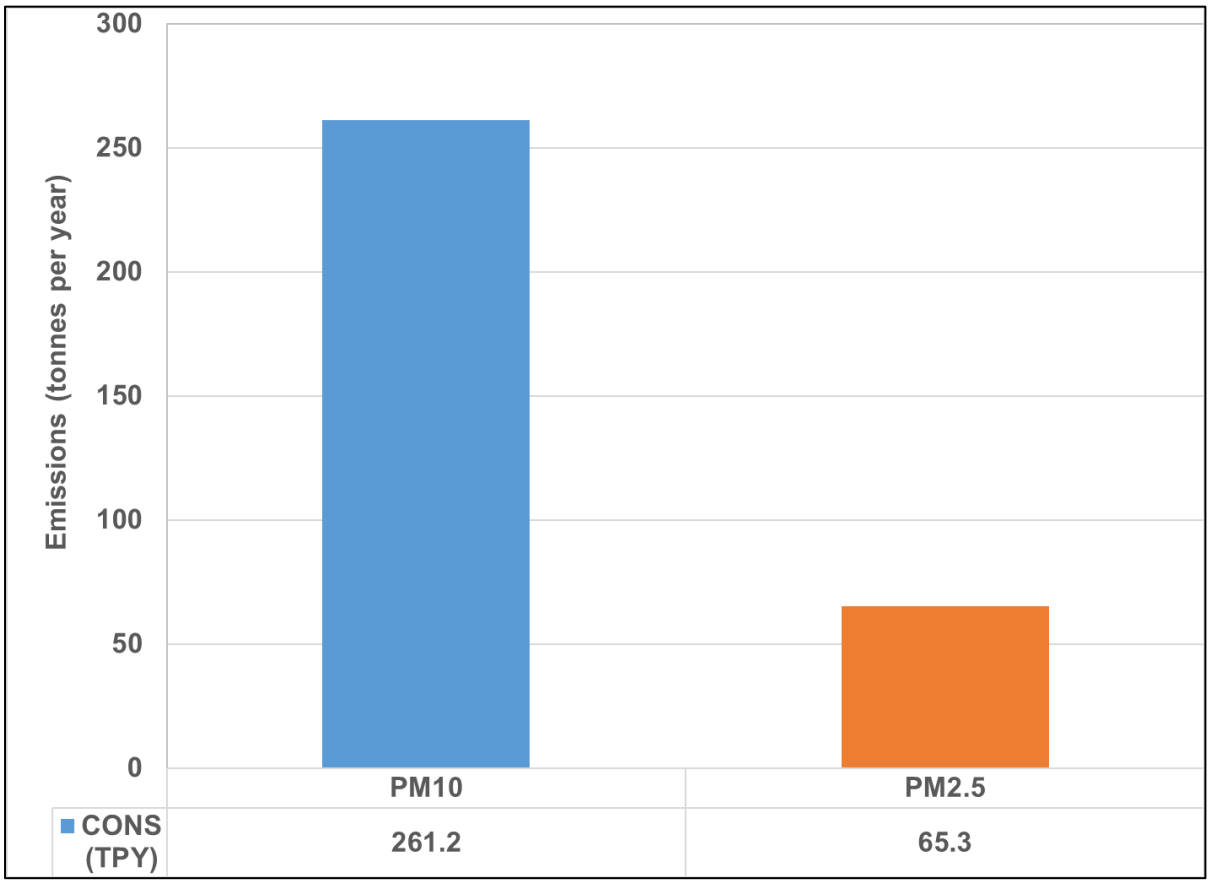

Figure 86: Emissions load (tons/year) of pollutants originating from construction activities in Rourkela region

(Note: Emission loads for pollutants other than PM_{10} and $PM_{2.5}$ are "NOT APPLICABLE")

3.2. Regional Emission Inventory

The overall baseline emission inventory (Year 2021) for the Rourkela region is presented in Table 15, while the spatial distribution of pollutants shown in Fig. 87-92. The sectoral contribution to pollutants is provided in Fig. 93 to 97.

The total PM_{10} emission load in the Rourkela region is estimated to be 16,986.1 tonnes per year. The top four contributors to PM_{10} emissions are industry (56.1%), followed by resuspended road dust (22.5%), fugitive (11.5%) and transport (3.4%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable Daily and seasonal emissions could be highly variable.

$PM_{2.5}$ emission load in the Rourkela region is estimated to be 6,666.8 tonnes per year. The top four contributors to $PM_{2.5}$ emissions are industry (65.8%), resuspended road dust (13.9%), transport (8.2%), and residential (4.2%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

SO_2 emission load in the Rourkela region is estimated to be 35,936.3 tonnes per year. Industrial sector is the top-most contributor to SO_2 emissions with contributions of 99.2%. This is mainly because of coal combustion in iron steel plants and sponge iron units located in Rourkela region. Other sectors together contribute less than 1% of the SO_2 emissions.

The annual NO_X emission load in the Rourkela region is estimated to be 33,217 tonnes per year. Industrial sector is the largest contributor to NO_X emissions (85.7%), followed by Transport sector (12.6%) and diesel generators (1.2%). Open waste burning, Residential and other sectors together contributes less than 1%.

The total annual CO emissions in the Rourkela region are estimated to be 1,11,621.7 tonnes per year. Industrial sector is the major contributor to CO emissions i.e86.2%, followed by Transport (8.5%), Residential (3.5%), open waste burning (0.8%) and brick kilns (0.6%).

Table 15: Baseline (Year 2021) Emission Inventory for the Rourkela region (tonnes per year)

SECTOR	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOC
INDU	9527.42 ± 1964.56	4384.76 ± 904.14	35658.99 ± 3986.67	28512.16 ± 5879.21	96194.31 ± 19835.27	--
TRAN	574.36 ± 150.77	545.64 ± 143.23	11.01 ± 2.17	4139.7 ± 2186.18	9518.31 ± 5026.62	6871.72 ± 3628.95
RDST	3823.46 ± 854.93	925.03 ± 206.84	NA	NA	NA	NA
WAST	175.77 ± 94.65	163.22 ± 87.89	11.2 ± 6.03	25.11 ± 13.52	841.21 ± 452.99	182.05 ± 98.04
CONS	261.23 ± 53.87	65.31 ± 13.47	NA	NA	NA	NA
DSGN	24.33 ± 12.41	21.27 ± 10.85	22.69 ± 5.07	343.97 ± 175.39	74.28 ± 37.88	491.38 ± 250.56
RESI	420.51 ± 214.42	280.45 ± 143	131.9 ± 18.65	186.86 ± 95.28	3952.98 ± 2015.63	1466.9 ± 747.97
BRIC	161.74 ± 87.1	46.31 ± 24.94	98.8 ± 53.2	0.01 ± 0.01	643.72 ± 346.64	18.51 ± 9.97
HRBE	43.96 ± 23.67	31.99 ± 17.23	1.25 ± 0.28	6.53 ± 3.52	291.28 ± 156.85	20.68 ± 11.14
CREM	21.1 ± 10.76	10.38 ± 5.29	0.46 ± 0.06	2.85 ± 1.45	106.09 ± 54.09	59.2 ± 30.19
FUGT	1952.08 ± 995.37	192.31 ± 98.06	NA	NA	NA	NA
TOTAL	16985.98 ± 4462.5	6666.67 ± 1654.93	35936.29 ± 4072.15	33217.28 ± 8354.58	111622.36 ± 27926.02	9110.54 ± 4776.84

NA: indicates the emissions quantification is not applicable for a particular sector. The value after ± indicates uncertainty in emission estimates (tonnes).

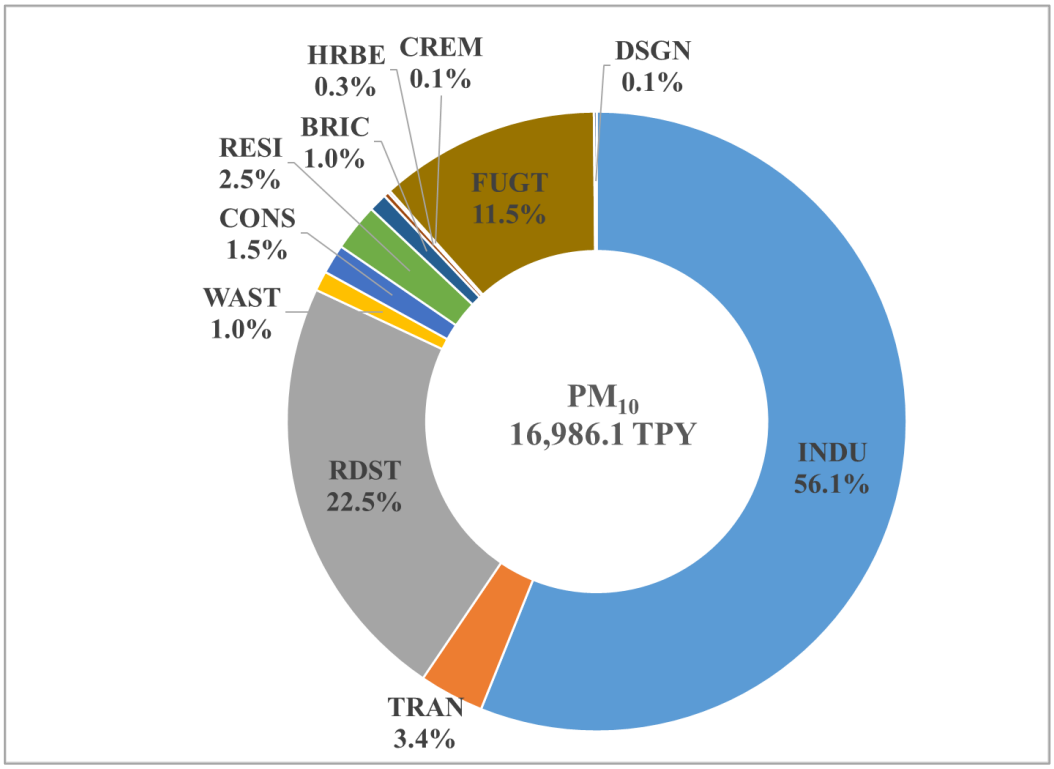

Figure 87 Sectoral contribution to PM_{10} *emissions in Rourkela*

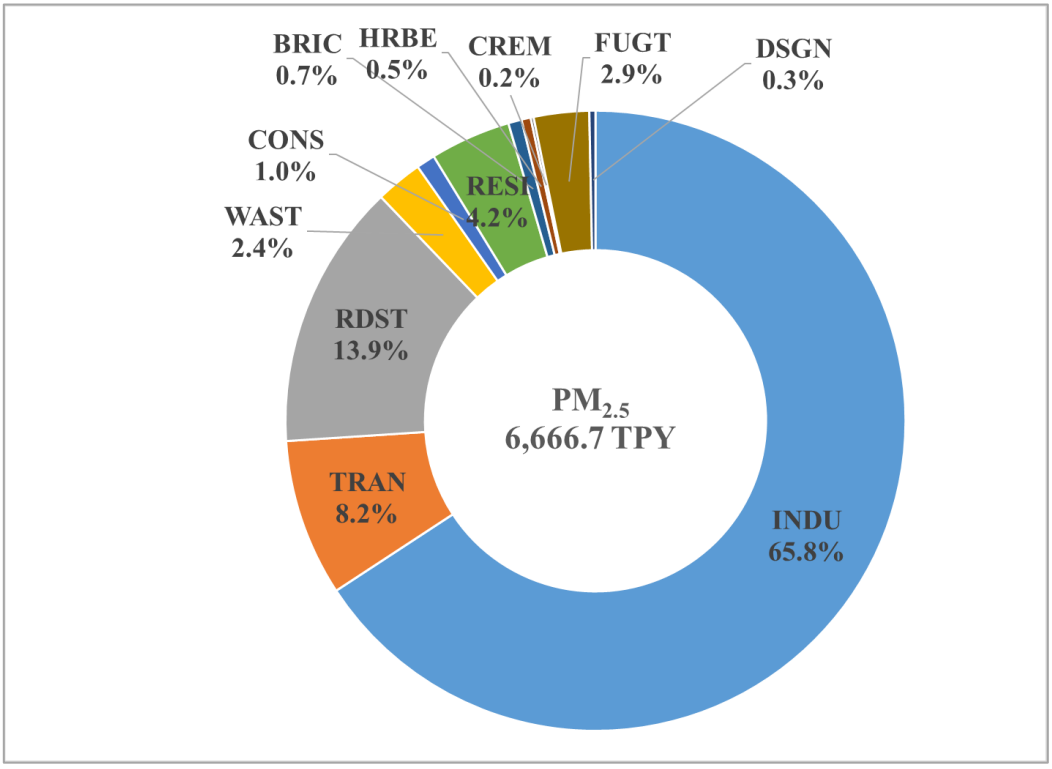

Figure 88 Sectoral contribution to $PM_{2.5}$ *emissions in Rourkela*

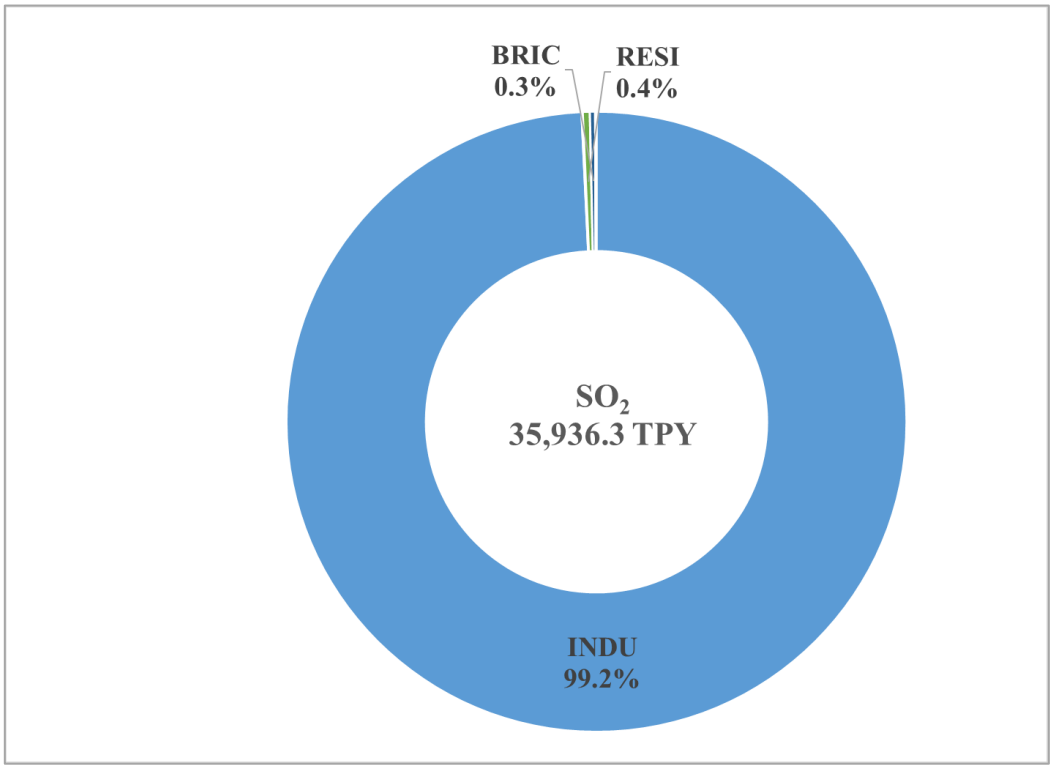

Figure 89 Sectoral contribution to SO_2 *emissions in Rourkela*

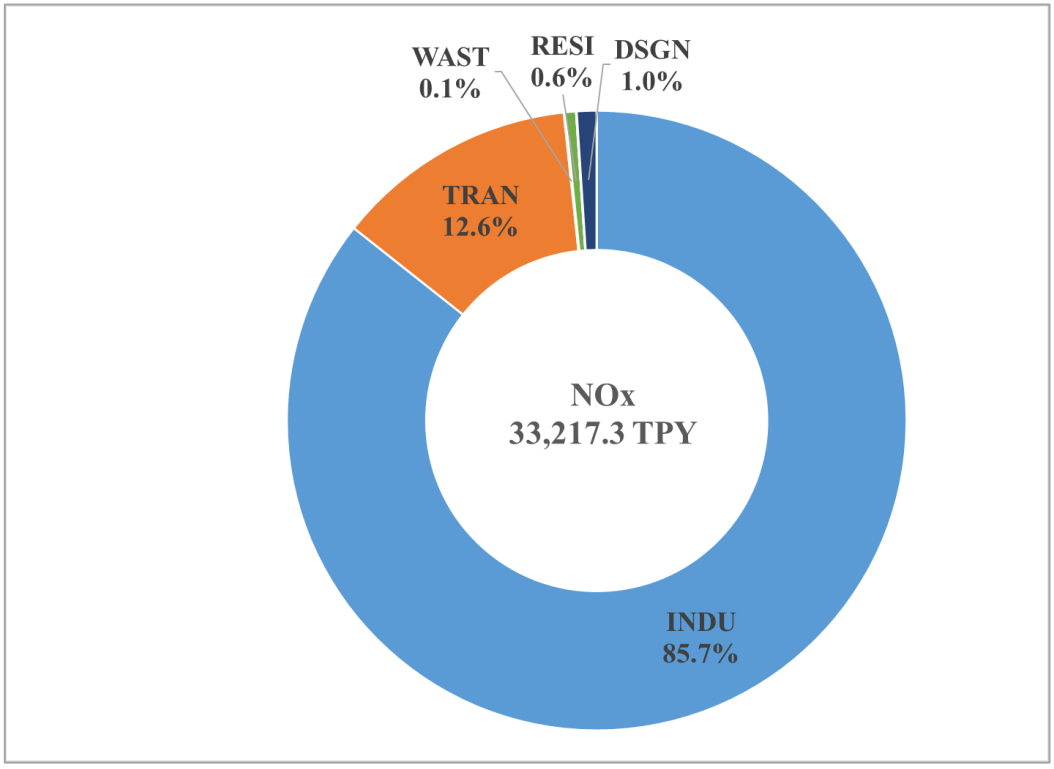

Figure 90 Sectoral contribution to NO_X *emissions in Rourkela*

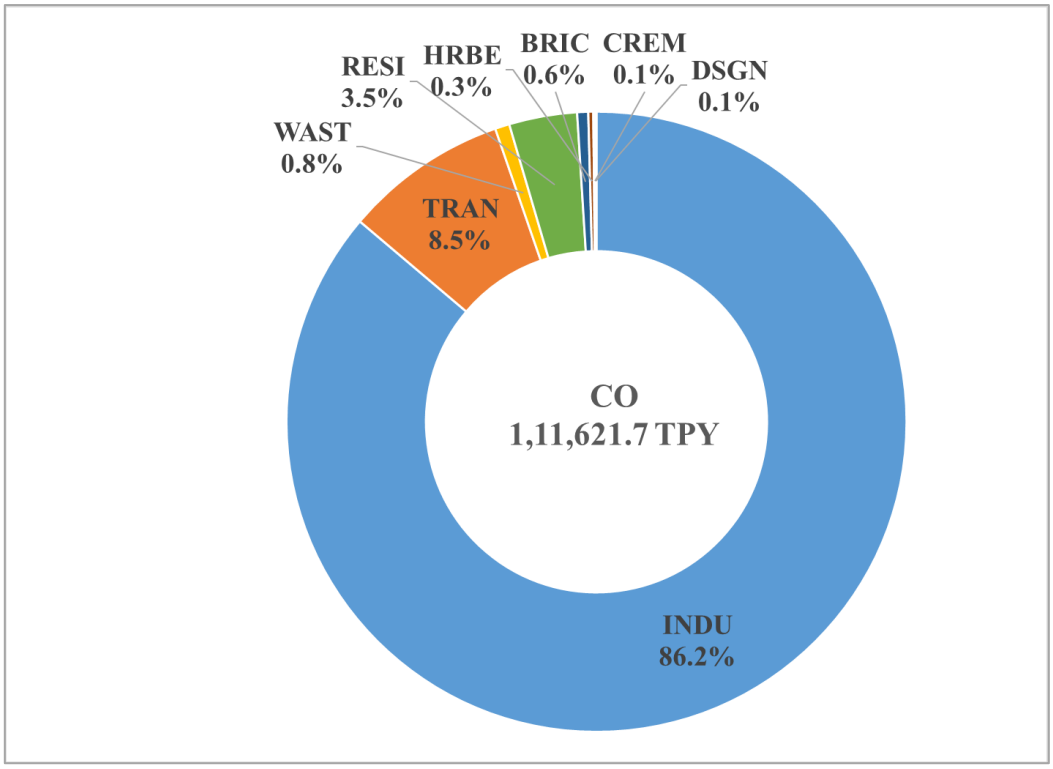

Figure 91 Sectoral contribution to CO emissions in Rourkela

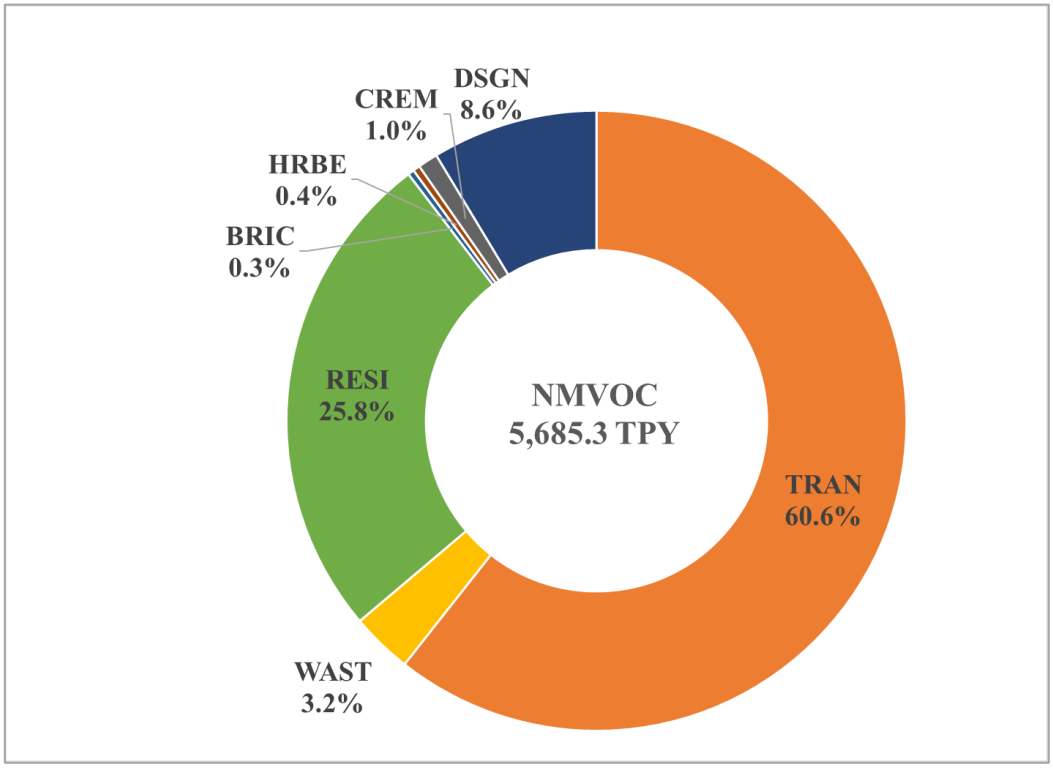

Figure 92 Sectoral contribution to NMVOC emissions in Rourkela

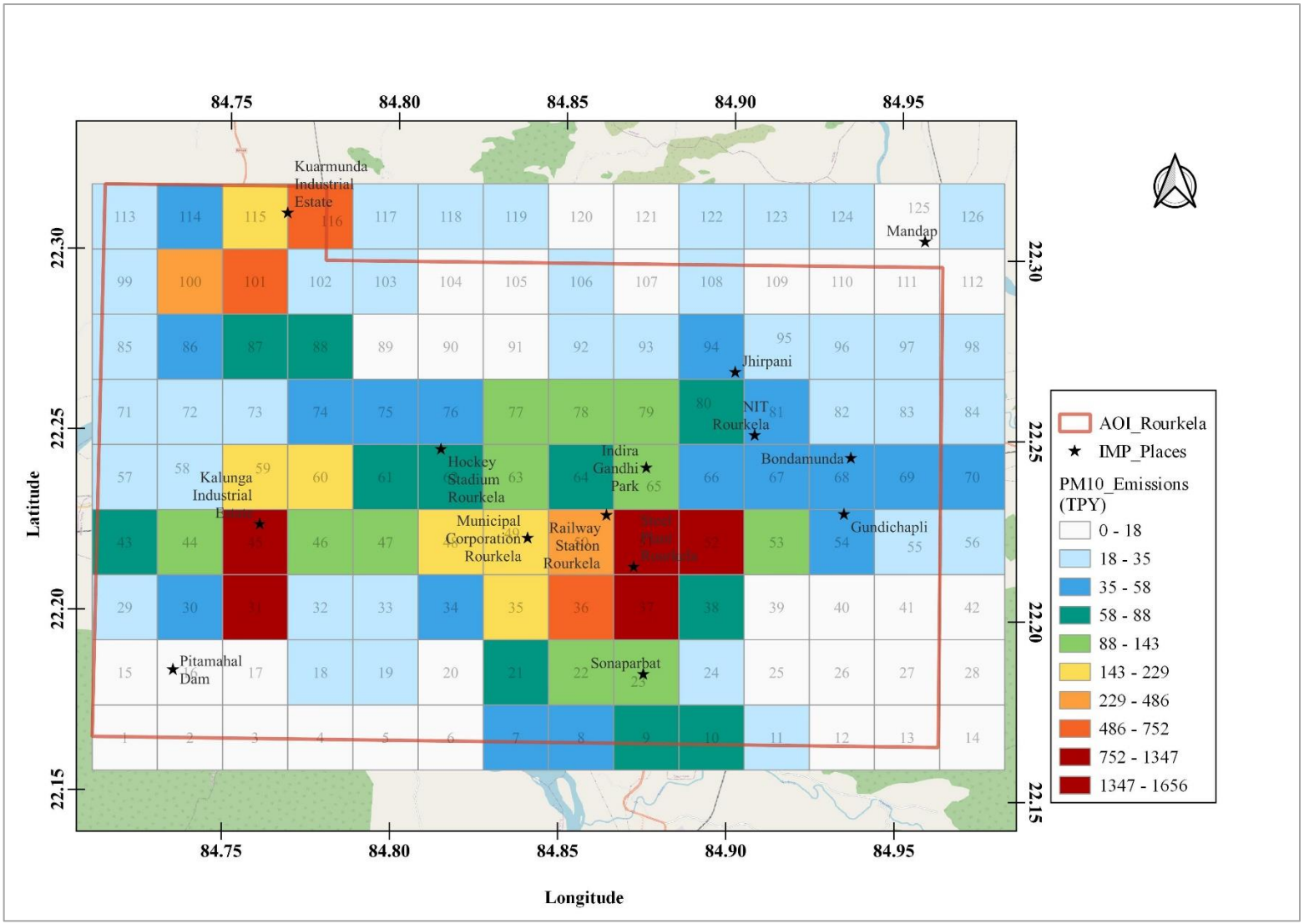

Figure 93: Spatial distribution of PM_{10} *emissions (tonnes per year) in Rourkela region, 2021*

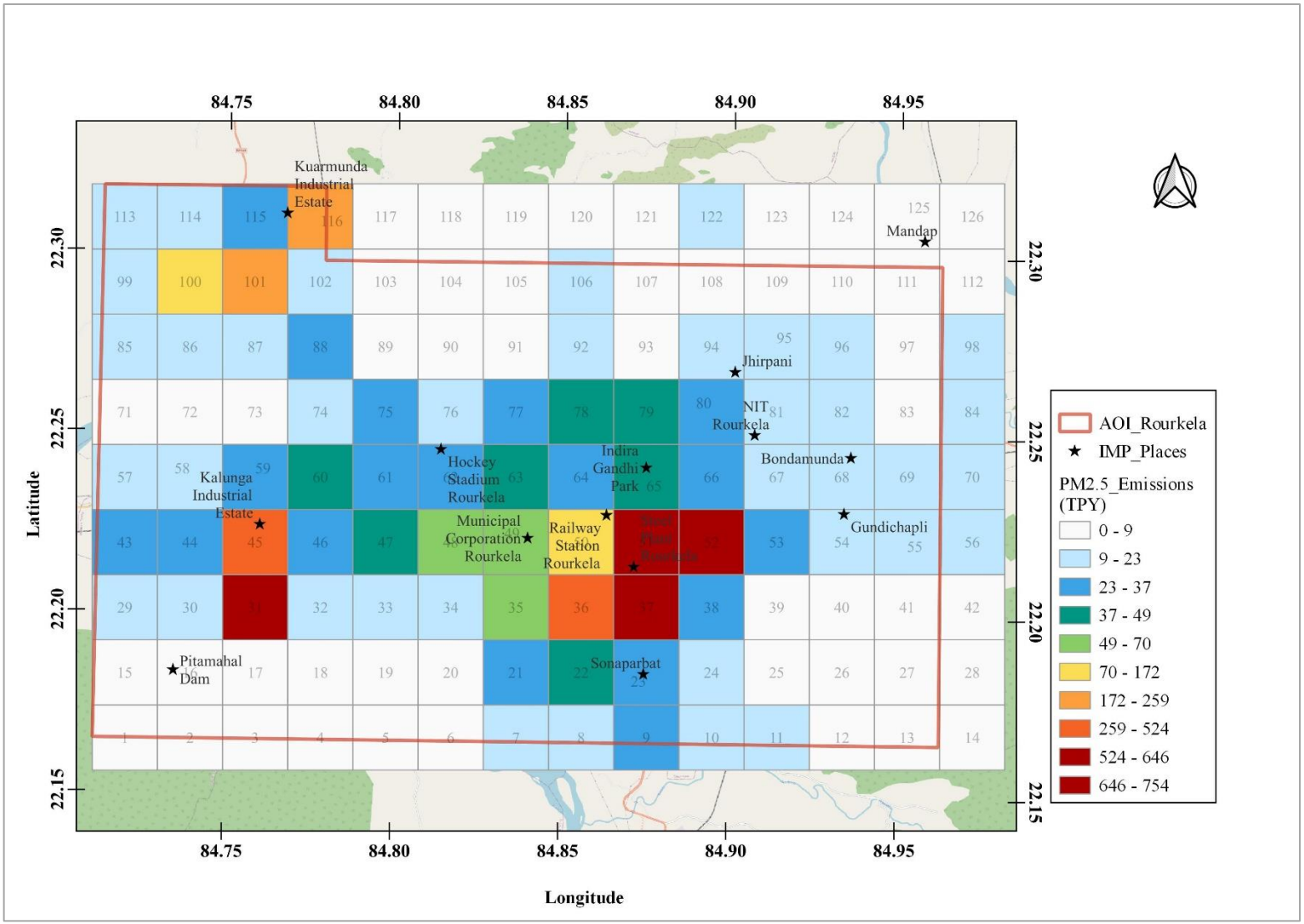

Figure 94: Spatial distribution of $PM_{2.5}$ *emissions (tonnes per year) over study domain in 2021*

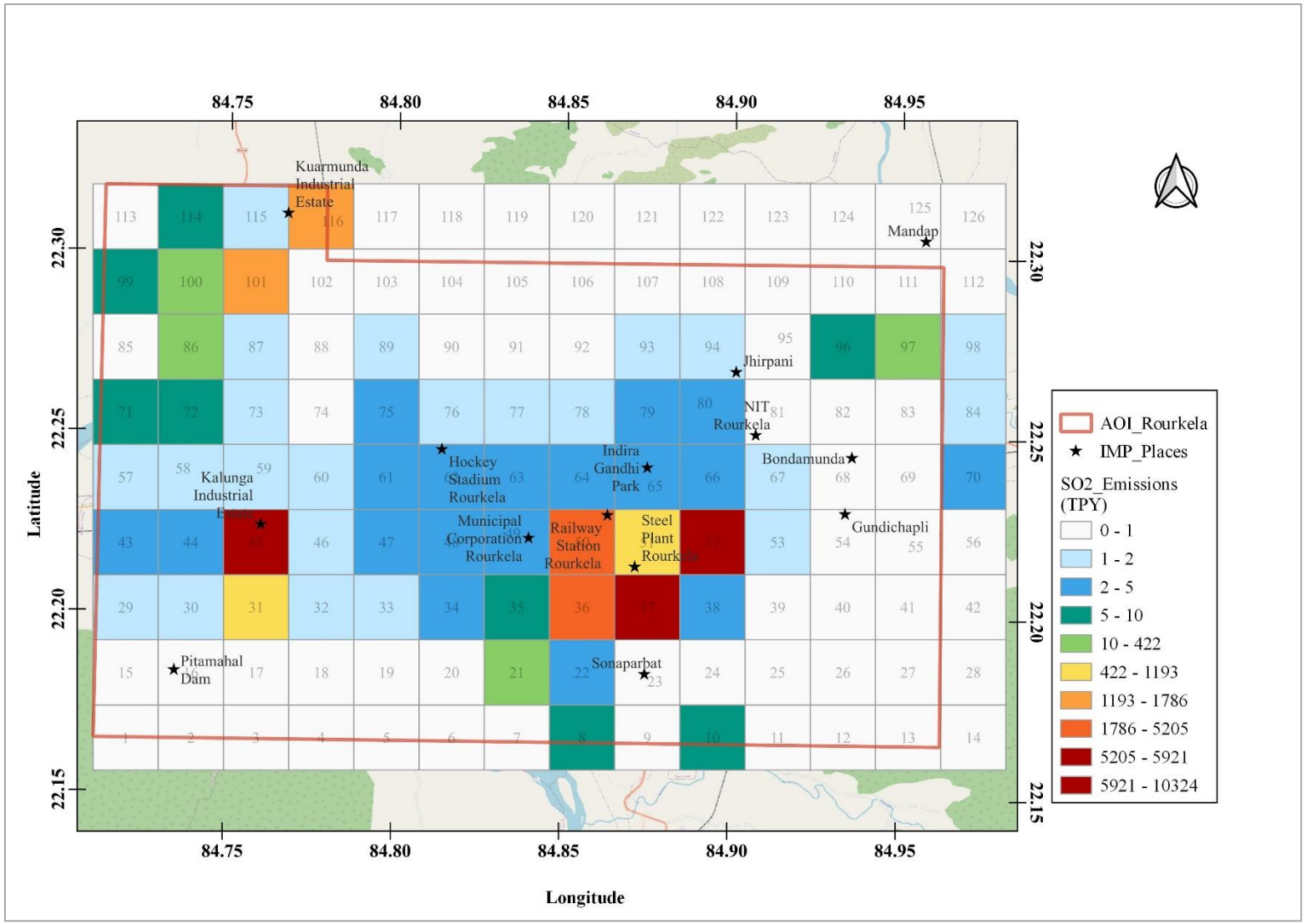

Figure 95 Spatial distribution of SO_2 *emissions (tonnes per year) in Rourkela region, 2021*

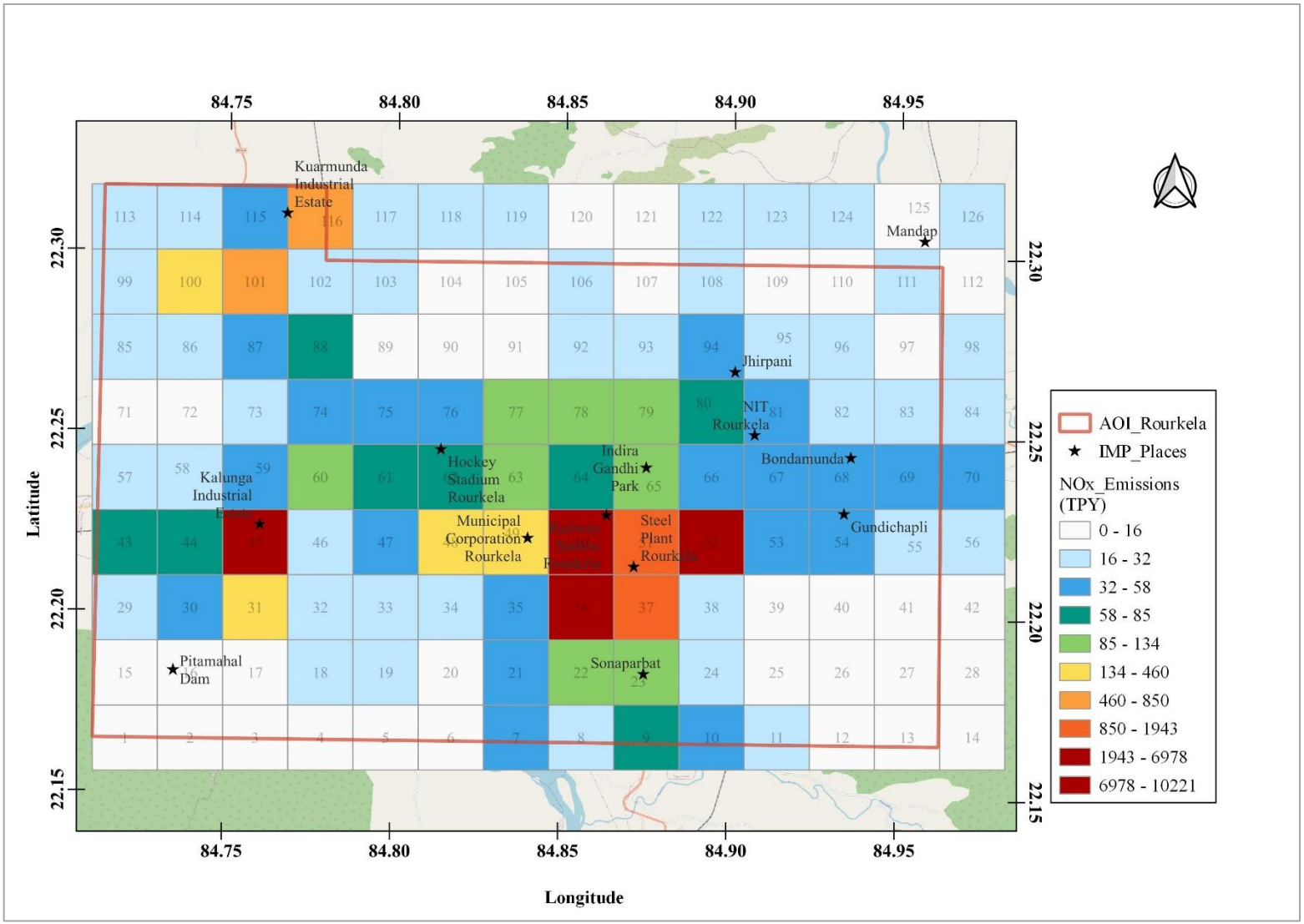

Figure 96 Spatial distribution of NO_X emissions (tonnes per year) in Rourkela region, 2021

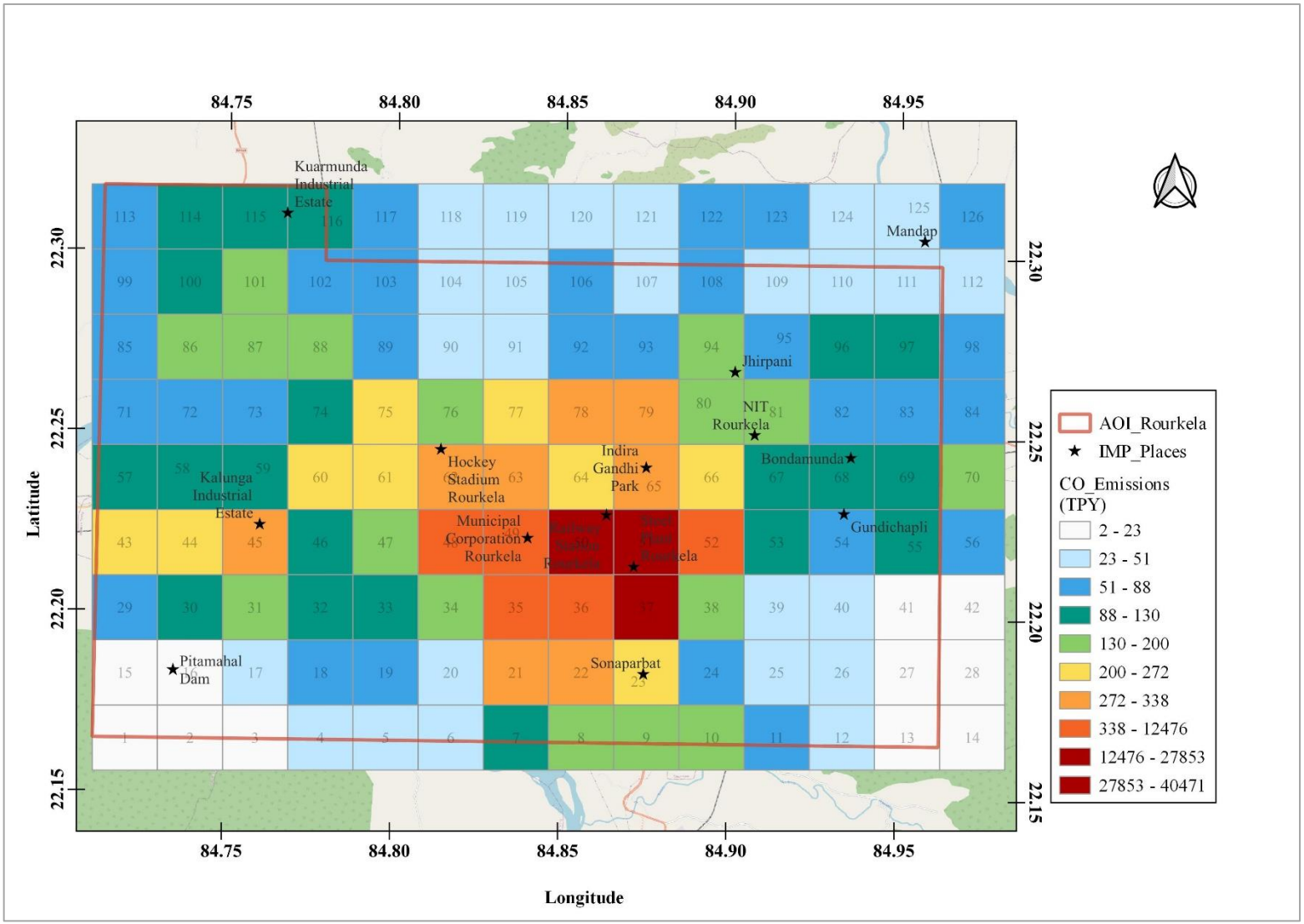

Figure 97 Spatial distribution of CO emissions (tonnes per year) in Rourkela region, 2021

Chapter 4: Dispersion Modelling

4.1. Background

The dispersion modelling is a tool for predicting the spatio- temporal variations of air pollutants. In general, the dispersion models employ mathematical algorithms that considers various atmospheric processes such as dispersion, chemical, and physical processes and calculate approximate concentrations of air pollutants (Zou et al., 2010). AERMOD (**A**MS/**E**PA **R**egulatory **MOD**el), is a state-of-science dispersion modelling system for regulatory applications and is aimed at modelling short-range (up to 50 km) dispersion from a variety of source types including point, area, line and volume sources (Cimorelli et al., 2003; Holmes et al., 2006).

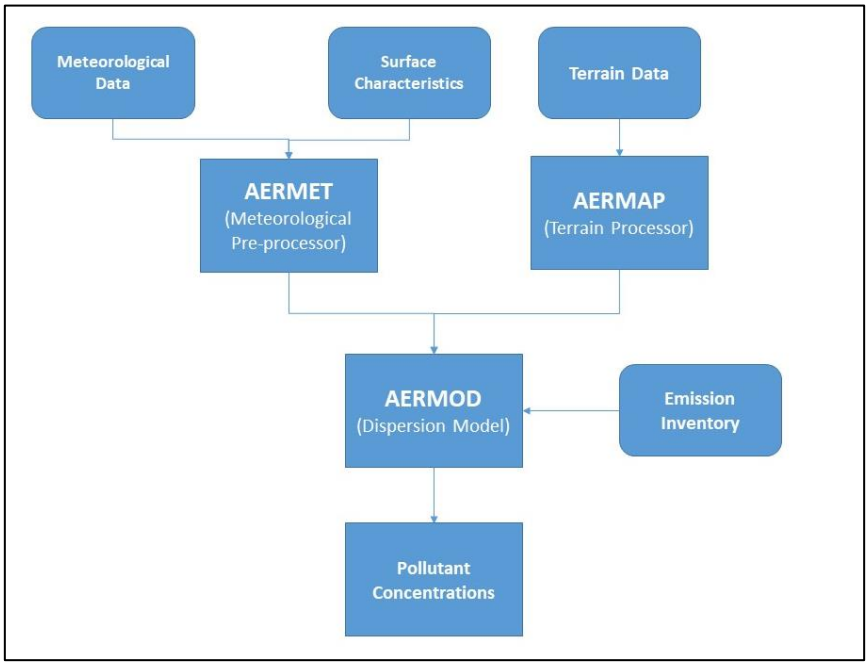

Figure 98 Flow diagram of AERMOD Modelling System used in this study to simulate the air pollutant concentrations

Fig. 98 shows the flow diagram of AERMOD modelling system. AERMOD is a steady-state gaussian plume model and consists of a dispersion model i.e. AERMOD and two pre-processors (AERMET and AERMAP). The major purpose of meteorological pre-processor i.e. AERMET, is to calculate boundary layer parameters for use by AERMOD. Surface characteristics in the form of albedo, surface roughness, and Bowen ratio, plus standard meteorological observations (wind speed, wind direction, temperature, and cloud cover), are input to AERMET. AERMET then calculates the PBL parameters: friction velocity (u*),

Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (θ*), mixing height (zi), and surface heat flux (H). The terrain pre-processor i.e. AERMAP uses gridded terrain data to calculate a representative terrain-influence height, also referred to as the terrain height scale. The terrain height scale, which is uniquely defined for each receptor location, is used to calculate the dividing streamline height. The gridded data needed by AERMAP is selected from Digital Elevation Model (DEM) data. AERMAP is also used to create receptor grids. The elevation for each specified receptor is automatically assigned through AERMAP. For each receptor, AERMAP passes the following information to AERMOD: the receptor's location, its height above mean sea level, and the receptor specific terrain height scale.

In this study, the AERMOD model is configured to consider the local meteorology, emissions and terrain information to simulate the air pollutant concentrations at specified receptors in the study domain. Figure 99 shows the modelling domain considered in this study.

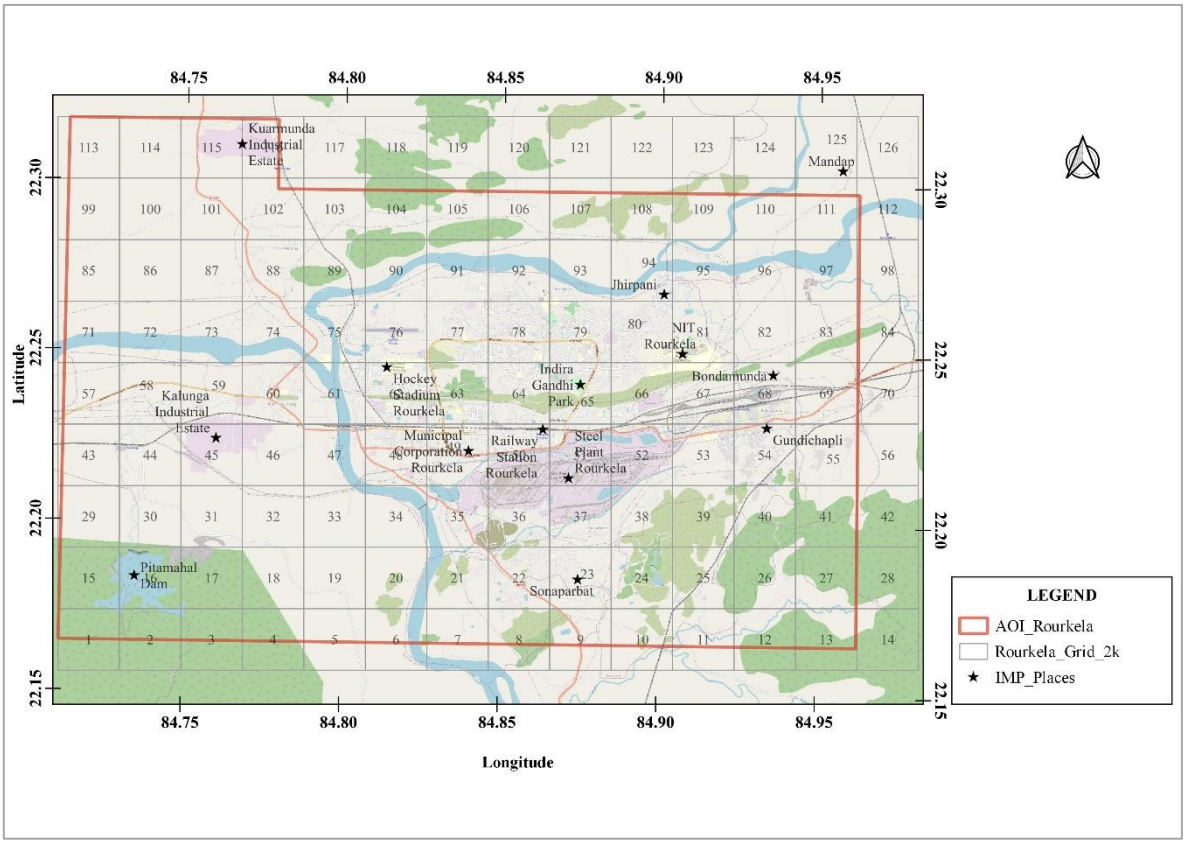

Figure 99 Map showing dispersion modelling domain i.e. Rourkela region limits and surrounding areas

(*Note: The meteorological data is used for location of Rourkela region airport shown in figure*)

4.2. Meteorological Data

AERMOD modelling system requires two types of meteorological datasets i.e. surface meteorological data and upper air soundings. This data is first pre-processed by the meteorological processor i.e. AERMET. The main purpose of AERMET is to calculate boundary layer parameters for use by AERMOD.

As the observed meteorology data is not available publicly over Rourkela region, this study uses ERA5 reanalysis data. ERA5 is the fifth generation ECMWF reanalysis for the global climate and weather for the past 4 to 7 decades. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics. Data has been re-gridded to a regular lat-lon grid of 0.25 degrees for the reanalysis and 0.5 degrees for the uncertainty estimate. Table 16 provides summary of ERA5 reanalysis dataset.

The surface level meteorological data over the Rourkela region is extracted from ERA-5 dataset. The minimum meteorological input data requirements for input to AERMOD are: Wind speed and direction, Ambient temperature, Opaque sky cover and/or total sky cover (EPA, 2004). The hourly meteorological data of specified weather parameters obtained from ERA-5 data for year 2022 is converted to Solar and Meteorological Surface Observation Network (SAMSON) format using customized python scripts following data quality assurance.

As discussed previously, in addition to surface meteorological data, AERMET also requires the twice daily upper air soundings i.e. 00Z and 12Z, for calculation of micro-meteorological parameters over the study domain. The pressure level data over Rourkela from ERA-5 database and is converted into Forecast Systems Laboratory (FSL) radiosonde format using Python and Fortran scripts.

Table 16 Details of ERA5 meteorological dataset used in this study

Data type	Gridded
Projection	Regular latitude-longitude grid
Horizontal coverage	Global
Horizontal resolution	Reanalysis: 0.25° x 0.25° (atmosphere), 0.5° x 0.5° (ocean waves) Mean, spread and members: 0.5° x 0.5° (atmosphere), 1° x 1° (ocean waves)
Temporal coverage	1979 to present
Temporal resolution	Hourly
Vertical coverage	1000 hPa to 1 hPa
Vertical resolution	37 pressure levels

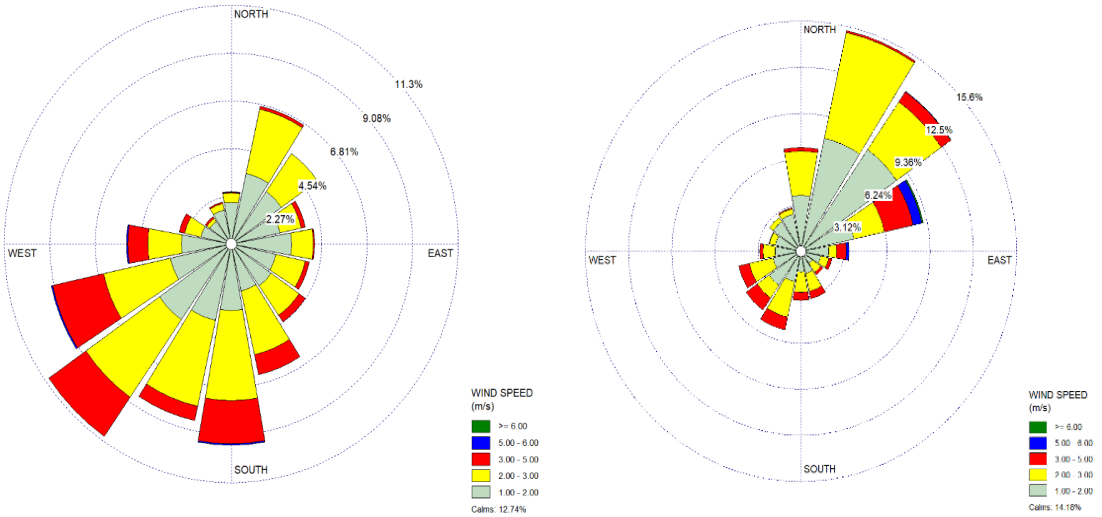

Figure 100 Windrose diagrams showing the wind speed and direction frequency distribution over Rourkela region during summer (A) and winter (B) seasons of year 2022

Fig. 100 shows the wind speed and direction frequency distribution over Rourkela region during summer (A) and winter (B) seasons of year 2022. A diverse range of wind speeds is observed during the summer season, with moderate percentage (~12%) of calm winds i.e. < 1 m/s. The predominant wind directions during the summer season over Rourkela region are observed to be from south-west (~11%); followed by south (S), and west of south-west (WSW) (frequencies > 5%).

In the winter season, lesser wind variations were observed with slightly higher frequencies of (~14%) calm winds (i.e. < 1 m/s) indicating stable atmospheric conditions. The predominant winds are observed to be blowing from north of north-east (NNE, ~15%) followed by north-east (NE, ~12%) and east of north-east (ENE, ~9%).

4.3. Terrain Data

The terrain data is required by AERMOD, to calculate a representative terrain-influence height, which in turn is used to calculate the dividing streamline height. A pre-processor program, AERMAP, processes the terrain data in conjunction with a layout of receptors and sources to be used in AERMOD simulations. AERMAP processor needs standardized computer files of terrain data. For Indian region, the terrain data available from NASA's Shuttle Radar Topography Mission (SRTM) global product having 1 arc second (~30 meter) spatial resolution. The SRTM DEM data over Rourkela region region was downloaded and processed using AERMAP processor.

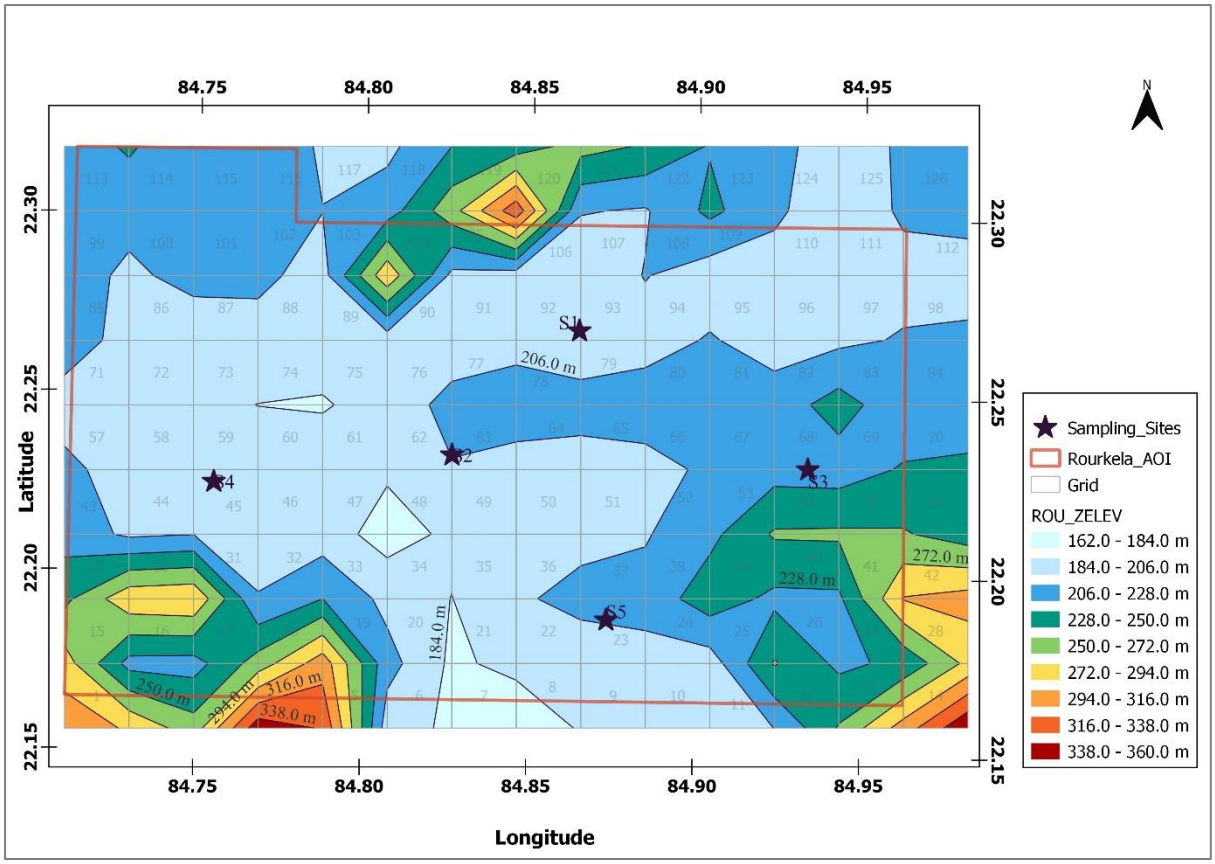

Figure 101 Contour map showing terrain elevations extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m)

Fig. 101 shows the contour map showing terrain elevations extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m). The terrain elevations are observed to vary from a minimum of ~167.0 m (above MSL) at the center to a maximum of ~358.4 m (above MSL) towards southern part of the modelling domain.

4.4. Source Configurations

AERMOD can simulate emissions originating from variety of source types including: point, area, line, and volume sources. The emissions from different sectors are modelled as area sources having dimensions 2 x 2 km^2, except the industries and thermal powerplants, industrial DG sets, and brick kilns. The stack emissions from industries and thermal powerplants, industrial DG sets and FCBTK brick kilns are modelled as point sources while clamp type brick kilns are modelled as volume sources.

4.5. Receptor Configurations

Receptor information is required by AERMOD to calculate the pollutant concentrations. Two types of receptors i.e. gridded and discrete, are used in this study to simulate the concentrations. The gridded receptors are placed at the vertex of each grid cell used in the emission inventorization, forming a network of 150 gridded receptors. Additionally, six discrete receptors are also configured to represent one CAAQM station operated by OSPCB at Panposh Chowk and five sampling locations for ARAI sampling sites. The AERMOD predicted concentrations at Panposh chowk were used for model validation purpose. The height of each receptor is set to 1.5 m above ground level i.e. average breathing level for humans. Figure 102 shows map of the modelling domain overlaid by gridded and discrete receptors configured in this study.

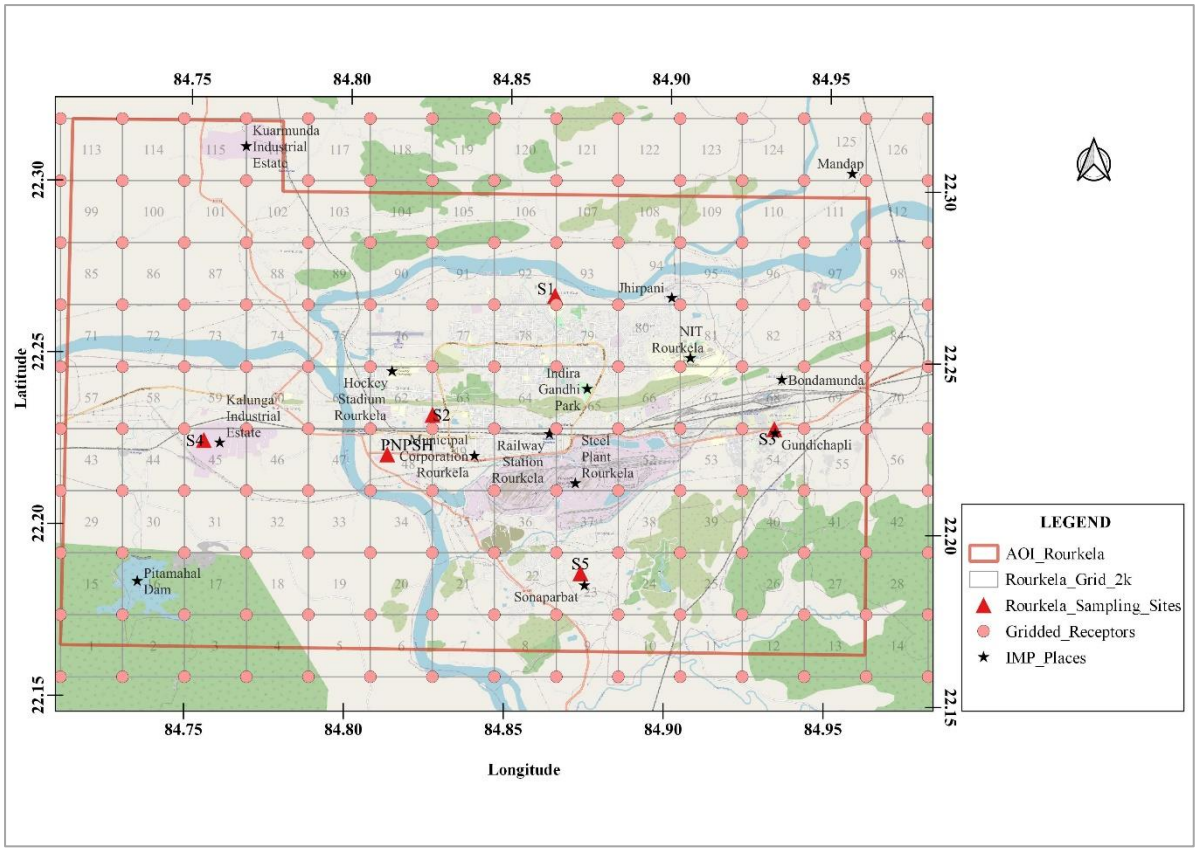

Figure 102 Map showing modelling domain overlaid by gridded and discrete receptors configured in this study.

Table 17 summarizes the details of dispersion model, source and receptor configurations, meteorology and geophysical data used for dispersion modelling simulations.

Table 17 Summary of AERMOD dispersion modelling setup used in this study

S. No.	Description	Symbol	Details
1.	Length of modelling domain in X-direction	X	28 km
2.	Length of modelling domain in Y-direction	Y	18 km
3.	X-direction receptor grid resolution	ΔX	2000 m
4.	Y-direction receptor grid resolution	ΔY	2000 m
5.	Receptor height	H_R	1.5 m
6.	Total number of gridded receptors	N_{GRD}	150
7.	Total number of discrete receptors	N_{DISC}	6
8.	Source configuration in AERMOD	--	• Industries, TPP, DG, FCBTK: Point source • Clamp Brick kilns: Volume source • All other sectors: Area sources having L=2000 m and W= 2000 m
9.	Meteorology: Surface data	--	ERA5 fifth generation ECMWF reanalysis: • Dry bulb temperature • Wet bulb temperature • Cloud cover • Wind speed • Wind direction
10.	Meteorology: Upper air soundings	--	ERA5 fifth generation ECMWF reanalysis • Dry bulb temperature • Wet bulb temperature • Wind speed • Wind direction
11.	Terrain data	--	NASA's Shuttle Radar Topography Mission (SRTM) global product having 1 arc second (~30 meter) spatial resolution

4.6. Background Concentrations

The background pollutant concentrations play an important role in dispersion model validation. In this study, the lowest daily concentration of a pollutant reported, in a particular season, at Panposh Chowk CAAQM station is used as the daily background concentration to reflect the regional-scale contributions from distant sources. A similar approach, has been

successfully used in the earlier AERMOD validation studies (Dresser and Huizer, 2011). The minimum daily observed concentration in season at Panposh Chowk CAAQM station i.e. seasonal background, is added to the daily averaged concentrations estimated by AERMOD to get total daily concentration of pollutant under consideration.

4.7. Dispersion Model Validation

The AERMOD simulated daily averaged concentrations of pollutants including $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO are compared against observations at CAAQM observations at Panposh Chowk for year 2022. The model performance is evaluated using six statistical measures including: mean, pearson correlation coefficient (R), Mean Bias (MB), Factor of two (FAC2) envelope and Mean Fractional bias (MFB) and Mean Fractional Error (MFE).

$$R = \frac{\overline{(C_o - \overline{C_o})\,(C_p - \overline{C_p})}}{\sigma_{C_o}\sigma_{C_p}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (18)}$$

$$MB = \frac{1}{N}\sum_{i=1}^{N}\left(C_{pi} - C_{oi}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (19)}$$

$$FAC2 = Fraction\ of\ data\ that\ satisfy\ 0.5 < \frac{C_p}{C_o} < 2.0 \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (21)}$$

$$MFB = \frac{2}{n}\sum_{i=1}^{N}\frac{\left(C_{pi} - C_{oi}\right)}{\left(C_{pi} + C_{oi}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. (22)$$

$$MFE = \frac{2}{n}\sum_{i=1}^{N}\frac{|\left(C_{pi} - C_{oi}\right)|}{\left(C_{pi} + C_{oi}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. (23)$$

Table 18 presents the summary of statistical measures obtained by comparing AERMOD simulated daily mean concentrations against the respective in-situ observations at Panposh Chowk CAAQM location in Rourkela region. Overall, the AERMOD model is found to simulate the daily mean concentrations of the pollutants with a good accuracy compared to observations.

Table 18 Statistical summary of model performance for monthly simulated AERMOD concentrations

Parameter	Unit	Benchmark	$PM_{2.5}$	PM_{10}	SO_2	NO2	CO
Mean Obs	µg/m^3	-	78.33	253.03	4.41	12.80	0.53
Mean Mod	µg/m^3	-	59.17	158.96	10.27	25.12	0.49
Pearson R	Unitless	1	0.50	0.45	0.35	0.39	0.68
Mean Bias	µg/m^3	0	-19.16	-94.07	6.03	12.88	-0.04
FAC2	%	100%	65	52	38	50	83
MFB	µg/m^3	<= ±0.6	0.15	0.35	-0.81	-0.70	0.00
MFE	µg/m^3	<= ±0.75	0.58	0.68	0.90	0.73	0.37

The difference between seasonal mean modelled and observed values is less than 50% except SO_2 and NO_2. The negative values of MB for $PM_{2.5}$, PM_{10}, and CO indicate under-estimation by AERMOD whereas positive MB values for SO_2 and NO_2 indicates over-estimation of daily modelled values. The higher model predicted values of SO_2 and NO2, could be partly explained by the fact that, AERMOD is a dispersion model which does not consider gas-to particle conversion (SO_2 to Sulfate and NO2 to Nitrate) and atmospheric chemistry reactions.

Correlation coefficient (R) ranges between 0.35 to 0.68 for different pollutants indicates the model is able to capture temporal evolution of these pollutants. Lowest R values (0.35-0.39) for SO_2 and NO_2 indicates model is unable to capture temporal variations in SO_2 and NO_2.

FAC2 values greater than 50% for all pollutants indicate that predicted values are within factor of two envelop for more than 50% of time, except SO_2 (38%). The mean fractional bias (MFB) and mean fractional error (MFE) are less than ±0.6 and ±0.75 for all pollutants except SO_2 and NO2, indicating a good model performance.

4.8. Spatial Distribution of Modelled Pollutants

Fig. 103 - 107 shows the spatial distribution of modelled pollutant annual average concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_2 and CO for year 2021, respectively. The spatial distribution of modelled pollutant concentrations in the study domain, is generally governed by emissions, terrain, land-use and meteorological factors. The highest estimated concentrations are observed centre and western part of the study domain. These highest concentrations can be attributed to the presence of industries such as SAIL, NTPC and sponge iron plants in Kalunga industrial estate (on west). Another reason for higher concentrations in central part is the presence of dense road network and vehicular activity which leads to road dust re-suspension and exhaust emissions. The lowest estimated pollutant concentrations on the peripheral part of the study domain, could be attributed to lower activities, emissions and effective diffusion, dispersion and removal of pollutants to some extent (Han et al., 2020).

Due to prevailing wind speeds and direction, the pollutant concentrations are tended to spread to the north-eastern and south-western part during summer and winter seasons, respectively.

The estimated concentrations show distinct seasonal pattern, being higher in summer and comparatively lower in winter. This reverse trend in ambient concentrations is mainly due to higher share of dusty sources such as fugitive, re-suspended road dust in the emissions. These sources contribute more during the summer season, compared to winter season mainly due to lower humidity and higher wind speeds. This implies that, the seasonal emissions and meteorology are adequately explained by the model.

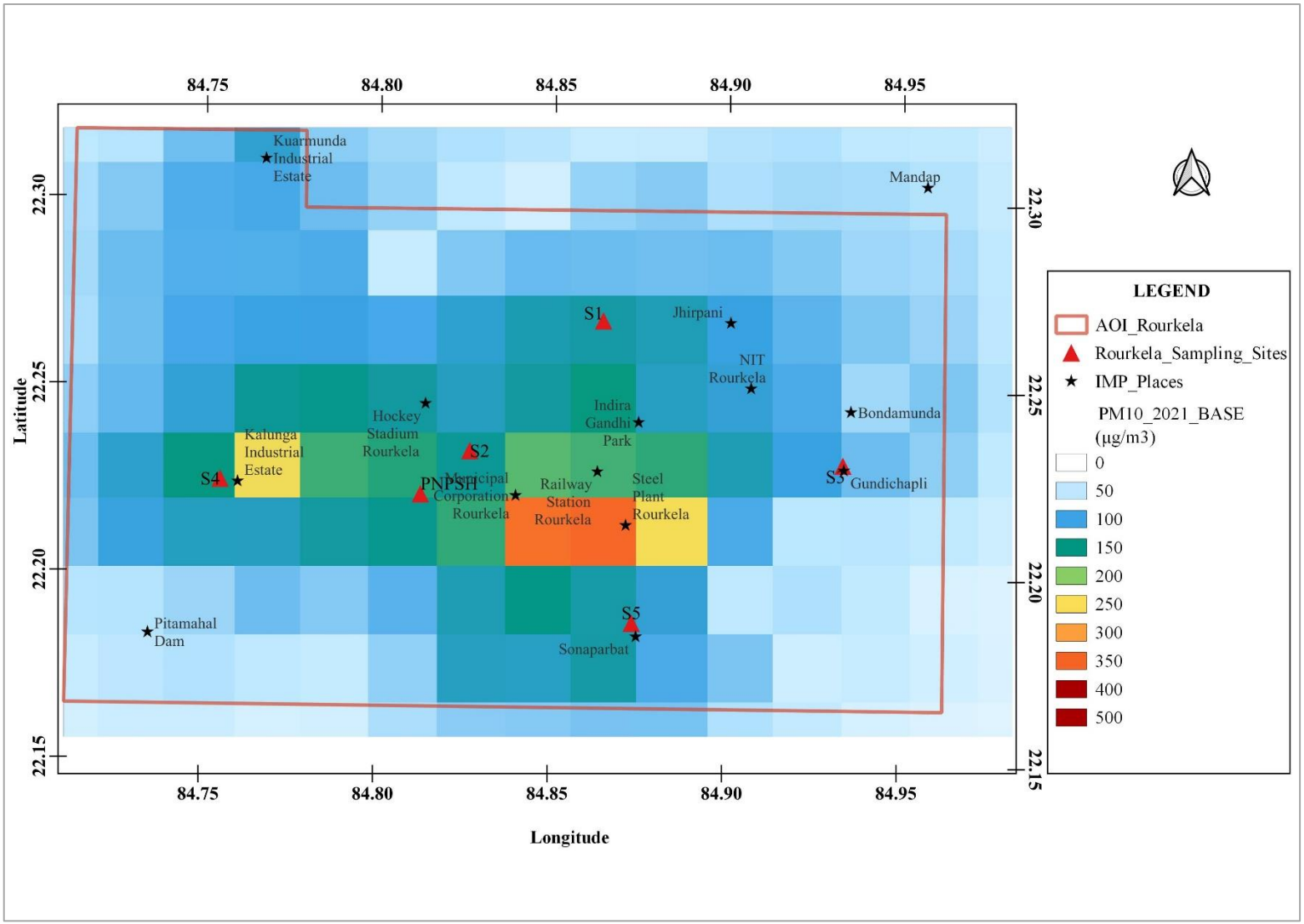

Figure 103 Map showing spatial distribution of annual average PM_{10} concentrations ($\mu g/m^3$) over Rourkela region for year 2021

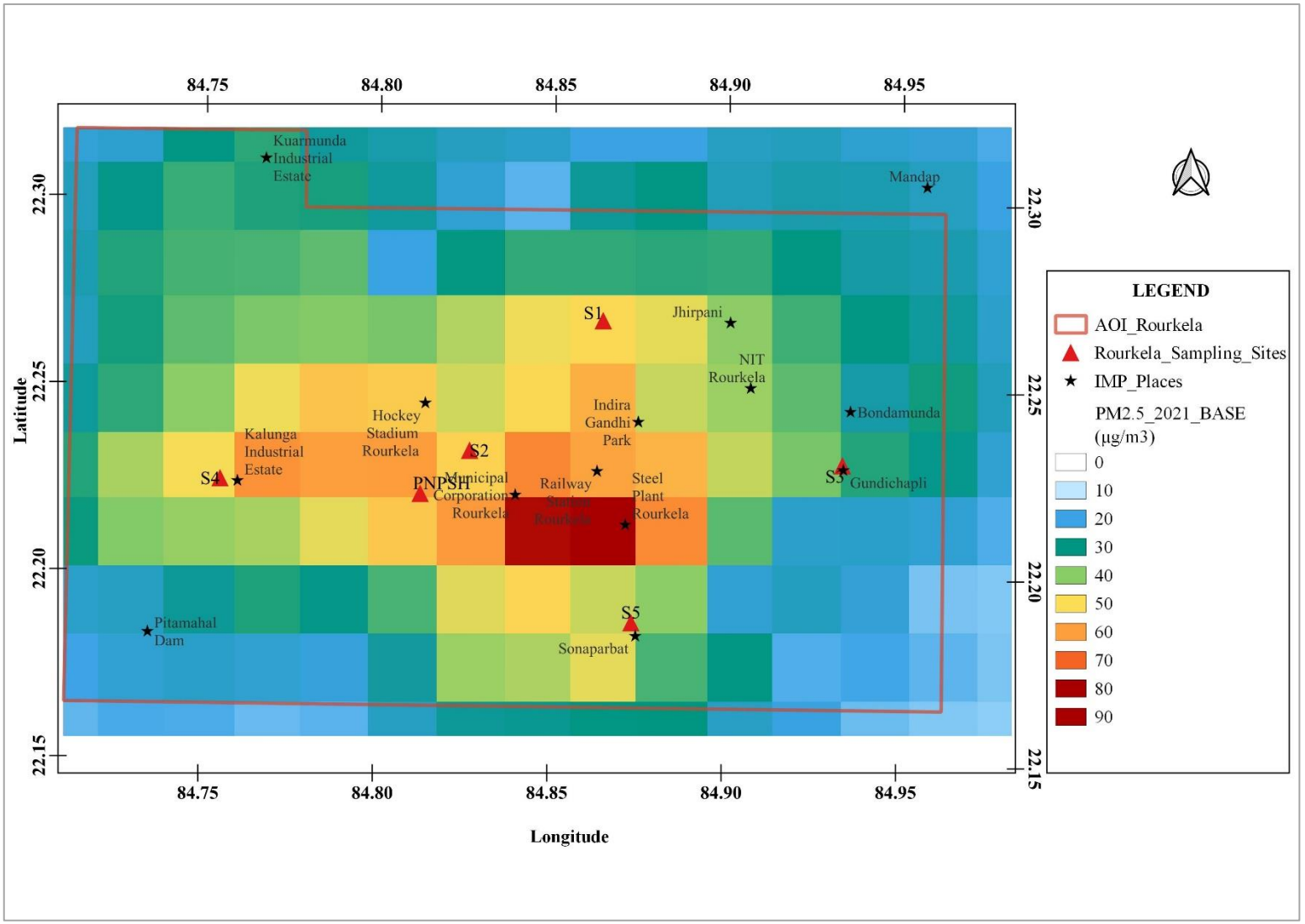

Figure 104 Map showing spatial distribution of annual average $PM_{2.5}$ concentrations ($\mu g/m^3$) over Rourkela region for year 2021

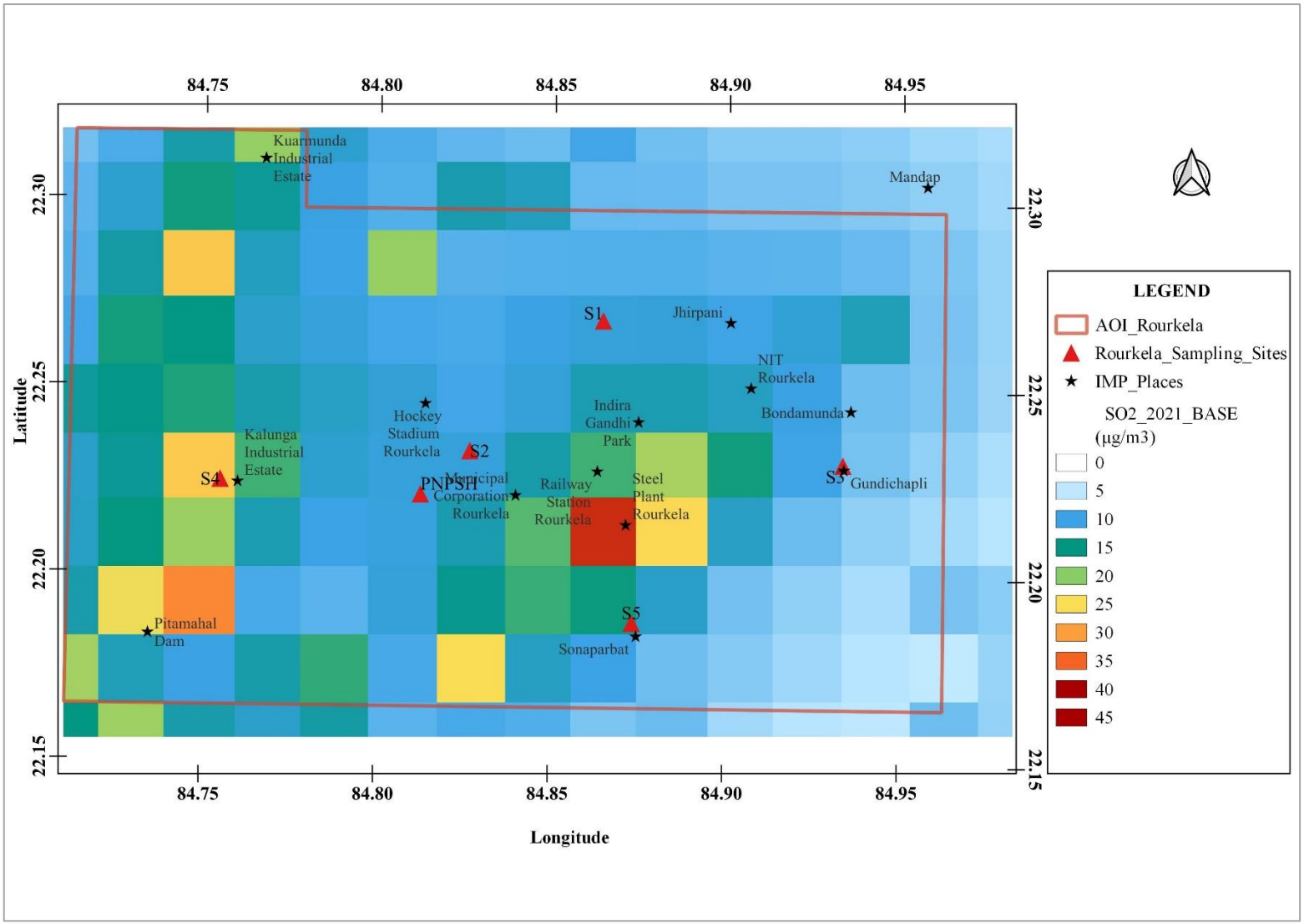

Figure 105 Map showing spatial distribution of annual average SO_2 concentrations ($\mu g/m^3$) over Rourkela region for year 2021

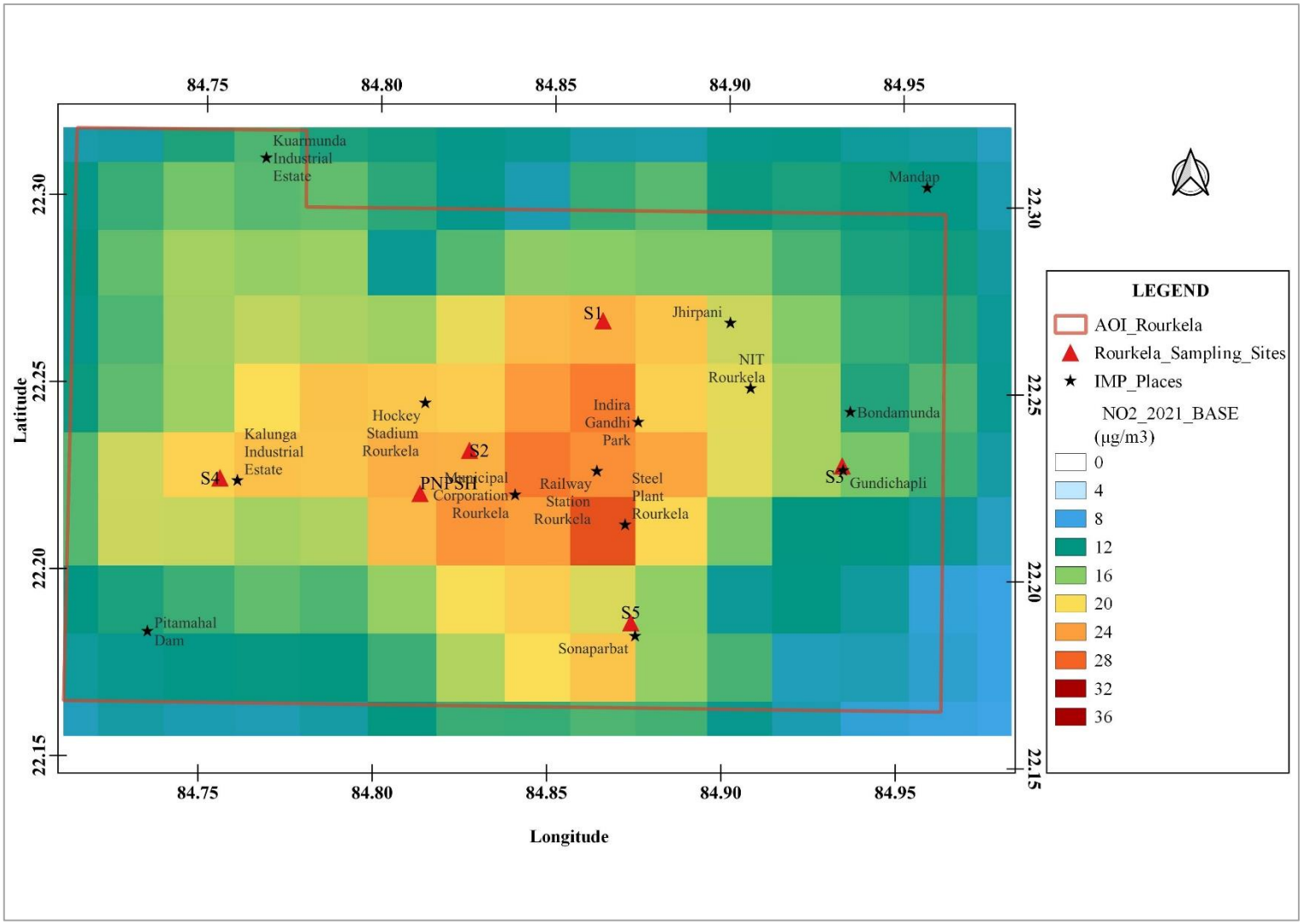

Figure 106 Map showing spatial distribution of annual average NO_2 concentrations ($\mu g/m^3$) over Rourkela region for year 2021

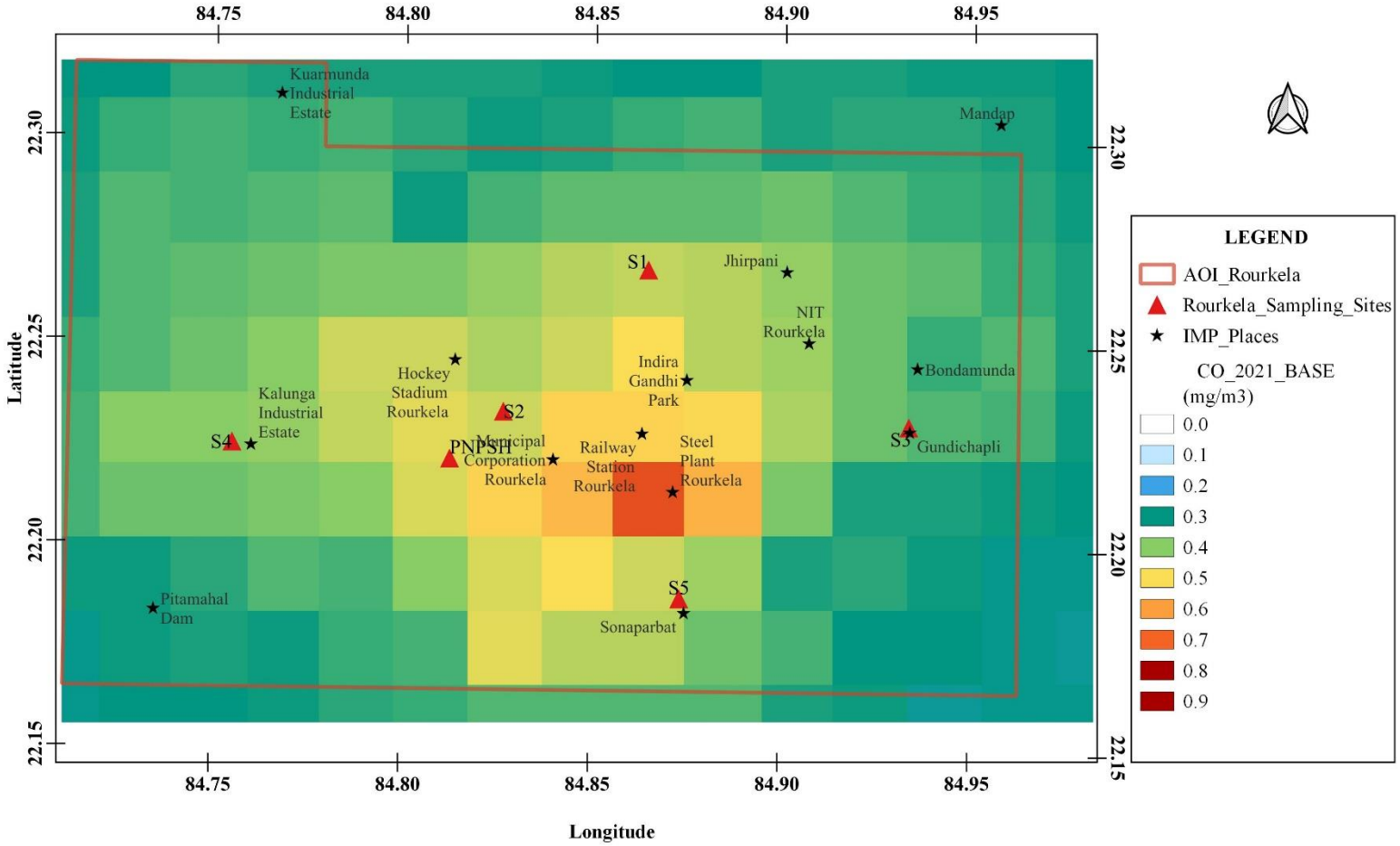

Figure 107 Map showing spatial distribution of annual average CO concentrations (mg/m3) over Rourkela region for year 2021

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Chapter 5: Future Projections

5.1. Future Projections of Emissions and Air Quality Benefits

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 2021. Four hypothetical emission scenarios viz. i) No further control (NFC), ii) Business-as-usual (BAU), iii) Scenario – I (SC-I) and iv) Scenario – II (SC-II); are developed for Rourkela region to include various existing and planned control interventions in each sector. These scenarios can be defined as given below:

i) **No further control (NFC):** No further control (NFC) scenario assume that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032 but the control measures would be similar to present/current levels in baseline year 2022.

For example, 20 percent ethanol blended gasoline i.e. E20 fuel is planned to be available by 2025, but presently it is not available. NFC scenario tries to quantify the emissions in future years assuming, E20 won't be used in future as well and transport sector only relies on present fuel options available.

ii) **Business-as-usual (BAU):** Business-as-usual (BAU) scenarios consider that there would be growth in the activities as per the sector-specific growth rates in 2027 and 2032. The control actions that are already planned and are expected to be complete or operational by respective projection years i.e. 2027 and 2032 are considered while designing the BAU scenarios. The sector-wise details on level of penetration and/or implementation are provided in sub-sequent sections of this chapter.

For example, 20 percent ethanol blended gasoline i.e. E20 fuel is planned to be available by 2025, but presently it is not available. BAU scenario tries to quantify the emissions in future years assuming, E20 will be available in future, as planned and vehicles using gasoline would shift to E20 fuel.

iii) **Scenario – I (SC-I):** Scenario – I (SC-I) consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the planned control measures would be implemented more aggressively compared to BAU scenarios.

iv) **Scenario – II (SC-II):** Scenario – II (SC-II) consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the

planned control measures would be implemented to the highest aggressive levels, possible.

These scenarios consider changes in technology and fuels which mainly include: faster EV adoption, implementation of BS-VI, increase in penetration of natural gas-based vehicles, roll-out of ethanol blended gasoline fuel (E20), reduction in silt loading on road surfaces, improvement in NMT & public transport, usage of clean fuel for cooking, improved waste collection efficiency, continuous supply of grid electricity, adoption of Zig-zag type brick kilns and various other control measures. The four emission scenarios investigated in the study can be further categorized as mid-term (2026) and long term (2031). The assumptions and considerations in each scenario are described in this section.

5.2. Transport Sector

In order to estimate vehicular emissions for four emission scenarios, change in fuel-wise vehicle penetration fractions for each category of vehicles, change in emission factors due to new technology and fuels, and reduction in vehicle kilometres travelled is considered for 2026 and 2031. This section explains the control measures used in the present study and the vehicle category-wise considerations for each scenario are provided in Annexure-H.

5.2.1. Increased penetration of Bharat Stage (BS) – VI vehicles

In April 2020, the Bharat Stage (BS) - VI standards were introduced and all new vehicles manufactured have to comply with BS-VI. BS-VI vehicles are significantly cleaner than the BS IV counterparts. For example, particulate matter (PM) limit for different segments of diesel cars will be 82 to 93 per cent lower while for trucks and buses it will be 50-67 per cent lower than BS IV level. Similarly, Nitrogen oxide (NOx) emissions limit will be 68 per cent lower compared to BS-IV norms (CSE, 2020). This effect is included in the present study considering increased penetration levels of these vehicles in future vehicle fleet of Rourkela region and reduced emissions per unit distance.

5.2.2. Roll-out of Ethanol blended Gasoline (E20) fuel

On the occasion of World Environment Day, 5 June 2021, the government of India released the Roadmap for Ethanol Blending in India. This roadmap is aimed at reducing the country's oil import bill and carbon dioxide pollution. The roadmap proposed some important milestones including: i) raising Pan-India ethanol production capacity from the current 700 to 1500 crore litres; ii) Phased rollout of E10 fuel by April 2022; iii) Phased rollout of E20 from April 2023; its availability by April 2025; iv) Rollout of E20 material-compliant and E10 engine-tuned

vehicles from April 2023; and v) Production of E20-tuned engine vehicles from April 2025 (NITI Aayog and MoPNG, 2021).

The impact of 20 per cent ethanol blending in gasoline i.e. E20 fuelled vehicles in Rourkela region, is included in the analysis in years 2026 and 2031. In modelling, the impact of E20 roll-out, it is considered that all vehicle categories which currently use gasoline, will be using E20 as fuel in 2030. It is also assumed that the vehicle fleet produced between the period from 2026 to 2031 will have an E20-tuned engine, which will in turn lead to change in emissions per unit distance. Although vehicles produced before 2025 will be using E20 as fuel in the subsequent years, yet it is assumed that there will not be a significant change in the emission factors for these vehicles.

5.2.3. Increased Penetration of Electric Vehicles (EV)

The conventional internal combustion engine (ICE) vehicles are one of the major contributors to city level air pollution and electric vehicles (EVs) are emerging as a promising alternative that could help in mitigating air pollution in urban centres (GIZ, 2021). The Government of India (GoI) has introduced several initiatives in EV sector with an aim to improve energy security, curb local air pollution, and curtail GHG emissions from the transport sector (CEEW, 2020). For example, India has set a goal of 30 per cent penetration of EV in new sales by 2030 (GIZ, 2021). Additionally, several state governments have also set their own targets to increase the electric vehicle penetration in near future by incentivising the EV purchases. Considering the government policies and initiatives, EV penetration is likely to improve substantially in Rourkela region as well, which will in turn lead to significant reduction in vehicular exhaust emissions. The effect of increased EV penetration in Rourkela region is included by referring to policies at national, state and city-level and the expected EV penetration.

5.2.4. Non-Motorised Transport (NMT) Share

Non-motorised transport (NMT) includes mainly walking, cycling and cycle rickshaws. NMT plays an important role in Indian cities as a last mile connector providing access to mass transit systems (Kumar et al., 2015). Several government policies and initiatives including but not limited to, National Urban Transport Policy (NUTP), National Mission for Sustainable Habitat (NMSH), and Ministry of Urban Development (MoUD) Service level benchmarks are aiming to adopt NMT as a key component of city's integrated urban transport system (Kumar et al., 2015).

As NMT is likely to play a vital role in Rourkela region urban transportation system in the years to come, we have evaluated the impact of increasing NMT share on vehicle kilometres travelled and subsequent emission reductions. It is assumed that increasing NMT share in future years would reduce VKT by two wheelers, cars and buses. Table 19 presents summary of assumed reduction percentages in vehicle kilometres travelled (VKT) in four scenarios for years 2026 and 2031, respectively, due to promotion of NMT in Rourkela region.

Table 19 Percentage VKT reduction of selected vehicle categories during future scenarios

Year	BAU	SC-I	SC-II
2026	0.25%	0.5%	1.0%
2031	0.5%	1.0%	2.0%

5.2.5. Public Transport Improvement (PTI)

Public transportation systems play a vital role in reducing traffic and environmental pollution. Many researchers world-wide have demonstrated the potential emission reductions from a shift towards public transport and zero emission buses (Al-Kheder, 2021; Carroll et al., 2019; Bakker and Konings, 2018). Rourkela region has also taken several steps to improve the public transportation system such as phase-out of older buses, and procurement of CNG and electric buses. The VKT shift approach used by Sharma et al. (2010 and 2014) is adopted to calculate the VKT shifted to buses and emission reductions achieved.

5.3. Re-suspended Road Dust

As discussed earlier, road dust re-suspension is a major source of PM emissions in Rourkela region. Hence, stringent measures are required to be taken up to reduce the amount of silt (i.e. dust particles having aerodynamic diameter less than or equal to 75 µm) on road. The impact of reducing silt loading on roads with high vehicular movement, followed by remaining roads is incorporated into emissions quantification under proposed scenarios in future years.

5.4. Industrial Sector

Rourkela is the Odisha's one of the main Industrial Townships and the results of emissions inventory as well as receptor modelling clearly suggests that industrial stack and fugitive dust emissions from iron and steel plants and sponge iron units are significant contributors to ambient PM levels. Hence, it is important to control these sources effectively, in order to bring down the particulate matter levels in future years. For industries, it has been suggested to first maintain the air pollution control equipment properly and parallelly adopt a suitable combination of Best Available Technologies (BAT) listed in Annexure-I to achieve emission reductions in future years.

5.5. Residential, HRBE and Open Waste Burning Sectors

The quantification of emissions for future years, from residential sector mainly considers the increase in population and changes in fuel usage pattern in Rourkela region. The LPG penetration is estimated to increase gradually based on historic trends in the region whereas use of solid fuels such as wood and coal, for domestic cooking and heating applications is discouraged.

Similar to residential sector, hotels and restaurants are assumed to reduce the solid fuel usage while promoting use of LPG and electricity for cooking and tandoor related applications. The open waste burning is assumed to decline in future years under different scenarios, except NFC owing to improved collection efficiency and effective solid waste management.

5.6. Brick Kilns Sector

Currently, the FCBTK and clamp type brick kilns are operational in the Rourkela region which are less efficient and more prone to air pollution. Further, they have no control devices installed, thereby aggravating the air pollution situation. While estimating the emissions for future years under different scenarios, it is proposed to shift the FCBTK and clamp type units to Zig-zag kilns, which are comparatively less polluting, in a phase-wise manner.

5.7. Construction Sector

With growth in economic activities and population the construction activities are also estimated to increase in upcoming years in the Rourkela region. The three scenarios assume a gradual implementation of good construction practices (GCP), which may lead to PM emission reductions in the range 5 to 30%.

5.8. Crematoria Sector

Although, the emissions originating from crematoria contribute less than 1% of total PM emissions at regional-scale, these emissions are very important for local scale air pollution problems. Hence, it is proposed to gradually shift the existing wood -based crematoria to gas-based or electric crematoria till 2031 under different scenarios.

The sector-wise quantification of the considerations, explained above, in each of the four future scenarios is presented in subsequent sections.

5.9. No Further Control (NFC) Scenario

The NFC scenario considers the activities in each sector would increase following the sectoral growth rates and no additional controls would be implemented till years 2026 and 2031. The growth rates of different sectors have been adopted through review of published literature. Table 20 summarizes the sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2026 and 2031.

Table 20 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2026 and 2031 NFC scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • The major control measures considered for the transport sector include: ○ Increased penetration of BS-VI vehicles • Refer Annexure-H for more details on penetration and applicability of each control measure listed above.	VAHAN database, Odisha EV Policy, 2019 Assumptions
2.	RDST	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • No change in the silt loading on different road types in 2026 and 2031.	Assumptions
3.	INDU	• Same as baseline year	
4.	RESI	• The population is estimated based on historic population growth rate. • The LPG penetration in study area for years 2026 and 2031 would remain same as baseline.	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	WAST	• The population is estimated based on historic population growth rate. • The MSW collection efficiency in the study area for years 2026 and 2031 would remain same as baseline.	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
6.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 6.6%. • The fuel usage characteristics and technology would remain same as the baseline inventory.	Based on growth rate acquired from FICCI report 2022
7.	BRIC	• The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. • No change in the technology compared to baseline year	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
8.	CONS	• The construction activities are assumed to increase at growth rate of 3.5% and 5.0% in 2026 and 2031, respectively. • No reduction in PM.	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
9.	CREM	• The deaths in 2026 and 2031 are estimated using the crude death rate (CDR). • No electric crematoria.	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	DSGN	• An average daily usage of 2 and 1 hours for 2026 and 2031, respectively. • No end-of-pipe control.	Assumptions
11.	FUGT	• Same as baseline year	Assumptions

5.10. Business-As-Usual (BAU) Scenario

The BAU scenario considers the activity changes due to already planned policies/interventions by the government in years 2026 and 2031. The growth rates of different sectors have been adopted through review of published literature. Table 21 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2026 and 2031 BAU scenario.

Table 21 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2026 and 2031 BAU scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • The major control measures considered for the transport sector include: ○ Increased penetration of BS-VI vehicles ○ Introduction of E20 fuel ○ Increased electric vehicles (EV) penetration ○ Increased CNG penetration ○ Reduction in VKT due to increase in Non-motorized transport (NMT) share ○ Improvement in public transport ○ Reduction in highly polluting vehicles/ super-emitters • Refer Annexure-H for more details on penetration and applicability of each control measure listed above.	VAHAN database, Odisha EV Policy, 2019 Assumptions
2.	RDST	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • The silt loading on different road types calculated by assuming following: ○ Year 2026: 15% silt load reduction @ Highways and Major roads and 5% silt load reduction @ Inter, Minor and residential roads	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		○ Year 2031: 25% silt load reduction @ Highways and Major roads and 10% silt load reduction @ Inter, Minor and residential roads	
3.	INDU	• Ensuring the PM control equipment are operating at minimum 99% control efficiency. • Adoption of suggested Best Available Technologies and Practices for Iron and Steel Industries (Refer Annexure – XX). • Assumed PM emission reduction (in addition to NFC scenarios) from Industries: ○ Within Rourkela city: 5% (2026) and 10% (2031) ○ Outside city limits: 5% (2026) and 10% (2031)	Assumptions
4.	RESI	• The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: ○ Year 2026: 1. LIG HH: 50% 2. Other HH: 80% ○ Year 2031: 1. LIG HH: 50% 2. Other HH: 80%	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	WAST	• The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency: ○ Year 2026: 1. Rural areas: 65% 2. Urban Areas: 90% ○ Year 2031: 1. Rural areas: 70% 2. Urban areas: 90%	Assumptions
6.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 6.6%.	Based on growth rate acquired

Sr. No.	Sector	Assumptions, considerations and controls	References
		• 10 and 25% facilities would be converted from wood/coal to LPG in years 2026 and 2031, respectively.	from FICCI report 2022
7.	BRIC	• The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. • All brick kilns within 2.5 radius from the Rourkela city centre will be converted to Zig-Zag kilns	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
8.	CONS	• The construction activities are assumed to increase at growth rate of 3.5% and 5.0% in 2026 and 2031, respectively. • 5% reduction in PM due to adoption of Good construction practices and stricter enforcement.	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
9.	CREM	• The deaths in 2026 and 2031 are estimated using the crude death rate. • The 10% of the operational crematoria would be converted to electricity.	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	DSGN	• An average daily usage of 1 hours in both 2026 and 2031, respectively. • No end-of-pipe control in 2026 and end-of-pipe control in 2031	Assumptions
11.	FUGT	• 10% and 25% emission reduction compared to NFC, in 2026 and 2031, respectively using Best Available Technologies (BAT) and Control Equipment.	Assumptions

5.11. Scenario – I (SC-I)

The SC-I scenario considers the activity changes due to already planned policies/interventions by the government in years 2026 and 2031. The growth rates of different sectors have been adopted through review of published literature. Table 22 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2026 and 2031 SC-I.

Table 22 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2026 and 2031 SC-I scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • The major control measures considered for the transport sector include: ○ Increased penetration of BS-VI vehicles ○ Introduction of E20 fuel ○ Increased electric vehicles (EV) penetration ○ Increased CNG penetration ○ Reduction in VKT due to increase in Non-motorized transport (NMT) share ○ Improvement in public transport ○ Reduction in highly polluting vehicles/ super-emitters • Refer Annexure-H for more details on penetration and applicability of each control measure listed above.	VAHAN database, Odisha EV Policy, 2019 Assumptions
2.	RDST	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • The silt loading on different road types calculated by assuming following: ○ Year 2026: 25% silt load reduction @ Highways and Major roads and 15% silt load reduction @ Inter, Minor and residential roads ○ Year 2031: 50% silt load reduction @ Highways and Major roads and 25% silt load reduction @ Inter, Minor and residential roads	Assumptions
3.	INDU	• Ensuring the PM control equipment are operating at minimum 99% control efficiency. • Adoption of suggested Best Available Technologies and Practices for Iron and Steel Industries (Refer Annexure – XX). • Assumed PM emission reduction (in addition to NFC scenarios) from Industries:	

Sr. No.	Sector	Assumptions, considerations and controls	References
		○ Within Rourkela city: 10% (2026) and 25% (2031) ○ Outside city limits: 10% (2026) and 25% (2031)	
4.	RESI	• The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: ○ Year 2026: 1. LIG HH: 70% 2. Other HH: 85% ○ Year 2031: 1. LIG HH: 80% 2. Other HH: 95%	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	WAST	• The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency: ○ Year 2026: 1. Rural areas: 75% 2. Urban Areas: 90% ○ Year 2031: 1. Rural areas: 80% 2. Urban areas: 90%	Assumptions
6.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 6.6%. • 20 and 50% facilities would be converted from wood/coal to LPG in years 2026 and 2031, respectively.	Based on growth rate acquired from FICCI report 2022
7.	BRIC	• The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. • All brick kilns within 5 km and 10 km radius from the Rourkela city centre will be converted to Zig-Zag kilns by 2026 and 2031, respectively.	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
8.	CONS	• The construction activities are assumed to increase at growth rate of 3.5% and 5.0% in 2026 and 2031, respectively. • 10 and 15% reduction in PM for years 2026 and 2031, respectively, due to adoption of Good construction practices and stricter enforcement.	Based on the gross domestic product of construction activities in Odisha during the year

Sr. No.	Sector	Assumptions, considerations and controls	References
			2017-2022, RBI Handbook, 2022 Assumptions
9.	CREM	• The deaths in 2026 and 2031 are estimated using the crude death rate. • The 25% and 50% of the crematoria would be converted to electricity, by 2026 and 2031, respectively.	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	DSGN	• An average daily usage of 0.75 hours in both 2026 and 2031, respectively. • No end-of-pipe control in 2026 and end-of-pipe control in 2031	Assumptions
11.	FUGT	• 20% and 50% emission reduction compared to NFC, in 2026 and 2031, respectively using Best Available Technologies (BAT) and Control Equipment.	Assumptions

5.12. Scenario – II (SC-II)

The SC-II scenario considers the activity changes due to already planned policies/interventions by the government in years 2026 and 2031. The growth rates of different sectors have been adopted through review of published literature. Table 23 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2026 and 2031 SC-II scenario.

Table 23 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2026 and 2031 SC-II scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • The major control measures considered for the transport sector include: ○ Increased penetration of BS-VI vehicles ○ Introduction of E20 fuel ○ Increased electric vehicles (EV) penetration ○ Increased CNG penetration ○ Reduction in VKT due to increase in Non-motorized transport (NMT) share ○ Improvement in public transport ○ Reduction in highly polluting vehicles/ super-emitters • Refer Annexure-H for more details on penetration and applicability of each control measure listed above.	VAHAN database, Odisha EV Policy, 2019 Assumptions
2.	RDST	• The vehicles in Rourkela region are estimated to grow at a CAGR of 6.0% till 2031. • The silt loading on different road types calculated by assuming following: ○ Year 2026: 50% silt load reduction @ Highways and Major roads and 25% silt load reduction @ Inter, Minor and residential roads ○ Year 2031: 90% silt load reduction @ Highways and Major roads and 50% silt load reduction @ Inter, Minor and residential roads	Assumptions
3.	INDU	• Ensuring the PM control equipment are operating at minimum 99% control efficiency. • Adoption of suggested Best Available Technologies and Practices for Iron and Steel Industries (Refer Annexure – XX).	

Sr. No.	Sector	Assumptions, considerations and controls	References
		• Assumed PM emission reduction (in addition to NFC scenarios) from Industries: ○ Within Rourkela city: 20% (2026) and 50% (2031) ○ Outside city limits: 20% (2026) and 50% (2031)	
4.	RESI	• The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: ○ Year 2026: 1. LIG HH: 90% 2. Other HH: 95% ○ Year 2031: 1. LIG HH: 100% 2. Other HH: 100%	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	WAST	• The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency: ○ Year 2026: 1. Rural areas: 90% 2. Urban Areas: 95% ○ Year 2031: 1. Rural areas: 95% 2. Urban areas: 98%	Assumptions
6.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 6.6%. • 30 and 75% facilities would be converted from wood/coal to LPG in years 2026 and 2031, respectively.	Based on growth rate acquired from FICCI report 2022
7.	BRIC	• The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. • All brick kilns within 10 km radius from the Rourkela city centre will be converted to Zig-Zag kilns by 2026 and all brick kilns within study domain would be converted to Zig-Zag kilns by 2031.	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
8.	CONS	• The construction activities are assumed to increase at growth rate of 3.5% and 5.0% in 2026 and 2031, respectively. • 15 and 30% reduction in PM for years 2026 and 2031, respectively, due to adoption of Good construction practices and stricter enforcement.	Based on the gross domestic product of construction activities in

Sr. No.	Sector	Assumptions, considerations and controls	References
			Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
9.	CREM	• The deaths in 2026 and 2031 are estimated using the crude death rate. • The 50% and 100% of the crematoria would be converted to electricity, by 2026 and 2031, respectively.	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	DSGN	• An average daily usage of 0.75 and 0.5 hours in 2026 and 2031, respectively. • End-of-pipe control in both 2026 and 2031	Assumptions
11.	FUGT	• 30% and 75% emission reduction compared to NFC, in 2026 and 2031, respectively using Best Available Technologies (BAT) and Control Equipment.	Assumptions

5.13. Projected Emissions for 2026 and 2031

This section discusses the projected emissions of pollutants under consideration with implementation of considered scenarios in 2026 and 2031 in Rourkela region. As discussed earlier, these scenarios consider implementation of various control measures explained in Section 5.12 in Rourkela region with varying factors for 2026 and 2031. Table 24 and Figures 108 to 112 presents the summary of estimated emissions (tonnes per year) of selected pollutants for four scenarios in Rourkela region for years 2026 and 2031.

The No further control (NFC) scenario emissions are compared against the baseline year emissions of 2021. The NFC scenario projections in Rourkela region indicate a potential increase in PM_{10} emissions to 17,387 tonnes per year in 2026 i.e. an increase of 2.4% w.r.t. baseline year 2021 and to 17,619 tonnes per year in 2031 i.e. an increase of 3.7% w.r.t. baseline year 2021. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to reach to 6482 (-2.8%) and 6,683 tonnes per year (i.e. 0.2%) in 2026 and 2031, respectively. The projected emissions of NO_X indicate a potential increase to 32,174 tonnes per year in 2026 i.e. a decrease

of 3.1% w.r.t. baseline year 2021 and to 31,491 tonnes per year in 2031 i.e. a decrease of 5.2% w.r.t. baseline year 2021. The CO emissions are expected to decrease to 94,447 tonnes per year in 2026 i.e. a decrease of 15.4% and 95,002 tonnes per year in 2031 i.e. an increase of 14.9% w.r.t. baseline year 2021.

The BAU projections in Rourkela indicate a potential decrease of PM_{10} emissions to 13,002 tonnes per year in 2026 i.e. a decrease of 25.2 % w.r.t. NFC_2026 and to 12,125 tonnes per year in 2031 i.e. a decrease of 31.2% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 5,082 (-21.6%%) and 4730 tonnes per year (i.e. -29.2%) in 2026 and 2031, respectively. The projected emissions of NO_X indicate a potential reduction to 30,418 tonnes per year in 2026 i.e. a decrease of 5.5% w.r.t. NFC_2026 and to 27,784 tonnes per year in 2031 i.e. a decrease of 11.8% w.r.t. NFC 2031. The CO emissions are expected to decrease to 88,755 tonnes per year in 2026 i.e. a decrease of 6% w.r.t. NFC_2026 and 82,751 tonnes per year in 2031 i.e. a decrease of 12.9% w.r.t. NFC 2031. Sulphur dioxide emissions are projected to decline by 6.1% (i.e. 33,830 tonnes per year) and 12.2% (i.e. 31,700 tonnes per year) in 2026 and 2031, respectively relative to their respective NFC scenarios.

The SC-I projections in Rourkela region indicate a potential decrease of PM_{10} emissions to 11,930 tonnes per year in 2026 i.e. a decrease of 31.4% w.r.t. NFC 2026 and to 9,381 tonnes per year in 2031 i.e. a decrease of 46.8% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 4,683 (27.8%) and 3,753 tonnes per year (i.e. 43.8%) in 2026 and 2031, respectively. Similarly, projected emissions of NO_X indicate a potential reduction to 28,653 tonnes per year in 2026 i.e. a decrease of 10.9 % w.r.t. NFC 2026 and to 21,703 tonnes per year in 2031 i.e. a decrease of 31.1% w.r.t. NFC 2031. The CO emissions are expected to decrease to 83,014 tonnes per year in 2026 i.e. a decrease of 12.1% w.r.t. NFC 2026 and 67,184 tonnes per year in 2031 i.e. a decrease of 29.3% w.r.t. NFC 2031. Sulphur dioxide emissions are projected to decline by 12.2% (i.e. 31,621 tonnes per year) and 35.9% (i.e. 23,163 tonnes per year) in 2026 and 2031, respectively, relative to their respective NFC scenarios.

The SC-II projections in Rourkela region indicate a potential decrease of PM_{10} emissions to 10,125 tonnes per year in 2026 i.e. a decrease of 41.8% w.r.t. NFC 2026 and to 5,493 tonnes per year in 2031 i.e. a decrease of 68.8% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$

emissions are also estimated to decrease to 3,960 (i.e. 38.9%) and 2,319 tonnes per year (i.e. 65.3%) in 2026 and 2031, respectively. Similarly, the projected emissions of NO_X indicate a potential reduction to 25,136 tonnes per year in 2026 i.e. a decrease of 21.9% w.r.t. NFC 2026 and to 14,234 tonnes per year in 2031 i.e. a decrease of 54.8% w.r.t. NFC 2031. The CO emissions are expected to decrease to 72,124 tonnes per year in 2026 i.e. a decrease of 23.6% w.r.t. NFC 2026 and 44,018 tonnes per year in 2031 i.e. a decrease of 53.7% w.r.t. NFC 2031. Sulphur dioxide (SO_2) emissions are projected to decline by 24.5% (i.e. 27,197 tonnes per year) and 60.8% (i.e. 14,146 tonnes per year) in 2026 and 2031, respectively, relative to their respective NFC scenarios.

Table 24 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Rourkela region for years 2021, 2026 and 2031

Year	Scenario	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
2021	BASE	16,986	6,667	35,936	33,217	1,11,622
2026	NFC	17,387	6,482	36,036	32,174	94,447
	BAU	13,002	5,082	33,830	30,418	88,755
	SC_I	11,930	4,683	31,621	28,653	83,014
	SC_II	10,125	3,960	27,197	25,136	72,124
2031	NFC	17,619	6,683	36,123	31,491	95,002
	BAU	12,125	4,730	31,700	27,784	82,751
	SC_I	9,381	3,753	23,163	21,703	67,184
	SC_II	5,493	2,319	14,146	14,234	44,018

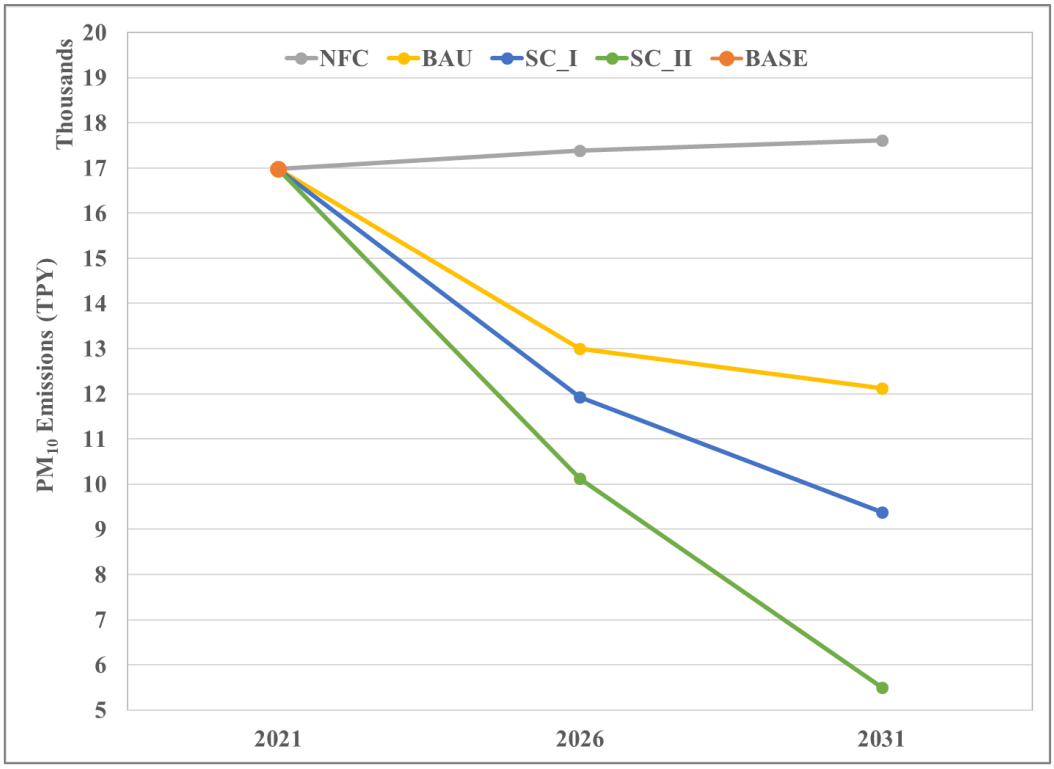

Figure 108 PM_{10} *Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031*

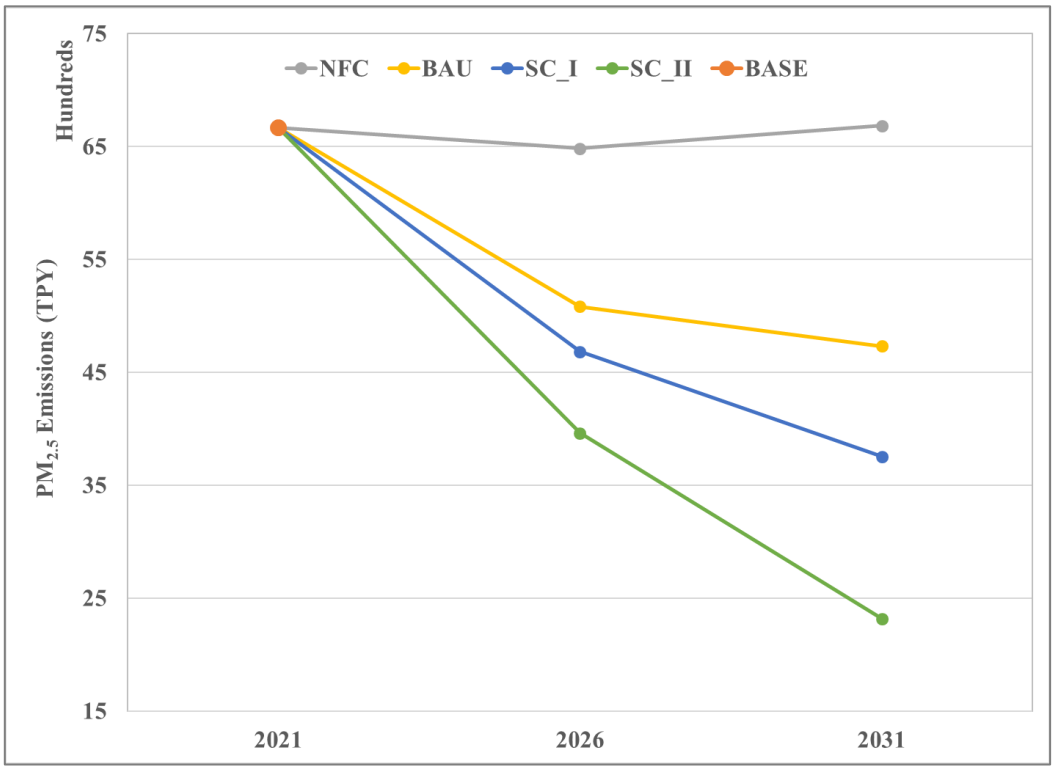

Figure 109 $PM_{2.5}$ *Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031*

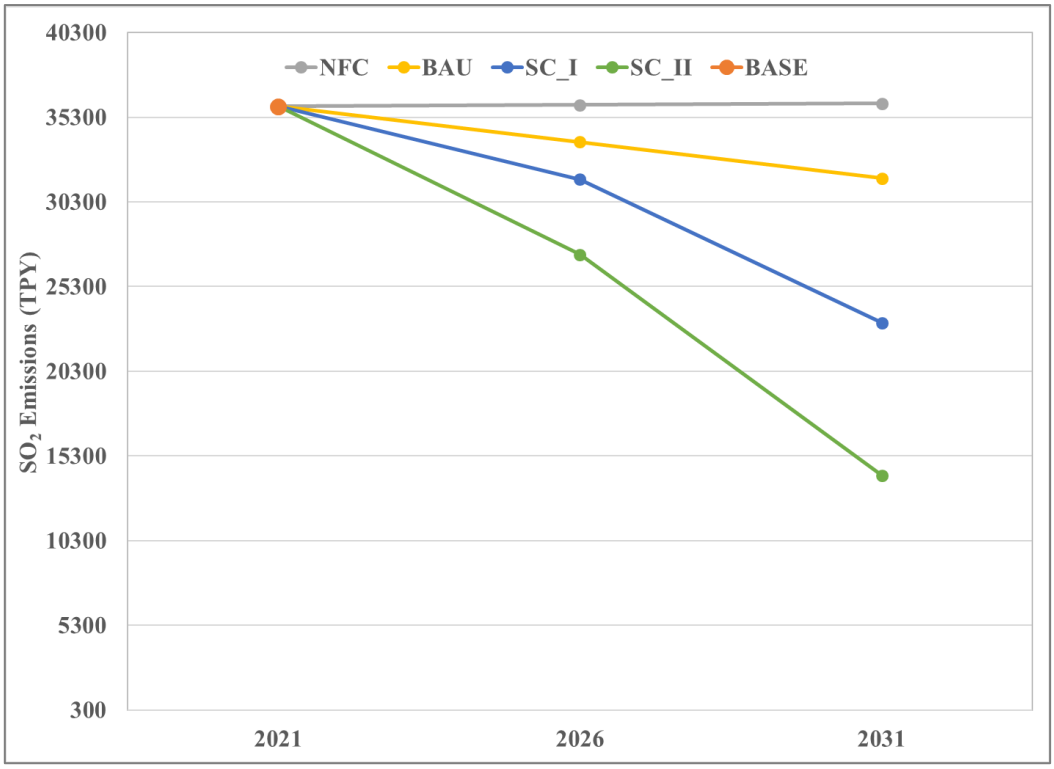

Figure 110 SO_2 *Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031*

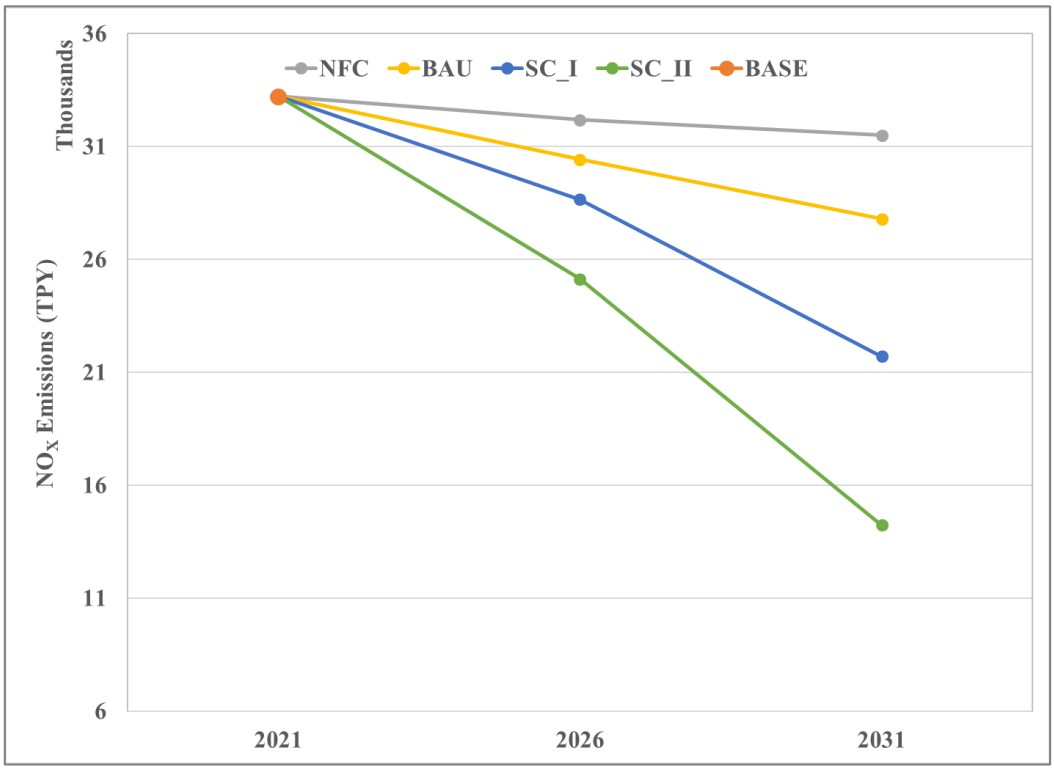

Figure 111 NO_X *Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031*

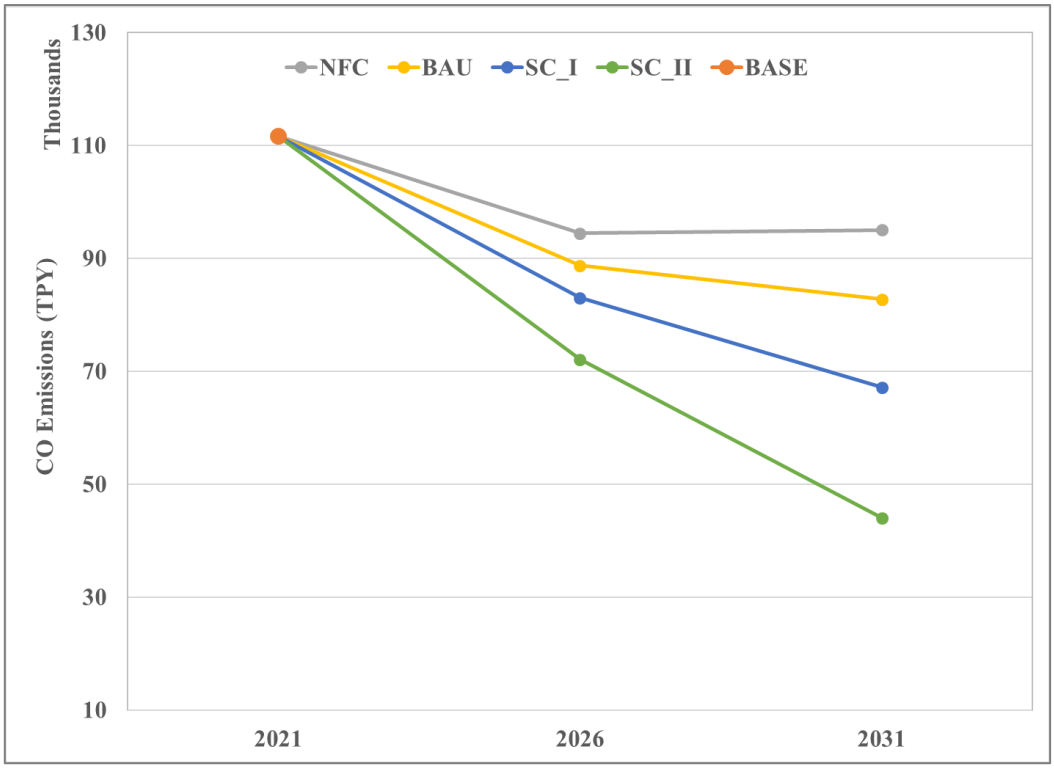

Figure 112 CO Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

5.13.1. Sector-wise emission reduction potentials

Table 25 and Fig. 113-117 shows sector-wise and total estimated emission reduction potential (%) of pollutants w.r.t. respective NFC scenarios in Rourkela region for years 2026 and 2031. The total particulate matter emissions in 2026 can be reduced upto maximum 41.8% and 38.9% in PM_{10} and $PM_{2.5}$, respectively w.r.t. NFC 2026 scenario. Similarly, total particulate matter emissions in 2031 can be reduced upto maximum 68.8% and 65.3% in PM_{10} and $PM_{2.5}$, respectively w.r.t. NFC 2031 scenario. The control measures considered in Industrial sector (INDU) sector have the highest potential (PM_{10}: 20.6 to 36.3% and $PM_{2.5}$: 20.19 to 41.4%) to reduce the particulate emissions among three different scenarios. The other sectors that can significantly reduce the PM_{10} emissions in future years include: re-suspended road dust sector (RDST; upto 15.2%), fugitive dust (FUGT; upto 10.0%), and residential (RESI; upto 2.9%). Similarly, for $PM_{2.5}$ significant emission reductions can be obtained in industrial (upto 41.4%), re-suspended road dust (upto 9.7%), residential (upto 4.9%), open waste burning (upto 3.6%), and fugitive dust (upto 2.6%).

Table 25 Sector-wise estimated emission reduction potential (%) for PM_{10} *and* $PM_{2.5}$ *w.r.t. respective NFC scenarios in Rourkela region*

Year	Sector	PM_{10}			$PM_{2.5}$		
		BAU	SC-I	SC-II	BAU	SC-I	SC-II
2026	**TOTAL**	**-25.2%**	**-31.4%**	**-41.8%**	**-21.6%**	**-27.8%**	**-38.9%**
	INDU	-20.6%	-22.4%	-26.0%	-20.1%	-22.6%	-27.6%
	TRAN	-0.1%	-0.2%	-0.3%	-0.3%	-0.5%	-0.7%
	RDST	-2.1%	-4.2%	-7.7%	-1.4%	-2.7%	-5.0%
	WAST	-0.5%	-0.7%	-1.1%	-1.3%	-1.7%	-2.9%
	CONS	-0.1%	-0.3%	-0.4%	-0.1%	-0.1%	-0.2%
	DSGN	0.0%	0.0%	-0.1%	0.0%	-0.1%	-0.2%
	RESI	-0.5%	-1.2%	-2.2%	-1.0%	-2.2%	-3.8%
	BRIC	0.0%	0.0%	-0.4%	0.0%	0.0%	-0.3%
	HRBE	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.2%
	CREM	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%
	FUGT	-1.1%	-2.2%	-3.4%	-0.3%	-0.6%	-0.9%
2031	**TOTAL**	**-31.2%**	**-46.8%**	**-68.8%**	**-29.2%**	**-43.8%**	**-65.3%**
	INDU	-22.1%	-27.4%	-36.3%	-22.0%	-29.2%	-41.4%
	TRAN	-0.1%	-0.2%	-0.3%	-0.3%	-0.5%	-0.8%
	RDST	-3.7%	-8.1%	-15.2%	-2.4%	-5.1%	-9.7%
	WAST	-0.7%	-0.8%	-1.5%	-1.6%	-2.0%	-3.6%
	CONS	-0.1%	-0.4%	-0.8%	-0.1%	-0.2%	-0.4%
	DSGN	-0.2%	-0.3%	-0.3%	-0.4%	-0.6%	-0.6%
	RESI	-0.8%	-2.1%	-2.9%	-1.4%	-3.6%	-4.9%
	BRIC	0.0%	-0.5%	-1.2%	0.0%	-0.4%	-0.6%
	HRBE	-0.1%	-0.2%	-0.3%	-0.2%	-0.4%	-0.6%
	CREM	0.0%	-0.1%	-0.1%	0.0%	-0.1%	-0.2%
	FUGT	-3.3%	-6.6%	-10.0%	-0.9%	-1.7%	-2.6%

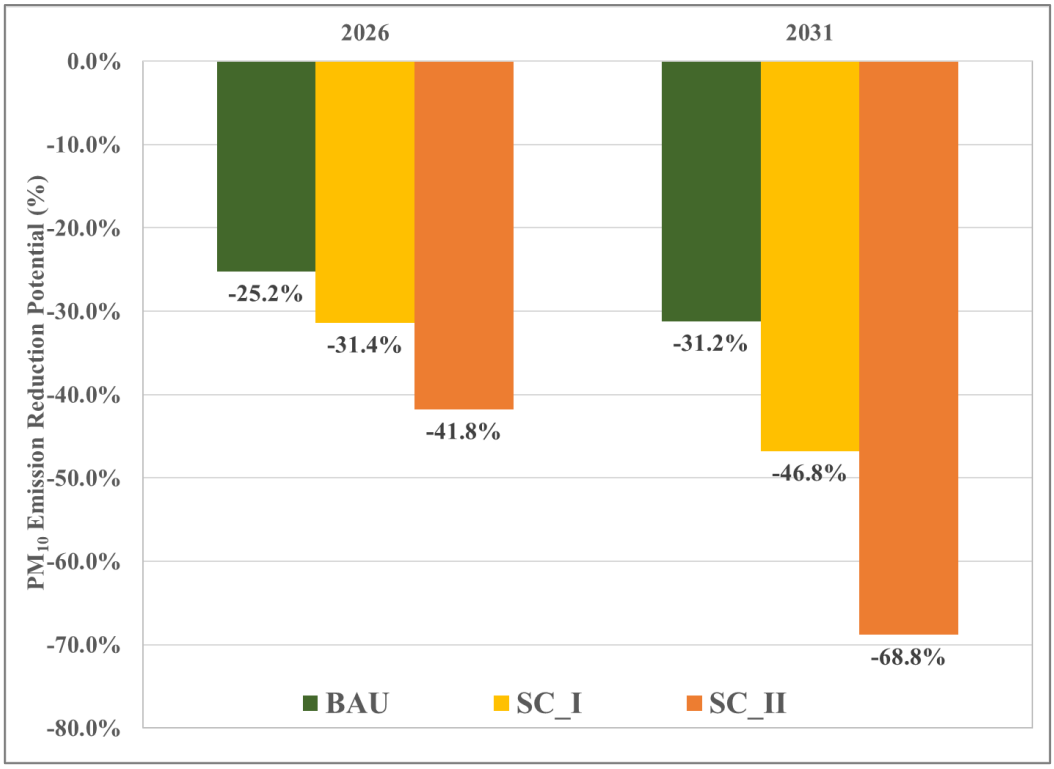

Figure 113 PM_{10} *Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)*

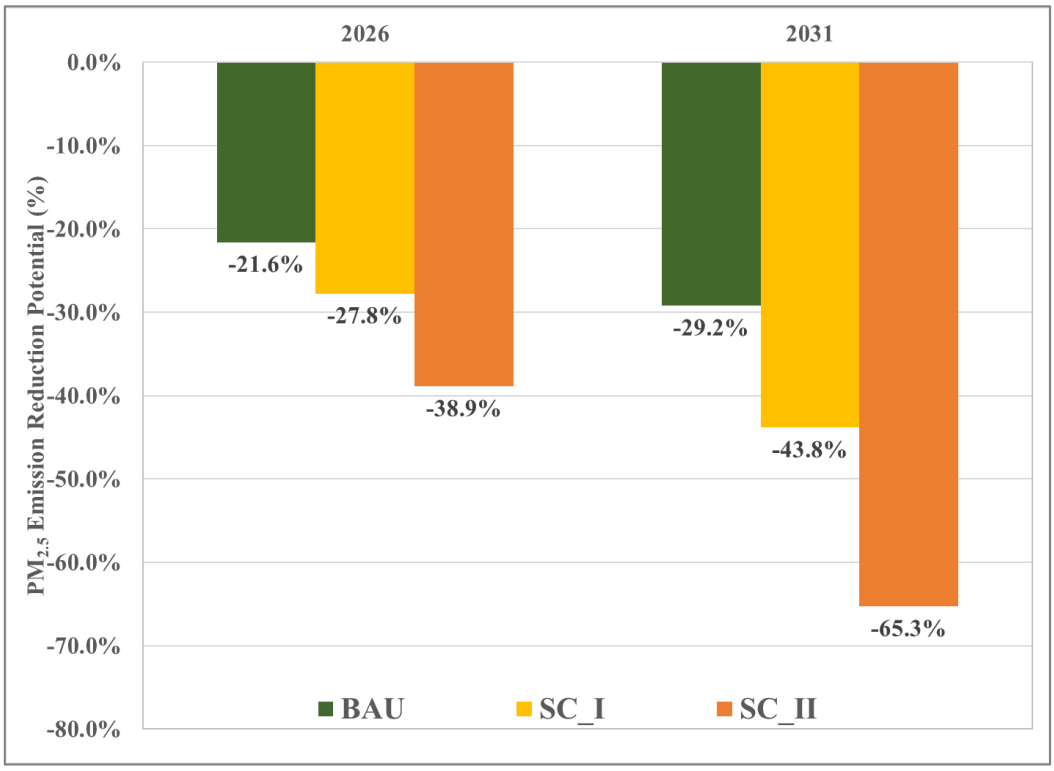

Figure 114 $PM_{2.5}$ *Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)*

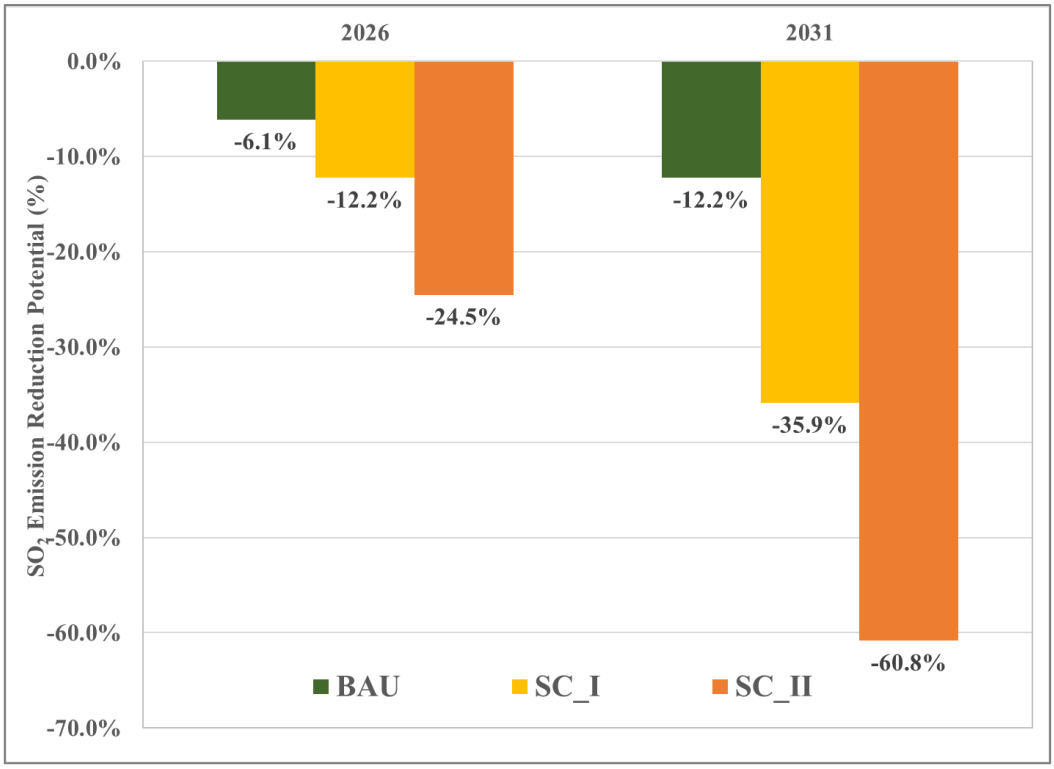

Figure 115 SO_2 *Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)*

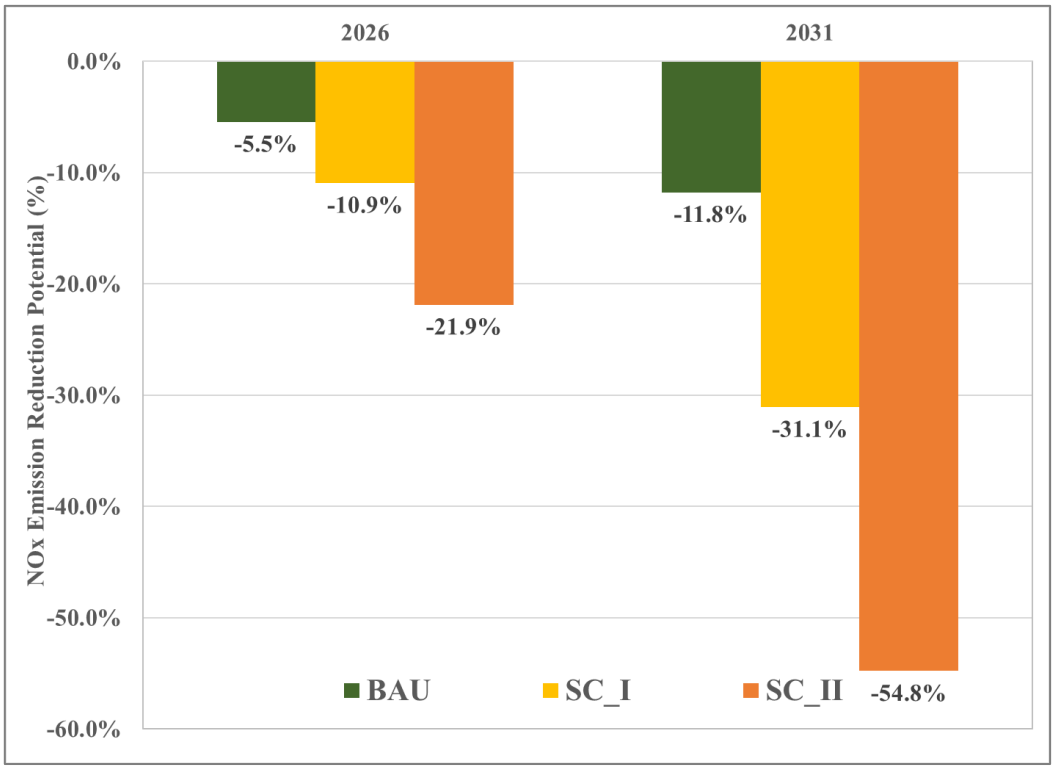

Figure 116 NO_X *Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)*

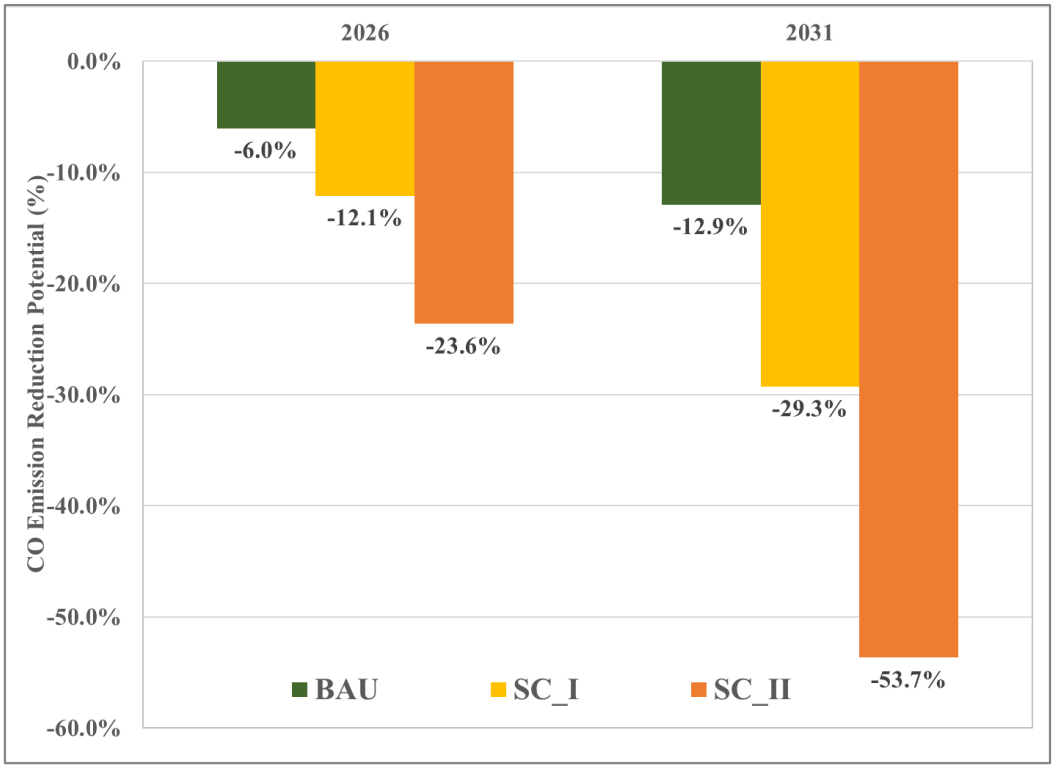

Figure 117 CO Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

5.14. Air Quality Benefits

Air quality benefits of four designed scenarios were assessed for years 2026 and 2031 using AERMOD modelled annual mean pollutant concentrations in Rourkela region. The spatial distribution of pollutant (PM_{10}, $PM_{2.5}$. SO_2, NO_2, CO) concentration levels over Rourkela are plotted in gridded format using QGIS. The annual mean concentrations are plotted for year 2026 and 2031 for different scenarios.

In general, the pollutants are mainly concentrated in the central part and the western part of the study domain. This spatial distribution can be mainly attributed to the fugitive dust and industrial activities in these areas. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2026 and 2031 due to proposed fugitive dust control measures, adoption of best available technologies in iron steel plants and sponge iron industries, changes in technology and fuels of vehicles such as EV adoption, implementation of BS VI, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, improvement in NMT & public transport, usage of clean fuel for cooking, improved

waste collection efficiency, adoption of Zig-zag type brick kilns and various other control strategies considered in different scenarios.

As shown in Fig 118-119, the PM_{10} concentrations for NFC scenario in 2026 and 2031, are mainly concentrated in the central part and the western part of the study domain. The highest annual average PM_{10} concentrations estimated by AERMOD during four scenarios are 353.4, 316.8, 284.1, and 241.7 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The highest annual PM_{10} concentrations during year 2031 are estimated to be 356.6, 282.4, 201.8, and 115.9 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 7.2%, 13.3%, and 23.0% in 2026 and 12.2%, 26.0%, 44.1% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 120-121, the $PM_{2.5}$ concentrations, are also concentrated in the central part and the western part of the study domain. The highest annual average $PM_{2.5}$ concentrations estimated by AERMOD during four scenarios are 81.6, 72.1, 65.1, 53.9 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The highest annual $PM_{2.5}$ concentrations during year 2031 are estimated to be 81.2, 66.4, 49.2, 32.2 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 6.3%, 11.5%, and 19.8% in 2026 and 10.1%, 21.5%, 35.0% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 122-123, the SO_2 concentrations, are also concentrated in the central, western and northern part of the study domain. The highest annual average SO_2 concentrations estimated by AERMOD during four scenarios are 38.0, 35.6, 33.3, and 28.7 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The highest annual SO_2 concentrations during year 2031 are estimated to be 38.5, 36.3, 25.3, and 18.9 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 4.3%, 9.9%, and 23.2% in 2026 and 28.7%, 49.8%, 63.3% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 124-125, the NO_2 concentrations, are also concentrated in the central, western and northern part of the study domain. The highest annual average NO_2 concentrations estimated by AERMOD during four scenarios are 25.6, 24.8, 24.2, and 22.9 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The highest annual NO_2 concentrations during year 2031 are estimated to be 22.9, 22.8, 19.8, and 16.7 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 1.6%, 2.9%, and 5.6% in 2026 and 3.8%, 9.2%, 14.5% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 126-127, the CO concentrations, are also concentrated in the central, western and northern part of the study domain. The highest annual average CO concentrations estimated by AERMOD during four scenarios are 0.66, 0.61, 0.58, and 0.51 mg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The highest annual CO concentrations during year 2031 are estimated to be 0.68, 0.66, 0.63, and 0.59 mg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 2.1%, 4.6%, and 8.8% in 2026 and 0.5%, 1.3%, 2.5% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

It is important to note that, these are domain averaged values and pollutant reductions are likely to vary significantly over the study domain. The values are highest at the receptors very close to sources.

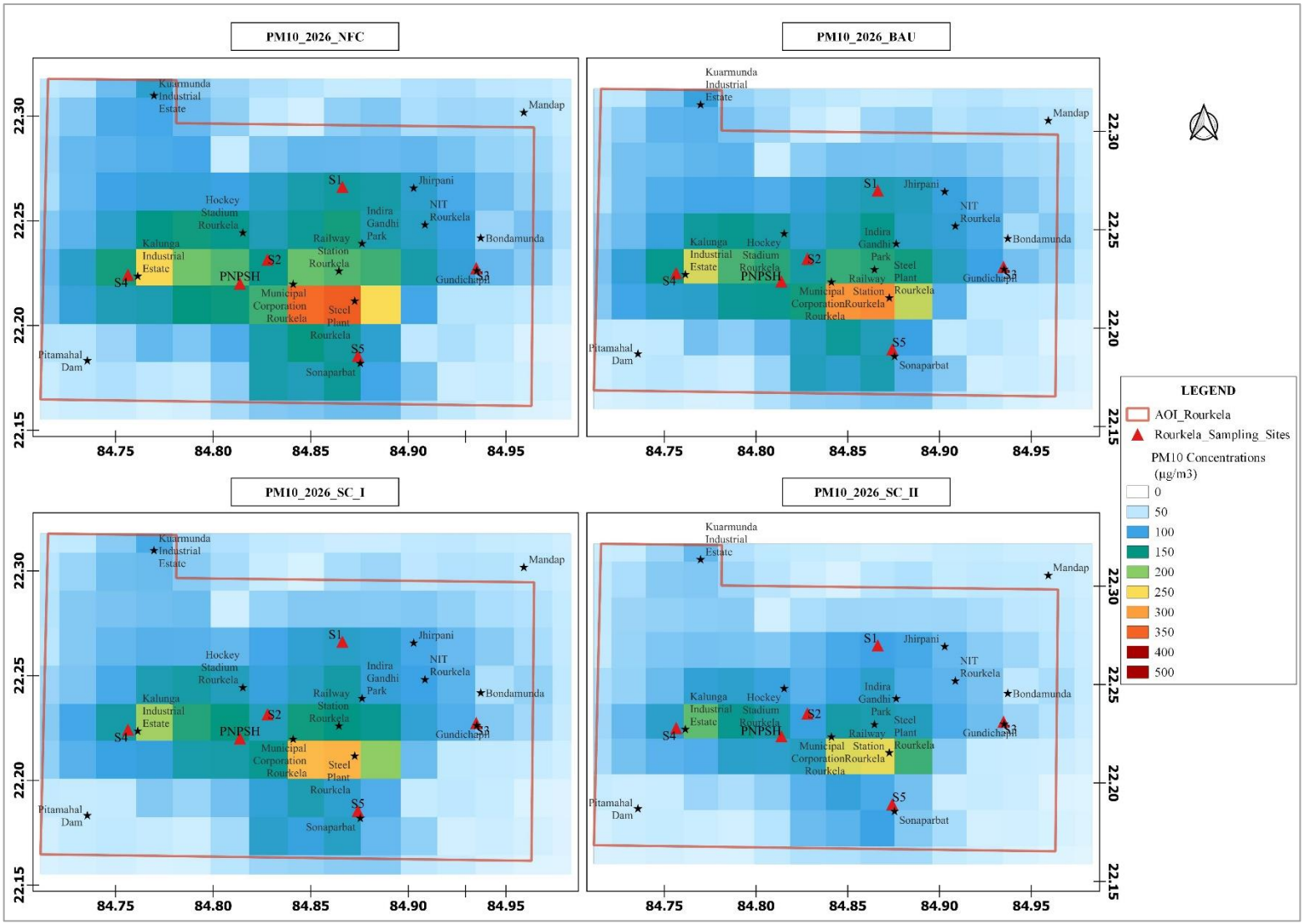

Figure 118 Spatial distribution of annual mean PM_{10} *concentrations* ($\mu g/m^3$) *for four scenarios in year 2026 over Rourkela region*

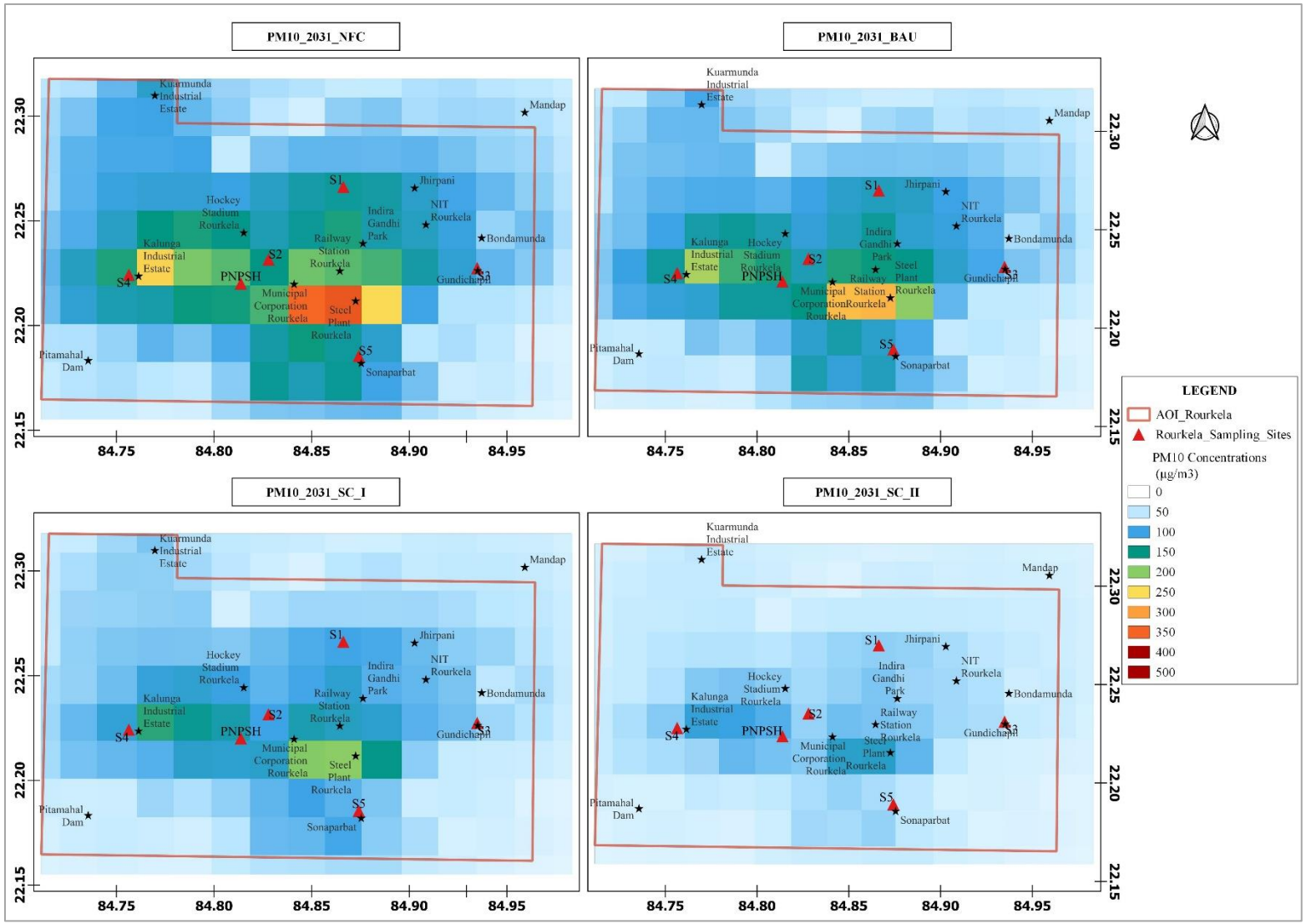

Figure 119 Spatial distribution of annual mean PM_{10} *concentrations* ($\mu g/m^3$) *for four scenarios in year 2031 over Rourkela region*

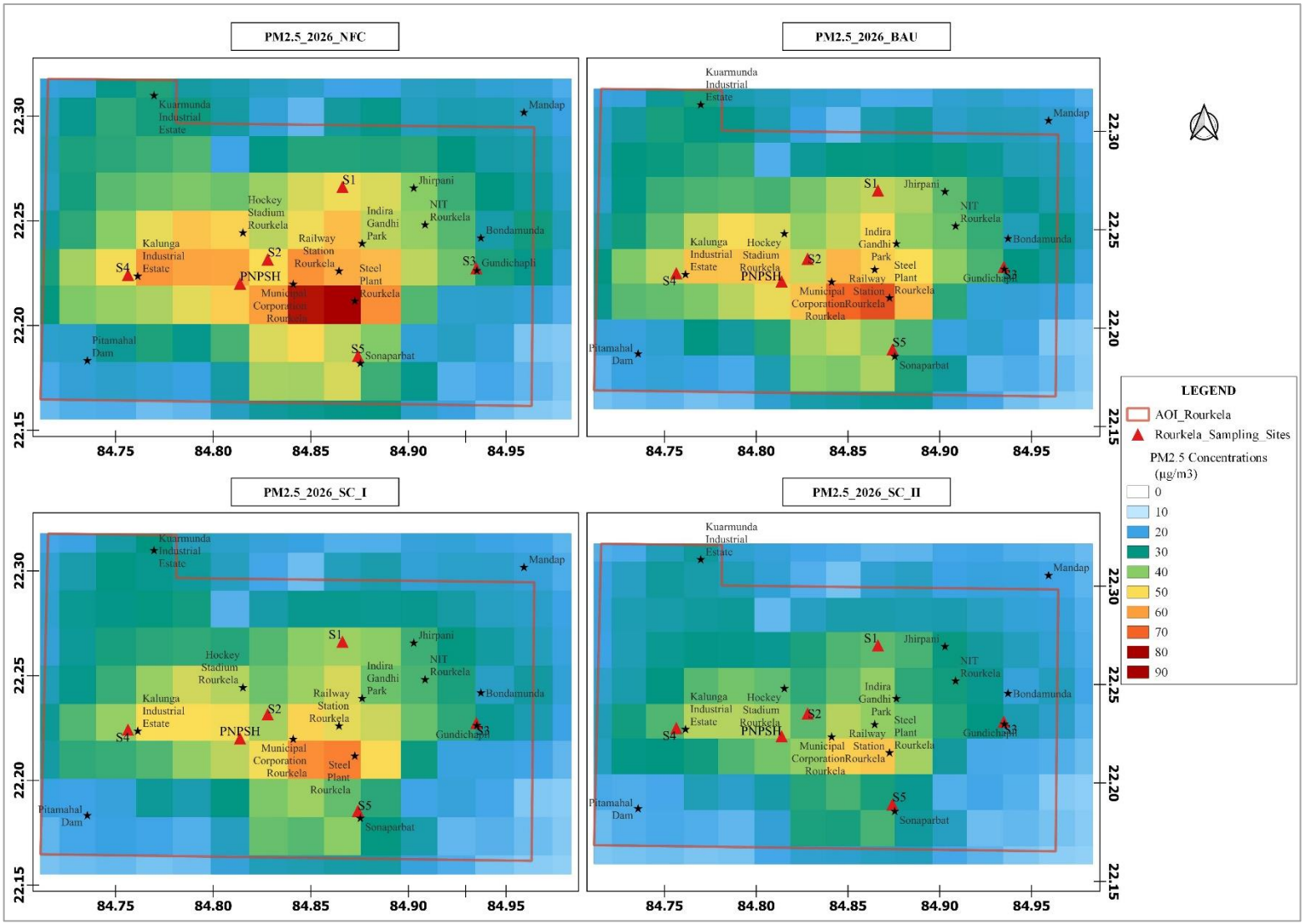

Figure 120 Spatial distribution of annual mean $PM_{2.5}$ *concentrations* ($\mu g/m^3$) *for four scenarios in year 2026 over Rourkela region*

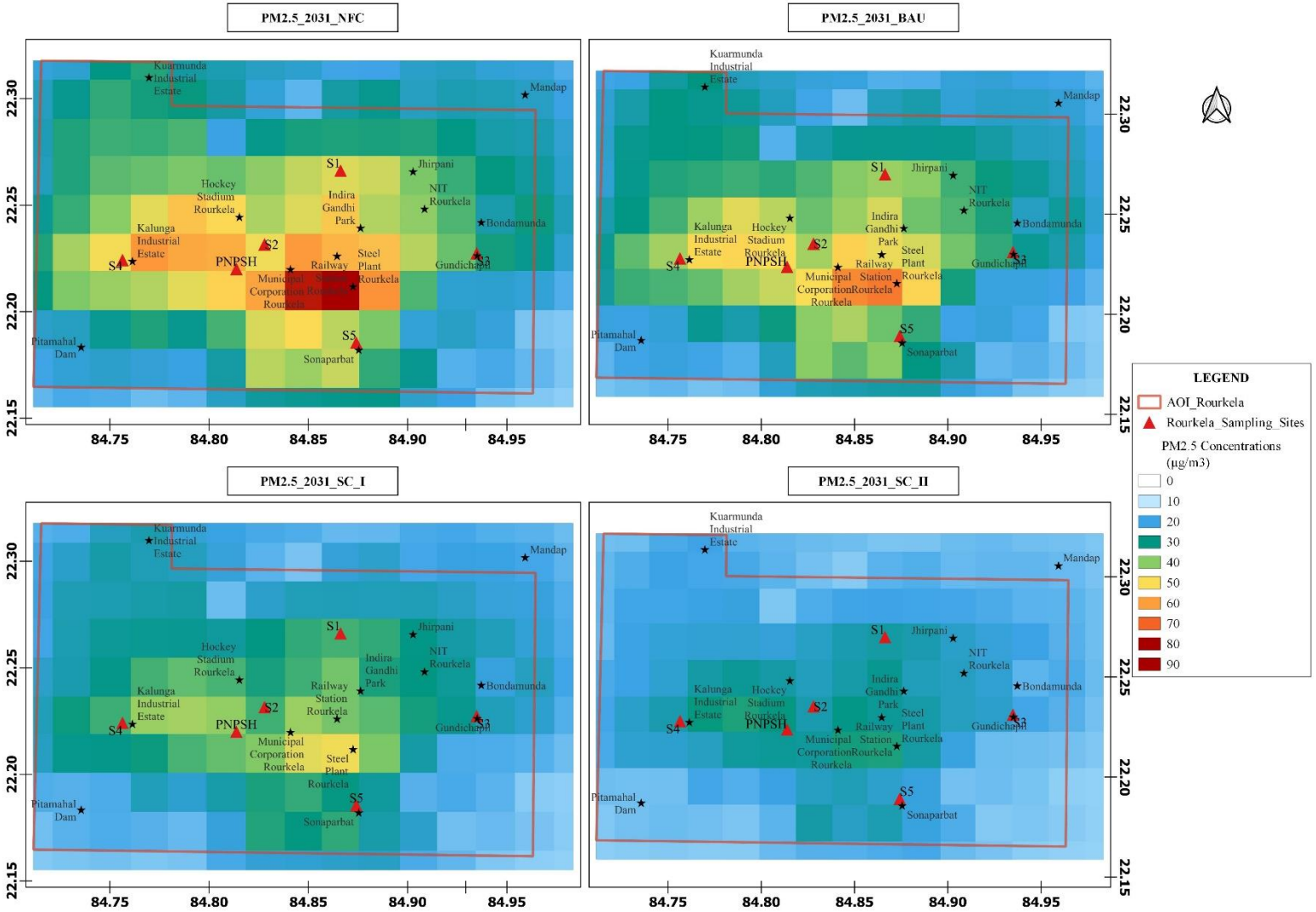

Figure 121 Spatial distribution of annual mean $PM_{2.5}$ *concentrations* ($\mu g/m^3$) *for four scenarios in year 2031 over Rourkela region*

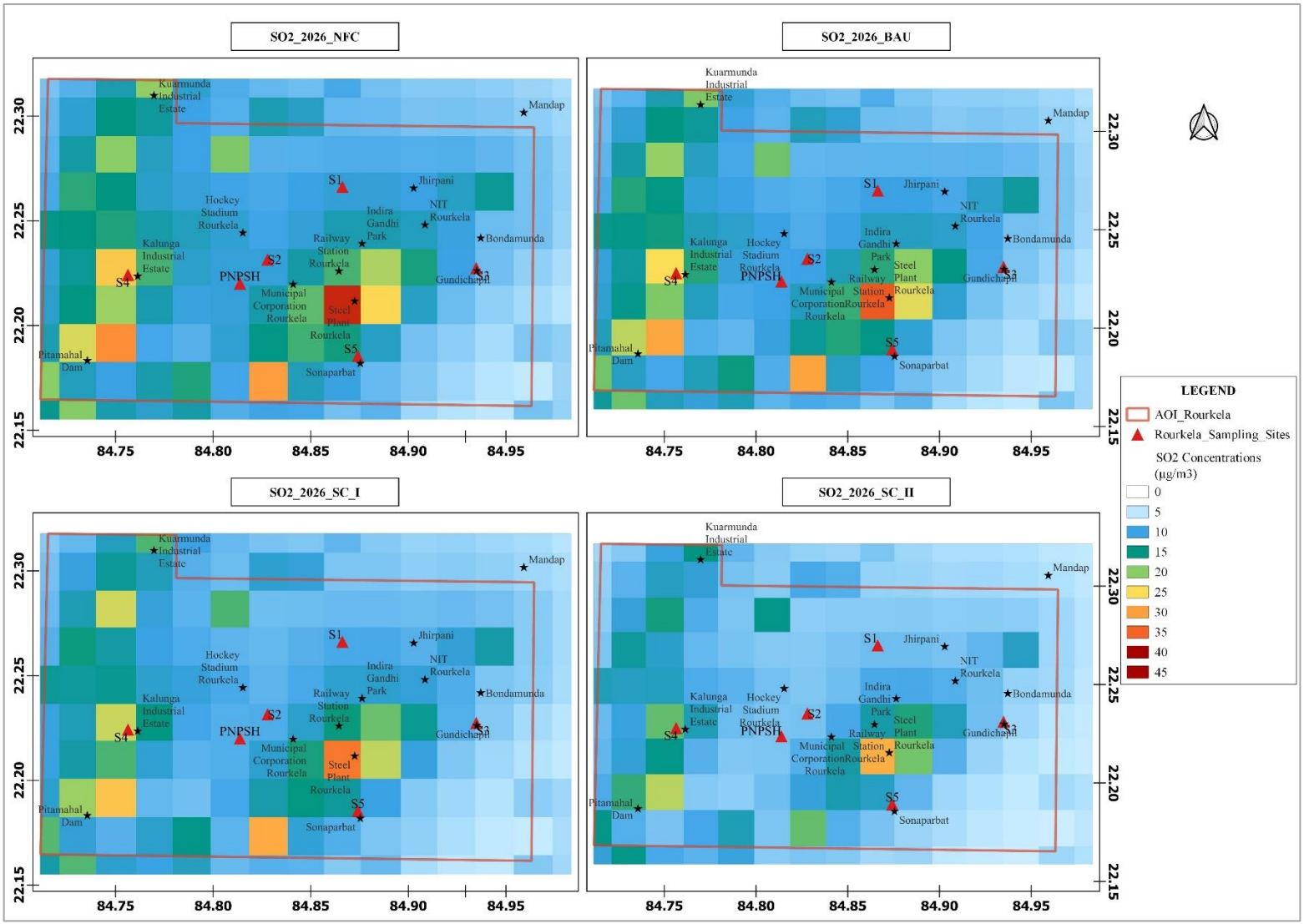

Figure 122 Spatial distribution of annual mean SO_2 *concentrations (*$\mu g/m^3$*) for four scenarios in year 2026 over Rourkela region*

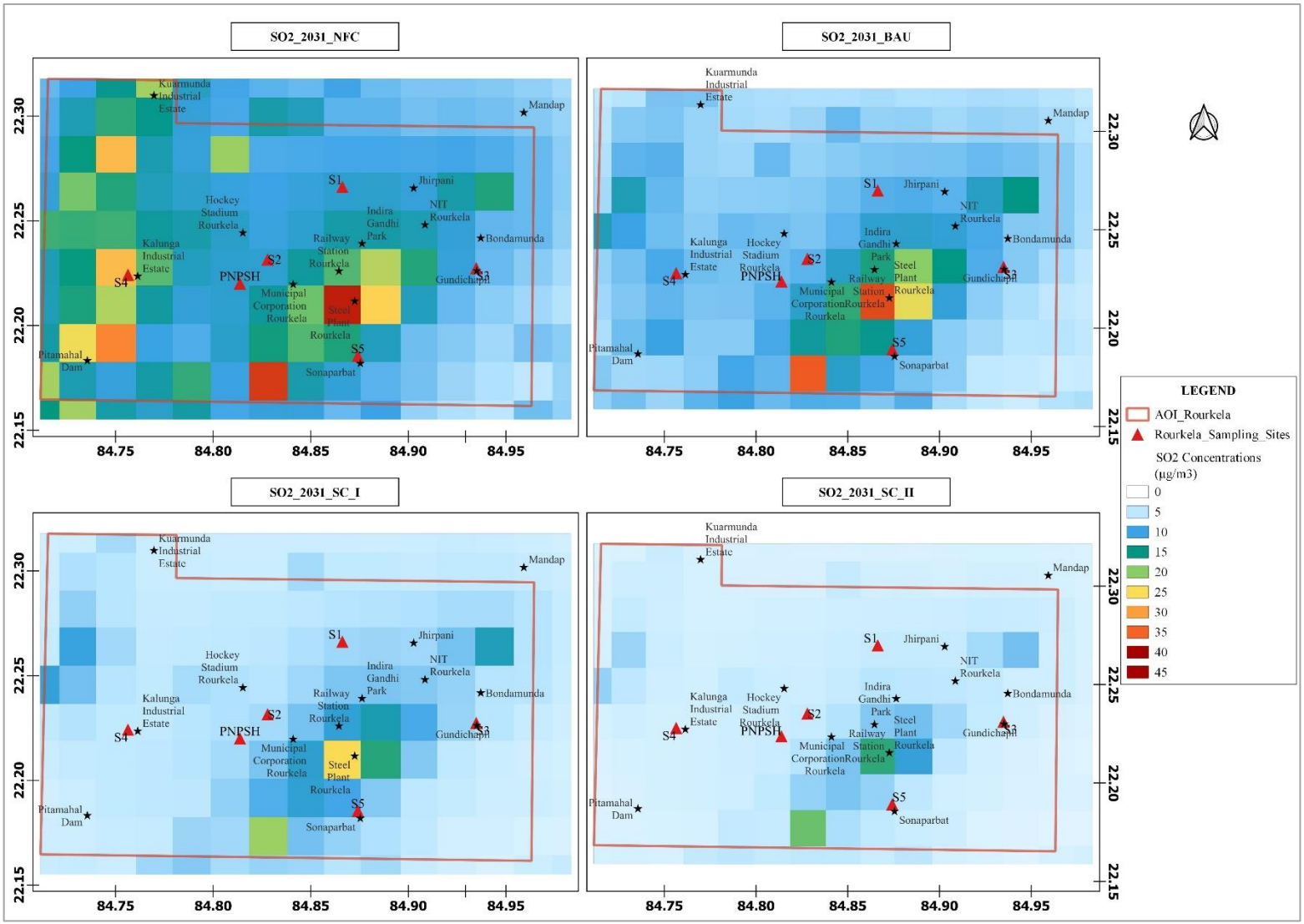

Figure 123 Spatial distribution of annual mean SO_2 *concentrations (*$\mu g/m^3$*) for four scenarios in year 2031 over Rourkela region*

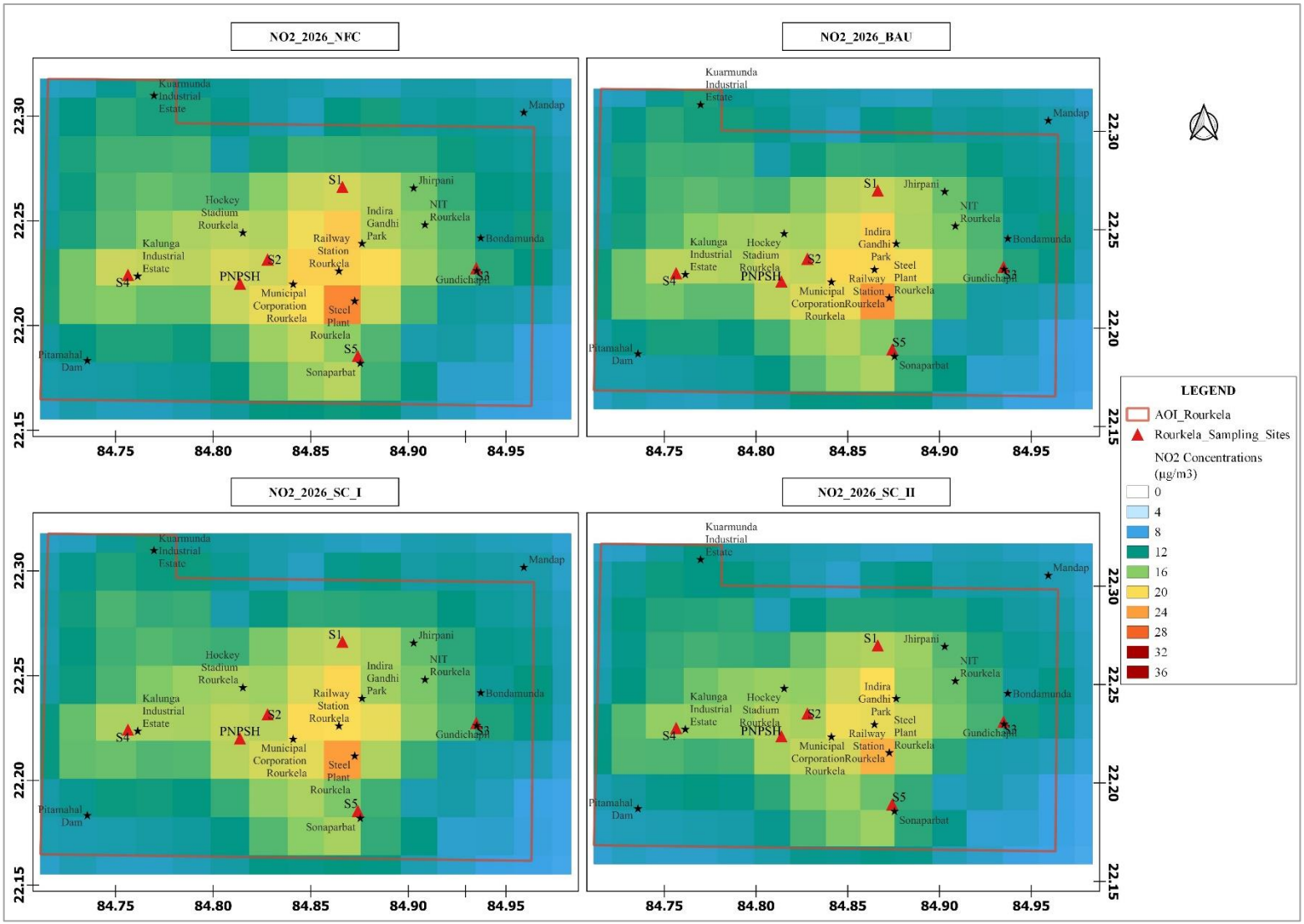

Figure 124 Spatial distribution of annual mean NO_2 concentrations (µg/m^3) for four scenarios in year 2026 over Rourkela region

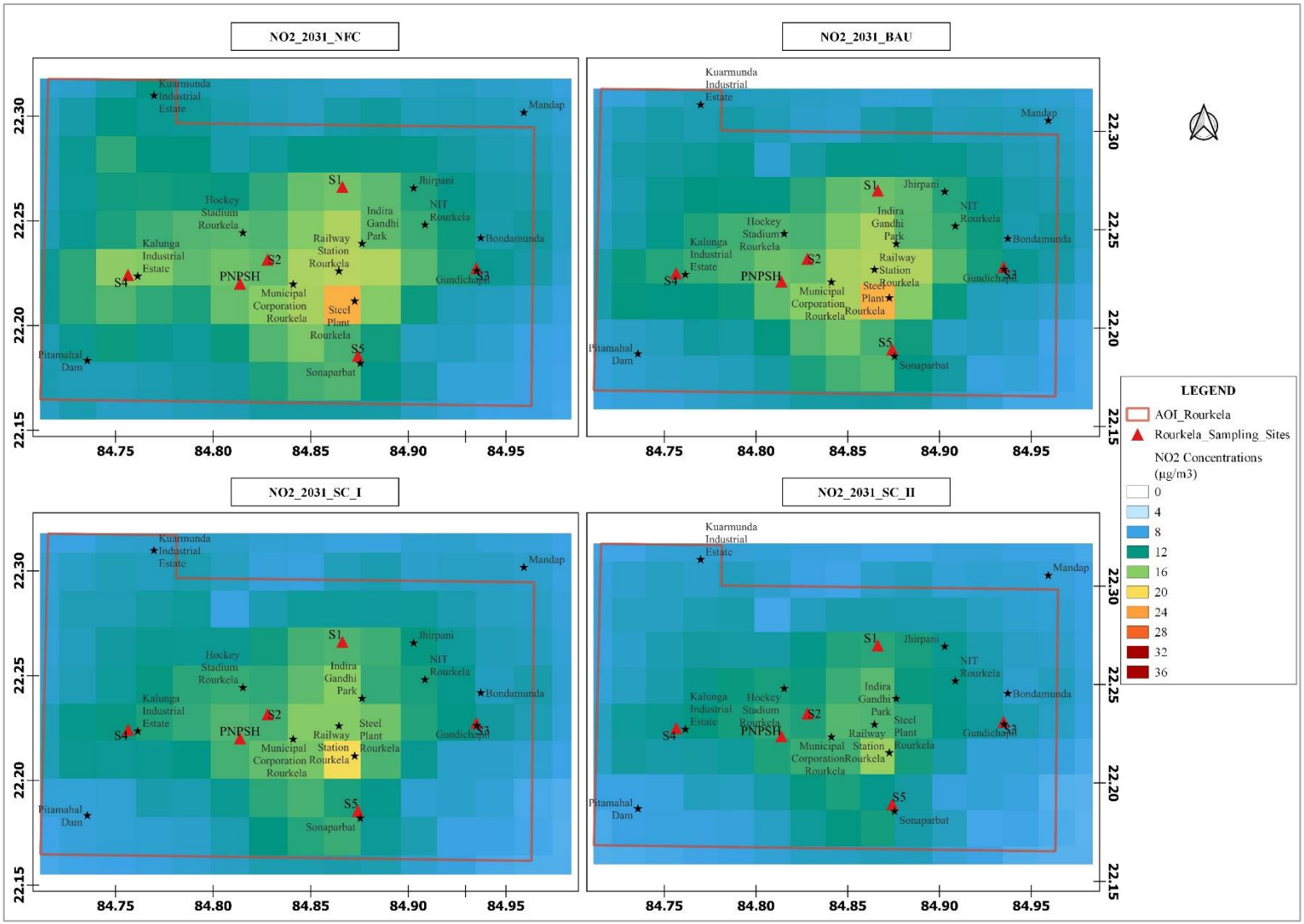

Figure 125 Spatial distribution of annual mean NO_2 concentrations (µg/m^3) for four scenarios in year 2031 over Rourkela region

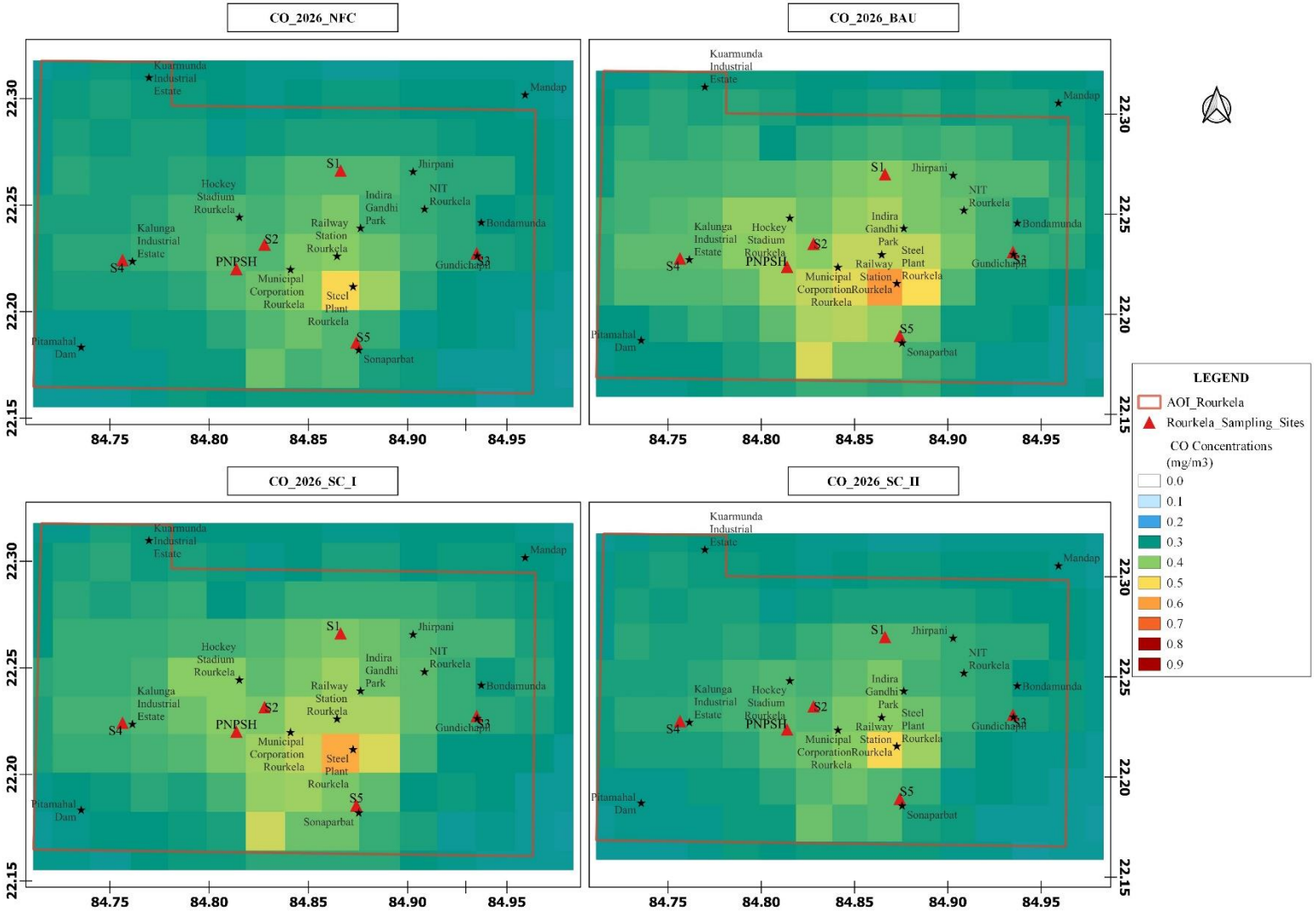

Figure 126 Spatial distribution of annual mean CO concentrations (mg/m^3) for four scenarios in year 2026 over Rourkela region

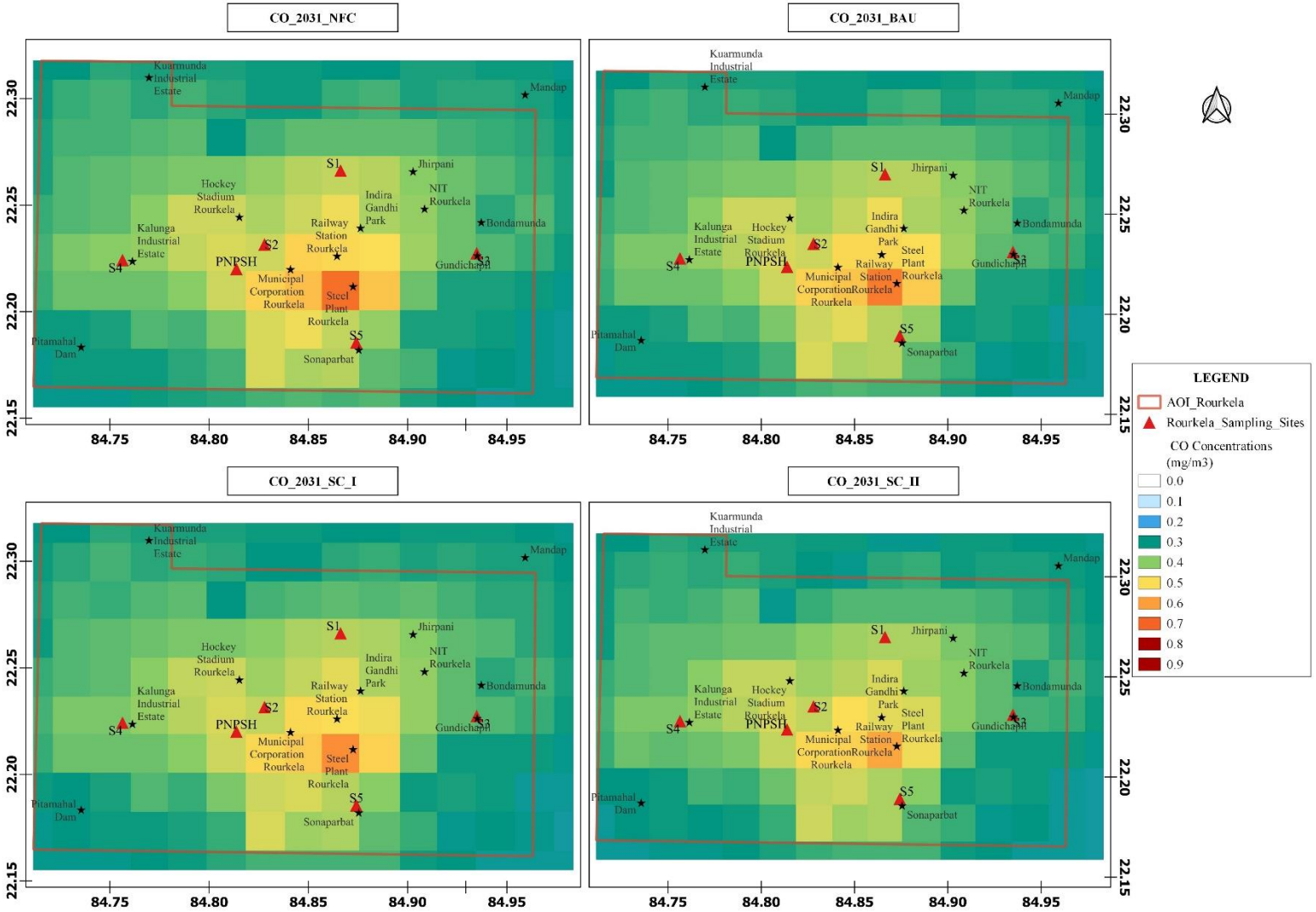

Figure 127 Spatial distribution of annual mean CO concentrations (mg/m^3) for four scenarios in year 2031 over Rourkela region

This study also extracted location -specific air quality benefits due to implementation of different scenarios in 2026 and 2031. Six representative locations, i.e. Panposh CAAQMS and five ARAI sampling locations, were selected to understand the impact of control measures on air quality. Tables 26 to 31 presents the percentage change in air pollutants annual mean concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at six selected locations in Rourkela.

Table 26 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at Panposh Chowk CAAQMS location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-8.2%	-15.7%	-27.4%	-13.2%	-29.5%	-51.3%
$PM_{2.5}$	-8.5%	-15.4%	-26.7%	-12.8%	-28.4%	-46.9%
SO_2	-6.9%	-13.6%	-28.2%	-23.8%	-48.1%	-62.6%
NO_2	-2.3%	-3.6%	-6.2%	-1.3%	-6.5%	-13.4%
CO	-4.3%	-8.4%	-15.6%	-9.1%	-20.3%	-35.5%

Table 27 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S1 i.e. Hamirpur Highschool sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-7.8%	-14.9%	-26.1%	-12.8%	-28.3%	-49.4%
$PM_{2.5}$	-7.4%	-13.4%	-23.2%	-11.3%	-24.9%	-41.5%
SO_2	-5.6%	-11.3%	-23.9%	-20.1%	-44.6%	-60.5%
NO_2	-2.0%	-3.2%	-5.8%	-1.1%	-7.1%	-14.1%
CO	-3.1%	-6.0%	-11.2%	-6.6%	-14.6%	-25.4%

Table 28 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S2 i.e. IDCO Office sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-8.9%	-16.5%	-29.0%	-14.6%	-31.8%	-54.6%
$PM_{2.5}$	-8.8%	-15.4%	-26.9%	-13.3%	-28.9%	-47.4%
SO_2	-6.5%	-12.7%	-26.6%	-22.1%	-46.6%	-61.6%
NO_2	-2.1%	-3.4%	-6.1%	-0.1%	-5.8%	-13.0%
CO	-4.0%	-7.7%	-14.2%	-8.5%	-18.6%	-32.3%

Table 29 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S3 i.e. College of Arts, Science & Technology, Bondamunda sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-7.0%	-13.6%	-24.0%	-11.6%	-26.0%	-46.2%
$PM_{2.5}$	-6.2%	-11.6%	-20.3%	-9.8%	-21.6%	-36.8%
SO_2	-4.7%	-9.4%	-20.9%	-12.2%	-37.4%	-55.8%
NO_2	-1.8%	-2.9%	-5.2%	-0.1%	-5.9%	-12.3%
CO	-2.1%	-4.3%	-8.0%	-4.4%	-10.3%	-18.1%

Table 30 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S4 i.e. Jay Matadi Plastics Ltd, Kalunga sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-8.9%	-17.6%	-27.6%	-18.4%	-39.0%	-61.2%
$PM_{2.5}$	-12.8%	-19.6%	-29.0%	-18.7%	-34.9%	-51.3%
SO_2	-7.4%	-15.7%	-31.9%	-73.2%	-89.7%	-92.5%
NO_2	-3.3%	-7.3%	-15.6%	-33.8%	-41.1%	-44.7%
CO	-2.9%	-6.3%	-11.6%	-6.2%	-15.2%	-26.4%

Table 31 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S5 i.e. IDL Outpost, Sonaparabat sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-8.2%	-15.6%	-27.1%	-14.6%	-32.0%	-53.2%
$PM_{2.5}$	-7.7%	-13.9%	-24.0%	-11.9%	-26.3%	-42.7%
SO_2	-5.4%	-10.7%	-23.9%	-11.2%	-39.1%	-57.0%
NO_2	-2.0%	-3.3%	-6.0%	-0.5%	-7.4%	-14.6%
CO	-3.2%	-6.2%	-11.7%	-6.8%	-14.9%	-26.6%

5.14.1. Air quality benefits in terms of Air Quality Indices

Air quality index (AQI) is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (*Ott, 1978*). In this study, a two-step methodology recommended by CPCB is used to calculate daily AQI values (*CPCB, 2015*). A sub-index (*CPCB, 2015*; refer Eq. (23)) was first calculated for each pollutant based on its observed and breakpoint concentrations using linear segmented principle. Then the individual sub-indices were aggregated using a maxima function to obtain an overall daily AQI (*CPCB, 2015*; refer Eq. (24)). The AQI values were then categorized into six different classes: Good (AQI <=50), Satisfactory (50 < AQI <=100), Moderate (100 < AQI <=200), Poor (200 < AQI <=300), Very poor (300 < AQI <=400) and Severe (400 < AQI <=500). The breakpoint concentrations used to calculate the AQI are provided in Annexure-J. In this study, we calculated the AQI using 24-hour mean concentrations of $PM_{2.5}$, PM_{10}, NO_2 and SO_2 and maximum 8-hour concentrations of CO for the corresponding day.

$$\mathbf{I_i = \left[\left\{\frac{(I_{HI} - I_{LO})}{(B_{HI} - B_{LO})}\right\} * (C_P - B_{LO})\right] + I_{LO} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)}$$

where, I_i = Sub-index for pollutant i, B_{HI}= Breakpoint concentration greater or equal to given concentration, B_{LO}= Breakpoint concentration smaller or equal to given concentration, I_{HI} =AQI value corresponding to B_{HI}, I_{LO} = AQI value corresponding to B_{LO}, and C_P = Pollutant concentration.

$$\mathbf{I = \max_{i=1,2,3\ldots,n} (I_i) \ldots\ldots\ldots\ldots\ldots (24)}$$

where, I = Overall aggregated AQI, and I_i= individual sub-indices of each pollutant.

This section discusses the summer and winter-time air quality indices (AQI) calculated at representative Panposh Chowk CAAQMS location for different scenarios in 2026 and 2031 and its implication to short and long-term national air quality goals and future directions. It is important to note that, the AQI values are calculated using the AERMOD estimated pollutant concentrations, only.

Fig. 128 shows the distribution of six AQI categories at Paposh Chowk CAAQMS location in Rourkela for observed and modelled concentrations, 2022, while Fig. 129 and Fig. 130 shows the distribution of AQI categories for different scenarios in 2026 and 2031 respectively.

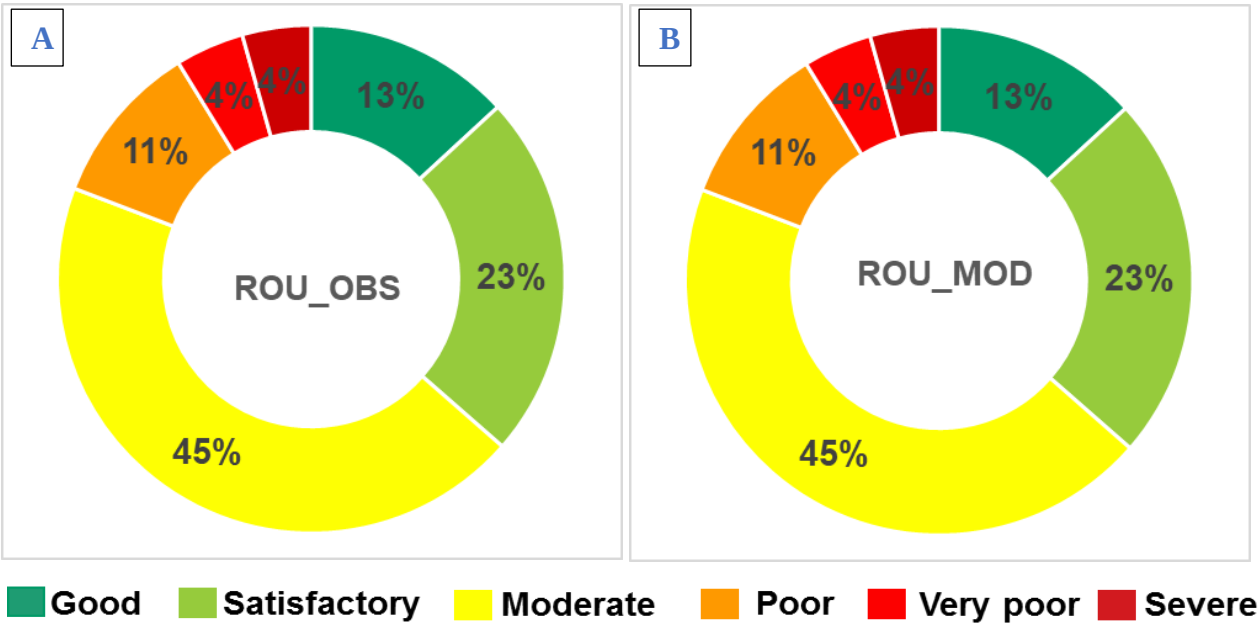

Figure 128 Distribution of six AQI categories at Panposh Chowk CAAQMS location in Rourkela for observed (A) and modelled (B) pollutant concentrations for baseline year

Initially, the AQI values calculated using modelled concentrations are compared against the AQI values calculated using observed pollutant concentrations. An examination of Fig. 128 (A and B) confirms that AQI values calculated using modelled concentrations agree well with observed AQI for year 2022. The AQI at the selected location during baseline scenario in 2022 is mainly driven by PM_{10} and on several occasions by $PM_{2.5}$. An examination of AQI for the baseline scenario revealed that air quality index, is mainly distributed in Moderate (45%) and Satisfactory (23%) classes while good category AQI is reported for approx. 13% of days in a year. It is also important to note that the poor, very poor and severe category AQI classes together constitute about 19% i.e. 69 days in a year.

The AQI distribution in NFC scenarios during year 2026 and 2031 shows a similar trend to baseline year with 13% Good, 21% satisfactory, 47% moderate, 10% poor, 4-5% very poor and 5% severe days. The air quality situation can gradually improve with implementation of proposed control measures. The combined proportion of Good and Satisfactory AQI classes are estimated to be substantially higher compared to the corresponding do-nothing or NFC

scenario. For example, the combined proportion of Good and Satisfactory AQI classes in NFC is 34% in both 2026 and 2031. This combined proportion of Good and Satisfactory AQI classes improves to 37% and 41% in 2026 and 2031, respectively under BAU scenario, to 41% and 51% in 2026 and 2031, respectively under SC-I, to 50% and 71% in 2026 and 2031, respectively under SC-II scenario. Fig 129 and 130 represents the distribution of AQI categories in four scenarios at Panposh Chowk CAAQMS station for year 2026 and 2031 respectively.

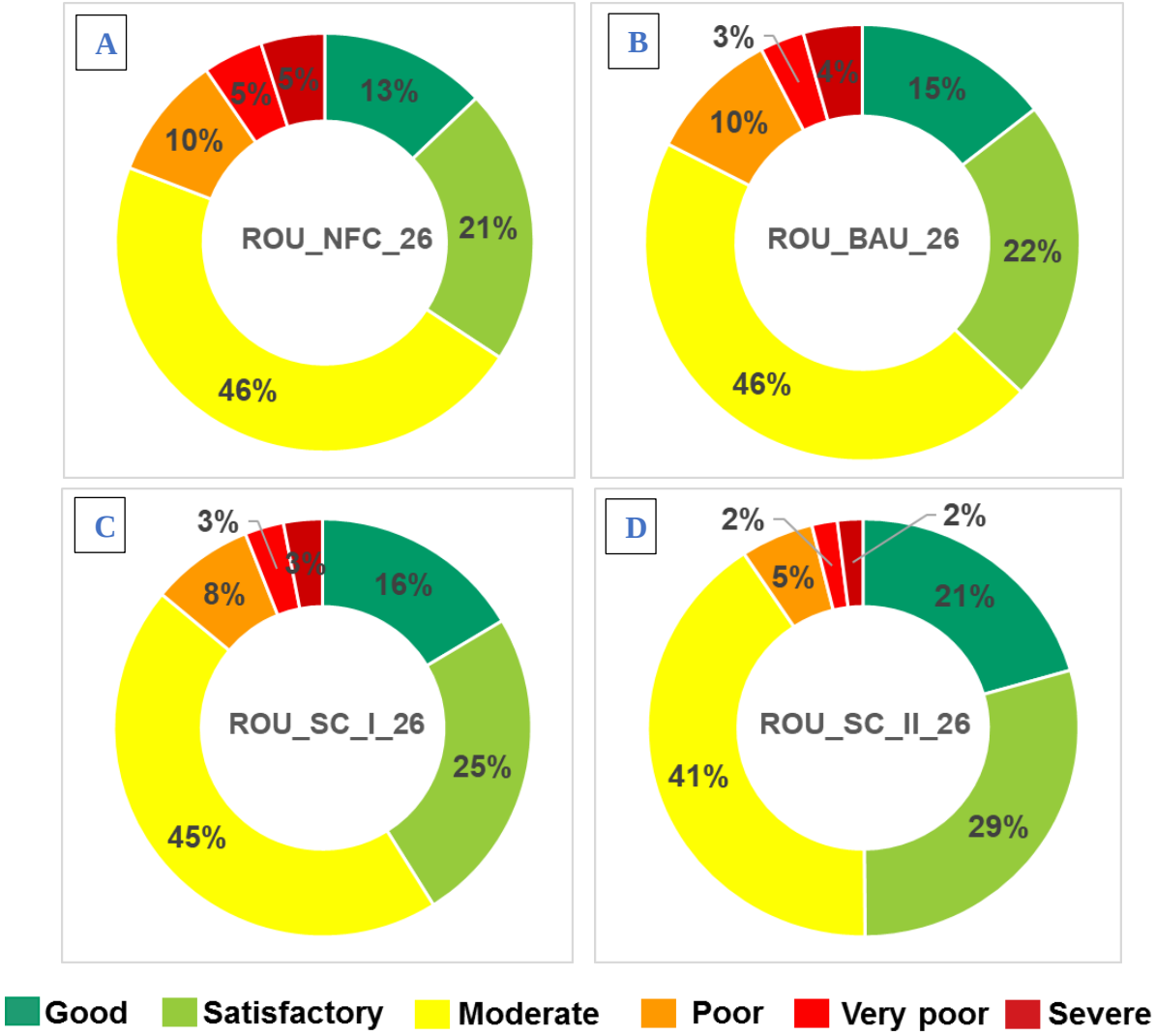

Figure 129 Distribution of six AQI categories at Panposh Chowk CAAQMS location in Rourkela for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2026

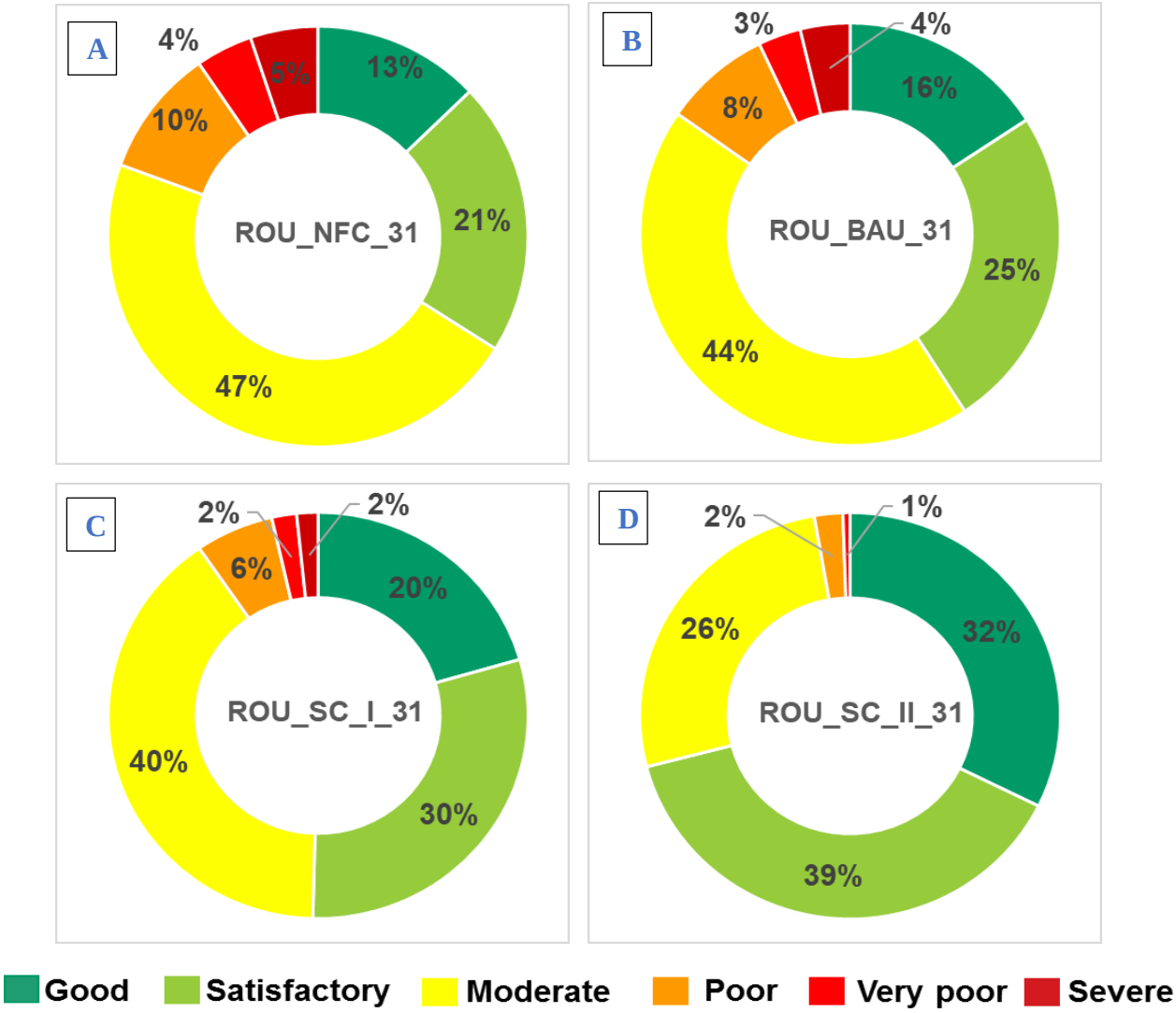

Figure 130 Distribution of six AQI categories at Panposh Chowk CAAQMS location in Rourkela for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2031

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Rourkela region as well. These findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level $PM_{2.5}$ and PM_{10} concentrations by 20-30% by the year 2024, as compared to 2017 i.e. base year.

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Chapter 6: Action Plan

6.1. Air Quality Action Plan for Rourkela

Table 32 presents the proposed air quality action plan for Rourkela region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

Table 32 Proposed Air quality action plan for Rourkela

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Transport	**A) Management**		
	TR12. Congestion Management: Identify the hotspot locations of traffic congestion. Introduce traffic actuated signals at such locations. Consider the one-way routes during peak hours at these locations. Also, regulate eateries along the kerb side, especially small ones to avoid traffic congestions.	RTO, Rourkela	Immediate
	TR13. Parking Policy: Formulate vehicle parking policy and ensure its effective implementation. Provide parallel parking system along the major roads of the town. Enforce strict action and penalty for vehicles parked in non-parking areas.	RMC / RTO, Rourkela	6 months
	TR14. Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses).	RMC	3 years
	TR15. Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	RMC	1 -2 years
	TR16. Declare NO-vehicle zones in hot-spots, university / school premises.	RMC / University / School	6 months
	TR17. Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO, Rourkela	Immediate

	TR18. Examine existing framework for removing broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.	RMC	6 months
	B) Technology		
	TR19. Improve and strengthen PUC program. (SMS based system to alerts, Linking of PUC centres with remote server and elimination of manual intervention in PUC testing, Fitness and calibration audits of PUC centres adopted with defined team for verification, Integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, Linking of PUC certificates with annual vehicle insurance, etc.)	RTO, Rourkela	1 year
	TR20. Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Rourkela / Oil Companies/ GAIL / State Government	3 years
	TR21. The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	RMC, Government Offices	3 years
	TR22. Encouraging EV adoption for personal and commercial vehicles through incentivisation or tax relaxation.	State Government, RTO	3 years
Road Dust	RD10. End-to-end paving of roads along with black-topping and maintaining potholes free roads.	PWD / RMC	Immediate / Continuous
	RD11. Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / RMC	Immediate / Continuous
	RD12. Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / RMC	Immediate / Continuous
	RD13. Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	RMC	Immediate / Continuous
	RD14. Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	RMC	6 months
	RD15. All the canals/nallah's side roads should be concrete / brick lined.	RMC	1 year

	RD16. Regular cleaning of roads and water spraying to suppress the dust. Remove road dust/silt regularly by using mechanical sweepers.	RMC	Immediate / Continuous
	RD17. Identify road stretches with high dust generation and use Foggers to supress the dust.	RMC	6 months
	RD18. Greening of traffic corridors, open areas, gardens, community places, schools and housing societies	RMC	1 year
Industries	All potential industries to be implemented with Continuous Emission Monitoring System (CEMS). Ensure regular calibration and working of this system and its online reporting is required.	OSPCB	1 year
	Assess the number of industrial units that are non-compliant and prepare unit/plant wise action plan for time bound compliance.	OSPCB	Immediate and Continuous
	Intensive polluting industries to be restricted from operations within urban zone. Restriction of any new red category industry to open within urban zone.	OSPCB	Immediate
	Strict compliance to be followed on industrial open waste burning.	OSPCB	Immediate
	Control of Fugitive Emissions: • Use of hoods and enclosure for all process equipment, • Scrap management programme for the prevention or minimization of waste and other feed materials. • Use of covered or enclosed conveyors and transfer points • Enclosures for emission controls of the charging and tapping operations. • Minimising the number of flanges by welding piping connections wherever possible and using appropriate sealing for flanges and valves • Use of larger oven chambers and regulation of pressure within oven chambers	OSPCB	Immediate
	Adoption of Cleaner Fuels: • Cleaner fuel implementation to be encouraged and incentivized.	OSPCB	1 year

	• Discourage the fuels with high sulphur content. • A favourable taxation and pricing policy for mass adoption.		
	Ensuring installation/Up-gradation and operation of air pollution control devices in industries	OSPCB	6 months
	Disposal of all non-hazardous wastes into the designated dumping sites	OSPCB	Continuous
	Industry shall prepare plant wise inventory of vents and ensure that it is routed to vapour recovery system followed by flare system, wherever applicable.	OSPCB	6 months
	Regeneration frequency of Adsorption / absorption system / Activated carbon bed should be clearly defined as per the trend data of previous cycles and should be documented.	OSPCB	6 months
	Industry should include a special training module regarding "fugitive emissions and its health impacts on individual and surrounding communities" for its staff, operating personnel & Drivers to spread awareness about risk/hazard associated with spills and leaks of various chemicals.	OSPCB	Continuous
	Bank guarantee should be taken for the compliance of conditions imposed in CTO/CTE for control of Environmental Pollution from industries.	OSPCB	6 months
	Industrial units to install water spraying system of internal roads and washing of tyres of vehicles	OSPCB	6 months
	Development of mobile facility/van for continuous ambient air quality monitoring for different localities.		
	Coke Ovens: • Coal fired boilers to be converted to oil/gas fired driers, preferably with coal bed methane (CBM) • Switch to coke dry quenching system (CDQ) • Increasing carbonization chamber height • High pressure ammonia liquor aspiration • Wet oxidative desulphurization of coke oven gas • Stationary land-based pushing emission control	OSPCB	
	Iron and Steel Industry: • Use of desulphurized coal	OSPCB	1 years

	• Use of pulverized coal injection method • Installation of coke dry quenching (CDQ) • Installation of top gas recovery Turbine (TRT) • Introduction of coal dust injection (CDI) • Introduction of coal dust injection (CDI); waste heat recovery in Sinter Plant; waste heat recovery at blast furnace stove • Use of by-product fuel for power generation • Waste heat recovery in Sinter Plant; Waste heat recovery at blast furnace stove • Switch to Direct Reduction Electric Arc Furnace from basic oxygen furnace		
	Thermal Power Plants • Implementation of new thermal power plant standards in all power plants by an early date. The power plants need to comply with the new emission standards. • Check status of compliance and prepare a transition plan for each plant to meet the new standards. This should apply to all state owned, private and captive power plants: • Plants found not meeting set emission reduction targets to be penalized. • Prepare plan for full utilization of flyash, and also carry out monitoring, sprinkling of water (recycled water) especially during summer months to curtail wind-blown ash. • Progressively close the older and more polluting thermal power plants and to move to cleaner natural gas • Installation of Flue Gas Desulfurization (FGD) units to reduce the SO_2 emissions. (Efficiency 50 to 99.8% based on age of plant, sulfur content in coal etc)	OSPCB	2 years

	• Prepare a roadmap for cleaner plants and Incentivize their operation by giving them the priority over other polluting plants.		
Open Waste Burning	Improving door to door waste collection efficiency to 100%.	RMC	1 year
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	RMC	Immediate
	Non-recyclable waste with a calorific value of 1,500 kcal or more must not be disposed of into landfills and must be used solely to generate energy	OSPCB, RMC	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	RMC	Immediate / Continuous
	Encouraging the reduce, recycle and reuse policy for waste in city	RMC / State Government	Immediate / Continuous
	Organic waste conversion (OWC) units can be installed in the city at a decentralized scale especially in more prominent societies and colonies based on the MSW characteristics of the area.	RMC	1 year
	Effective management of landfill sites through increasing the recycling rate, installing waste to energy conversion plants, restricting illegal waste dumping, proper disposal of hazardous waste, as per Hazardous waste management rule 2016, to prevent greenhouse gas emissions from site	RMC	1 year
	Reduce the VKT of waste collection vehicles with route optimisation technique.	RMC	6 months
Construction	Adoption of Good Construction Practices (GCP) to minimize the waste generation. Promote recycling of materials. Encourage the use of environmentally friendly material. Ensure compliance check for GCP regularly	RMC / OSPCB	Immediate
	Strict enforcement of CPCB guidelines for construction activity such as use of green screens, side covering of digging sites, etc.	RMC / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	RMC / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	RMC	Immediate

	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	RMC / OSPCB	Immediate
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	RMC / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	RMC / Site Developer	3 months
	Develop and implement dust control measures such as site covering, fugitive emission control, installing air pollution controlling devices for all types of construction activities i.e. buildings and infrastructure.	RMC	1 year
	C&D waste should be sent to construction and demolition processing facility only. Strict action against non-compliance of the same on any individual or developers.	RMC	Immediate
	Mandatory use of RMC plants at large construction sites and preparation of guidelines for dust control measures for operation of RMC plants.	RMC / OSPCB	1 Year
DG sets	Ensure uninterrupted electric supply to avoid the use of DG sets, especially in commercial and industrial zones.	State Electricity Board	1 Year
	Curtail use of DG Sets in social events by providing temporary electric connections	RMC / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	RMC	6 months
	Develop the city into a Renewable Energy Hub with a focus on creation of RE Equipment Manufacturing Eco-system as per Odisha Renewable energy policy	RMC / State Government	5 years
	Leverage rooftop solar programme to reduce dependence on DG sets.	BMC	1 year
	Installation of Retrofitted Emission Control Devices (RECD) to diesel generators as per CPCB guidelines	OSPCB	1 year
Residential	Ensure easy availability of affordable cleaner cooking fuels (LPG/ PNG/biogas) for all to achieve 100% LPG adoption.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP/BP, etc.)	1-3 years

	Expanding coverage of LPG under Pradhan Mantri Ujjwala Yojana (PMUY).	State / Central Government	1-2 years
	Introduce schemes for providing subsidized LPG connections as well as providing means of finance to small tea vendors/hawkers who are using kerosene stoves in order to reduce emissions from burning of kerosene	State / Central Government	1-2 years
	Introduction of improved *Chullahs* (low emission *Chullahs*) in rural areas	RMC, NGOs	1 year
	Encouraging use of electricity for domestic cooking. (for example: Induction cooktops)	Department of Food, Civil Supplies and Consumer Affairs	2 year
	Provide centralized solar based hot water in slum areas to avoid solid fuel usage for water heating purposes	RMC	1 year
Hotel, restaurant and bakeries	Coal and wood-based cooking in restaurants to be shifted to electricity and LPG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1-2 years
	Promoting mini LPG cylinders to small open eateries.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
Brick kilns	Ensure the compliance checking routinely. Provide design specifications for improved kilns.	RMC / OSPCB	Immediate
	Enforce restrictions for the operations of brick kilns in urban zone. Zig-Zag technology to be encouraged and promoted. Ensure the mass adoption of Zig-Zag or improved technology	RMC / OSPCB	1-3 years
	Closure of unauthorized brick kilns, if any.	OSPCB	Immediate
Crematoria	Convert all existing traditional crematoria (wood based) to electric. Installing new electric crematoria as per requirement.	RMC	1 year
Public Awareness	Launch Public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicle, lane discipline, etc.	RMC, OSPCB, NGOs	Immediate
	Encourage the use of public transport for daily commute.	RMC, OSPCB, NGOs	Immediate
	Education program to create awareness among citizens through various mass media tools, such as local newspapers, local news channels on TV or radio, street plays, social media platforms, citizen engagement events, recording	RMC, OSPCB, NGOs	Immediate

	announcements through waste collection vehicle, organizing awareness seminars at the community level		
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	RMC	1 year
CAAQMS	Increase the number of air quality monitoring stations	OSPCB	1 -2 year

Chapter 7: Future Research Work

7.1. Suggestions for future research work in non-attainment cities

Although latest available data and methods have been used in this study to identify and quantify the sources of air pollution in non-attainment cities of Odisha, it is suggested to advance the air pollution research to ingest/generate more accurate data and minimize the uncertainties in estimates. Air pollution research is advancing at a rapid pace with development of new and innovative monitoring and analysis techniques, data analysis and modelling tools. Considering the current global trends and situation in non-attainment cities of Odisha, following studies or research areas could be targeted to improve present results and track impact of proposed air action plans.

- **Health impacts analysis of PM using oxidative potential as a metric:** Inhaled PM can directly introduce PM-bound reactive oxygen species (ROS) to the surface of the lung, where they react with and deplete lung-lining fluid antioxidants. The oxidative potential (OP) of ambient particulate matter is a metric commonly used to link the aerosol exposure to its adverse health effects. Research could be taken up to determine the oxidative potential and health risk associated with PM2.5 particulates in non-attainment cities.
- **Volatile organic compounds (VOCs) and Ozone monitoring:** Unlike primary pollutants, which are emitted directly, tropospheric ozone forms photochemically, involving precursors such as carbon monoxide (CO), volatile organic compounds (VOCs) and oxides of nitrogen (NOx), supplemented by transport from the stratosphere (e.g. Crutzen, 1974; Atkinson, 2000; Monks et al., 2015). It can be transported over long distances resulting in enhanced concentrations even in areas remote from the sources of precursors (Cox et al., 1975). It is suggested to augment current monitoring network, to include monitoring of VOCs and Ozone in non-attainment cities.
- **Advanced source apportionment:** Near real time advanced source apportionment using set of state-of-the-art equipment. This can typically include an aerosol chemical speciation monitors (ACSM) to monitor organic aerosols and selected ions (such as sulfate, nitrate, ammonium, and chlorides); along with a black carbon and a metals analyzer. This set-up can provide high resolution near real time data

measurements which can be then followed by PMF analysis to identify sources of air pollution in near real time and on a longer time scale.

- **Improvement in emission inventories:** The present emission inventories could be routinely updated with latest available activity data from secondary data sources and emission factors. With more accurate and high-resolution activity data, uncertainties in emission estimates could be minimized to a great extent.
- **Air quality forecasting systems:** It is very important for decision makers and local administration to understand the levels and possible source contributions in advance. Chemical Transport Modelling based forecasting systems could be developed for non-attainment cities, to forecast air quality in advance. An air pollution decision support system could also be developed to understand the primary contributors and take appropriate actions on ground.

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Annexures

Annexure-A: Air Quality Monitoring

Air quality monitoring is to be done with the speciation samplers to collect PM_{10} and $PM_{2.5}$ samples. Equipment operational details, working procedure, equipment and sample preparation and maintenance are discussed in detail below.

A-1 Speciation Samplers: Sampling of Particulate Matter PM_{10} and $PM_{2.5}$ from Ambient Air by Speciation Sampler

1.0 Scope

This procedure is applicable to air sampling for PM_{10} and $PM_{2.5}$ using speciation/multi -channel sampler on Teflon / Quartz filter paper.

2.0 Referred Documents

2.1 SOP MLD 055 by California Air Research Board

2.2 Model standard operating procedures (SOPs) for sampling and analysis by Central Pollution Control Board, New Delhi

3.0 Significance and Use

This test procedure is used for collecting Particulate Matter 10 (PM_{10}) and Particulate Matter 2.5 ($PM_{2.5}$) from Ambient Air using multichannel speciation samplers.

4.0 Apparatus

Following apparatus/ instruments will be used: -

4.1 Multi-channel/dual channel speciation samplers

4.2 Cartridge having Speciation impactor heads and/or impactor channels for PM_{10} and $PM_{2.5}$ fractions

4.3 Filter papers (Teflon/ Quartz)

4.4 Proper (blunt) forceps

4.5 Labelled Filter paper petri dish for storing Filter paper

4.6 Sample Storage Kit

5.0 Chemicals/ consumables:

5.1 High Vacuum Grease

5.2 Teflon Filter: PTFE with Polymethyl pentane support ring, Micron size 1 um, 47 mm dia

5.3 Quartz Filter paper: Binder free pure Quartz with high flow rate and filtration efficiency, 47 mm dia, Temp stability up to 1100^0C

6.0 PPEs TO BE USED:

Cotton hand gloves, safety shoes

7.0 Procedure:

7.1 Install speciation sampler as per Manual on stand provided by Manufacturer.

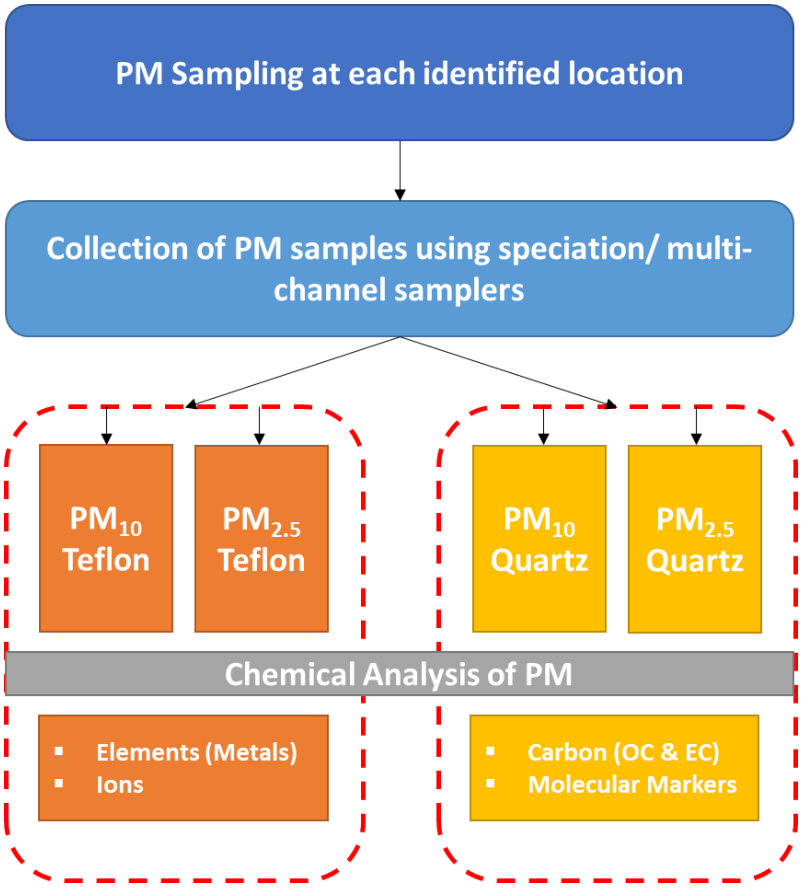
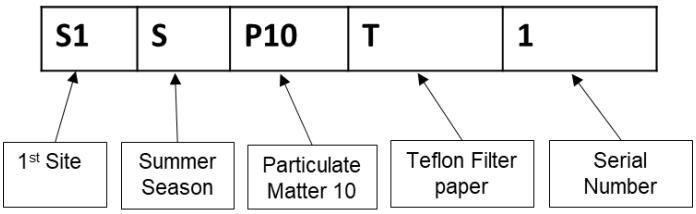


Fig. A-1: Arrangement of filter papers for multi-channel speciation samplers

7.2 Check Temperature and Humidity sensor connections.

7.3 Filter papers are numbered with Site id, Season, PM type, Filter type, serial number.



Similarly, for Winter Season ➔"W," $PM_{2.5}$ ➔"P2.5" and Quartz filter paper ➔"Q"

7.4 Select filter paper as per above nomenclature. Visually inspect filter paper for any damages, pinholes or any other collection. If any anomalies are found, then discard filter paper.

7.5 Load filter paper in cartridge as per below table:

Channel	PM head	Paper
A	10	Teflon
B	10	Quartz
C	2.5	Teflon
D	2.5	Quartz

7.6 Start Speciation sampler as per standard procedure.

Sampling Site photographs

IDL Post Output

Jay Matadi Plastics Pvt. Ltd., Kalunga

IDCO, Rourkela

College of Arts, Science & Tech., Bandhamunda

Hamirpur High School, Rourkela	Gaseous Sampling Collection (Sox, NOx & VOC)	
VOC Sampling Collection through Tenax Sorbent Tubes	Loading of filter papers post sampling	

Annexure-B: Filter sample preparation, handling and weighing

1.0 Scope

This procedure is applicable for weighing of Teflon Filter paper and Preconditioning of Quartz filter paper used for collecting PM_{10} and $PM_{2.5}$

2.0 Referred Documents

2.1 Weighing balance Operation Manual

2.2 Model Standard Operating Procedures (SOPs) For Sampling and Analysis by Central Pollution Commission Board, New Delhi

2.3 Furnace

3.0 Significance and Use

Pre-conditioned blank filter paper is weighed using weighing balance. The weighed filter paper is sent to the field for sampling. The filter paper which has undergone field sampling is received in the laboratory. The received filter paper is kept for conditioning. The conditioned field sample is again weighed using weighing balance and is used for further analysis.

4.0 Apparatus

The designated chemist, engineer will select the appropriate testing reforming master list of instruments.

4.1 Weighing balance (Make: Metter Toledo, Model: XP2UV, Mesh Type)

4.2 Teflon coated forceps

4.3 Millipore Petrislides

4.4 Cool kit

4.5 Filter Paper used for Sampling:

4.5.1 Teflon Filter paper: 2 µm PTFE 47 mm filter with PP Ring supported (Whatman make)

4.5.2 Quartz Filter paper: Tissue quartz 2500QAT-UP (Pall Make)

5.0 Procedure

5.1 Guidelines for Conditioning of Filter Papers:

Filter papers selected for different analytical objectives should be conditioned by following steps:

- Inspect all the filter papers for holes or cracks. Reject, if any deformity is found.
- Note down the batch/lot in log sheet.
- Label all the filters following a general lab coding technique, which should be unique to represent a sample.
- Put the marked filters in petri dishes.
- Use always proper (blunt) twizers/forceps (made of non-reactive material) to handle the filter papers in lab and field as well.
- Prepare a sample-tracking sheet for each filter paper or a batch of filter paper.

5.2 Filter Inspection and Stability

To equilibrate, the filters are transferred from their sealed manufacturer's packaging to a filter-handling container such as a plastic petri-slide. The filters are handled with non-serrated forceps. Lab personnel must wear vinyl gloves as secondary when filters are being prepared for conditioning and weighing. Before any filter is placed in a filter-handling container, it must be inspected for defects. This is done be an examination of the filter on a "light table". A filter must be discarded if any defects are identified. Specific defects to look for are:

- **Pinhole** – A small hole appearing as a distinct and obvious bright point of light when examined over a light table.
- **Separation of ring** –Any separation or lack of seal between the filter and the filter support ring.
- **Chaff or flashing** – Any extra material on the reinforcing ring or on the heat-seal area that would prevent an airtight seal during sampling.
- **Loose materials** –Any extra loose materials or dirt particles on the filter.
- **Discoloration** –Any obvious discoloration that might be evidence of contamination.
- **Other** – A filter with any imperfection not described above, such as irregular surfaces or other results of poor workmanship.

6.0 Filter Conditioning

6.1 Pre-firing of Quartz-Fiber Filters

Quartz-fiber filters absorb organic vapors over time. Blank quartz-fiber filters should be heated for a lot at least three hours at 900°C. One sample of each batch of 100 pre-fired filters is tested for carbon blank levels prior to sampling, and sets of filters with carbon levels exceeding

1µg/cm^3 are re-fired or rejected. All pre-fired filters should be sealed and stored in a freezer prior to preparation for field sampling.

6.2 Weighing of Teflon-Membrane Filters before and after sampling

Gravimetric measurement is the net mass on a filter by weighing the filter before and after sampling with a balance in a temperature and relative humidity controlled environment as described in SOPs. To minimize particle volatilization and aerosol liquid water bias, $PM_{2.5}$ reference methods require that filters be equilibrated for 24 hours at a constant (within ±5%) relative humidity between 30% and 40% and at a constant (within ±2ºC) temperature between 20ºC and 23ºC, which is a more stringent requirement than for PM_{10} filter equilibration. PM_{10} filters are required to be equilibrated at 20% to 45% relative humidity (±5%) and 15ºC to 30ºC temperature (±3ºC).

These filter equilibrium conditions are intended to minimize the liquid water associated with soluble compounds and to minimize the loss of volatile species. Nominal values of 30% RH and 20ºC best conserve the particle deposits during sample weighing. Accurate gravimetric analyses require the use of filters with low dielectric constants, high filter integrity, and inertness with respect to absorbing water vapor and other gases.

Annexure-C: Analysis of Ions

Method for measurement of Anions and Cations in Particulate matter (PM) samples by Ion Chromatography

1.0 Scope

Method for measurement of Anions and Cations in Particulate matter (PM) samples by Ion Chromatography

2.0 Reference Document

2.1 Standard Operating Procedure (SOP) MLD 064 Standard Operating Procedure for the analysis of anions and cations in $PM_{2.5}$ speciation samples by Ion Chromatography.

2.2 Operation manual of Dionex make Ion Chromatograph.

2.3 Methods of Air Sampling and Analysis, 3rd Edition by James p. Lodger

2.4 Refer file No. CHL/MSDS/74 for Applicable MSDS for proper handing storage use disposal of chemicals for --

- Sodium Carbonate (Na_2CO_3)
- Sodium Bi-Carbonate ($NaHCO_3$)
- Methane Sulphonic Acid (MSA)

3.0 Summary of Test Procedure

The method determines the anions and cations present in PM e.g. PM_{10} / $PM_{2.5}$ dust collected on Teflon filter papers from ambient air which are collected from different sites. The filters are extracted in deionized water by sonicating for one hour, and filtered through 0.22-micron membrane filters. Ion Chromatography using a system comprising of guard column, analytical column, suppressor and a conductivity detector analyzes the final extract. The peak analysis is determined by using Chromeleon softeare Software Version 7.2.9

- Ions analyzed by Ion chromatograph:
  - Cations : Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}
  - Anions: F^-, Cl^-, Br^-, NO_2^-, NO_3^- , SO_4^{2-}, PO_4^{3-}

4.0 Apparatus:

The test procedure assumes Dionex Ion Chromatographic system. For detailed instructions in the operation of the Dionex IC refer to the operation manual of Dionex.

4.1 Dionex Ion Chromatographic system comprised of following modular units, one for Anions and Cations:

- Isocratic pump
- Guard and Analytical Column
- Suppressor
- Conductivity detector
- Automated Sampler

4.2 IC Operating Conditions:

Sample loop volume:	**25 µl for anions and cations**
Analytical Column: Anions Cations	 Dionex Ion Pac AS23 Analytical column Ion Pac SCS1 Separator column
Guard Column: Anions Cations	 Dionex Ion Pac AG23 guard column Dionex Ion Pac SCG1 guard column
Eluent solutions: Anions	 4.5 mM carbonate / 0.8 mM bicarbonate
Eluent solutions: Cations	3.5 mM Methane Sulphonic Acid (MSA)
Eluent flow rates: Anions Cations	 1.5ml/min 1.0ml/min
Acquisition Software	Chromeleon Software Version 7.2.9

Sample loop volume:	**25 µl for anions and cations**
Pressure	Max. 5000 Psi
Suppressor for anion Suppressor for Cation	AERS type 600 (4mm) suppressor CERS type 600 (4mm) suppressor
Analysis Time: Anion Cation	 20min 35min

4.3 Other Equipment:

- Ultrasonicator
- Analytical balance

4.4 Glassware:

- Volumetric flasks: 50, 100, 1000 ml sizes
- Polyethylene storage bottles
- Beakers: 100 ml size
- Thermoscientific Autosampler Vials with caps
- Gloves disposable
- Micropipettes: Ranging from 10 µl to 1000 µl

5.0 Reagents:

(All reagents should confirm to ACS specifications for reagent grade materials unless otherwise specified.)

- Sodium Carbonate (Na_2CO_3)
- Sodium Bi-Carbonate ($NaHCO_3$)
- Methane Sulphonic Acid (MSA)
- Milli-Q Grade ASTM type 1 deionized water (18.2 Mega Ohm cm-$^{1)}$
- Anion Standard (F^-, Cl^-, Br^-, NO_2^-, NO_3^- , SO_4^{2-}, PO_4^{3-})
- Cation Standard (Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2})

6.0 Procedure:

Preparation of Eluents-

Stock eluents are prepared in ultrapure water. The following table lists the amounts of each chemical used to make one batch of stock solution:

	Chemicals	**Amount of Chemicals**
Anion Eluent	Sodium carbonate and Sodium bicarbonate	4.5 mM (0.4770gm/lit) and 0.8 mM (0.0672gm/lit)
	Nanopure Water	Type 1 grade (Qty req as above)
Cation Eluent	Methane Sulphonic Acid	30 mM (2000 µl/lit)
	Nanopure Water	Type 1 grade (Qty req as above)

	Chemicals	**Amount of Chemicals**
Anion Eluent	Sodium carbonate and Sodium bicarbonate	4.5 mM (0.4770gm/lit) and 0.8 mM (0.0672gm/lit)
	Nanopure Water	Type 1 grade (Qty req as above)
Cation Eluent	Methane Sulphonic Acid	3.8 mM (253.3 µl/lit)
	Nanopure Water	Type 1 grade (Qty req as above)

6.1 Anion Eluent – Weigh Sodium carbonate and Sodium bicarbonate as per quantity given in the above table and transfer into a 1 lit volumetric flask containing about 500 ml of Milli-Q water. Mix the contents and sonicate to dissolve. Once all chemicals have dissolved make up the volume to 1 lit. Sonicate the mobile phase for about 5 minutes. Always use clean and oven dried glassware for eluent preparation.

6.2 Cation Eluent – Pipette 2000 µl of MSA and transfer into a l lit volumetric flask containing about 500 ml of Milli-Q water. Mix it and make up the volume to 1 lit. Sonicate the mobile phase for about 5 minutes. Always use clean and oven dried glassware for eluent preparation.

6.3 Preparation of Anion and Cation Calibration Standards –Multi-point Calibration Curve of different concentrations ranging from 1 ppm to 10ppm are selected which includes 1, 3, 5 and 10 ppm. All the dilutions are made in Milli-Q grade deionized water.

6.4 The concentration levels that have to be selected for Multi-point Calibrations are to be repeated for minimum three times before using for Calibration. Relative Standard Deviation (RSD) for each anion should be below 3%. In order to accept the Calibration Curve, Correlation Coefficient should always be greater than or equals to 0.990. Otherwise Calibration standards should be re-analyzed

6.5 Filter Analysis:

Filter papers are stored in a controlled temperature and humidity conditions. Following steps were followed before taking samples for analysis:

- Prepare a work list of samples to be analyzed containing details of date of collection of sample, site identification, duration of sample collection and any other observations interfering the analysis.
- Label the samples properly with above details and should be numbered.
- Always consider one field blank and one laboratory blank for each set of samples.
- Prepare sequence for the analytical run that begins with the calibration standards in order of increasing concentration, followed by water blank and sample. Follow this list including at least 10 % duplicate and after each set of analysis another check standard. At the end of the samples field blank and laboratory blank are analyzed.
- Cut the exposed filter into small pieces with cutter and place it in a 50 ml beaker. Add 30 ml deionized water into it. Also take one blank filter (unexposed to air) and follow same procedure.
- Place all the beakers in ultrasonicator bath for 60 min. After sonication remove them from bath and wipe the bottom of beaker with towel or tissue paper.
- After sonication shake the samples and stir the contents in the beaker.
- Filter the samples now through 0.22-micron size membrane (Pall Gelman make or equivalent) filters using vacuum extraction assembly. Ensure that the extract is clear and transparent after filtration. Make up the volume of sample up to 50 to 100 ml depending upon the analysis requirement. If concentration of an analyte is beyond the range of calibration, dilute the sample accordingly. The sample is now ready for analysis on Ion Chromatograph.
- Transfer the contents of sample into autosampler vials and cap each vial. Run the sequence of samples as mentioned above and operate the IC Software for analysis

of anions and cations at above instrumental conditions. The results are given in ppm or mg / lit.

7.0 Calculations:

7.1 Calculation of Volume of Air Sampled

V = QT

V = Volume of air sampled in m^3

Q = Average flow rate in m^3/minute

T = Total sampling time in minute

7.2 Calculation of Anions and Cations in PM in Ambient Air

Concentration of Ion µg/ m^3 = $[(C \times V_1) - B] / (V \times F)$

Where,

C= concentration of (µg or mg of Ion / ml) in the aliquot

V_1 = Volume of aliquot (ml)

B = total µg or mg of Ion in blank

F = Fraction of total sample in the aliquot used for measurement

V = Volume of air sampled

Report

Report Concentration of desired anions and cations in mg and percentage (%) and micrograms (µg) per cubic meter (m^3) of ambient particulate matter.

9.0 Calibration Records:

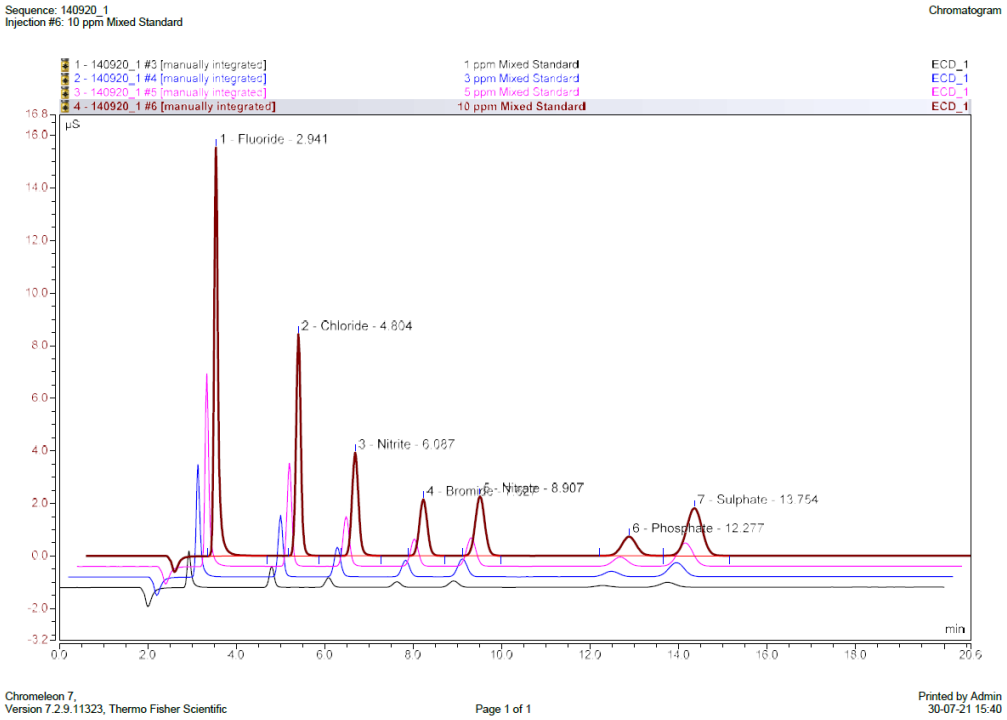


Fig. C-1: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Anion

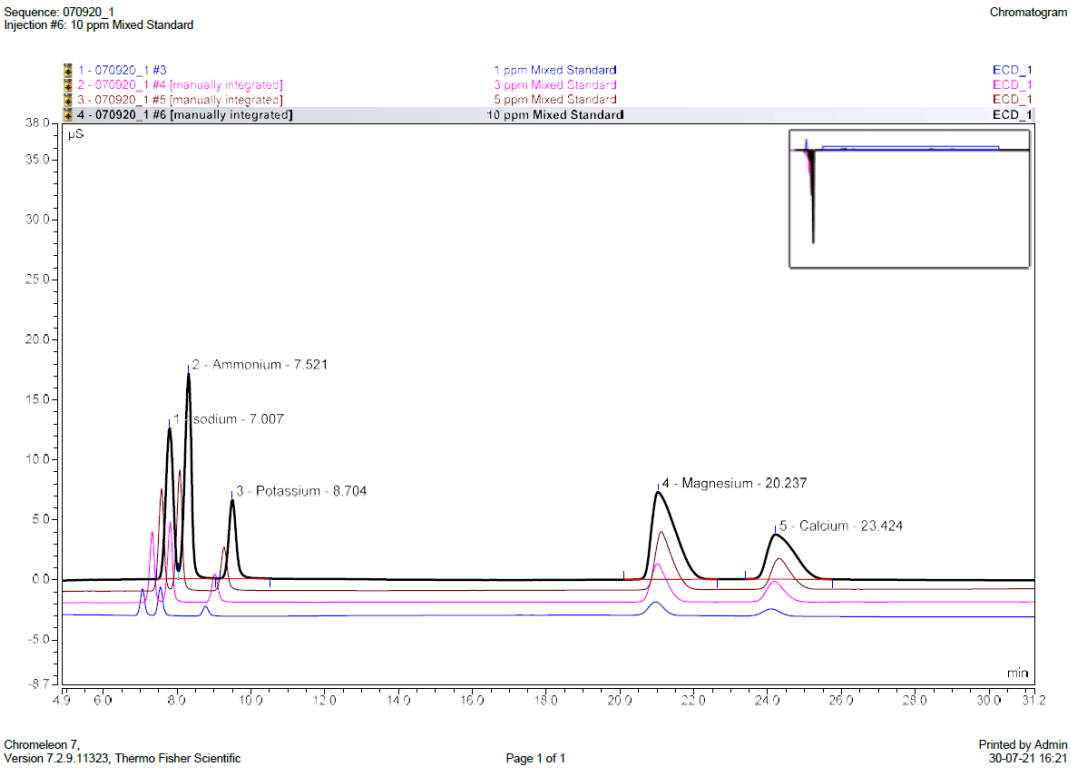


Fig. C-2: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Cation

Annexure-D: Analysis of Elements

Determination of Metal Content in Particulate Matter (PM) Collected on Teflon Filter Paper by X-Ray Fluorescence Spectrometer

1.0 Scope

1.1 This procedure is applicable to analysis of particulate matter (PM) collected on Teflon filter papers from ambient air.

2.0 Reference Document

2.1 Compendium Method IO-3.3, Determination of metals in ambient particulate matter using X-Ray Fluorescence (XRF) Spectroscopy, US EPA, June 1999

3.0 Summary of Test Procedure

Elemental Analysis of Air Particulate by Energy Dispersive X-ray Fluorescence (EDXRF). This method applies to the analysis of ambient air particulate collected on 47mm diameter Teflon Filters.

This method describes quantitative determination of elements in ambient air particulate collected on Teflon membrane filters. The elements that are determined by this method include many of the elements with atomic numbers 11 (Na) to 82 (Pb). (Note: both Na and Mg are analysed but measured as ION only).

The method assumes that the particulate is collected as a surface deposit on top of the filter media, that the particulate loading level is less than approximately 100 µg/cm^2.

An X-ray source removes electrons from the inner shells of atoms by exciting the atoms to energy states above the stable configuration. As electrons move to refill the ground state energy levels, the atomic system maintains its fundamental energy balance by emission of electromagnetic radiation. The emitted radiation is an x-ray whose energy is characteristic of the excited element. The samples are quantitatively analyzed by counting the number of

observed x-rays over a set period, as compared with the number of fluoresced x-rays from similarly analyzed standards.

- Elements analysed by XRF : Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb

4.0 Apparatus

X-ray Fluorescence Spectrometer

5.0 Certified Reference Material

5.1 Single-element Thin-film calibration standards from Micromatter

6.0 Procedure

6.1 Switch on the equipment as per Work Instruction No. ERL/WI/106.

6.2 Double click on the "PCEDX Pro" icon on the desktop for qualitative or quantitative analysis

6.3 The "Start up" and "Analysis" windows will open. From the "Start up" window, a message "Instrument is not initialized" will pop up. Now, click on "Initialize". Initialization will take 15 mins.

6.4 Click in sample schedule on analysis window, select instrument calibration and click on "OK".

6.5 Place the energy check sample over the beam window and click on "Start" from the Analysis window. After energy check analysis is completed remove the energy check sample.

6.6 For the analysis of sample, place the sample on the beam window. Click on "Sample Schedule". Click on "Sample Registration". Click on "Analytical group" from the "Analysis" tab and select the appropriate analytical group for air as per the sample.

6.7 Give proper name and position where the sample is to be placed and click on "Apply".

6.8 Click on "Start" from "Analysis" window. On completion of analysis, Results window with Pop up.

6.9 Take out the sample from the sample chamber.

6.10 Similarly carry out the analysis in Helium by selecting appropriate "Analytical group" for helium by following clauses 7.5 to 7.8. Take out the sample from the sample chamber.

6.11 To generate the report of sample, click on "Data" from the main menu and select the sample. Click on "File" then click on "Create Ex Report", select the format as Excel and click on "Create". Click on "Option" and select "Enable this content". Now, click on "OK". Save the file in the desired location. The report is in the form of excel with the elements identified and its concentration in µg/cm2.

6.12 Periodically carry out the analysis of Micrometer XRF Calibration Standards. The obtained value of concentration should be within ± 5 % of specified value.

6.12.1 Record the result of the calibration in the form of enclosed format.

6.13 Calibration:

6.13.1 The Micromatter thin film standard material and sample under test are analysed by XRF in the same run. The equipment is said to be in a state of acceptable valid calibration if the acceptance criteria (10% deviation) is met.

7.0 Calculations

7.1 Concentration of the elements in the sample are calculated by the software in µg/cm^2.

7.2 Results are converted to µg/m^3 by using exposed area of filter and volume of air sampled.

8.0 Reporting

a) Report the result in the desired unit e.g. µg/cm^2 up to 2 decimal places.

Annexure-E: Carbon Analysis

Analysis of Organic Carbon (OC) and Elemental Carbon (EC) in Particulate matter (PM_{10} and $PM_{2.5}$)

1.0 Scope

This procedure describes the analysis of exposed quartz micro fiber filters for organic carbon (OC) and elemental carbon (EC) in Particulate matter (PM) samples using a Desert Research Institute (DRI) Multi-Wavelength Thermal/Optical Carbon Analyzer

2.0 Referred Documents

2.1 Standard Operating Procedure (SOP) MLD 065 Standard Operating Procedure for the analysis of Organic and Elemental Carbon in Particulate matter (PM) samples by using DRI Model 2015 series 2 Multi-Wavelength Thermal/Optical Carbon Analyzer.

2.2 Operation manual of DRI make Multi-Wavelength Thermal/Optical Carbon Analyzer.

3.0 Summary of test Procedure

The operation of the DRI Model 2001 Thermal/Optical Carbon Analyzer is based on the preferential oxidation of organic carbon (OC) compounds and elemental carbon (EC) at different temperatures. The principle function of Modulated diode lasers is to measure the reflectance from, and transmittance through, each filter at wavelengths 405, 445, 532, 635, 780, 808 and 980nm.

4.0 Apparatus

The designated chemist, engineer will select the appropriate testing reforming master list of instruments.

4.1 Desert Research Institute (DRI) Model 2015 Thermal Optical Carbon Analyzer (AML/ INST/ 149) System with computer.

4.2 Stainless steel punching tool: 5/16-inch diameter, 0.5 cm2 nominal area.

4.3 Syringes: Hamilton Gas-Tight 1000 µl syringe for calibration injections; 25 µl syringe for carbonate analysis and for analyzer calibration.

4.4 Flat-tip tweezers.

4.5 Flat glass plate.

4.6 Tissue paper

4.7 Glassware

4.8 **Gases:** All gases are required of high purity grade

Sr. No.	Name of the gas	Regulated pressure (psi)	Purpose
1.	Helium	15-40	As a carrier gas
2.	10 % O_2 in helium	15	As a carrier gas
3.	Zero air	100	For pneumatic activation
4.	5% methane in He	10	Internal Calibration
5.	5% CO_2 in He	10	Calibration

5.0 Chemicals:

5.1 Potassium Hydrogen Phthalate (KHP)

5.2 Sucrose

5.4 Ultrapure ASTM type 1 deionized water (>16 Mega Ohm-cm).

6.0 Procedure

6.1 Analyzer start-up (When the analyzer is started up for the first time, or after an extended period of non-operation):

- Check the gases for their pressures/settings.
- Start all the gases on panel
- **Start PC only.**
- Put on Analyzer (Switch is on the rear side of the analyzer.)
- Wait for 3.5 min and then start EC OC application software carbon 2015.
- Go to calibration control from DRI Model 2015 Thermal optical carbon analyzer page

- Heat Oxygenator to 900°C with an increment of 100°C withhold time 30 minutes at each increment.
- When system stabilization is achieved then perform the leak check test. For daily routine operation, start the operation with leak check test onwards.

6.2 Leak Check test

- Close sample back valve – it becomes red. (All the valves should be off i. e red)
- Click on Leak test Valve. System pressure should be increased by at least 1 psi from the previous valve
- After the leak check test is PASS, click on Leak test to Turn it OFF
- Click on Back valve it should be Green

6.3 Oven Baking

- Oven Baking is performed after Leak Check is passed
- Select "Analysis" from the "Main" submenu of the Welcome form. This will initiate the analysis protocol.
- Select BAKE protocol
- Enter the Sample ID number Enter the Run #, Punch area and Deposit area for the filter being analyzed. Punch area and Deposit area should be "1". Enter technician initials in the "Tech initials" field.
- Click "OK" on the analysis "Setup" screen.
- Repeat until the system is clean. Sample runs or calibrations may then begin.
- System blanks are run after the oven bake.

6.4 Auto-calibration

- Auto-calibration is performed after system bake
- Select "Analysis" from the "Main" submenu of the Welcome form. This will initiate the analysis protocol.
- Select Bake Protocol from analysis window.
- In the analysis "Setup" form, enter "Sample" for the Type.
- Enter the Sample ID number as "AutoCalib_Date", Enter the Run #, Punch area and Deposit area for the filter being analyzed. Punch area and Deposit area should be "1". Enter technician initials in the "Tech initials" field.
- Click "OK" on the analysis "Setup" screen.

- After the run time is over, computer will prompt the calibration check result.
- Do not proceed to sample analysis unless calibration is established or confirmed. There should not be more than 10% difference in three peak areas of calibration.

6.5 Sample analysis

- Note down the sample details.
- Examine the filter visually and note any non-uniformity or unusual deposit. Place the filter on the flat glass plate and remove a sample punch using punching tool.
- Select "Analysis" from the "Main" submenu of the Welcome form. This will initiate the analysis protocol.
- In analysis window, select IMPOVE A protocol
- Enter the Sample ID number, Enter the Run #, Punch area and Deposit area for the filter being analyzed. Enter technician initials in the "Tech initials" field.
- Click "OK" on the analysis "Setup" screen. Computer will prompt to load the filter punch. But when prompted to load filter punch,
- Load the punch in boat and Click "OK" to start analysis.

6.6 Filter blank

- Filter blank analysis is performed similar to sample analysis with pre-baked blank filter paper punch loaded instead of sample punch.
- Pre-baking of blank filter paper is carried out by heating the blank filter paper in furnace at 900°C for 4 hrs using porcelain dishes and preserved in dessicator.

6.7 Calibration

- The instrument is calibrated every six months or the internal calibration gas cylinder is changed, whichever is earlier. 5% CO2 in He, 5% CH4 in He and KHP are used for calibration. 5% CH4 in He is also used for end of run calibration automatically injected by the instrument.
- 5% CO2 in He is injected in the volume 100 ul, 200 ul, 500 ul, 700 ul and 1000 ul.
- 5% CH4 in He is injected in the volume 100 ul, 200 ul, 500 ul, 700 ul and 1000 ul.

- The gas standard concentrations are corrected for temperature and pressure at laboratory conditions using ideal gas law and certified percent of gas in cylinder.
- The injection peak counts divided by calibration peak counts is calculated and slope is determined by plotting calculated carbon in ug vs. injection peak area/calibration peak area. The line is forced through zero.
- The slope value determined from calibration standards is entered into *carbon.par* table

7.0 Calculations

The conversion of integrated peak counts to µg of carbon for each peak in the thermogram is performed by the computer at the end of the analysis program based on analysis result, punch area, deposit area, internal calibration peak area.

8.0 Reporting

Report Concentration of Organic carbon fractions (OC1, OC2, OC3 and OC4) and Elemental Carbon Fractions (EC1, EC2 and EC3) in the PM.

9.0 Calibration Graphs

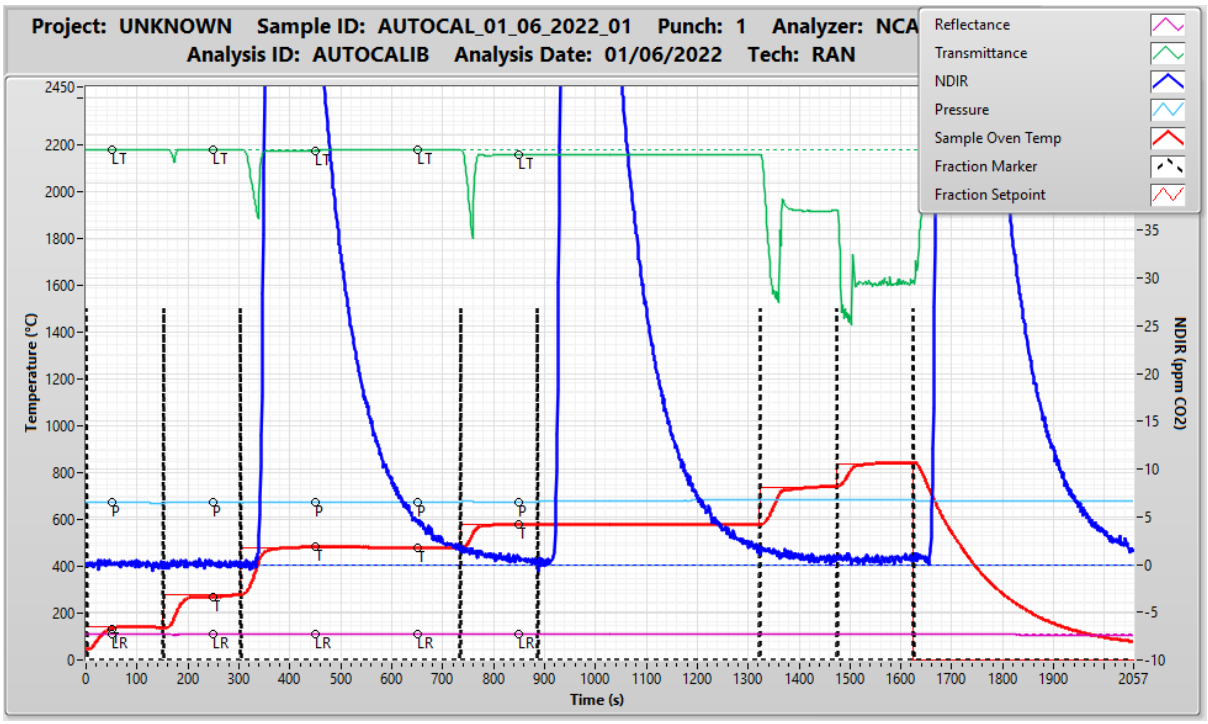


Fig. E-1: Typical example of Auto-calibration run taken on every day before actual testing starts

Annexure-F: QA/QC

Outlines of Field and Laboratory Performance Audits

Sr. No.	Parameter	Standard Ref. Method	Test procedure/ SOP	Analytical technique/ method	Calibration standard details	Performance test method	Perform. test frequency	Calibration periodicity	Primary standard
1	Sample flow	ERT/DRI modified	TP-AQM-Samp-AML	Instrumex samplers	Calibrated rotameter	Calibrated rotameter	Once a day	At the beginning or when the performance tests out of specifications	Certified root meter
2	PM_{10}	CARB/MLD NO.031	TP-AQM-PM_{10}-AML	Gravimetric	NBS Class M standards weights	NBS Class M standards weights	Once a day	At the beginning of weighing session	NBS Class M standards weights
3	$PM_{2.5}$	CARB/MLD NO.055	TP-AQM-$PM_{2.5}$-AML	Gravimetric	NBS Class M standards weights	NBS Class M standards weights	Once a day	At the beginning of weighing session	NBS Class M standards weights
4	Elements	Method IO – 3.3 for XRF CARB	TP-AQM-Elements-AML	Energy dispersive -X-Ray fluorescence (ED-XRF)	Micromatter thin film standards	Replicate thin film standard	1/10th sample	Once in two months or when the performance test not met	Micromatter thin film standards
5	Ions	CARB/MLD NO.064	TP-155-AML	Ion Chromatograph with conductivity detector	NIST Traceable MERCK make Certipur Standards	Standard solution	1/10th sample	At the beginning of each run	Certified NIST traceable standards
6	EC/OC	CARB/MLD NO.065	TP-156-AML	Thermal optical reflectance carbon analyzer	Methane, CO_2 gas, and ACS-certified KHP	Replicate methane gas run	1/10th sample	Once in two months or when performance test not met	ACS certified chemicals

Annexure-G: Emission Inventory Activities

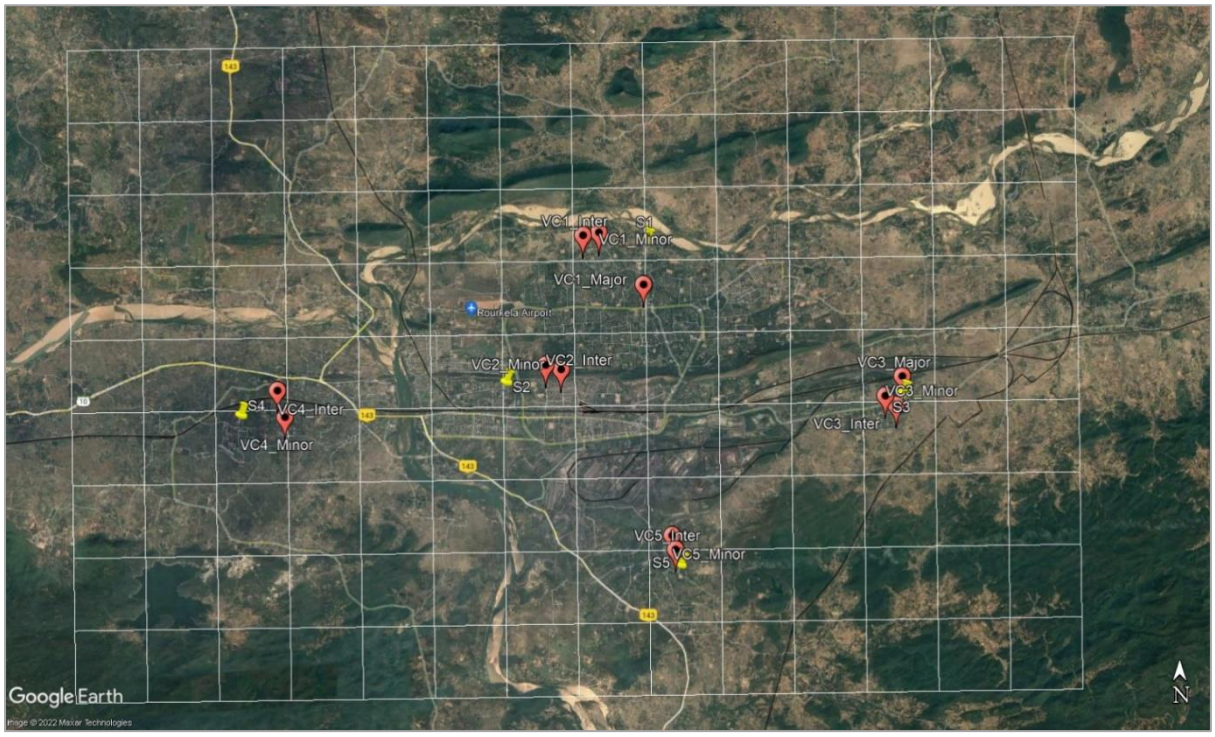


Figure G.131 Map showing location of 10 vehicle counting stations (VC1-VC10) over study domain

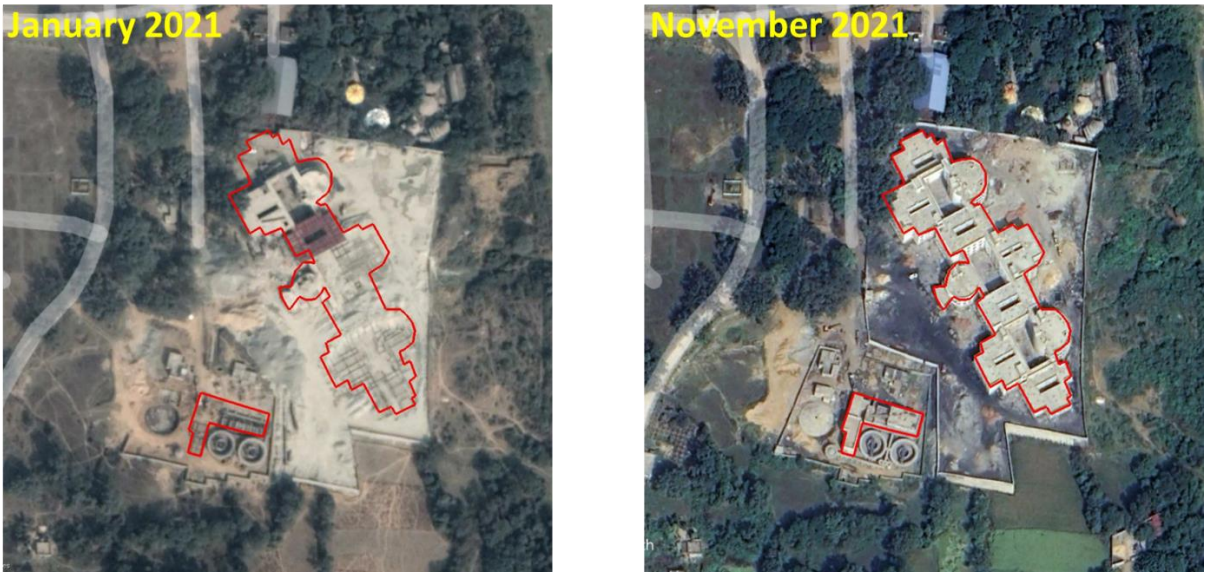
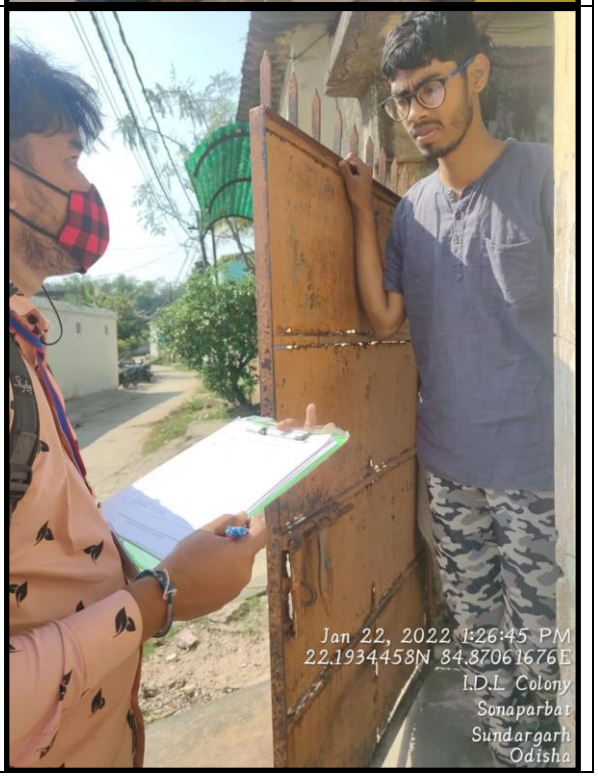


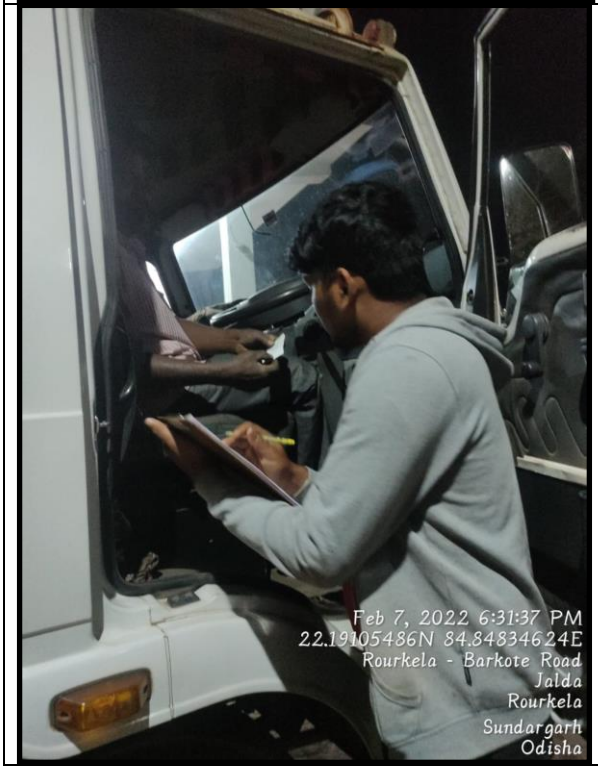
Figure G.132 Construction activity in Rourkela in January 2021 and November 2021

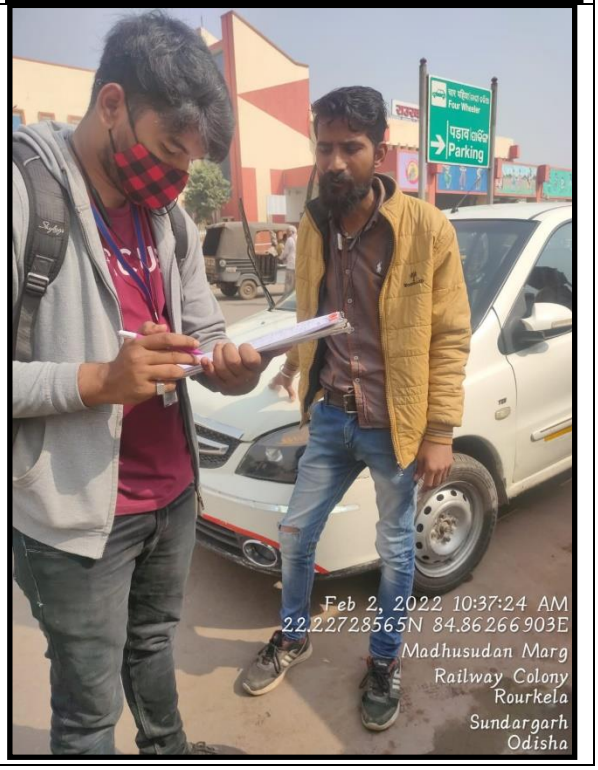
Photographs taken during primary data collection surveys in Rourkela region



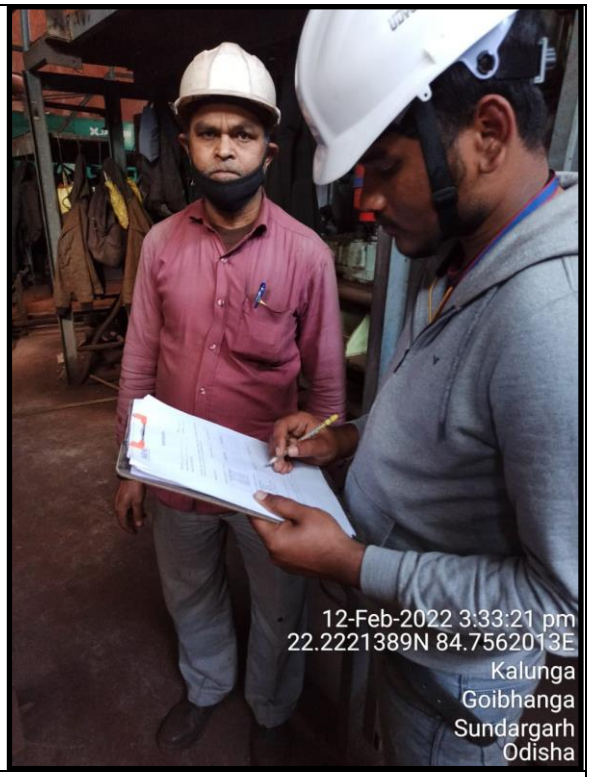
07-Feb-2022 6:38:48 pm
22.190985N 84.84846166666667E
Rourkela - Barkote Road
Jalda
Rourkela
Sundargarh
Odisha

07-Feb-2022 6:35:25 pm
22.191108333333332N 84.84826833333334E
Rourkela - Barkote Road
Jalda
Rourkela
Sundargarh
Odisha


Feb 7, 2022 6:31:37 PM
22.19105486N 84.84834624E
Rourkela - Barkote Road
Jalda
Rourkela
Sundargarh
Odisha


Parking
Feb 2, 2022 10:37:24 AM
22.22728565N 84.86266903E
Madhusudan Marg
Railway Colony
Rourkela
Sundargarh
Odisha

Jan 25, 2022 12:44:43 PM
22.22917083N 84.82560324E
Chhend Colony
Rourkela
Sundargarh
Odisha


12-Feb-2022 3:33:21 pm
22.2221389N 84.7562013E
Kalunga
Goibhanga
Sundargarh
Odisha

Jan 25, 2022 1:18:15 PM
22.22985234N 84.82429528E
Chhend Colony
Rourkela
Sundargarh
Odisha

Photographs taken during road dust sampling at Rourkela

Photographs showing activities in Rourkela region

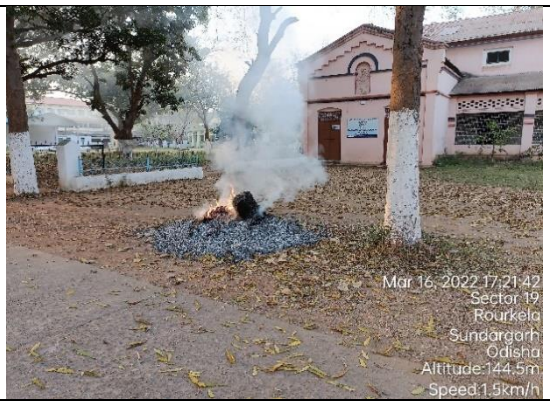
Industrial Pollution

Traffic Congestion

Industrial Pollution

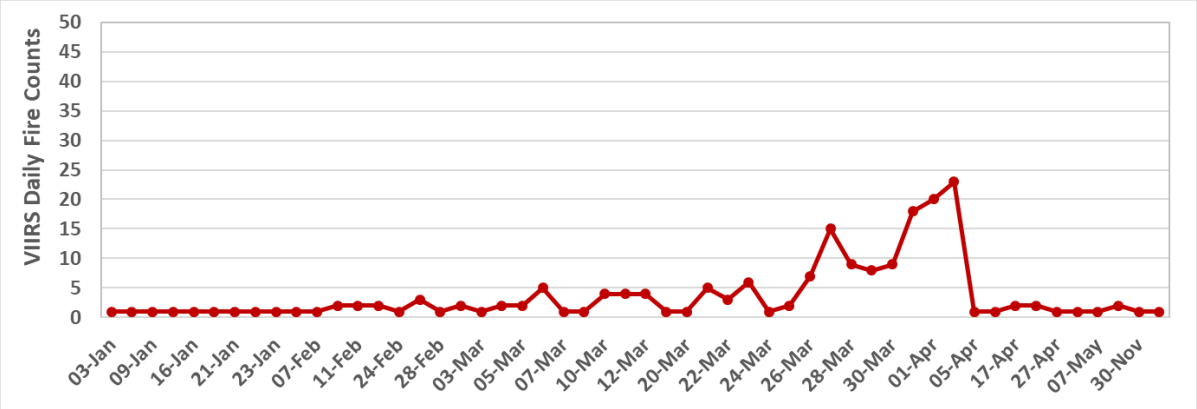
Road Dust

Open Garbage



Open Burning

Fire counts observed over Rourkela study domain in baseline year 2021



Annexure-H: Break-up of Emissions originating from the Industrial Sectors

Table H- 1 presents the emissions of important pollutants viz. PM10, PM2.5, SO2 and NOx originating from Industrial sectors in Rourkela Region for baseline year 2021.

Table H- 1: Emissions originating from Industrial sectors in Rourkela Region for baseline year 2021

Industry Sector	PM10	PM2.5	SO2	NOx
Sponge Iron	6211.1	2173.9	11475.6	5296.4
Iron and Steel	2264.7	1509.8	13864.3	13032.6
Thermal Powerplants	1051.6	701.1	10319.1	10183.2
Fugitive Emissions	1,952.10	192.3	-	-
Total	**9527.4**	**4384.8**	**35659.0**	**28512.2**

Annexure-I: Assumptions for Transport Sector

Table H.1: Considerations/Assumptions for quantification of vehicular emissions for four scenarios in 2026

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
1	**Emission Standards**	**ALL**	Implementation of BS-VI standards starting April, 2020						
2	**Roll-out of E20 fuel**	**NFC 2026**	NA	NA	NA	NA	NA	NA	NA
		BAU 2026	NA	NA	NA	NA	NA	NA	NA
		SC_I_2026	NA	NA	NA	NA	NA	NA	NA
		SC_II_2026	NA	NA	NA	NA	NA	NA	NA
3	**Increased EV Penetration**	**NFC 2026**	NA	NA	NA	NA	NA	NA	NA
		BAU 2026	EV penetration in newly registered vehicles a) 12% between 2021-26	EV penetration in newly registered vehicles a) 7% between 2021-26	EV penetration in newly registered vehicles a) 1% between 2021-26		NA	NA	EV penetration in newly registered vehicles a) 2% between 2021-26
		SC_I_2026	EV penetration in newly registered vehicles a) 15% between 2021-26	EV penetration in newly registered vehicles a) 10% between 2021-26	EV penetration in newly registered vehicles a) 2% between 2021-26	EV penetration in newly registered vehicles a) 5% between 2021-26	NA	NA	EV penetration in newly registered vehicles a) 2% between 2021-26
		SC_II_2026	EV penetration in newly registered	EV penetration in newly	EV penetration in newly	EV penetration in newly	EV penetration in newly	NA	EV penetration in newly

			vehicles a) 21% between 2021-26	registered vehicles a) 16% between 2021-26	registered vehicles a) 4% between 2021-26	registered vehicles a) 10% between 2021-26	registered vehicles a) NA between 2021-26		registered vehicles a) 5% between 2021-26
3	**Increased CNG Penetration**	**NFC 2026**	Same as baseline year						
		BAU 2026	NA	CNG penetration in newly registered vehicles a) 1% between 2021-26	CNG penetration in newly registered vehicles a) 10% between 2021-26	CNG penetration in newly registered vehicles a) 10% between 2021-26	NA	NA	CNG penetration in newly registered vehicles a) 5% between 2021-26
		SC_I_2026	NA	CNG penetration in newly registered vehicles a) 10% between 2021-26	CNG penetration in newly registered vehicles a) 20% between 2021-26	CNG penetration in newly registered vehicles a) 20% between 2021-26	CNG penetration in newly registered vehicles a) 10% between 2021-26	NA	CNG penetration in newly registered vehicles a) 25% between 2021-26
		SC_II_2026	NA	CNG penetration in newly registered vehicles a) 30% between 2021-26	CNG penetration in newly registered vehicles a) 40% between 2021-26	CNG penetration in newly registered vehicles a) 40% between 2021-26	CNG penetration in newly registered vehicles a) 20% between 2021-26	CNG penetration in newly registered vehicles a) NA% between 2021-26	CNG penetration in newly registered vehicles a) 30% between 2021-26
6	**NMT Share**	**NFC 2026**	No VKT reduction by 2026	No VKT reduction by 2026	No VKT reduction by 2026	No VKT reduction by 2026	NA	NA	No VKT reduction by 2026

		BAU 2026	0.25% VKT reduction by 2026	0.25% VKT reduction by 2026	0.25% VKT reduction by 2026	0.25% VKT reduction by 2026	NA	NA	0.25% VKT reduction by 2026
		SC_I_2026	0.5% VKT reduction by 2026	0.5% VKT reduction by 2026	0.5% VKT reduction by 2026	0.5% VKT reduction by 2026	NA	NA	0.5% VKT reduction by 2026
		SC_II_2026	1% VKT reduction by 2026	1% VKT reduction by 2026	1% VKT reduction by 2026	1% VKT reduction by 2026	NA	NA	1% VKT reduction by 2026
4	**Mass Rapid Transit System (MRTS)/ Metro**	**NFC 2026**	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		BAU 2026	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		SC_I_2026	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		SC_II_2026	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
5	**Improved Public Transport/ VKT Reduction (%)**	**NFC 2026**	No improvement in public transport						
		BAU 2026	0.35% VKT reduction by year 2026	1.66% VKT reduction by year 2026	0.95% VKT reduction by year 2026		NA	NA	15 buses per lakh population and all new buses procured would be Electric vehicles
		SC_I_2026	0.47% VKT reduction by year 2026	2.20% VKT reduction by year 2026	1.26% VKT reduction by year 2026		NA	NA	20 buses per lakh population and all new buses procured

									would be Electric vehicles
		SC_II_2026	0.82% VKT reduction by year 2026	3.87% VKT reduction by year 2026	2.22% VKT reduction by year 2026		NA	NA	25 buses per lakh population and all new buses procured would be Electric vehicles
6	**Improve and strengthen PUC programme**	**NFC 2026**	No Change in super-emitters percentage						
		BAU 2026	No Change in super-emitters percentage						
		SC_I_2026	10% Reduction in super-emitters percentage compared to NFC 2026						
		SC_II_2026	25% Reduction in super-emitters percentage compared to NFC 2026						

Table H.2: Considerations/Assumptions for quantification of vehicular emissions for four scenarios in 2031

Sr. No.	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
1	**Emission Standards**	**ALL**	Implementation of BS-VI standards starting April, 2020						
2	**Roll-out of E20 fuel**	**NFC**	NA	NA	NA		NA	NA	NA
		BAU 2031	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
		SC_I_2031	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
		SC_II_2031	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
3	**Increased EV Penetration**	**NFC**	NA	NA	NA	NA	NA	NA	NA
		BAU 2031	EV penetration in newly registered vehicles a) 12% between 2021-26 b) 18% between 2026-31	EV penetration in newly registered vehicles a) 7% between 2021-26 b) 17% between 2026-31	EV penetration in newly registered vehicles a) 1% between 2021-26 b) 6% between 2026-31		NA	NA	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 7% between 2026-31
		SC_I_2031	EV penetration in newly registered vehicles a) 15% between 2021-26	EV penetration in newly registered vehicles a) 10% between 2021-26	EV penetration in newly registered vehicles a) 2% between 2021-26	EV penetration in newly registered vehicles a) 5% between 2021-26	NA	NA	EV penetration in newly registered vehicles a) 2% between 2021-26 b) 14%

			b) 32% between 2026-31	b) 30% between 2026-31	b) 11% between 2026-31	b) 26% between 2026-31			between 2026-31
		SC_II_2031	EV penetration in newly registered vehicles a) 21% between 2021-26 b) 62% between 2026-31	EV penetration in newly registered vehicles a) 16% between 2021-26 b) 60% between 2026-31	EV penetration in newly registered vehicles a) 4% between 2021-26 b) 22% between 2026-31	EV penetration in newly registered vehicles a) 10% between 2021-26 b) 51% between 2026-31	EV penetration in newly registered vehicles a) NA between 2021-26 b) 15% between 2026-31	NA	EV penetration in newly registered vehicles a) 5% between 2021-26 b) 30% between 2026-31
3	**Increased CNG Penetration**	**NFC**	Same as baseline year						
		BAU 2031	NA	CNG penetration in newly registered vehicles a) 10% between 2021-26 b) 10% between 2026-31	CNG penetration in newly registered vehicles a) 10% between 2021-26 b) 20% between 2026-31	CNG penetration in newly registered vehicles a) 10% between 2021-26 b) 20% between 2026-31	NA	NA	CNG penetration in newly registered vehicles a) 5% between 2021-26 b) 20% between 2026-31
		SC_I_2031	NA	CNG penetration in newly registered vehicles a) 20%	CNG penetration in newly registered vehicles a) 20%	CNG penetration in newly registered vehicles a) 20%	CNG penetration in newly registered vehicles a) 10%	NA	CNG penetration in newly registered vehicles a) 25%

				between 2021-26 b) 30% between 2026-31	between 2021-26 b) 40% between 2026-31	between 2021-26 b) 40% between 2026-31	between 2021-26 b) 20% between 2026-31		between 2021-26 b) 40% between 2026-31
		SC_II_2031	NA	CNG penetration in newly registered vehicles a) 30% between 2021-26 b) 40% between 2026-31	CNG penetration in newly registered vehicles a) 40% between 2021-26 b) 40% between 2026-31	CNG penetration in newly registered vehicles a) 40% between 2021-26 b) 35% between 2026-31	CNG penetration in newly registered vehicles a) 20% between 2021-26 b) 40% between 2026-31	CNG penetration in newly registered vehicles a) NA% between 2021-26 b)10% between 2026-31	CNG penetration in newly registered vehicles a) 30% between 2021-26 b) 50% between 2026-31
6	**NMT Share**	**NFC**	No VKT reduction by 2031	No VKT reduction by 2031	No VKT reduction by 2031	No VKT reduction by 2031	NA	NA	No VKT reduction by 2031
		BAU 2031	0.5% VKT reduction by 2031	0.5% VKT reduction by 2031	0.5% VKT reduction by 2031	0.5% VKT reduction by 2031	NA	NA	0.5% VKT reduction by 2031
		SC_I_2031	1% VKT reduction by 2031	1% VKT reduction by 2031	1% VKT reduction by 2031	1% VKT reduction by 2032	NA	NA	1% VKT reduction by 2031
		SC_II_2031	2% VKT reduction by 2031	2% VKT reduction by 2031	2% VKT reduction by 2031	2% VKT reduction by 2031	NA	NA	2% VKT reduction by 2031
4	**Mass Rapid Transit System (MRTS)/ Metro**	**NFC**	No MRTS						
		BAU 2031	No MRTS						
		SC_I_2031	No MRTS						
		SC_II_2031	No MRTS						

5	**Improved Public Transport/ VKT Reduction (%)**	**NFC**	No improvement in public transport						
		BAU 2031	0.48% VKT reduction by year 2031	2.27% VKT reduction by year 2031	1.30% VKT reduction by year 2031	1.30% VKT reduction by year 2031	NA	NA	20 buses per lakh population and all new buses procured would be Electric vehicles
		SC_I_2031	0.72% VKT reduction by year 2031	3.40% VKT reduction by year 2031	1.95% VKT reduction by year 2031	1.95% VKT reduction by year 2031	NA	NA	30 buses per lakh population and all new buses procured would be Electric vehicles
		SC_II_2031	1.35% VKT reduction by year 2031	6.37% VKT reduction by year 2031	3.65% VKT reduction by year 2031	3.65% VKT reduction by year 2032	NA	NA	40 buses per lakh population and all new buses procured would be Electric vehicles
6	**Improve and strengthen PUC programme**	**NFC**	No Reduction in super-emitters percentage						
		BAU 2031	10% Reduction in super-emitters percentage compared to NFC 2031						
		SC_I_2031	25% Reduction in super-emitters percentage compared to NFC 2031						
		SC_II_2031	50% Reduction in super-emitters percentage compared to NFC 2031						

ANNEXURE – J

Compilation of Best Available Techniques (BAT) for Iron and Steel and Allied Industries

This annexure summarizes the Best Available Techniques (BAT) for Iron and Steel Industry in order to prevent and minimize the emissions. The details of each technique can be found in the original report i.e. Remus et al., 2013. Best Available Techniques (BAT) Reference Document for Iron and Steel Production, Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).

I.1 Sinter plants

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
1.	**Primary dust emissions from blending/mixing**	Prevent or reduce diffuse dust emissions by agglomerating fine materials by adjusting the moisture content	
2.	**Primary dust emissions from sinter strand waste gas**	Reduce dust emissions from the sinter strand waste gas by means of a bag filter	
		Reduce dust emissions from the sinter strand waste gas by using advanced electrostatic precipitators when bag filters are not applicable.	
3.	**Primary SOx emissions from sinter strands**	Primary sulphur oxide (SOX) emissions can be reduced by using one or a combination of the following techniques: I. lowering the sulphur input by using coke breeze with a low sulphur content II. lowering the sulphur input by minimisation of coke breeze consumption III. lowering the sulphur input by using iron ore with a low sulphur content	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		IV. injection of adequate adsorption agents into the waste gas duct of the sinter strand before dedusting by bag filter V. wet desulphurisation or regenerative activated carbon (RAC) process (with particular consideration for the prerequisites for application).	
4.	**Primary NOx emissions from sinter strands**	Primary NOx emissions can be reduced by using one or a combination of the following techniques: I. process integrated measures which can include: a. waste gas recirculation b. other primary measures, such as the use of anthracite or the use of low-NOX burners for ignition II. End-of-pipe techniques which can include: a. the regenerative activated carbon (RAC) process b. selective catalytic reduction (SCR).	
5.	**Secondary dust emissions**	secondary emissions from sinter strand discharge, sinter crushing, cooling, screening and conveyor transfer points is to prevent dust emissions and/or to achieve an efficient extraction and subsequently to reduce dust emissions by using a combination of the following techniques: I. hooding and/or enclosure II. an electrostatic precipitator or a bag filter.	

I.2 Pelletisation Plants

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
1.	**Primary dust emissions in the waste gases**	The dust emissions in the waste gases from the raw materials pre-treatment, drying, grinding, wetting, mixing and the balling; from the induration strand; and from the pellet handling and screening, can be reduced by using one or a combination of the following techniques: I. an electrostatic precipitator II. a bag filters III. a wet scrubber	
2.	**Sulphur oxides (SOX), hydrogen chloride (HCl) and hydrogen fluoride (HF) emissions**	Emissions of sulphur oxides (SOX), hydrogen chloride (HCl) and hydrogen fluoride (HF) from the induration strand waste gas can be reduced by using one of the following techniques: I. a wet scrubber II. semi-dry absorption with a subsequent dedusting system	
3.	**NOX emissions from the drying and grinding section and induration strand waste gases**	NOX emissions from the drying and grinding section and induration strand waste gases can be reduced by applying one of the following techniques: I. selective catalytic reduction (SCR) as an end-of-pipe technique II. any other technique with a NOX reduction efficiency of at least 80%.	

I.3 Coke Oven Plants

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
1.	**Dust emissions from coal grinding plants**	The dust emissions from coal grinding plants (coal preparation including crushing, grinding, pulverising and screening) can be prevented or reduced by using one or a combination of the following techniques: I. building and/or device enclosure (crusher, pulveriser, sieves) and II. efficient extraction and use of a subsequent dry dedusting systems	
2.	**Fugitive or Diffuse dust emissions from storage and handling of coal**	Fugitive or Diffuse dust emissions from storage and handling of pulverised coal can be prevented or reduced by using one or a combination of the following techniques: I. storing pulverised materials in bunkers and warehouses II. using closed or enclosed conveyors III. minimising the drop heights depending on the plant size and construction IV. reducing emissions from charging of the coal tower and the charging car V. using efficient extraction and subsequent dedusting	
3.	**Dust emissions from coal charging**	The emissions can be reduced by using emission-reduced charging systems to charge coke oven chambers. From an integrated point of view, 'smokeless' charging or sequential charging with double ascension pipes or jumper pipes are the preferred types, because all gases and dust are treated as part of the coke oven gas treatment.	
4.	**Emissions from coking plants**	The emissions from a coke plant can be reduced through achieving continuous undisrupted coke production by using the following techniques:	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		I. extensive maintenance of oven chambers, oven doors and frame seals, ascension pipes, charging holes and other equipment (a systematic programme should be carried out by specially-trained detection and maintenance personnel) II. avoiding strong temperature fluctuations III. comprehensive observation and monitoring of the coke oven IV. cleaning of doors, frame seals, charging holes, lids and ascension pipes after handling (applicable at new and, in some cases, existing plants) V. maintaining a free gas-flow in the coke ovens VI. adequate pressure regulation during coking and application of spring-loaded VII. flexible sealing doors or knife-edged doors (in cases of ovens f5 m high and in good working order) VIII. using water-sealed ascension pipes to reduce visible emissions from the whole apparatus which provides a passage from the coke oven battery to the collecting main, gooseneck and stationary jumper pipes IX. luting charging hole lids with a clay suspension (or other suitable sealing material), to reduce visible emissions from all holes X. ensuring complete coking (avoiding green coke pushes) by application of adequate techniques XI. installing larger coke oven chambers (applicable to new plants or in some cases of a complete replacement of the plant on the old foundations) where possible, using variable pressure regulation to oven chambers during coking (applicable to new plants and can be an option for existing plants; the possibility of installing this technique in existing plants should be assessed	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		carefully and is subject to the individual situation of every plant). XII. Extract the coke oven gas (COG) during coking as much as possible. XIII. reduce the sulphur content of the coke oven gas (COG) by using one of the following techniques: a. desulphurisation by absorption systems b. wet oxidative desulphurisation.	
5.	**Fugitive gaseous emissions from gas treatment plant**	The fugitive gaseous emissions from the gas treatment plant can be minimised by using the following techniques: I. minimising the number of flanges by welding piping connections wherever possible II. using appropriate sealings for flanges and valves III. using gas-tight pumps (e.g. magnetic pumps) IV. avoiding emissions from pressure valves in storage tanks by: a. connecting the valve outlet to the coke oven gas (COG) collecting main or b. collecting the gases and subsequent combustion.	
6.	**Emissions from Coke Oven**	The emissions from the coke oven under firing can be reduced by using the following techniques: I. preventing leakage between the oven chamber and the heating chamber by means of regular coke oven operation II. repairing leakage between the oven chamber and the heating chamber (only applicable to existing plants) III. incorporating low-nitrogen oxides (NOX) techniques in the construction of new batteries, such as staged combustion and the use of thinner bricks and refractory with a better thermal conductivity (only applicable to new plants) IV. using desulphurised coke oven gas (COG) process gases.	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
7.	**Dust emissions from coke pushing**	The dust emissions from coke pushing can be reduced by using the following techniques: I. extraction by means of an integrated coke transfer machine equipped with a hood II. using land-based extraction gas treatment with a bag filter or other abatement systems III. using a one point or a mobile quenching car.	
8.	**Dust emissions from coke quenching**	The dust emissions from coke quenching can be reduced by using the following techniques: I. using coke dry quenching (CDQ) with the recovery of sensible heat and the removal of dust from charging, handling and screening operations by means of a bag filter II. using emission-minimised conventional wet quenching III. using coke stabilisation quenching (CSQ).	
9.	**Dust emissions from coke grading and handling**	The dust emissions from coke grading and handling can be reduced by using the following techniques in combination: I. use of building or device enclosures II. efficient extraction and subsequent dry dedusting.	

I.4 Blast Furnaces

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
1.	**Dust emissions**	The dust emissions from the displaced air during loading from the storage bunkers of the coal injection unit shall be captured and subsequent dry dedusting shall be performed.	
2.	**Dust emissions from burden preparation**	The dust emissions from burden preparation (mixing, blending) and conveying can be minimised and, where relevant, extracted with subsequent dedusting by means of an electrostatic precipitator or bag filter	
3.	**Fugitive dust emissions from Casting house**	The fugitive dust emissions from casting house (tap holes, runners, torpedo ladles charging points, skimmers) can be prevented or reduced by using the following techniques: I. covering the runners II. optimising the capture efficiency for diffuse dust emissions and fumes with subsequent off-gas cleaning by means of an electrostatic precipitator or bag filter III. fume suppression using nitrogen while tapping, where applicable and where no collecting and dedusting system for tapping emissions is installed	
4.	**Release of blast furnace gas**	The release of blast furnace gas during charging can be minimised by using one or a combination of the following techniques: a. bell-less top with primary and secondary equalising b. gas or ventilation recovery system c. use of blast furnace gas to pressurise the top bunkers.	
5.	**Dust emissions from the blast furnace gas**	The dust emissions from the blast furnace gas by using one or a combination of the following techniques: I. using dry pre-dedusting devices such as: a. deflectors	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		b. dust catchers c. cyclones d. electrostatic precipitators. II. subsequent dust abatement such as: a. hurdle-type scrubbers b. venturi scrubbers c. annular gap scrubbers d. wet electrostatic precipitators e. disintegrators	
6.	**Emissions from hot blast stoves**	The emissions from hot blast stoves can be reduced by using desulphurised and dedusted surplus coke oven gas, dedusted blast furnace gas, dedusted basic oxygen furnace gas and natural gas, individually or in combination.	

I.5 Basic Oxygen Steelmaking and Casting

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
1.	**General considerations for basic oxygen furnace (BOF)**	It is recommended to extract the BOF gas during blowing as much as possible and to clean it by using the following techniques in combination: I. I use of a suppressed combustion process II. Pre-dedusting to remove coarse dust by means of dry separation techniques (e.g. deflector, cyclone) or wet separators III. dust abatement by means of: a. dry dedusting (e.g. electrostatic precipitator) for new and existing plants b. wet dedusting (e.g. wet electrostatic precipitator or scrubber) for existing plants.	
		It is recommended to practice the gas recovery during oxygen blowing in the case of full combustion is to reduce dust emissions by using one of the following techniques: I. dry dedusting (e.g. ESP or bag filter) for new and existing plants II. wet dedusting (e.g. wet ESP or scrubber) for existing plants.	
2.	**dust emissions from the oxygen lance hole**	The dust emissions from the oxygen lance hole can be minimised by using one or a combination of the following techniques: I. covering the lance hole during oxygen blowing II. inert gas or steam injection into the lance hole to dissipate the dust III. use of other alternative sealing designs combined with lance cleaning devices.	
3.	**Dust emissions**	The best technique is secondary dedusting, including the emissions from the different associated processes is to minimise dust emissions	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		by means of process integrated techniques, such as general techniques to prevent or control diffuse or fugitive emissions, and by using appropriate enclosures and hoods with efficient extraction and a subsequent off-gas cleaning by means of a bag filter or an ESP.	
4.	**Dust emissions from on-site slag processing**	The dust emissions from on-site slag processing can be minimised by using one or a combination of the following techniques: I. efficient extraction of the slag crusher and screening devices with subsequent offgas cleaning, if relevant II. II transport of untreated slag by shovel loaders III. extraction or wetting of conveyor transfer points for broken material IV. wetting of slag storage heaps V. use of water fogs when broken slag is loaded.	

I.6 Electric Arc Furnace Steelmaking and Casting

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
1.	**Mercury emissions from EAF**	The mercury emissions from the electric arc furnace (EAF) process can be prevented by avoiding, as much as possible, raw materials and auxiliaries which contain mercury.	
2.	**Dust emissions from EAF**	An efficient extraction of all emission sources in the electric arc furnace (EAF) primary and secondary dedusting (including scrap preheating, charging, melting, tapping, ladle furnace and secondary metallurgy) can be achieved by using one of the techniques listed below and to use subsequent dedusting by means of a bag filter: I. a combination of direct off-gas extraction (4th or 2nd hole) and hood systems II. direct gas extraction and doghouse systems III. III. direct gas extraction and total building evacuation (low-capacity electric arc furnaces (EAF) may not require direct gas extraction to achieve the same extraction efficiency).	
3.	**Dust emissions from on-site slag processing**	The dust emissions from on-site slag processing can be minimised by using one or a combination of the following techniques: I. efficient extraction of the slag crusher and screening devices with subsequent offgas cleaning, if relevant II. II transport of untreated slag by shovel loaders III. extraction or wetting of conveyor transfer points for broken material IV. wetting of slag storage heaps use of water fogs when broken slag is loaded.	

Annexure-J: Breakpoints for AQI

Table J.1: Breakpoints for Air Quality Index (AQI) Scale 0 to 500 (Source: CPCB, 2015)

AQI Category	AQI Range	$PM_{2.5}$	PM_{10}	NO2	SO_2	O3	CO
	Unit less	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**mg/m3**
Good	0-50	0-30	0-50	0-40	0-40	0-50	0-1
Satisfactory	51-100	31-60	51-100	41-80	41-80	51-100	1.1-2.0
Moderate	101-200	61-90	101-250	81-180	81-380	101-168	2.1-10.0
Poor	201-300	91-120	251-350	181-280	381-800	169-208	10.1-17.0
Very poor	301-400	121-250	351-430	281-400	801-1600	209-748	17.1-34.0
Severe	401-500	251+	431+	401+	1601+	748+	34.1+

---- END OF THE REPORT---