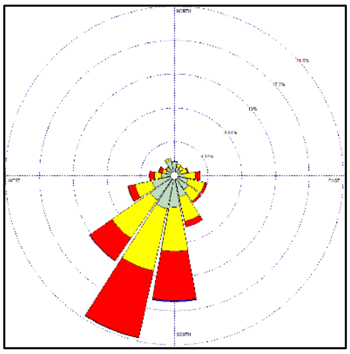
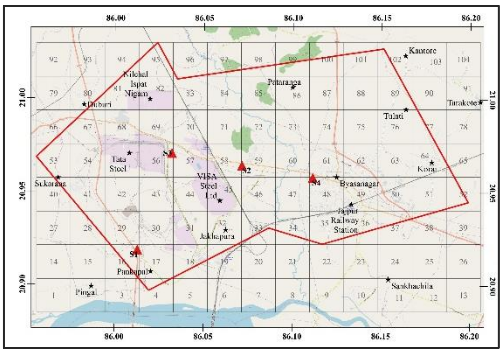
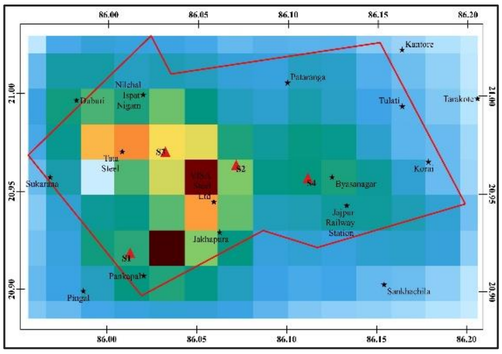
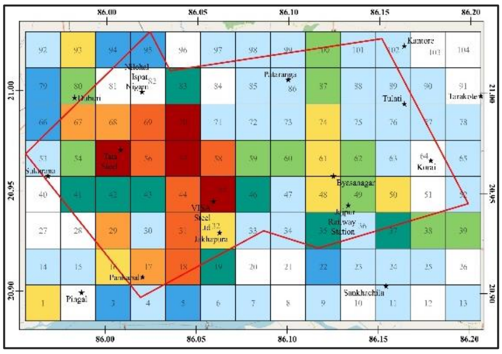
Report No.: ARAI/ERL/OSPCB_PKG_II/KLN/2024-25/Final_Report

FINAL REPORT

Emission Inventory and Source Apportionment Study of Kalinganagar-Jajpur Region in Odisha

Submitted to

State Pollution Control Board, Odisha
ରାଜ୍ୟ ପ୍ରଦୂଷଣ ନିୟନ୍ତ୍ରଣ ବୋର୍ଡ, ଓଡ଼ିଶା

State Pollution Control Board, Odisha (OSPCB)

Submitted by

ए आर ए आई
ARAI
Progress through Research

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

December 2024

[THIS PAGE INTENTIONALLY LEFT BLANK]

Suggested format for citation:

ARAI (2024), Emission Inventory and Source Apportionment Study of Kalinganagar-Jajpur Region in Odisha, The Automotive Research Association of India, Pune, M.S., India

Disclaimer

This report is the outcome of the project "Emission Inventory and Source Apportionment Study of Kalinganagar-Jajpur 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 Kalinganagar-Jajpur during the project duration. Due care has been taken to validate the authenticity and correctness of the information.

ARAI disclaim any and all liability for the use that may be made of the information contained in this report. None of the information in this report may be reproduced, republished or re-disseminated in any manner or form without the prior written permission of competent authority.

Project Team

- Dr. Sukrut S. Thipse, Head – Environment Research Laboratory (ERL)
- Mr. Moqtik A. Bawase, Principal Investigator
- Mr. Yogesh V. Sathe, Co- Principal Investigator
- Dr. Yamini J. Patil
- Mr. Jeetendra Kumar Purohit
- Mr. Hemant L. Khandaskar
- Mr. Ajim R. Shaikh
- Mr. Satyajit Swain
- Mr. Rohit N. Bacche
- Ms. Pratiksha Sable
- Mr. Harshvardhan V. Bhoite
- Mr. Aditya S. Sharma
- Mr. Shrikant B. Jadhav
- Mr. Mayur R. Ekhare
- Mr. Rushant A. Nandkhile
- Mr. Kiran Kandhare

[THIS PAGE INTENTIONALLY LEFT BLANK]

Acknowledgements

The project "Emission Inventory and Source Apportionment Study of Kalinganagar-Jajpur Region in Odisha" was sponsored by State Pollution Control Board, Odisha (OSPCB).

We gratefully acknowledge support and guidance received from Chairman and Member Secretary, OSPCB during the project duration. We would like to express sincere thanks to Chief Environmental Engineer – Head Office, The Regional Officer – Kalinganagar-Jajpur and their respective teams for coordination, assistance and ground support during the execution of this project.

We would also like to thank National Centers for Environmental Information (NCEI) of National Oceanic and Atmospheric Administration (NOAA), USA for making available surface meteorological observations through Integrated Surface Database (ISD).

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.

[THIS PAGE INTENTIONALLY LEFT BLANK]

Abbreviations

AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model

AQI: Air Quality Index

ARAI: Automotive Research Association of India

BAU: Business-as-usual

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

MSL: Mean Sea Level

TPY: Tonnes Per Year

VKT: Vehicle Kilometres Travelled

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

[THIS PAGE INTENTIONALLY LEFT BLANK]

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.

To address the air pollution issues of the Kalinganagar-Jajpur 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 Kalinganagar-Jajpur Region in Odisha”. The main aim of this study is to identify and characterize various emission sources in Kalinganagar-Jajpur 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 Kalinganagar-Jajpur region.
- To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Kalinganagar-Jajpur 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 in subsequent sections.

Study Area

Kalinga Nagar – Jajpur region, located at approximately 20.8833° N latitude and 86.0833° E longitude in the Jajpur district of Odisha, India, is a prominent industrial hub known for its significant contributions to the steel and metal industries. Established as a major industrial area, it houses numerous steel plants, including those of Tata Steel and Jindal Stainless Steel, and plays a vital role in the region's economic development. With an average elevation of 51 meters above mean sea level, it's relatively low-lying terrain.

Air quality sampling and chemical analysis

Based on the reconnaissance surveys and inputs from OSPCB four sampling locations were identified for this study which represent various land-use patterns, and include 1 background site, 2 residential sites, and 1 industrial site. These sites are located in different parts of Kalinganagar-Jajpur region and can provide an integrated insight into the characteristics of $PM_{2.5}$ and PM_{10} over Kalinganagar-Jajpur 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 Kalinganagar-Jajpur region

Code	Location	Latitude	Longitude	Category
S1	JCDL	20° 55' 6.74" N	86° 0' 47.45" E	Background
S2	Tehsil Office	20° 57' 0.18" N	86° 7' 43.10" E	Residential (LIG) + Others
S3	TATA Steel	20° 59' 49.47" N	86° 1' 55.27" E	Industrial
S4	RO Office	20° 55' 8.72" N	86° 0' 46.30" E	Residential (MIG+HIG)

The ambient $PM_{2.5}$ and PM_{10} samples were collected in the study area, during two critical seasons i.e. winter (January 1 to 20, 2022) and summer (April 22 to May 14, 2022).

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). After the carbon fraction analysis, remaining part of the quartz filter papers were subjected to molecular markers (alkanes, hopanes, amides, levoglucosan and stigmasterol) analysis using Gas chromatography – mass spectrometry (GC-MS) method.

In addition to particulate matter, the present study also analysed the levels of gaseous pollutants such as SO_2 and NO_2 and Volatile Organic Compounds (VOCs) such as Benzene, Toluene, Ethyl Benzene and Xylene, during winter season.

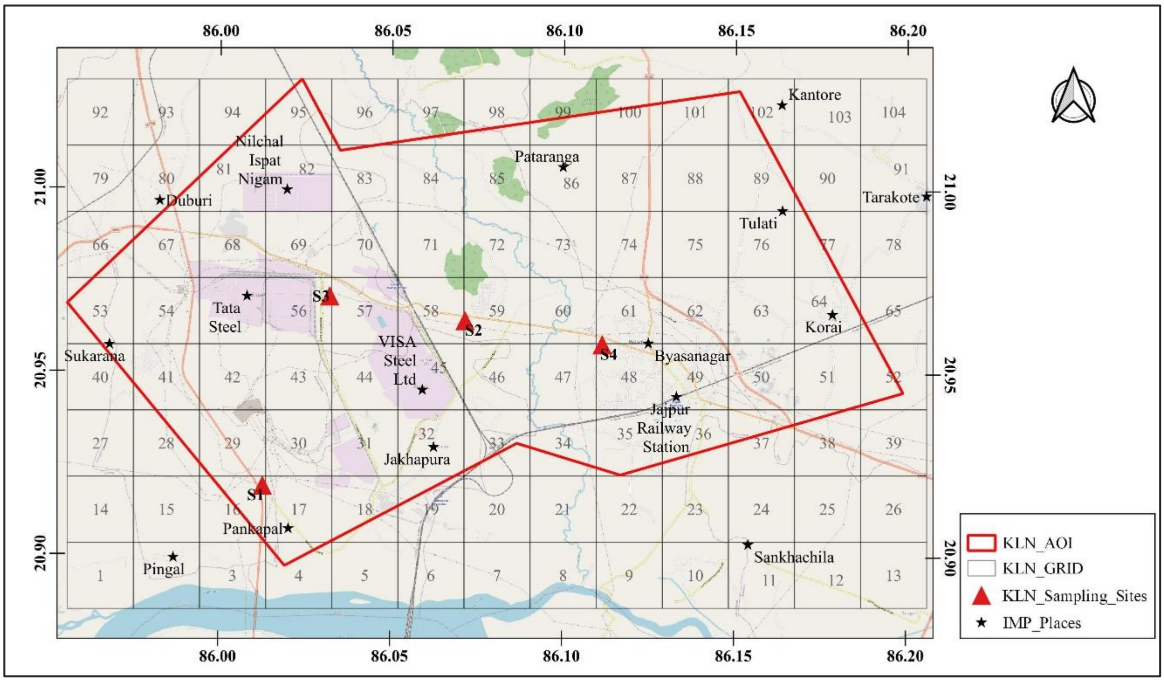


Figure ES-1 Kalinganagar – Jajpur region map showing different land-use classes. The blue pins show the location of four sampling sites selected for source apportionment study

The winter-season mean $PM_{2.5}$ and PM_{10} mass concentrations over all sites were 64.2 and 171.2 µg/m^3, respectively. The highest seasonal mean $PM_{2.5}$ concentrations were observed at Tehsil Office i.e. S2 (105.9 µg/m^3) while the lowest were recorded at JCDL i.e. S1 (33.4 µg/m^3). Similarly, the highest seasonal mean PM_{10} concentrations were observed at JCDL i.e. S1 (309.7 µg/m^3) while the lowest were recorded at RO Office i.e. S6 (67.8 µg/m^3). The mean value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.39, varying from 0.15 to 0.61, 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 24.0 and 90.9 µg/m^3, respectively. The highest seasonal mean $PM_{2.5}$ concentration was observed at Tehsil Office i.e. S2 (56.3 µg/m^3) while the lowest was recorded at Tehsil Office i.e. S2 (8.7 µg/m^3). Similarly, the highest seasonal mean PM_{10} concentration was observed at TATA Steel i.e. S3 (176.9 µg/m^3) while the lowest was recorded at RO Office i.e. S4 (34.5 µg/m^3). The mean value of $PM_{2.5}$ to PM_{10} ratios during the summer season over all sites was found to be 0.29, varying from 0.11 to 0.67, 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, R2 is found to be 0.72 (winter) and 0.78 (summer) for $PM_{2.5}$ whereas it is found to be 0.88 (winter) and 0.95 (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 both $PM_{2.5}$ 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 > SNA > EC > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM> SNA > CM > EC > 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.

As discussed earlier, the gaseous pollutants i.e. SO_2 and NO_2 and VOCs (i.e. Benzene, Toluene, Ethyl Benzene and Xylene) were also monitored at four sampling locations in Kalinganagar-Jajpur region, during the winter season sampling period i.e. January 1-20, 2022. The winter season mean concentrations of SO_2 are observed to be 6.3 µg/m^3 at JCDL (S1), 12.7 µg/m^3 at Tehsil Office (S2), and 9.5 µg/m^3 at Tata Steel (S3). Similarly, the winter season mean concentrations of NO_2 are observed to be 12.3 µg/m^3 at JCDL (S1), 15.2 µg/m^3 at Tehsil Office (S2), 19.7 µg/m^3 at Tata Steel (S3) and 11.2 µg/m^3 at RO Office (S4). In case of VOCs, the winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites ranged from 0.8 to 1.9 ng/m^3, 0.9 to 2.6 ng/m^3, 0.5 to 6.8 ng/$m^3$and 1.4 to 6.7 ng/m^3, respectively.

Receptor modelling

The data generated from chemical analysis of ambient PM samples 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 Kalinganagar-Jajpur 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 four sampling sites in Kalinganagar-Jajpur region. Five pollution sources were apportioned using the mean concentration data including i) transport (TRAN), ii) road and construction dust (DUST), iii) biomass and solid waste combustion (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 Kalinganagar-Jajpur (Fig. ES-2 - A) are found to be dominated by dust and industrial sectors with contribution of 56.2% and 9.3%, respectively. The other sources of $PM_{2.5}$ at Kalinganagar-Jajpur are identified as secondary aerosols (8.4%), transport (7.6%) and biomass and solid waste combustion (2.9%). Similarly, the winter-time PM_{10} mass at Kalinganagar-Jajpur is also found to be dominated by road and construction dust (54.4%), followed by industries and powerplants (20.9%), secondary aerosols (7.5%), transport (5.8%) and biomass and solid waste combustion (2.3%). Additionally, about 15.7% and 9.1% 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 in Kalinganagar-Jajpur region (Fig. ES-2 - B) is found to be dominated by dust with highest contribution of 45.8%. The other summer-time sources of $PM_{2.5}$ in Kalinganagar-Jajpur region are identified as secondary aerosols (16.6%), industries and powerplants (13.4%), transport (5.9%) and biomass and solid waste combustion (1.7%). The summer-time PM_{10} mass in Kalinganagar-Jajpur Region is found to be dominated by road and construction dust (41.6%), followed by industries and powerplants (29.8%), secondary aerosols (12.3%). The transport and biomass and solid waste combustion were found to be minor contributors with a contribution of 3.7% and 1.1%. Additionally, about 16.6% and 11.5% 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.

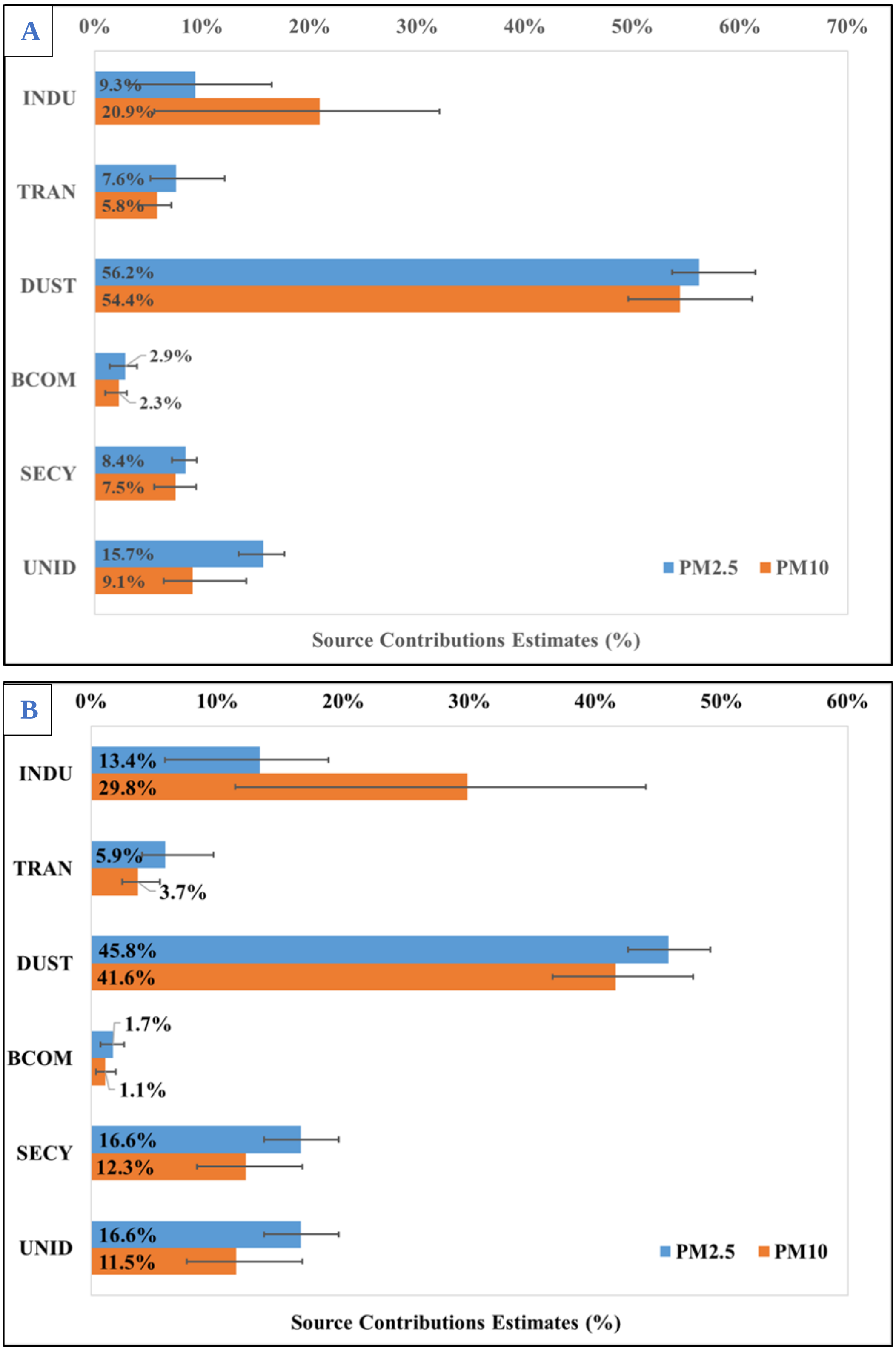


Figure ES-2 City-level source contribution estimates (SCE) for Kalinganagar-Jajpur region using CMB receptor model during winter (A) and summer (B) seasons

Emission Inventory

The development of emission inventory for Kalinganagar-Jajpur region involved quantification of emission loads originating from sectors including: Industries and thermal powerplants, Fugitive dust, Transport, Re-suspended road dust, Open Waste Burning, Residential, Industrial 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 Kalinganagar – Jajpur region is presented in Table ES-2, while the pollutant wise contribution is shown in Fig. ES-3. The Kalinganagar – Jajpur regional spatial distribution of the pollutants is provided in Fig. ES-4, ES-5 and ES-6. The total PM_{10} emission load in the Kalinganagar - Jajpur region is estimated to be 16,895 tonnes per year. The top four contributors to PM_{10} emissions are resuspended road dust (58.1%), followed by industries and thermal powerplants (17.9%), fugitive emissions (17.9%), and transport (2.3%). Similarly, $PM_{2.5}$ emission load in the Kalinganagar - Jajpur region is estimated to be 5,539 tonnes per year. The top four contributors to $PM_{2.5}$ emissions are re-suspended road dust (42.9%), industries and thermal powerplants (36.4%), fugitive emissions (7.5%), and transport (6.4%). Other $PM_{2.5}$ contributors include open waste burning

(2.5%), hotel, restaurants and bakeries (1.8%) and residential (1.1%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

Table ES-2 Emission Inventory (tonnes per year) for Kalinganagar – Jajpur Region in year 2021

Sector	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	NMVOC
Industries and powerplants	3024 ± 623	2016 ± 416	17654 ± 1974	11669 ± 2406	96969 ± 19995	4269 ± 880
Fugitive emissions	3017 ± 1538	417 ± 212	NA	NA	NA	NA
Transport	396 ± 104	357 ± 2	10 ± 1961	3713 ± 3442	6519 ± 2329	NA
Road dust	9812 ± 2194	2374 ± 531	NA	NA	NA	NA
Residential	90 ± 46	62 ± 31	12 ± 2	36 ± 19	874 ± 445	301 ± 153
Open waste burning	146 ± 79	136 ± 73	9 ± 5	21 ± 377	700 ± 82	#N/A
Hotels, Restaurants, Bakeries and Open eateries	157 ± 84	98 ± 53	116 ± 26	39 ± 21	459 ± 247	89 ± 48
Construction	188 ± 39	32 ± 7	NA	NA	NA	NA
Brick Kilns	53 ± 28	40 ± 22	12 ± 7	0.01 ± 0	405 ± 218	6 ± 3
Industrial DG	4 ± 2	4 ± 2	4 ± 1	63 ± 32	14 ± 7	NA
Crematoria	8 ± 4	4 ± 2	0.2 ± 0.1	1 ± 0.5	41 ± 21	23 ± 12
Total	**16895 ± 4742**	**5539 ± 1442**	**17818 ± 2016**	**15543 ± 4451**	**105980 ± 24753**	**9339 ± 3553**

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

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 17818, 15543, 105980 and 9339 tonnes per year, respectively.

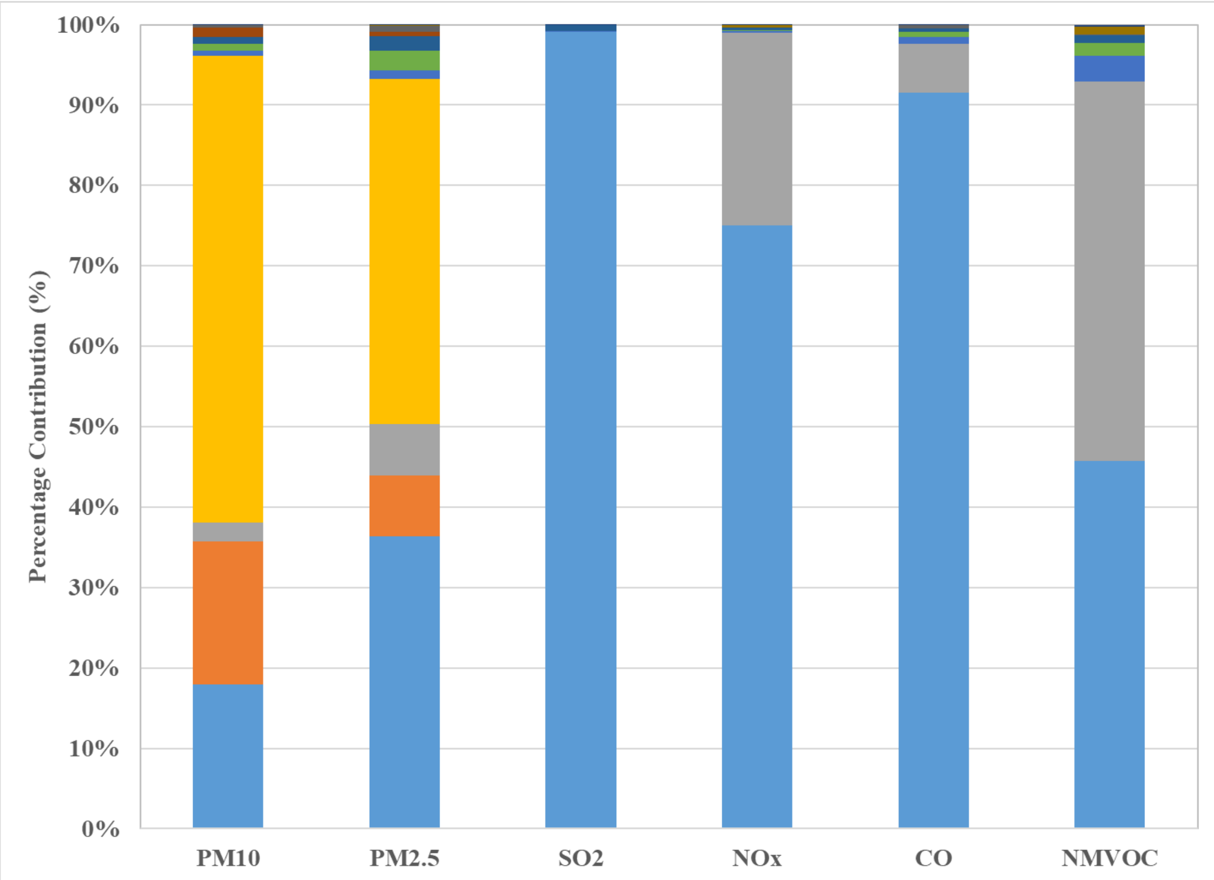
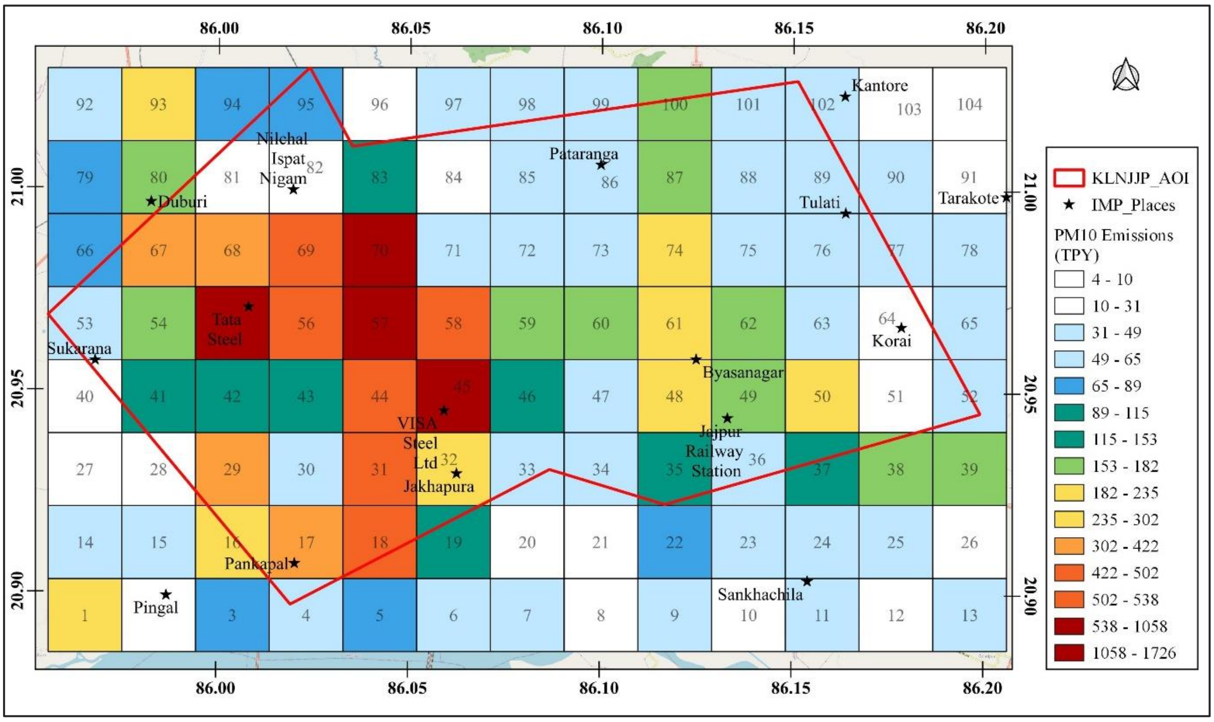


Figure ES-3 Sector-wise contribution to air pollutant emissions of A) PM_{10}, B) $PM_{2.5}$, C) SO_2, D) NOX, E) CO and F) NMVOC in Kalinganagar – Jajpur region in 2021



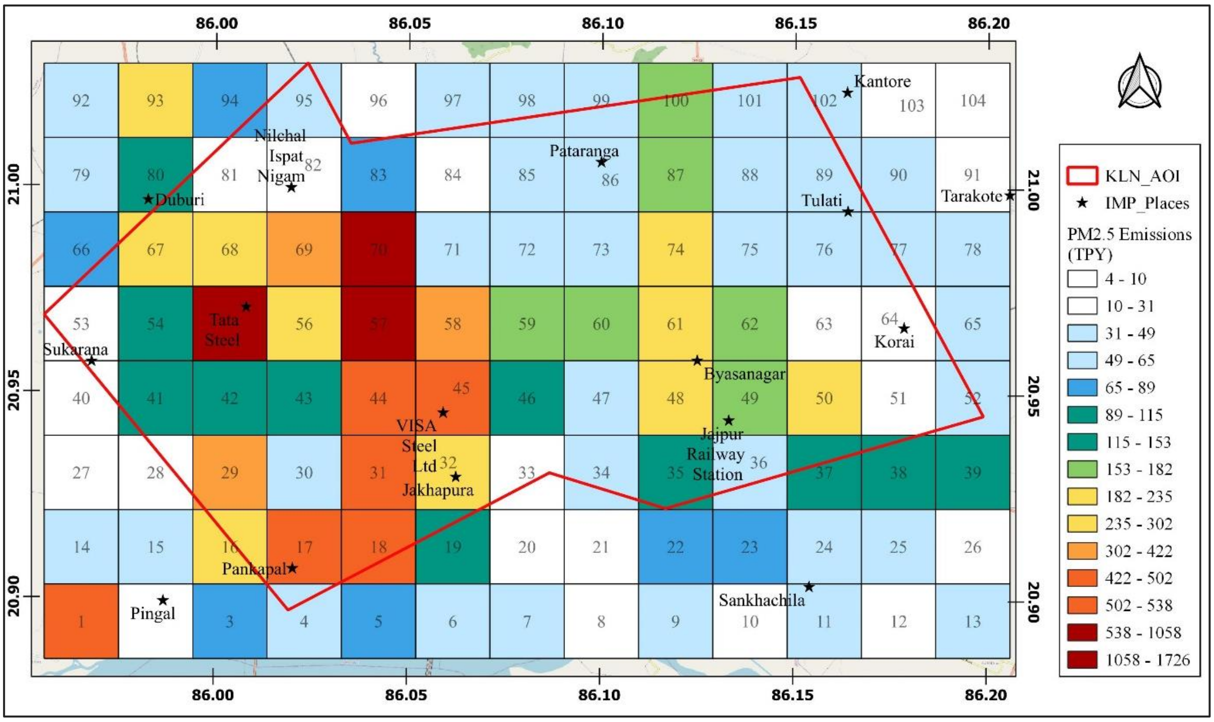
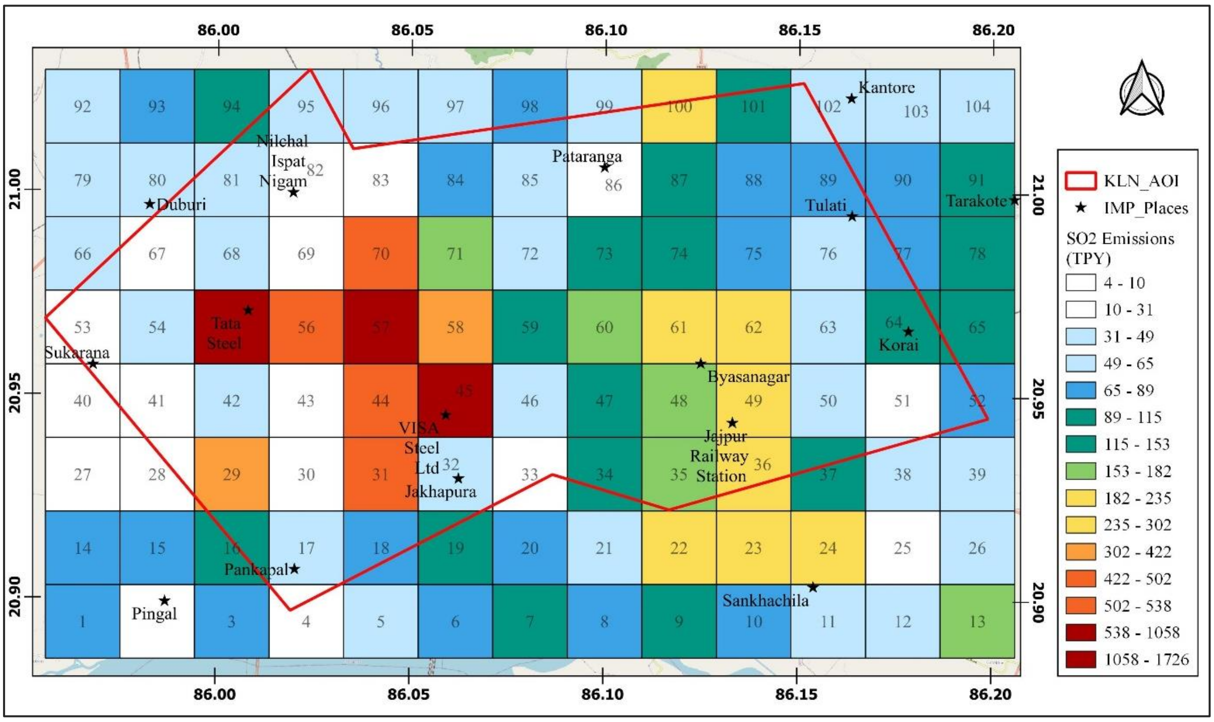


Figure ES-4 Spatial distribution of air pollutant emissions A)** PM_{10}**, B)** $PM_{2.5}$ **(tonnes per year) in Kalinganagar – Jajpur region in 2021.



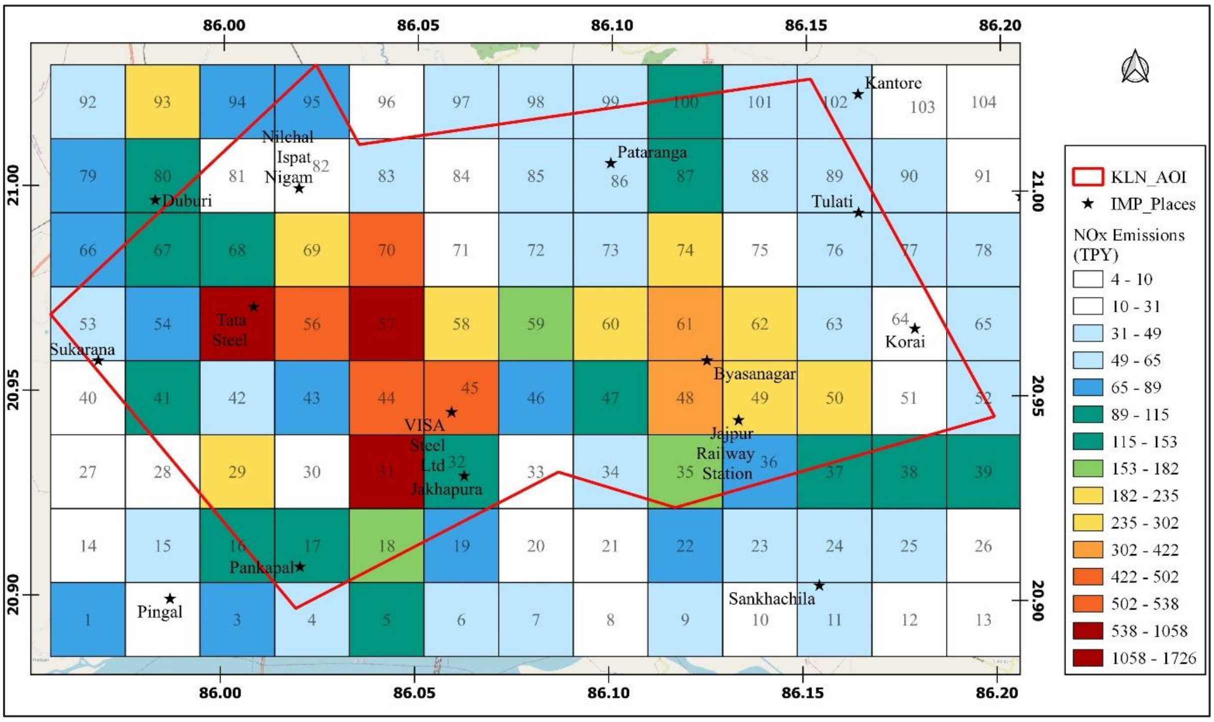


Figure ES-5 Spatial distribution of air pollutant emissions C) SO_2, ***D)*** NO_X ***(tonnes per year) in Kalinganagar – Jajpur region in 2021.***

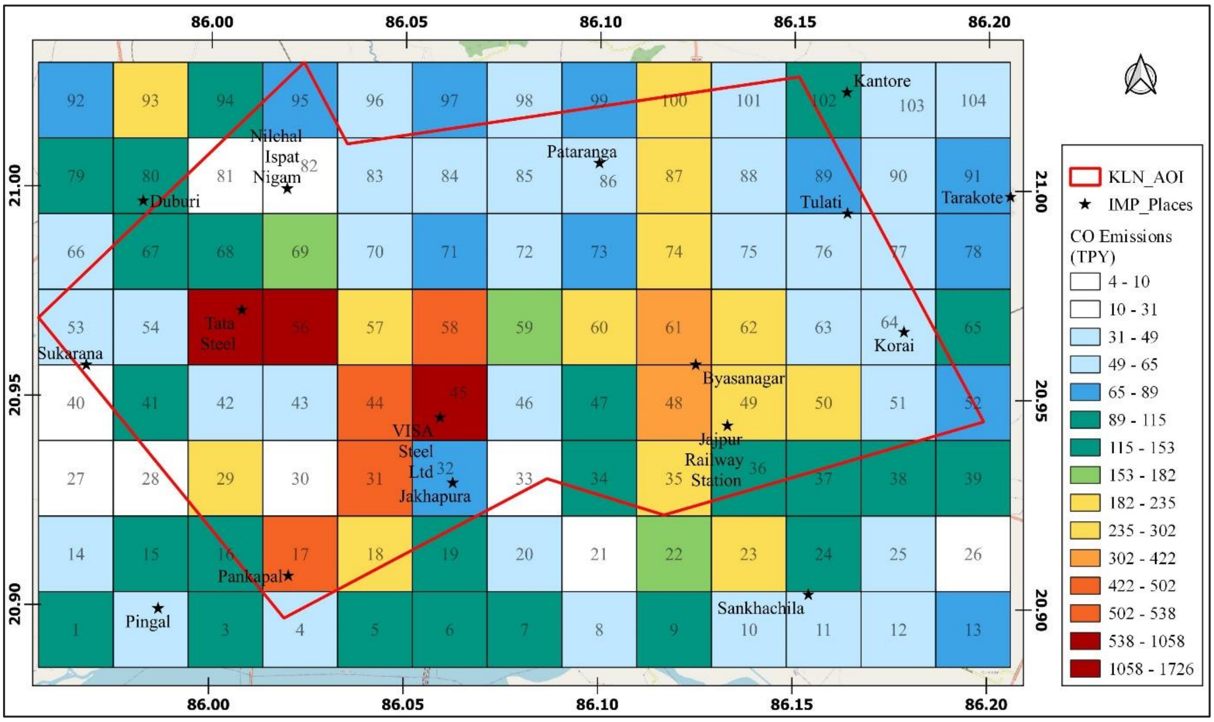


Figure ES-6 Spatial distribution of air pollutant emissions E) CO (tonnes per year) in Kalinganagar – Jajpur region in 2021.

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 and brick kilns. The stack emissions from industries and thermal powerplants, industrial DG sets, and FCBTK brick kilns are modelled as point sources. Industrial fugitive dust sources are modelled as area polygon 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 126 gridded receptors (refer Fig. ES-7). Additionally, four discrete receptors are also configured at ARAI sampling sites locations. The height of each receptor is set to 1.5 m above ground level i.e. mean breathing level for humans. Further, suitable background concentrations are also considered, to reflect the regional-scale contributions from distant sources.

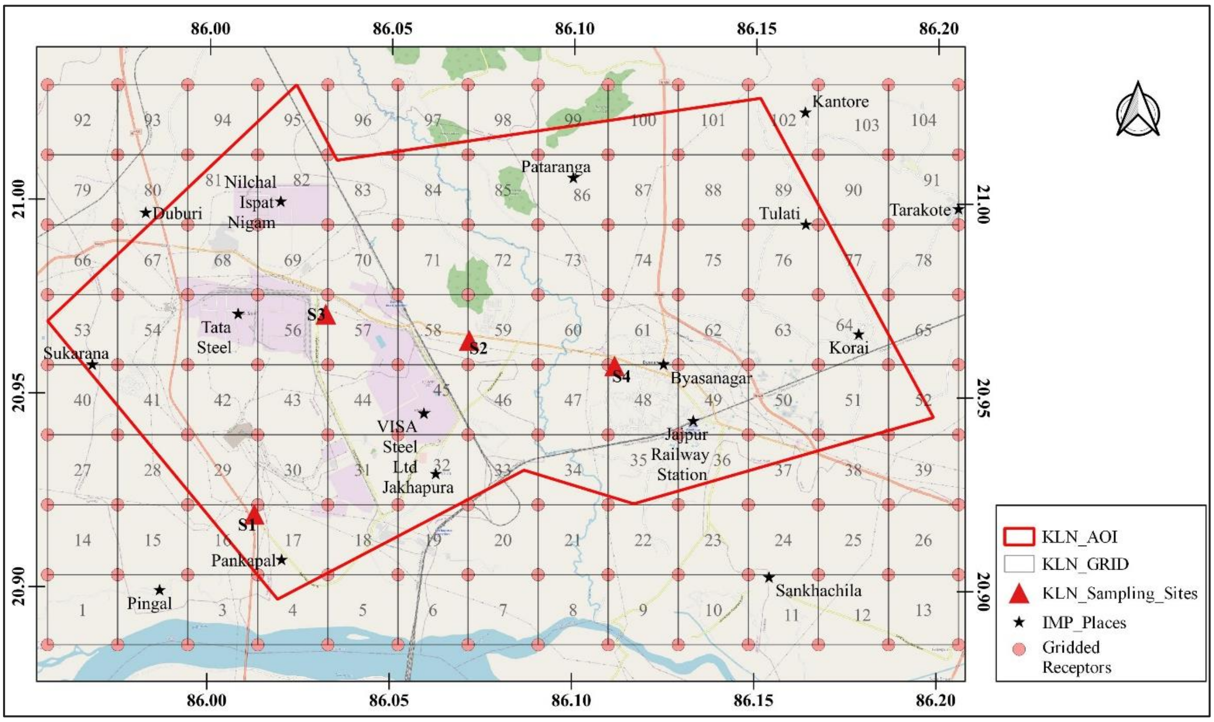
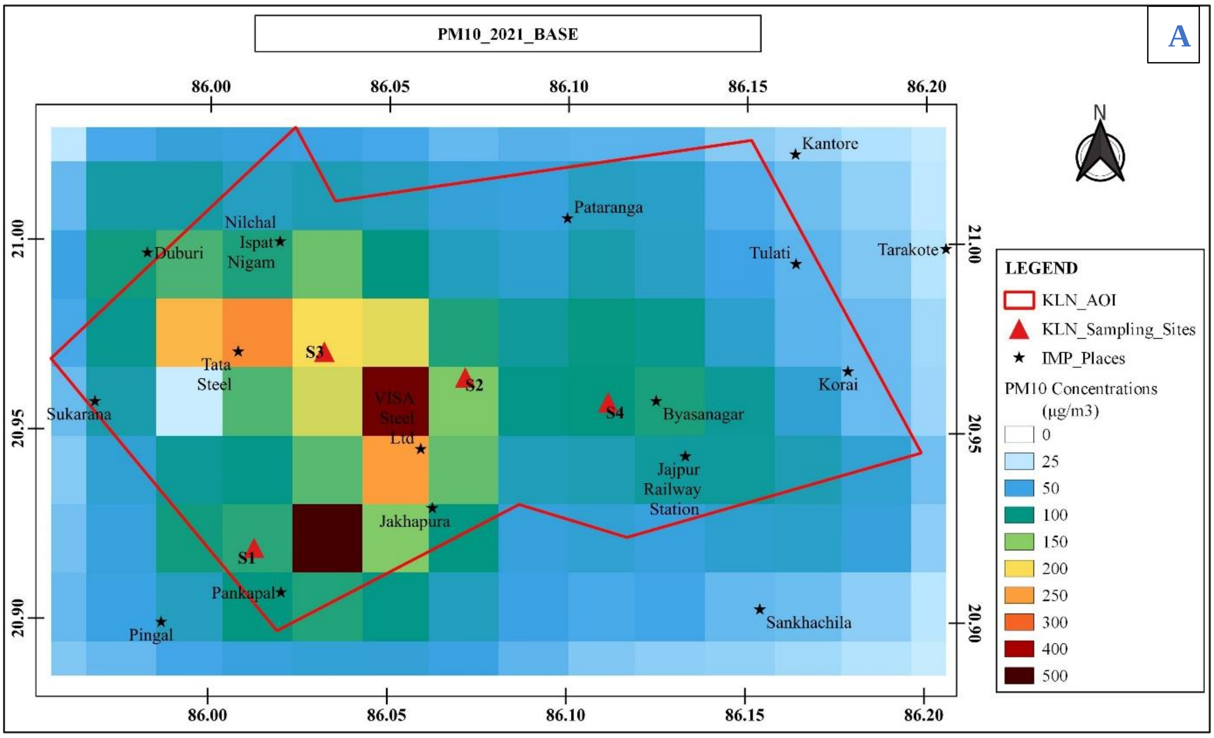


Figure ES-7 Map showing AERMOD modelling domain overlaid by gridded and discrete receptors configured in this study.

In order to validate the dispersion modelling set-up, the AERMOD simulated average concentrations of pollutants including $PM_{2.5}$, PM_{10}, SO_2, and NO_2 are compared against ARAI seasonal observations conducted during the study period. Based on the statistical analysis, the AERMOD model has been found to estimate the pollutant concentrations in Kalinganagar – Jajpur 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.



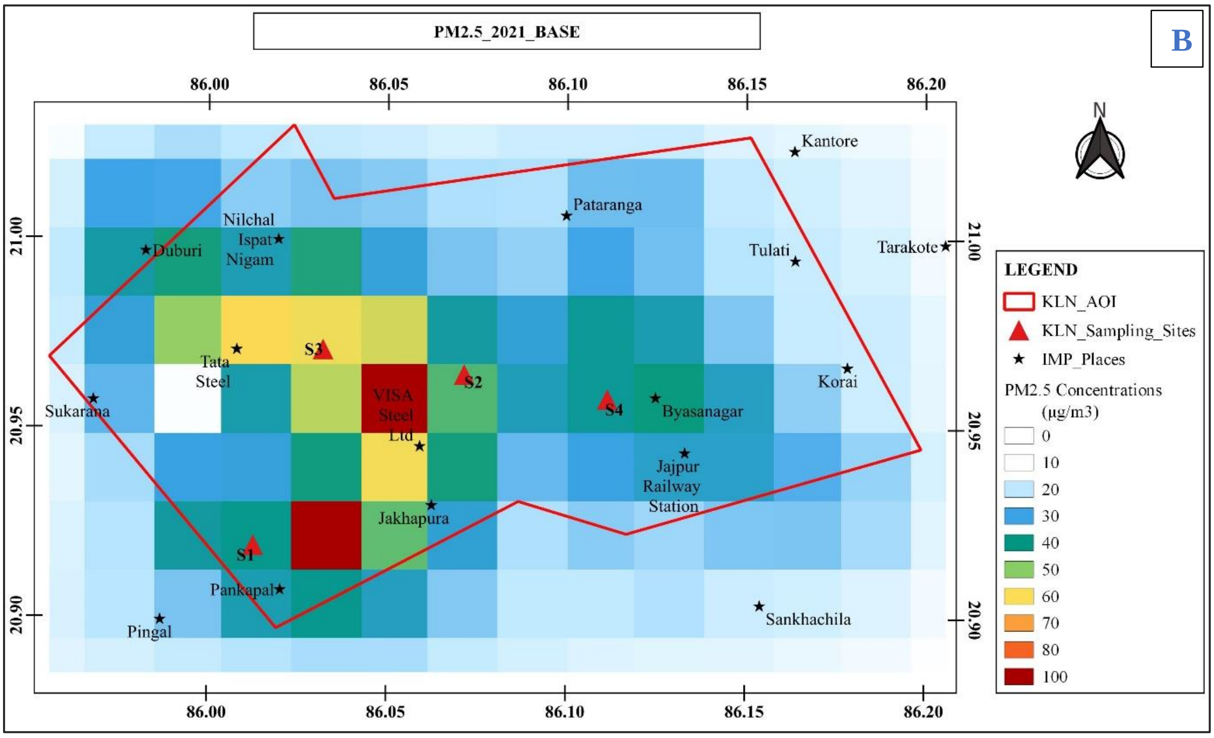


Figure ES-8 Map showing spatial distribution of PM_{10} (A) and $PM_{2.5}$ (B) annual mean concentrations (µg/m^3) over Kalinganagar – Jajpur region for year 2022

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 Kalinganagar – Jajpur 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 already 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 blended 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-3 summarizes the estimated emissions (tonnes per year) of selected pollutants under four scenarios in Kalinganagar – Jajpur region for years 2021, 2026 and 2031.

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

Year	Scenario	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
2021	BASE	16,895	5,539	17,818	15,543	1,05,980
2026	NFC	26,974	8,086	26,727	23,835	1,58,176
	BAU	24,179	7,842	25,378	22,840	1,50,157
	SC_I	21,378	7,065	24,032	21,852	1,42,218
	SC_II	16,282	5,490	20,042	18,880	1,16,562
2031	NFC	38,093	11,405	27,452	24,506	1,59,338
	BAU	29,725	9,201	24,680	22,642	1,43,932
	SC_I	20,797	6,746	20,556	19,387	1,20,355
	SC_II	8,110	3,175	13,736	13,889	82,018

The NFC scenario projections in Kalinganagar - Jajpur region indicate a potential increase in PM_{10} emissions to 26,974 tonnes per year in 2026 i.e. an increase of 59.7% w.r.t. baseline year 2021 and to 38,093 tonnes per year in 2031 i.e. an increase of 125.5% w.r.t. baseline year 2021. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to reach to 8,086 (46.0%) and 11,405 tonnes per year (i.e. 105.9%) in 2026 and 2031, respectively. The BAU projections in Kalinganagar - Jajpur indicate a potential decrease of PM_{10} emissions to 24,179 tonnes per year in 2026 i.e. a decrease of 10.4 % w.r.t. NFC_2026 and to 29,725 tonnes per year in 2031 i.e. a decrease of 22% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 7,842 (-3.0%) and 9,201 tonnes per year (i.e. -19.3%) in 2026 and 2031, respectively.

The SC-I projections in Kalinganagar - Jajpur region indicate a potential decrease of PM_{10} emissions to 21,378 tonnes per year in 2026 i.e. a decrease of 20.7% w.r.t. NFC 2026 and to 20,797 tonnes per year in 2031 i.e. a decrease of -45.4% % w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 7,065 (-12.6%) and 6,746 tonnes per year (i.e. 40.8%) in 2026 and 2031, respectively. The SC-II projections in Kalinganagar - Jajpur region indicate a potential decrease of PM_{10} emissions to 16,282 tonnes per year in 2026 i.e. a decrease of 39.6% w.r.t. NFC 2026 and to 8,110 tonnes per year in 2031 i.e. a decrease of 78.7% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 5,490 (i.e. -32.1%) and 3,175 tonnes per year (i.e. -72.2%) in 2026 and 2031, respectively.

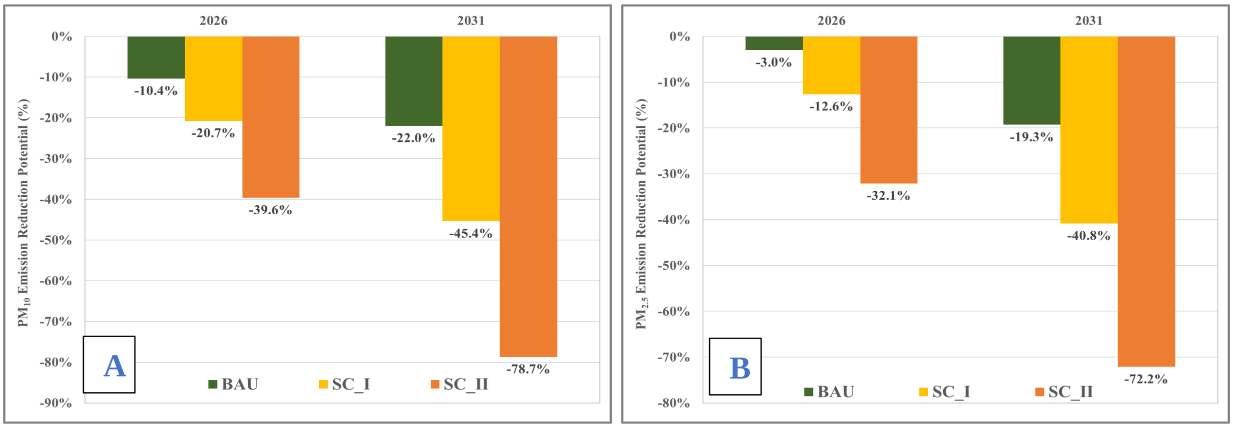


Figure ES-9 Estimated PM_{10} (A) and $PM_{2.5}$ (B) emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

Air quality benefits of four designed scenarios were assessed for years 2026 and 2031 using AERMOD simulated seasonal mean pollutant concentrations in Kalinganagar – Jajpur 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, thermal powerplants 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, an estimated reduction of 9.7%, 19.4%, 34.8% in 2026 and 20.8%, 42.4%, 73.2% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively. In case of $PM_{2.5}$, with implementation of control measures considered in different scenarios, an estimated reduction of 8.4%, 16.8%, and 30.5% in 2026 and 18.6%, 37.9%, and 65.5% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

This study also extracted location -specific air quality benefits due to implementation of different scenarios in 2026 and 2031. Four representative locations, i.e. ARAI sampling locations, were selected to understand the impact of controls measures on air quality. Table ES-4 presents the Percentage change in predicted ambient air quality concentrations, w.r.t.

corresponding NFC scenarios in 2026 and 2031 at Byasnagar location in Kalinganagar – Jajpur region.

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

Year/Scenario	2026			2031		
Pollutant	**BAU**	**SC-I**	**SC-II**	**BAU**	**SC-I**	**SC-II**
PM_{10}	-10.2%	-20.4%	-34.0%	-21.0%	-43.0%	-75.1%
$PM_{2.5}$	-9.0%	-17.8%	-29.9%	-19.4%	-39.6%	-69.1%
SO_2	-5.1%	-9.8%	-17.9%	-10.9%	-22.9%	-36.5%
NO_2	0.1%	-0.1%	-0.5%	5.3%	2.9%	-3.4%
CO	-1.9%	-3.4%	-7.2%	-0.1%	-4.9%	-13.2%

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 31% and 18% in 2026 and 2031, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 33% and 25% in 2026 and 2031, respectively under BAU scenario, to 40% and 35% in 2026 and 2031, respectively under SC-I, to 52% and 92% in 2026 and 2031, respectively under SC-II scenario.

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Kalinganagar – Jajpur 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 concentrations by 40% by the year 2026, as compared to 2017 i.e. base year.

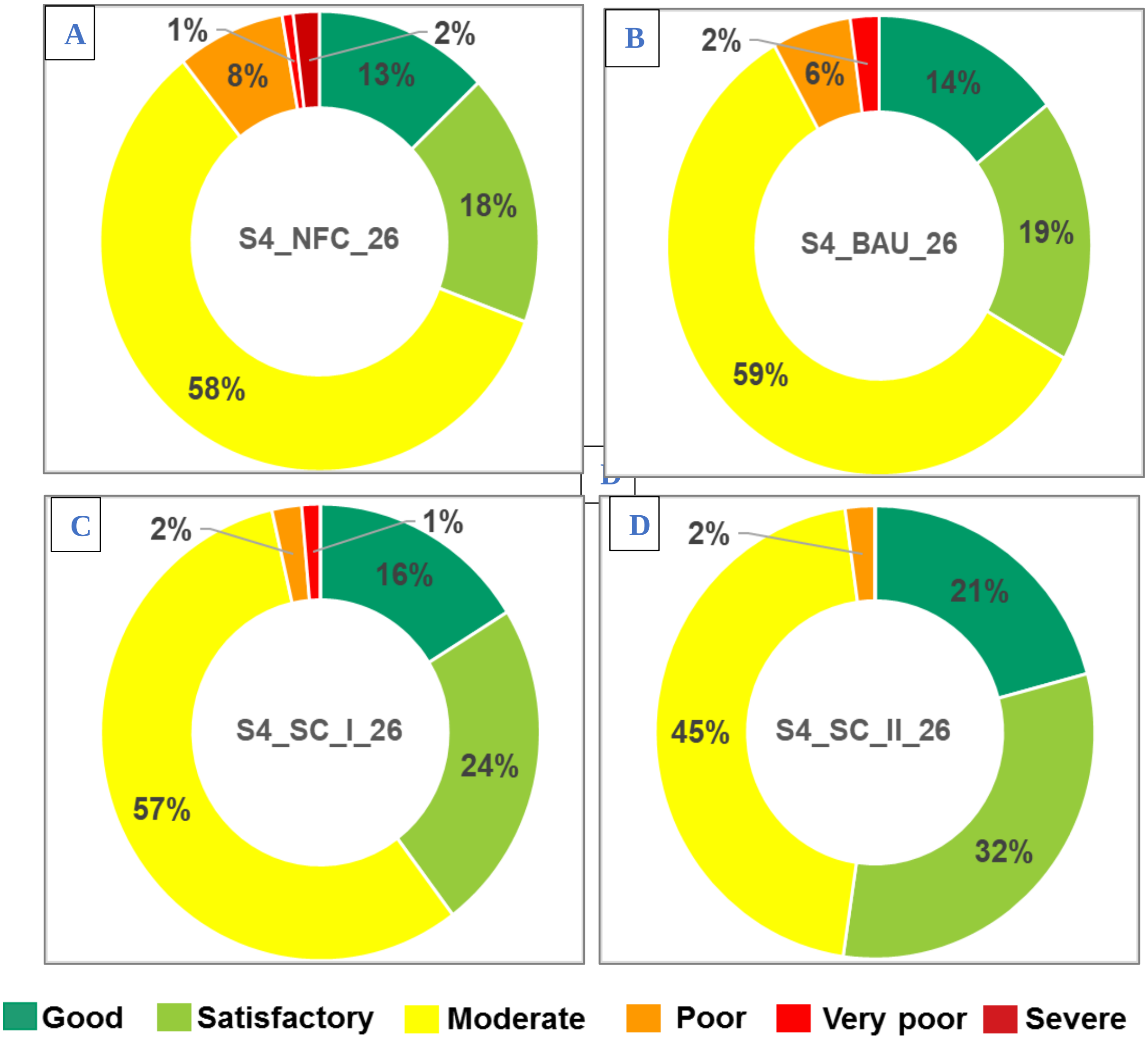


Figure ES-10 Distribution of six AQI categories at Byasnagar location in Kalinganagar – Jajpur region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2026

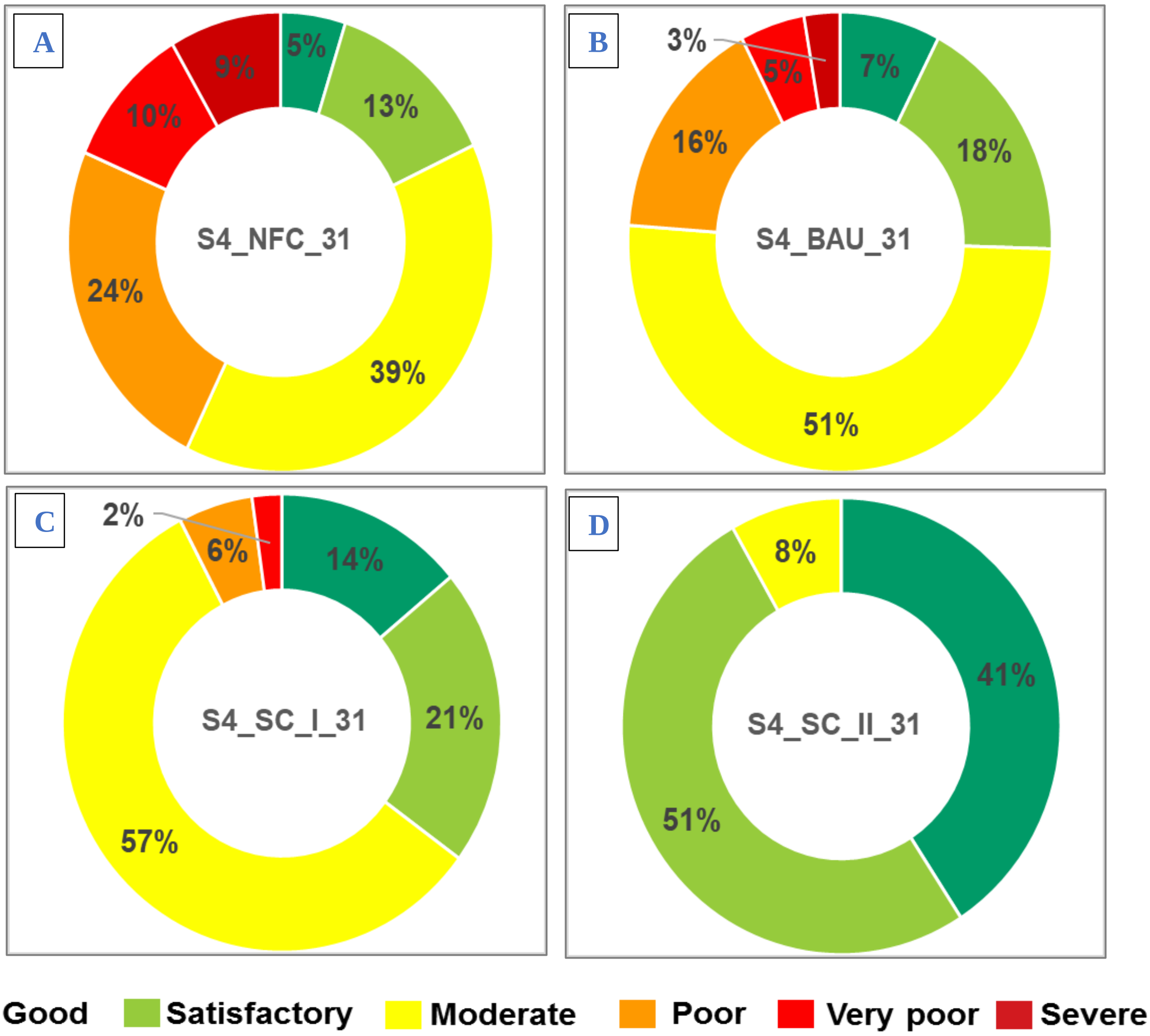


Figure ES-11 Distribution of six AQI categories at Byasnagar location in Kalinganagar – Jajpur region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2031

Clean Air Action Plan

Table ES-5 presents the proposed air quality action plan for Kalinganagar – Jajpur region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

Table ES-5 Proposed Air quality action plan for Kalinganagar – Jajpur Region

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Transport	**A) Management**		
	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 kerbside, especially small ones to avoid traffic congestions.	RTO	Immediate
	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.	Municipality / RTO	6 months
	Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses).	Municipality	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	Municipality	1 -2 years
	Declare NO-vehicle zones in hot-spots, university / school premises.	Municipality / University / School	6 months
	Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO	Immediate
	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.	Municipality/ Local Govt. Body	6 months

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	B) Technology		
	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	1 year
	Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Oil Companies/ GAIL / State Government	3 years
	The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	Municipality/ Local Govt. Body, Government Offices	3 years
	Encouraging EV adoption for personal and commercial vehicles through incentivisation or tax relaxation.	State Government, RTO	3 years
Road Dust	End-to-end paving of roads along with black-topping and maintaining potholes free roads.	PWD / Municipality/ Local Govt. Body	Immediate / Continuous
	Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / Municipality/ Local Govt. Body	Immediate / Continuous
	Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / Municipality/ Local Govt. Body	Immediate / Continuous
	Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	Municipality/ Local Govt. Body	Immediate / Continuous
	Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	Municipality/ Local Govt. Body	6 months
	All the canals/nallah's side roads should be concrete / brick lined.	Municipality/ Local Govt. Body	1 year
	Regular cleaning of roads and water spraying to suppress the dust. Remove road dust/silt regularly by using mechanical sweepers.	Municipality/ Local Govt. Body	Immediate / Continuous

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Identify road stretches with high dust generation and use Foggers to supress the dust.	Municipality/ Local Govt. Body	6 months
	Greening of traffic corridors, open areas, gardens, community places, schools and housing societies	Municipality/ Local Govt. Body	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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	• 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	

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Iron and Steel Industry: • Use of desulphurized coal • 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	OSPCB	1 years
	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	OSPCB	2 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	• 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) • 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%.	Municipality/ Local Govt. Body	1 year
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	Municipality/ Local Govt. Body	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, Municipality/ Local Govt. Body	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	Municipality/ Local Govt. Body	Immediate / Continuous
	Encouraging the reduce, recycle and reuse policy for waste in city	Municipality/ Local Govt. Body / 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.	Municipality/ Local Govt. Body	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	Municipality/ Local Govt. Body	1 year
	Reduce the VKT of waste collection vehicles with route optimisation technique.	Municipality/ Local Govt. Body	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	Municipality/ Local Govt. Body / OSPCB	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Strict enforcement of CPCB guidelines for construction activity such as use of green screens, side covering of digging sites, etc.	Municipality/ Local Govt. Body / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	Municipality/ Local Govt. Body / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	Municipality/ Local Govt. Body	Immediate
	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	Municipality/ Local Govt. Body / OSPCB	Immediate
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	Municipality/ Local Govt. Body / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	Municipality/ Local Govt. Body / 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.	Municipality/ Local Govt. Body	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.	Municipality/ Local Govt. Body	Immediate
	Mandatory use of RMC plants at large construction sites and preparation of guidelines for dust control measures for operation of RMC plants.	Municipality/ Local Govt. Body / 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	Municipality/ Local Govt. Body / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	Municipality/ Local Govt. Body	6 months

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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	Municipality/ Local Govt. Body / State Government	5 years
	Leverage rooftop solar programme to reduce dependence on DG sets.	Municipality/ Local Govt. Body	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	Municipality/ Local Govt. Body, 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	Municipality/ Local Govt. Body	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.	Municipality/ Local Govt. Body / OSPCB	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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	Municipality/ Local Govt. Body / 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.	Municipality/ Local Govt. Body	1 year
Public Awareness	Launch Public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicle, lane discipline, etc.	Municipality/ Local Govt. Body, OSPCB, NGOs	Immediate
	Encourage the use of public transport for daily commute.	Municipality/ Local Govt. Body, 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	Municipality/ Local Govt. Body, OSPCB, NGOs	Immediate
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	Municipality/ Local Govt. Body	1 year
CAAQMS	Increase the number of air quality monitoring stations	OSPCB	1 -2 year

----X----

[THIS PAGE INTENTIONALLY LEFT BLANK]

Contents

[THIS PAGE INTENTIONALLY LEFT BLANK]

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 earlier/original targets were recently revised to achieve reductions up to 40% of PM_{10} concentrations by 2025-26 (MoEFCC, 2023). 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)

Seven cities including Angul, Balasore, Bhubaneswar, Cuttack, Rourkela, Talcher, Kalinga Nagar 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 Kalinganagar-Jajpur Region in Odisha".

1.2. Brief Description of the study area

Kalinga Nagar – Jajpur region, located at approximately 20.8833° N latitude and 86.0833° E longitude in the Jajpur district of Odisha, India, is a prominent industrial hub known for its significant contributions to the steel and metal industries. Established as a major industrial area, it houses numerous steel plants, including those of Tata Steel and Jindal Stainless Steel, and plays a vital role in the region's economic development. Kalinga Nagar – Jajpur region stands as a testament to Odisha's industrial prowess and its strategic importance in India's manufacturing sector.

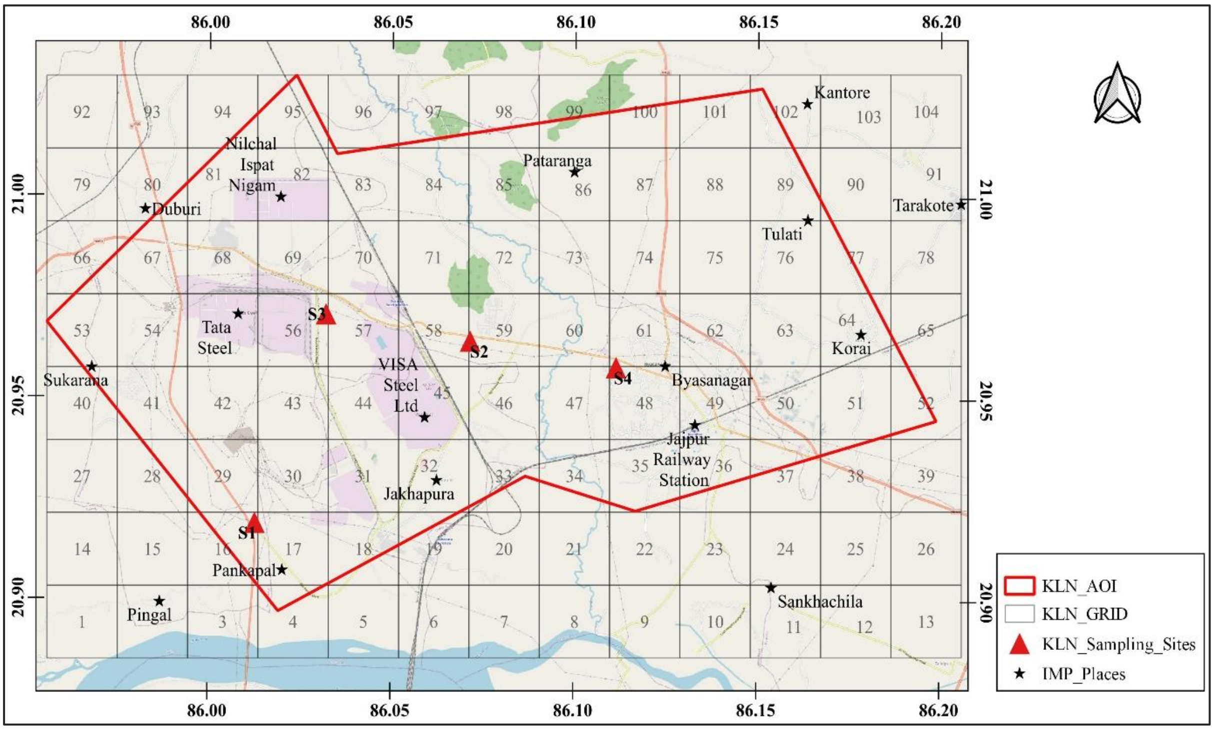


Figure 2 Map showing study area i.e. Kalinganagar region

1.2.1. Geography

Kalinganagar - Jajpur region is located in the Jajpur district of Odisha at a mean elevation of about 51 meters above mean sea level. It is important to note that, the study area for this study extends beyond the municipal limits of Byasanagar municipality and covers an area of 458.78 sq. km. 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

Kalinganagar-jajpur, located in the coastal state of Odisha, experiences a tropical climate with distinct wet and dry seasons throughout the year. Kalinganagar - Jajpur experiences a hot and humid climate during the majority of the year, with the monsoon season bringing substantial rainfall. These weather conditions contribute to the region's agricultural productivity and industrial activities.

1.2.3. Demography

According to Census of India 2011, the total population of Kalinganagar - Jajpur town was 49,415. 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 of the study area in year 2011 was about 2.4 lakhs. 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 2,55,876 for year 2021. Fig. 3 shows the gridded population of the study area for year 2021.

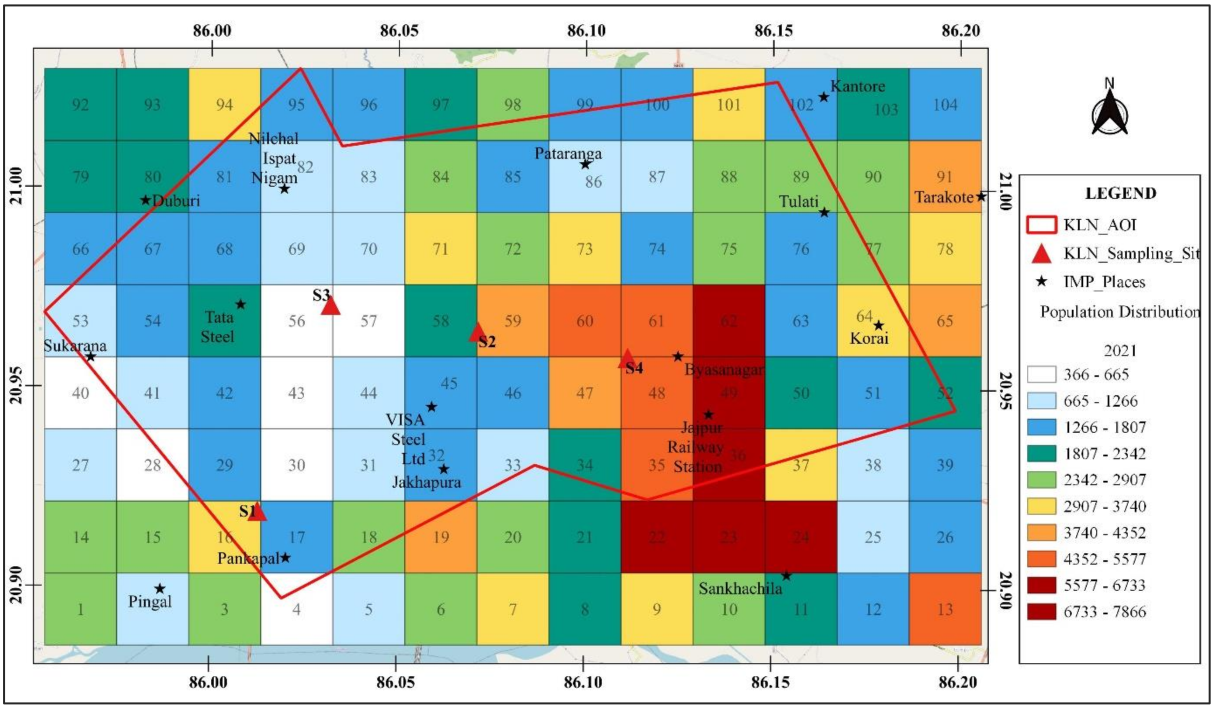


Figure 3: The estimated gridded population of the study area for year 2021.

1.3. Objectives of the Project

The main aim of this study is to identify and characterize various emission sources in Kalinganagar - Jajpur 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 Kalinganagar - Jajpur region.

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

1.4. Scope of Work

1.1. Sampling of Particulate Matter (PM_{10} & $PM_{2.5}$) using speciation samplers at identified sites (4 locations in Kalinganagar - Jajpur region). Sampling (24 hrs) for minimum 15 days at each location in 2 critical seasons i.e. winter and summer. Additionally, sampling and analysis for SO_2, NO_2, Benzene, Toulene, Ethyl Benzene and Xylene 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 Kalinganagar – Jajpur 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. 4) and (B) top-down or receptor model-based approach (Fig. 5).

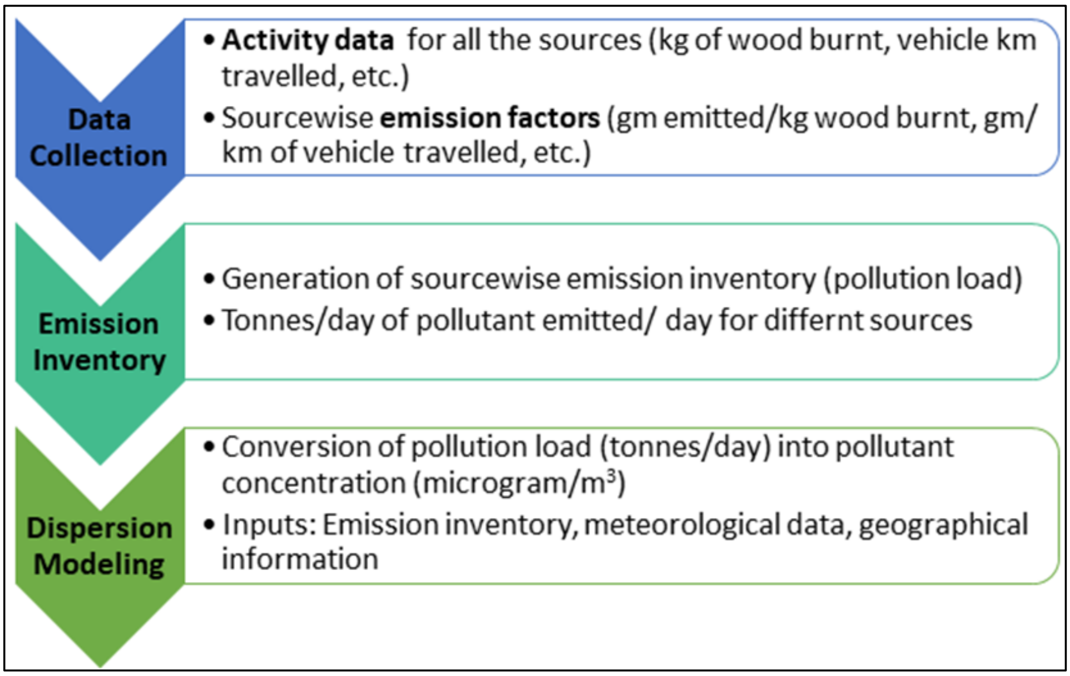


Figure 4 Bottom-up approach for Particulate Matter Source Apportionment

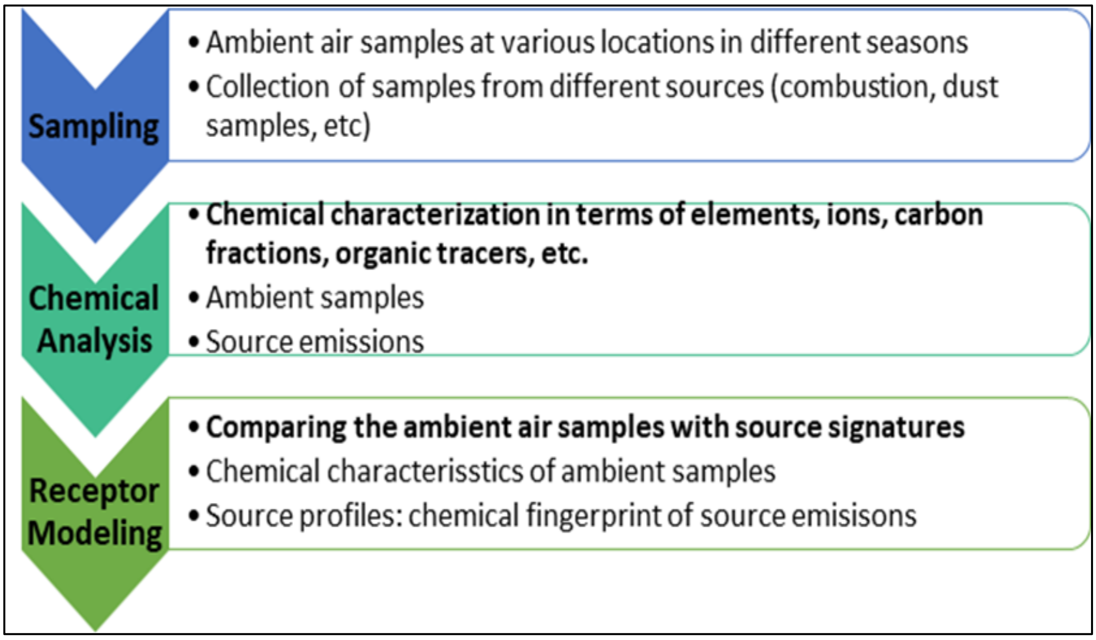


Figure 5 Top-down approach for Particulate Matter Source Apportionment

The bottom-up approach includes identification of air pollution sources and their emission strengths using activity data and available emission factors (Fig. 4). 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. 5). These two approaches and their inter-relations are described in a step-wise manner in the following sections.

Fig. 6 illustrates the details of the integrated approach, combining the two approaches described above, adopted for Emission Inventory and Source Apportionment study of Kalinganagar - Jajpur 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 four 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 Kalinganagar – Jajpur 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.

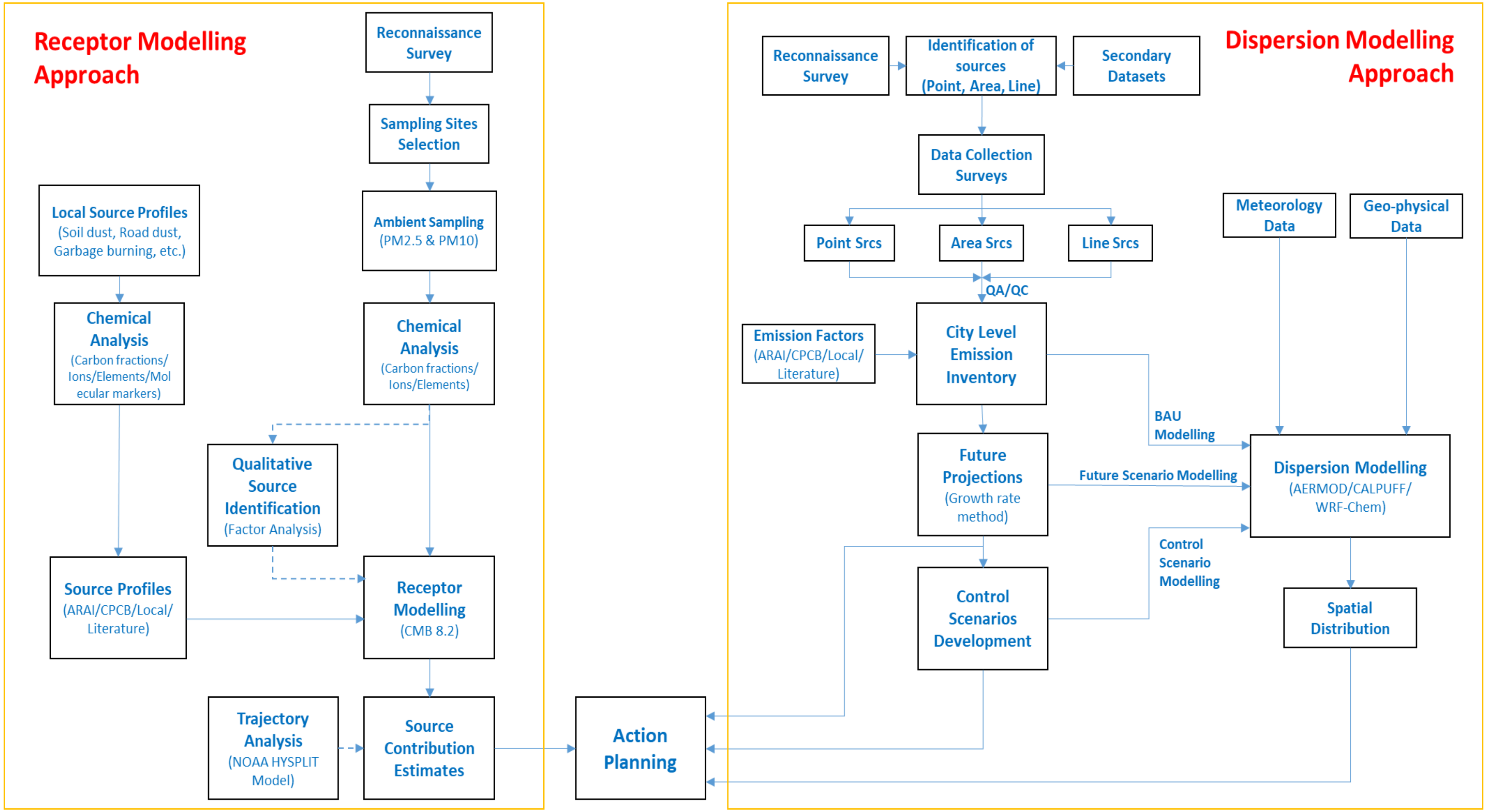


Figure 6 Framework for integrated emission inventory and source apportionment study of Kalinganagar - Jajpur region in Odisha

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 1 to 20, 2022 and summer season i.e. April 22 to May 14, 2022 at 4 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) four sampling locations are identified for this study in Kalinganagar - Jajpur region. Figure 7 and Table 1, show the geographic distribution and details of the sampling sites, respectively. The sites include 1 background site, 2 residential sites, and 1 industrial site. These sites are located in different parts of the study domain and can provide integrated insights into the characteristic of $PM_{2.5}$ and PM_{10} over Kalinganagar-Jajpur. For example, the residential sites, such as those at Tehsil office (S2) and RO office (S4), are surrounded by typical residential areas with low and middle-to-high income group households, respectively. The background site such as JCDL (S1), is located in natural habitat, which are slightly away from anthropogenic emissions and are less influenced by human activities. The other site i.e. TATA Steel (S3) typically represents the industrial site.

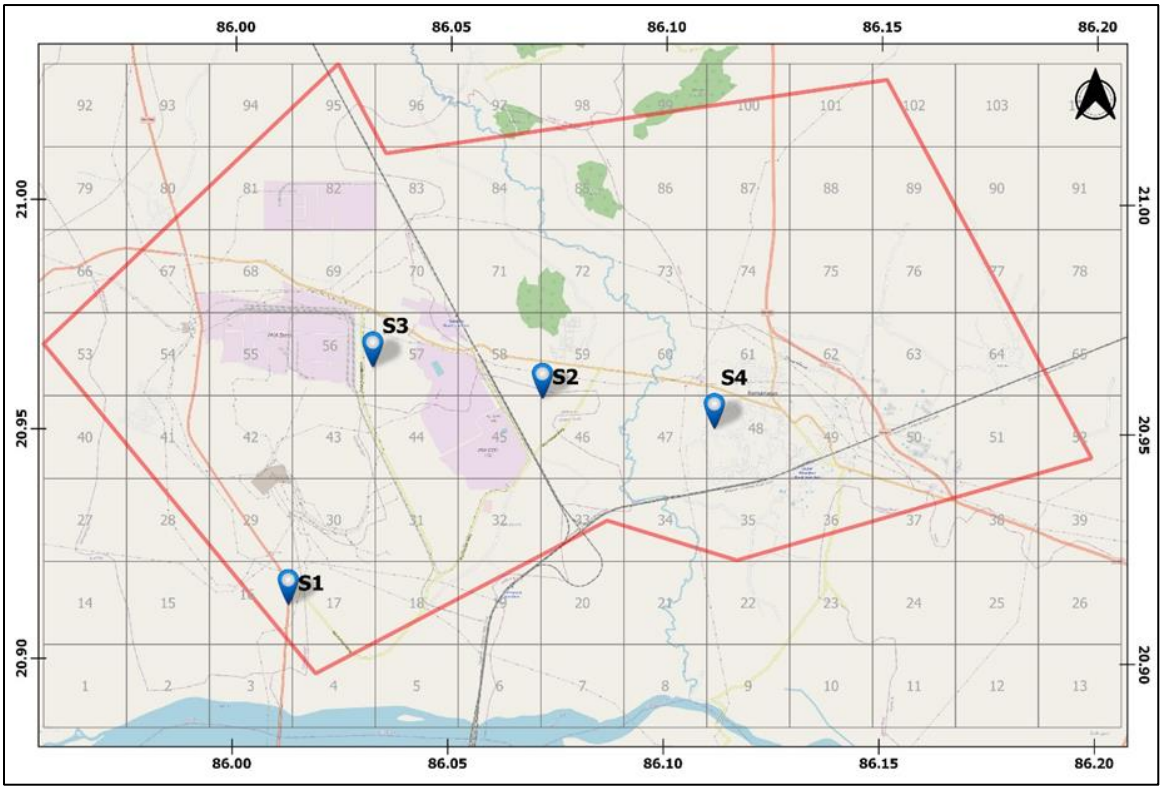


Figure 7 Kalinganagar - Jajpur region map showing location of four sampling sites selected for source apportionment study

Table 1 Geographic information of the selected sampling sites in Kalinganagar - Jajpur region

Code	Location	Latitude	Longitude	Category
S1	JCDL	20° 55' 6.74" N	86° 0' 47.45" E	Background
S2	Tehsil Office	20° 57' 0.18" N	86° 7' 43.10" E	Residential (LIG) + Others
S3	TATA Steel	20° 59' 49.47" N	86° 1' 55.27" E	Industrial
S4	RO Office	20° 55' 8.72" N	86° 0' 46.30" E	Residential (MIG+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. 8, the winter season sampling was conducted at identified locations from January 01 to 20, 2022 while summer season sampling was conducted from April 22 to May 14, 2022.

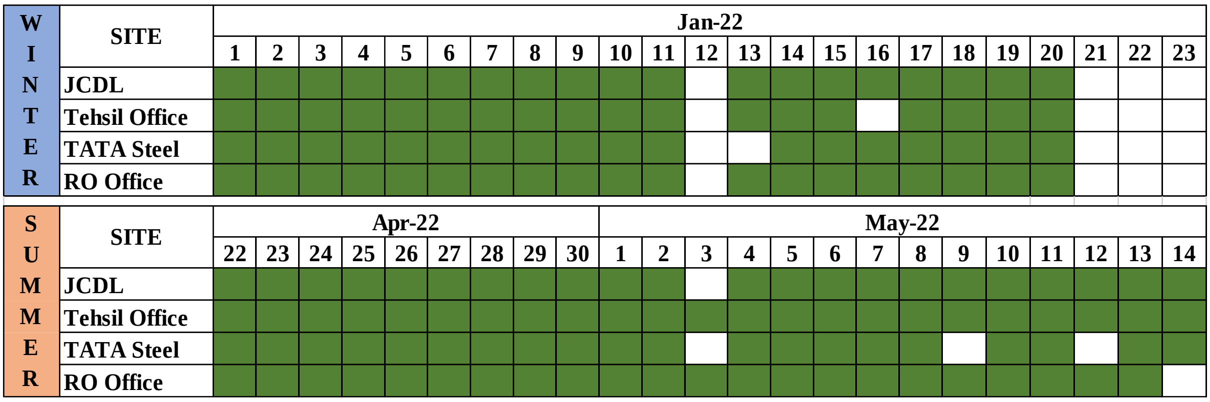


Figure 8 The sampling schedule for collection of PM samples during winter and summer seasons in Kalinganagar - Jajpur region

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 and molecular markers including alkanes, hopanes, amides, levoglucosan and stigmasterol. 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 Kalinganagar - Jajpur region. The details of the instrumental techniques utilized for analysing PM are given below.

2.2.4.1. 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.

2.2.4.2. 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.

2.2.4.3. 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.

2.2.4.4. Molecular Markers

After the carbon analysis, remaining PM samples on quartz filters were used for molecular marker analysis. For analysis of molecular markers, the daily PM samples were extracted together, to form composite samples and have sufficient mass to represent the whole monitoring period. Prior to analysis, composite samples were extracted by Soxhlet extraction with 1:1 dichloromethane: acetone solvent mixture for a period of 16 hrs. The extracts were evaporated to 4 ml by using a Kuderna-Danish apparatus. Gas chromatography – mass spectrometry (GC-MS) system (GC-MS Make; Thermofisher Scientific) with TB5 column was used for quantitative determination of 55 molecular marker species, including n-Heptane, n-Octane, n-Nonane, n-Decane, n-Undecane, n-Dodecane, n-Tridecane, n-Tetradecane, n-Hexadecane, n-Pentadecane, n-Heptadecane, n-Octadecane, n-Nonadecane, n-Eicosane, n-Heneicosane, n-Docasane, n-Tricosane, n-Tetracosane, n-Pentacosane, n-Hexacosane, n-Heptacosane, n-Octacosane, Nonacosane, n-Tricontane, n-Hentriacontane, n-Dotriacontane, n-Tritriacontane, n-Tetracontane, n-Pentatriacontane, n-Hexatriacontane, Heptatriacontane, Octatriacontane, Nonatriacontane, n-Tetracontane, Naphthalene, Acenaphthalene, Acenaphthene , Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo(e)pyrene, Benzo[a]pyrene Perylene, Indeno[1,2,3,-cd]pyrene, Dibenz[a,h]anthracene, Benzo[g,h,i]perylene, Hexadecanamide, Octadecanamide, Levoglucosan, Stigmasterol. A five-point calibration curve in SIM mode was obtained for determining concentrations of the molecular markers in the particulate samples. All the molecular markers are identified by comparing retention times and mass spectra with the calibration standards and National Institute of Standards and Technology (NIST) spectral reference library. The molecular markers were first identified by comparing the retention time with standards within a window of ± 0.1 min, secondly the quantification ions, and finally the particular ratios of several relatively abundant ions.

2.2.5. Gases and Volatile Organic Compounds (VOCs)

As described in the Scope of Work section, in addition to particulate matter the present study also analysed the levels of gaseous pollutants such as SO_2 and NO_2 and Volatile Organic Compounds (VOCs) such as Benzene, Toluene, Ethyl Benzene and Xylene, during winter season only. This section explains the details of sampling and chemical analysis methodology followed.

The gaseous samples for ambient SO_2 and NO_2 determination, were collected at four sampling sites, on daily basis during the winter season sampling period i.e. January 1 – 20, 2022. The samples were collected by sampling for 24-hours, at a flowrate of 0.2 LPM, in two separate impingers containing appropriate absorbing solutions for SO_2 and NO_2. The ambient SO_2 and NO_2 concentrations were determined in the laboratory following the procedure prescribed in Indian standard IS:5182, 2001, RA 2017, part 2 and 6, respectively.

For determination of Volatile Organic Compounds (VOCs) in the ambient air, the grab samples were collected, at four sampling sites, in Tenax sorbent tubes (Make; Markes International) for 15 minutes at a flow rate of 3 LPM. Before sampling, these sorbent tubes were pre-conditioned at 320°C and screened for contamination. To prevent contamination during shipping, the conditioned tubes are sealed with brass storage caps. The quantitative analysis of benzene, toluene, ethylbenzene and xylene (BTEX), collected using Tenax sorbent tubes, was carried out by Gas chromatography – mass spectrometry method (GC-MS, Make; Thermofisher Scientific, TD make; Markes International). A three-point calibration curve was obtained for determining concentrations of BTEX in full scan mode. BTEX compounds were identified by comparing retention time with standards and National Institute of Standards and Technology (NIST) spectral reference library.

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):

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

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):

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

The chemical reconstruction method explained above was applied to all 4 sites over Kalinganagar - Jajpur region 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 Kalinganagar - Jajpur 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.

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

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. 9, presents the distribution of daily $PM_{2.5}$ and PM_{10} concentrations observed at four sampling locations in Kalinganagar - Jajpur region during the winter season i.e. January 1 – 20, 2022. The mean $PM_{2.5}$ and PM_{10} mass concentrations during the entire sampling period over all sites were 64.2 and 171.2 µg/m^3, respectively. The mean $PM_{2.5}$ concentrations exhibited a 3-fold range and ranged from a minimum of 33.4 µg/m^3 (at JCDL i.e. S1) to a maximum of 105.9 µg/m^3 (at Tehsil Office i.e. S2). Similarly, the mean PM_{10} concentrations exhibited a 5-fold range and ranged from 67.8 µg/m^3 (at RO Office i.e. S4) to 309.7 µg/m^3 (at JCDL i.e. S1). 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 (53 to 72% of sampling days) with minimum exceedance at RO Office i.e. S4 (53%) and maximum exceedance at JCDL i.e. S1 (72%). The daily averaged PM_{10} concentrations exceeded the NAAQS limit at all sites (82-94% of sampling days) with minimum exceedance at RO Office i.e. S4 (82%) and maximum exceedance at JCDL (S1) and Tehsil Office (S2) violated the PM_{10} limit value for all sampling days (94%) during winter season.

2.6.1.2. Spatial variability

The highest seasonal mean $PM_{2.5}$ concentrations were observed at JCDL i.e. S1 (65.5 µg/m^3) while the lowest were recorded at Tata Steel i.e. S3 (64.2 µg/m^3). These two locations also reported the highest and lowest variability in daily $PM_{2.5}$ concentrations, respectively. For example, daily $PM_{2.5}$ concentrations ranged from 33.4 to 99.4 µg/m^3 at JCDL i.e. S1 while it ranged from 39.6 to 100.5 µg/m^3 at TATA Steel i.e. S3.

The highest seasonal mean PM_{10} concentrations were observed at JCDL i.e. S1 (213.9 µg/m^3) while the lowest were recorded at RO Office i.e. S4 (127.5 µg/m^3). The daily PM_{10} concentrations showed highest and lowest variability at JCDL i.e. S1 and TATA Steel i.e. S3 sites, respectively. For example, daily PM_{10} concentrations ranged from a minimum of 97.2 to a maximum of 309.7 µg/m^3 at JCDL i.e. S1 while it ranged between 73.5 and 261.8 µg/m^3 at TATA Steel i.e. S3.

These concentration levels can be attributed to air polluting activities around each site. For example, TATA Steel i.e. S3 is located in the Industrial area. 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.

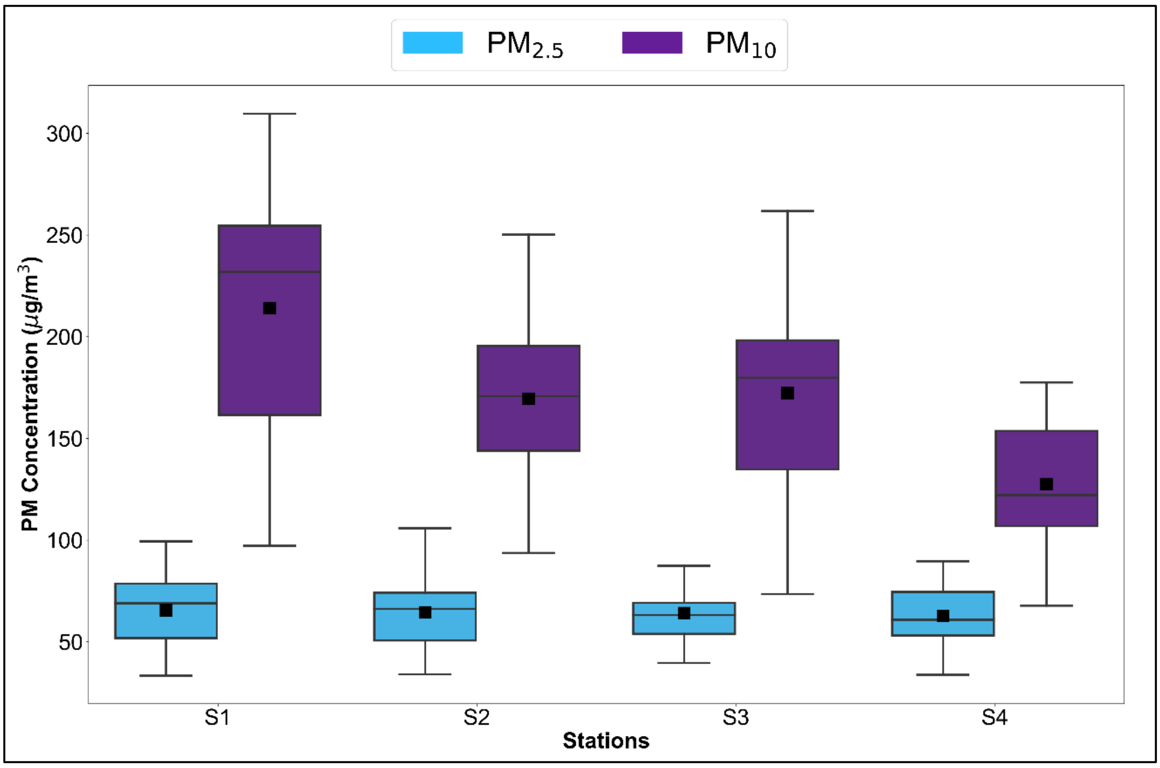


Figure 9 Boxplot showing distribution of daily** $PM_{2.5}$ **(blue colored boxes) and** PM_{10} **(violet colored boxes) concentrations observed at four sampling sites in Kalinganagar - Jajpur region during the winter season sampling period (January 1 – 20, 20222).

Note: Each box represents: mean (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. 10 shows daily time-series of $PM_{2.5}$ and PM_{10} observed at four selected sampling locations in Kalinganagar - Jajpur region during the winter season sampling period. Only valid samples between January 1 – 20, 20222 are considered for this analysis. Overall, the PM concentrations showed an increasing trend from January 1 – 20, 20222 at all sites. This could be attributed to the meteorological conditions over Kalinganagar - Jajpur region during the winter season.

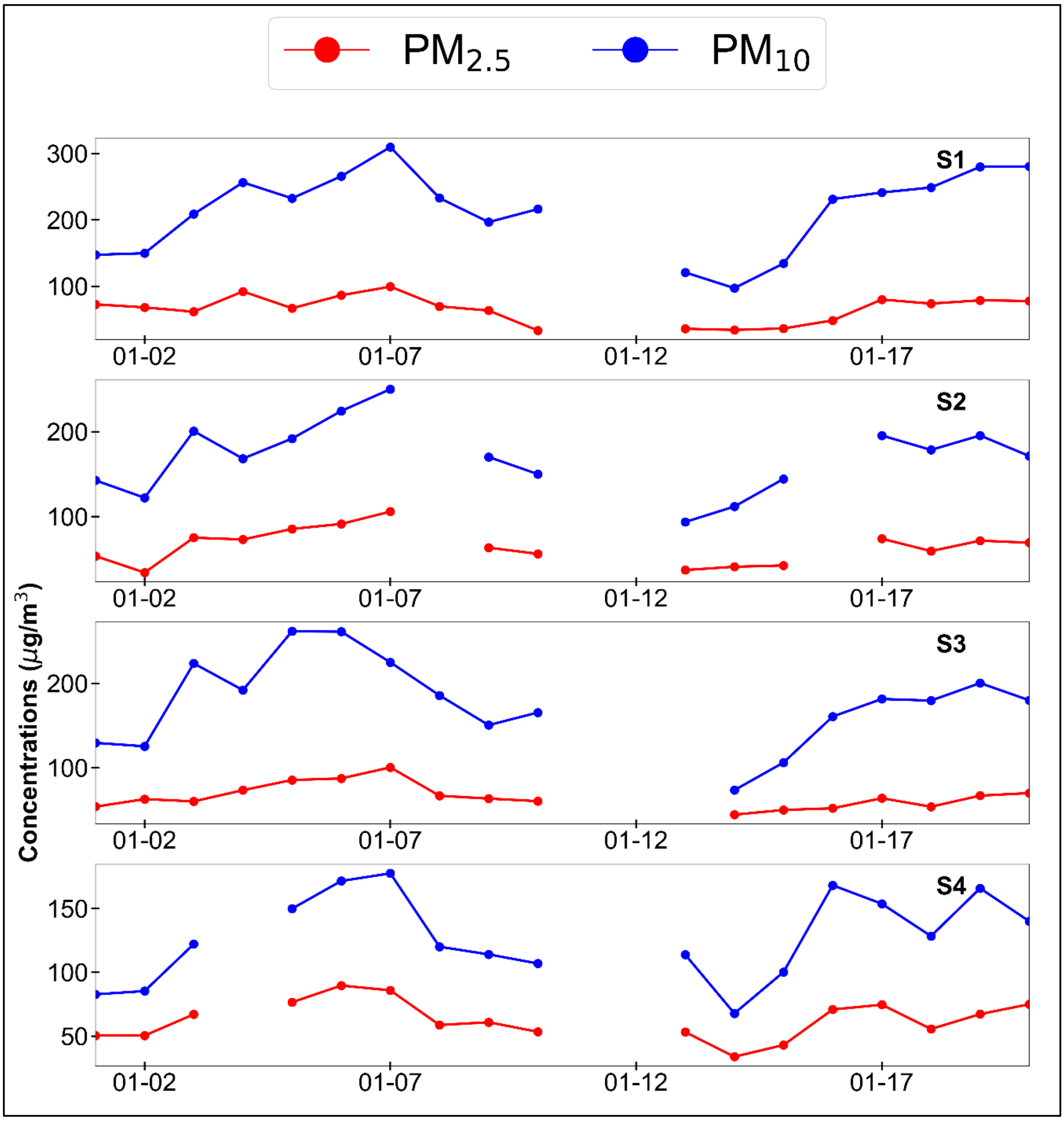


Figure 10 Daily time-series of $PM_{2.5}$ *(red) and* PM_{10} *(blue) concentrations observed at four sites in Kalinganagar - Jajpur region during the winter season sampling (January 1 – 20, 20222)*

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

Fig. 11 shows distribution of daily $PM_{2.5}$ to PM_{10} ratios observed at four sampling sites during the winter season. The mean value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.39, varying from 0.15 to 0.61. The highest winter season mean $PM_{2.5}$ to PM_{10} ratio was observed at RO Office i.e. S4 (0.61) while the lowest was observed at JCDL i.e. S1 (0.15). 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.

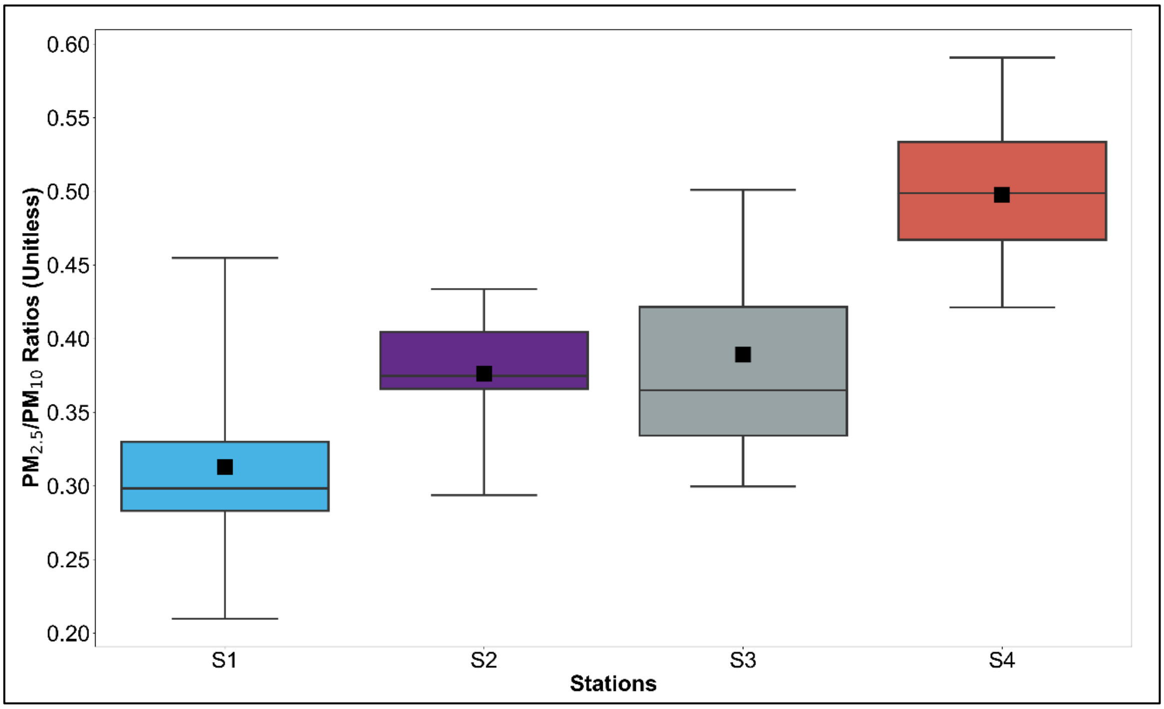


Figure 11 Boxplot showing distribution of** $PM_{2.5}$ **to** PM_{10} **ratios at four sampling sites in Kalinganagar - Jajpur region during the winter season (January 1 – 20, 20222)

Note: Each box represents: mean (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: JCDL (S1)

Fig. 12 shows the frequency distribution of different species observed in $PM_{2.5}$ and PM_{10} at JCDL i.e. S1 in Kalinganagar - Jajpur region during the winter season. OC, EC, and SO4-- 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.

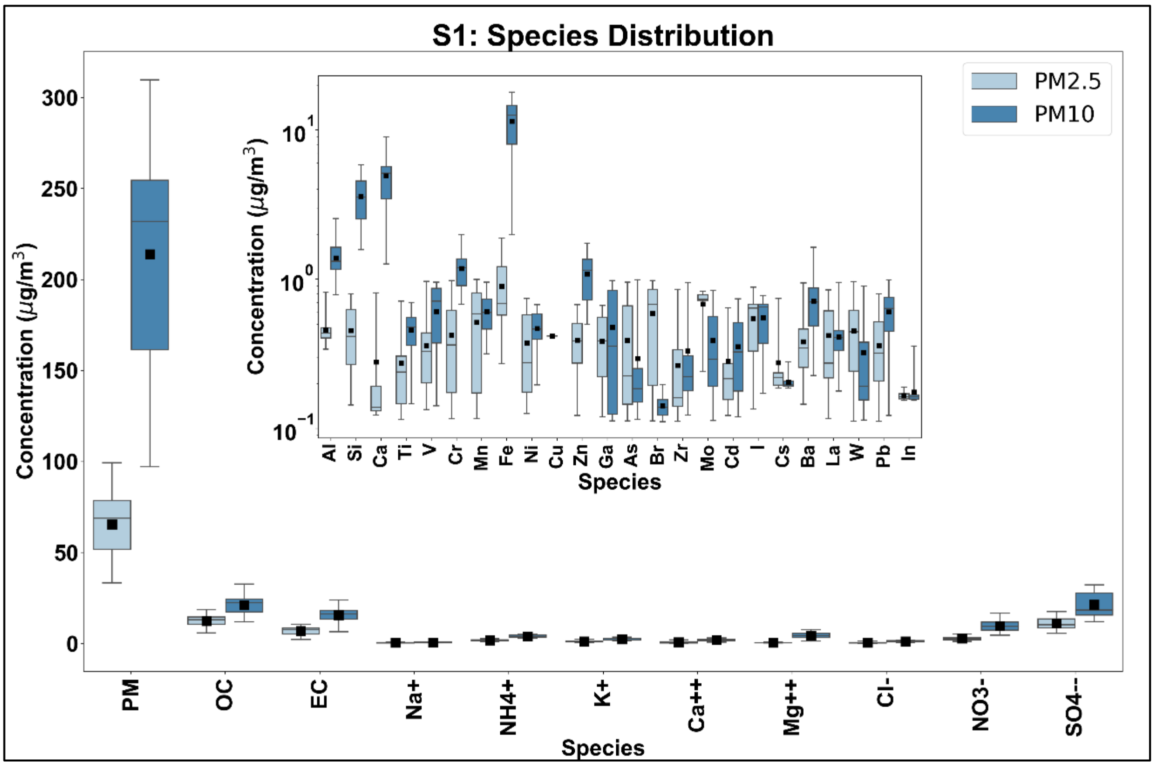


Figure 12 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at JCDL (S1) in Kalinganagar - Jajpur region during the winter season*

Note: Each box represents: mean (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: Tehsil Office (S2)

Fig. 13 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions (Na+, NH4+, K+, Ca2+, Mg2+, Cl-, NO3-, and SO4--) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in $PM_{2.5}$ and PM_{10} observed at Tehsil Office Site (S2) during winter season (January 1-20, 2022). OC, EC, and SO4-- in $PM_{2.5}$ and OC, EC, NH4+, NO3-, SO4--, 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.

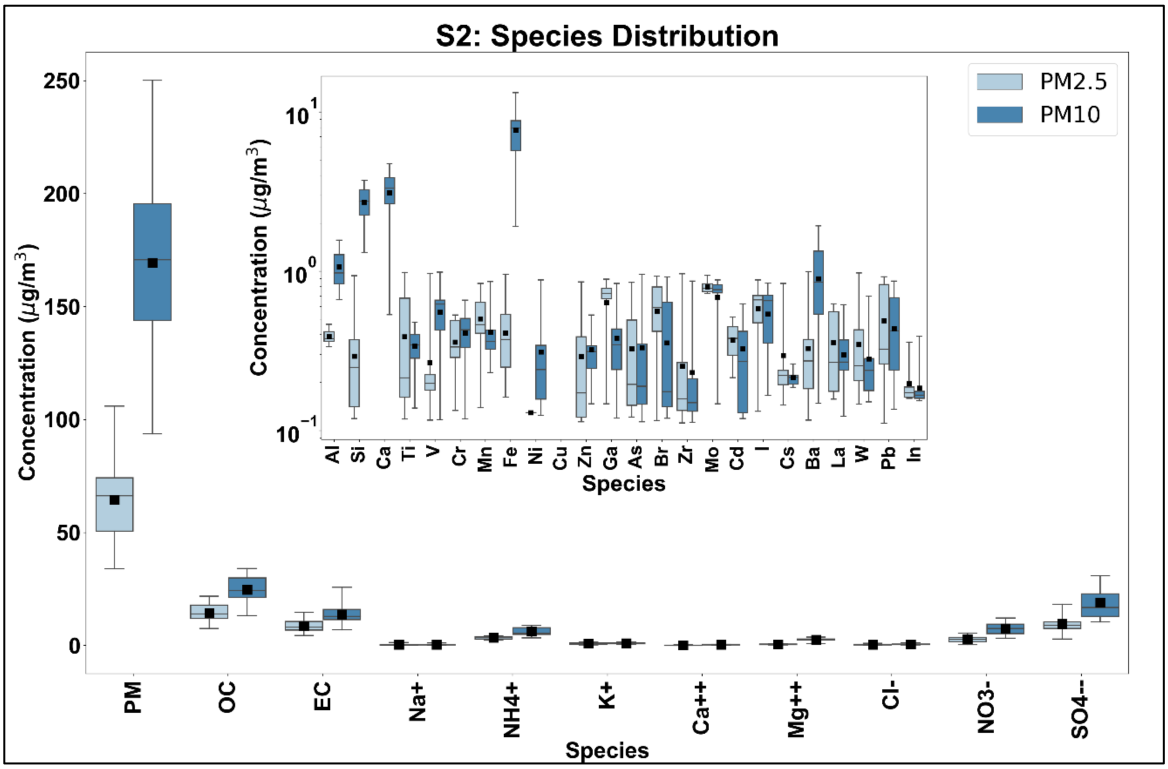


Figure 13 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at Tehsil Office (S2) in Kalinganagar - Jajpur region during the winter season*

Note: Each box represents: mean (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: TATA Steel (S3)

Fig. 14 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na+, NH4+, K+, Ca2+, Mg2+, Cl-, NO3-, and SO4--) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in $PM_{2.5}$ and PM_{10} observed at TATA Steel site (S3) during winter season (January 1-20, 2022). OC, EC, and SO4-- in $PM_{2.5}$ and OC, EC, NO3-, SO4-- 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.

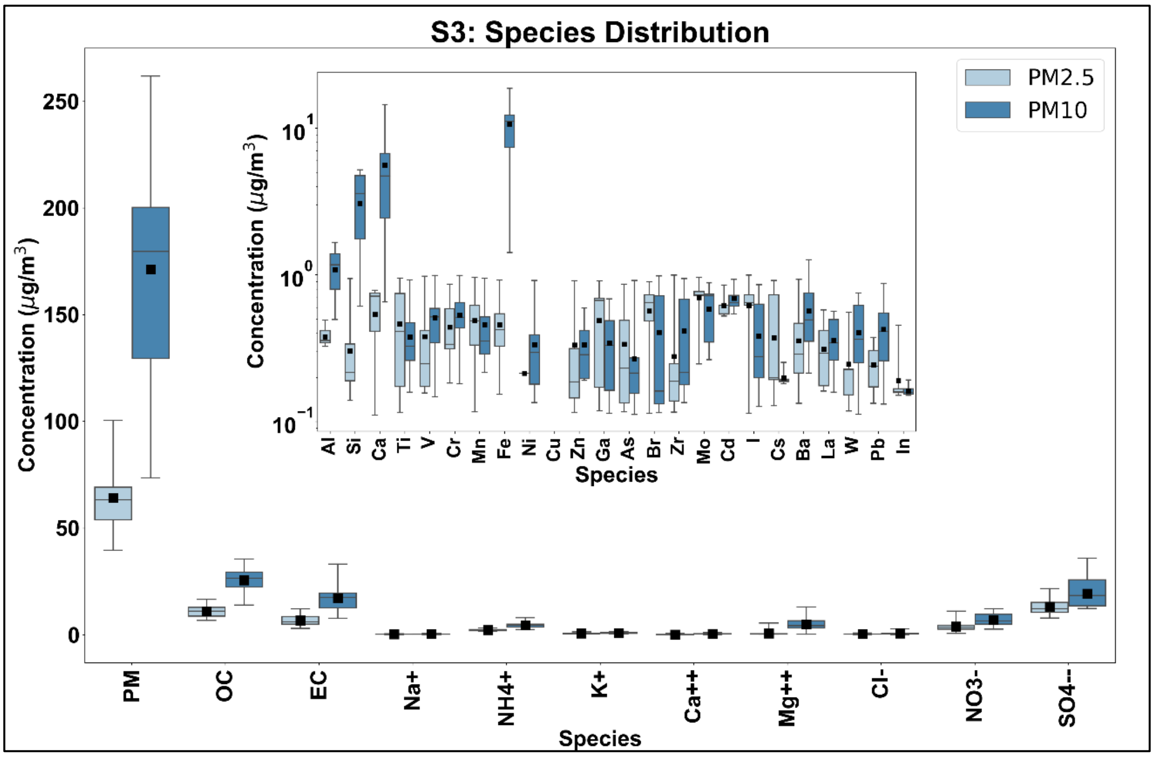


Figure 14 Box plots showing distribution of different species observed in $PM_{2.5}$ ***and*** PM_{10} ***at TATA Steel (S3) in Kalinganagar - Jajpur region during the winter season***

Note: Each box represents: mean (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: RO Office (S4)

Fig. 15 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na+, NH4+, K+, Ca2+, Mg2+, Cl-, NO3-, and SO4--) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in $PM_{2.5}$ and PM_{10} observed at RO Office site (S4) during winter season (January 1-20, 2022). OC, EC, and SO4-- 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.

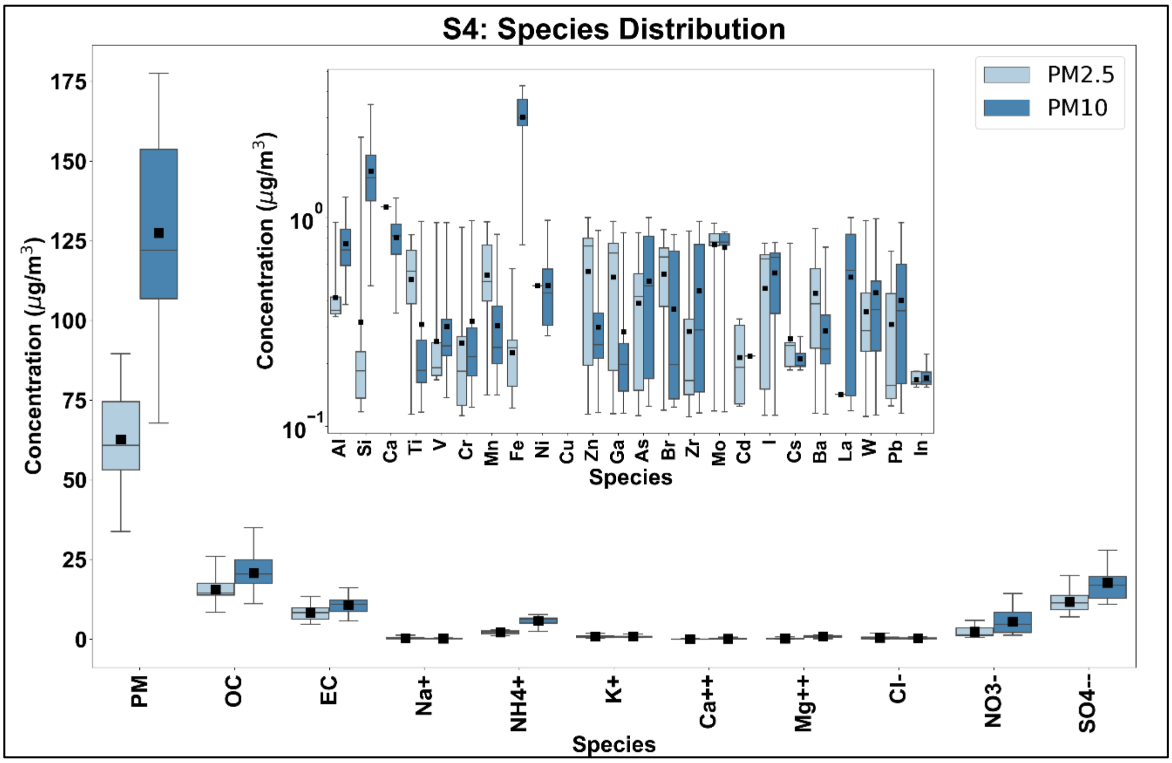


Figure 15 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at RO Office (S4) in Kalinganagar - Jajpur region during the winter season*

Note: Each box represents: mean (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

2.6.1.6. Molecular Markers in $PM_{2.5}$ and PM_{10}

Fig. 16 and 17, represents the seasonal mean concentrations of molecular markers observed at four sampling locations in Kalinganagar - Jajpur region, during the winter season sampling period i.e. January 1-20, 2022. Alkane group and levoglucosan are found to dominate the molecular markers mass, during the winter season over Kalinganagar - Jajpur region. Amides, which are considered as tracers for biomass burning emissions (CPCB, 2010), are also detected in significant amounts, in PM samples collected over Kalinganagar - Jajpur region during winter season.

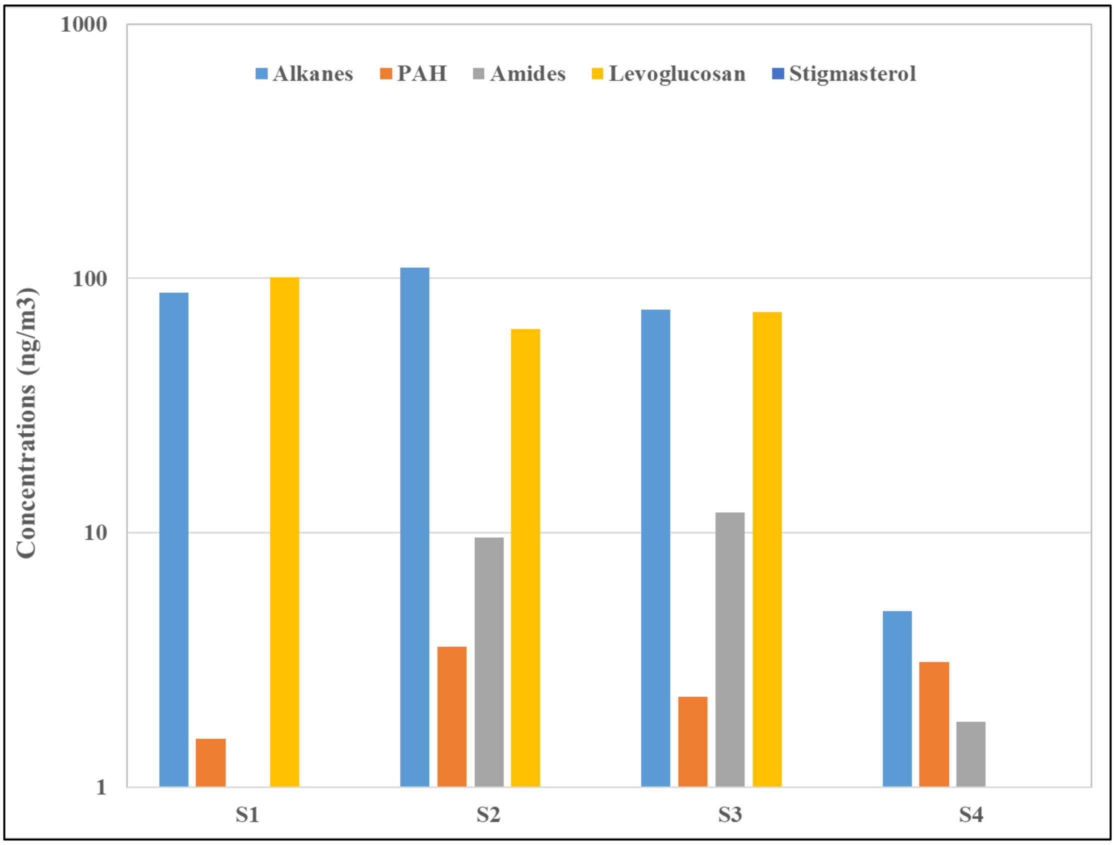


Figure 16: The seasonal mean concentrations of molecular marker species in $PM_{2.5}$ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Kalinganagar - Jajpur region during the winter season sampling period (January 1-20, 2022).

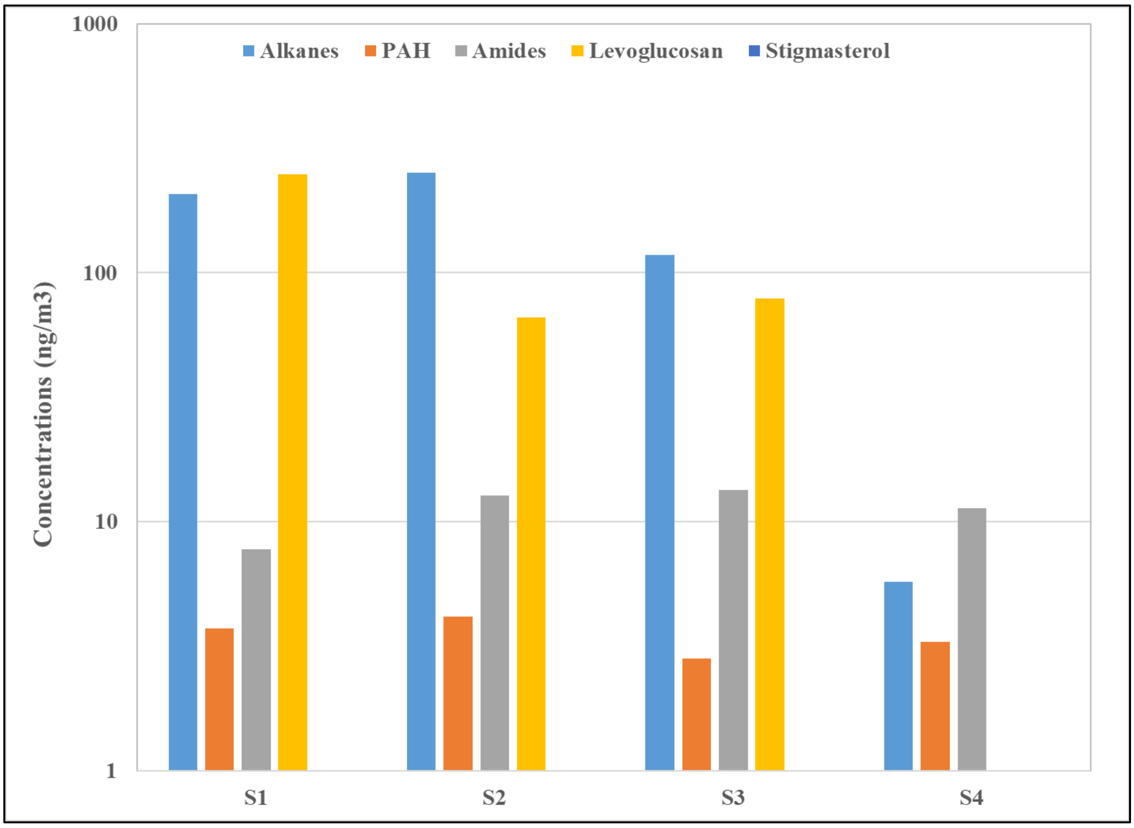


Figure 17: The seasonal mean concentrations of molecular marker species in PM_{10} ***(grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Kalinganagar - Jajpur region during the winter season sampling period (January 1-20, 2022).***

2.6.1.7. Gaseous pollutants and VOCs

Fig. 18, represents the seasonal mean concentrations of gaseous pollutants i.e. SO_2 and NO_2 observed at four sampling locations in Kalinganagar - Jajpur region, during the winter season sampling period i.e. January 1-20, 2022.

The winter season mean concentrations of SO_2 are observed to be 6.3 µg/m^3 at JCDL (S1), 12.7 µg/m^3 at Tehsil Office (S2), 9.5 µg/m^3 at Tata Steel (S3). SO_2 concentrations were less than 5 µg/m^3 at RO Office (S4) and hence are not reported. Similarly, the winter season mean concentrations of NO_2 are observed to be 12.3 µg/m^3 at JCDL (S1), 15.2 µg/m^3 at Tehsil Office (S2), 19.7 µg/m^3 at Tata Steel (S3) and 11.2 µg/m^3 at RO Office (S4).

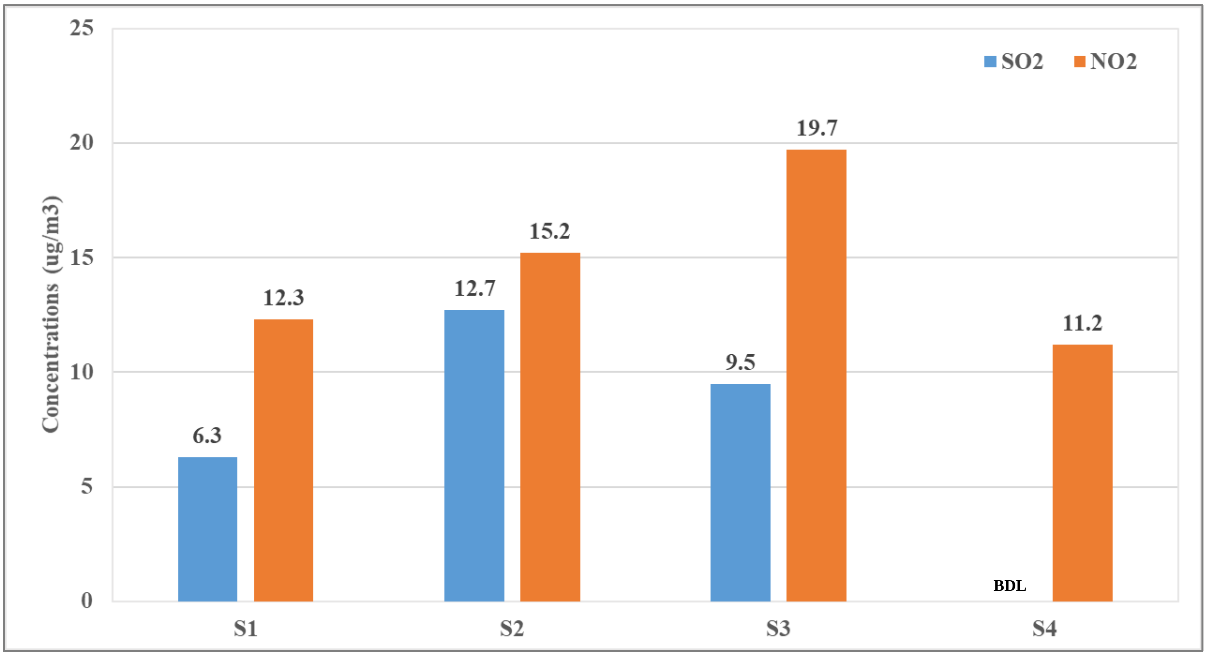


Figure 18: The seasonal mean concentrations of* SO_2 *and* NO_2 *observed at four sampling sites in Kalinganagar - Jajpur region during the winter season sampling period (January 1-20, 2022).

Fig. 19, represents the seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX), observed at four sampling locations in Kalinganagar - Jajpur region, during the winter season sampling period i.e. January 1-20, 2022. The winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites range from 0.8 to 1.9 ng/m^3, 0.9 to 2.6 ng/m^3, 0.5 to 6.8 ng/m^3 and 1.4 to 6.7 ng/m^3, respectively. In general, the lowest concentrations were observed at JCDL (S1) while the highest concentrations were observed at TATA Steel (S3). It is important to note that, these VOC concentrations represent the general levels during the typical sampling period and may vary considerably during other time of day and/or season.

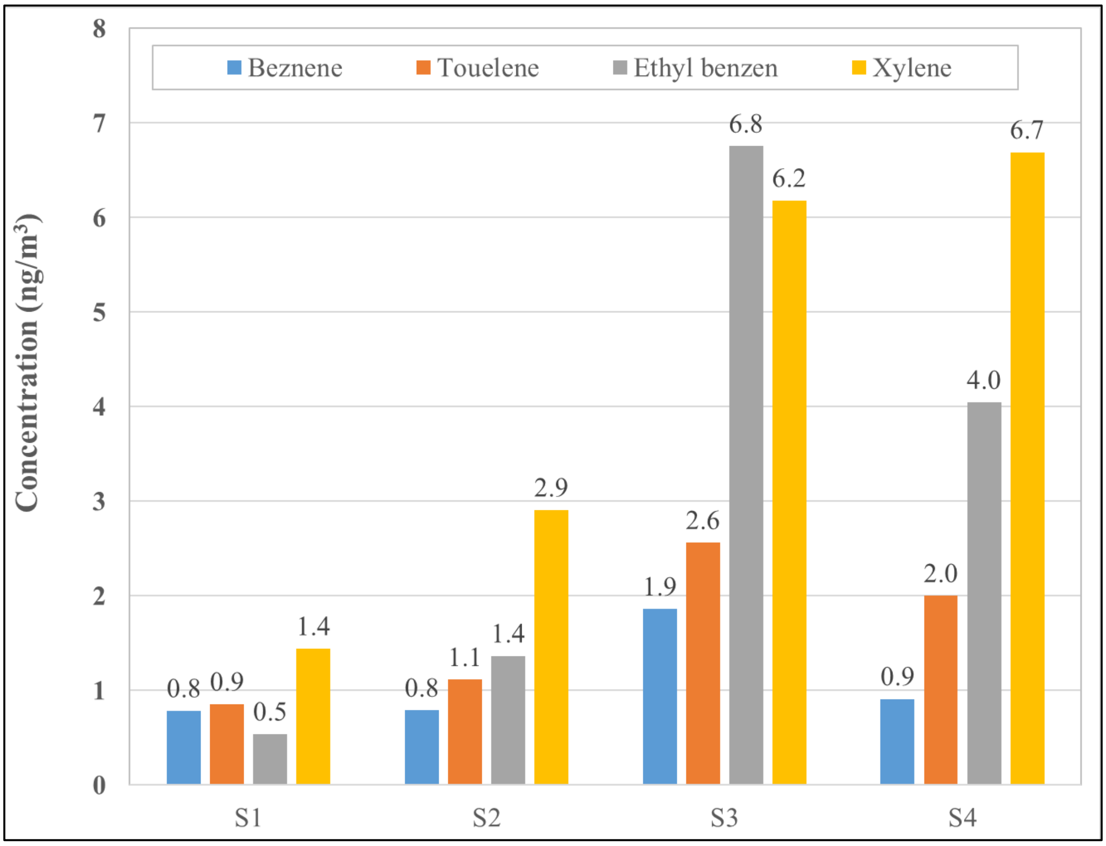


Figure 19: The seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) observed at four sampling sites in Kalinganagar - Jajpur region during the winter season sampling period (January 1-20, 2022).

2.6.2. Summer season

2.6.2.1. PM mass concentrations

Fig. 20, presents the distribution of daily $PM_{2.5}$ and PM_{10} concentrations observed at four sampling locations in Kalinganagar - Jajpur region during the summer season i.e. April 22 – May 14, 2022. The mean $PM_{2.5}$ and PM_{10} mass concentrations during the entire sampling period over all sites were 24.0 and 90.9 µg/m^3, respectively. The daily mean $PM_{2.5}$ concentrations exhibited a 6-fold range and ranged from a minimum of 8.7 µg/m^3 (at Tehsil Office i.e. S2) to a maximum of 56.3 µg/m^3 (at Tehsil Office i.e. S2). Similarly, the mean PM_{10} concentrations exhibited a 5-fold range and ranged from 34.5 µg/m^3 (at RO Office i.e. S4) to 176.9 µg/m^3 (at TATA Steel i.e. S3). 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 comply with the daily NAAQS limit at all sites. The daily averaged PM_{10} concentrations exceeded the NAAQS limit at all sites (6-67% of sampling days) with minimum exceedance at RO Office i.e. S4 (6%) and maximum exceedance at TATA Steel i.e. S3 (67% of sampling days) during summer season.

2.6.2.2. Spatial variability

The highest seasonal mean $PM_{2.5}$ concentrations were observed at Tehsil Office i.e. S2 (26.2 µg/m^3) while the lowest were recorded at JCDL i.e. S1 (21.8 µg/m^3). The daily $PM_{2.5}$ concentrations showed highest and lowest variability at Tehsil Office i.e. S2 and RO Office i.e. S4 sites, respectively. For example, daily $PM_{2.5}$ concentrations ranged from 8.7 to 56.3 µg/m^3 at Tehsil Office i.e. S2 while it ranged from 11.3 to 48.9 µg/m^3 at RO Office i.e. S4.

The highest seasonal mean PM_{10} concentrations were observed at TATA Steel i.e. S3 (118.0 µg/m^3) while the lowest were recorded at RO Office i.e. S4 (65.5 µg/m^3). The daily PM_{10} concentrations showed highest and lowest variability at Tehsil Office i.e. S2 and JCDL i.e. S1 sites, respectively. For example, daily PM_{10} concentrations ranged from a minimum of 36.8 to a maximum of 162.8 µg/m^3 at Tehsil Office i.e. S2 while it ranged between 35.0 and 141.3 µg/m^3 at JCDL i.e. S1.

These concentration levels can be attributed to air polluting activities around each site. For example, TATA Steel i.e. S3 is located in the Industrial area. 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.

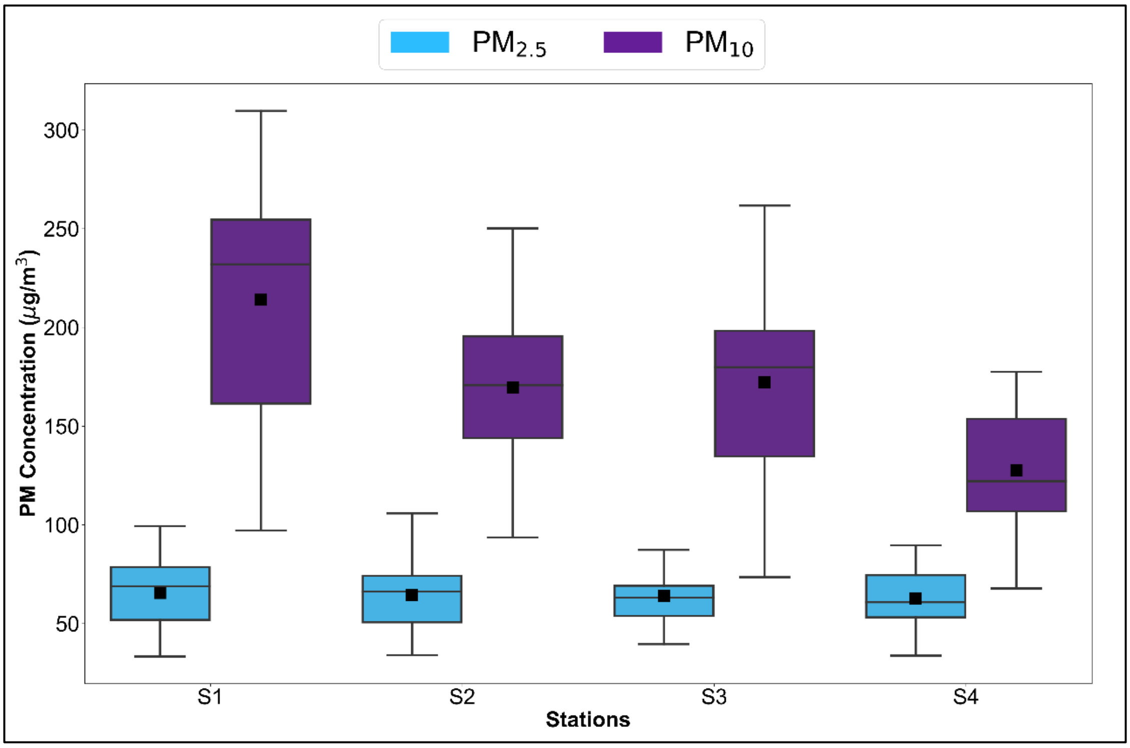


Figure 20 Boxplot showing distribution of daily $PM_{2.5}$ ***(blue colored boxes) and*** PM_{10} ***(violet colored boxes) concentrations observed at four sampling sites in Kalinganagar - Jajpur region during the summer season sampling period (April 22 – May 14, 2022).***

Note: Each box represents: mean (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. 21 shows daily time-series of $PM_{2.5}$ and PM_{10} observed at four selected sampling locations in Kalinganagar - Jajpur region during the summer season sampling period. Only valid samples between April 22 – May 14, 2022 are considered for this analysis. Overall, the PM concentrations showed mixed trend from April 22 – May 14, 2022 at all sites. This could be attributed to the unstable meteorological conditions over Kalinganagar - Jajpur region during the summer season.

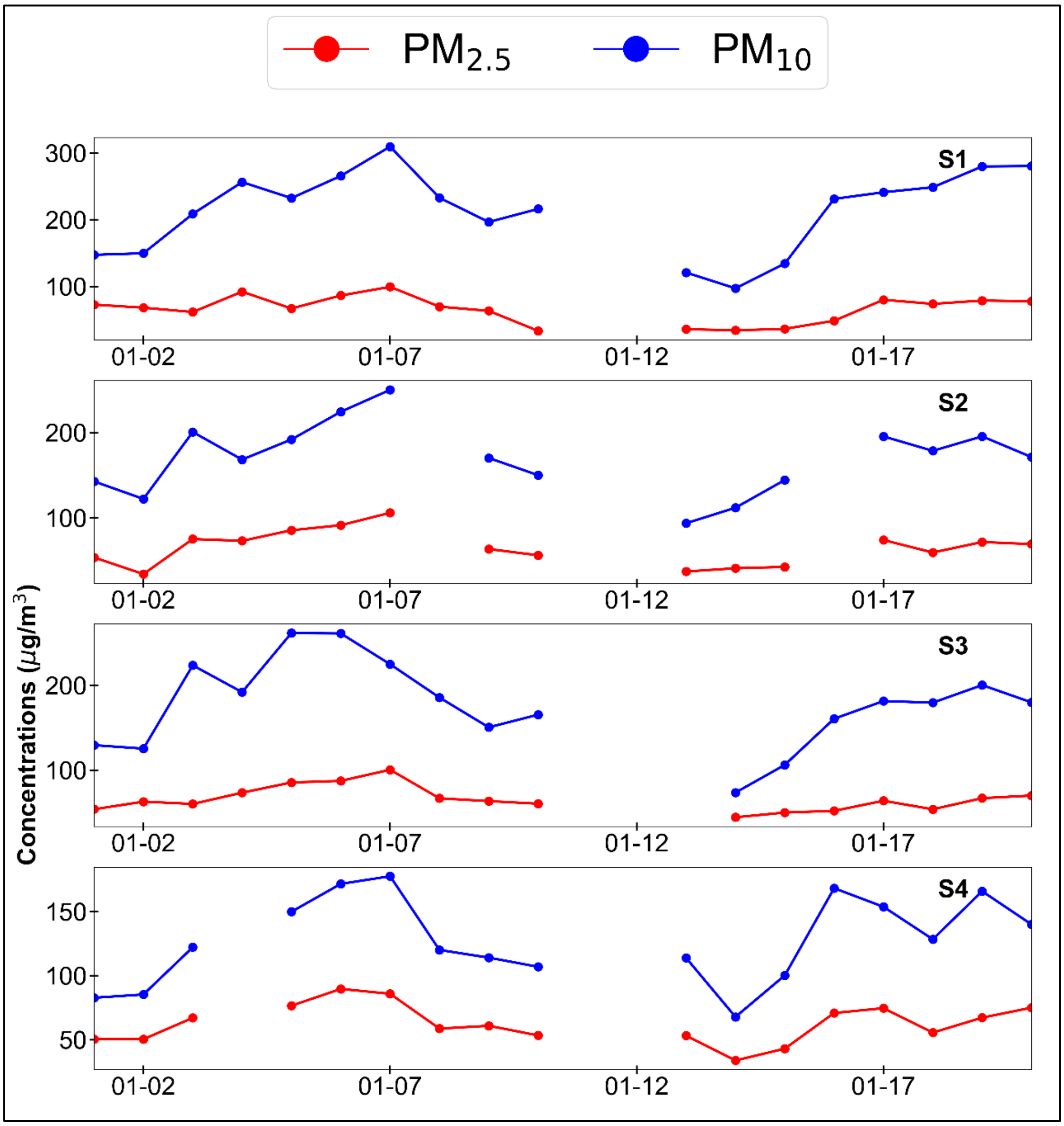


Figure 21 Daily time-series of $PM_{2.5}$ *(red) and* PM_{10} *(blue) concentrations observed at four sites in Kalinganagar - Jajpur region during the summer season sampling (April 22 – May 14, 2022)*

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

Fig. 22 shows distribution of daily $PM_{2.5}$ to PM_{10} ratios observed at four sampling sites during the summer season. The mean value of $PM_{2.5}$ to PM_{10} ratios during the summer season over all sites was found to be 0.29, varying from 0.11 to 0.67. The highest and lowest summer season mean $PM_{2.5}$ to PM_{10} ratio at JCDL i.e. S1 was observed 0.67 and 0.11. 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.

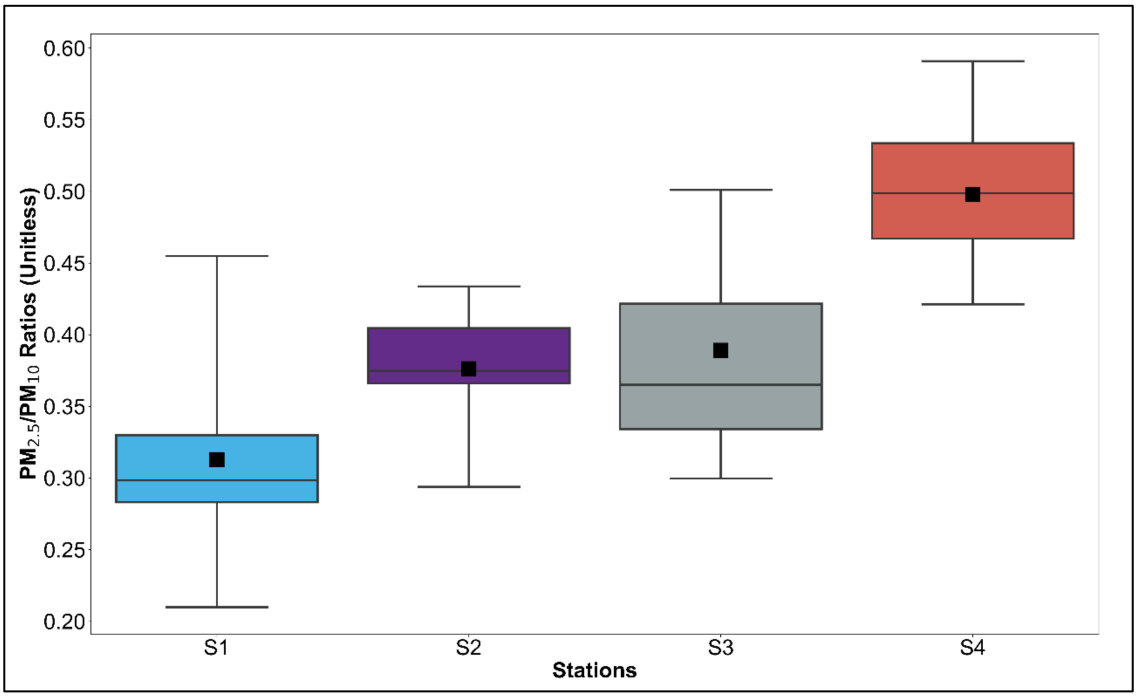


Figure 22 Boxplot showing distribution of $PM_{2.5}$ to PM_{10} ratios at four sampling sites in Kalinganagar - Jajpur region during the winter season (April 22 – May 14, 2022)

Note: Each box represents: mean (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

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

2.6.2.5.1. Site 1: JCDL (S1)

Fig. 23 shows the frequency distribution of different species observed in $PM_{2.5}$ and PM_{10} at JCDL i.e. S1 in Kalinganagar - Jajpur region during the summer season. OC in $PM_{2.5}$ and OC, and EC 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.

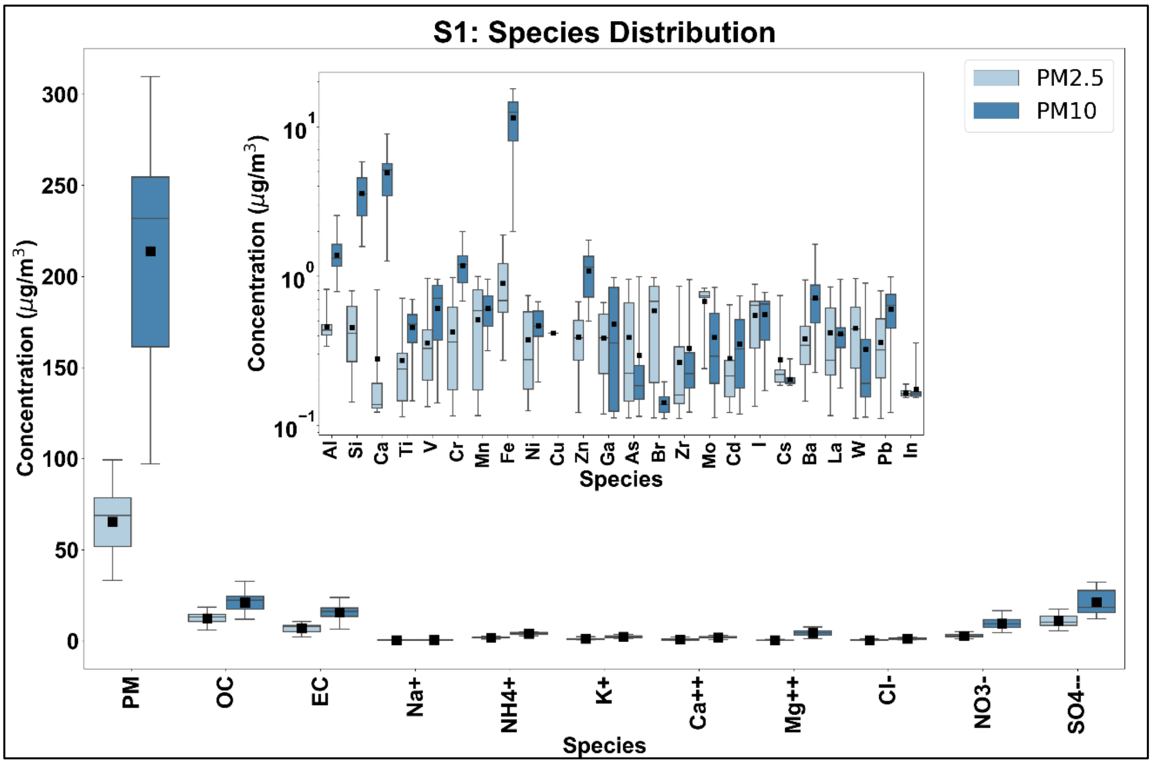


Figure 23 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at JCDL (S1) in Kalinganagar - Jajpur region during the summer season*

Note: Each box represents: mean (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

2.6.2.5.2. Site 2: Tehsil Office (S2)

Fig. 24 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions (Na+, NH4+, K+, Ca2+, Mg2+, Cl-, NO3-, and SO4--) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in $PM_{2.5}$ and PM_{10} observed at Tehsil Office Site (S2) during summer season (April 22 – May 14, 2022). OC in $PM_{2.5}$ and OC, and EC 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.

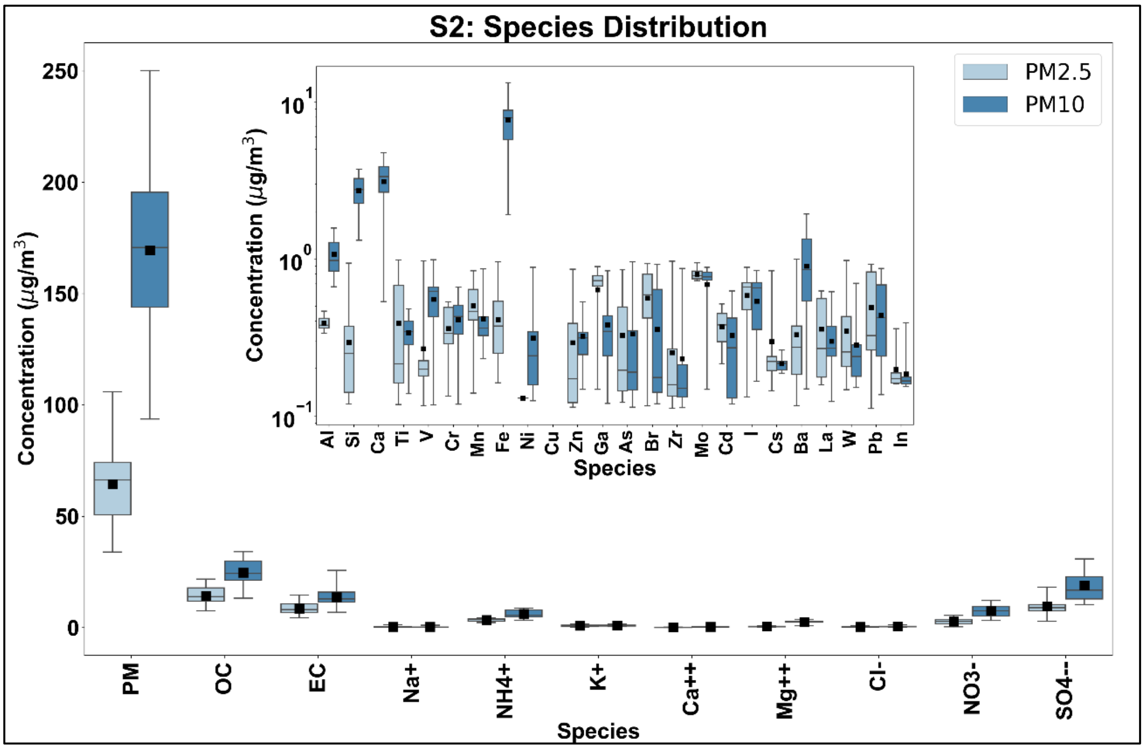


Figure 24 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at Tehsil Office Site (S2) in Kalinganagar - Jajpur region during the summer season*

Note: Each box represents: mean (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

2.6.2.5.3. Site 3: TATA Steel (S3)

Fig. 25 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na+, NH4+, K+, Ca2+, Mg2+, Cl-, NO3-, and SO4--) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in $PM_{2.5}$ and PM_{10} observed at TATA Steel (S3) during summer season (April 22 – May 14, 2022). OC in $PM_{2.5}$ and OC, EC, 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.

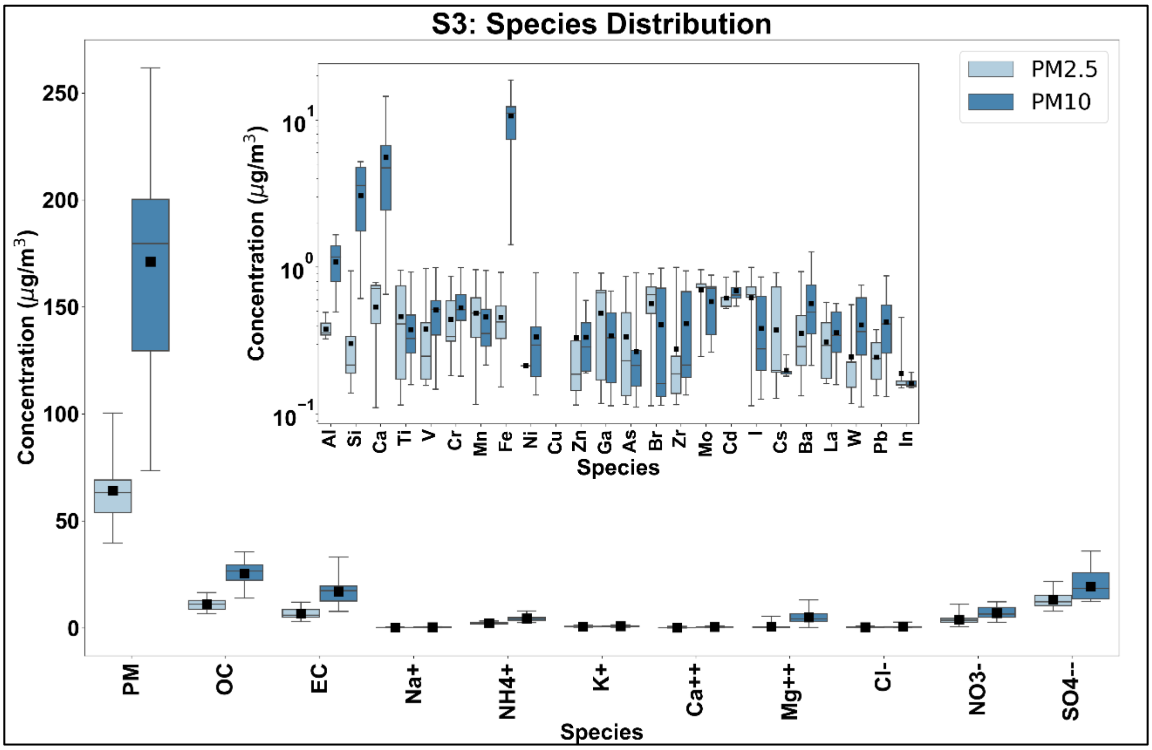


Figure 25 Box plots showing distribution of different species observed in $PM_{2.5}$ ***and*** PM_{10} ***at TATA Steel (S3) in Kalinganagar - Jajpur region during the summer season***

Note: Each box represents: mean (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

2.6.2.5.4. Site 4: RO Office (S4)

Fig. 26 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na+, NH4+, K+, Ca2+, Mg2+, Cl-, NO3-, and SO4--) and elements (Al, Si, Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Zr, Mo, Cd, I, Cs, Ba, La, W, Pb, In) in $PM_{2.5}$ and PM_{10} observed at RO Office (S4) during summer season (April 22 – May 14, 2022). OC in $PM_{2.5}$ and 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.

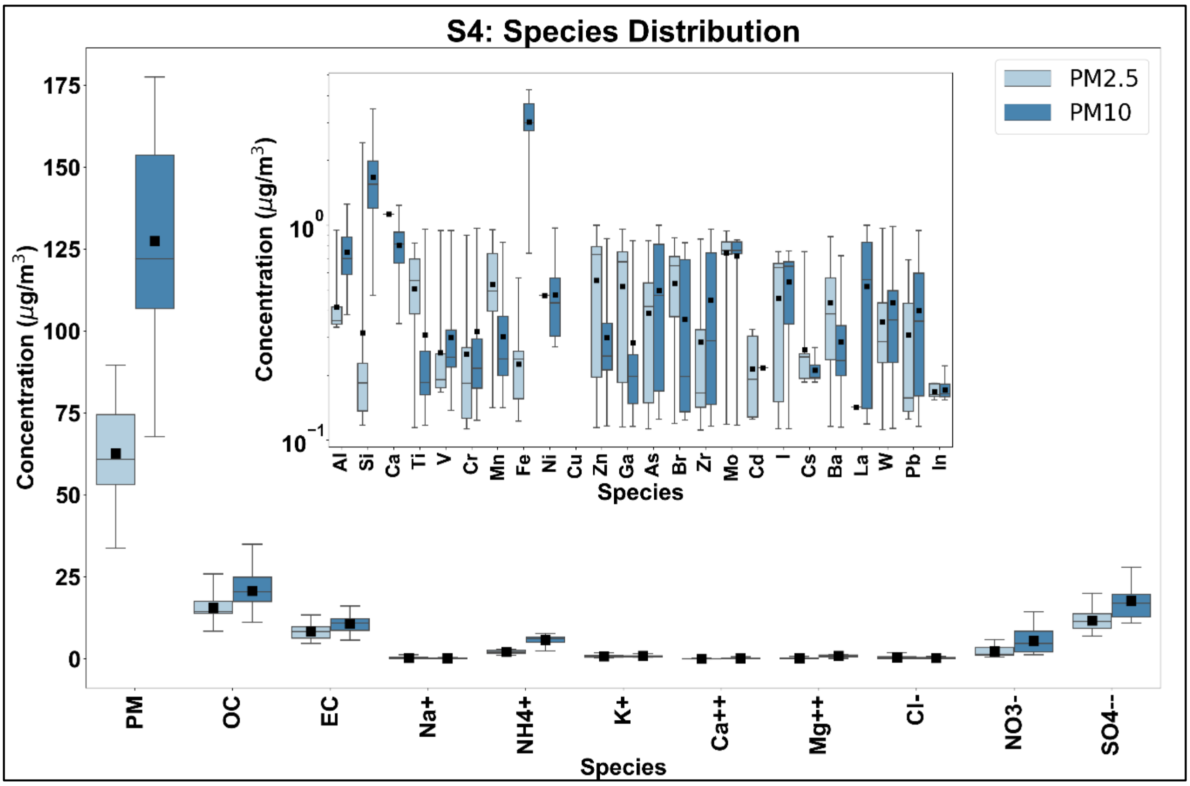


Figure 26 Box plots showing distribution of different species observed in $PM_{2.5}$ *and* PM_{10} *at RO Officee (S4) in Kalinganagar - Jajpur region during the summer season*

Note: Each box represents: mean (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

2.6.2.6. Molecular Markers in $PM_{2.5}$ and PM_{10}

Fig. 27 and 28, represents the seasonal mean concentrations of molecular markers observed at four sampling locations in Kalinganagar - Jajpur region, during the summer season sampling period i.e. April 22 -May 14, 2022. Levoglucosan, a biomass burning tracer (CPCB, 2010), is found to dominate the molecular markers mass, during the summer season in Kalinganagar - Jajpur region. Apart from Levoglucosan, Alkanes, and Amides are also detected in trace amounts, in PM samples collected over Kalinganagar - Jajpur region during summer season. The concentration levels of molecular markers in both the seasons are found to be similar.

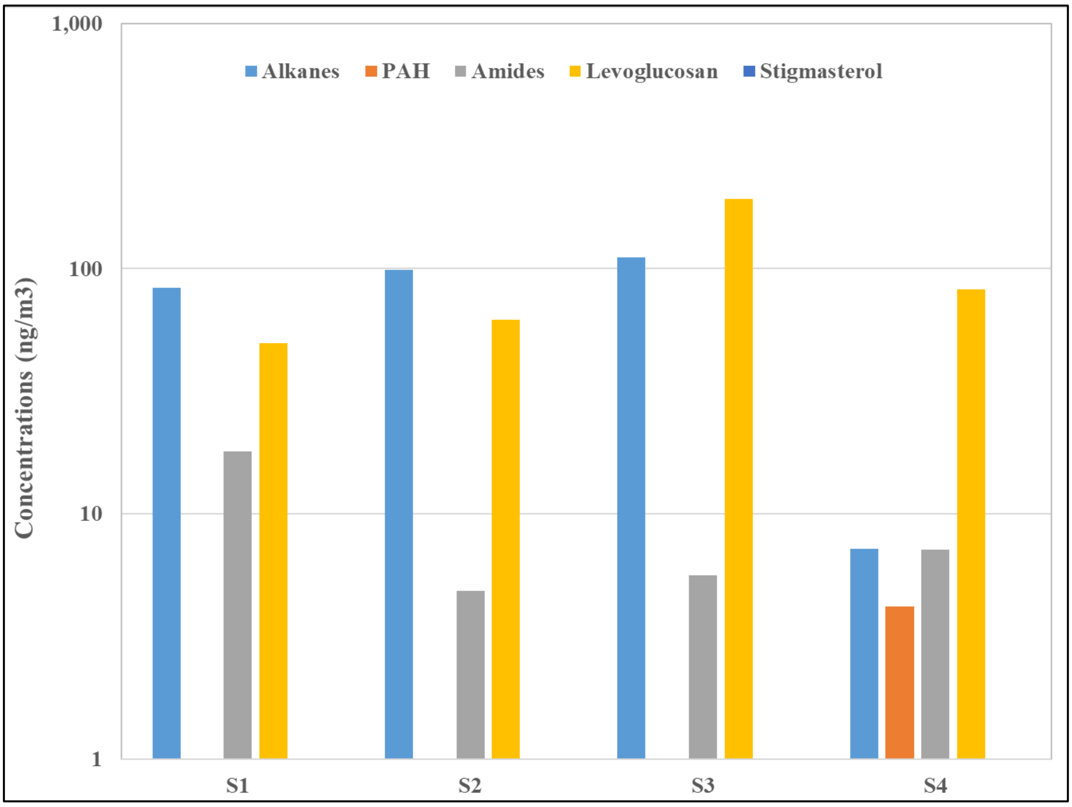


Figure 27: The seasonal mean concentrations of molecular marker species in $PM_{2.5}$ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Kalinganagar - Jajpur region during the summer season sampling period (April 22 -May 14, 2022).

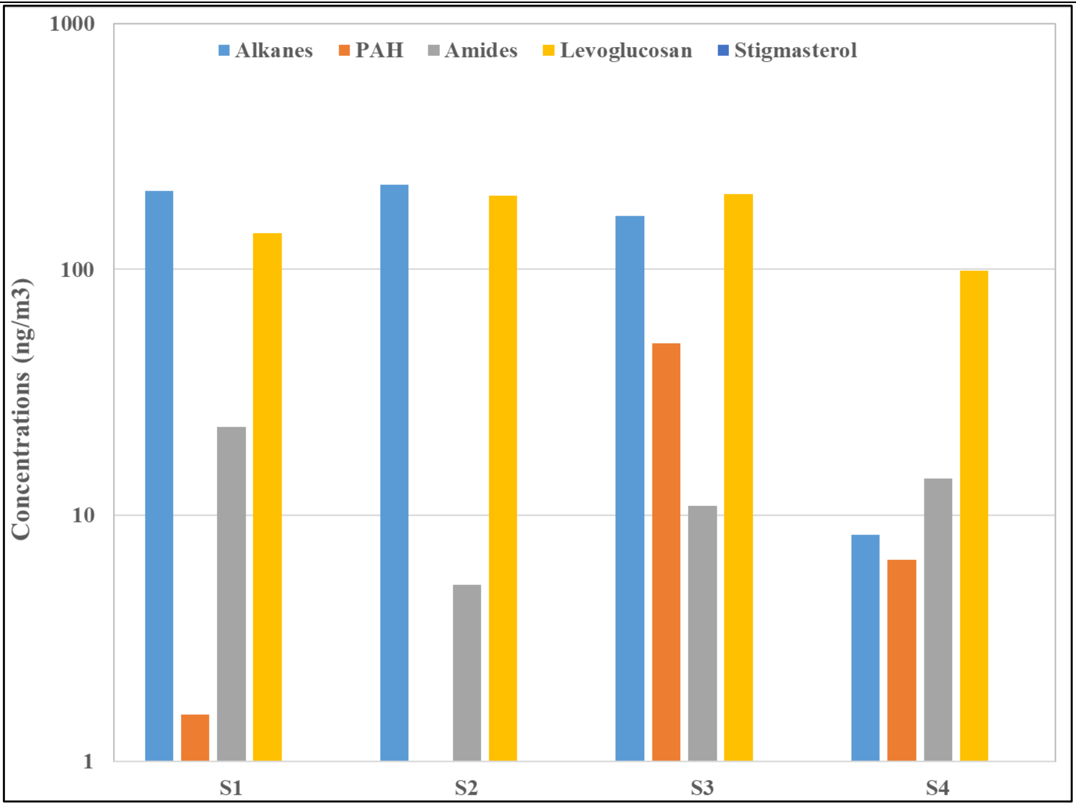


Figure 28: The seasonal mean concentrations of molecular marker species in PM_{10} *(grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Kalinganagar - Jajpur region during the summer season sampling period (April 22 -May 14, 2022).*

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. 29 and 30 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 0.72 (winter) and 0.78 (summer) for $PM_{2.5}$ whereas it is found to be 0.88 (winter) and 0.95 (summer) for PM_{10}, respectively. These correlation coefficients are consistent with other published literature, with mean 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).

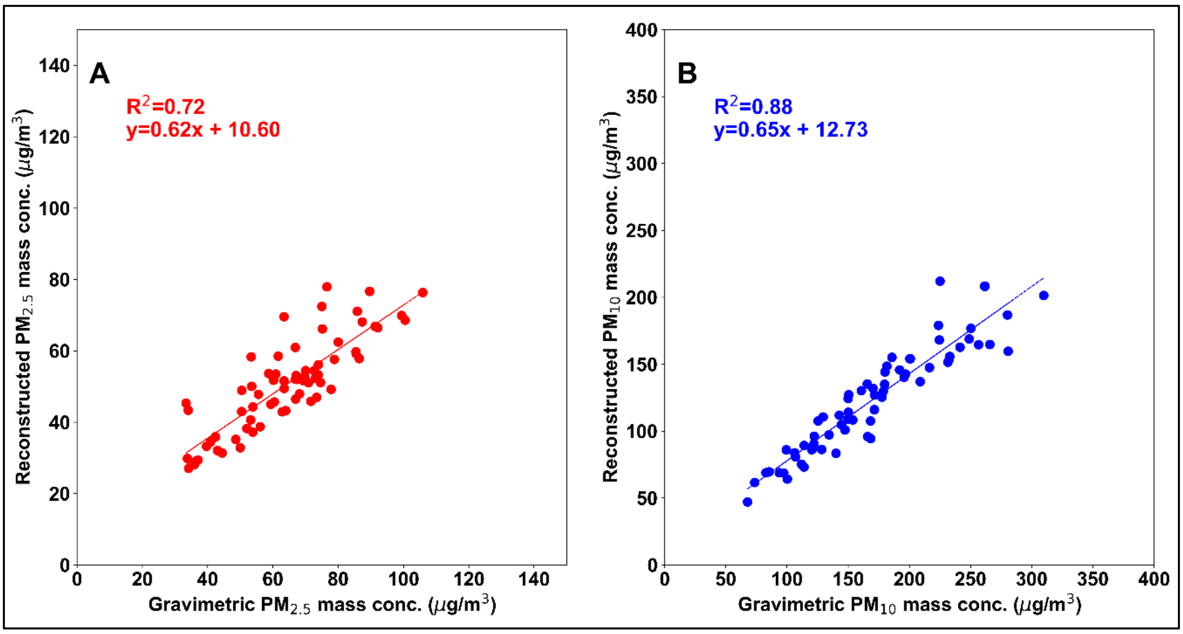


Figure 29 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) $PM_{2.5}$ *and (B)* PM_{10} *in Kalinganagar - Jajpur region during the winter season sampling period (Jan 01-20, 2022)*

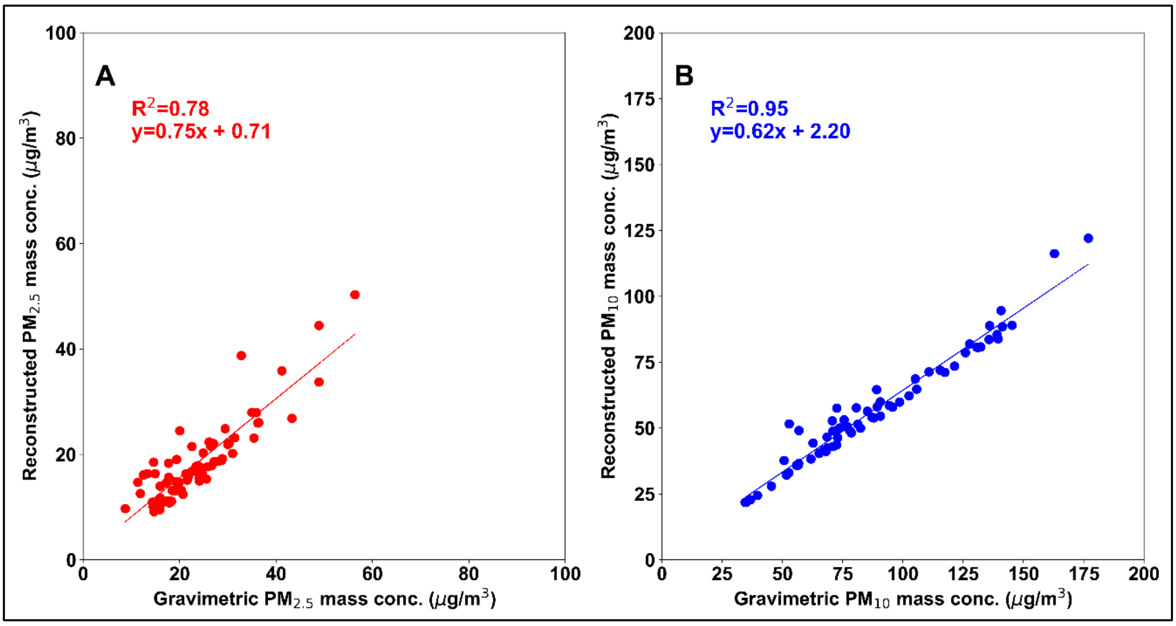


Figure 30 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) $PM_{2.5}$ *and (B)* PM_{10} *in Kalinganagar - Jajpur region during the summer season sampling period (April 22 - May 14, 2022)*

2.7.2. Winter Season: Reconstructed chemical mass

Fig. 31 to 34 and 35 to 38 presents the reconstructed chemical compositions of $PM_{2.5}$ and PM_{10} during the winter season at four sampling locations in Kalinganagar - Jajpur 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 ranging from 27.6 to 39.9% in $PM_{2.5}$ and 15.8 to 26.1% in PM_{10}. The seasonal mean OM concentrations among the four sites in the winter season ranged from 17.7 to 25.0 µg/m3 in $PM_{2.5}$ while it ranged from 33.3 to 40.8 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 Kalinganagar - Jajpur region. The seasonal mean contributions from SNA varied from 24.2 to 30.0% in $PM_{2.5}$ while it varied from 16.4 to 22.9% in PM_{10}. The seasonal mean SNA concentrations among the four sites ranged from 15.9 to 19.3 $\mu g/m^3$ in $PM_{2.5}$ whereas it ranged from 29.2 to 35.1 $\mu g/m^3$ 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 of SO_2 and NOx to sulfate and nitrate particles.

Elemental Carbon (EC) the third important component observed the seasonal mean contributions ranged between 10.5 and 13.3% in $PM_{2.5}$ while it ranged between 7.3 and 10.0% in PM_{10}. The seasonal mean elemental carbon (EC) concentrations during winter season varied from 6.7 to 8.6 $\mu g/m^3$ in $PM_{2.5}$ whereas it ranged from 10.7 to 17.1 $\mu g/m^3$ in PM_{10}.

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 3.6 to 6.2% in $PM_{2.5}$ while it varied from 10.9 to 27.5% in PM_{10}. The seasonal mean CM concentrations in PM_{10} varied from a minimum of 13.9 to 49.1 $\mu g/m^3$ in PM_{10}. In contrast, the CM concentrations in fine fraction i.e. $PM_{2.5}$ were relatively lower and ranged from 2.3 to 4.0 $\mu g/m^3$.

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 1.8 to 3.1%. The seasonal mean TE concentrations ranged from 1.0 to 2.1 µg/m^3 and 2.2 to 6.6 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 Kalinganagar-Jajpur, with contributions ranging from 0.9 to 1.6% in $PM_{2.5}$ and 0.4 to 0.9% in PM_{10}. The seasonal mean SS concentrations ranged from 0.6 to 1.0 µg/m^3 in $PM_{2.5}$ while it ranged from 0.6 to 1.9 µg/m^3 in PM_{10}.

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

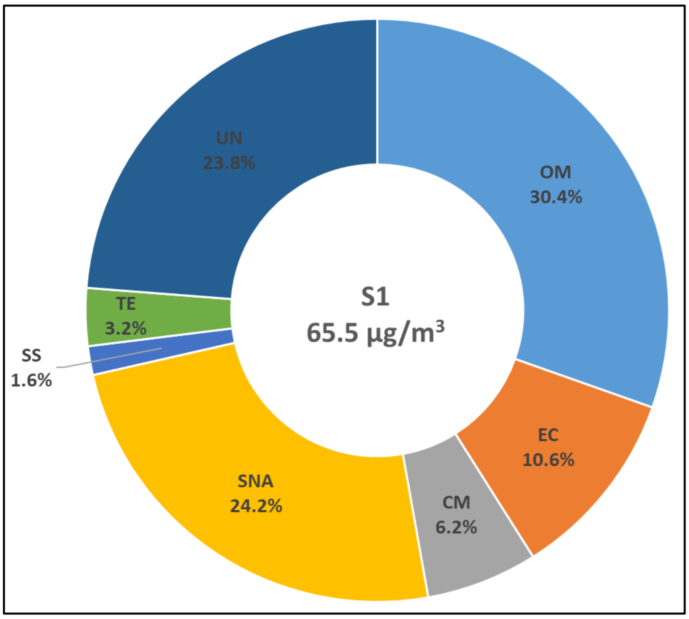


Figure 31: The reconstructed mass of $PM_{2.5}$ ***at S1 i.e. JCDL in Kalinganagar - Jajpur region during the winter season***

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.

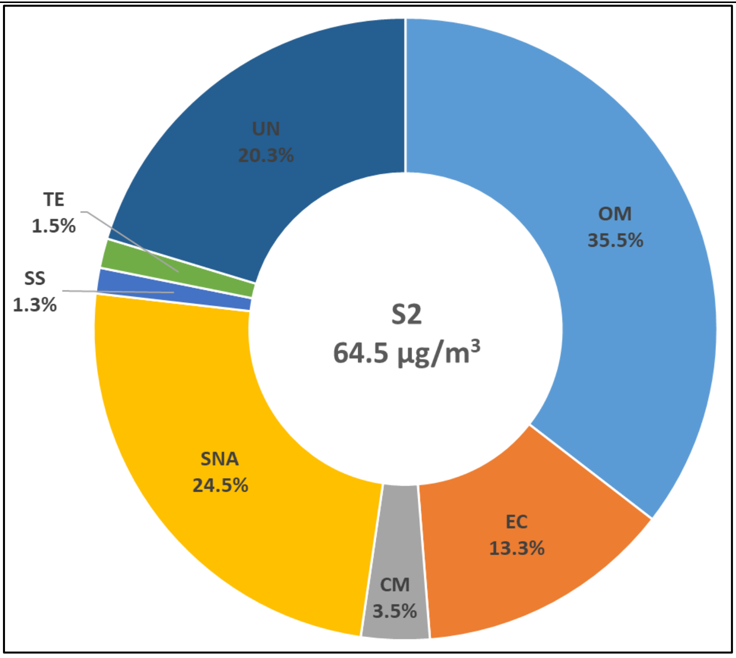


Figure 32: The reconstructed mass of $PM_{2.5}$ *at S2 i.e. Tehsil Office in Kalinganagar - Jajpur region during the winter season*

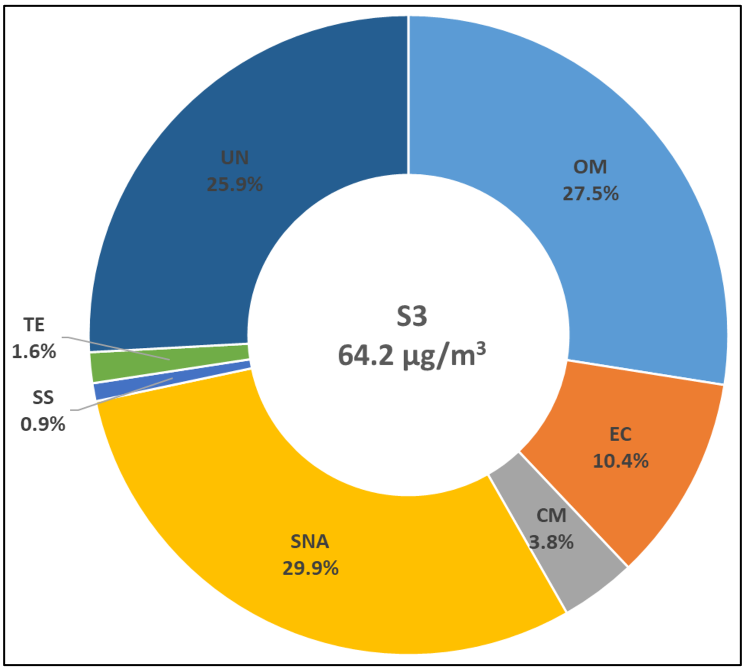


Figure 33: The reconstructed mass of $PM_{2.5}$ *at S3 i.e. TATA Steel in Kalinganagar - Jajpur region during the winter season*

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.

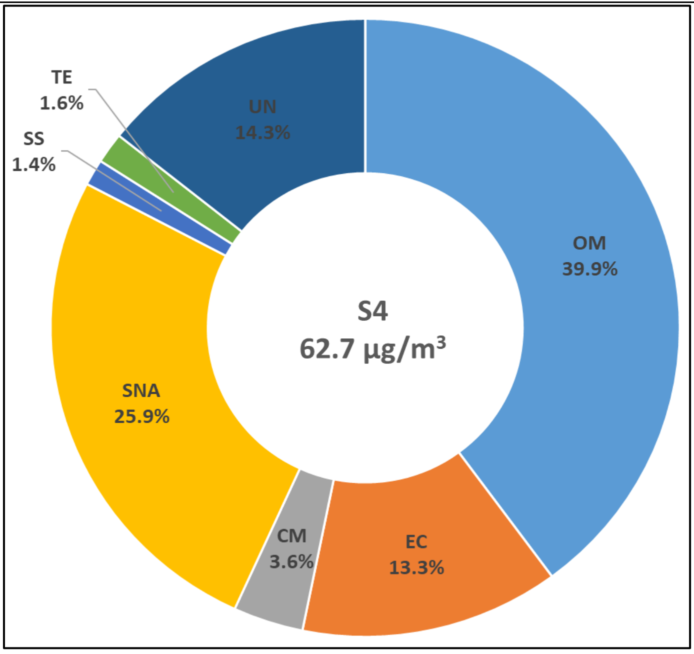


Figure 34: The reconstructed mass of $PM_{2.5}$ *at S4 i.e. RO Office in Kalinganagar - Jajpur region during the winter season*

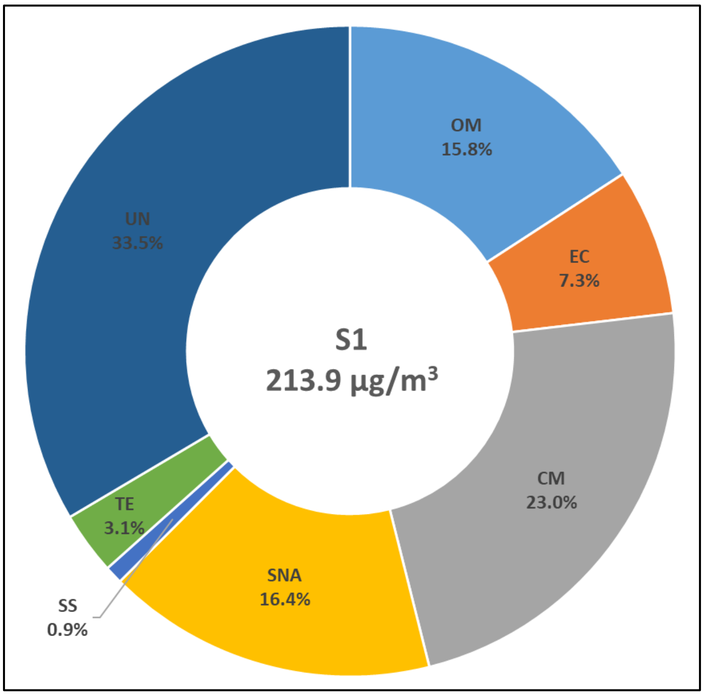


Figure 35: The reconstructed mass of PM_{10} *at S1 i.e. JCDL in Kalinganagar - Jajpur region during the winter season*

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.

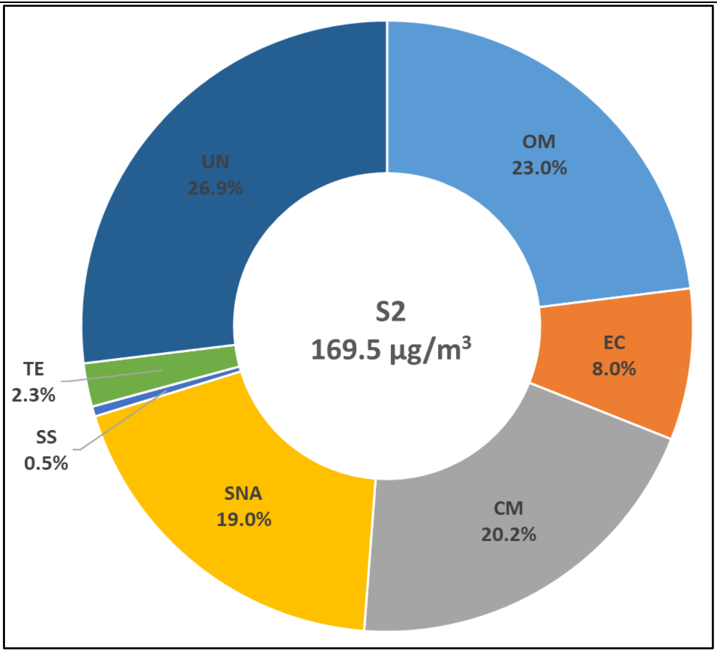


Figure 36: The reconstructed mass of PM_{10} *at S2 i.e. Tehsil Office in Kalinganagar - Jajpur region during the winter season*

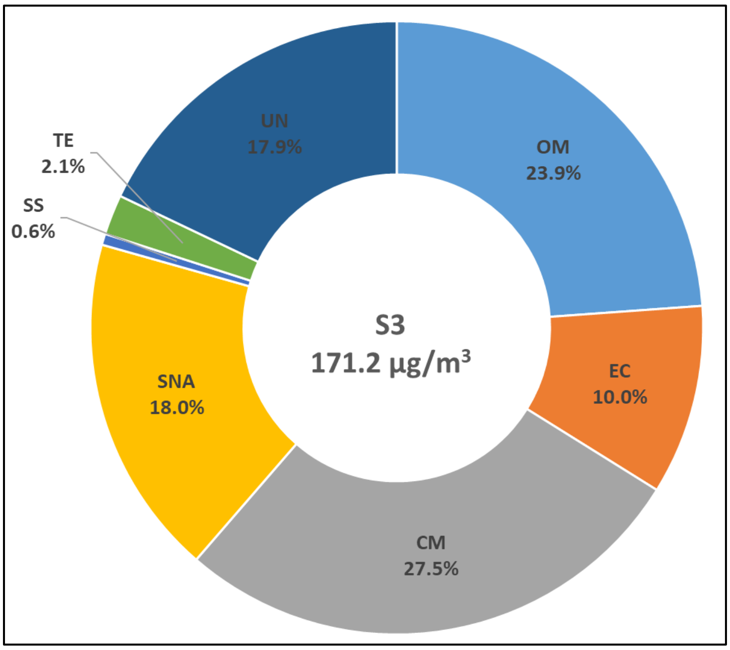


Figure 37: The reconstructed mass of PM_{10} *at S3 i.e. TATA Steel in Kalinganagar - Jajpur region during the winter season*

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.

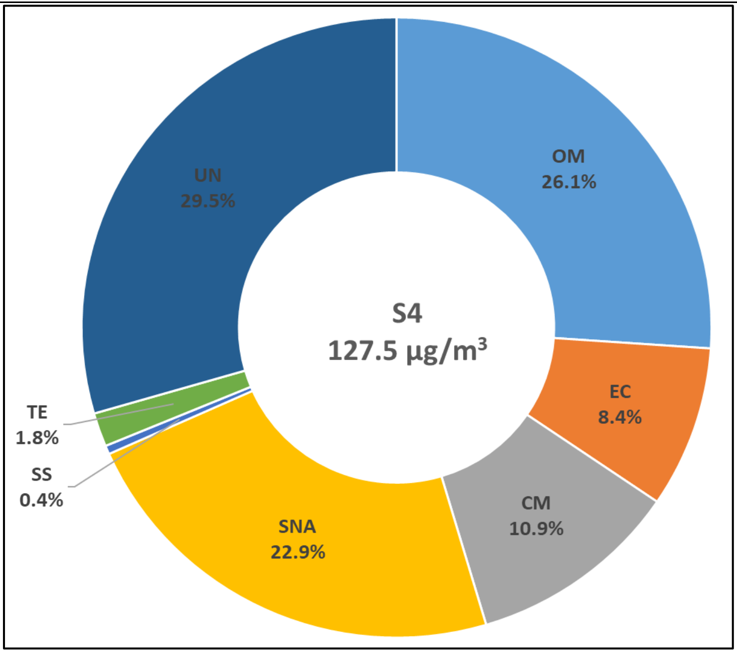


Figure 38: The reconstructed mass of PM_{10} ***at S4 i.e. RO Office in Kalinganagar - Jajpur region during the winter season***

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. 39 to 42 and 43 to 46 presents the reconstructed chemical compositions of $PM_{2.5}$ and PM_{10} during the summer season at four sampling locations in Kalinganagar - Jajpur 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 CM > OM > SNA > EC > 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 33.9 to 40.6% in $PM_{2.5}$ and 14.1 to 20.2%. The seasonal mean OM concentrations in the summer season ranged from 7.4 to 9.6 $\mu g/m^3$ in $PM_{2.5}$ while it ranged from 13.2 to 16.8 $\mu g/m^3$ in PM_{10}.

Crustal Mass (CM) is the second most important contributor to coarse fraction i.e. PM_{10} during summer season. The seasonal mean contributions from CM varied from 8.4 to 11.1% in $PM_{2.5}$ while it varied from 25.0 to 33.7% in PM_{10}. The seasonal mean CM concentrations in PM_{10} varied from a minimum of 16.4 to 39.0 $\mu g/m^3$ in PM_{10}. In contrast, the CM concentrations in fine fraction i.e. $PM_{2.5}$ were relatively lower and ranged from 2.0 to 2.4 $\mu g/m^3$.

Secondary inorganic aerosols, represented as SNA, is the third major component observed in $PM_{2.5}$ and PM_{10} fractions during the summer season in Kalinganagar - Jajpur region. The seasonal mean contributions from SNA varied from 11.0 to 22.8% in $PM_{2.5}$ while it varied from 5.5 to 9.8% in PM_{10}. The seasonal mean SNA concentrations ranged from 2.5 to 5.5 $\mu g/m^3$ in $PM_{2.5}$ whereas it ranged from 5.5 to 10.7 $\mu g/m^3$ 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 11.4 and 13.2% in $PM_{2.5}$ while it ranged between 4.7 and 7.0% in PM_{10}. The daily averaged elemental carbon (EC) concentrations during summer season varied from 2.7 to 3.0 $\mu g/m^3$ in $PM_{2.5}$ whereas it ranged from 3.9 to 6.1 $\mu g/m^3$ 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 2.4 to 3.4%. The seasonal mean TE concentrations ranged from 0.6 to 1.0 $\mu g/m^3$ and 2.2 to 3.1 $\mu g/m^3$ 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 Kalinganagar - Jajpur region, with contributions ranging from 0.5 to 1.7%. The seasonal mean SS ranged from 0.1 to 0.4 μg/m^3 in $PM_{2.5}$ while it ranged from 1.4 to 1.7 μg/m^3 in PM_{10}.

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

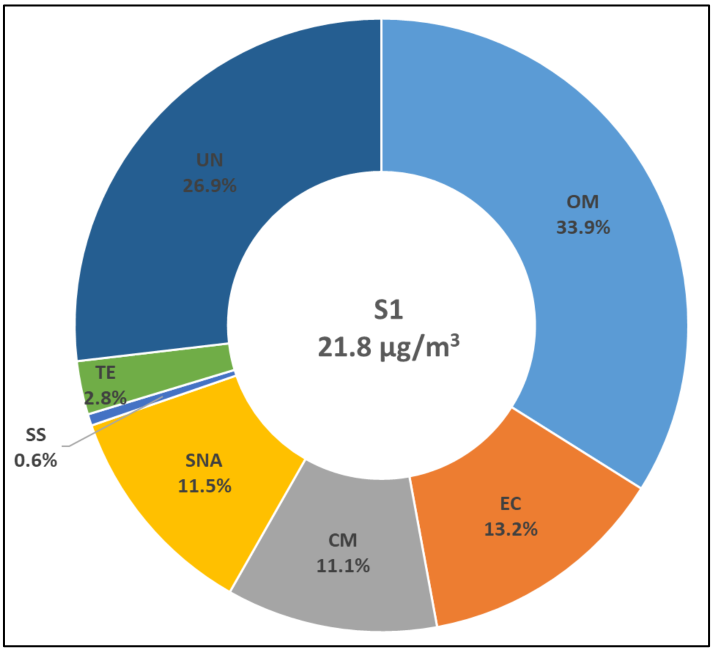


Figure 39: The reconstructed mass of** $PM_{2.5}$ **at S1 i.e. JCDL in Kalinganagar - Jajpur region during the summer season

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.

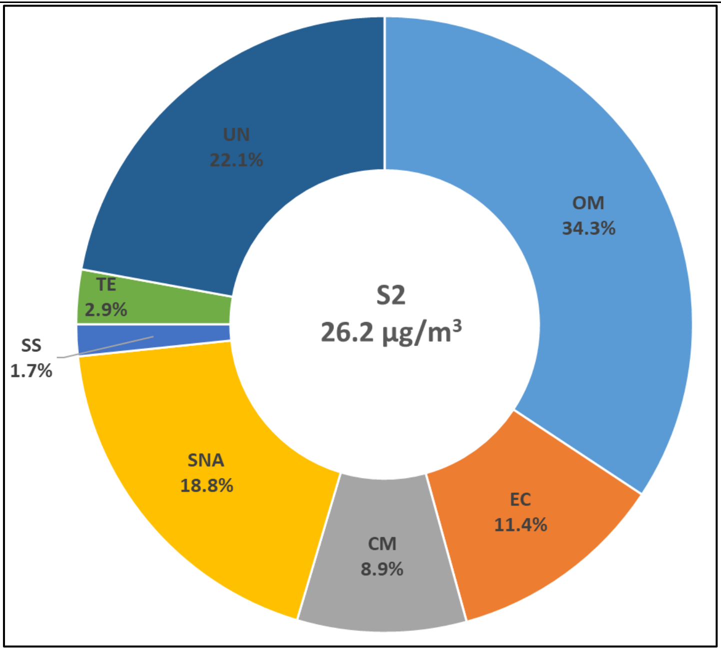


Figure 40: The reconstructed mass of $PM_{2.5}$ ***at S2 i.e. Tehsil Office in Kalinganagar - Jajpur region during the summer season***

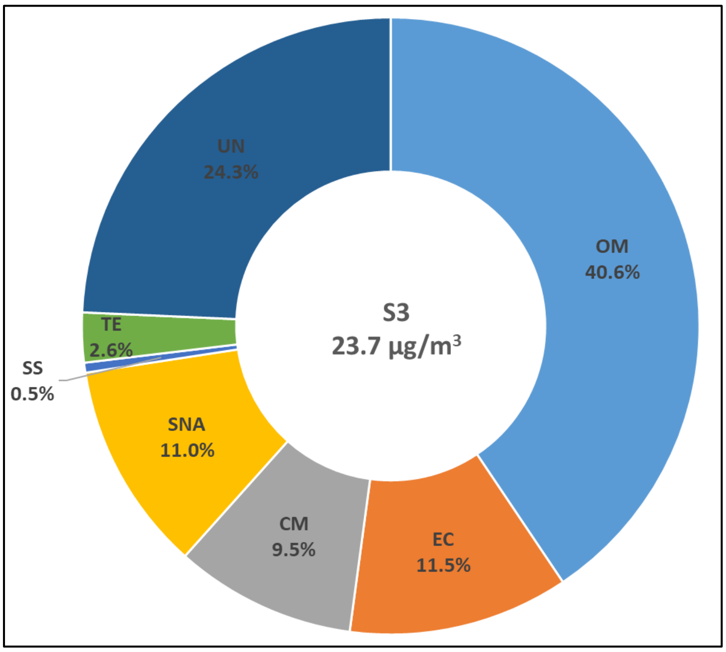


Figure 41: The reconstructed mass of $PM_{2.5}$ ***at S3 i.e. TATA Steel in Kalinganagar - Jajpur region during the summer season***

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.

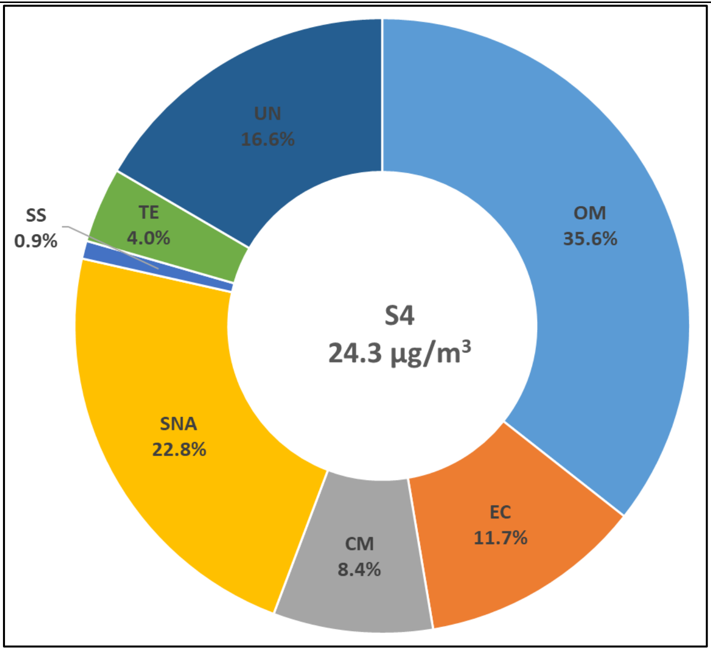


Figure 42: The reconstructed mass of $PM_{2.5}$ *at S4 i.e. RO Office in Kalinganagar - Jajpur region during the summer season*

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.

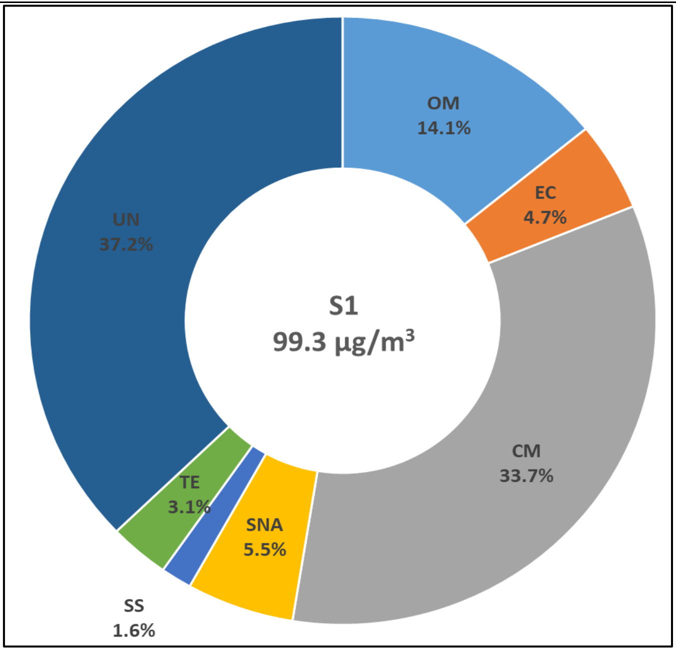


Figure 43: The reconstructed mass of PM_{10} *at S1 i.e. JCDL in Kalinganagar - Jajpur region during the summer season*

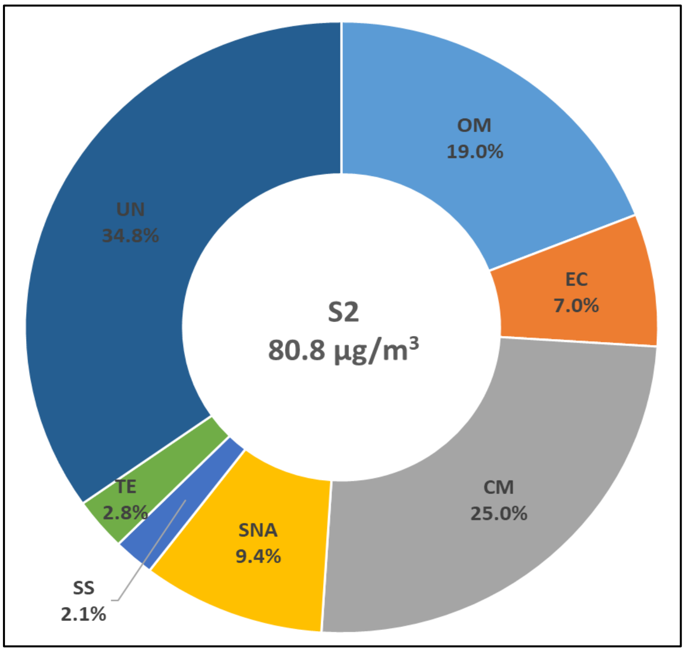


Figure 44: The reconstructed mass of PM_{10} *at S2 i.e. Tehsil Office in Kalinganagar - Jajpur region during the summer season*

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.

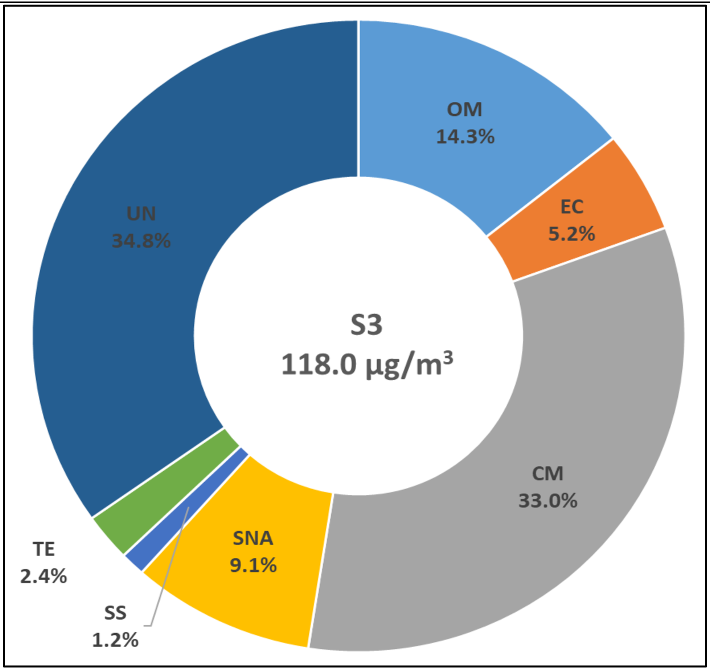


Figure 45: The reconstructed mass of PM_{10} *at S3 i.e. TATA Steel in Kalinganagar - Jajpur region during the summer season*

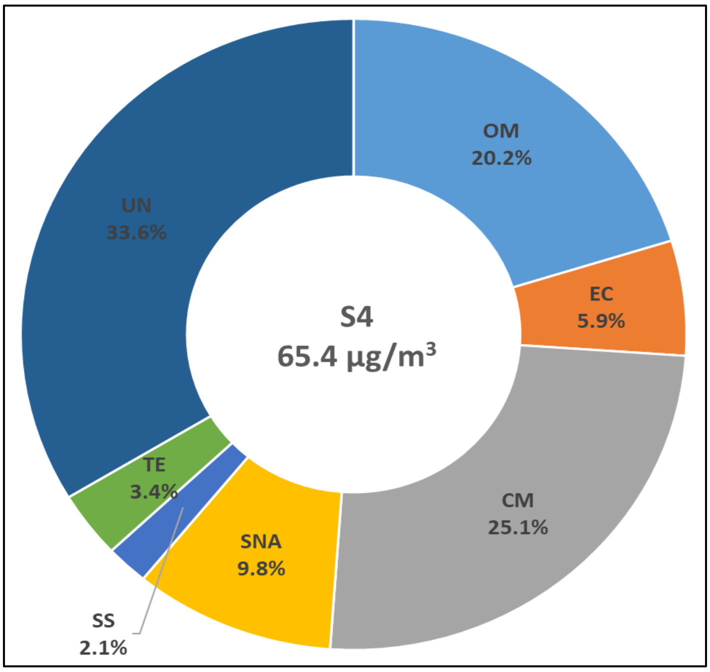


Figure 46: The reconstructed mass of PM_{10} *at S4 i.e. RO Office in Kalinganagar - Jajpur region during the summer season*

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. 47 and 48 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 four sampling locations in Kalinganagar - Jajpur region during the winter and summer seasons, respectively. Table 2 provides summary of mean 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 mean 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 S1 i.e. JCDL, 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 0.12 in $PM_{2.5}$ and PM_{10}. Similarly, K^+/EC ratios ranged from 0.05 to 0.20 in $PM_{2.5}$ and PM_{10}. The summer season K^+/OC ratios ranged from 0.01 to 0.06 $PM_{2.5}$ and PM_{10}. Similarly, K^+/EC ratios ranged from 0.02 to 0.13 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 0.19 to 0.29 in $PM_{2.5}$ whereas it varied from 0.29 to 0.46 PM_{10}. Similarly, summer-time NO_3^-/SO_4^{--} ratios varied from 0.01 to 0.10 in $PM_{2.5}$ whereas it varied from 0.39 to 0.47 in PM_{10}. The ratios much lesser than unity indicates the dominance of stationary sources over mobile sources in Kalinganagar - Jajpur region.

The mean 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 1.05 to 1.33 in $PM_{2.5}$ whereas it ranged from 1.33 to 2.12 in PM_{10}. The summer season mean Cl^-/Na^+ ratio ranged from 0.18 to 0.72 in $PM_{2.5}$ whereas it ranged from 0.54 to 0.87 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.

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

In winter season, the mean DON values ranged from 0.39 to 0.95 in $PM_{2.5}$ and 0.41 to 0.79 in PM_{10} at four sampling locations in Kalinganagar - Jajpur region. The winter-season ratios show the complete neutralization or slight ammonium abundance at all sites during the winter season, which in turn implies the basic or slightly acidic nature of sulfate and nitrate particles. In summer season, the mean DON values ranged from 1.89 to 3.58 in $PM_{2.5}$ and 0.62 to 3.48 in PM_{10} at four sampling locations in Kalinganagar - Jajpur region. It also shows the complete neutralization or presence of excess ammonium during the summer season, which in turn implies the neutral to basic nature of sulfate and nitrate particles.

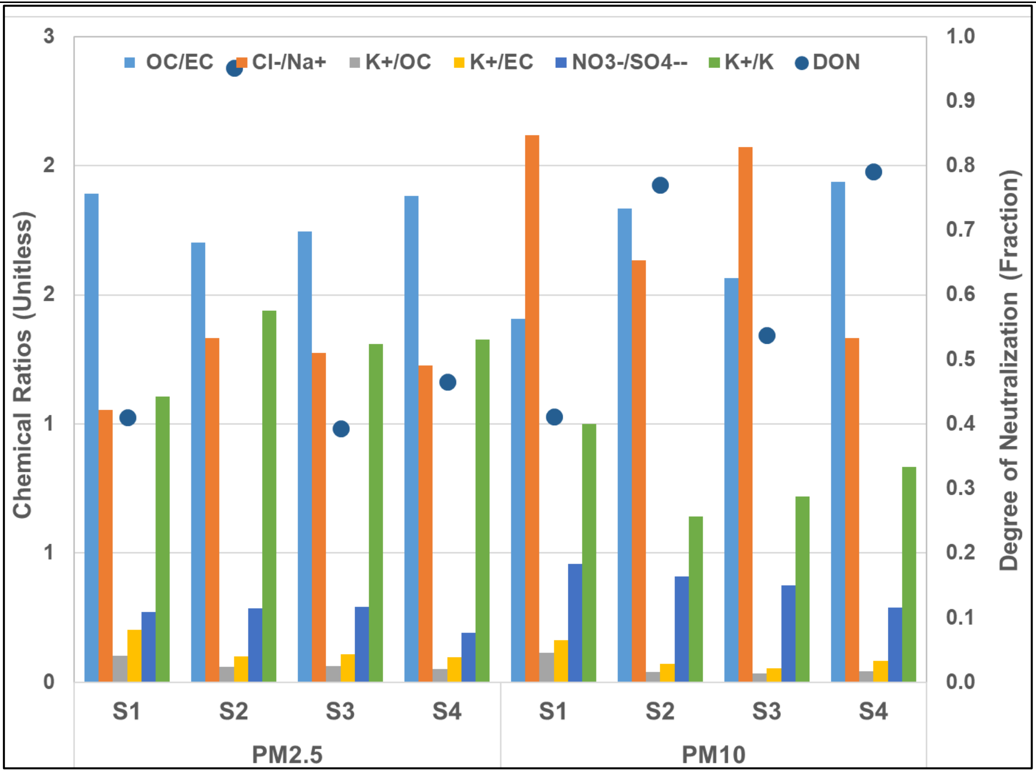


Figure 47: Chemical ratios i.e. OC to EC ratio, Cl^- to Na^+ ratio, K^+ to OC ratio, K^+ to EC, NO_3^- to SO_4^{--} ratio, and degree of neutralization (DON) observed at four sampling locations during the winter season in Kalinganagar - Jajpur region.

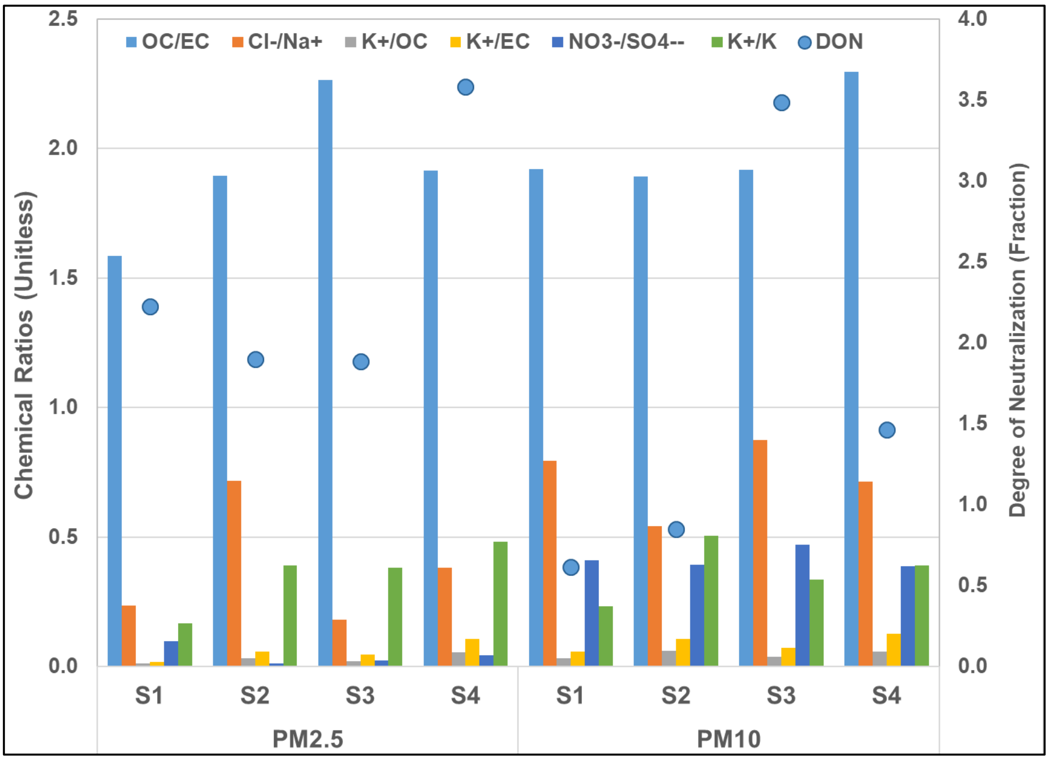


Figure 48: Chemical ratios i.e. OC to EC ratio, Cl^- to Na^+ ratio, K^+ to OC ratio, K^+ to EC, NO_3^- to SO_4^{--} ratio, and degree of neutralization (DON) observed at four sampling locations during the summer season in Kalinganagar - Jajpur region.

Table 2 Summary of different chemical ratios observed at four sampling locations during the winter and summer seasons in Kalinganagar - Jajpur region

Fraction	Site	OC/EC	Cl^-/Na^+	K^+/OC	K^+/EC	NO_3^-/SO_4^{--}	DON
Winter $PM_{2.5}$	S1	1.89	1.05	0.10	0.20	0.27	0.41
	S2	1.70	1.33	0.06	0.10	0.29	0.95
	S3	1.75	1.28	0.06	0.11	0.29	0.39
	S4	1.88	1.23	0.05	0.10	0.19	0.47
Winter PM_{10}	S1	1.41	2.12	0.12	0.16	0.46	0.41
	S2	1.83	1.63	0.04	0.07	0.41	0.77
	S3	1.56	2.07	0.03	0.05	0.38	0.54
	S4	1.94	1.33	0.04	0.08	0.29	0.79
Summer $PM_{2.5}$	S1	1.58	0.23	0.01	0.02	0.10	2.22
	S2	1.89	0.72	0.03	0.06	0.01	1.90
	S3	2.27	0.18	0.02	0.05	0.02	1.89
	S4	1.92	0.38	0.05	0.11	0.04	3.58
Summer PM_{10}	S1	1.92	0.79	0.03	0.06	0.41	0.62
	S2	1.89	0.54	0.06	0.11	0.39	0.85
	S3	1.92	0.87	0.04	0.07	0.47	3.48
	S4	2.30	0.71	0.06	0.13	0.39	1.46

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 four sampling sites in Kalinganagar - Jajpur region. Five pollution sources were apportioned using the mean concentration data including i) transport (TRAN), ii) road and construction dust (DUST), iii) biomass burning (BCOM), iv) industry, 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: JCDL

Fig. 49 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at JCDL i.e. S1 during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 65.5 µg/m^3 and 213.9 µg/m^3, respectively. Dusty sources, particularly road and construction dust, dominated $PM_{2.5}$ at Site 1, contributing the highest proportion at 54.0%, industries and power plants (16.5%), secondary aerosols (7.6%), Transport (5.2%), and biomass and solid waste combustion (2.6%) were also identified as significant contributors. At Site 1, road and construction dust was the primary contributor to PM_{10}, with a substantial contribution of 49.6%. Industries and power plants constituted 30.1%, secondary aerosols for 6.5%, transport for 5.1%, and biomass and solid waste combustion accounted for 2.1%, and. About 14.1% and 6.7% 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.

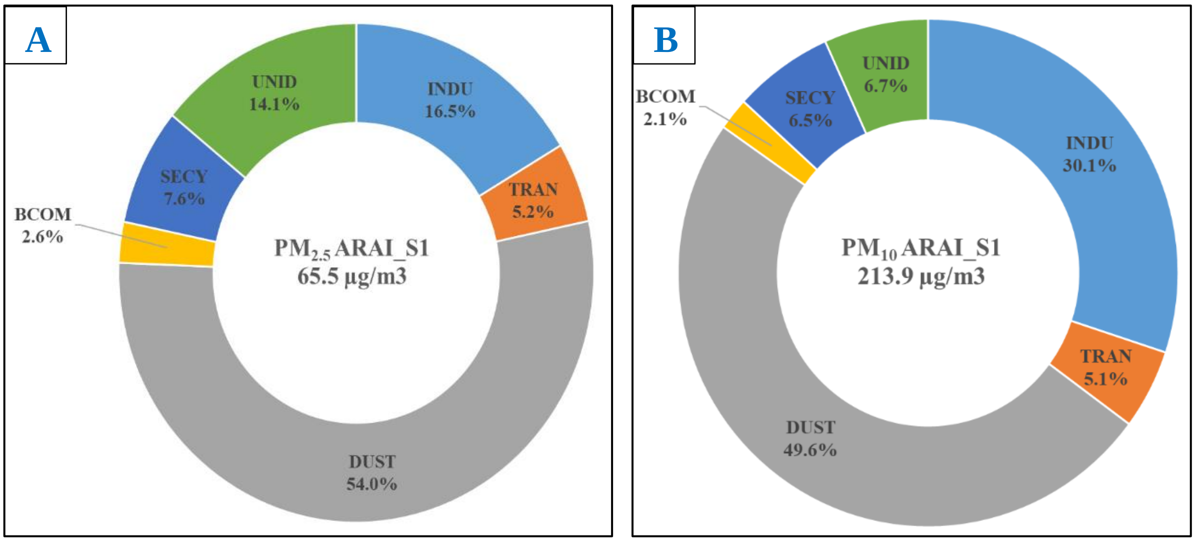


Figure 49 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S1 i.e. JCDL during the winter season in Kalinganagar - Jajpur region*

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: Tehsil Office (S2)

Fig. 50 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at Tehsil Office i.e. S2 during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 64.5 µg/m^3 and 169.5 µg/m^3, respectively.

Road and construction dust were the primary contributors to $PM_{2.5}$ at Site 2, with a substantial contribution of 55.6%. Secondary aerosols 9.4%, transport accounted for 7.8%, while industries and power plants followed at 6.3%, and biomass and solid waste combustion 3.5%. Road and construction dust dominated PM_{10} concentrations at Site 2, contributing the highest proportion at 56.1%. Industries and power plants followed at 15.9%, secondary aerosols 8.6%, transport contributed 7.1%, and biomass and solid waste combustion 3.0%. About 17.5% and 9.3% 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.

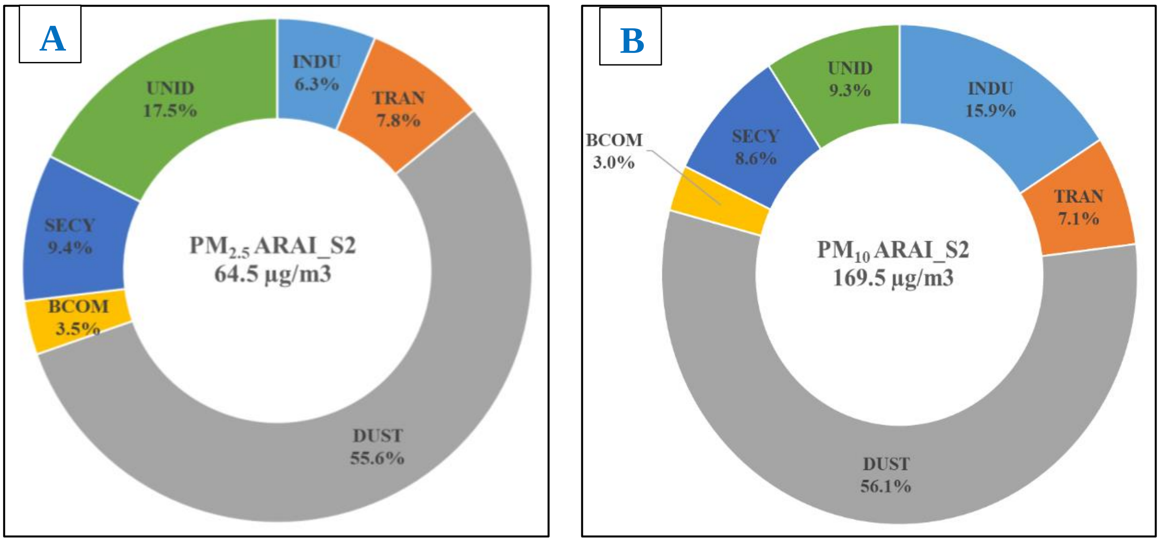


Figure 50 Sectoral source contributions to** $PM_{2.5}$ **(A) and** PM_{10} **(B) at S2 i.e. Tehsil Office during winter season in Kalinganagar - Jajpur region

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.

2.9.1.3. Site 3: TATA Steel (S3)

Fig. 51 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at TATA Steel (S3) during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 64.2 µg/m^3 and 171.2 µg/m^3, respectively. Road and construction dust had the highest contribution to $PM_{2.5}$ at Site 3, with a significant proportion of 61.4%, Industries and power plants followed at 11.4%, while secondary aerosols 7.2%, transport accounted for 5.2%. Biomass and solid waste combustion contributed 1.4%. Similar to $PM_{2.5}$, Road and construction dust also had the highest contribution to PM_{10} at Site 3, with a significant proportion of 50.9%, followed by Industries and power plants at 32.1%, secondary aerosols 5.6%, transport contributed 4.1%. Biomass and solid waste combustion 1.0%. About 13.4% and 6.4% 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.

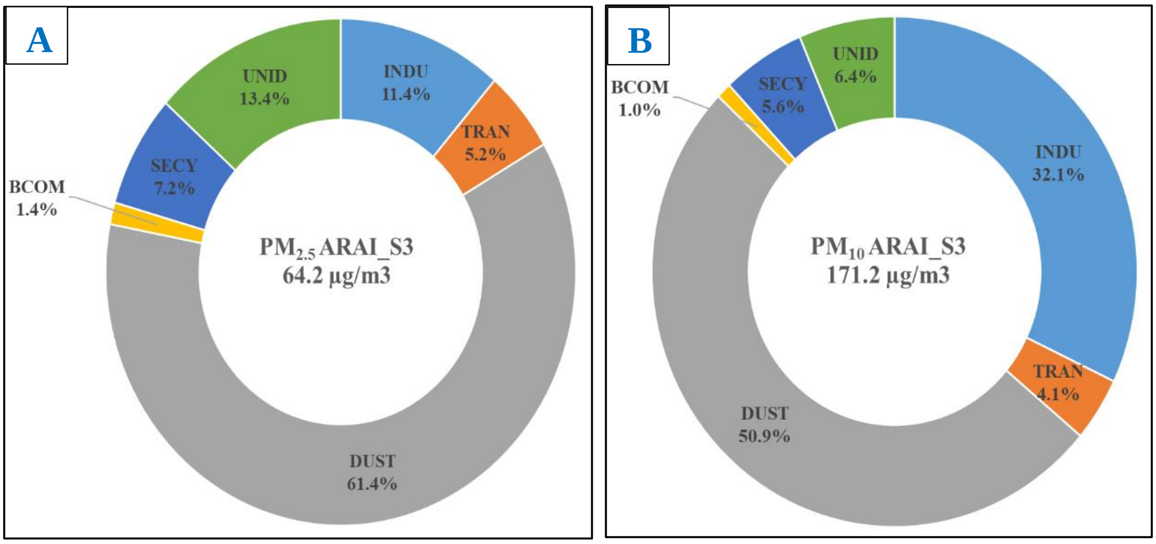
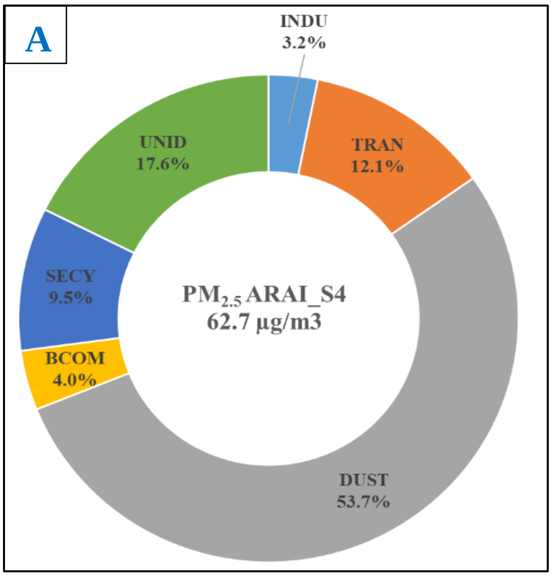


Figure 51 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S3 i.e. TATA Steel during winter season in Kalinganagar - Jajpur region*

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.

2.9.1.4. Site 4: RO Office (S4)

Fig. 52 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at RO Office (S4) site during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 62.7 µg/m^3 and 127.5 µg/m^3, respectively. During the winter season, Road and construction dust were the leading contributors to $PM_{2.5}$ at Site 4, accounting for 53.7%. Transport follow closely, contributing 12.1%, secondary aerosols 9.5%, biomass and solid waste combustion accounted for 4.0%, while industries and power plants 3.2%. The winter-season PM_{10} concentrations at Site 4 were primarily influenced by road and construction dust, contributing the highest proportion at 61.1%. Secondary aerosols followed at 9.4%, transport 6.9%. Industries and power plants 5.5%, while biomass and solid waste combustion contributed 3.0%. About 17.6% and 14.1% 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.



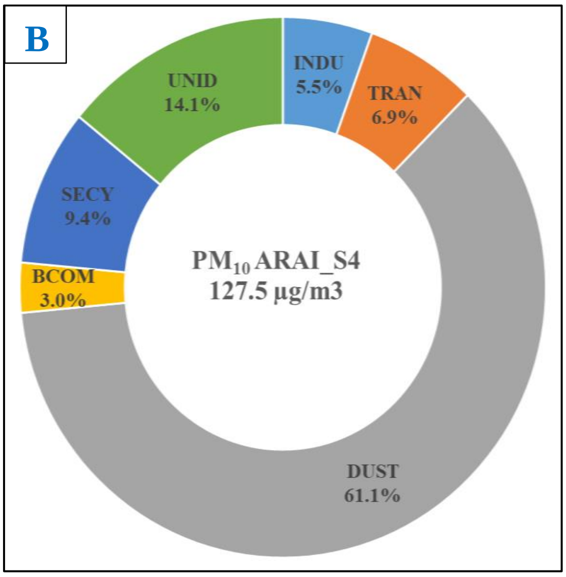


Figure 52 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S4 i.e. RO Office during winter season in Kalinganagar - Jajpur region*

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. SUMMMER SEASON

2.9.2.1. Site 1: JCDL

Fig. 53 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at JCDL (S1) during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 21.8 µg/m^3 and 99.3 µg/m^3, respectively. Road and construction dust were the largest contributor to $PM_{2.5}$ levels at Site 1, accounting for 46.0%. Secondary aerosols follow closely, contributing 17.7%. Industries and power plants contribute 12.2%, while Transport emissions and biomass combustion, 4.5% and 2.0%, respectively. Similar to $PM_{2.5}$, the road and construction dust were the largest contributor to PM_{10} levels at Site 1, constituting the highest contribution at 44.9%. Industries and power plants and Secondary aerosols follow closely, contributing 23.5% and 14.0% of the total, respectively. Transport emissions and biomass combustion make smaller contributions at this site, with 3.5% and 1.3% respectively. About 17.7% and 12.8% 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.

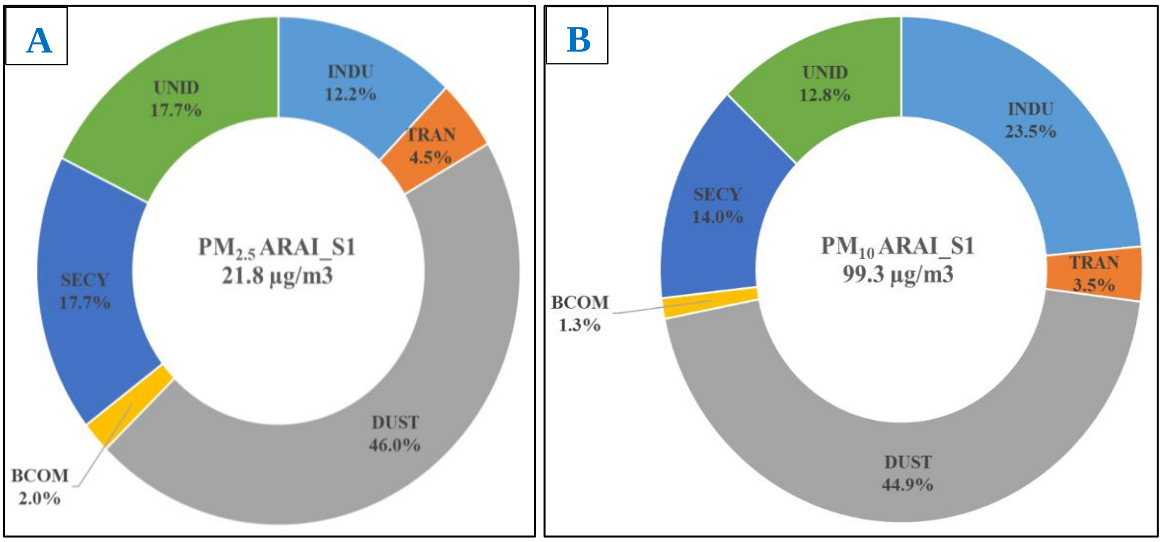


Figure 53 Sectoral source contributions to** $PM_{2.5}$ **(A) and** PM_{10} **(B) at S1 i.e. JCDL during the summer season in Kalinganagar - Jajpur region

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: Tehsil Office (S2)

Fig. 54 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at Tehsil Office (S2) during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 26.2 µg/m^3 and 80.8 µg/m^3, respectively.

$PM_{2.5}$ levels at Site 2 are primarily influenced by road and construction dust, contributing 45.4%. Industries and power plants and Secondary aerosols unidentified sources follow closely, contributing 16.6% and 15.5%, respectively, while transport emissions and biomass and solid waste combustion contribute 5.3% and 1.7%, respectively. The summer season, PM_{10} concentrations at Site 2 are primarily influenced by Industries and power plants, constituting the highest contribution at 40.4%. Road and construction dust follow closely, contributing 36.6% of the total PM_{10} levels. Secondary aerosols also make notable contributions, accounting for 9.9%. Transport emissions make smaller contributions at this site, with 3.3%. Biomass and solid waste combustion contribute 0.9% to the total PM_{10} levels. About 15.5% and 8.8% 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.

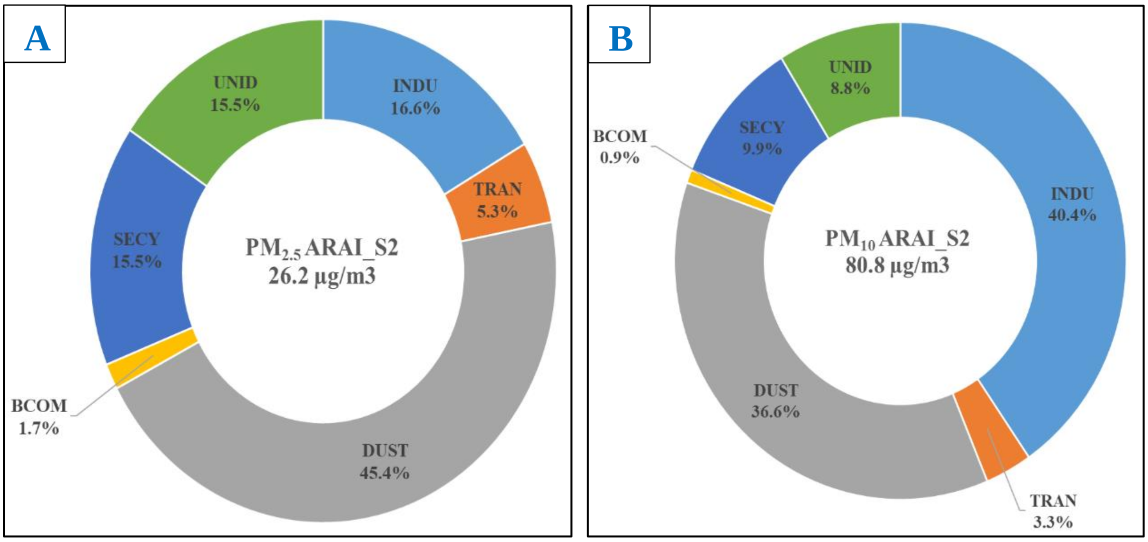


Figure 54 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S2 i.e. Tehsil Office during summer season in Kalinganagar - Jajpur region*

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.

2.9.2.3. Site 3: TATA Steel (S3)

Fig. 55 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at TATA Steel (S3) during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 23.7 µg/m^3 and 118.0 µg/m^3, respectively. Road and construction dust are the main contributors to summer season $PM_{2.5}$ levels at Site 3, accounting for 49.1%. Industries and power plants and Secondary aerosols follow closely, contributing 18.8% and 13.7%, respectively. Transport emissions contribute 4.0%, while biomass combustion contribute 0.7%. Industries and power plants are the top contributors to summer season PM_{10} levels at Site 3, accounting for the highest proportion at 44.0%. Road and construction dust follow at a distant second, constituting 37.2% of the particulate matter. Secondary aerosols also make significant contribution, accounting for 8.4% of the total PM_{10} levels. Transport emissions and biomass and solid waste combustion make smaller contributions at this site, with 2.4% and 0.4%, respectively. About 13.7% 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.

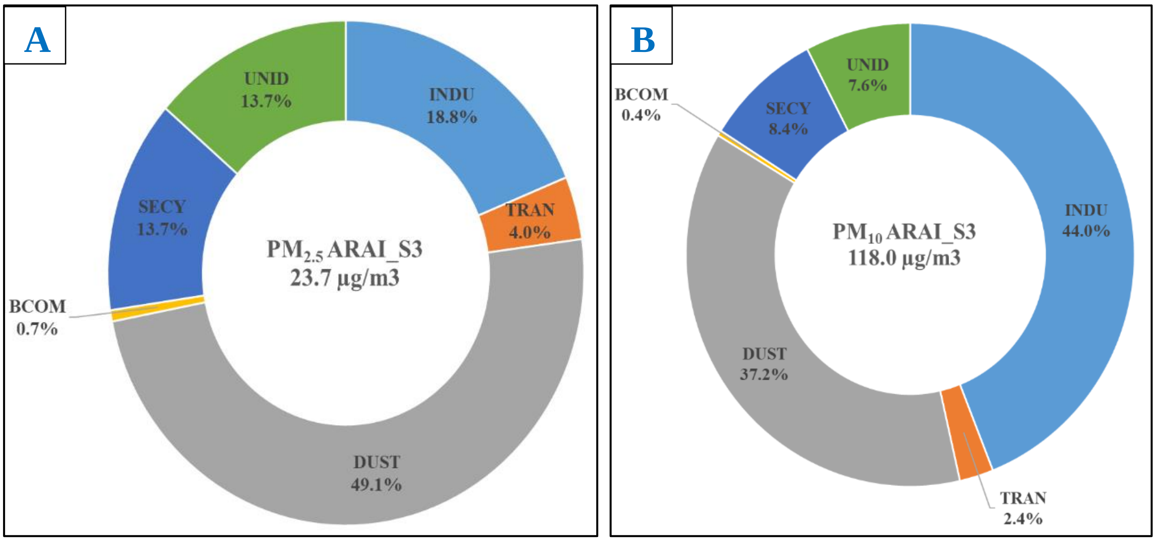


Figure 55 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S3 i.e. TATA Steel during summer season in Kalinganagar - Jajpur region*

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.

2.9.2.4. Site 4: RO Office (S4)

Fig. 56 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at RO Office (S4) site during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 24.3 µg/m^3 and 65.5 µg/m^3, respectively. Road and construction dust are the largest contributor to $PM_{2.5}$ levels at Site 4, accounting for 42.6%. Secondary aerosols follow closely, contributing 19.6%, while transport emissions contribute 9.7%. The other sources industries and power plants and biomass combustion contribute to 5.9% and 2.6% of the total $PM_{2.5}$ levels, respectively. Similar to $PM_{2.5}$, road and construction dust are the primary contributors to summer season PM_{10} levels, constituting the highest contribution at 47.7%. Secondary aerosols follow closely, contributing 16.7% of the total PM_{10} levels. Industries and power plants make a significant contribution of 11.4% to the total, while transport emissions and biomass and solid waste combustion make smaller contributions at this site, with 5.4% and 2.0% respectively. About 19.6% and 16.7% 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.

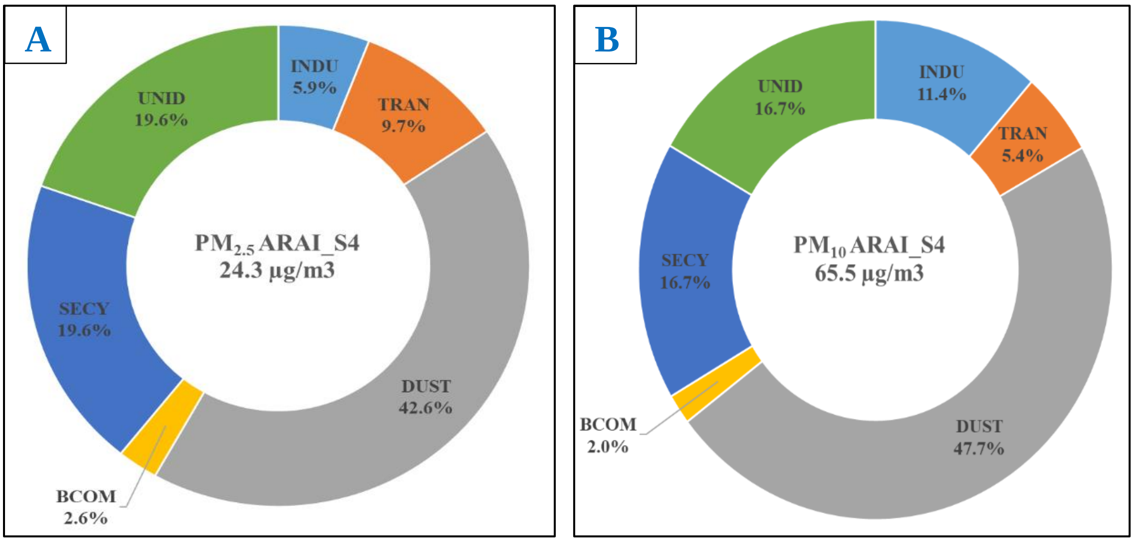


Figure 56 Sectoral source contributions to $PM_{2.5}$ *(A) and* PM_{10} *(B) at S4 i.e. RO Office during summer season in Kalinganagar - Jajpur region*

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.

2.9.3. City-level source contribution analysis

The city-level mean source contributions were determined, using the site-wise source contribution estimates obtained in the previous section. Fig. 57 and 58 presents the mean source contributions to ambient $PM_{2.5}$ and PM_{10} at Kalinganagar - Jajpur during winter and summer seasons, respectively. Overall, the winter-time $PM_{2.5}$ mass at Kalinganagar - Jajpur (Fig. 57) are found to be dominated by dust and industrial sectors with contribution of 56.2% and 9.3%, respectively. The other sources of $PM_{2.5}$ at Kalinganagar - Jajpur are identified as secondary aerosols (8.4%), transport (7.6%) and biomass and solid waste combustion (2.9%). Similarly, the winter-time PM_{10} mass at Kalinganagar - Jajpur is also found to be dominated by road and construction dust (54.4%), followed by industries and powerplants (20.9%), secondary aerosols (7.5%), transport (5.8%) and biomass and solid waste combustion (2.3%). Additionally, about 15.7% and 9.1% 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.

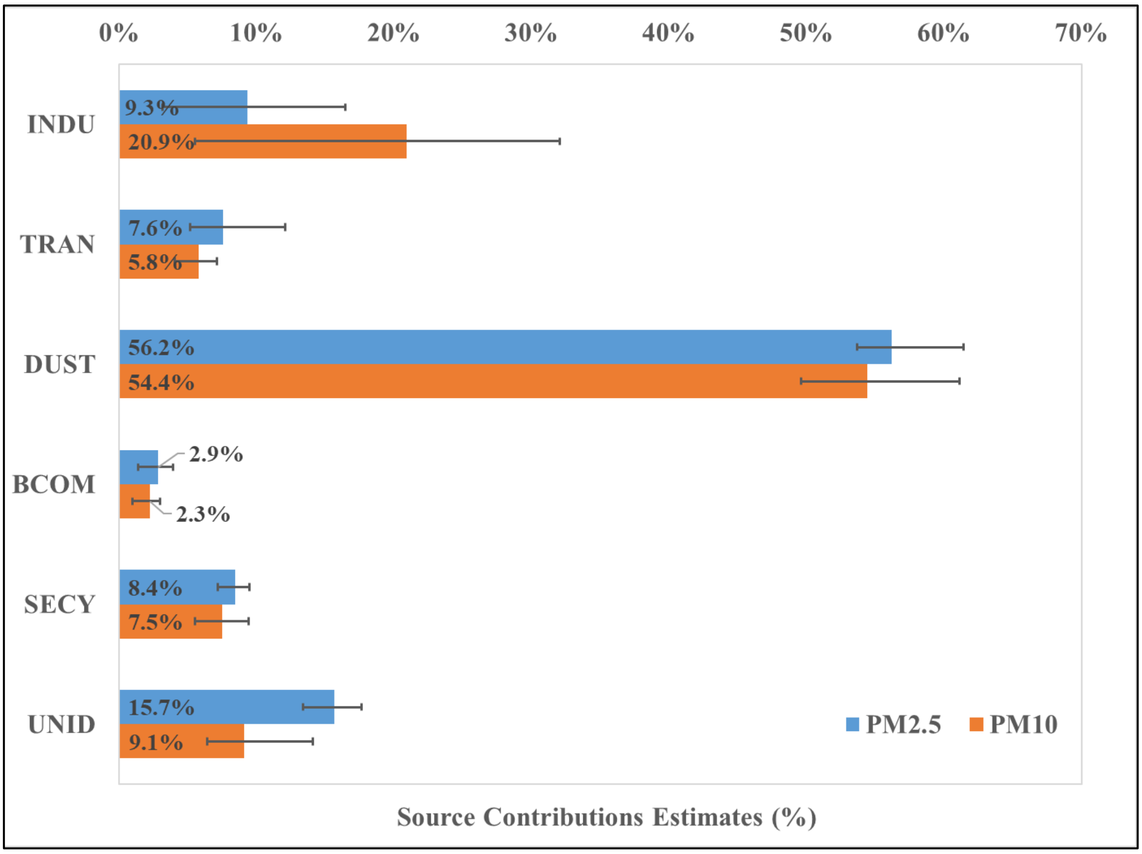


Figure 57 City-level source contribution estimates (SCE) for Kalinganagar - Jajpur region using CMB receptor model during winter season (January 1 – 20, 2022)

The summer-time $PM_{2.5}$ mass in Kalinganagar - Jajpur region (Fig. 58) is found to be dominated by dust with highest contribution of 45.8%. The other summer-time sources of $PM_{2.5}$ in Kalinganagar - Jajpur region are identified as secondary aerosols (16.6%), industries and powerplants (13.4%), transport (5.9%) and biomass and solid waste combustion (1.7%). The summer-time PM_{10} mass in Kalinganagar - Jajpur Region is found to be dominated by road and construction dust (41.6%), followed by industries and powerplants (29.8%), secondary aerosols (12.3%). The transport and biomass and solid waste combustion were found to be minor contributors with a contribution of 3.7% and 1.1%. Additionally, about 16.6% and 11.5% 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.

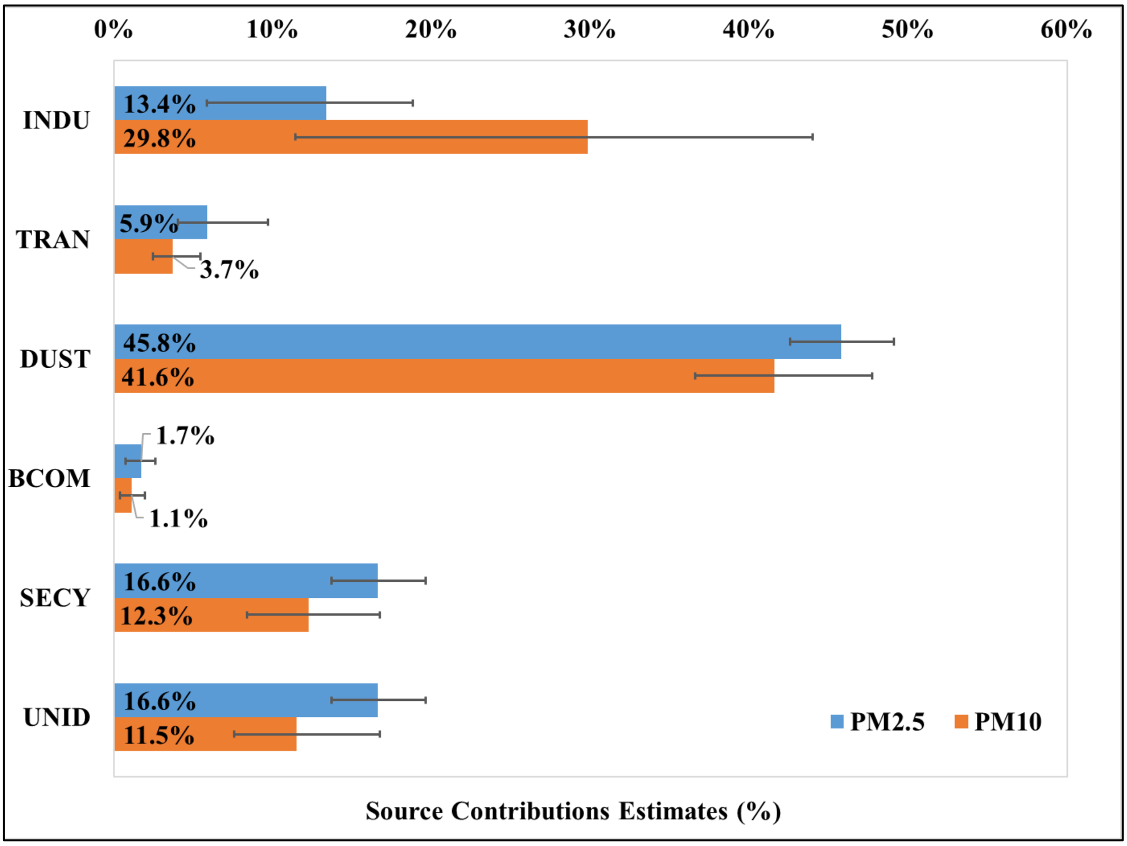


Figure 58 City-level source contribution estimates (SCE) for Kalinganagar - Jajpur region using CMB receptor model during summer season (April 22 – May 14, 2022)

(Note: The horizontal blue and orange coloured bars in Fig 57 and 58 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 Kalinga nagar- Jajpur region. The scope of this study includes:

- Quantification of emission loads originating from sectors including: Industries and thermal powerplants, Fugitive dust, Transport, Re-suspended road dust, Open waste burning, Residential, Diesel generators, Hotels, Restaurants and Bakeries, Crematoria, Brick kilns, and Construction activities in Kalinga nagar- Jajpur 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 59 shows the methodology adopted in development of emission inventory for Kalinga nagar- Jajpur 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.

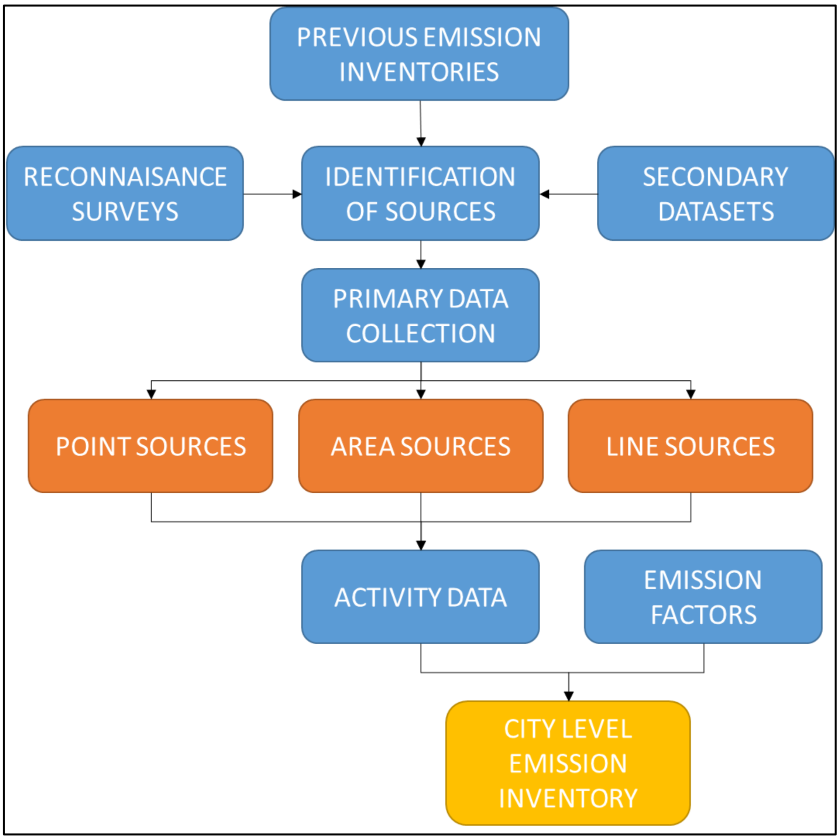


Figure 59: Approach adopted for emission inventory development at regional level

The study area was divided into high resolution grid cells at 2 X 2 km^2 grids using GIS tools. A total 104 grid cells were formed. Emission inventory has been prepared for the study area and thereafter allocated to high resolution grid cells. Fig. 60 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.

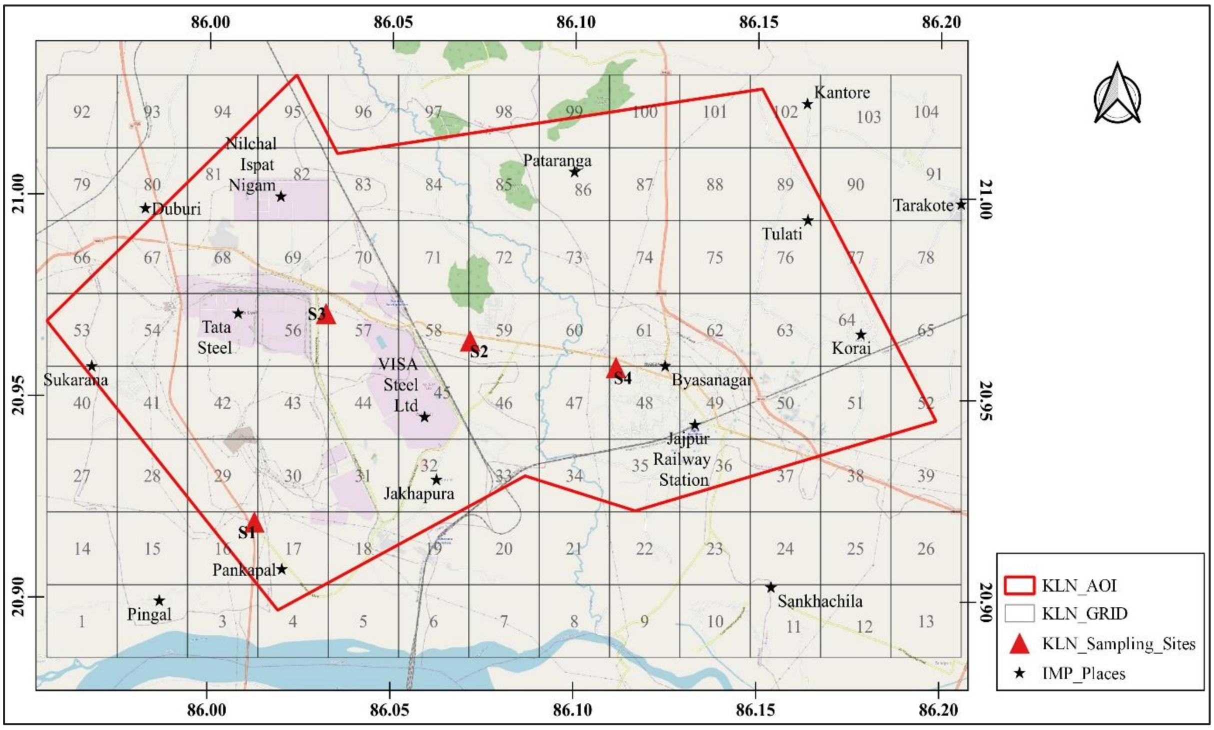


Figure 60: Map showing study area overlaid with emission inventory grids with horizontal spacing of 2 x 2 km^2

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 region-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 Kalinga nagar-Jajpur region

Source Type	Sources Included
Point Sources	Industries and thermal powerplants, Crematoria, Brick kilns
Area Sources	Fugitive dust, Residential, Open waste burning, Hotels, restaurants and bakeries, Construction, Diesel generators
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 3. 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
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. Industries and thermal powerplants

Kalinganagar is a major global hub in steel, power and ancillary products. The major industries in Kalinganagar region are Iron & Steel plants, Cement Industry, Sponge Iron and Power Industry, etc. The major industries and thermal powerplants in Kalinganagar region include: Tata Steel Ltd., Jindal Stainless Steel Ltd., Neelachal Ispat Nigam Limited, VISA Steel, JSW Cement Ltd., and Nu Vista (formerly Emami) Cement. For the steel industries, raw materials like coal, iron ore, limestone, dolomite etc. are available within a short radius. Generally, coal is the dominant fuel used by these industries (OSPCB, 2019). Figure 61 shows the major industrial areas and stack locations in the Kalinga nagar- Jajpur region. It is important to note that, important major industries which are outside the gridded study domain, but can influence the regional air quality are also considered in this assessment.

The emissions from major industries in Kalinga nagar- Jajpur 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 Kalinga nagar 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, NO_2, and SO_2). As CO and NMVOC emissions from industrial stacks are not routinely monitored, these emissions are estimated based on the production capacity.

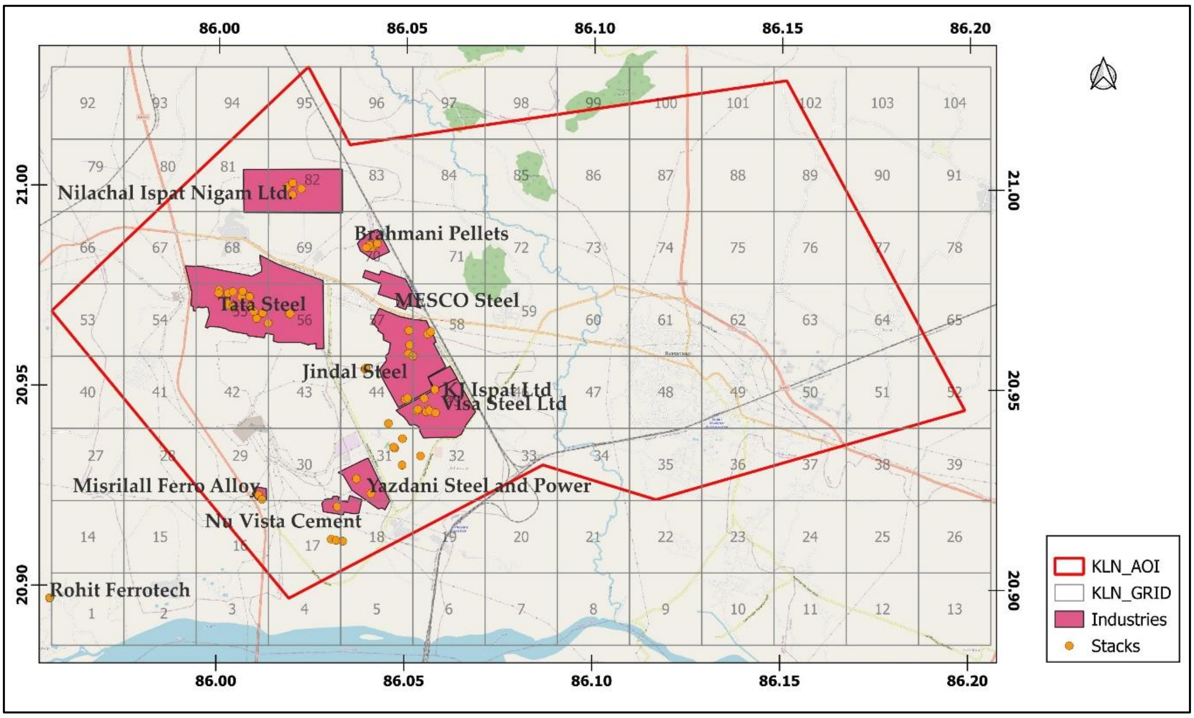


Figure 61: Map showing major industrial areas and stack locations in the Kalinganagar – Jajpur Road region

Table 6 List of major industries in Kalinganagar – Jajpur region

Sr. No.	Unit Name	Major Product(s)	Annual Capacity
1	Tata Steel Limited	Integrated steel plant	6 MTPA
2	Jindal Stainless Limited	Integrated steel plant	2.2 MTPA
3	Jindal United Steel Limited	Hot Strip Mill	1.6 MTPA
4	Jindal Coke Limited	Coke Oven	0.425 MTPA
5	Visa Steel Limited	Ferro Chrome Plant (FAP), Electricity (75 MW),	1.5 MTPA
6	Visa Special Steel Limited	Blast Furnace (250 m3), DRI 2x 500 TPD, SMS and Rolling mill.	1.5 MTPA
7	Visa Coke	Coke oven plant	4 LTPA
8	Neelachal Ispat Nigam Limited	Coke oven and By product plant, Electricity (62.5 MW), Blast Furnace (1950 m3), Sinter Plant (1.71 MTPA) and Steel Melting Shop.	1.81 MTPA
9	Yazdan Steel & Power Limited	DRI 2 x 100 TPD kiln), Electricity (10 MW (4 MW WHRB + 6 MW AFBC), Induction Furnace and Rolling mill.	0.16 MTPA
10	Rohit Ferro tech Limited	Ferro alloy	4 X 16.5 MVA
11	KJ Ispat Limited	DRI 2 x 100 Ton per day capacity	200 TPD
12	Brahmani River Pellets Limited	Iron Ore Pellet	4 MTPA
13	JSW Cement Ltd	Cement Grinding Unit	1.2 MTPA
14	Nu Vista (Emami) Cement Limited	Cement Grinding Unit	2 MTPA
15	Misrilal Mines Private Limited (Ferro Alloy Unit)	High Carbon Ferro Chrome	15000 TPA

3.4.3. Fugitive dust

In addition to industrial process emission sources described previously, industrial fugitive dust sources also contribute significantly to the atmospheric particulate burden. These fugitive dust sources mainly include raw material handling in industries, vehicle movement on paved and unpaved roads, and wind erosion from storage piles and exposed terrain. The impact of a fugitive dust sources on air pollution depends on the quantity and drift potential of the dust particles injected in to the atmosphere. In addition to large dust particles that settle down near the source, considerable amounts of fine particles also are emitted and dispersed over much greater distances from the source.

In the present study, the fugitive dust emissions are calculated based on material handling data in Industries and emission factors specified by GAINS Asia model. Table 7 provides the emission factors for material handling used in this study.

Table 7: Emission factors of PM_{10} *and* $PM_{2.5}$ *(units: kg/tonnes) from material handling and allied operations*

Raw Material	PM_{10}	$PM_{2.5}$
Iron Ore (kg/tonnes)	0.094	0.008
Coal (kg/tonnes)	0.060	0.006
Dolomite / Other (kg/tonnes)	0.037	0.004

3.4.4. 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):

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

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.

3.4.4.1. Road network digitization

Road network in the study area was digitized using Google Earth application (Fig. 62). Roads in Kalinga nagar- Jajpur region are classified into five categories viz. i) highways, ii) major roads, iii) intermediate roads, iv) minor roads and v) residential 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.

3.4.4.2. Reconnaissance survey

A Reconnaissance survey was conducted in the Kalinga nagar- Jajpur 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 7 survey locations were identified in the Kalinga nagar- Jajpur region to perform the classified vehicle count surveys and 4 areas/localities were selected for Parking lot surveys.

3.4.4.3. 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 Kalinga nagar- Jajpur 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. 63 depicts the vehicle categories used in this study.

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 March to April, 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 4 areas/localities around the selected sampling sites (S1-S4) in Kalinga nagar- Jajpur region during March to April, 2022. Table 8 and 9 shows the details of locations of vehicle count surveys and parking lot surveys respectively.

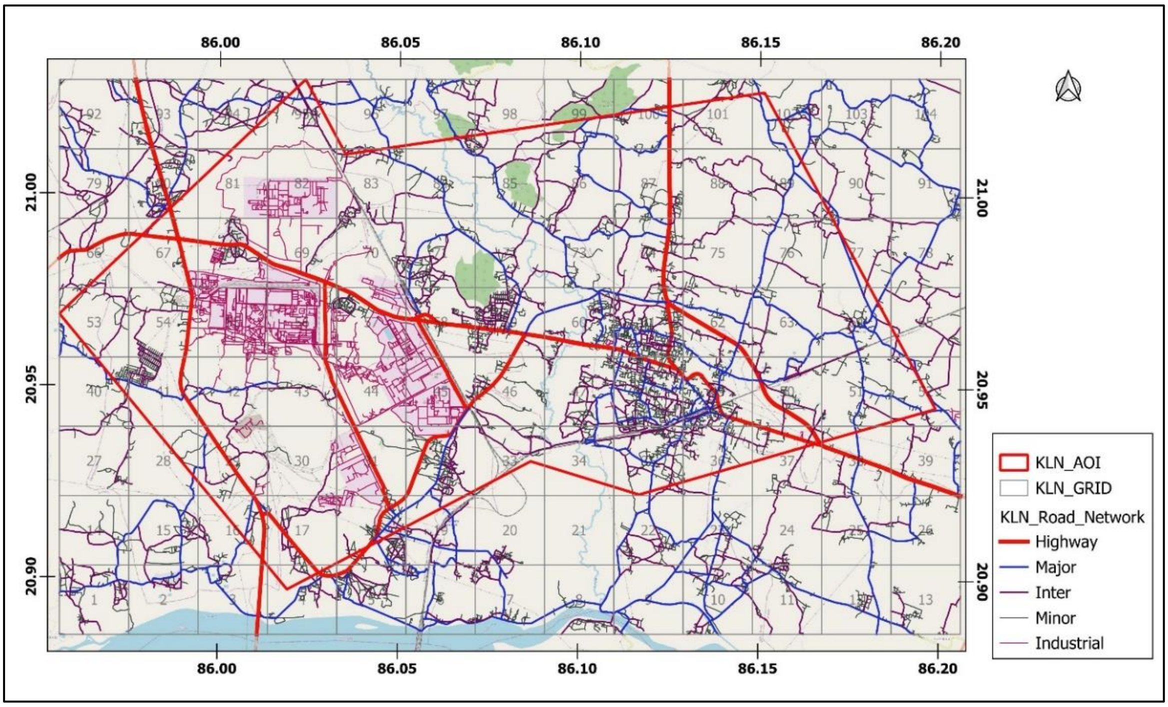


Figure 62: Map showing road network in Kalinga nagar- Jajpur region and surrounding areas digitized using OpenStreetMap and Google Earth Applications

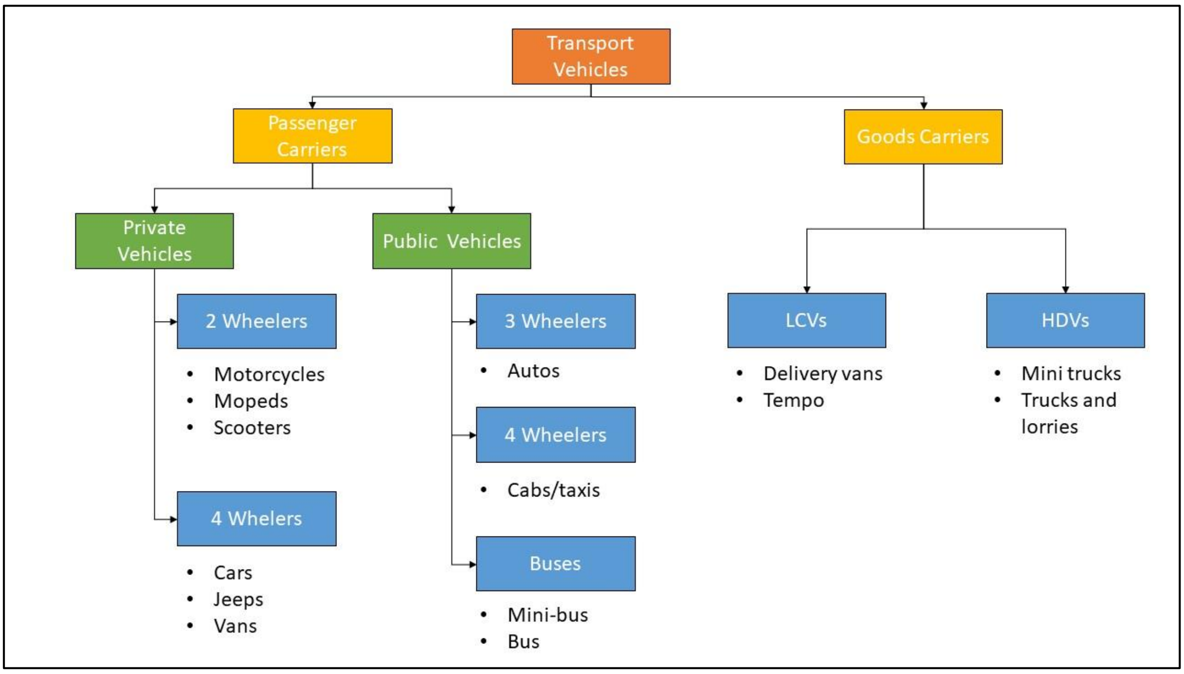


Figure 63: Vehicle categories used in this study

Each vehicle category is further differentiated in up to four fuel or engine types respectively: Gasoline, Diesel, Natural Gas, and 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 Kalinganagar - Jajpur 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 8: Locations of vehicle count surveys in Kalinga nagar- Jajpur region

Code	Road Name	Road Type	Latitude	Longitude	Direction
VC1	Satsang Road	Major	20.9488	86.1326	Satsang Marg To Medical
VC2	Stadium Road	Minor	20.9457	86.1304	Towards Radhanath Marg
VC3	Radhanath Marg	Intermediate	20.9464	86.1320	Radhanath Marg To Bus Stand
VC4	NH-53	Highway	20.9198	86.0109	Chandikhol To Duburi Road
VC5	Corridor Road	Industrial	20.9327	86.0415	Rabana To Tata Gate 3
VC6	Danagadi Road	Major	20.9640	86.0816	Jajpur To Duburi Road
VC7	Nimapali Road	Minor	20.9089	86.0074	Bangala Chowk To Pingal
VC8	Trijanga Road	Minor	20.9731	86.0788	Trijanga To
VC9	Chorda Road	Intermediate	20.9670	86.0797	Gopabandhu Chowk To Chorda

Table 9 Locations of Parking Lot Surveys in Kalinga nagar- Jajpur region

Location No.	Area Name
P1	JCDL Area
P2	Tata Steel Area
P3	Tehsil Office
P4	Byasnagar Area

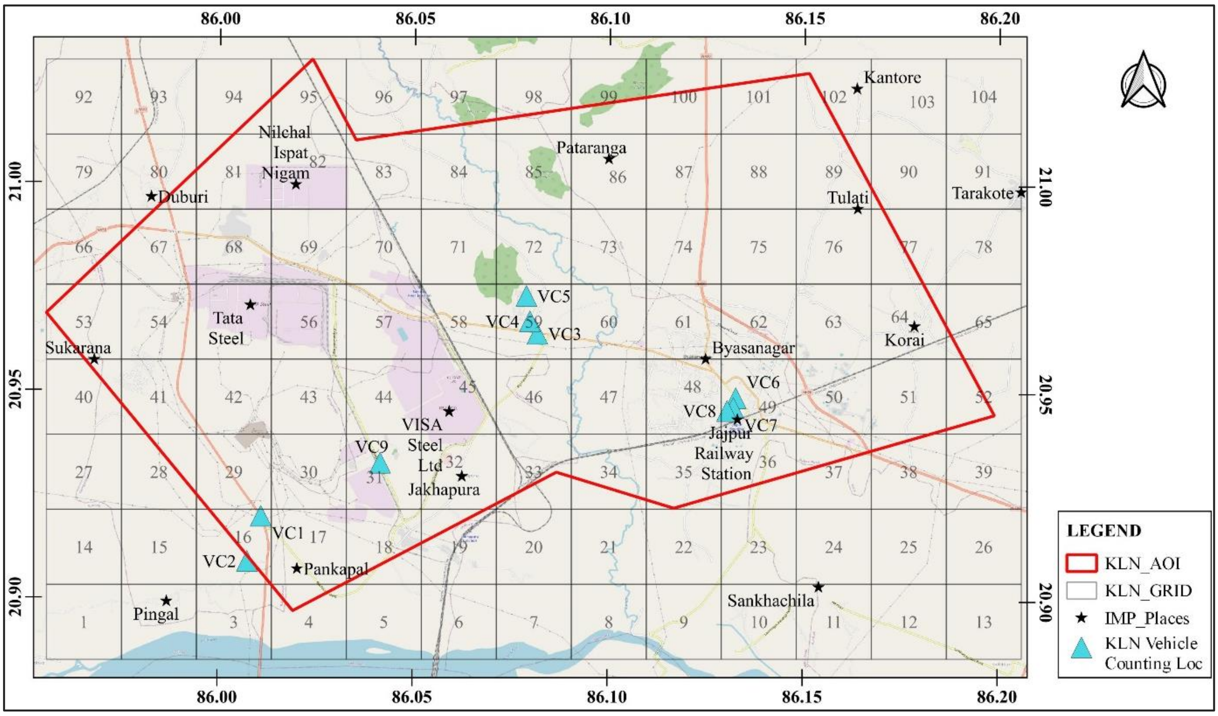


Figure 64: Map showing selected locations in Kalinganagar- Jajpur region for vehicle counting surveys.

Fig. 64 presents the classified vehicle count observed at different types of roads in Kalinganagar- Jajpur region. Major roads such as VC6 and VC9 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 except VC1, VC6 and VC9 locations, which exhibited a significant contrast in vehicular population. This can be attributed to regular traffic during office hours on weekdays.

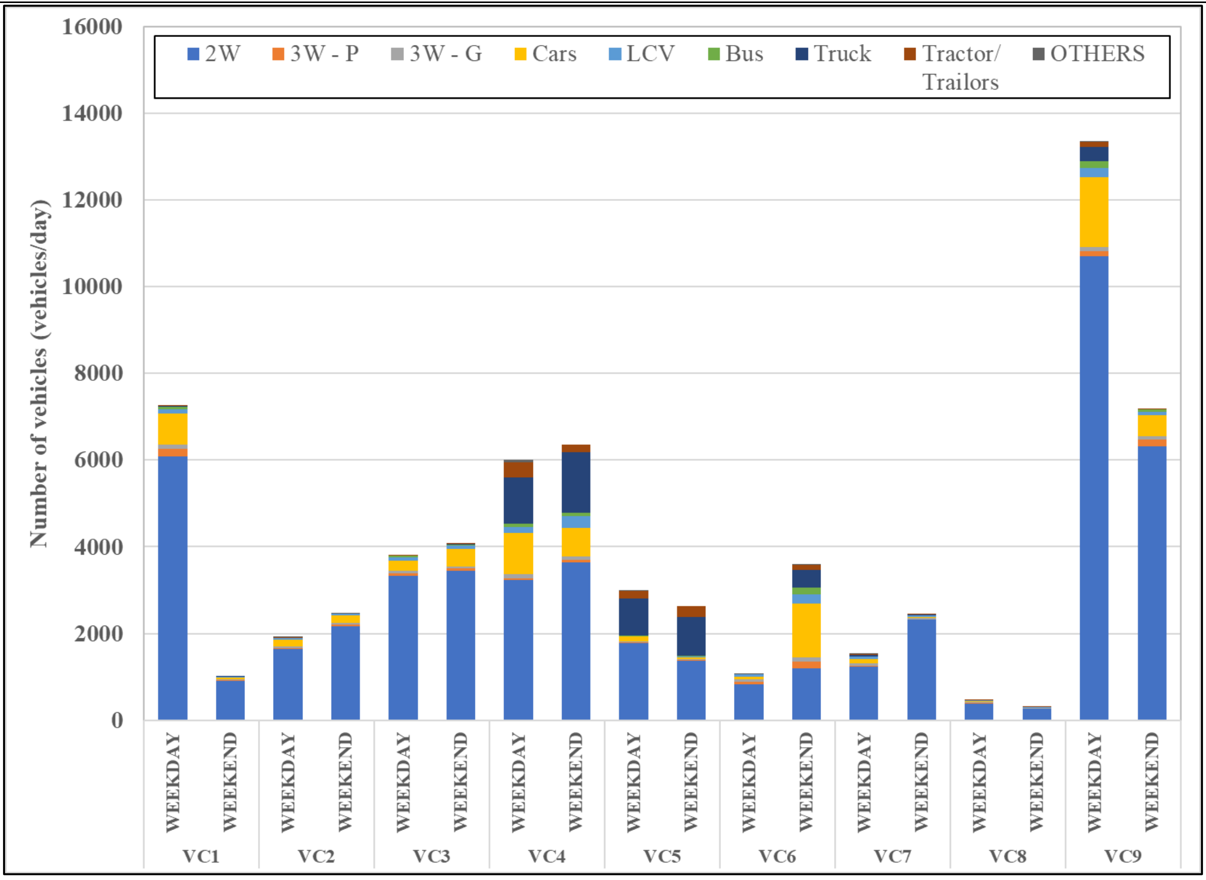


Figure 65: Classified vehicle counts observed at selected locations in Kalinga nagar-Jajpur region during the primary surveys.

Fig. 65 depicts the observed percentage distribution of vehicles according to Bharat standards in Kalinganagar- Jajpur region. A total of 506 vehicles were surveyed in the region during the primary surveys. The BS-III category vehicles are observed to be maximum (43%) followed by BS-IV (29%), BS-VI (12%), BS-II (11%), and BS-I (5%).

Fig. 67 shows the estimated daily vehicle kilometres travelled by each category of vehicles in the Kalinganagar- Jajpur region. The daily VKT is estimated to be 87.9 lakh km and is dominated by two wheelers (74.5%) followed by HDVs (7.9%), and cars (7.7%). All other vehicle categories together constitute about 10% of the daily VKT in Kalinga nagar- Jajpur region.

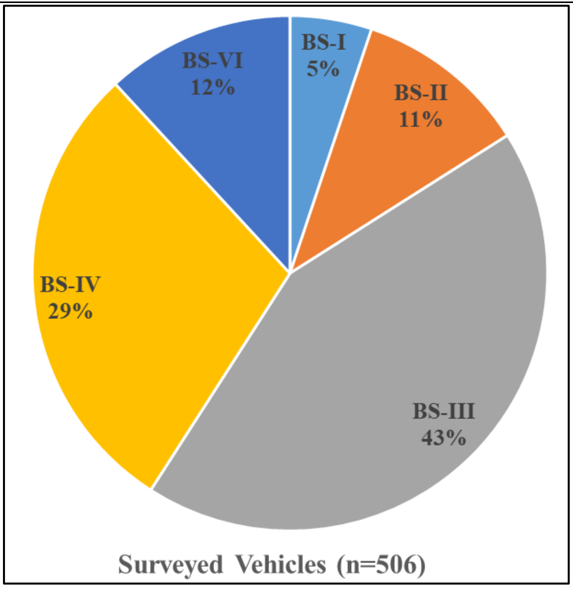


Figure 66: Distribution of vehicles as per different Baharat standards (BS) in Kalinganagar- Jajpur region obtained through parking lot surveys.

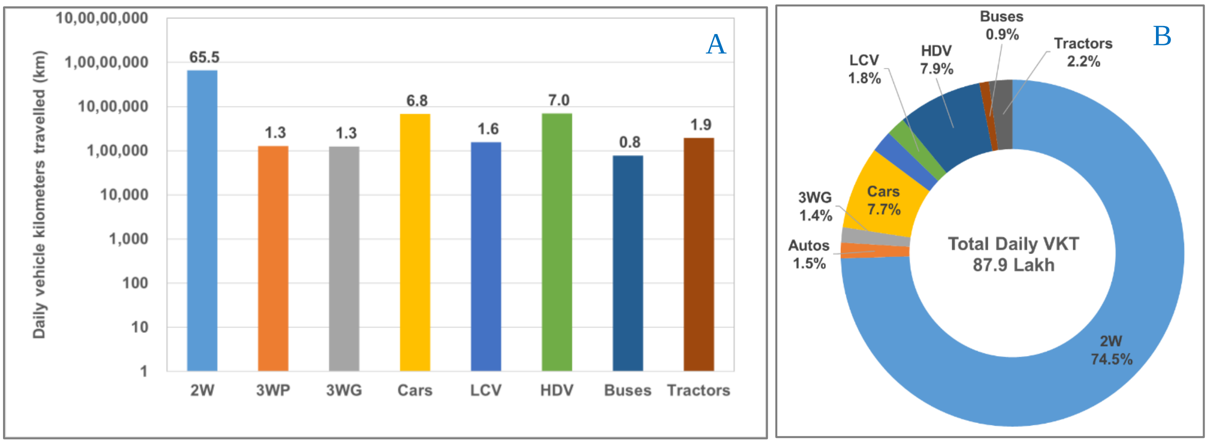


Figure 67: Daily vehicle kilometres travelled (A) and percent distribution (B) by different category of vehicles in Kalinganagar- Jajpur region.

In 69 (A), the numbers of top of each bar represent daily VKT in lakh and y-axis scale is expressed as a logarithmic scale.

3.4.5. 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:

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

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

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

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 Kalinga nagar- Jajpur 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 10. These emission factors are then multiplied by gridded VKT values obtained earlier for calculation of vehicular emissions to obtain total road dust emissions.

Table 10: Road dust re-suspension emission factors (in g/km) used in this study

Fraction	AREA TYPE	HIGHWAY	MAJOR	INTERMEDIATE	MINOR	RESI
$PM_{2.5}$	Urban	3.24	0.64	2.66	0.32	0.36
$PM_{2.5}$	Rural	4.05	0.80	3.33	0.40	0.45
$PM_{2.5}$	Industrial	8.10	1.60	6.65	0.80	0.90
PM_{10}	Urban	13.39	2.65	11.00	1.32	1.48
PM_{10}	Rural	16.74	3.31	13.75	1.64	1.85
PM_{10}	Industrial	33.48	6.62	27.50	3.29	3.71

3.4.6. Residential

The basic equation (10) employed for emission estimation from the residential sector is:

$$E_p = \sum_{f=1}^{6} Pop_f \text{ x } C_f \text{ x } EF_{f,p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(10)$$

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 Kalinga nagar- Jajpur region is available for year 2011 but the 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. 68) 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 Kalinganagar- Jajpur region as a part of this study. The emission factors for residential sector used in this study are summarized in Table 11.

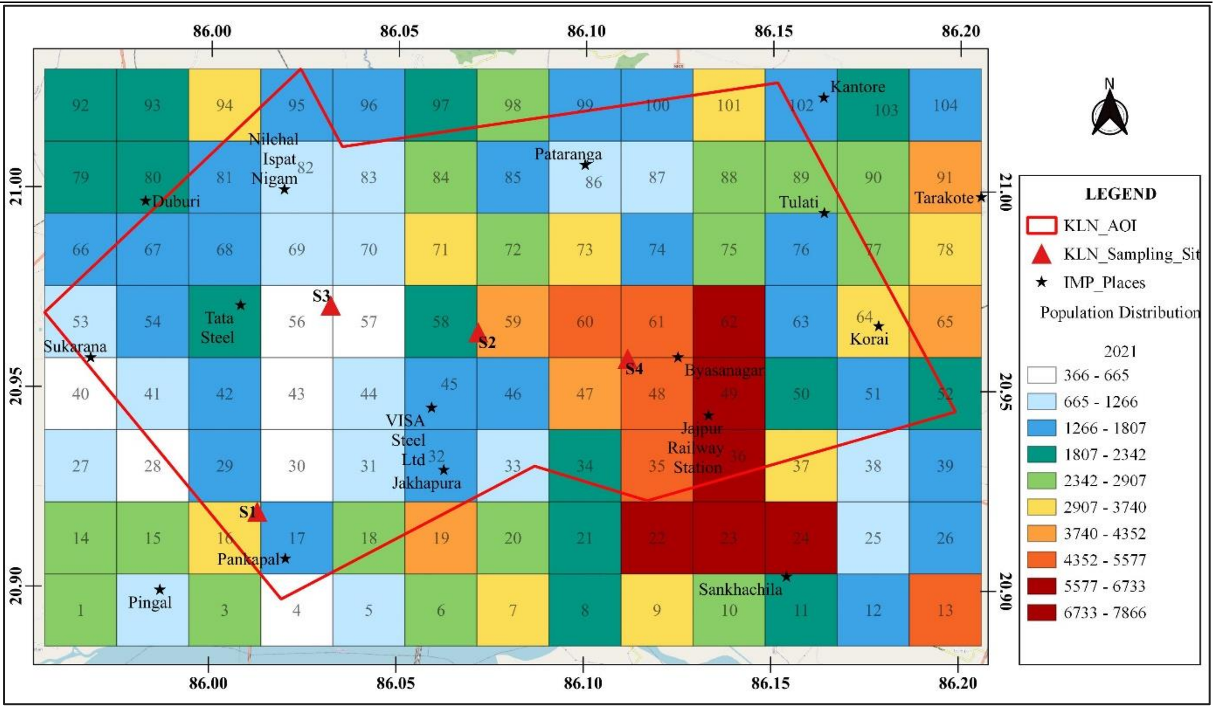


Figure 68 Map showing the estimated gridded population of the study area in year 2021

Table 11: 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)

3.4.7. Open Waste Burning

The basic equation (11) followed to estimate the emissions of different pollutants from the open burning of solid waste is:

$$E_p = W_b \text{ x } EF_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(11)$$

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 ~450 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. 12 stands for the inert fraction of the waste (ash and dust), which is estimated to be about 11.73% for similar regions. 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).

$$\mathbf{W_b = (MSW_P - MSW_C - MSW_R - MSW_F)\ x\ (1 - f_i)\ x\ 0.6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)}$$

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 12.

Table 12: 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

3.4.8. 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. 69 shows the map of construction locations identified using the satellite imagery. The emissions are obtained by using equation 13.

$$\mathbf{E = A_s\ x\ EF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. (13)}$$

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.

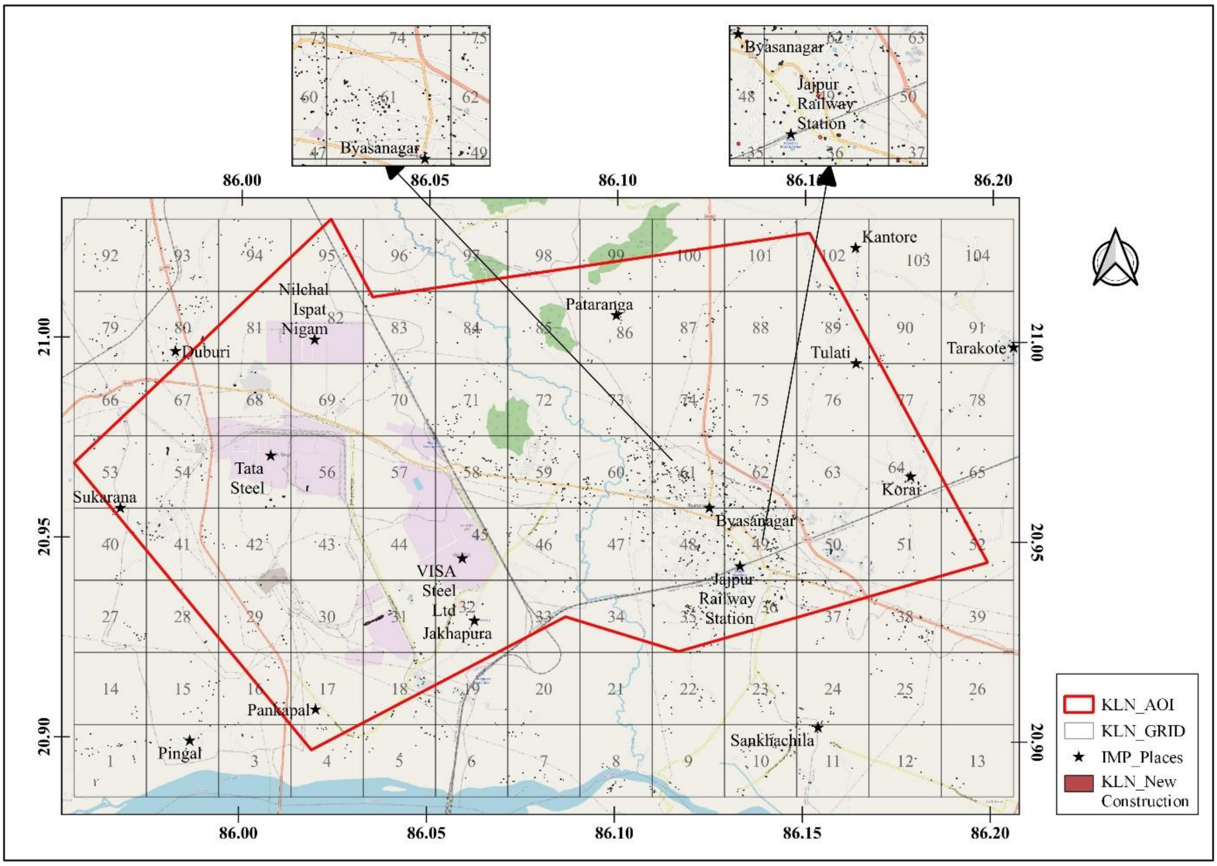


Figure 69 Map showing construction areas identified using the satellite imagery in Kalinga nagar- Jajpur region. The inset view shows zoomed in view of new construction activities in grid no. 49 and 61 of the study domains.

3.4.9. 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 19 number of brick kilns. Most of the brick kilns are of traditional clamp type brick kilns. Fig. 70 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 13. The total emissions from brick kilns calculated using Eq. 14

$$\mathbf{E_P = W_b \text{ x } EF \ldots\ldots\ldots\ldots..(14)}$$

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.

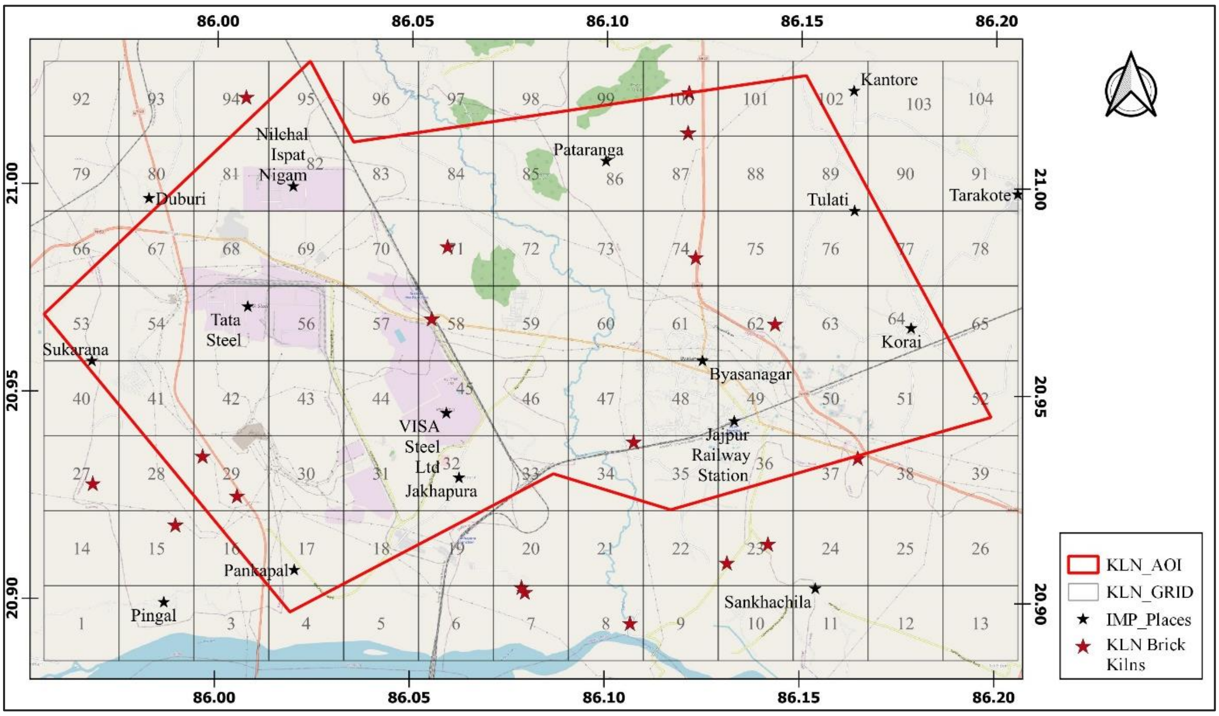


Figure 70 Map showing locations of brick kilns in the Kalinganagar - Jajpur study domain identified using satellite imagery

Table 13 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

3.4.10. Industrial 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 Kalinga nagar 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 14.

Table 14 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

3.4.11. Crematoria

Cremating the bodies of dead people is an ancient ritual and practice in India. The total emissions from cremation calculated using Eq. 15.

$$E_p = F_b \text{ x } EF_{f,p} \dots\dots\dots\dots\dots\dots\dots..(15)$$

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 average number of dead bodies cremated each month is calculated based on crude death rate of Jajpur 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 15. The emissions are quantified using equation 14.

Table 15: Emission Factors for crematoria (g/body)

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

3.4.12. Hotels, Restaurants and Bakeries

Emissions from this sector are mainly generated due to coal and wood used for cooking activities in hotels, restaurants, bakeries and open eateries. Additionally, coal is also used in tandoors and/or barbeques. The common fuels used by restaurants/hotels in Kalinganagar - Jajpur region are LPG, coal and wood. The equation (16) used for calculating emissions by this sector:

$$\mathbf{E_p = C_f \ x \ EF_{f,p} \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . (16)}$$

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 Kalinganagar - Jajpur 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 and google maps. 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 16). It is also assumed that no control devices are installed in the restaurants to control the emissions.

Table 16 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

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 13 source sectors in development of emission inventory for the Angul region. Although, the sectors discussed above represent regional emissions in Angul 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 2021. 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 Angul region. Annexure G-6 depicts the time series plot of daily fire counts observed during year 2021 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 6, during summer months. These fire incidents are mainly observed over the forest and remote areas 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. Industries and thermal powerplants

As discussed earlier, Kalinganagar - Jajpur region is home to large industrial units including iron and steel plants, steel rolling mills, ferro-alloy industries, coking industries, cement industry, captive powerplants and a few sponge iron and chemical units. Many of these industries mainly use coal as the primary fuel. Figure 71, shows the stack emissions originating from these industries. Due to large usage of coal in industries, SO_2 emerged as one of the major pollutants in the region, emitting 17,654 tonnes per year in the base year i.e. 2021. This is followed by NO_X (11,669 tonnes per year), PM_{10} (3,024 tonnes per year) and $PM_{2.5}$ (2,016 tonnes per year). CO emissions from industrial stacks are estimated using production capacity-based method and are on higher side i.e. 96,969 tonnes per year.

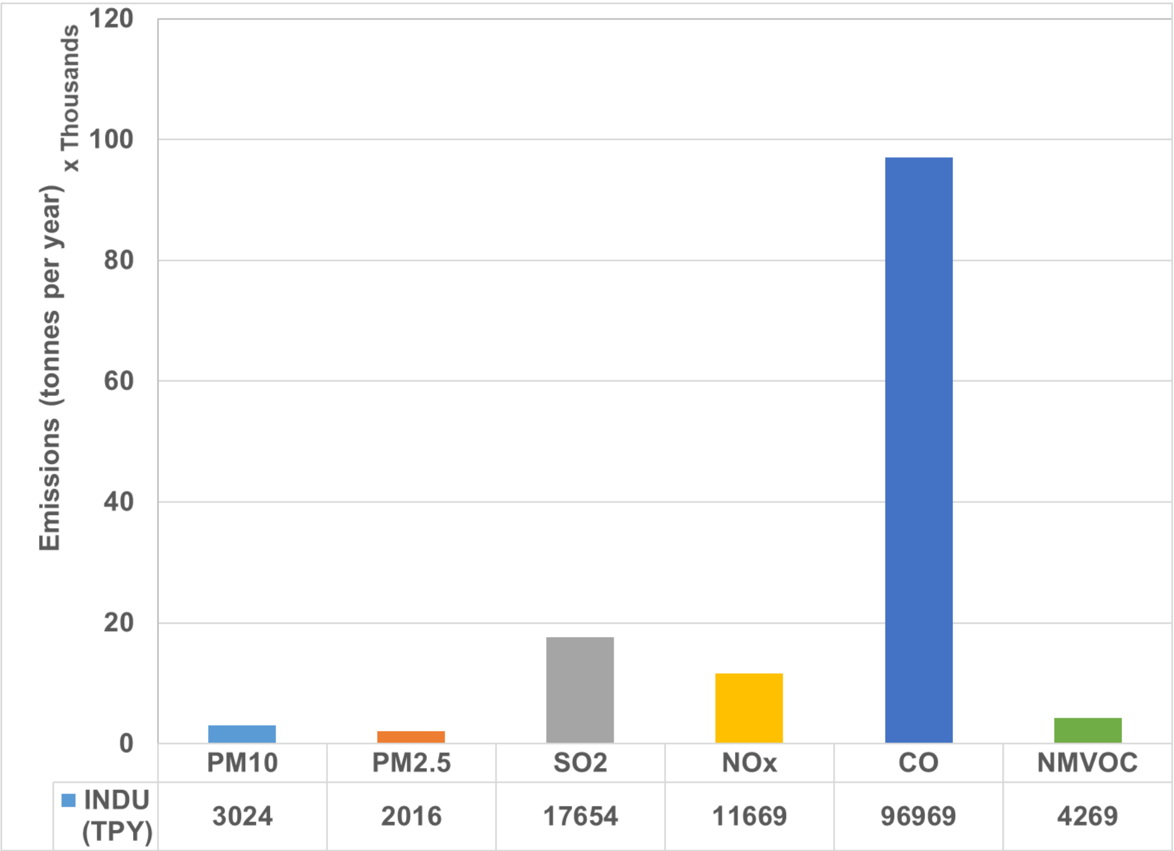


Figure 71: Emissions load (tonnes per year) of pollutants originating from industrial sector in Kalinganagar - Jajpur region

3.7.2. Industrial 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 72 shows the fugitive emissions load originating from different industrial operations in Kalinganagr - Jajpur region. PM_{10} was estimated to be 3,017 tonnes per year, followed by $PM_{2.5}$ (417 tonnes per year).

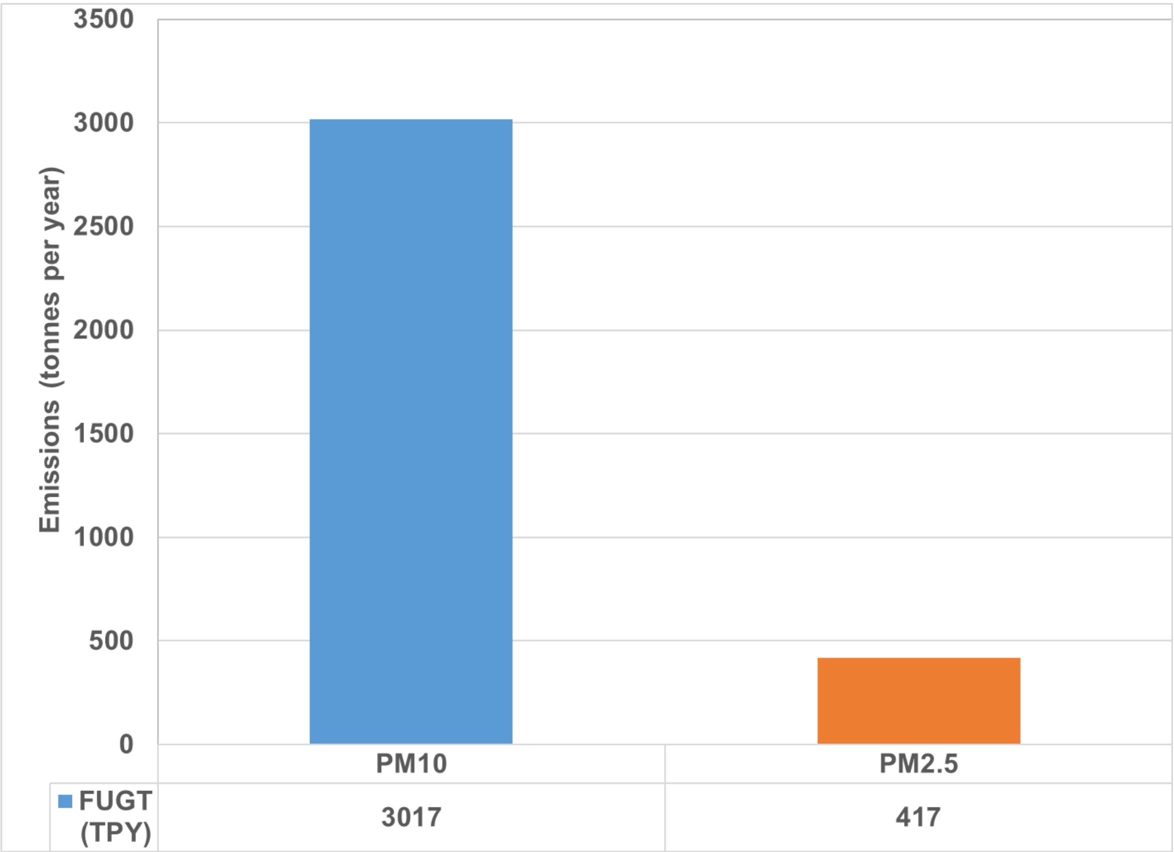


Figure 72: Emissions load (tonnes per year) of pollutants originating from fugitive operations in Kalinganagar - Jajpur region

3.7.3. Transport

Figure 73 shows the emissions of pollutants originating from transport sector in Kalinganagar - Jajpur region. It can be seen that CO is the maximum contributing pollutant from transport sector in Kalinganagar - Jajpur with emissions of 6519 tonnes per year, followed by NMVOCs (4,410 tonnes per year), and NO_X (3,713 tonnes per year). Transport sector contribution to regional PM_{10} and $PM_{2.5}$ emissions was found to be 396 and 357 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.

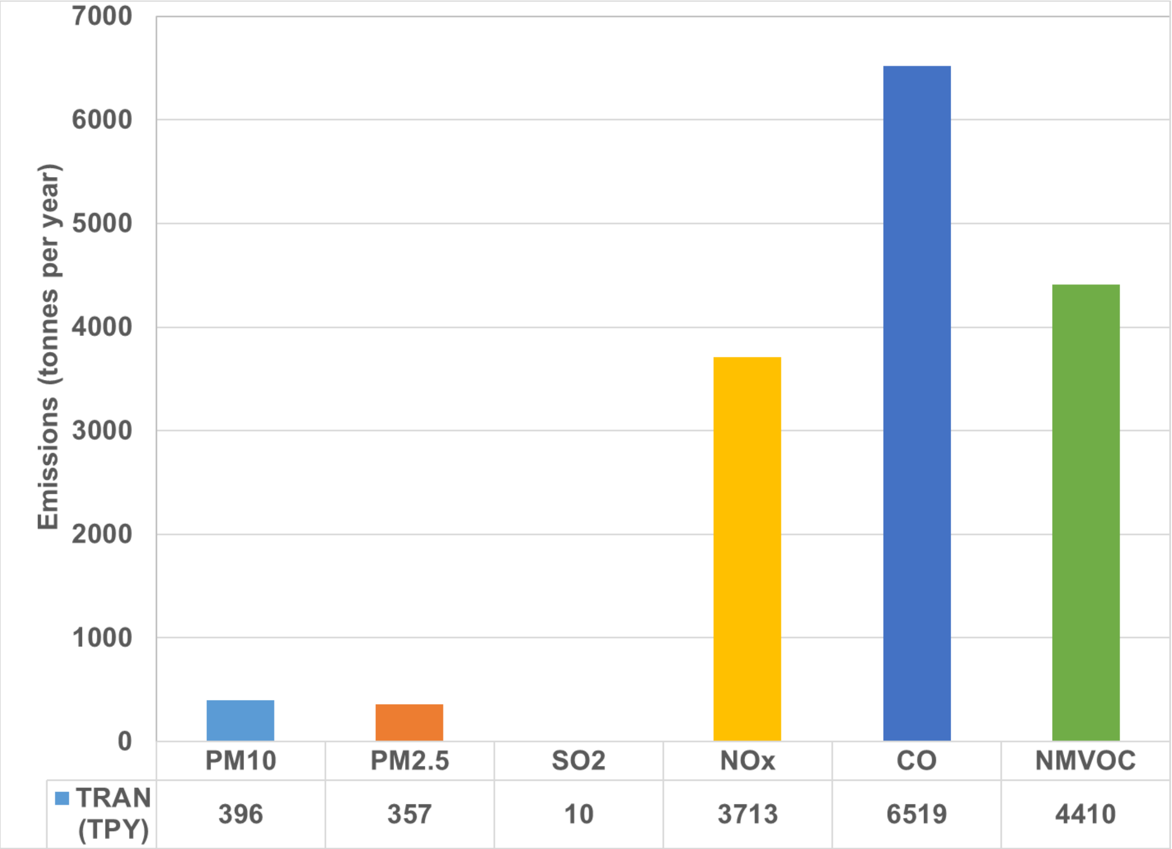


Figure 73: Emission loads (tonnes per year) of pollutants originating from the transport in Kalinganagar - Jajpur region

3.7.4. Road dust resuspension

The PM emissions generated due to road dust re-suspension in Kalinganagar - Jajpur region are depicted in Fig. 74. 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 9,812 tonnes per year. The fine fraction i.e. $PM_{2.5}$ emissions are estimated to be 2,374 tonnes per year in 2021. $PM_{2.5}$ emissions from road dust re-suspension are about four times lower than PM_{10} emissions.

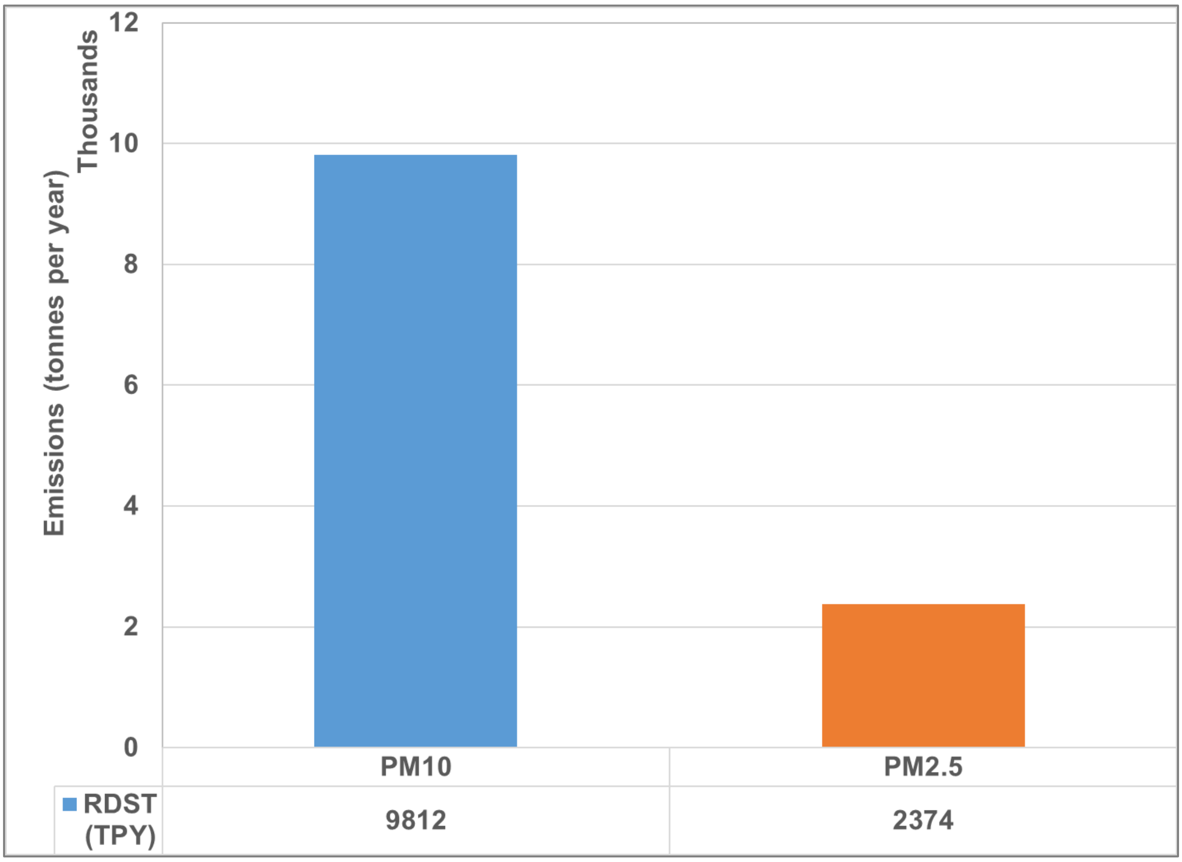


Figure 74: Emission load (tonnes per year) of pollutants originating from the road dust resuspension sector in Kalinganagar - Jajpur region

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

3.7.5. Residential

Figure 75 depicts the emission loads originating from residential sector in Kalinganagar - Jajpur region. The residential sector emissions are largely attributed to use of wood and coal as fuel for cooking and heating applications. Although LPG connections are available with individual households, the gas refilling is avoided citing the higher costs involved. Further, wood and coal are easily and cheaply available in surrounding areas. Due to incomplete combustion of solid fuels, CO is found to be the major pollutant from residential sector with annual emissions of 874 tonnes per year, followed by NMVOCs (301 tonnes per year), PM_{10} (90 tonnes per year), $PM_{2.5}$ (62 tonnes per year), NO_X (36 tonnes per year) and SO_2 (12 tonnes per year).

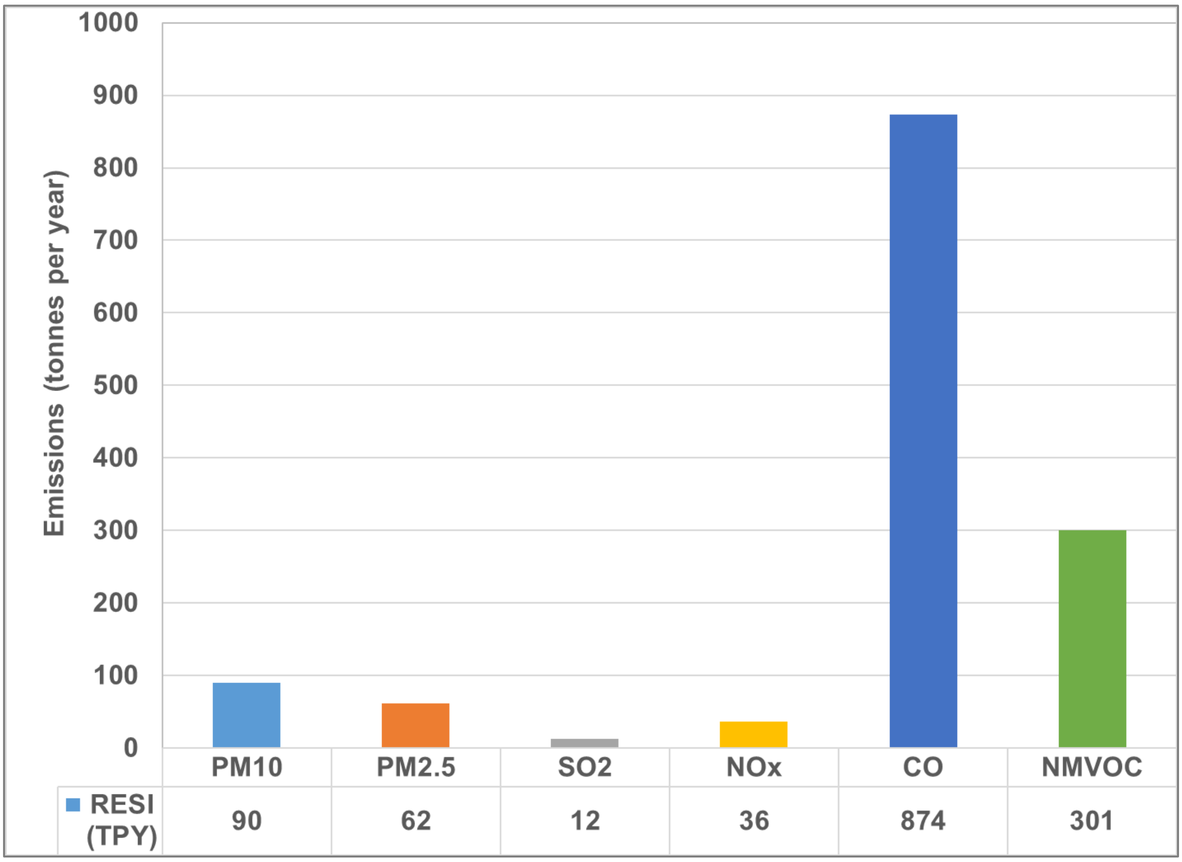
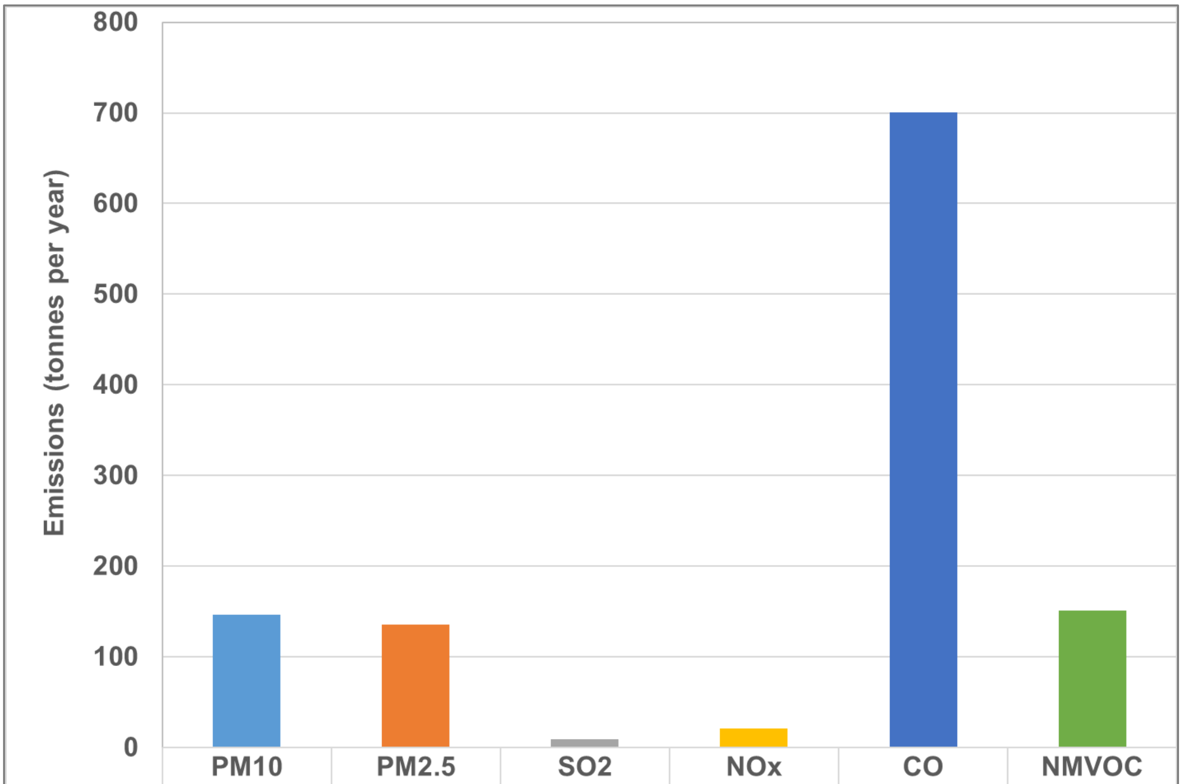


Figure 75: Emissions load (tonnes/year) of pollutants originating from residential sector in Kalinganagar - Jajpur region

3.7.6. Open waste burning

Figure 76 presents the emissions of air pollutants originating from open waste burning in Kalinganagar - Jajpur region. It is observed that, due to incomplete combustion of the waste a large amount of CO would be introduced into the atmosphere (700 tonnes per year) followed by NMVOCs (152 tonnes per year), PM_{10} (146 tonnes per year), $PM_{2.5}$ (136 tonnes per year), NO_X (21 tonnes per year) and SO_2 (9 tonnes per year).

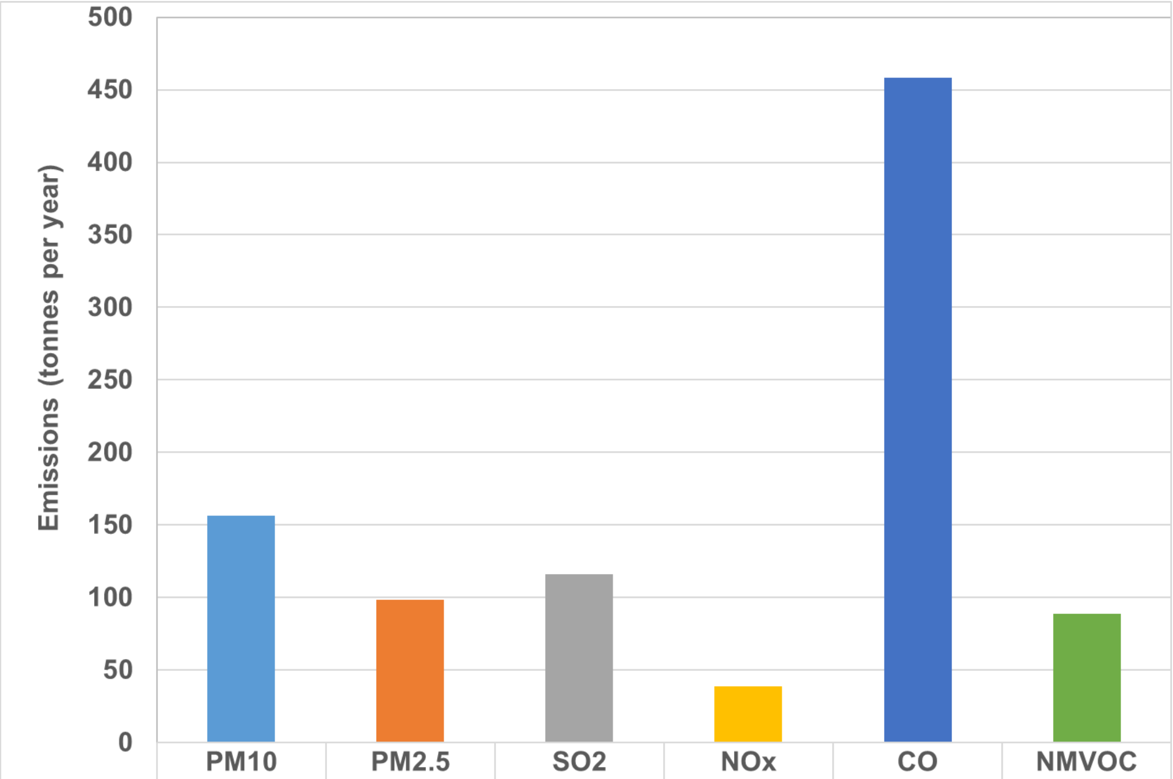


	PM10	PM2.5	SO2	NOx	CO	NMVOC
WAST (TPY)	146	136	9	21	700	152

Figure 76 Emission load (tonnes per year) of pollutants originating from the open waste burning sector in Kalinganagar - Jajpur region

3.7.7. Hotels, restaurants and bakeries

Figure 77 presents the emissions load contributed by hotels, restaurants, bakeries and open eateries in Kalinganagar - Jajpur region. CO has been found to be the major contributor 459 tonnes per year, followed by, PM_{10} (157 tonnes per year), SO_2 (116 tonnes per year), $PM_{2.5}$ (98 tonnes per year), NMVOC (89 tonnes per year), and NO_x (39 tonnes per year).



	PM10	PM2.5	SO2	NOx	CO	NMVOC
HRBE (TPY	157	98	116	39	459	89

Figure 77: Emissions load (tonnes per year) of pollutants originating from hotels, restaurants and bakeries in Kalinganagar - Jajpur region

3.7.8. Construction

Figure 78 shows the PM_{10} and $PM_{2.5}$ emissions originating from construction activities in Kalinganagar - Jajpur region. Construction sector is estimated to contribute about 188 tonnes per year of PM_{10} and 32 tonnes per year of $PM_{2.5}$.

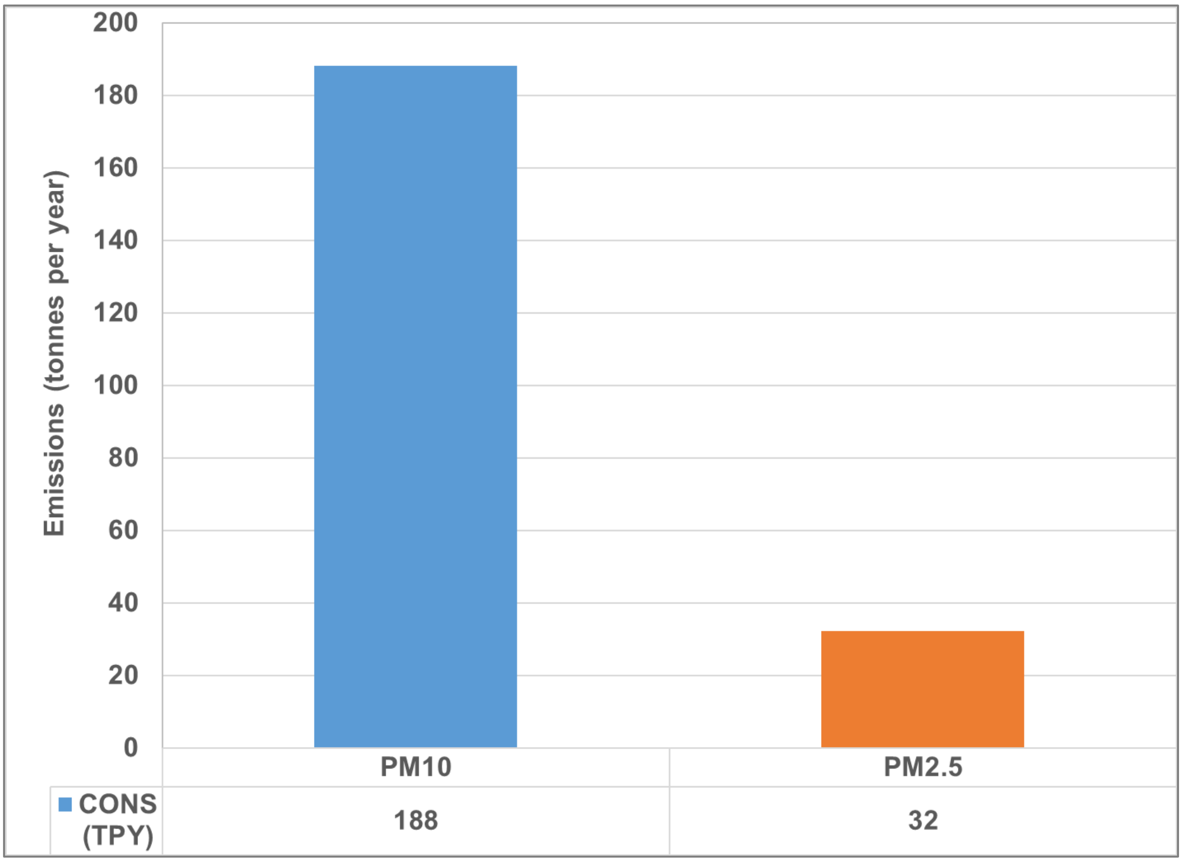


Figure 78: Emissions load (tons/year) of pollutants originating from construction activities in Kalinganagar - Jajpur region

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

3.7.9. Brick Kilns

Figure 79 shows the emissions of pollutants originating from brick kilns in Kalinganagar - Jajpur region. CO is the maximum contributor with emissions of 405 tonnes per year, followed by PM_{10} (53 tonnes per year), $PM_{2.5}$ (40 tonnes per year), SO_2 (12 tonnes per year), and NMVOC (6 tonnes per year). NO_X was found to be lowest contributor with emission of less than 0.1 tonnes per year.

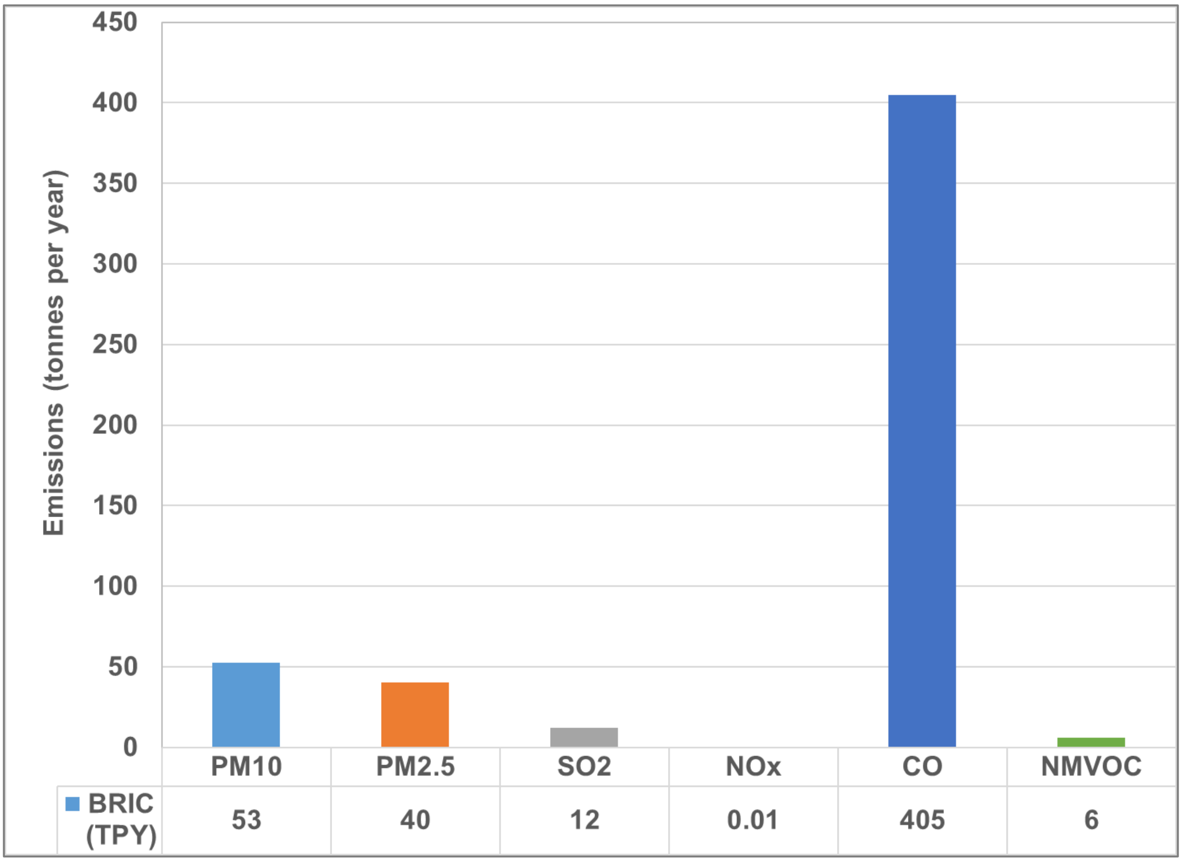


Figure 79 Emissions loads (tonnes per year) of pollutants originating from brick kilns in Kalinganagar - Jajpur region

3.7.10. Industrial diesel generators

As discussed earlier, industrial diesel generators are only used during the power failure emergency, they have very less emissions. Figure 80 shows emissions of pollutants originating from diesel generators usage in Kalinganagar - Jajpur region. NMVOC is the major contributor (90 tonnes per year) from industrial diesel generators, followed by NO_X (63 tonnes per year), CO (14 tonnes per year). The industrial DG sets in the region emit about 4 tonnes per year PM_{10}, $PM_{2.5}$ and SO_2, each.

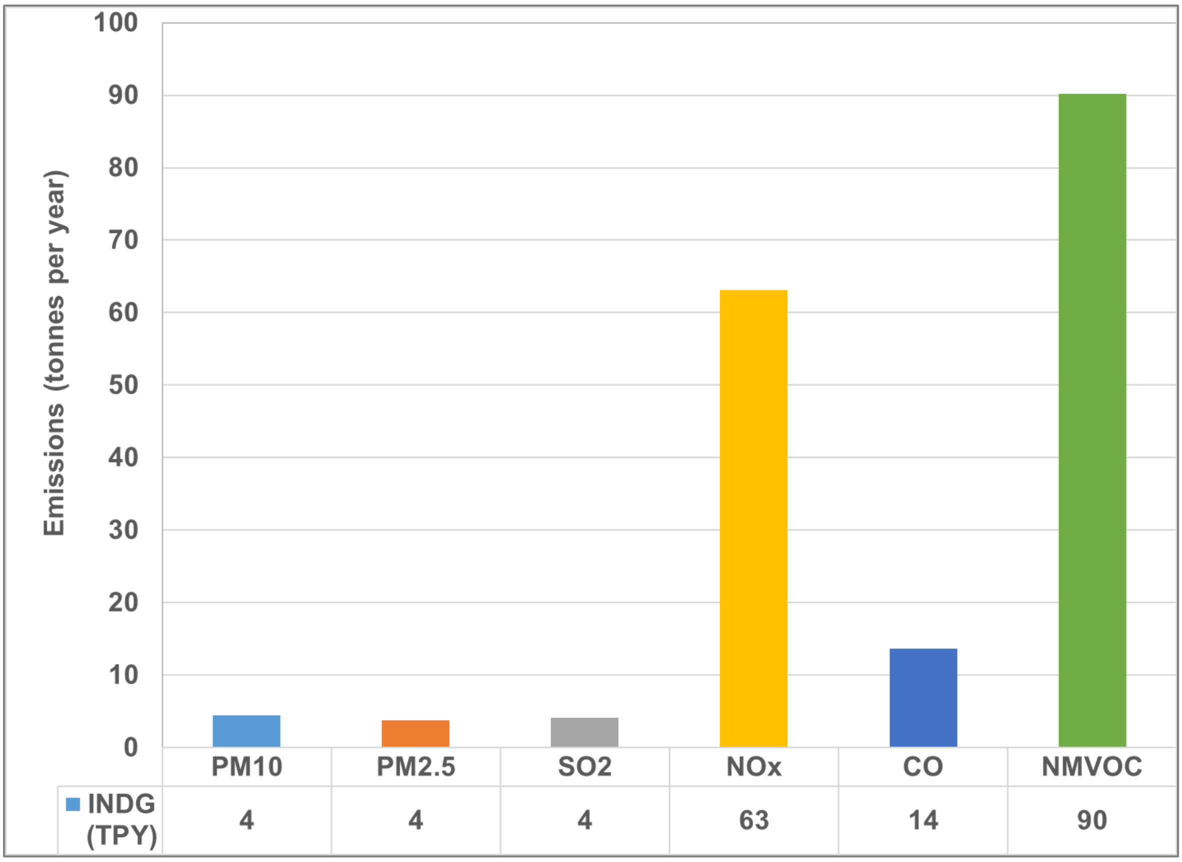


Figure 80 Emissions load (tonnes per year) of pollutants originating from industrial diesel generators usage in Kalinganagar - Jajpur region

3.7.11. Crematoria

Figure 81 shows the emissions of pollutants originating from cremation activities in Kalinganagar - Jajpur region. Due to incomplete combustion of wood in wood pyres, CO is the maximum contributor with emissions of 41 tonnes per year, followed by NMVOCs (23 tonnes per year), PM_{10} (8 tonnes per year) and $PM_{2.5}$ (4 tonnes per year). NO_X was found to contribute 1 tonne per year of emissions, while SO_2 was found to be the lowest among all pollutants with less than 0.5 tonnes per year of emissions.

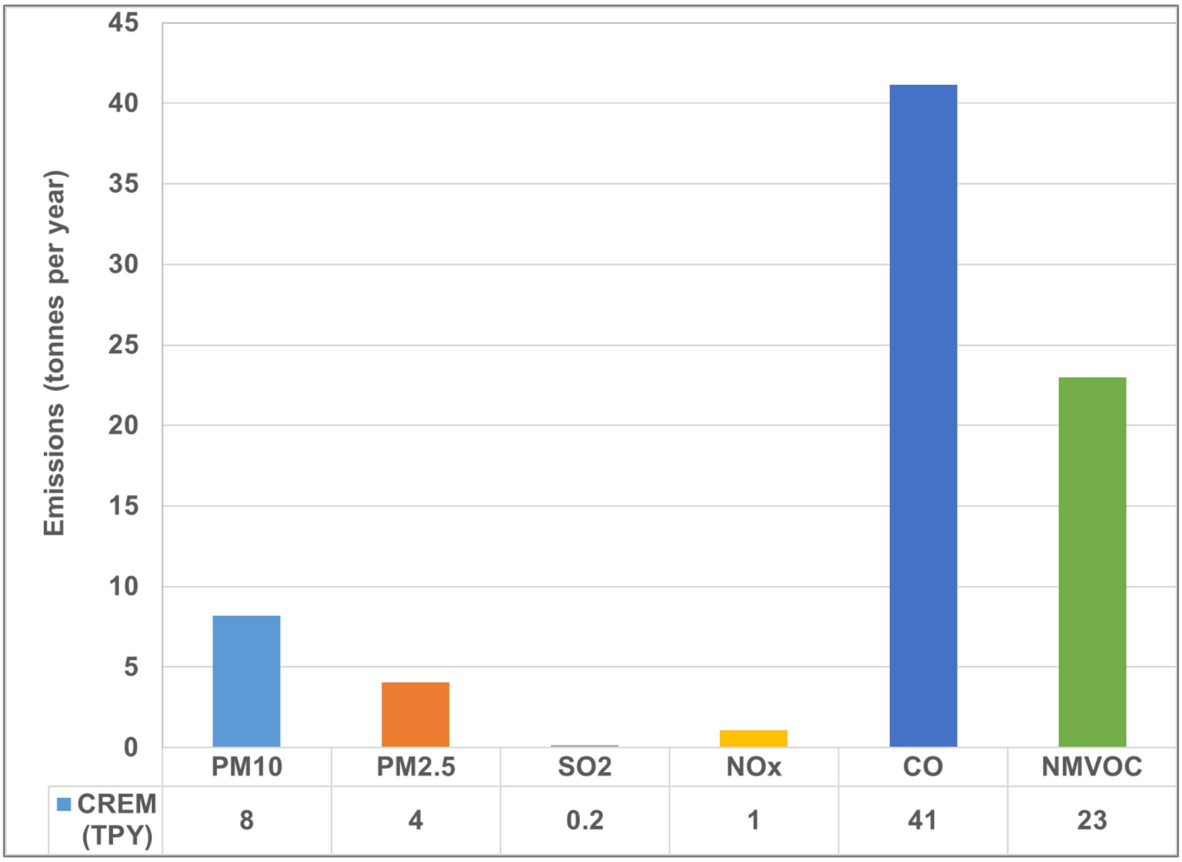


Figure 81 Emissions loads (tonnes per year) of pollutants originating from crematoria in Kalinganagar - Jajpur region

3.6. Regional Emission Inventory

The overall baseline emission inventory (Year 2021) for the Kalinganagar - Jajpur region is presented in Table 17. The sectoral contribution to pollutants is provided in Fig. 82 to 87.

The total PM_{10} emission load in the Kalinganagar - Jajpur region is estimated to be 16,895 tonnes per year. The top four contributors to PM_{10} emissions are resuspended road dust (58.1%), followed by industries and thermal powerplants (17.9%), fugitive emissions (17.9%), and transport (2.3%). 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 Kalinganagar - Jajpur region is estimated to be 5,539 tonnes per year. The top four contributors to $PM_{2.5}$ emissions are re-suspended road dust (42.9%), industries and thermal powerplants (36.4%), fugitive emissions (7.5%), and transport (6.4%). Other $PM_{2.5}$ contributors include open waste burning (2.5%), hotel, restaurants and bakeries (1.8%) and residential (1.1%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

SO_2 emission load in the Kalinganagar - Jajpur region is estimated to be 17,818 tonnes per year. Due to large coal usage, Industries and thermal powerplants constitute more than 99% emissions of SO_2 in the region. All other sectors together contribute less than 1% of the SO_2 emissions.

The annual NO_X emission load in the Kalinganagar - Jajpur region is estimated to be 15,543 tonnes per year. Similar to SO_2, industries and thermal powerplants (75.1%) and transport sector (23.9%) are the largest contributors to NO_X emissions. Remaining sectors such as open waste burning, residential together contributes less than 1%.

The total annual CO emissions in the Kalinganagar - Jajpur region are estimated to be 1,05,980 tonnes per year. Industries and thermal powerplants are the major contributor to CO emissions i.e. 91.5%, followed by transport (6.2%). All remaining sectors together contribute about 2.4% of total CO emissions in the region.

Fig. 88-92 shows the spatial distribution of pollutants over Kalinganagar - Jajpur region for baseline year 2021.

Table 17: Baseline (Year 2021) Emission Inventory for the Kalinganagar - Jajpur region (tonnes per year) of Odisha

Sector	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	NMVOC
Industries and powerplants	3024 ± 623	2016 ± 416	17654 ± 1974	11669 ± 2406	96969 ± 19995	4269 ± 880
Fugitive emissions	3017 ± 1538	417 ± 212	NA	NA	NA	NA
Transport	396 ± 104	357 ± 2	10 ± 1961	3713 ± 3442	6519 ± 2329	NA
Road dust	9812 ± 2194	2374 ± 531	NA	NA	NA	NA
Residential	90 ± 46	62 ± 31	12 ± 2	36 ± 19	874 ± 445	301 ± 153
Open waste burning	146 ± 79	136 ± 73	9 ± 5	21 ± 377	700 ± 82	#N/A
Hotels, Restaurants, Bakeries and Open eateries	157 ± 84	98 ± 53	116 ± 26	39 ± 21	459 ± 247	89 ± 48
Construction	188 ± 39	32 ± 7	NA	NA	NA	NA
Brick Kilns	53 ± 28	40 ± 22	12 ± 7	0.01 ± 0	405 ± 218	6 ± 3
Industrial DG	4 ± 2	4 ± 2	4 ± 1	63 ± 32	14 ± 7	NA
Crematoria	8 ± 4	4 ± 2	0.2 ± 0.1	1 ± 0.5	41 ± 21	23 ± 12
Total	**16895 ± 4742**	**5539 ± 1442**	**17818 ± 2016**	**15543 ± 4451**	**105980 ± 24753**	**9339 ± 3553**

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

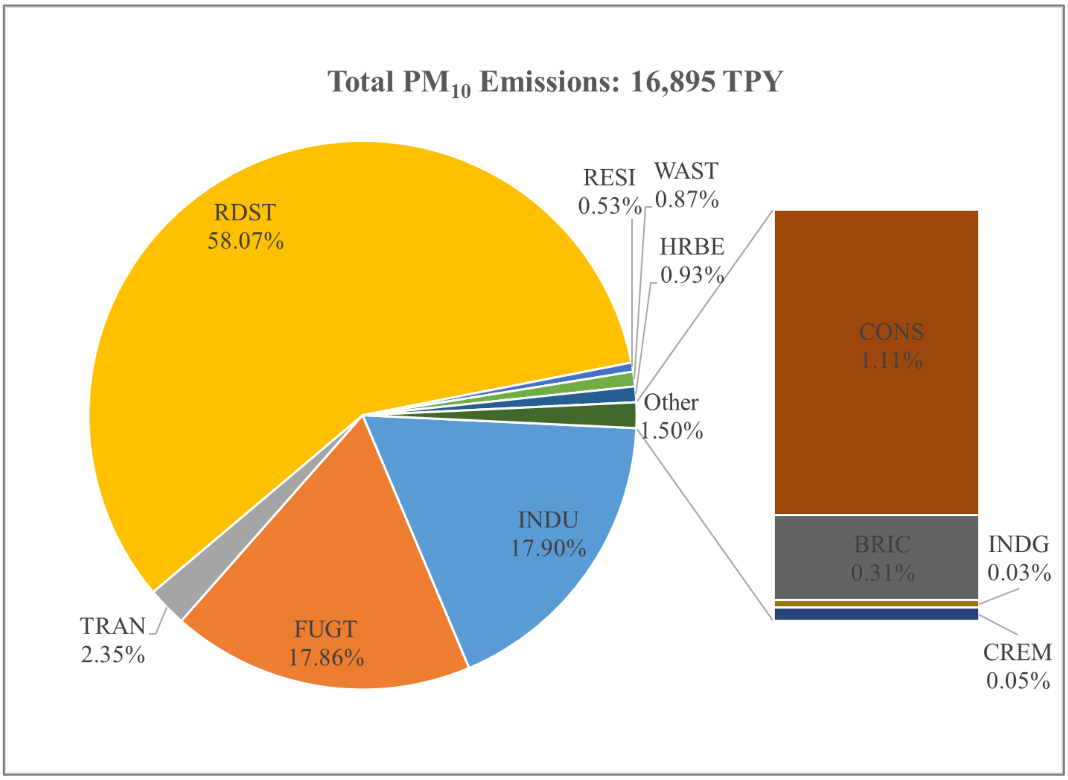


Figure 82 Sectoral contribution to annual PM_{10} *emissions in Kalinganagar - Jajpur Region*

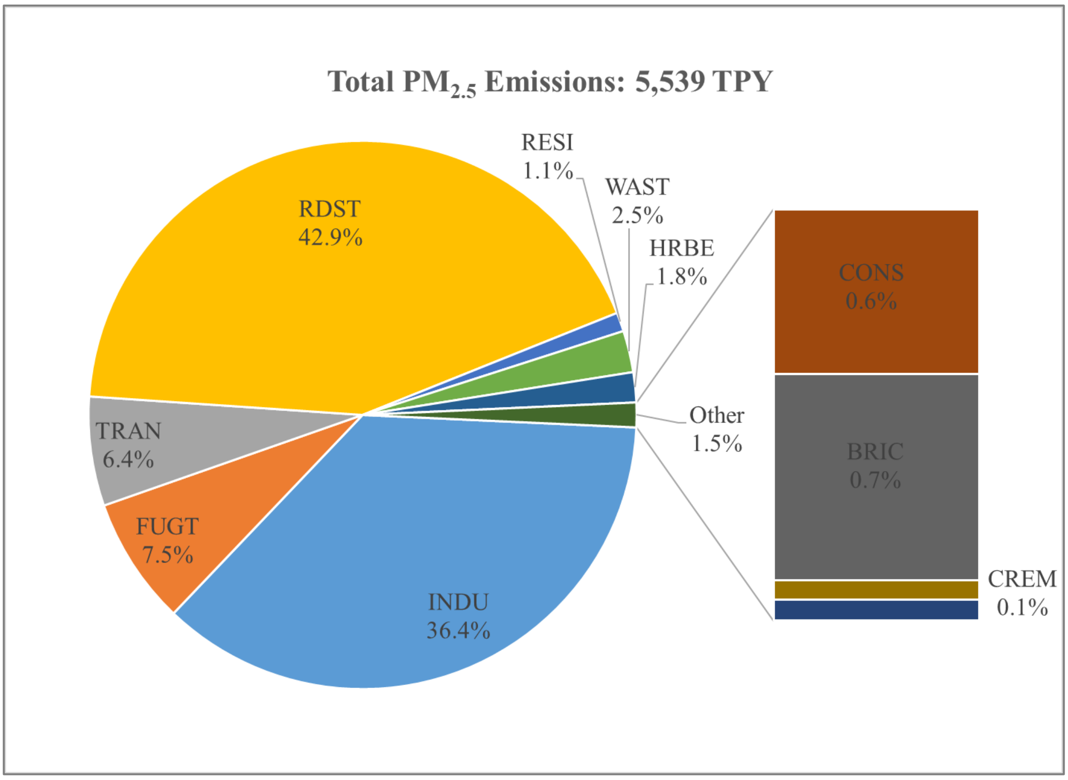


Figure 83 Sectoral contribution to annual $PM_{2.5}$ *emissions in Kalinganagar - Jajpur region*

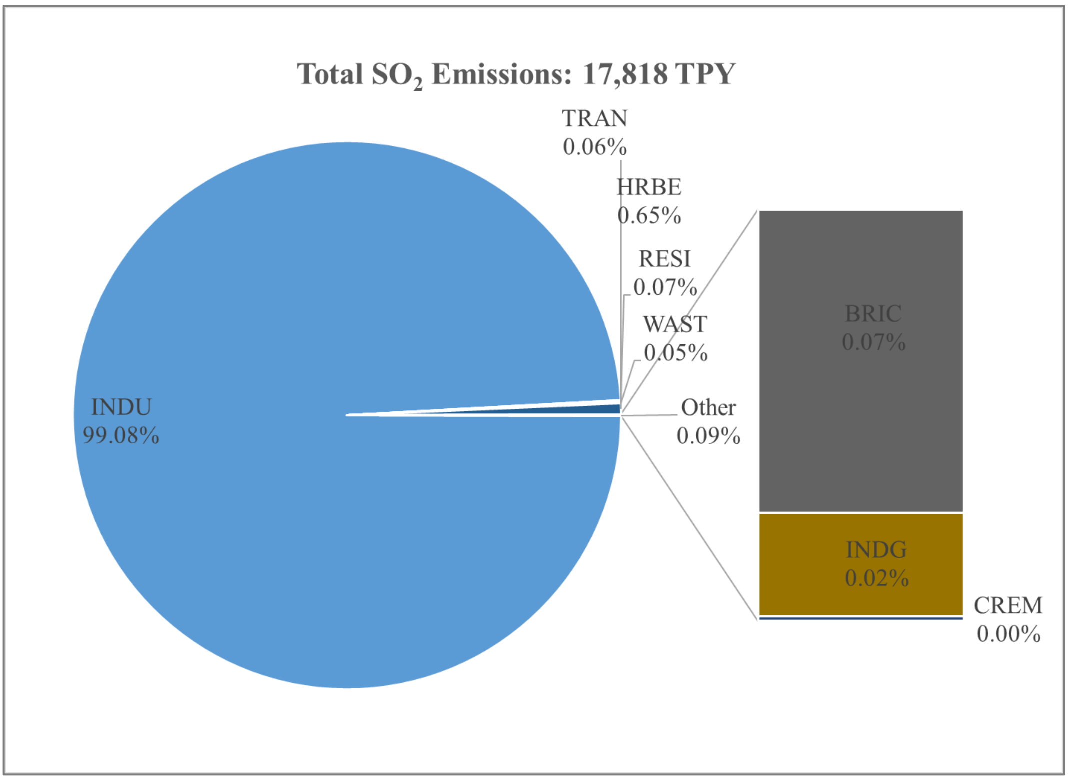


Figure 84 Sectoral contribution to annual SO_2 *emissions in Kalinganagar - Jajpur region*

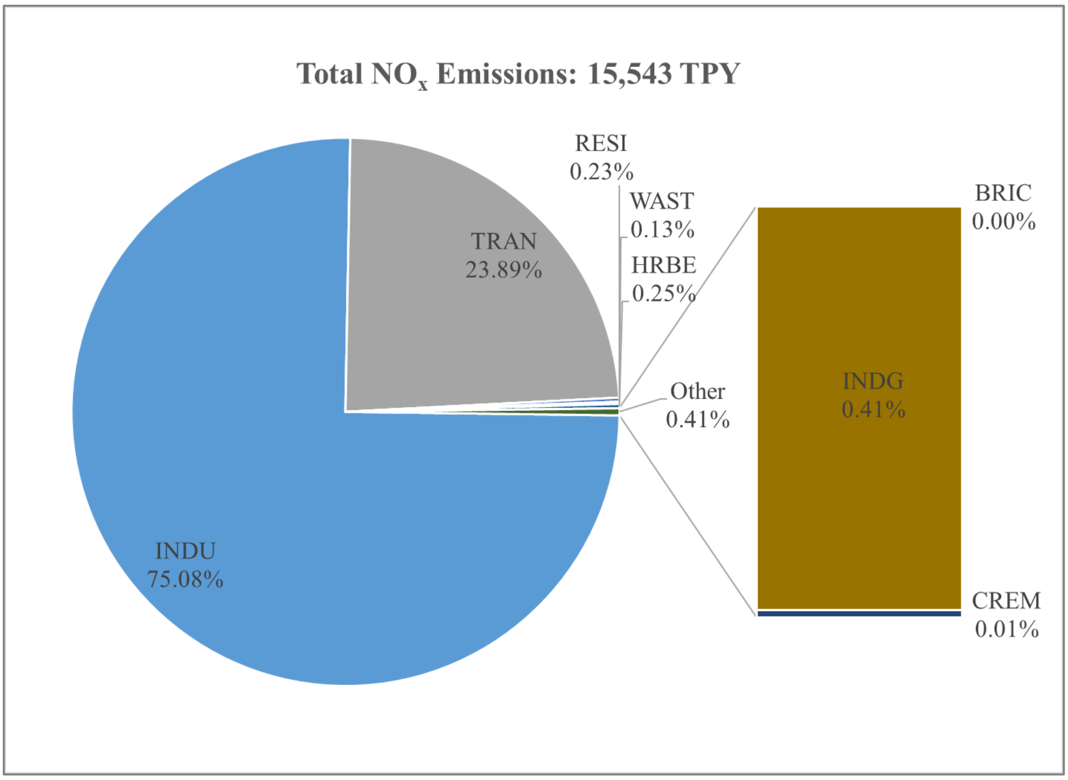


Figure 85 Sectoral contribution to annual NO_X *emissions in Kalinganagar - Jajpur region*

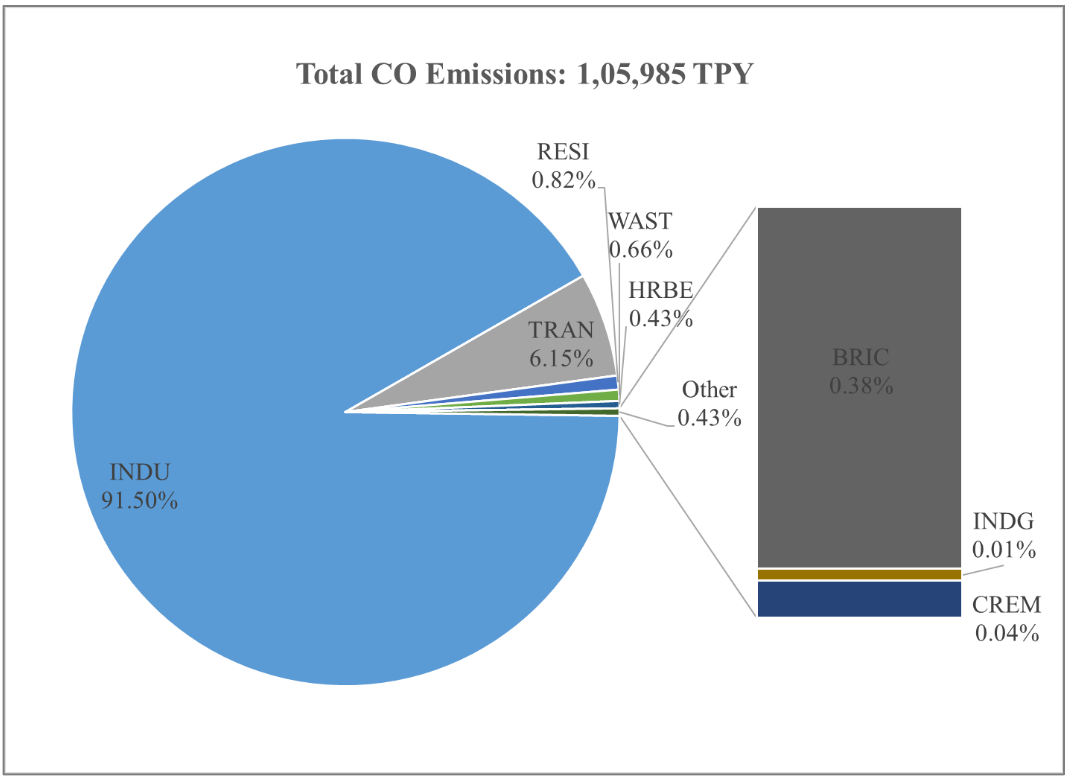


Figure 86 Sectoral contribution to annual CO emissions in Kalinganagar - Jajpur region

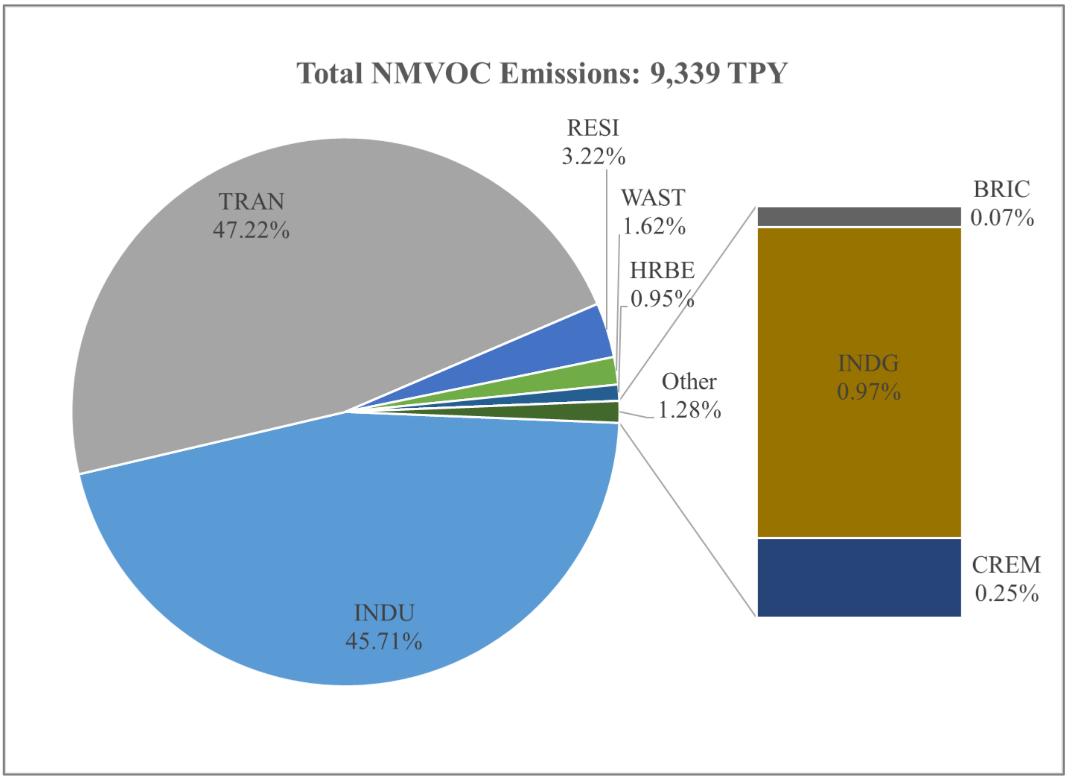


Figure 87 Sectoral contribution to annual NMVOC emissions in Kalinganagar – Jajpur region

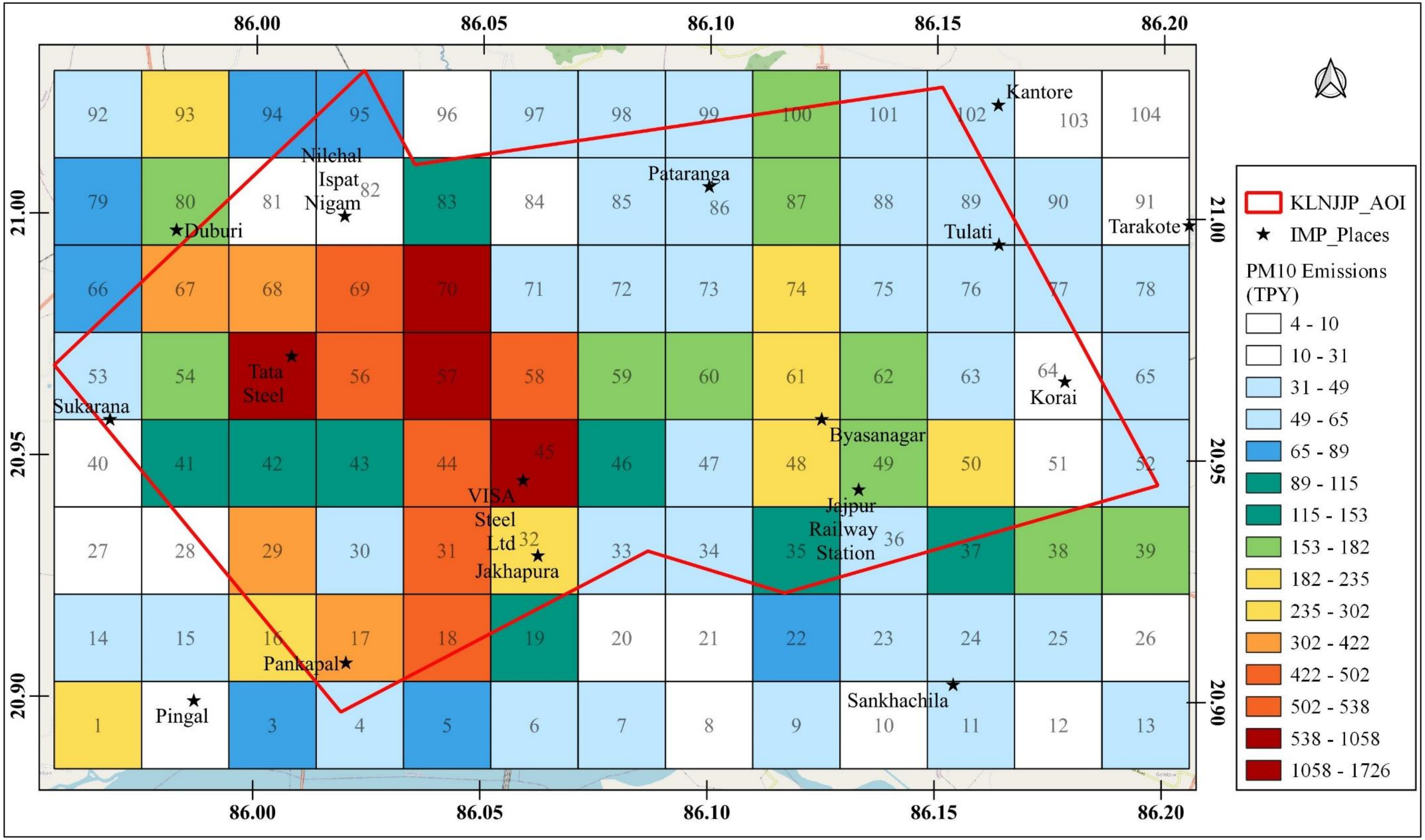


Figure 88: Spatial distribution of PM_{10} *emissions (tonnes per year) in Kalinganagar - Jajpur region for year 2021*

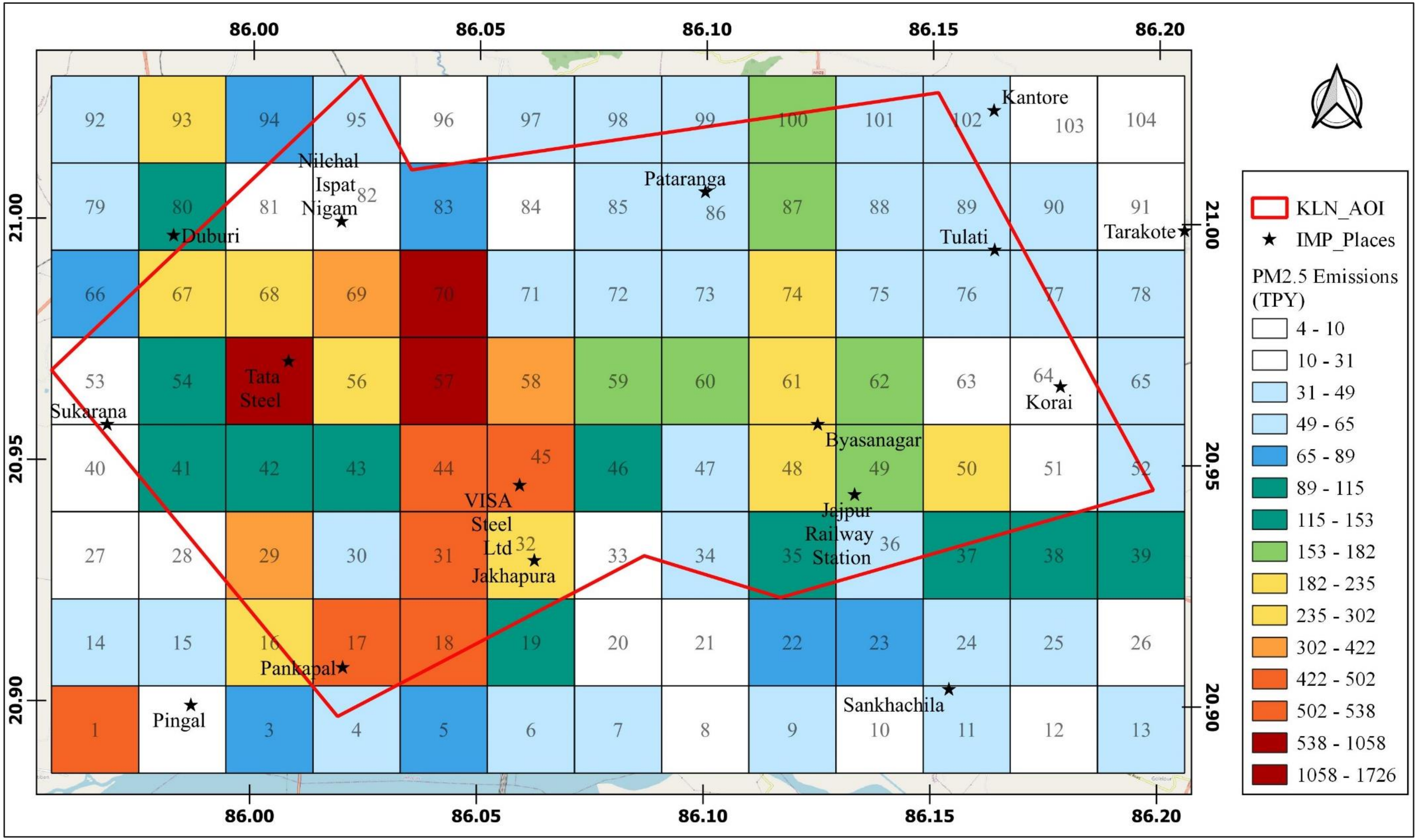


Figure 89: Spatial distribution of PM2.5 *emissions (tonnes per year) in Kalinganagar - Jajpur region for year 2021*

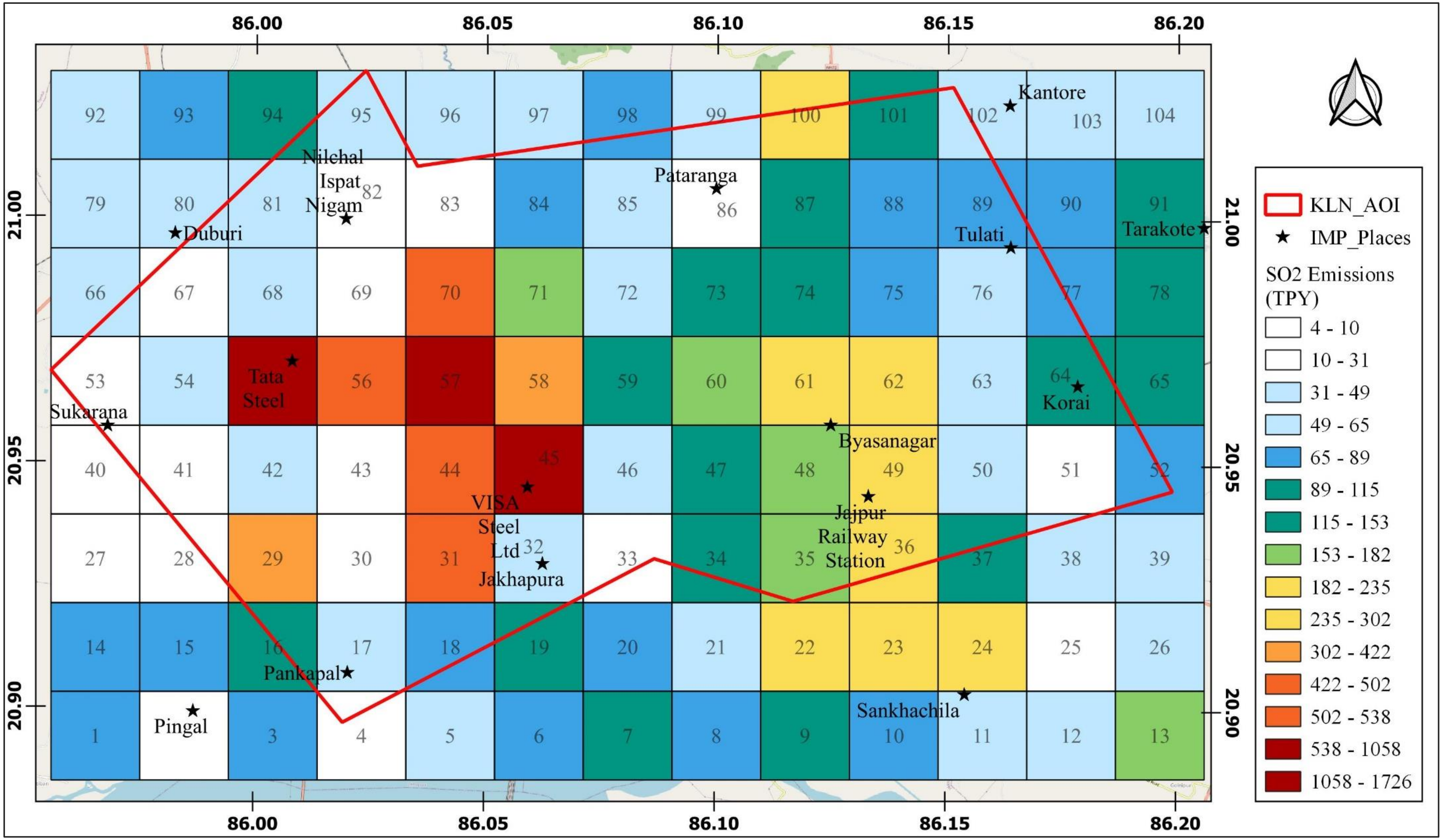


Figure 90 Spatial distribution of SO_2 *emissions (tonnes per year) in Kalinganagar - Jajpur region for year 2021*

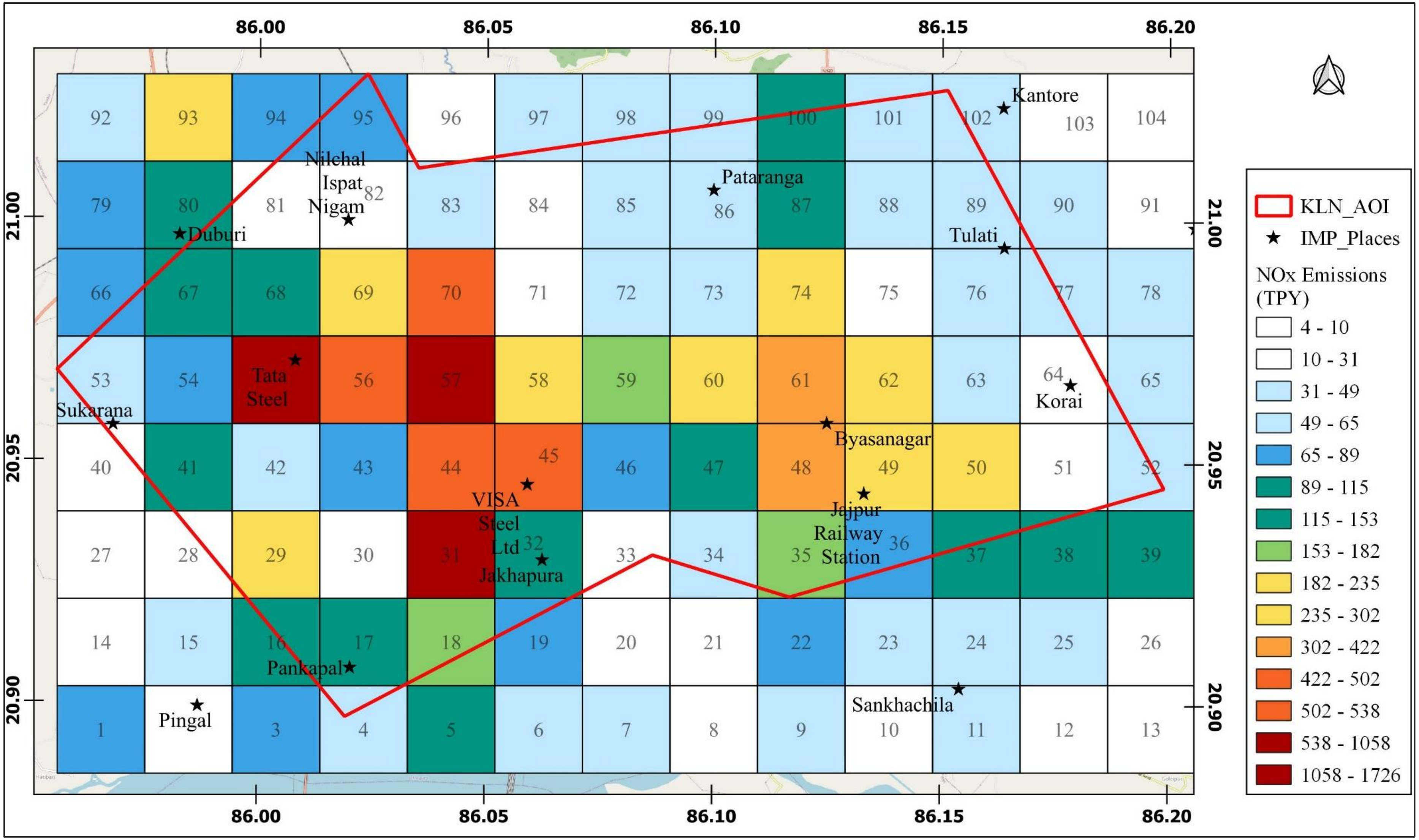


Figure 91 Spatial distribution of NO_X emissions (tonnes per year) in Kalinganagar - Jajpur region for year 2021

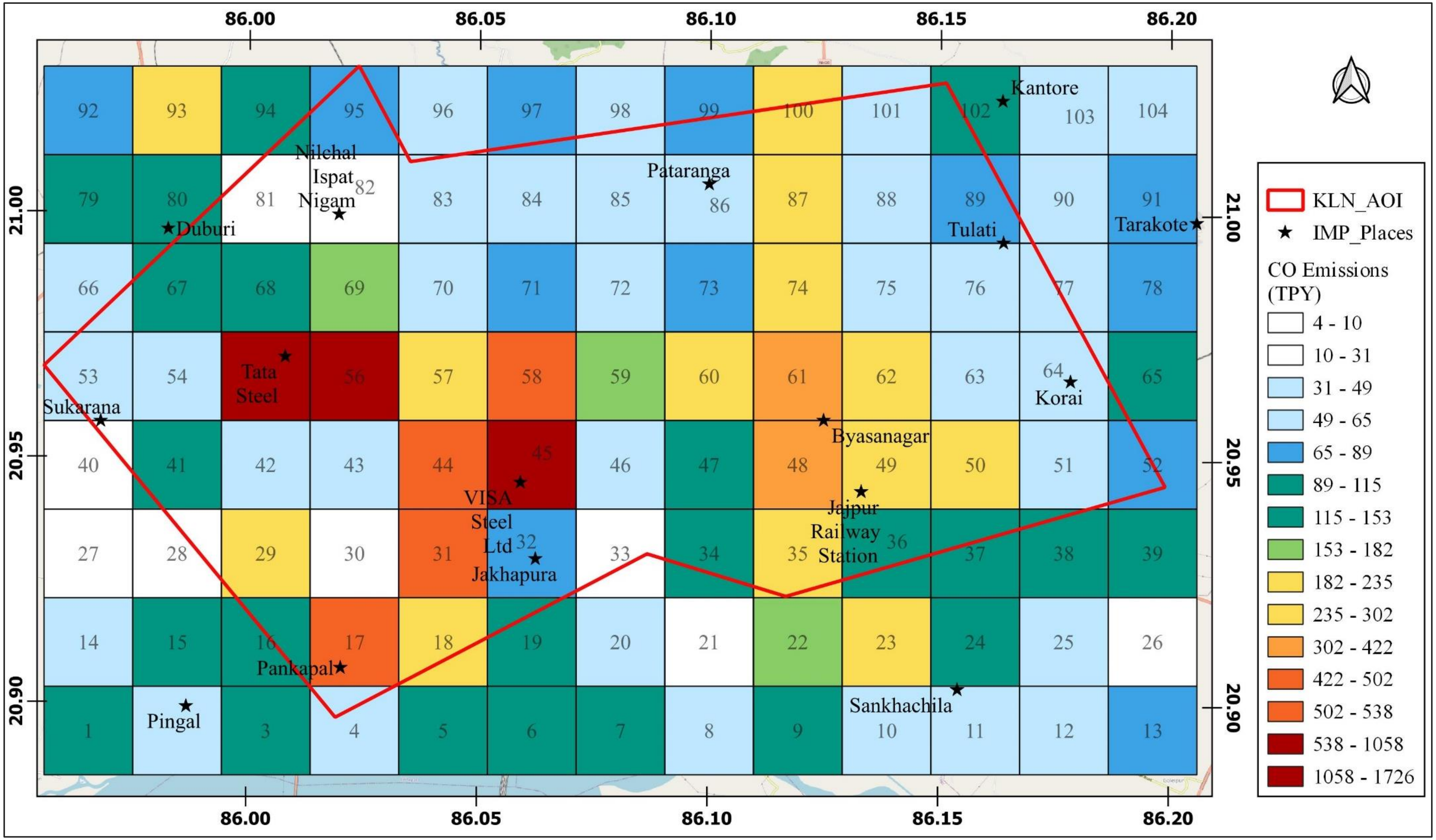


Figure 92 Spatial distribution of CO emissions (tonnes per year) in Kalinganagar - Jajpur region for year 2021

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).

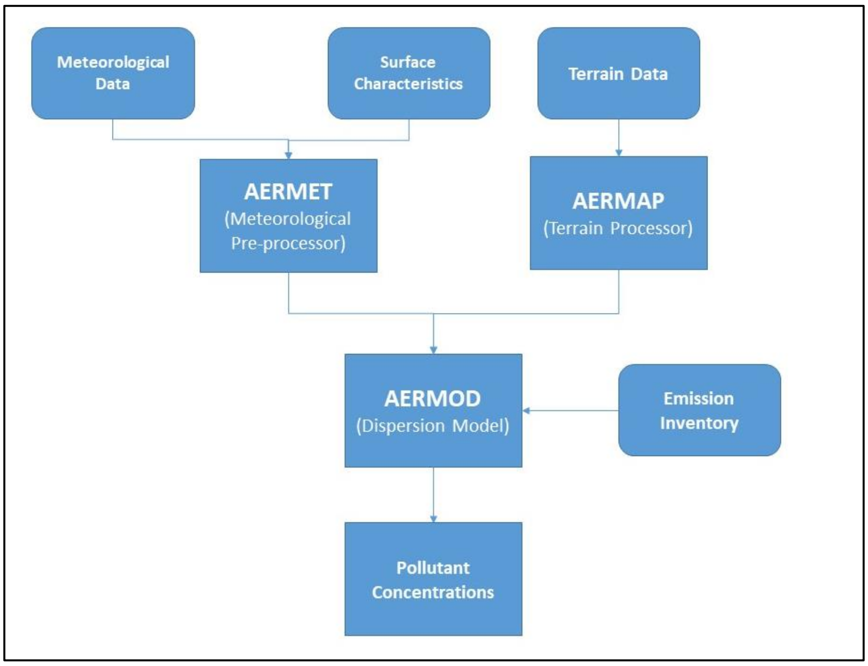


Figure 93 Flow diagram of AERMOD Modelling System used in this study to simulate the air pollutant concentrations

Fig. 93 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.

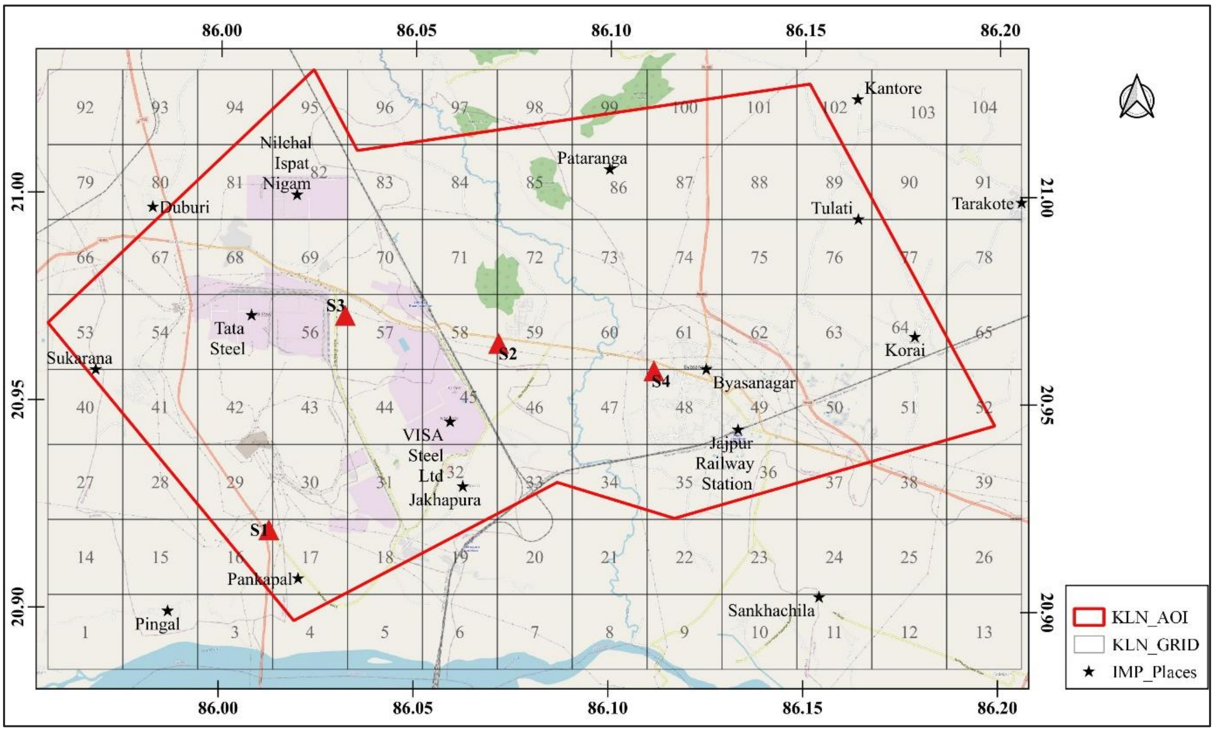


Figure 94 Map showing dispersion modelling domain i.e. Kalinganagar - Jajpur region and surrounding areas

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 94). Due to proximity and importance of regional sources, Kalinganagar - Jajpur regions are modelled together in AERMOD System.

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 Kalinganagar - Jajpur 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 18 provides summary of ERA5 reanalysis dataset.

The surface level meteorological data over the Kalinganagar - Jajpur 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 Kalinganagar - Jajpur from ERA-5 database and is converted into Forecast Systems Laboratory (FSL) radiosonde format using Python and Fortran scripts.

Table 18 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

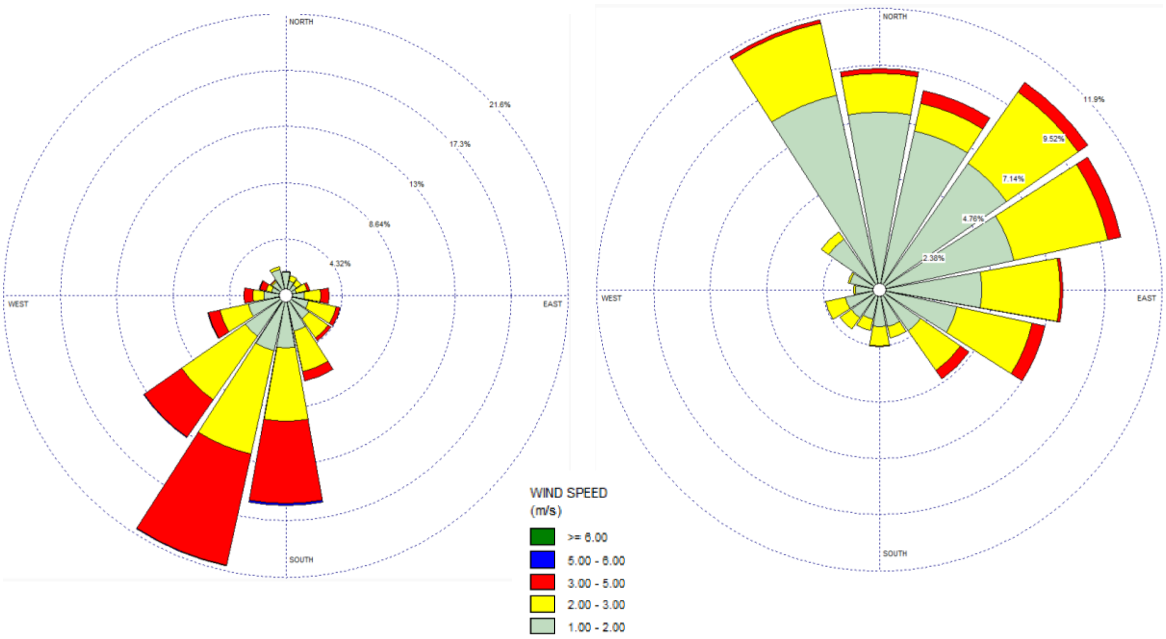


Figure 95 Windrose diagrams showing the wind speed and direction frequency distribution over Kalinganagar - Jajpur region during summer (A) and winter (B) seasons of year 2022

Fig. 95 shows the wind speed and direction frequency distribution over Kalinganagar - Jajpur 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 (~9%) of calm winds i.e. < 1 m/s. The predominant wind directions during the summer season over Kalinganagar - Jajpur region are observed to be from south of south-west (SSW) (~22%); followed by south (S, >16%), and south-west (SW, ~13%).

In the winter season, lesser wind variations were observed with slightly higher frequencies of (~13%) calm winds (i.e. < 1 m/s) indicating stable atmospheric conditions. The predominant winds are observed to be blowing from north of north-west (NNW, ~12%), followed by east of north-east (ENE, ~10%), north-east (NE, ~10%), North (N, ~9%), north-east (NE, 8%).

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 Kalinganagar - Jajpur region was downloaded and processed using AERMAP processor.

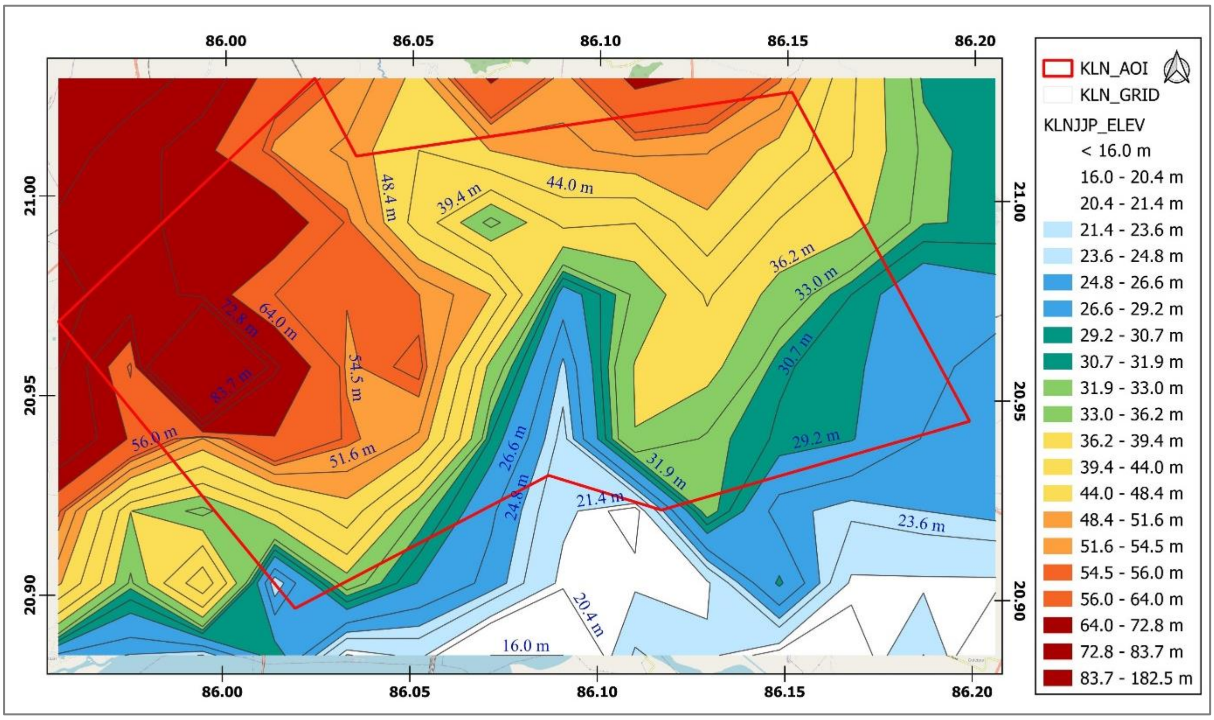


Figure 96 Contour map showing terrain elevations extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m)

Fig. 96 shows the contour map showing terrain elevations over Kalinganagar - Jajpur modelling domain, 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 ~16 m (above MSL) towards southern part i.e. near the river channel, to a maximum of ~182 m (above MSL) towards north-western 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, except the industries and thermal powerplants, industrial DG sets, industrial fugitive dust and brick kilns. The stack emissions from industries and thermal powerplants, industrial DG sets, and FCBTK brick kilns are modelled as point sources. Industrial fugitive dust sources are modelled as area polygon 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 126 gridded receptors. Additionally, four discrete receptors are also configured, to represent the locations for ARAI sampling sites. The height of each receptor is set to 1.5 m above ground level i.e. mean breathing level for humans. Figure 97 shows map of the modelling domain overlaid by gridded and discrete receptors configured in this study.

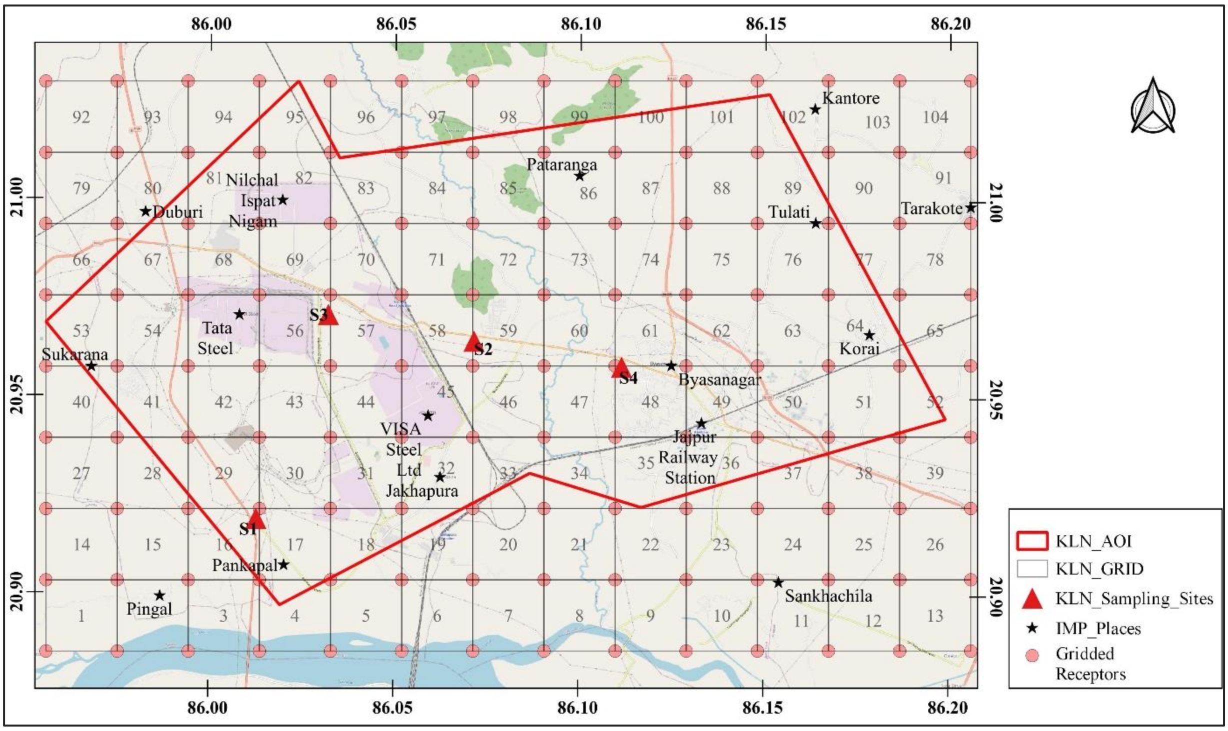


Figure 97 Map showing modelling domain overlaid by gridded and discrete receptors configured in this study.

Table 19 summarizes the details of dispersion model, source and receptor configurations, meteorology and geophysical data used for dispersion modelling simulations.

Table 19 Summary of AERMOD dispersion modelling setup used in this study

S. No.	Description	Symbol	Details
1.	Length of modelling domain in X-direction	X	26 km
2.	Length of modelling domain in Y-direction	Y	16 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}	126
7.	Total number of discrete receptors	N_{DISC}	4
8.	Source configuration in AERMOD	--	• Industries, TPP, DG, FCBTK: Point source • Clamp Brick kilns: Volume source • Industrial fugitive dust: area polygon sources • 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. Continuous air quality monitoring stations were not operational during baseline year 2022, hence NAMP observations were used to derive the background concentrations. NAMP monitoring stations are operated manually and the background concentrations are derived using annual average concentrations reported at NAMP stations with suitable assumptions.

Based on literature review, results of receptor modelling in this study, and expert judgement, the background pollutant concentrations are expected to contribute between 30 and 20%. A series of sensitivity AERMOD simulations were conducted with varying background concentrations to cover the previously reported range of 20% to 50%. The best model results were obtained when the background concentrations were ~ 40% for particulates and ~20% for gases, hence this value is used to get the monthly background concentrations. The derived background concentration is added to the modelled concentrations estimated by AERMOD to get total concentration of pollutant under consideration.

4.7. Dispersion Model Validation

Due to lack of CAAQM measurements in Kalinganagar - Jajpur region, the AERMOD simulated concentrations of pollutants including $PM_{2.5}$, PM_{10}, SO_2, and NO_2, are compared against seasonal observations obtained at four ARAI sampling locations. Overall, the AERMOD model is found to simulate the seasonal average concentrations of the pollutants with a good accuracy compared to observations.

4.8. Spatial Distribution of Modelled Pollutants

Fig. 98 - 102 shows the spatial distribution of modelled pollutant annual mean 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 of particulate matter i.e. PM_{10} and $PM_{2.5}$ are observed towards central and southern parts of the study domain. These highest concentrations can be attributed to the air polluting sources industries and powerplants operating in Kalinganagar industrial complex. The exhaust emissions and to road dust re-suspension due to heavy vehicles movement in the central part of the study domain, also adds to the particulate levels. The lowest estimated

pollutant concentrations on the peripheral part of the study domain i.e. south-eastern (SE), could be attributed to no and or less air polluting activities, emissions and effective diffusion, dispersion and removal of pollutants to some extent (Han et al., 2020).

The spatial distribution of gaseous pollutants such as SO_2 (Refer Fig. 100) is mainly governed by the stack emissions from industries and thermal powerplants. The NO_2 and CO concentrations are found to be distributed across the domain. The industries and vehicular exhaust emissions are main sources of NOx. In addition to industries and traffic, incomplete combustion of solid fuels such as coal and wood for domestic and commercial purposes in the region, explains the persistent CO concentrations.

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

The estimated concentrations show distinct seasonal pattern, being higher in winter and comparatively lower in summer, except a few locations very close to fugitive dust sources. This trend in ambient concentrations is mainly due to prevailing stable meteorological conditions with lower ambient temperatures, higher relative humidity and lower mixing heights, which hinders the dispersion of pollutants. This implies that, the seasonal emissions and meteorology are adequately explained by the model.

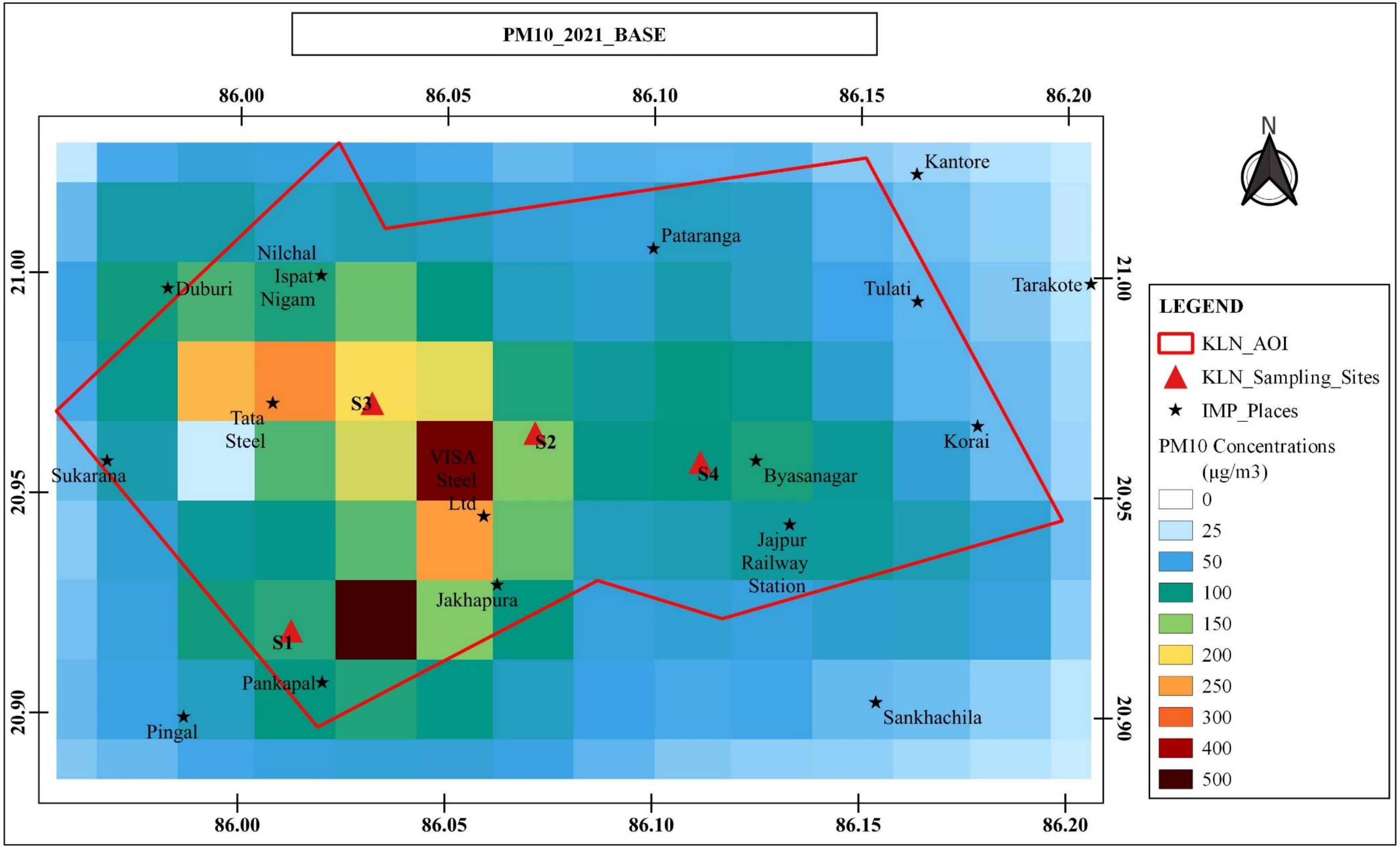


Figure 98 Map showing spatial distribution of annual mean PM_{10} concentrations ($\mu g/m^3$) over Kalinganagar - Jajpur region for year 2021

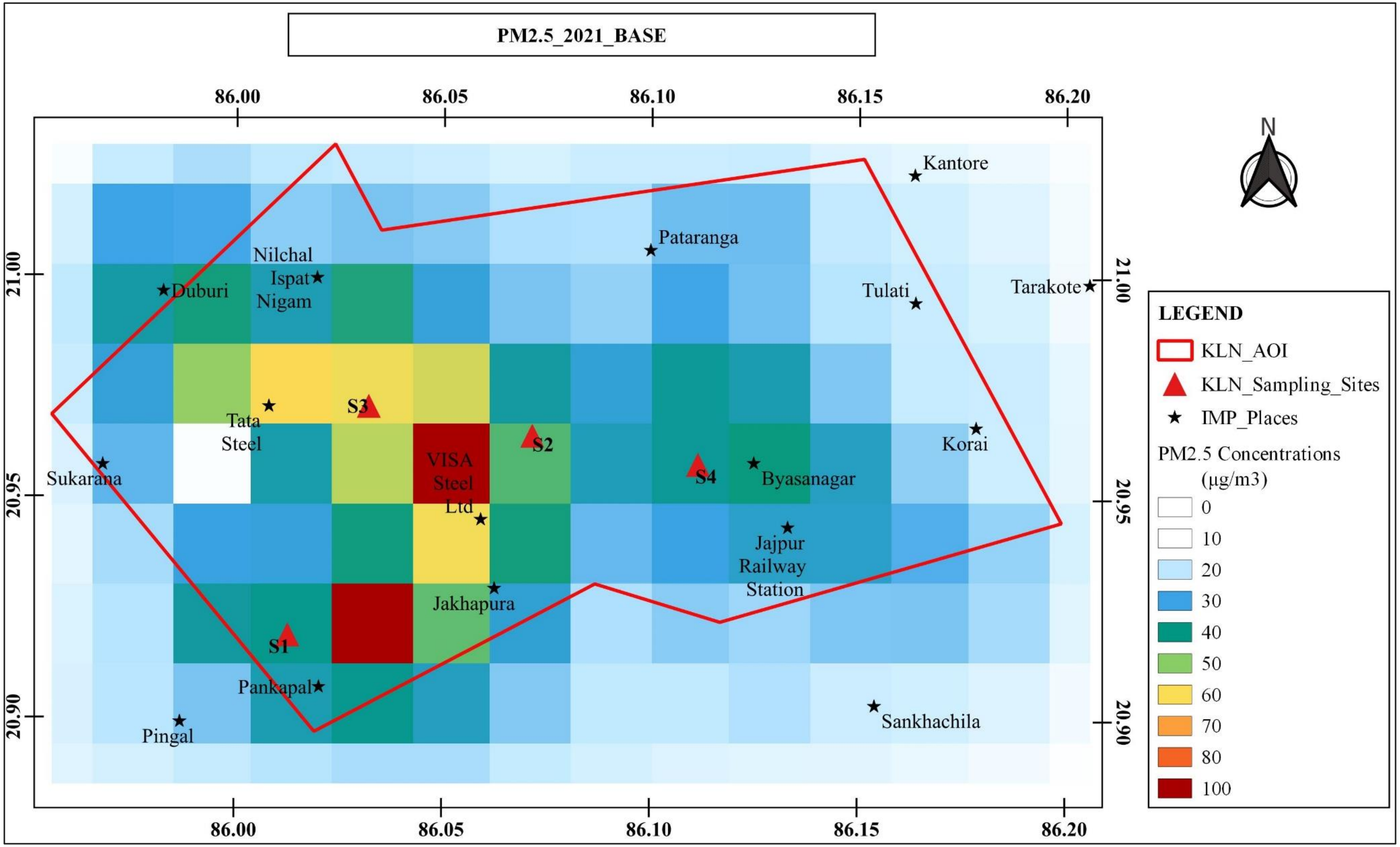


Figure 99 Map showing spatial distribution of annual mean $PM_{2.5}$ concentrations ($\mu g/m^3$) over Kalinganagar - Jajpur region for year 2021

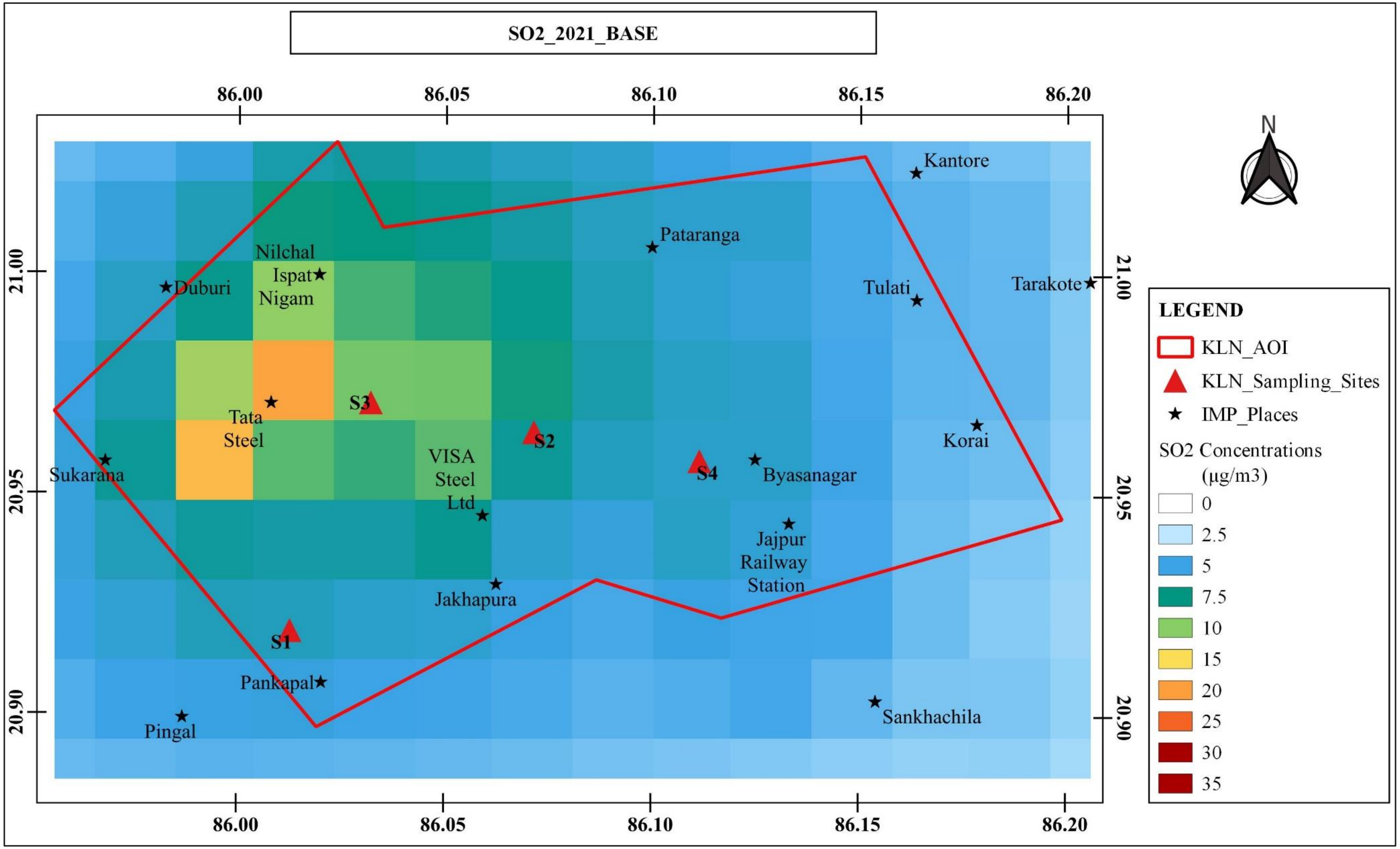


Figure 100 Map showing spatial distribution of annual mean SO_2 concentrations ($\mu g/m^3$) over Kalinganagar - Jajpur region for year 2021

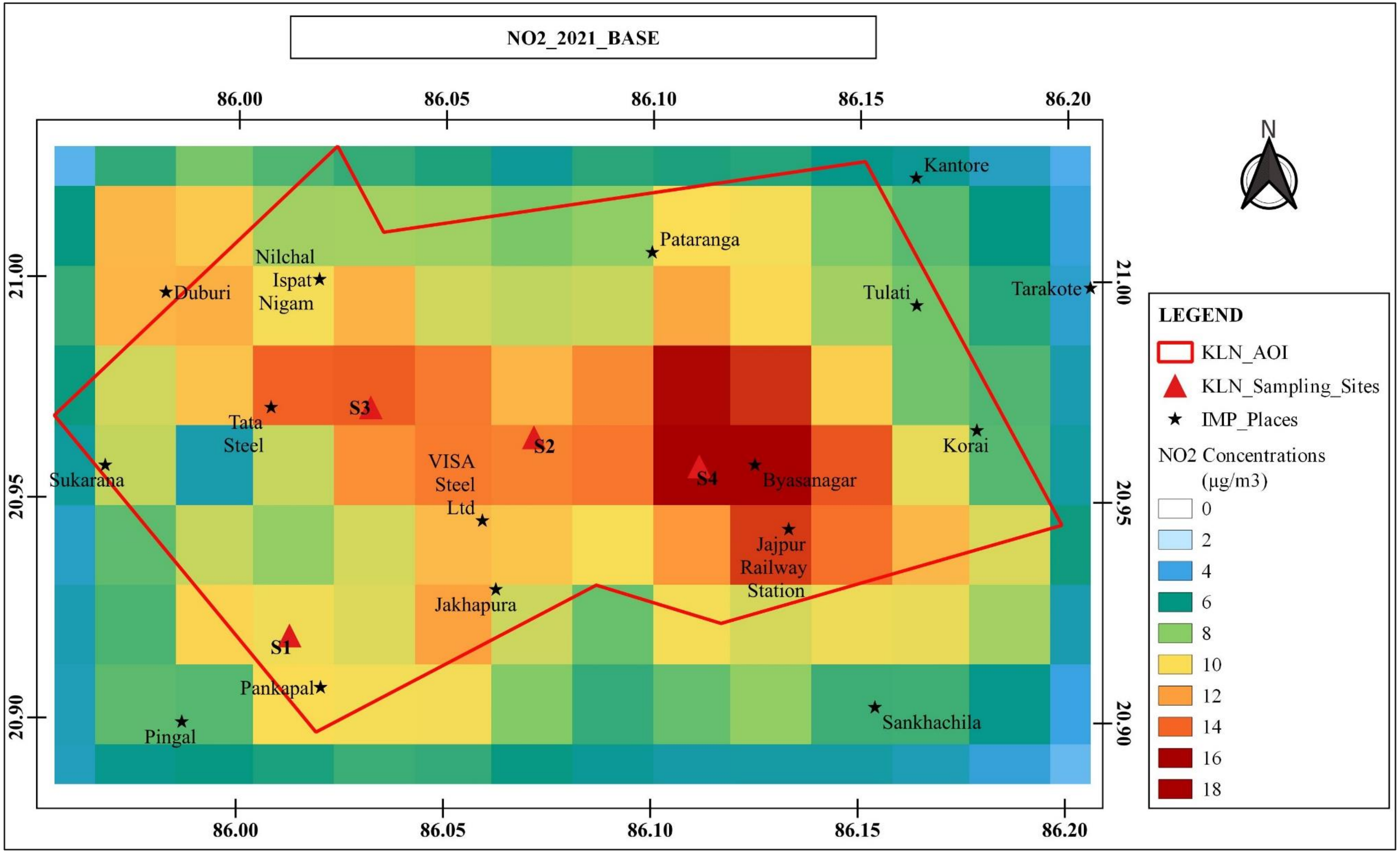


Figure 101 Map showing spatial distribution of annual mean NO_2 concentrations ($\mu g/m^3$) over Kalinganagar - Jajpur region for year 2021

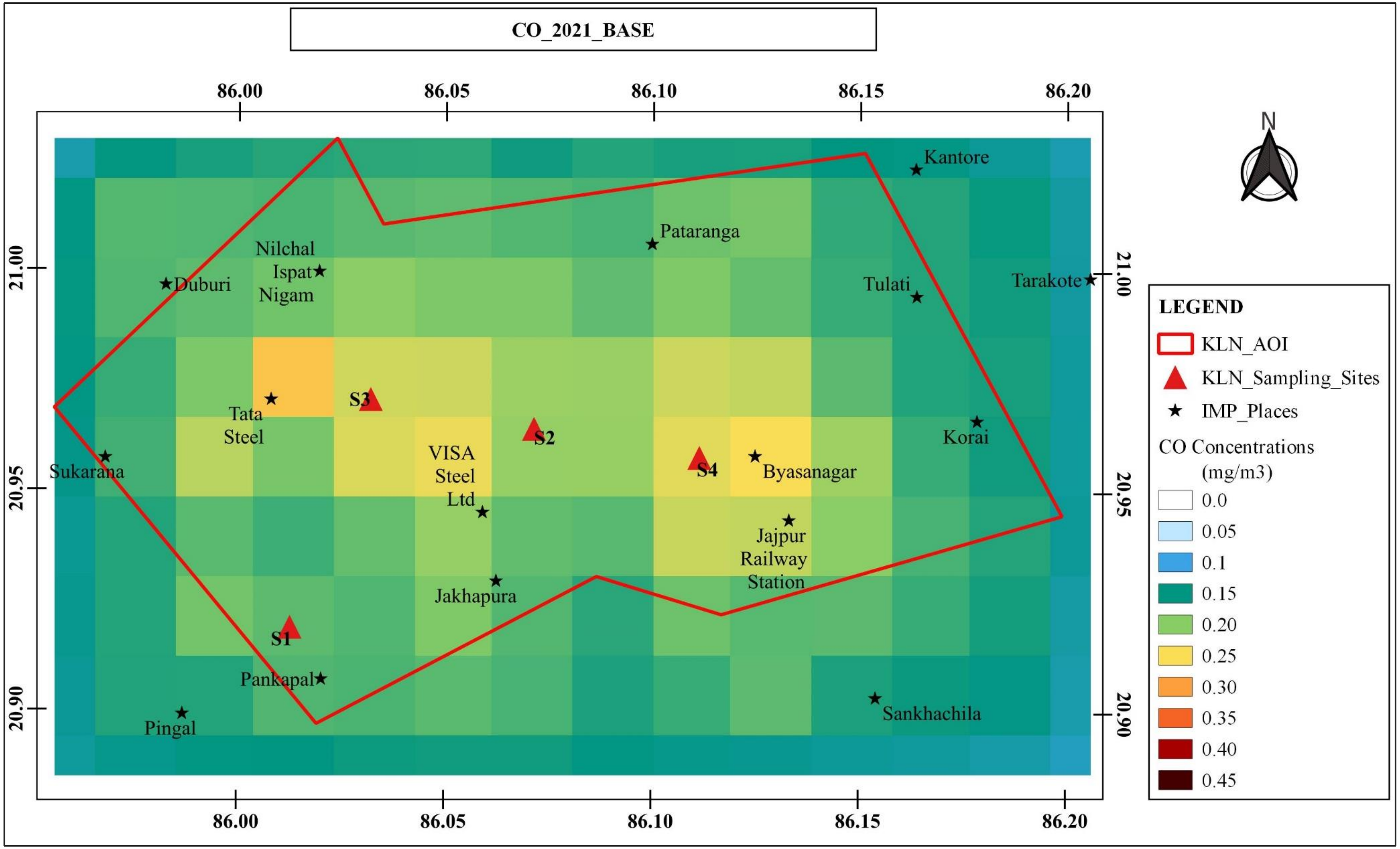


Figure 102 Map showing spatial distribution of annual mean CO concentrations (mg/m3) over Kalinganagar - Jajpur region for year 2021

[THIS PAGE INTENTIONALLY LEFT BLANK]

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 Kalinganagar - Jajpur 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. This effect is included in the present study considering increased penetration levels of these vehicles in future vehicle fleet of Kalinganagar - Jajpur 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 Kalinganagar - Jajpur 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 Kalinganagar - Jajpur region as well, which will in turn lead to significant reduction in vehicular exhaust emissions. The effect of increased EV penetration in Kalinganagar - Jajpur 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 may play a vital role in Kalinganagar - Jajpur 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 20 presents summary of assumed reduction percentages in vehicle kilometres travelled (VKT) in three scenarios for years 2026 and 2031, respectively, due to promotion of NMT in Kalinganagar - Jajpur region.

Table 20 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). 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 Kalinganagar - Jajpur 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 roads. 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

Kalinganagar - Jajpur region 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. Fugitive emissions

As discussed earlier, fugitive dust emissions are an important source of air pollution in the Kalinganagar - Jajpur region, mainly due to industries and thermal powerplants. Further, these emissions are released near the ground surface and can cause more nuisance in nearby areas, than elevated sources. This study assesses the impact of controlling the fugitive sources by 10% to 75% compared to No Further Control (NFC) scenario, in future years.

5.6. 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 Kalinganagar - Jajpur 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 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.

5.7. Brick Kilns Sector

Currently, the clamp type brick kilns are operational in the Kalinganagar - Jajpur 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 clamp type units to Zig-zag kilns, which are comparatively less polluting, in a phase-wise manner.

5.8. Construction Sector

With growth in economic activities and population the construction activities are also estimated to increase in upcoming years in the Kalinganagar - Jajpur 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%.

5.9. Crematoria Sector

Although, the emissions originating from crematoria contribute less than 0.5% 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.

5.10. 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 21 summarizes the sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2026 and 2031.

Table 21 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 Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% 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

Sr. No.	Sector	Assumptions, considerations and controls	References
2.	RDST	• The vehicles in Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% till 2031. • No change in the silt loading on different road types in 2026 and 2031.	Assumptions
3.	INDU	• Information on new/upcoming industries to be operational by year 2031 is considered • No additional emission reduction measures in-place i.e. same as baseline year 2021	OSPCB, Assumptions
4.		•	
5..	FUGT	• Information on new/upcoming industries to be operational by year 2031 is considered • No additional controls in-place	Assumptions
6.	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 year.	Assumptions
7.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • The fuel usage characteristics and technology would remain same as the baseline year.	Odisha Economic Survey 2022-23, Assumptions
8.	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
9.	CONS	• The construction activities are assumed to increase at an annual growth rate of 5.65% till 2031 • No reduction in PM.	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
10.	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

5.11. 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 22 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2026 and 2031 BAU scenario.

Table 22 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 Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% 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 Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% till 2031. • The silt loading on different road types calculated by assuming following: ○ Year 2026: 15% silt load reduction @ Highways and Major roads and 10% silt	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		load reduction @ Inter, Minor and residential roads ○ Year 2031: 30% silt load reduction @ Highways and Major roads and 20% silt load reduction @ Inter, Minor and residential roads	
3.	INDU	• Information on new/upcoming industries to be operational by year 2031 is considered • Adoption of suggested Best Available Technologies and Practices for Iron and Steel Industries (Refer Annexure – K). • Assumed an emission reduction (in addition to NFC scenarios) from Industries: ○ 2026: 5% reduction in all pollutants w.r.t. corresponding NFC ○ 2031: 10% reduction in all pollutants w.r.t. corresponding NFC	Assumptions
4.		•	
5..	FUGT	• Information on new/upcoming industries to be operational by year 2031 is considered • 10% and 25% reduction in fugitive emissions by 2026 and 2031, respectively, compared to corresponding NFC scenario	Assumptions
6.	RESI	• The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: ○ Year 2026: 1. Urban HH: 100% 2. Rural HH: 30% ○ Year 2031: 1. Urban HH: 100% 2. Rural HH: 60%	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
7.	WAST	• The population is estimated based on historic population growth rate.	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		• The assumed MSW collection efficiency: o Year 2026: 1. Rural areas: 65% 2. Urban Areas: 90% o Year 2031: 1. Rural areas: 70% 2. Urban areas: 90%	
8.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • 10% and 20% facilities would be converted from wood/coal to LPG in years 2026 and 2031, respectively.	Based on growth rate acquired from FICCI report 2022
9.	BRIC	• The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. • All brick kilns within 2 km and 5 km radius from the domain 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
10.	CONS	• The construction activities are assumed to increase at growth rate of 5.65% till 2031 • 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
11.	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

5.12. 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 23 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2026 and 2031 SC-I.

Table 23 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 Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% 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 Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% till 2031. • The silt loading on different road types calculated by assuming following: ○ Year 2026: 30% silt load reduction @ Highways and Major roads and 20% silt load reduction @ Inter, Minor and residential roads ○ Year 2031: 60% silt load reduction @ Highways and Major roads and 40% silt load reduction @ Inter, Minor and residential roads	Assumptions
3.	INDU	• Information on new/upcoming industries to be operational by year 2031 is considered • 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: ○ 2026: 10% reduction in all pollutants w.r.t. corresponding NFC ○ 2031: 25% reduction in all pollutants	
4.		•	
5.	FUGT	• Information on new/upcoming industries to be operational by year 2031 is considered • 20% and 50% reduction in fugitive emissions by 2026 and 2031, respectively, compared to NFC scenario	Assumptions
6.	RESI	• The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: ○ Year 2026: 1. Urban HH: 100% 2. Rural HH: 40% ○ Year 2031: 1. Urban HH: 100% 2. Rural HH: 80%	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
7.	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
8.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • 20 and 40% facilities would be converted from wood/coal to LPG in years 2026 and 2031, respectively.	Based on growth rate acquired from FICCI report 2022
9.	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 study area 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

Sr. No.	Sector	Assumptions, considerations and controls	References
10.	CONS	• The construction activities are assumed to increase at growth rate of 5.65% till 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 2017-2022, RBI Handbook, 2022 Assumptions
11.	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

5.13. 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 24 summarizes the sector-wise growth rate, assumptions and considerations used to estimate the emissions for 2026 and 2031 SC-II scenario.

Table 24 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 Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% 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 Kalinganagar - Jajpur region are estimated to grow at a CAGR of 6.9% 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	• Information on new/upcoming industries to be operational by year 2031 is considered • 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:
		  ○ 2026: 25% reduction in all pollutants w.r.t. corresponding NFC
		  ○ 2031: 50% reduction in all pollutants w.r.t. corresponding NFC	

4.		•	
5.	FUGT	• Information on new/upcoming industries to be operational by year 2031 is considered • 30% and 75% reduction in fugitives emissions by 2026 and 2031, respectively, compared to NFC scenario	Assumptions

6.	RESI	• The population is estimated based on historic population growth rate.
		• The assumed LPG penetration in study area:
		  ○ Year 2026:
		    1. Urban HH: 100%
		    2. Rural HH: 50%
		  ○ Year 2031:
		    1. Urban HH: 100%
		    2. Rural HH: 100%
			ARAI Surveys, 2021
			Census 2011 and NFHS 2019-2021 report
			Assumptions

7.	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

8.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • 25 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
9.	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 study area 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

Sr. No.	Sector	Assumptions, considerations and controls	References
			2017-2022, RBI Handbook, 2022 Assumptions
10.	CONS	• The construction activities are assumed to increase at growth rate of 5.65% till 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 Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
11.	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

5.14. 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 Kalinganagar - Jajpur region. As discussed earlier, these scenarios consider implementation of various control measures explained in Section 5.12 in Kalinganagar - Jajpur region with varying factors for 2026 and 2031. Table 25 and Figures 103 to 107 presents the summary of estimated emissions (tonnes per year) of selected pollutants for four scenarios in Kalinganagar - Jajpur 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 Kalinganagar - Jajpur region indicate a potential increase in PM_{10} emissions to 26,974 tonnes per year in 2026 i.e. an increase of 59.7% w.r.t. baseline year 2021 and to 38,093 tonnes per year in 2031 i.e. an increase of 125.5% w.r.t. baseline year 2021. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to reach to 8,086 (46.0%) and 11,405 tonnes per year (i.e. 105.9%) in 2026 and 2031, respectively. As this is an industrial region, the SO_2 emissions are of particular interest. The projected emissions of SO_2 indicate a potential increase to 26,727 tonnes per year in 2026 i.e. an increase of 50% w.r.t. baseline year 2021 and to 57,452 tonnes per year in 2031 i.e. an increase of 54.1% w.r.t. baseline year 2021. The projected emissions of NO_X indicate a potential increase to 23,835 tonnes per year in 2026 i.e. an increase of 53.4% w.r.t. baseline year 2021 and to 24,506 tonnes per year in 2031 i.e. an increase of 57.7% w.r.t. baseline year 2021. The CO emissions are expected to increase to 1,58,176 tonnes per year in 2026 i.e. a decrease of 49.3% and 1,59,338 tonnes per year in 2031 i.e. an increase of 50.3% w.r.t. baseline year 2021.

The BAU projections in Kalinganagar - Jajpur indicate a potential decrease of PM_{10} emissions to 24,179 tonnes per year in 2026 i.e. a decrease of 10.4 % w.r.t. NFC_2026 and to 29,725 tonnes per year in 2031 i.e. a decrease of 22% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 7,842 (-3.0%) and 9,201 tonnes per year (i.e. -19.3%) in 2026 and 2031, respectively. Sulphur dioxide (SO_2) emissions are also projected to decline by 5% (i.e. 25,378 tonnes per year) and 10.1% (i.e. 24,680 tonnes per year) in 2026 and 2031, respectively relative to their respective NFC scenarios. The projected emissions of NO_X indicate a potential reduction to 22,840 tonnes per year in 2026 i.e. a decrease of 4.2% w.r.t. NFC_2026 and to 22,642 tonnes per year in 2031 i.e. a decrease of 7.6% w.r.t. NFC 2031. The CO emissions are expected to decrease to 1,50,157 tonnes per year in 2026 i.e. a decrease of 5.1% w.r.t. NFC_2026 and 1,43,932 tonnes per year in 2031 i.e. a decrease of 9.7% w.r.t. NFC 2031.

The SC-I projections in Kalinganagar - Jajpur region indicate a potential decrease of PM_{10} emissions to 21,378 tonnes per year in 2026 i.e. a decrease of 20.7% w.r.t. NFC 2026 and to 20,797 tonnes per year in 2031 i.e. a decrease of -45.4% % w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 7,065 (-12.6%) and 6,746 tonnes per year (i.e. 40.8%) in 2026 and 2031, respectively. Sulphur dioxide emissions are projected to decline by 10.1% (i.e. 24,032 tonnes per year) and 25.1% (i.e. 20,556 tonnes per year) in 2026 and 2031, respectively, relative to their respective NFC scenarios. Similarly, projected emissions of NOx indicate a potential reduction to 21,852 tonnes per year in 2026 i.e. a decrease of 8.3% w.r.t. NFC 2026 and to 19,387 tonnes per year in 2031 i.e. a decrease of 20.9% w.r.t. NFC 2031. The CO emissions are expected to decrease to 1,42,218 tonnes per year in 2026 i.e. a decrease of 10.1% w.r.t. NFC 2026 and 1,20,355 tonnes per year in 2031 i.e. a decrease of 24.5% w.r.t. NFC 2031.

The SC-II projections in Kalinganagar - Jajpur region indicate a potential decrease of PM_{10} emissions to 16,282 tonnes per year in 2026 i.e. a decrease of 39.6% w.r.t. NFC 2026 and to 8,110 tonnes per year in 2031 i.e. a decrease of 78.7% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 5,490 (i.e. -32.1%) and 3,175 tonnes per year (i.e. -72.2%) in 2026 and 2031, respectively. Sulphur dioxide (SO_2) emissions are projected to decline by 25% (i.e. 20,042 tonnes per year) and 50% (i.e. 13,736 tonnes per year) in 2026 and 2031, respectively, relative to their respective NFC scenarios. Similarly, the projected emissions of NO_X indicate a potential reduction to 18,880 tonnes per year in 2026 i.e. a decrease of 20.8% w.r.t. NFC 2026 and to 13,889 tonnes per year in 2031 i.e. a decrease of 43.3% w.r.t. NFC 2031. The CO emissions are expected to decrease to 1,16,562 tonnes per year in 2026 i.e. a decrease of 26.3% w.r.t. NFC 2026 and 82,018 tonnes per year in 2031 i.e. a decrease of 48.5% w.r.t. NFC 2031.

Table 25 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Kalinganagar - Jajpur region for years 2021, 2026 and 2031

Year	Scenario	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
2021	BASE	16,895	5,539	17,818	15,543	1,05,980
2026	NFC	26,974	8,086	26,727	23,835	1,58,176
	BAU	24,179	7,842	25,378	22,840	1,50,157
	SC_I	21,378	7,065	24,032	21,852	1,42,218
	SC_II	16,282	5,490	20,042	18,880	1,16,562
2031	NFC	38,093	11,405	27,452	24,506	1,59,338
	BAU	29,725	9,201	24,680	22,642	1,43,932
	SC_I	20,797	6,746	20,556	19,387	1,20,355
	SC_II	8,110	3,175	13,736	13,889	82,018

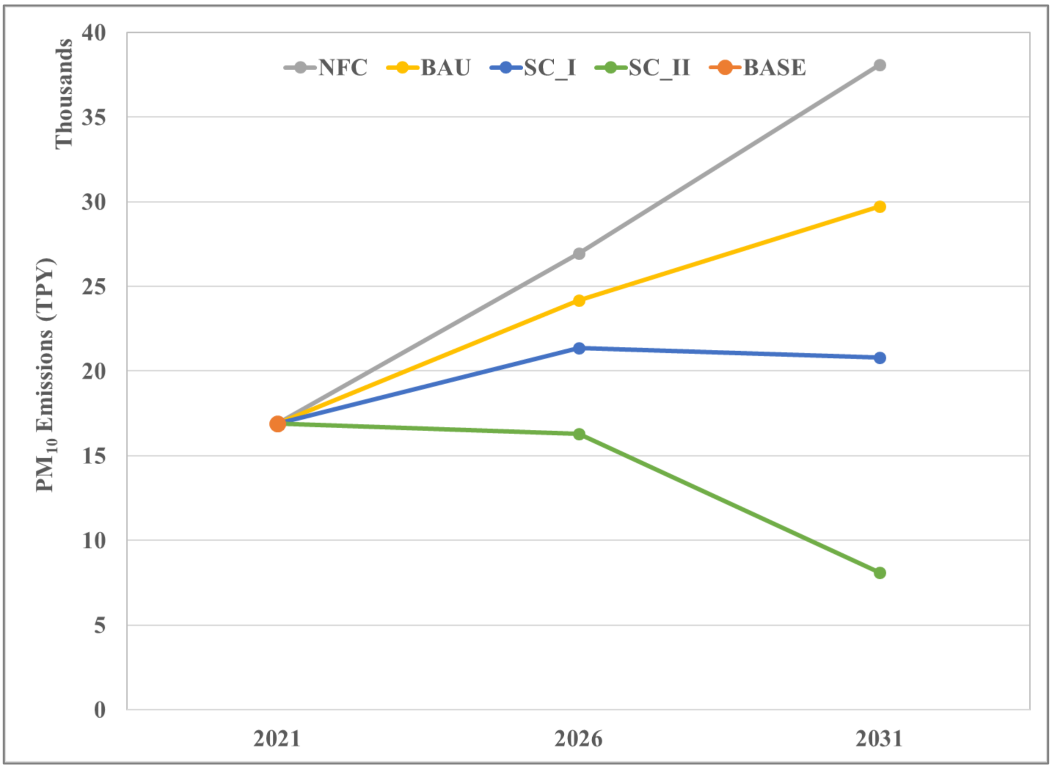


Figure 103 PM10 Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

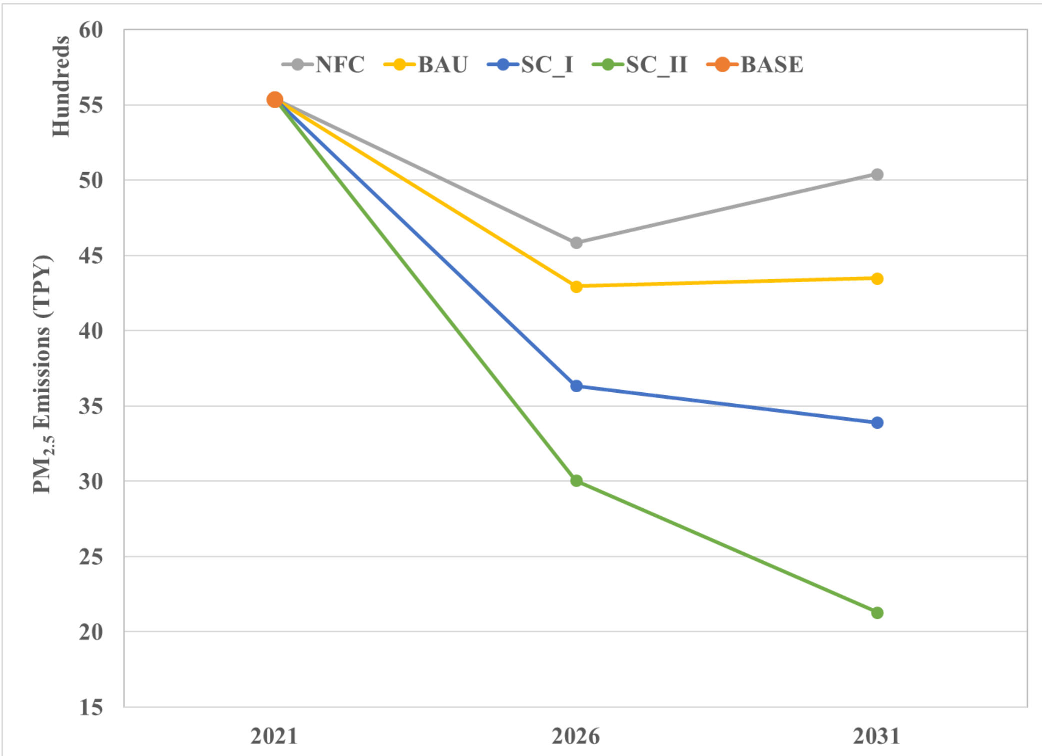


Figure 104 PM2.5 Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

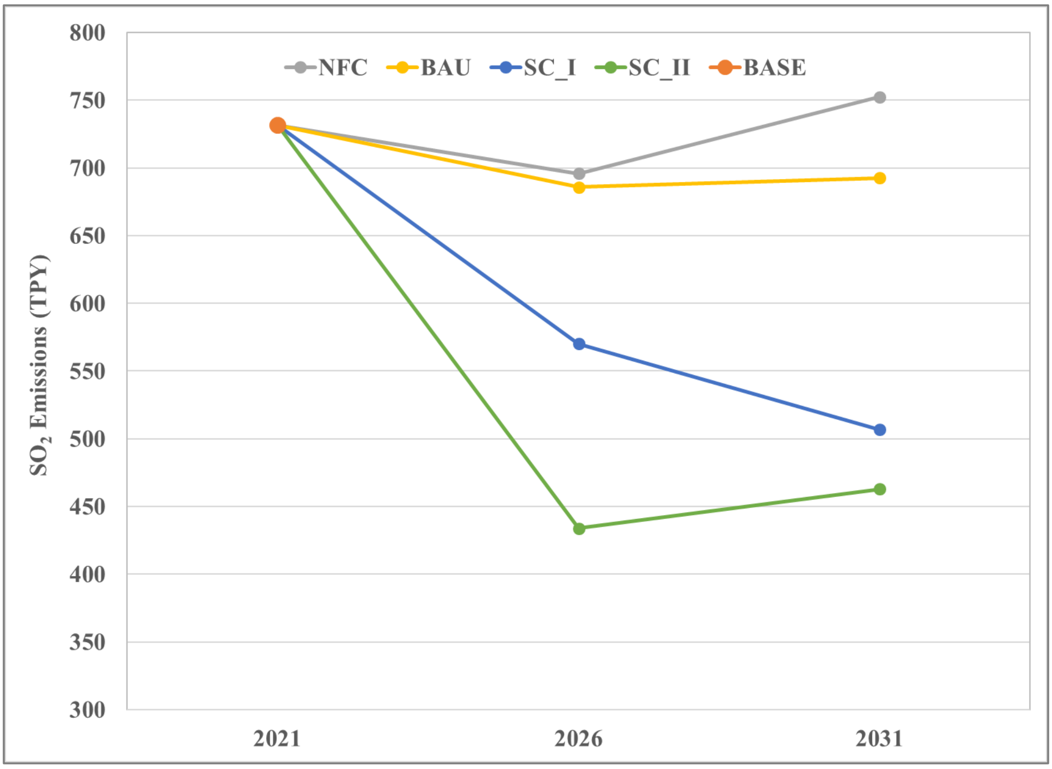


Figure 105 SO2 Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

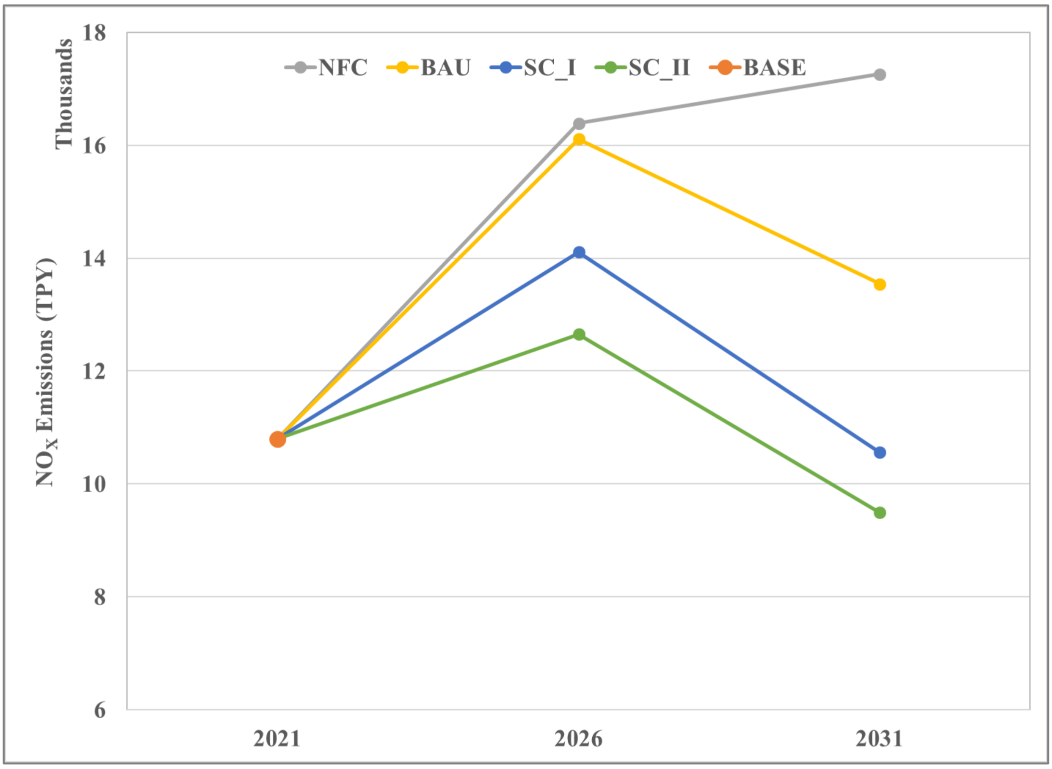


Figure 106 NO_X Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

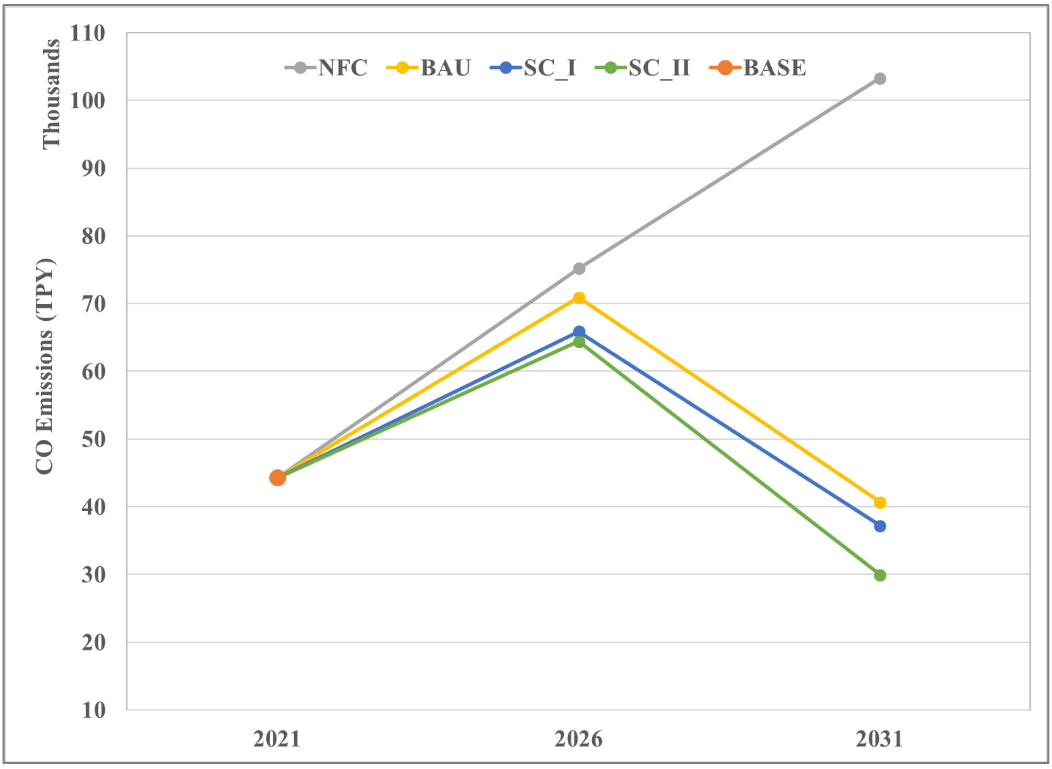


Figure 107 CO Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

5.14.1. Sector-wise emission reduction potentials

Table 26 and Fig. 108-112 shows sector-wise and total estimated emission reduction potential (%) of pollutants w.r.t. respective NFC scenarios in Kalinganagar - Jajpur region for years 2026 and 2031. The total particulate matter emissions in 2026 can be reduced upto maximum 39.6% and 32.1% 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 78.7% and 72.2% in PM_{10} and $PM_{2.5}$, respectively w.r.t. NFC 2031 scenario. In year 2031 the sectoral emission reduction potential for PM_{10} in decreasing order of reduction are road dust (upto 61.33%), fugitive sources (upto 8.54%), and industries (upto 6.81%). Remaining PM_{10} emission sources together contribute about 23% reduction in PM_{10}. Similarly, for $PM_{2.5}$ significant emission reductions can be obtained in re-suspended road dust (upto 49.56%), industrial (upto 14.94%), fugitive dust (upto 3.51%) sectors.

Table 26 Sector-wise estimated emission reduction potential (%) for PM_{10} and $PM_{2.5}$ w.r.t. respective NFC scenarios in Kalinganagar - Jajpur region

Year	Sector	PM_{10}			$PM_{2.5}$		
		BAU	SC-I	SC-II	BAU	SC-I	SC-II
2026	INDU	-0.91%	-1.83%	-4.56%	-2.0%	-4.0%	-9.99%
	TRAN	-0.02%	-0.02%	-0.03%	-0.1%	-0.1%	-0.08%
	RDST	-7.46%	-14.95%	-28.90%	-6.0%	-12.1%	-23.32%
	WAST	-0.09%	-0.24%	-0.48%	-0.3%	-0.7%	-1.48%
	CONS	-0.06%	-0.12%	-0.18%	0.0%	-0.1%	-0.10%
	DSGN	< 0.01%	< 0.01%	< 0.01%	< 0.01%	< 0.01%	< 0.01%
	RESI	-0.14%	-0.21%	-0.31%	-0.3%	-0.5%	-0.69%
	BRIC	< 0.01%	-0.04%	-0.20%	< 0.01%	-0.1%	-0.55%
	HRBE	-0.08%	-0.16%	-0.20%	-0.2%	-0.3%	-0.41%
	CREM	< 0.01%	< 0.01%	< 0.01%	< 0.01%	< 0.01%	< 0.01%
	FUGT	-1.58%	-3.17%	-4.75%	-0.7%	-1.3%	-1.96%
	Total	**-10.4%**	**-20.7%**	**-39.6%**	**-3.0%**	**-12.6%**	**-32.1%**
2031	INDU	-1.36%	-3.40%	-6.81%	-2.99%	-7.47%	-14.94%
	TRAN	-0.03%	-0.07%	-0.14%	-0.10%	-0.20%	-0.44%
	RDST	-17.17%	-35.01%	-61.33%	-13.88%	-28.29%	-49.56%
	WAST	-0.13%	-0.24%	-0.44%	-0.40%	-0.75%	-1.35%
	CONS	-0.09%	-0.27%	-0.53%	-0.05%	-0.15%	-0.31%
	DSGN	< 0.01%	< 0.01%	< 0.01%	< 0.01%	< 0.01%	< 0.01%
	RESI	-0.14%	-0.21%	-0.30%	-0.30%	-0.47%	-0.67%
	BRIC	-0.03%	-0.19%	-0.20%	-0.10%	-0.52%	-0.55%
	HRBE	-0.15%	-0.31%	-0.39%	-0.31%	-0.62%	-0.78%
	CREM	< 0.01%	< 0.01%	-0.03%	< 0.01%	-0.02%	-0.04%
	FUGT	-2.85%	-5.69%	-8.54%	-1.17%	-2.34%	-3.51%
	Total	**-22.0%**	**-45.4%**	**-78.7%**	**-19.3%**	**-40.8%**	**-72.2%**

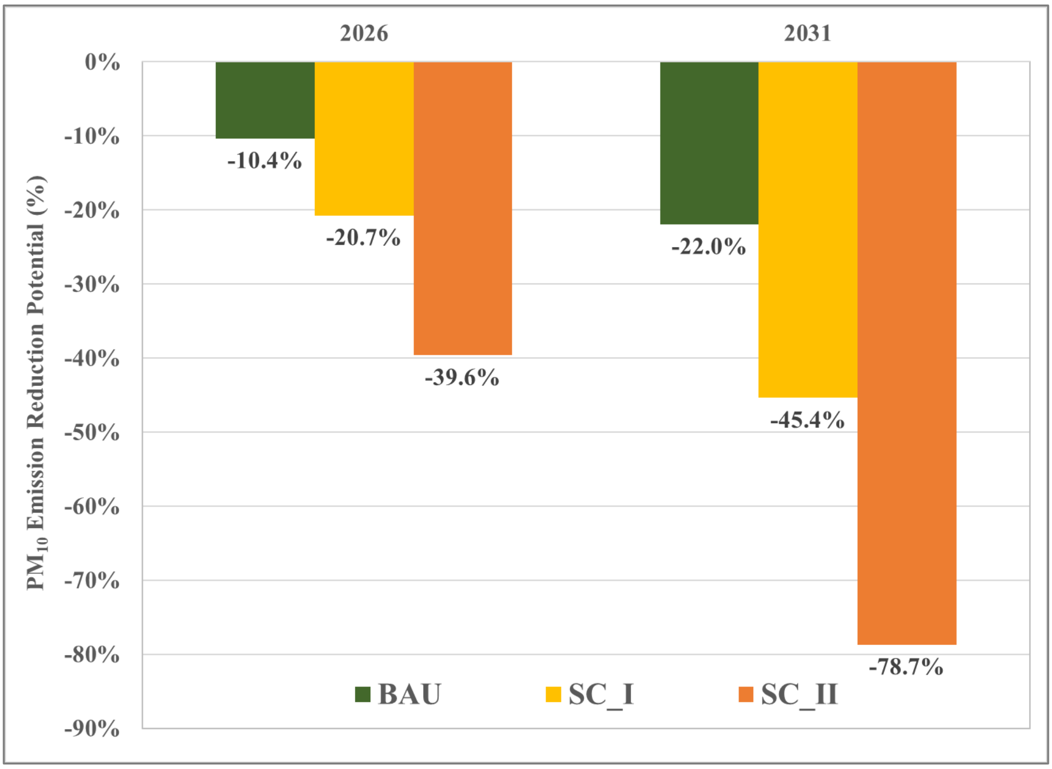


Figure 108 PM10 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

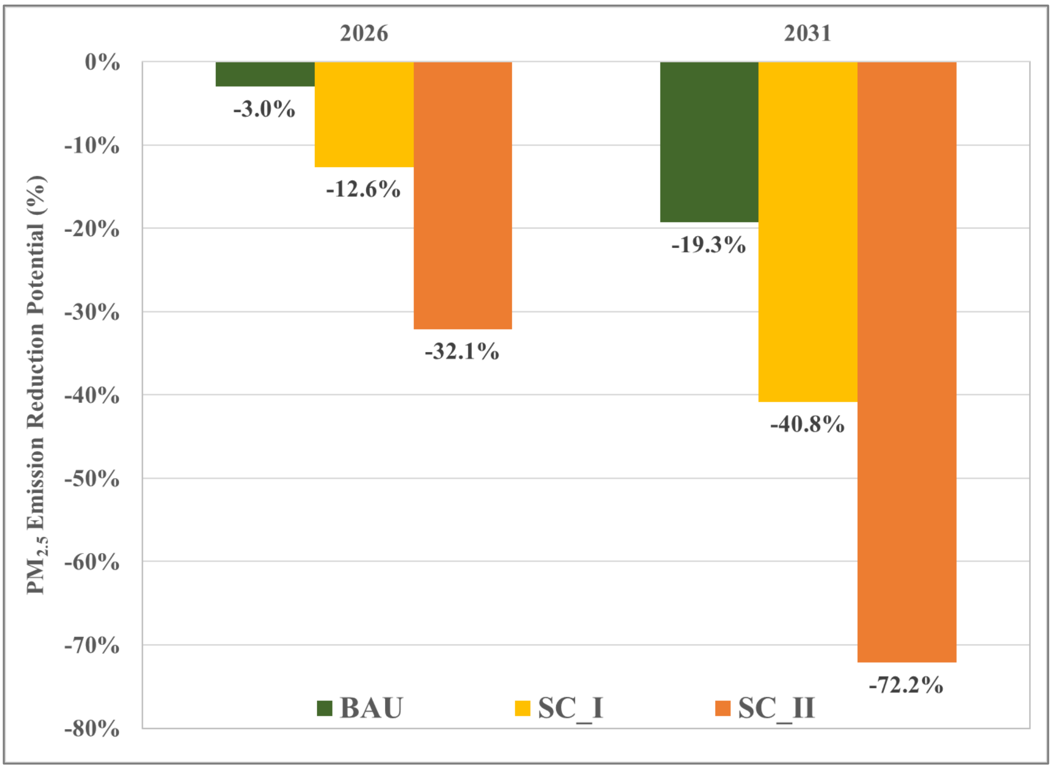


Figure 109 PM2.5 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

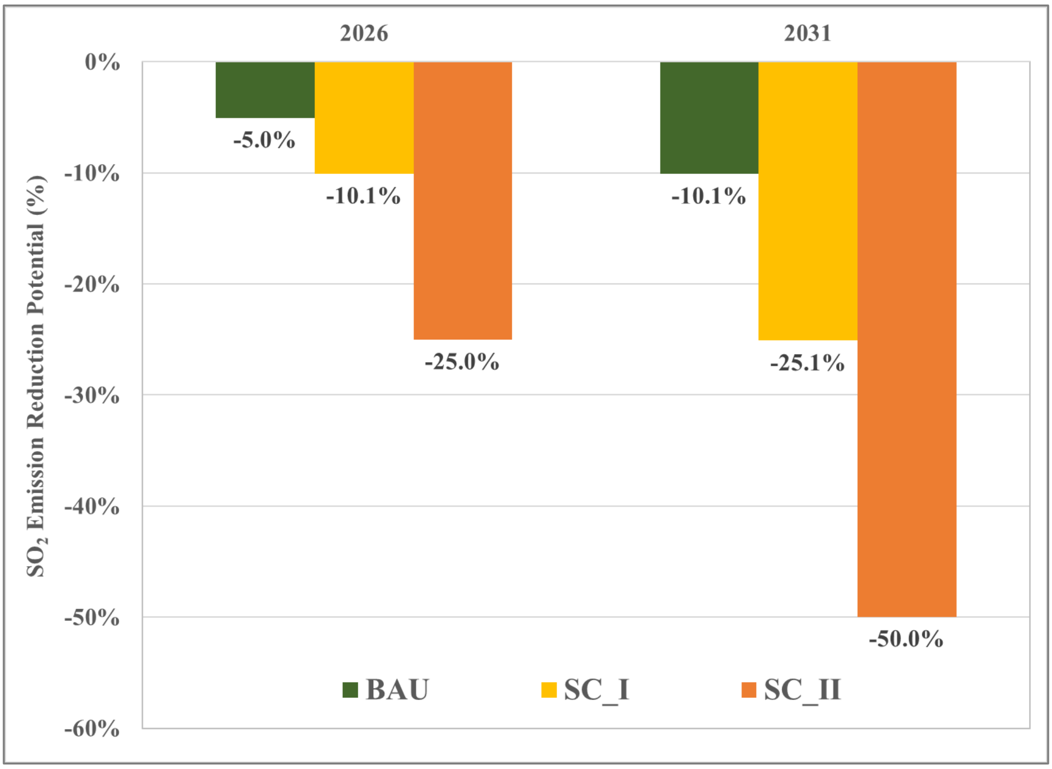


Figure 110 SO2 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

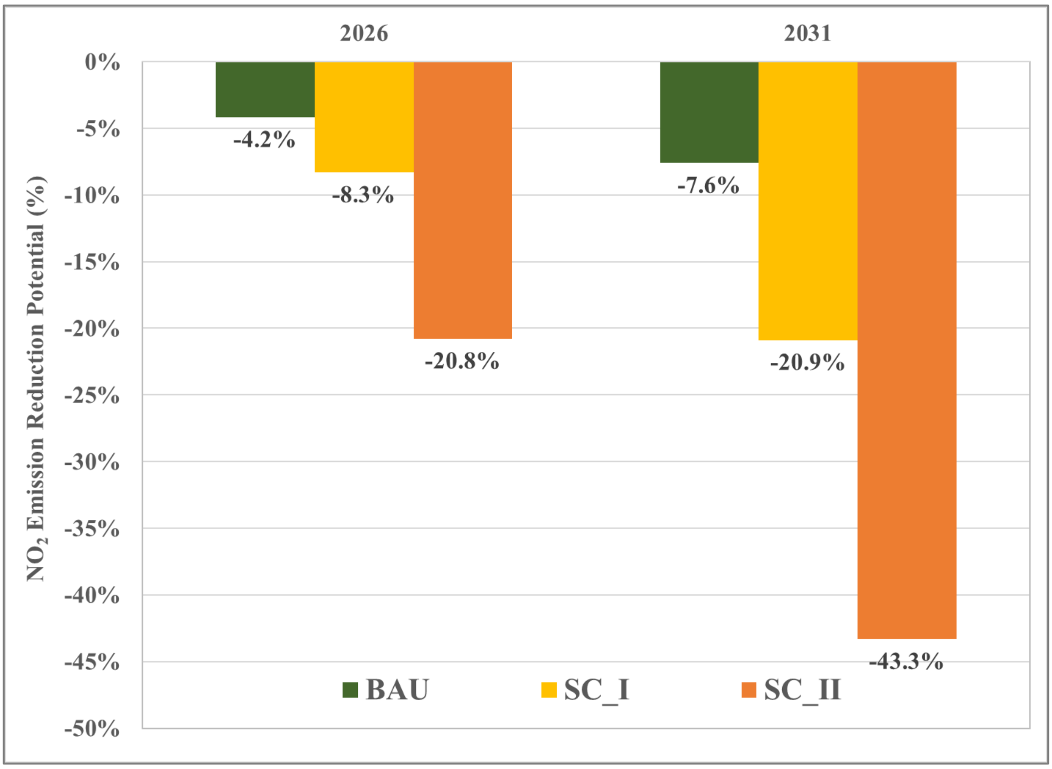


Figure 111 NO_X Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

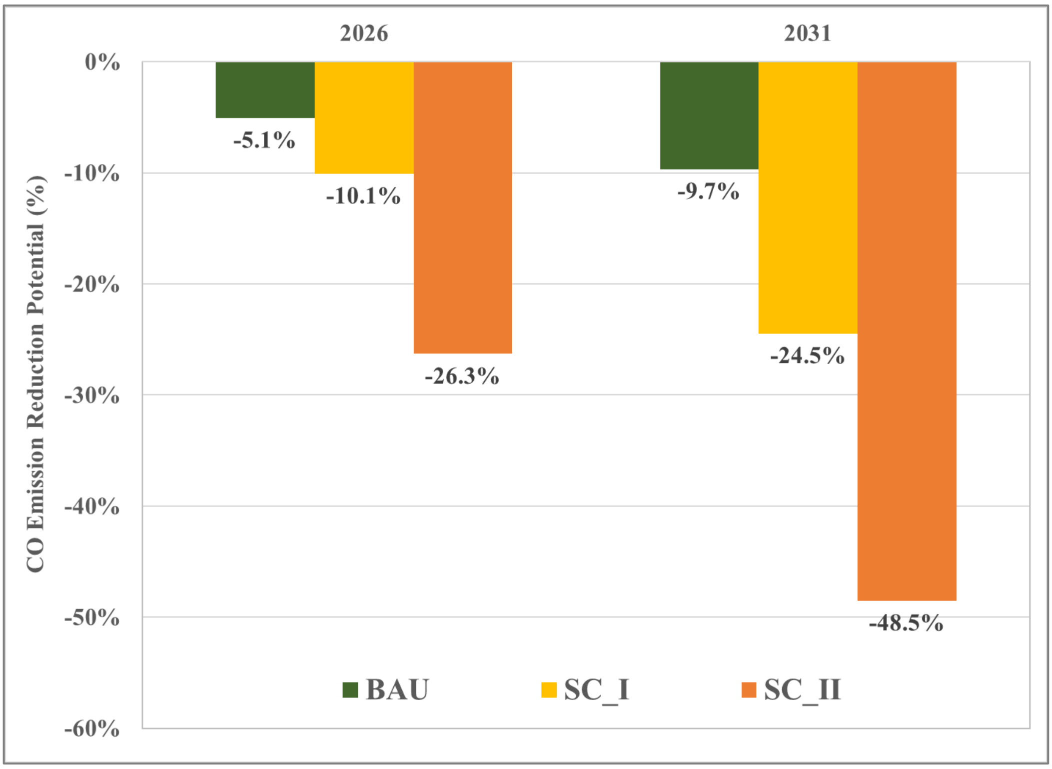


Figure 112 CO Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

5.15. 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 Kalinganagar – Jajpur region. The spatial distribution of pollutant (PM_{10}, $PM_{2.5}$. SO_2, NO_2, CO) concentration levels over Kalinganagar – Jajpur 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 southern part of the study domain. This spatial distribution can be mainly attributed to the industrial activities and heavy vehicle movement 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, increased penetration of BS VI vehicles, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, NMT & improvement in 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 113-114, the PM_{10} concentrations for NFC scenario in 2026 and 2031, are mainly concentrated in the central part and the southern part of the study domain. The domain-averaged annual PM_{10} concentrations (i.e. mean of annual concentrations of 126 receptors in the study domain) estimated by AERMOD during four scenarios are 118.8, 106.5, 94.3, and 74.1 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The domain-averaged annual PM_{10} concentrations during year 2031 are estimated to be 167.8, 130.5, 92.0, and 38.7 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 9.7%, 19.4%, 34.8% in 2026 and 20.8%, 42.4%, 73.2% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 115-116, the $PM_{2.5}$ concentrations, are also concentrated in the central part and southern part of the study domain. The domain-averaged annual $PM_{2.5}$ concentrations (i.e. mean of annual concentrations of 126 receptors in the study domain) estimated by AERMOD during four scenarios are 38.3, 34.8, 31.3, and 25.4 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The domain-averaged annual $PM_{2.5}$ concentrations during year 2031 are estimated to be 52.6, 41.9, 31.0, and 15.6 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 8.4%, 16.8%, and 30.5% in 2026 and 18.6%, 37.9%, and 65.5% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 117-118, the SO_2 concentrations, are concentrated in the central and western part of the study domain. The domain-averaged annual SO_2 concentrations (i.e. mean of annual concentrations of 126 receptors in the study domain) estimated by AERMOD during four scenarios are 7.1, 6.8, 6.5, and 5.8 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The domain-averaged annual SO_2 concentrations (i.e. mean of annual concentrations of 126 receptors in the study domain) are estimated to be 7.6, 6.9, 6.0, and 4.8 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 4.5%, 8.7%, 17.4% in 2026 and 9.2%, 20.4%, and 35.0% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 119-120, the NO_2 concentrations, are concentrated in central and eastern part of the study domain. Ambient NO_2 concentrations are mainly driven by ground-level line sources and are found to be highest in the vicinity of highways and major rods where heavy vehicle movement is high. The domain-averaged annual NO_2 concentrations (i.e. mean of annual concentrations of 126 receptors in the study domain) estimated by AERMOD during four scenarios are 9.2, 9.1, 9.1, and 9.0 $\mu g/m^3$ for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The domain-averaged annual NO_2 concentrations during year 2031 are estimated to be 8.4, 8.7, 8.4, and 7.8 $\mu g/m^3$ for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 0.5%, 0.9%, 2.3% in 2026. With an increase in penetration of E20 vehicle and CNG operated goods vehicles till year 2031, NO_2 concentrations are likely to slightly increase. Hence, with implementation of control measures considered in different scenarios, an estimated increase of 3.4%, 0.0%, and a reduction of 7.0% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 121-122, the CO concentrations, are also concentrated in the central, and eastern part of the study domain. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 126 receptors in the study domain) estimated by AERMOD during four scenarios are 0.19, 0.19, 0.18, and 0.17 mg/m3 for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 126 receptors in the study domain) estimated to be 0.20, 0.19, 0.18, and 0.16 mg/m3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 2.44%, 4.34%, and 8.58% in 2026 and 2.59%, 7.54%, and 15.01% 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.

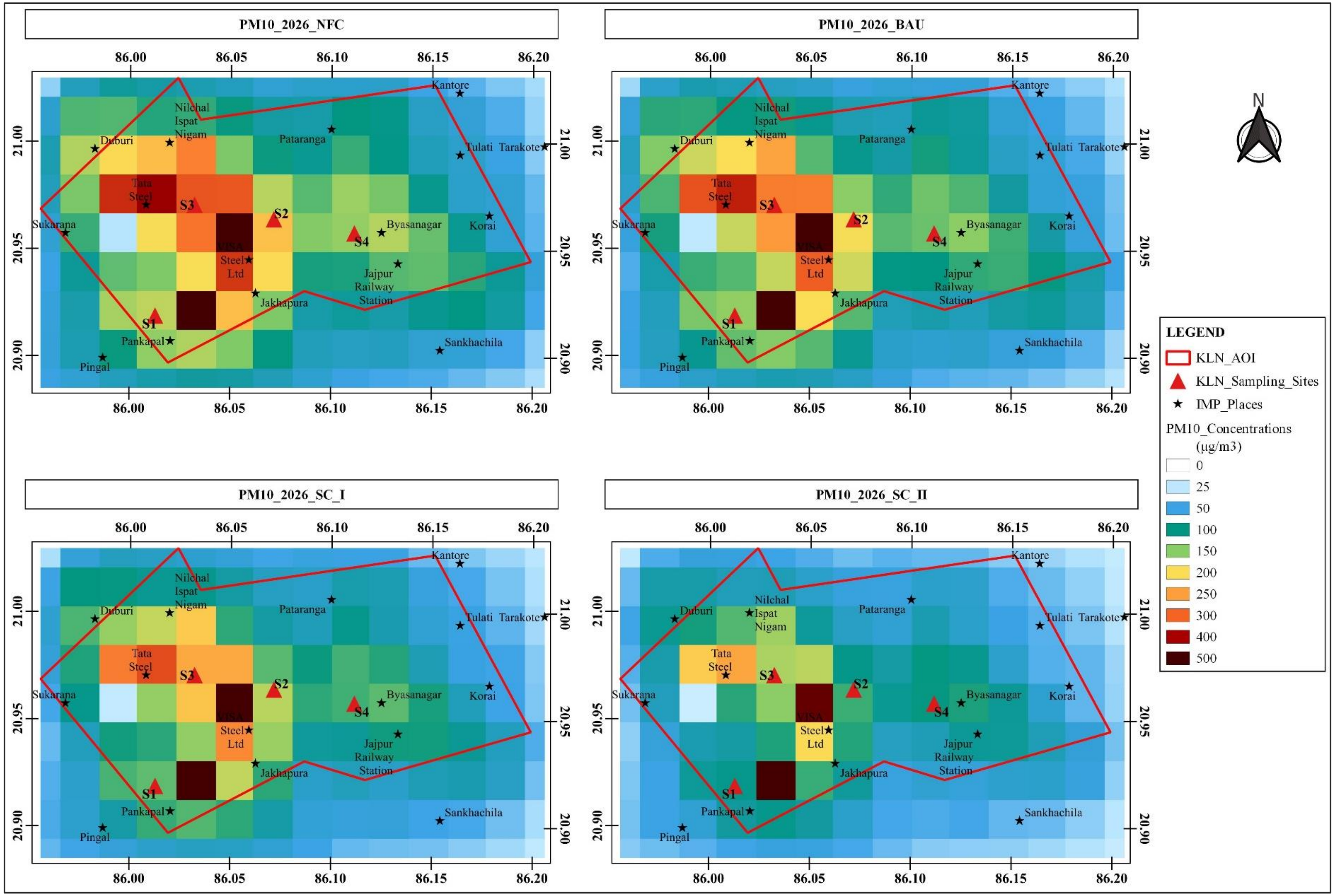


Figure 113 Spatial distribution of annual mean PM$_{10}$ *concentrations* (µg/m^3) *for four scenarios in year 2026 over Kalinganagar – Jajpur region*

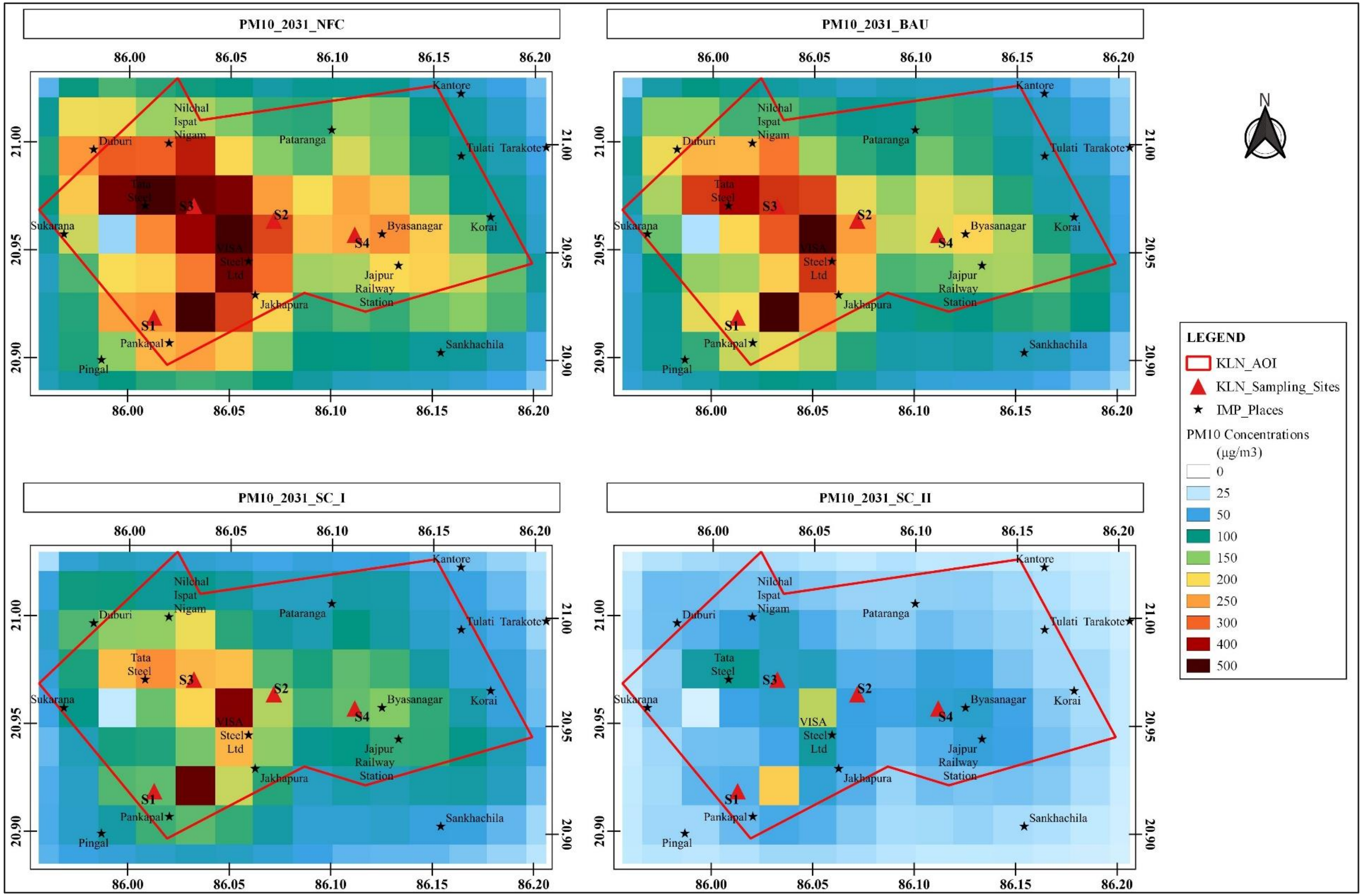


Figure 114 Spatial distribution of annual mean PM_{10} *concentrations* ($\mu g/m^3$) *for four scenarios in year 2031 over Kalinganagar – Jajpur region*

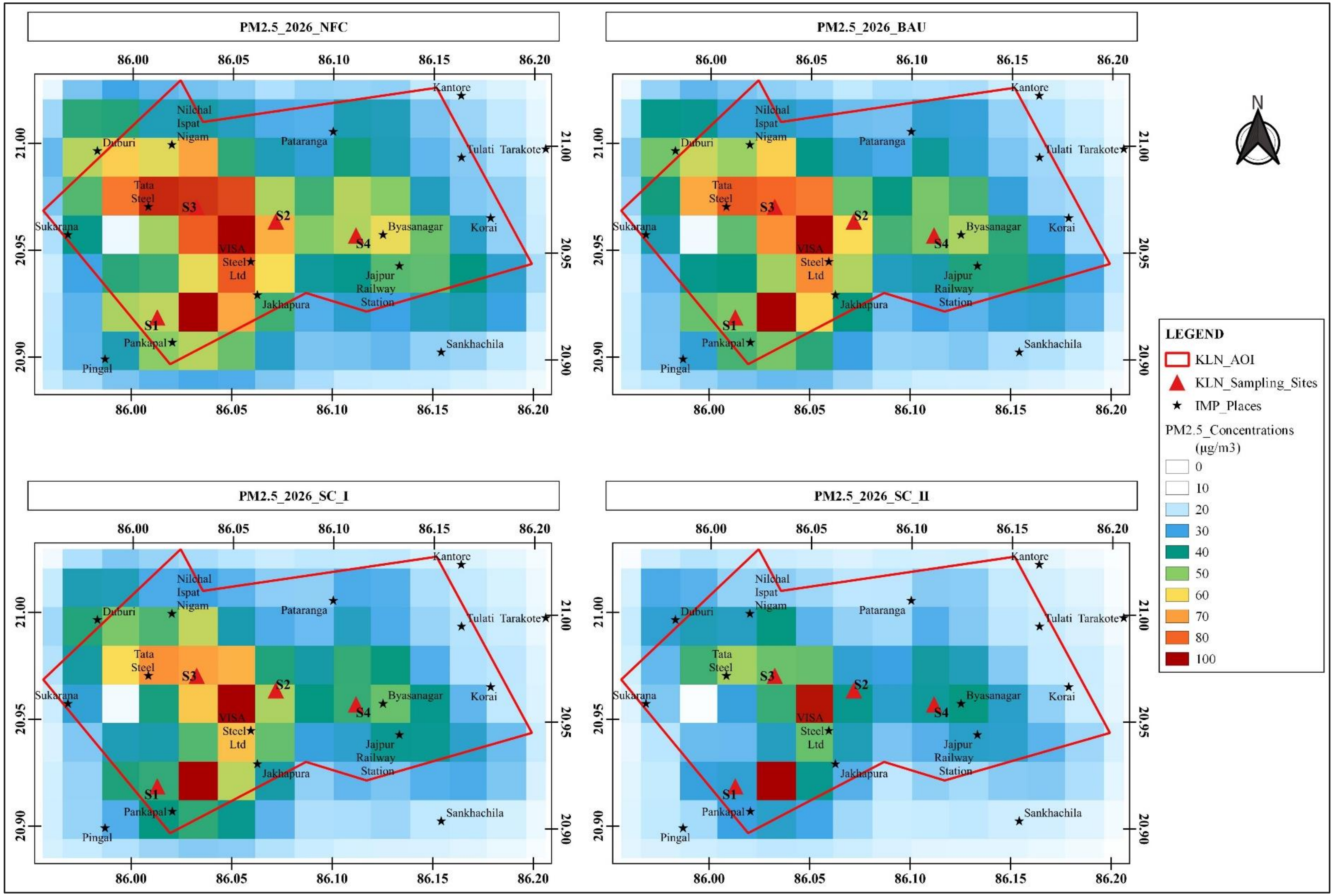


Figure 115 Spatial distribution of annual mean PM$_{2.5}$ ***concentrations*** (µg/m^3) ***for four scenarios in year 2026 over Kalinganagar – Jajpur region***

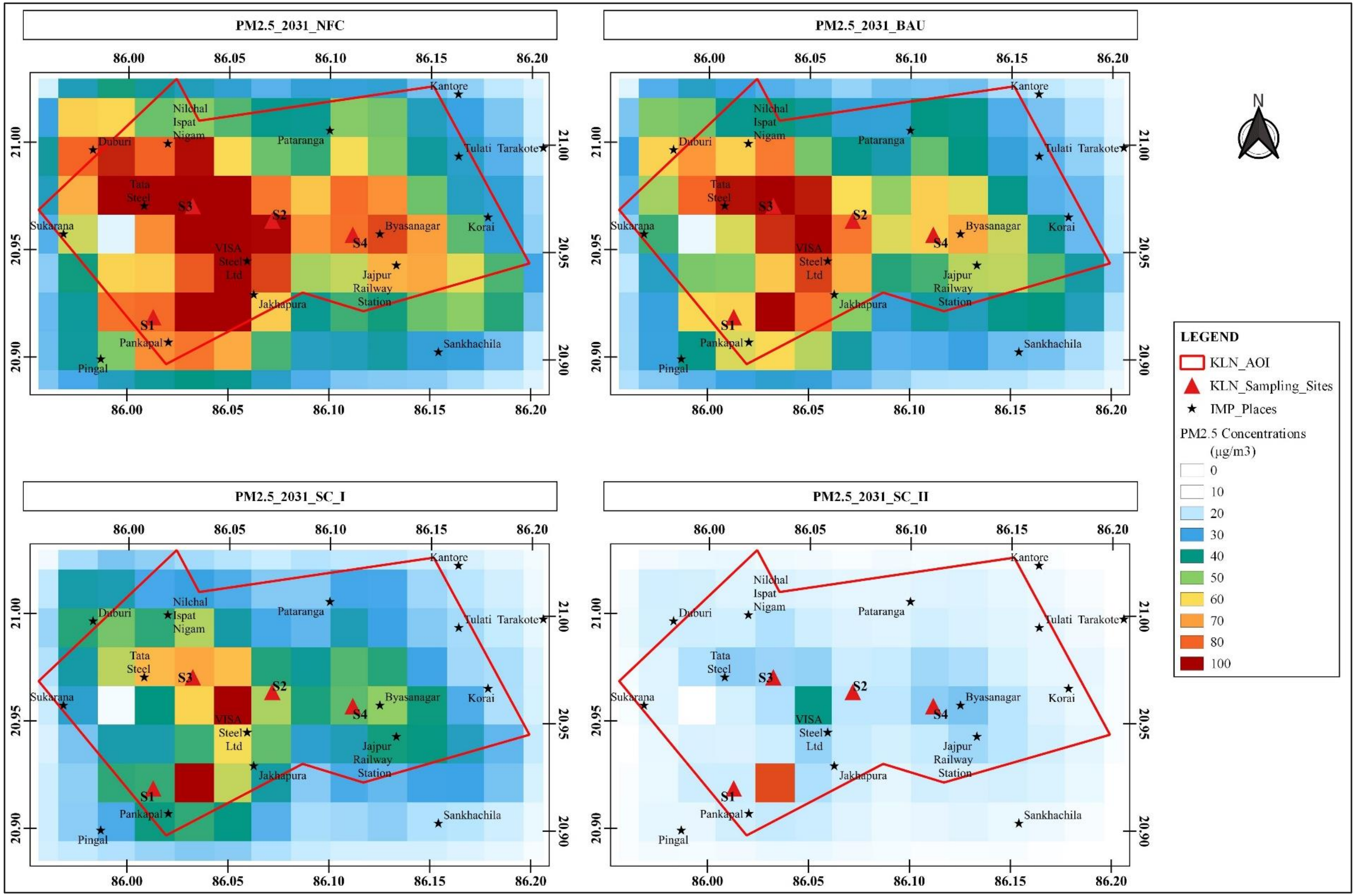


Figure 116 Spatial distribution of annual mean PM$_{2.5}$ *concentrations* (µg/m^3) *for four scenarios in year 2031 over Kalinganagar – Jajpur region*

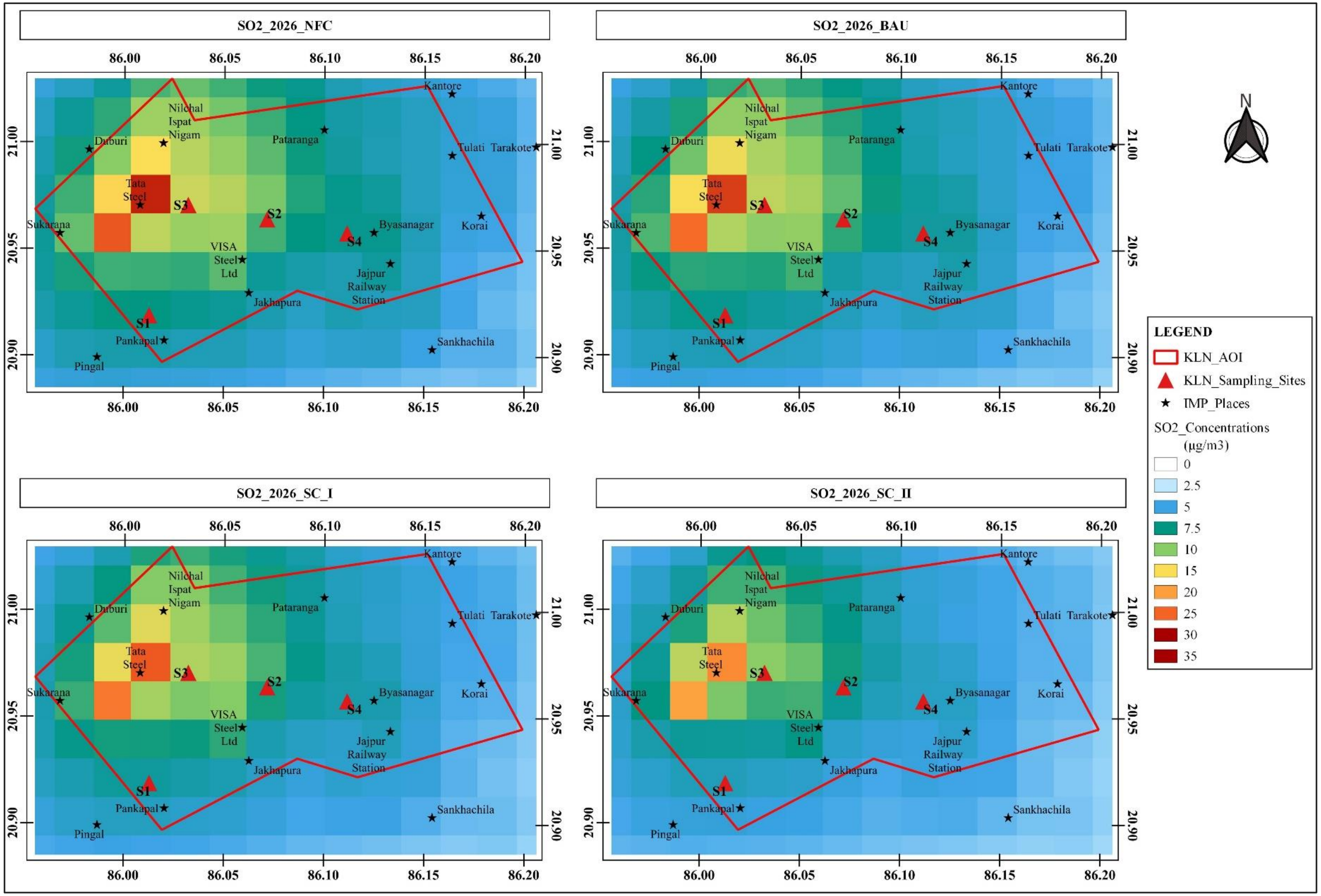


Figure 117 Spatial distribution of annual mean** SO_2 **concentrations** (µg/m^3) **for four scenarios in year 2026 over Kalinganagar – Jajpur region

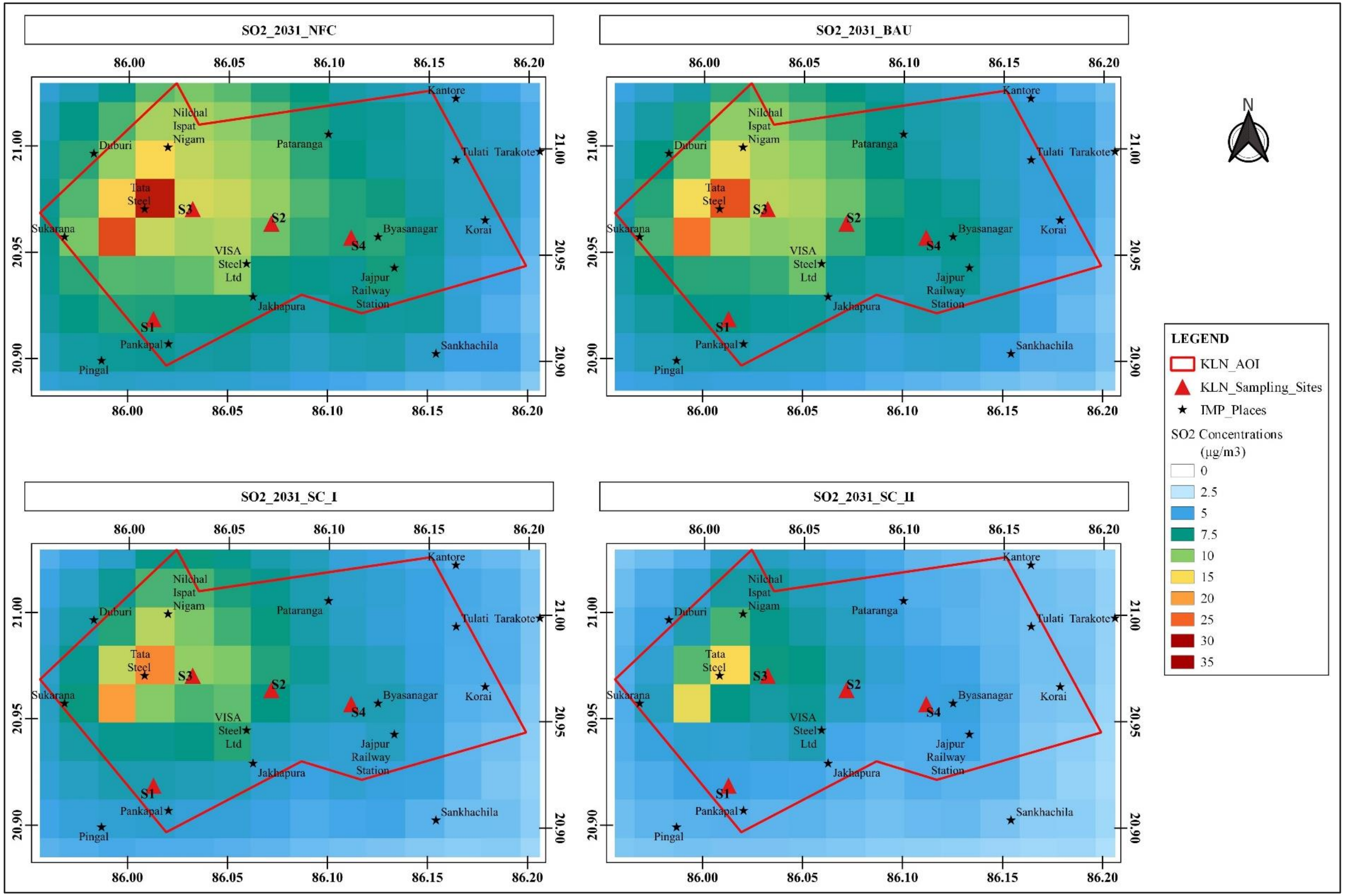


Figure 118 Spatial distribution of annual mean SO_2 ***concentrations*** (µg/m^3) ***for four scenarios in year 2031 over Kalinganagar – Jajpur region***

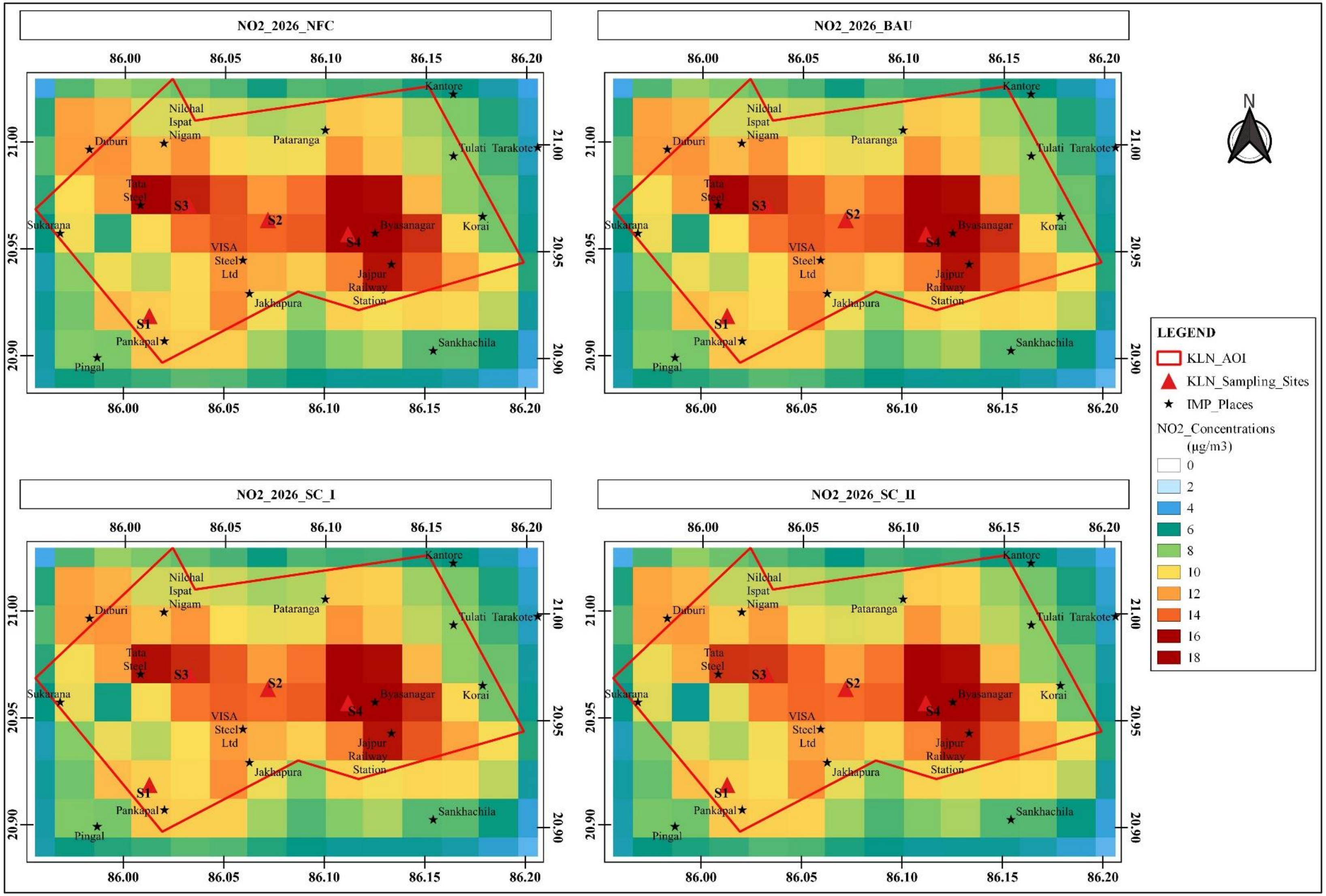


Figure 119 Spatial distribution of annual mean NO_2 *concentrations* (µg/m^3) *for four scenarios in year 2026 over Kalinganagar – Jajpur region*

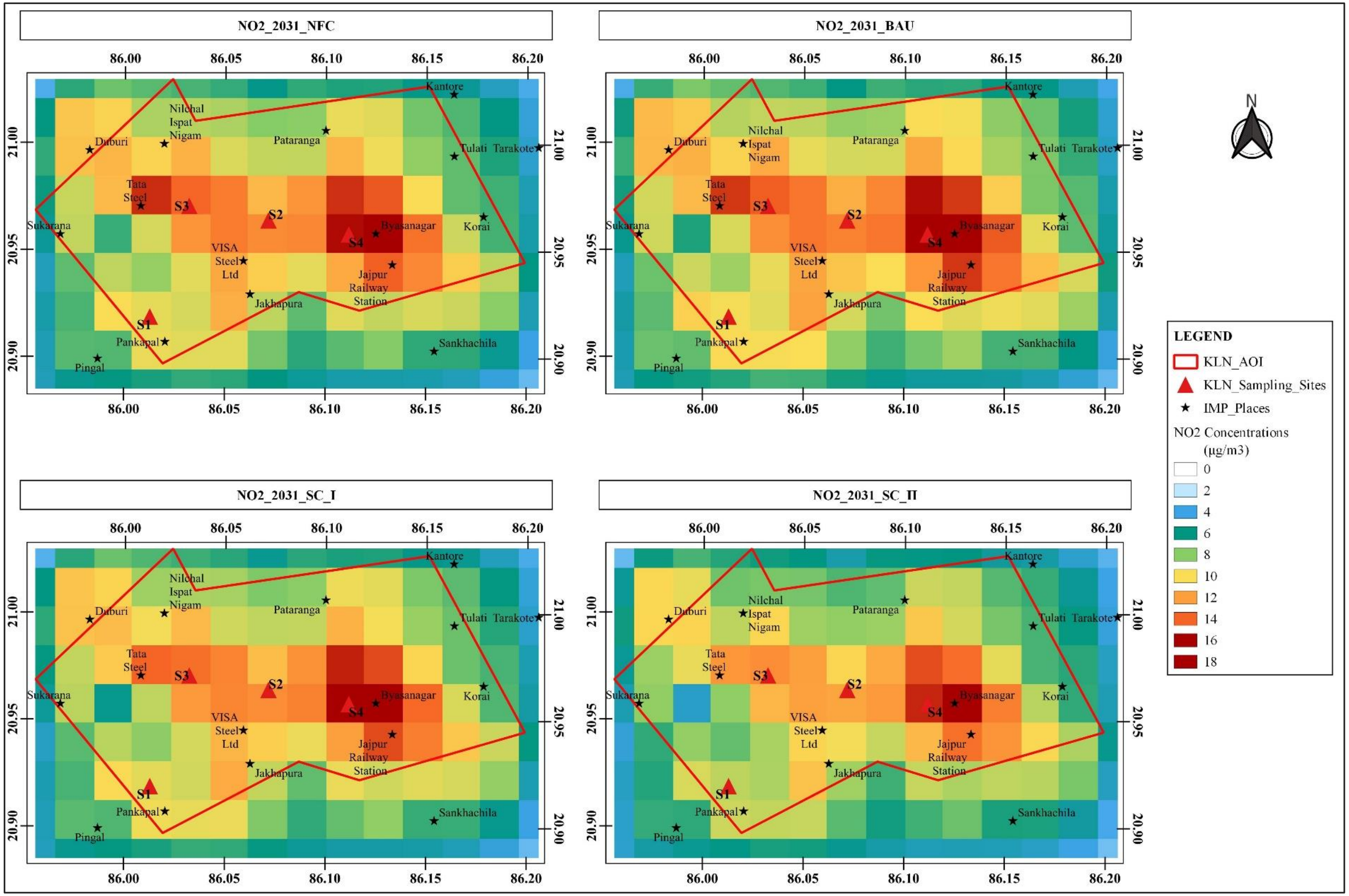


Figure 120 Spatial distribution of annual mean NO_2 *concentrations* ($\mu g/m^3$) *for four scenarios in year 2031 over Kalinganagar – Jajpur region*

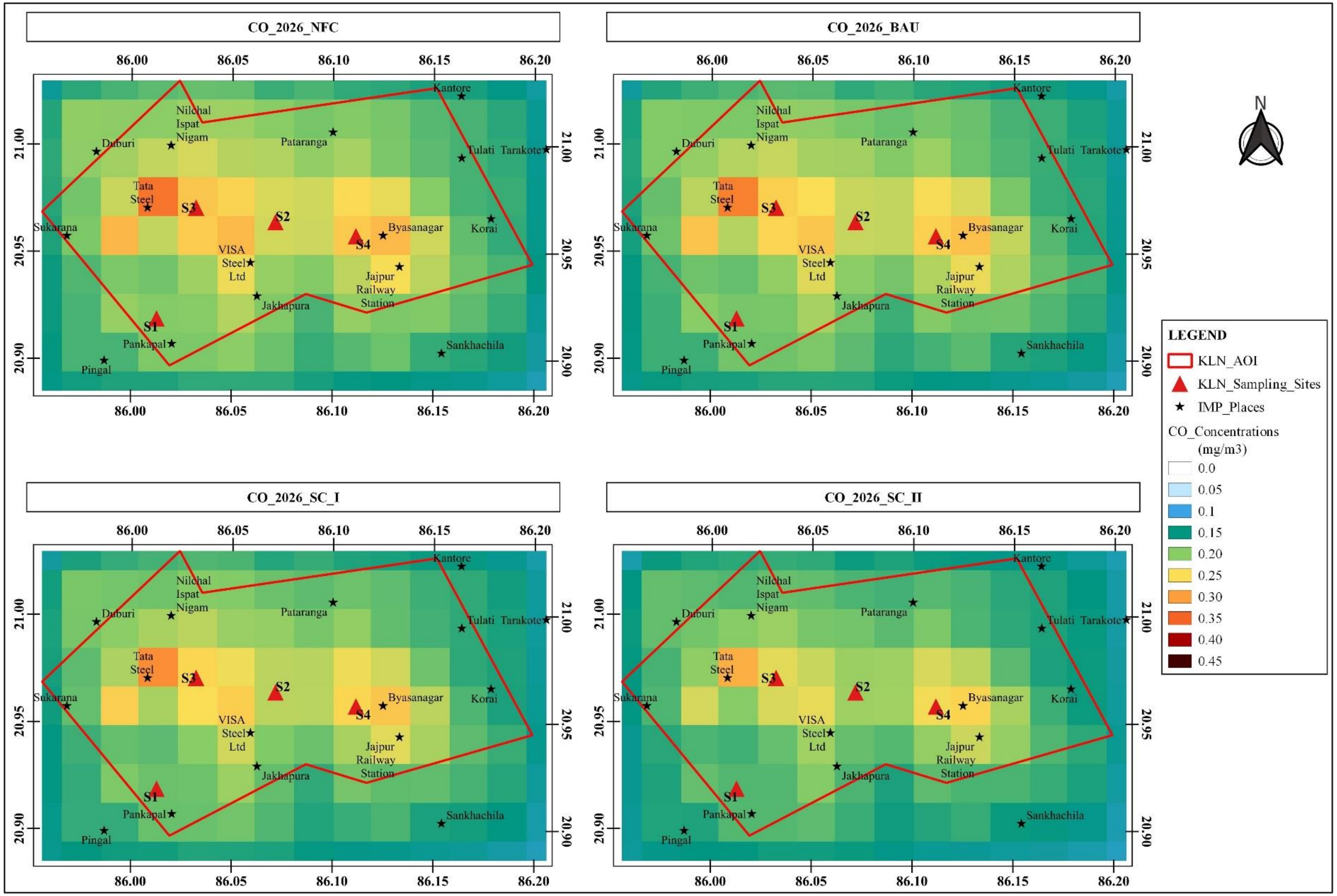


Figure 121 Spatial distribution of annual mean CO concentrations (mg/m^3) for four scenarios in year 2026 over Kalinganagar – Jajpur region

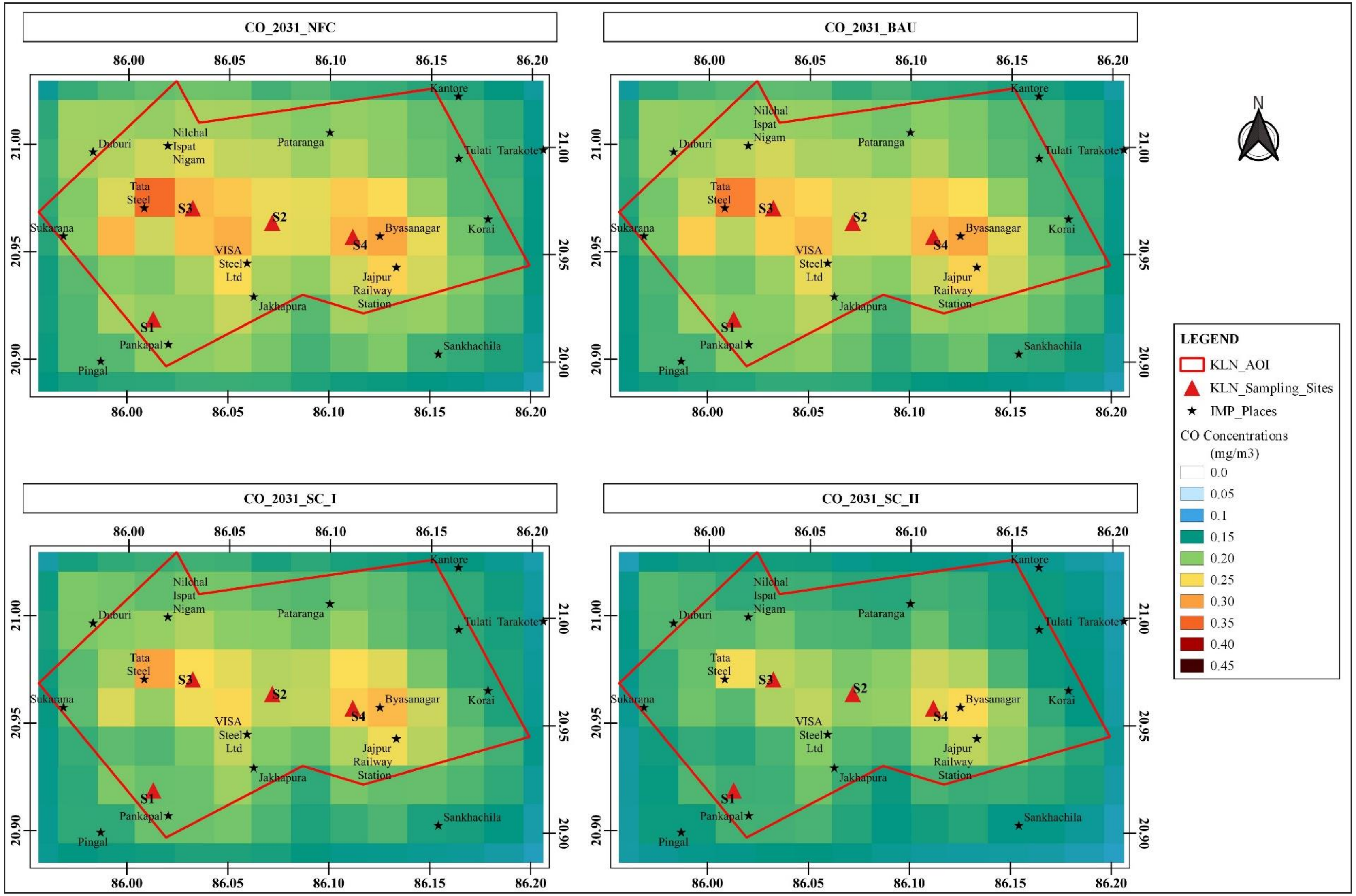


Figure 122 Spatial distribution of annual mean CO concentrations (mg/m^3) for four scenarios in year 2031 over Kalinganagar – Jajpur region

This study also assessed location -specific air quality benefits due to implementation of different scenarios in 2026 and 2031. Four representative locations, i.e. ARAI sampling locations, were selected to understand the impact of control measures on air quality. Tables 27 to 30 presents the percentage change in air pollutants annual mean concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at eight selected locations in Kalinganagar – Jajpur region.

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

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-11.3%	-22.6%	-47.1%	-23.6%	-48.0%	-83.6%
$PM_{2.5}$	-10.5%	-20.9%	-43.6%	-22.1%	-45.2%	-79.0%
SO_2	-4.7%	-9.2%	-18.8%	-9.7%	-21.6%	-37.7%
NO_2	-0.5%	-0.8%	-1.8%	3.1%	0.0%	-6.6%
CO	-2.8%	-4.9%	-9.6%	-3.0%	-8.4%	-16.4%

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

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-11.3%	-22.7%	-43.5%	-23.9%	-48.8%	-82.8%
$PM_{2.5}$	-10.5%	-20.9%	-40.3%	-22.4%	-45.8%	-78.1%
SO_2	-4.9%	-9.6%	-19.8%	-10.1%	-22.7%	-39.9%
NO_2	-0.4%	-0.7%	-1.8%	2.3%	-0.6%	-7.0%
CO	-2.4%	-4.5%	-10.2%	-2.9%	-8.5%	-17.5%

Table 29 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S3 i.e. TATA Steel sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-11.6%	-23.3%	-47.3%	-24.7%	-50.4%	-85.5%
$PM_{2.5}$	-11.0%	-22.1%	-46.0%	-23.6%	-48.2%	-82.4%
SO_2	-4.5%	-9.0%	-21.0%	-9.2%	-22.0%	-42.0%
NO_2	-0.7%	-1.2%	-3.2%	1.1%	-2.5%	-9.9%
CO	-2.6%	-4.9%	-11.2%	-3.7%	-10.2%	-20.7%

Table 30 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S4 i.e. RO Office sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-10.2%	-20.4%	-34.0%	-21.0%	-43.0%	-75.1%
$PM_{2.5}$	-9.0%	-17.8%	-29.9%	-19.4%	-39.6%	-69.1%
SO_2	-5.1%	-9.8%	-17.9%	-10.9%	-22.9%	-36.5%
NO_2	0.1%	-0.1%	-0.5%	5.3%	2.9%	-3.4%
CO	-1.9%	-3.4%	-7.2%	-0.1%	-4.9%	-13.2%

5.15.1. 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. (17)) 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. (18)). 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.

$$\mathbf{I_i} = \left[\left\{\frac{(\mathbf{I_{HI}} - \mathbf{I_{LO}})}{(\mathbf{B_{HI}} - \mathbf{B_{LO}})}\right\} * (\mathbf{C_P} - \mathbf{B_{LO}})\right] + \mathbf{I_{LO}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{17})$$

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.

$$\mathbf{I} = \max_{\mathbf{i}=\mathbf{1,2,3\ldots,n}} (\mathbf{I_i}) \ldots\ldots\ldots\ldots\ldots (\mathbf{18})$$

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

This section discusses the air quality indices (AQI) calculated at representative site i.e. S4 in Byasnagar 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. 123 shows the distribution of six AQI categories at Byasnagar location in Kalinganagar – Jajpur region for modelled concentrations in year 2021, while Fig. 126 and Fig. 127 shows the distribution of AQI categories for different scenarios in 2026 and 2031 respectively.

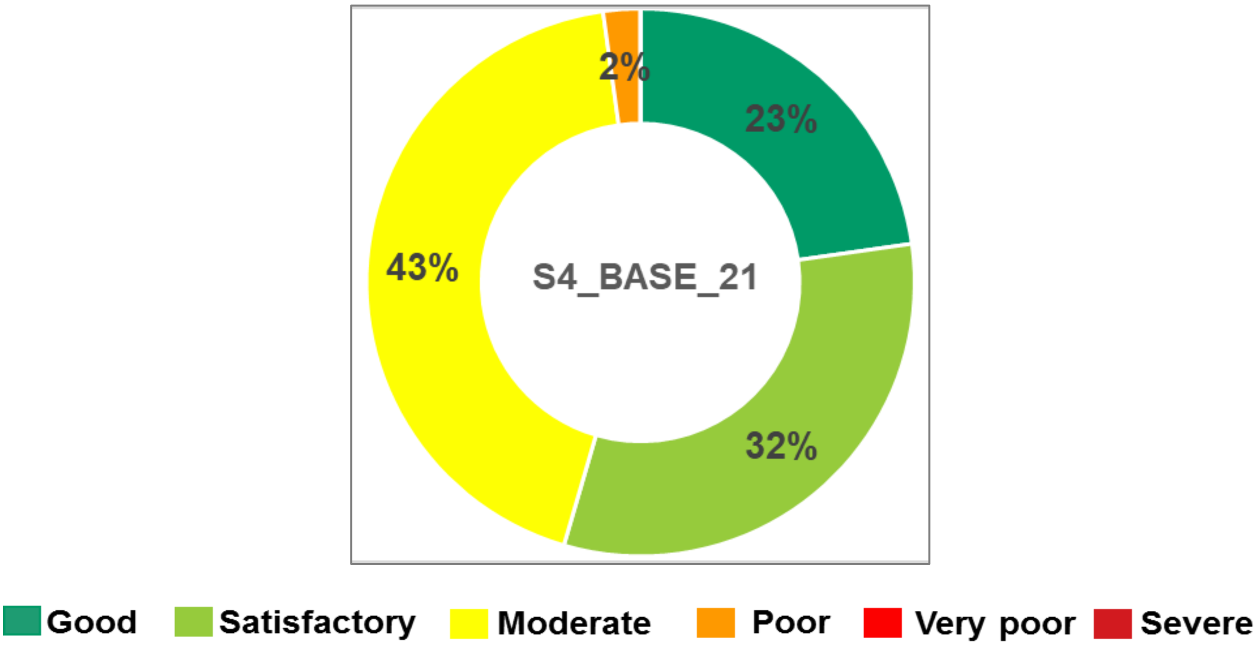


Figure 123 Distribution of six AQI categories at Byasnagar location in Kalinganagar – Jajpur for modelled pollutant concentrations for baseline year

The AQI at the selected location during baseline scenario in 2021 is mainly driven by PM_{10} and on few occasions by $PM_{2.5}$. An examination of modelled AQI for the baseline scenario revealed that air quality index, is mainly distributed in Moderate (43%), Satisfactory (32%) and Good (23%) classes while Poor category AQI is reported for approx. 2% of days in a year.

The AQI distribution in NFC scenarios during year 2026 shows degraded air quality compared to baseline year with 13% Good, 18% satisfactory, 59% moderate, 8% poor, 1% very poor and 2% severe days. In year 2031, the air quality situation would further degrade if no further actions are taken. For example, The AQI distribution in NFC scenarios during year 2031 shows degraded air quality compared to baseline year with 5% Good, 13% satisfactory, 39% moderate, 24% poor, 10% very poor and 8% 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 31% and 18% in 2026 and 2031, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 33% and 25% in 2026 and 2031, respectively under BAU scenario, to 40% and 35% in 2026 and 2031, respectively under SC-I, to 52% and 92% in 2026 and 2031, respectively under SC-II scenario. Fig 124 and 125 represents the distribution of AQI categories in four scenarios at Byasnagar location for year 2026 and 2031 respectively.

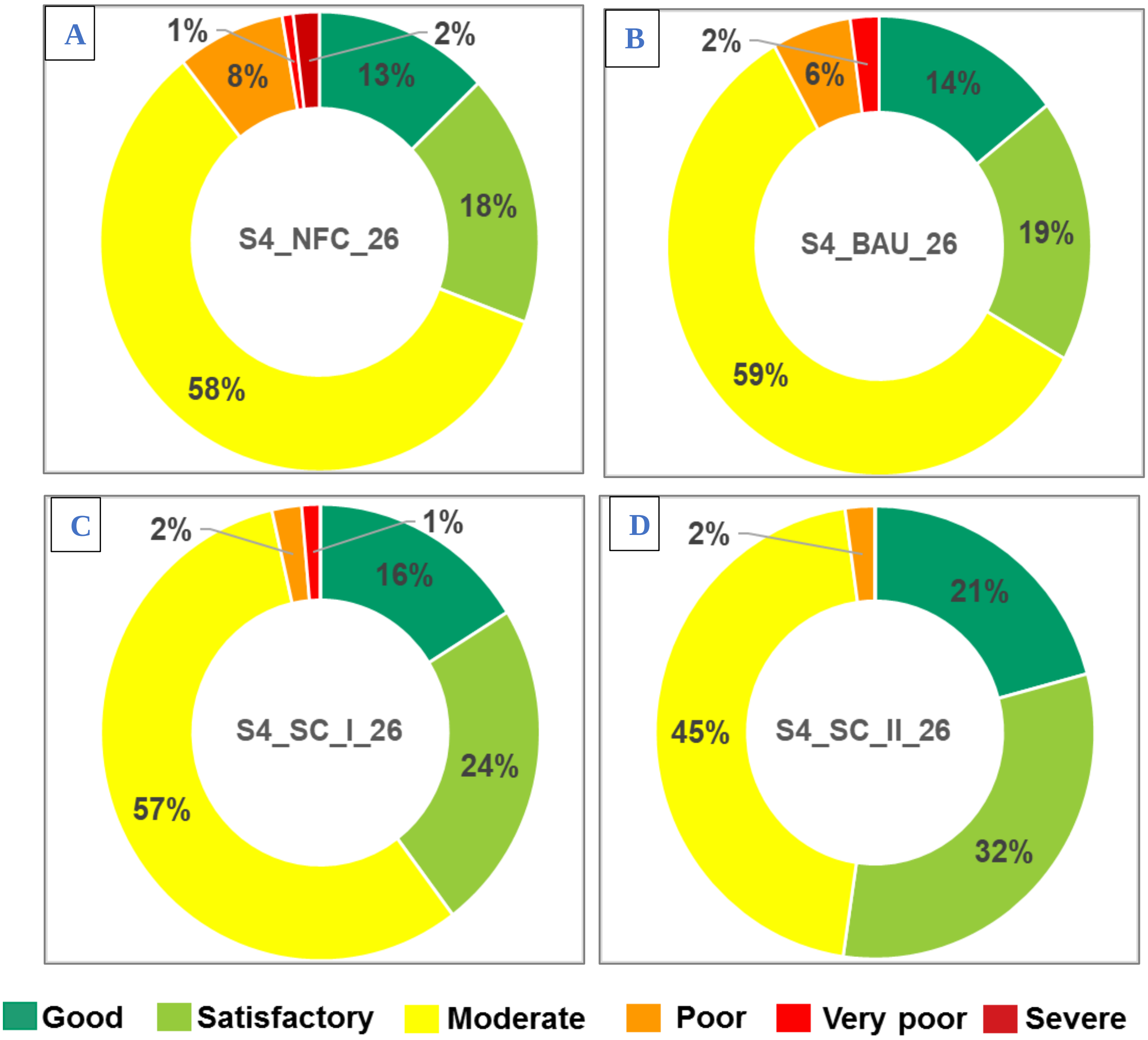


Figure 124 Distribution of six AQI categories at Byasnagar location in Kalinganagar – Jajpur for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2026

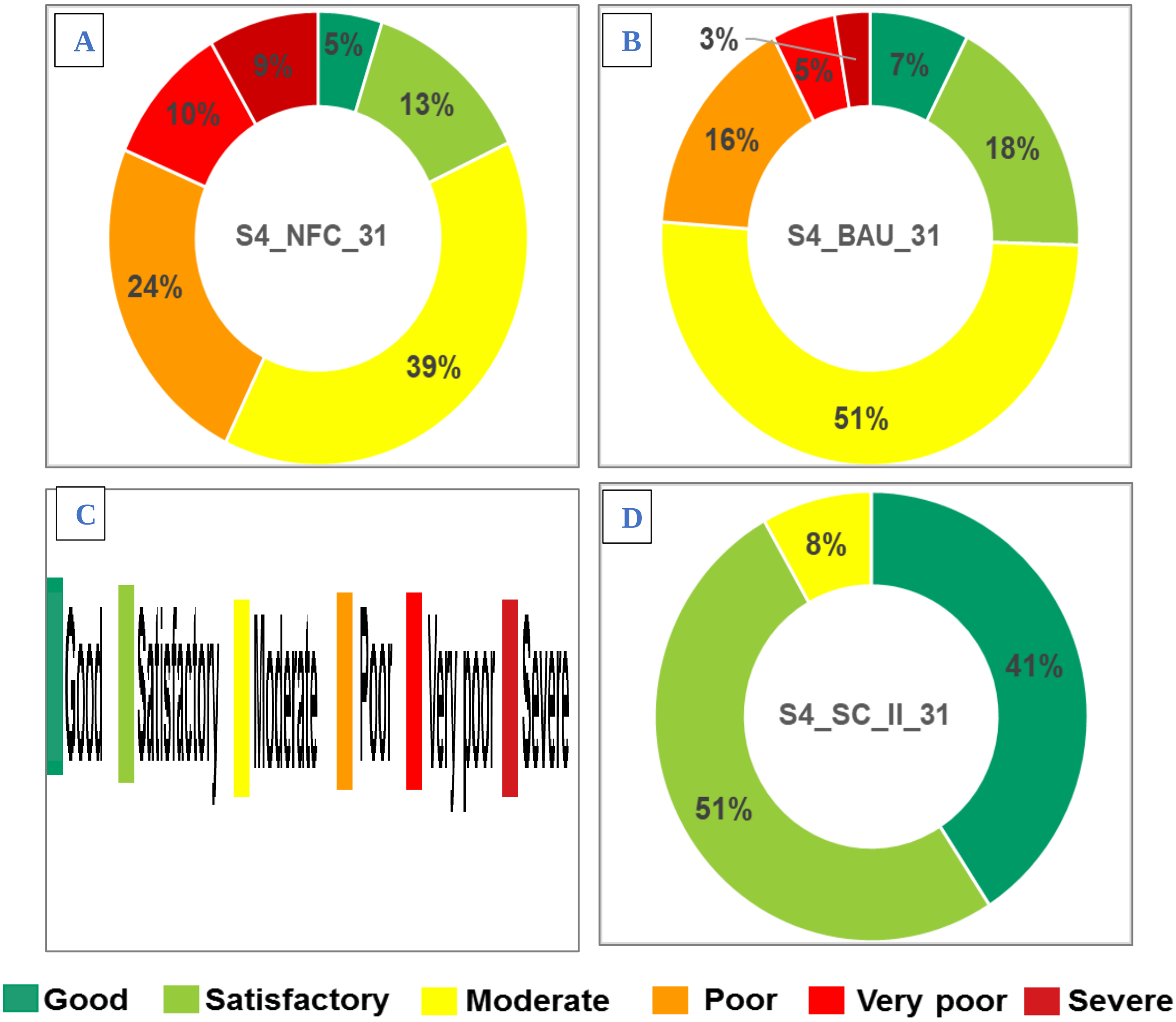


Figure 125 Distribution of six AQI categories at Byasnagar location in Kalinganagar – Jajpur for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2031

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Kalinganagar – Jajpur 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 concentrations by 40% by the year 2026, as compared to 2017 i.e. base year.

[THIS PAGE INTENTIONALLY LEFT BLANK]

Chapter 6: Action Plan

6.1. Air Quality Action Plan for Kalinganagar - Jajpur Region

Table 31 presents the proposed air quality action plan for Kalinganagar - Jajpur region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

Table 31 Proposed Air quality action plan for Kalinganagar - Jajpur region

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Transport	**A) Management**		
	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 kerbside, especially small ones to avoid traffic congestions.	RTO	Immediate
	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.	Municipality / RTO	6 months
	Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses).	Municipality	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	Municipality	1 -2 years
	Declare NO-vehicle zones in hot-spots, university / school premises.	Municipality / University / School	6 months
	Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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.	Municipality/ Local Govt. Body	6 months
	B) Technology		
	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	1 year
	Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Oil Companies/ GAIL / State Government	3 years
	The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	Municipality/ Local Govt. Body, Government Offices	3 years
	Encouraging EV adoption for personal and commercial vehicles through incentivisation or tax relaxation.	State Government, RTO	3 years
Road Dust	End-to-end paving of roads along with black-topping and maintaining potholes free roads.	PWD / Municipality/ Local Govt. Body	Immediate / Continuous
	Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / Municipality/ Local Govt. Body	Immediate / Continuous
	Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / Municipality/ Local Govt. Body	Immediate / Continuous
	Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	Municipality/ Local Govt. Body	Immediate / Continuous
	Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	Municipality/ Local Govt. Body	6 months
	All the canals/nallah's side roads should be concrete / brick lined.	Municipality/ Local Govt. Body	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Regular cleaning of roads and water spraying to suppress the dust. Remove road dust/silt regularly by using mechanical sweepers.	Municipality/ Local Govt. Body	Immediate / Continuous
	Identify road stretches with high dust generation and use Foggers to supress the dust.	Municipality/ Local Govt. Body	6 months
	Greening of traffic corridors, open areas, gardens, community places, schools and housing societies	Municipality/ Local Govt. Body	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:	OSPCB	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	• Cleaner fuel implementation to be encouraged and incentivized. • 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	

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Iron and Steel Industry: • Use of desulphurized coal • 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	OSPCB	1 years
	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	OSPCB	2 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	• 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) • 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%.	Municipality/ Local Govt. Body	1 year
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	Municipality/ Local Govt. Body	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, Municipality/ Local Govt. Body	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	Municipality/ Local Govt. Body	Immediate / Continuous
	Encouraging the reduce, recycle and reuse policy for waste in city	Municipality/ Local Govt. Body / 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.	Municipality/ Local Govt. Body	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	Municipality/ Local Govt. Body	1 year
	Reduce the VKT of waste collection vehicles with route optimisation technique.	Municipality/ Local Govt. Body	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	Municipality/ Local Govt. Body / OSPCB	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Strict enforcement of CPCB guidelines for construction activity such as use of green screens, side covering of digging sites, etc.	Municipality/ Local Govt. Body / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	Municipality/ Local Govt. Body / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	Municipality/ Local Govt. Body	Immediate
	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	Municipality/ Local Govt. Body / OSPCB	Immediate
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	Municipality/ Local Govt. Body / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	Municipality/ Local Govt. Body / 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.	Municipality/ Local Govt. Body	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.	Municipality/ Local Govt. Body	Immediate
	Mandatory use of RMC plants at large construction sites and preparation of guidelines for dust control measures for operation of RMC plants.	Municipality/ Local Govt. Body / 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	Municipality/ Local Govt. Body / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	Municipality/ Local Govt. Body	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	Municipality/ Local Govt. Body / State Government	5 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Leverage rooftop solar programme to reduce dependence on DG sets.	Municipality/ Local Govt. Body	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	Municipality/ Local Govt. Body, 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	Municipality/ Local Govt. Body	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.	Municipality/ Local Govt. Body / 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	Municipality/ Local Govt. Body / OSPCB	1-3 years
	Closure of unauthorized brick kilns, if any.	OSPCB	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Crematoria	Convert all existing traditional crematoria (wood based) to electric. Installing new electric crematoria as per requirement.	Municipality/ Local Govt. Body	1 year
Public Awareness	Launch Public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicle, lane discipline, etc.	Municipality/ Local Govt. Body, OSPCB, NGOs	Immediate
	Encourage the use of public transport for daily commute.	Municipality/ Local Govt. Body, 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	Municipality/ Local Govt. Body, OSPCB, NGOs	Immediate
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	Municipality/ Local Govt. Body	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.

References

Adams, P.J., Seinfeld, J.H., Koch, D.M.: Global concentrations of tropospheric sulfate, nitrate, and ammonium aerosol simulated in a general circulation model. Journal of Geophysical Research. 104 (D11), 13791–13823 (1999).

Andreae, M. O., Merlet, P.: Emission of trace gases and aerosols from biomass burning. Glob Biogeochem Cycles. 15, 955–66 (2001)

Andreae, M. O.: Soot carbon and excess fine potassium: long-range transport of combustion derived aerosols. Science. 220, 1148–1151 (2018)

ARAI, 2008. Emission Factor development for Indian Vehicles as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies. The Automotive Research Association of India. Project Rep No.: AFL/2006-07/IOCL/Emission Factor Project/Final Rep.

ARAI, 2010. Air Quality Monitoring and Emission Source Apportionment Study for Pune. The Automotive Research Association of India. ARAI/IOCl-AQM/R-12/2009-10.

ARAI, 2018. Emission factors for Indian in-use post-2005 vehicles. The Automotive Research Association of India.

Arimoto, R., Duce, R. A., Savoie, D. L., Prospero, J., Talbot, R.,Cullen, J., Tomza, U., Lewis, N., Ray, B.: Relationships among aerosol constituents from Asia and the North Pacific during PEM-West A, J. Geophys. Res. 101, 2011–2023 (1996)

Bawase, M., Sathe, Y., Khandaskar, H. Thipse, S.: Chemical composition and source attribution of $PM_{2.5}$ and PM_{10} in Delhi-National Capital Region (NCR) of India: results from an extensive seasonal campaign. J Atmos Chem., (2021). https://doi.org/10.1007/s10874-020-09412-7.

Bawase, M., Sathe, Y., Mulla, S., Thipse, S., 2021. Chemical Profiling of Exhaust Particulate Matter from Indian In-Service Vehicles, Conference proceedings of Symposium on International Automotive Technology, 2021. DOI: 10.4271/2021-26-0192

CEEW, 2020. Can Electric Mobility Support India's Sustainable Economic Recovery Post COVID-19?, CEEW Report, November 2020.

Census of India, 2022. Website: https://censusindia.gov.in/census.website/data/census-tables#, Last accessed: June, 2022.

Cheung, K., Daher, N., Kam, V., Shafer, M. M., Ning, Z., Schauer, J. J., Sioutas, C.: Spatial and temporal variation of chemical composition and mass closure of ambient coarse particulate matter (PM_{10}-2.5) in the Los Angeles area. Atmospheric Environment, 45, 2651-2662 (2011).

Chow, J.C., Lowenthal, D.H., Chen, L.-W.A., Wang, X.L., Watson J.G.: Mass reconstruction methods for $PM_{2.5}$: A review. Air Qual. Atmos. Health. 8, 243–63 (2015). doi:10.1007/s11869-015-0338-3

Cimorelli, A.J., Venkatram, A., Weil, J.C., Paine, R.J., Wilson, R.B., Lee, R.F., Peters, W.D., 2003. AERMOD description of model formulation, US EPA Report 454/R-03002d, p. 85.

Copernicus Climate Change Service (2023): ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), DOI: 10.24381/cds.adbb2d47 (Accessed on 07-MAR-2023)

Coulter, C. T., 2004. EPA-CMB8.2 Users Manual, Air Quality Modeling Group Emissions, Monitoring & Analysis Division Office of Air Quality Planning & Standards Research Triangle Park, NC 27711, EPA-452/R-04-011

CPCB, 2011. Air quality monitoring, emission inventory and source apportionment study for Indian cities, National Summary Report. Central Pollution Control Board, New Delhi.

CSE, 2020. Website: https://www.downtoearth.org.in/blog/air/bharat-stage-vi-india-leapfrogs-today-and-it-is-no-fool-s-day-70155, accessed: 10th December, 2021.

Dresser, A.L., Huizer, R.D., 2011. CALPUFF and AERMOD Model Validation Study in the Near Field: Martins Creek Revisited. Journal of the Air & Waste Management Association 61, 647–659. https://doi.org/10.3155/1047-3289.61.6.647

Echalar, F., Artaxo, P., Martins, J.V., Yamasoe, M., Gerab, F., Maenhaut, W., et al.: Long-term monitoring of atmospheric aerosols in the Amazon Basin: source identification and apportionment. J Geophys Res. 103, 31849–64 (1998)

EPA, 2022. Website: https://www.epa.gov/air-quality-management-process/managing-air-quality-emissions-inventories

Gani, S., Bhandari, S., Seraj, S., Wang, D. S., Patel, K., Soni, P., Arub, Z., Habib, G., Hildebrandt Ruiz, L., and Apte, J. S.: Submicron aerosol composition in the world's most polluted megacity: the Delhi Aerosol Supersite study, Atmos. Chem. Phys., 19, 6843–6859 (2019). doi: https://doi.org/10.5194/acp-19-6843-2019.

GIZ, 2021. Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India

Gordon, G.E., 1980. Receptor models. Environ. Sci. Technol. 14: 792-800.

Han, L., Zhao, J., Gao, Y., Gu, Z., Xin, K., Zhang, J., 2020. Spatial distribution characteristics of $PM_{2.5}$ and PM_{10} in Xi'an City predicted by land use regression models. Sustainable Cities and Society 61, 102329. https://doi.org/10.1016/j.scs.2020.102329

Health Effects Institute: State of Global Air 2019. Special Report. Boston, MA: Health Effects Institute. ISSN 2578-6873, (2019).

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., Thépaut, J-N. (2018): ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), DOI: 10.24381/cds.adbb2d47 , (Accessed on 07-MAR-2023)

Hidy, G.M. and C. Venkataraman, 1996. The chemical mass balance method for estimating atmospheric particle sources in Southern California. Chem. Eng. Comm. 151: 187-209.

Holmes, N.S., Morawska L., 2006. A review of dispersion modeling and its application to the dispersion of particles: an overview of different dispersion models available, Atmos. Environ. 40, 5902–5928.

Huang, X., Liu, Z., Liu, J., Hu, B., Wen, T., Tang, G., Zhang, J., Wu, F., Ji, D., Wang, L., and Wang, Y.: Chemical characterization and source identification of $PM_{2.5}$ at multiple sites in the Beijing–Tianjin–Hebei region, China. Atmos. Chem. Phys. 17, 12941–12962 (2017). doi: https://doi.org/10.5194/acp-17-12941-2017.

Huang, X.H., Bian, Q., Ng, W.M., Louie, P.K. and Yu, J.Z.: Characterization of $PM_{2.5}$ Major Components and Source Investigation in Suburban Hong Kong: A One Year Monitoring Study. Aerosol Air Qual. Res. 14, 237-250 (2014). doi: https://doi.org/10.4209/aaqr.2013.01.0020

IMD, 2015. Climatological Normals 1981–2010, India Meteorological Department, Govt. of India.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories; National Greenhouse Gas Inventories Programme Japan; IPCC: Geneva, Switzerland, 2006.

Jaiprakash, Singhai, A., Habib, G., Raman, R. S., and Gupta, T.: Chemical characterization of PM1 aerosol in Delhi and source apportionment using positive matrix factorization, Environ. Sci. Pollut. Res., 24, 445–462 (2017). doi: https://doi.org/10.1007/s11356-016-7708-8.

Katzman T.L., Rutter, A.P., Schauer, J.J., et al.: $PM_{2.5}$ and PM_{10}-$PM_{2.5}$ compositions during wintertime episodes of elevated PM concentrations across the Midwestern USA. Aero Air Qual Res. 10, 140-53, (2010).

Ketzel, M., Omstedt, G., Johansson, C., Düring, I., Aarnio, M., Oettl, D., Gidhagen, L., Wåhlin, P., Lohmeyer, A., Haakana, M., and Berkowicz, R., 2007. Estimation and validation of $PM_{2.5}$/PM_{10} exhaust and non-exhaust emission factors for practical street pollution modelling, Atmospheric Environment, 41, 9370-9385. doi: 10.1016/j.atmosenv.2007.09.005.

Kumar K. et al., 2015. Non-Motorised Transport Policy in India: The need for a reform agenda, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Malm, W.C., Sisler, J.F., Huffman, D., Eldred, R.A., Cahill, T.A.: Spatial and seasonal trends in particle concentration and optical extinction in the United States. J Geophys Res. 99, 1347–1370 (1994)

MoEFCC: National Clean Air Programme (NCAP). Ministry of Environment, Forest & Climate Change, New Delhi, INDIA, (2020).

MoSPI, 2014. Household Consumption of Various Goods and Services in India 20ll-12, NSS 68th Round (JULY 2011 - JUNE 2012), Report No. 558(68/1.0/2), Ministry of Statistics and Programme Implementation, Govt. of India.

NITI Aayog & MoPNG, 2021. Roadmap for Ethanol Blending in India 2020-25: Report of the Expert Committee, NITI Aayog and Ministry of Petroleum and Natural Gas, June 2021.

NITI Aayog, 2018. Transforming India's Mobility: A perspective, NITI Aayog & The Boston Consulting Group.

Niu, X., Cao, J., Shen, Z., et al.: $PM_{2.5}$ from the Guanzhong Plain: Chemical composition and implications for emission reductions. Atmospheric Environment. 147, 458-469, (2016).

Olivier, J. G. J., 2002. On the quality of global emission inventories. Approached, methodologies and uncertainty, Wilco BV Amersfoort, the Netherlands, ISBN 90-393-3103-0, 58–88.

Pandey A., Sadavarte P., Rao A.B., Venkataraman C., 2014. Trends in multi-pollutant emissions from a technology linked inventory for India: II. Residential, agricultural and informal industry sectors, Atmos. Environ. 99, 341-352.

Pappu, A., Saxena, M. and Asolekar, S. R., 2007. Solid wastes generation in India and their recycling potential in building materials. Building and Environment 42(6): 2311–2320.

Patil, R.S., Kumar, R., Menon, R., Munna Kumar Shah, Sethi, V., 2013. Development of particulate matter speciation profiles for major sources in six cities in India. Atmospheric Research 132-133, 1–11. https://doi.org/10.1016/j.atmosres.2013.04.012

Pope, C.A. III, Burnett, R.T., Thun, M.J., et al.: Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Journal of the American Medical Association, 287(9), 1132–1141, (2002).

Pope, C.A. III, Dockery, D.W.: Health effects of fine particulate air pollution: lines that connect. J. Air Waste Manag. Assoc. 56, 709-742, (2006).

Ram, K., Sarin, M.M.: Spatio-temporal variability in atmospheric abundances of EC, OC and WSOC over northern India. J. Aerosol Sci. 41(1), 88-98 (2010)

Rypdal, K. and Winiwarter, W., 2001. Uncertainties in greenhouse gas emission inventories – evaluation, comparability and implications, Environ. Sci. and Policy, 4, 107–116.

Salameh, D., Detournay, A., et al.: $PM_{2.5}$ chemical composition in five European Mediterranean cities: A 1-year study. Atmospheric Research. 155, 102–117.

Sharma S., Kumar A. (Eds), 2016, Air pollutant emissions scenario for India. The Energy and Resources Institute. New Delhi.

Sharma, N., Gangopadhyay, S., and Dhyani, R. 2010. Methodology for estimation of CO2 reduction from mass rapid transit system (MRTS) projects, Journal of Scientific & Industrial Research, Vol. 69, August 2010, pp. 586-593.

Sharma, N., Singh, A., and Dhyani, R., Gaur S., 2014. Emission reduction from MRTS projects – A case study of Delhi metro, Atmospheric Pollution Research, 5, 721-728.

Shrestha, R.M., Kim Oanh, N.T., Shrestha, R. P., Rupakheti, M., Rajbhandari, S., Permadi, D.A., Kanabkaew, T., and Iyngararasan, M., 2013. Atmospheric Brown Clouds (ABC) Emission Inventory Manual, United Nations Environment Programme, Nairobi, Kenya.

Solazzo et al., 2021. Uncertainties in the Emissions Database for Global Atmospheric

Research (EDGAR) emission inventory of greenhouse gases, Atmos. Chem. Phys., 21, 5655–5683, 2021; doi: https://doi.org/10.5194/acp-21-5655-2021

Srinivas, B, and Sarin, M.M.: $PM_{2.5}$, EC and OC in atmospheric outflow from the Indo-Gangetic Plain: Temporal variability and aerosol organic carbon-to-organic mass conversion factor. Science of the Total Environment. 487, 196–205 (2014).

Srivastava, A., Jain, V., 2008. Source apportionment of suspended particulate matters in a clean area of Delhi: A note. Transportation Research Part D-transport and Environment 13, 59–63. https://doi.org/10.1016/j.trd.2007.09.001

Turpin, B.J. and Lim, H.J.: Species contributions to $PM_{2.5}$ mass concentrations: revisiting common assumptions for estimating organic mass. Aerosol Sci Technol. 35, 602–10 (2001)

USEPA, 2015. AP-42 emission factor database. Washington, DC: United State Environment Protection Agency. Available at: <www.epa.gov/ttnchie1/ap42/>.

Watson, J.G., 1984. Overview of receptor model principles. JAPCA 34: 619-23.

Watson, J.G., Cooper, J.A. and J.J. Huntzicker, 1984. The effective variance weighting for least squares calculations applied to the mass balance receptor model. Atmos. Environ. 18: 1347-55.

Wiedinmyer, C., Yokelson, R.J., and Gullett, B.K., 2014. Global Emissions of Trace Gases, Particulate Matter, and Hazardous Air Pollutants from Open Burning of Domestic Waste. Environ. Sci. Technol. 48, 9523−9530. doi:dx.doi.org/10.1021/es502250z.

World Bank and Institute for Health Metrics and Evaluation: The Cost of Air Pollution: Strengthening the Economic Case for Action. Washington, DC: World Bank, (2016).

Xu, Bin, Xiangyu You, Yaoyu Zhou, Chunhao Dai, Zhan Liu, Shaojian Huang, Datong Luo, and Hui Peng, 2020. "The Study of Emission Inventory on Anthropogenic Air Pollutants and Source Apportionment of $PM_{2.5}$ in the Changzhutan Urban Agglomeration, China" Atmosphere 11, no. 7: 739. https://doi.org/10.3390/atmos11070739

Zou, B.; Zhan, F.B.; Wilson, J.G.; Zeng, Y., 2010. Performance of AERMOD at different time scales. Simul. Model. Pract. Theory, 18, 612–623.

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.

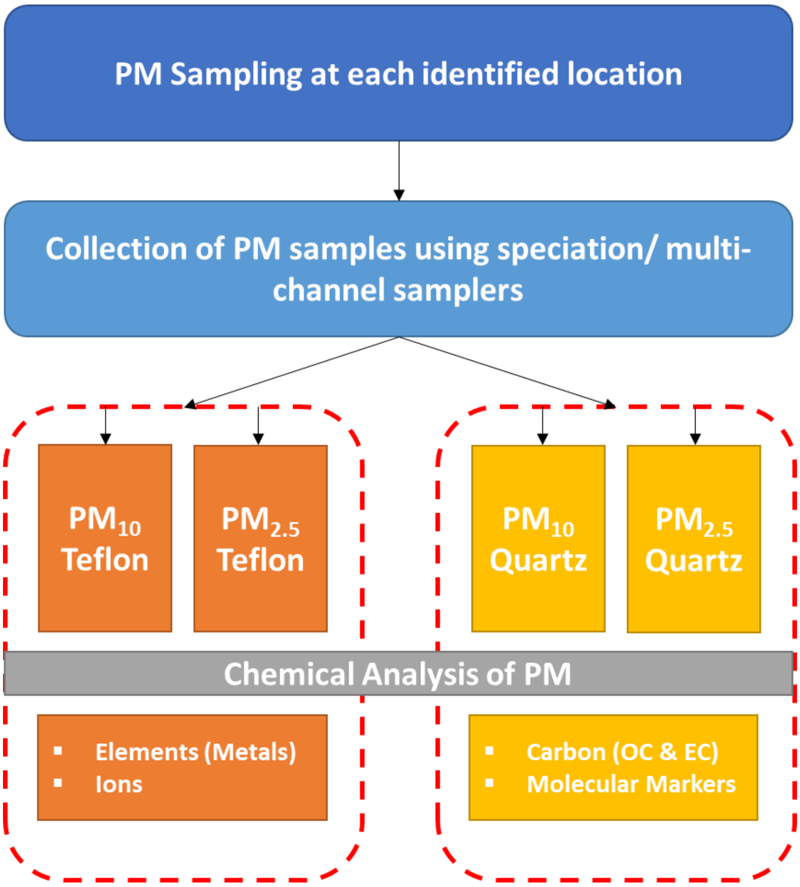
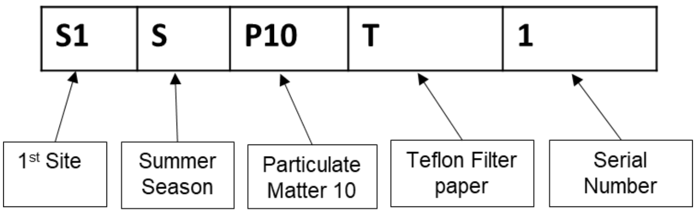


Fig. A-1: Arrangement of filter papers for multi-channel speciation samplers

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.

8.0 Sampling Site photographs

JCDL

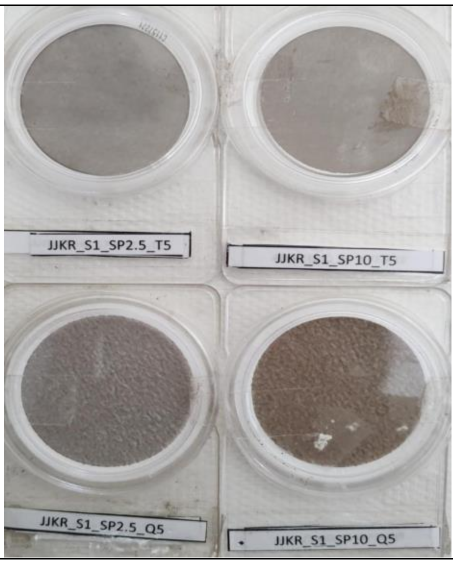
Tehsil Office

TATA Steel

RO Office

VOC Sampling Collection through Tenax Sorbent Tubes

Gaseous Sampling Collection (SO_2 &NOx)



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 samples, 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 = Mean 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:

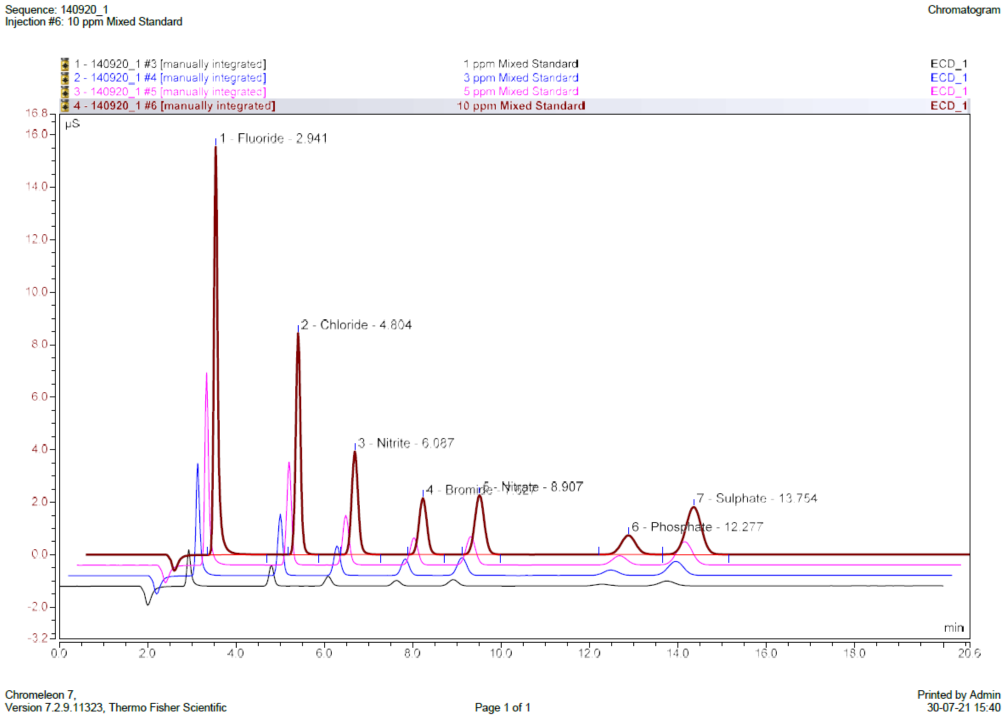


Fig. C-1: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Anion

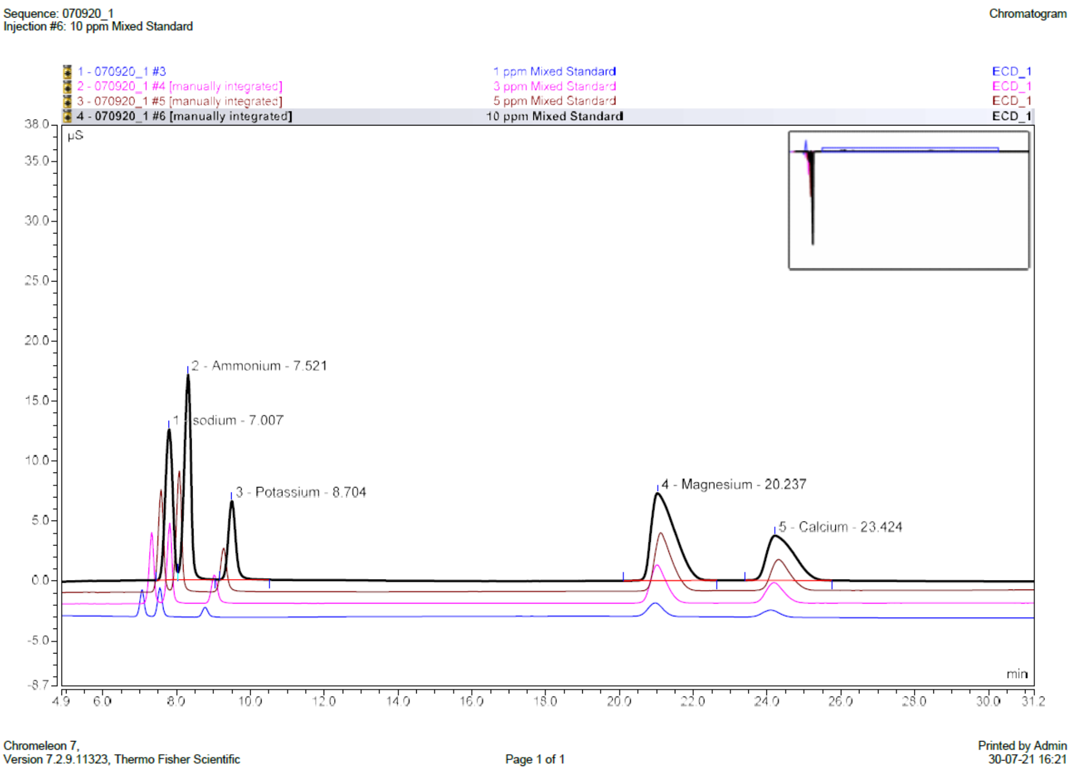


Fig. C-2: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Cation

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 $\pm$ 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 $\mu g/cm^2$.

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

8.0 Reporting

a) Report the result in the desired unit e.g. $\mu g/cm^2$ 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^{o}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

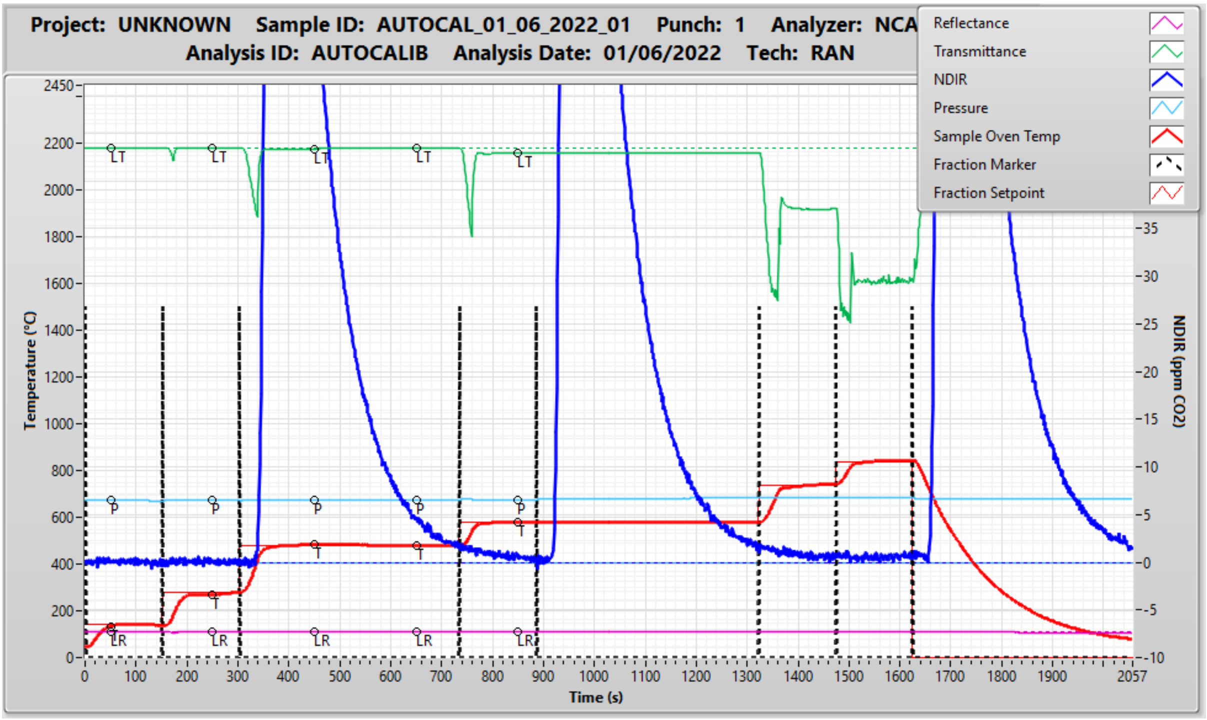


Fig. E-1: Typical example of Auto-calibration run taken on every day before actual testing starts

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 Chromatograp h 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.126 Construction activity in Kalinganagar - Jajpur in February 2021 and December 2021

Photographs taken during primary data collection surveys in Kalinganagar - Jajpur region

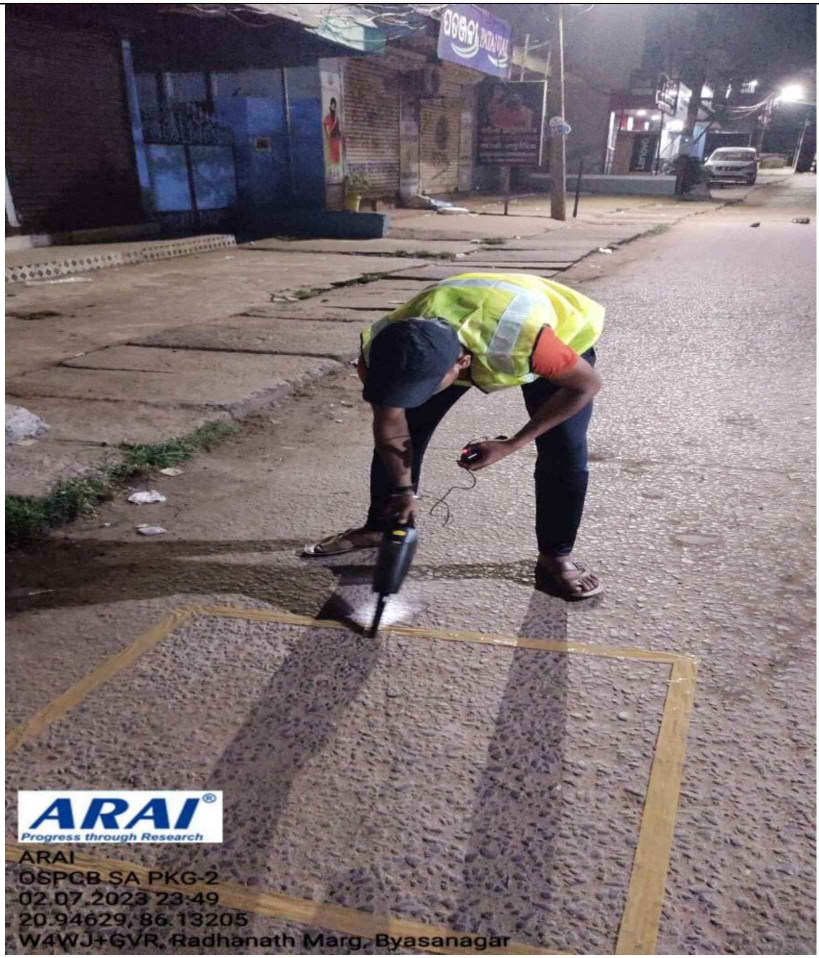

Power Generation
JAKSON
www.cumminsindia.com
Monday, April 18, 2022 10:27:54
20.9523286N 86.1297657E ±104.10m
Byasanagar
Odisha 755019
India


JAKSON
20.9501868N 86.1288684E
Byasanagar, Jajpur 755019
India
Apr 18, 2022 11:04:30 AM


KOEL
20.94855709N 86.1389791E
Byasanagar, Jajpur 755019
India
Apr 16, 2022 11:23:36 AM


sudhir
Monday, April 18, 2022 11:23:22
Byasanagar
Odisha 755019
India

Photographs taken during road dust sampling at Kalinganagar-Jajpur

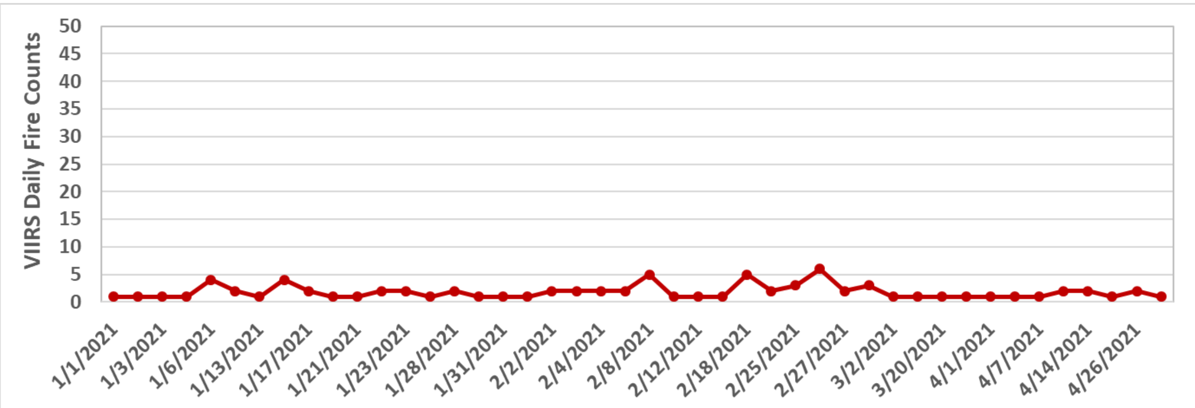


Photographs showing activities in Kalinganagar - Jajpur region

Open Waste Burning

Open Burning

Fire Counts observed over Kalinga Nagar - Jajpur Region over study area during baseline year 2022



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 Kalinga Nagar-Jajpur Region for baseline year 2021.

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

Industry Sector	PM10	PM2.5	SO2	NOx
Cement	53.8	35.8	0.0	0.0
Coke Oven	47.7	31.8	456.7	284.9
Ferro Alloys	269.4	179.6	11.1	14.4
Iron and Steel	2241.5	1494.3	16756.1	10997.9
Pelletization	411.3	274.2	430.5	371.7
Fugitive Emissions	3017.0	417.0	-	-
Total	**3023.6**	**2015.8**	**17654.4**	**11669.0**

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: I. extensive maintenance of oven chambers, oven doors and frame seals, ascension pipes, charging holes and other equipment (a	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		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 carefully and is subject to the individual situation of every plant).	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		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.	
7.	**Dust emissions from coke pushing**	The dust emissions from coke pushing can be reduced by using the following techniques:	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		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}	NO_2	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---