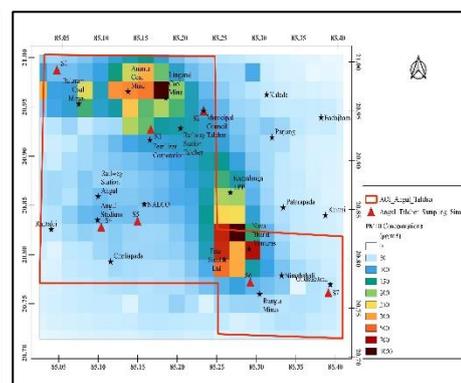
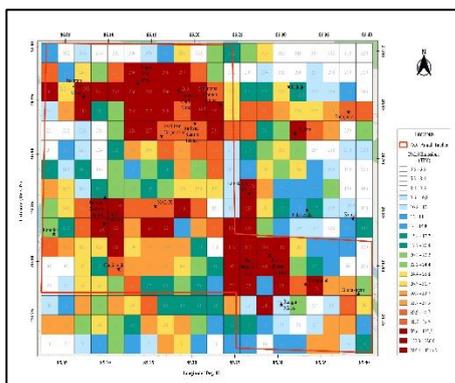
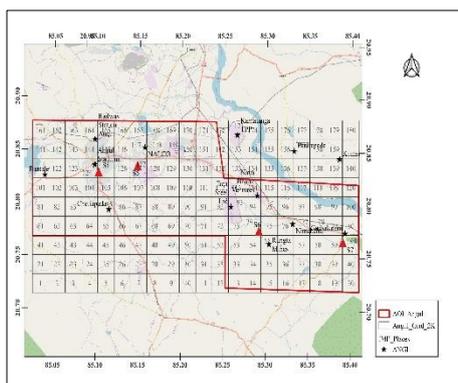
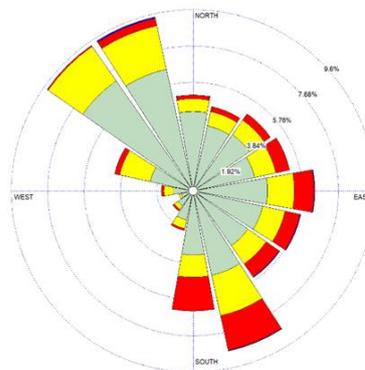


FINAL REPORT

Emission Inventory and Source Apportionment Study of Angul Region in Odisha



Submitted to



State Pollution Control Board, Odisha (OSPCB)

Submitted by



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

December 2024

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Disclaimer

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Abbreviations

AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model

AQI: Air Quality Index

ARAI: Automotive Research Association of India

BAU: Business-as-usual

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

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Executive Summary

Air pollution has become a serious problem recently and it is considered as a major challenge for pollution and health regulatory agencies around the world. The Central Pollution Control Board (CPCB), New Delhi has identified 131 cities in India where the prescribed annual National Ambient Air Quality Standards (NAAQS) are violated. In this regard, Ministry of Environment, Forest and Climate Change (MoEFCC) have launched National Clean Air Program (NCAP) in 2019 which aims to reduce the national level PM_{2.5} and PM₁₀ concentrations.

To address the air pollution issues of the Angul 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 Angul Region in Odisha”. The main aim of this study is to identify and characterize various emission sources in Angul 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 (PM₁₀ & PM_{2.5}) source apportionment using receptor modelling approach for Angul region.
- To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Angul 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

Situated in the heart of Odisha, the Angul region stands as one of India's oldest and most historically significant industrial zones. Spanning latitudes, 20.71427 °N to 20.88076 °N and longitudes 85.02578 °E to 85.40797 °E, this area, located just 120 km from Bhubaneswar, the capital city of Odisha, has been a key player in India's industrial evolution since the early 19th century.

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 mixed site, 2 residential sites, and 1 industrial site. These sites are located in different parts of Angul region and can provide an integrated insight into the characteristics of PM_{2.5} and PM₁₀ over Angul 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 Angul region

Code	Location	Latitude	Longitude	Category
S4	Government College Angul	20.829118	85.102152	Mixed
S5	Nalco CISF Quarters	20.835580	85.148018	Industrial
S6	Galapada	20.774936	85.291356	Residential (LIG) + Others
S7	Gudiakateni	20.765197	85.390308	Residential (LIG) + Others

The ambient PM_{2.5} and PM₁₀ samples were collected in the study area, during two critical seasons i.e. winter (December 7 to 26, 2021) and summer (May 21 to June 7, 2022). It is important to note that, the summer season sampling could not be conducted in summer season of 2021 due to the COVID-19 lockdown/movement restrictions.

The ambient PM_{2.5} and PM₁₀ 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 stigmaterol) 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 SO₂ and NO₂ and Volatile Organic Compounds (VOCs) such as Benzene, Toluene, Ethyl Benzene and Xylene, during winter season.

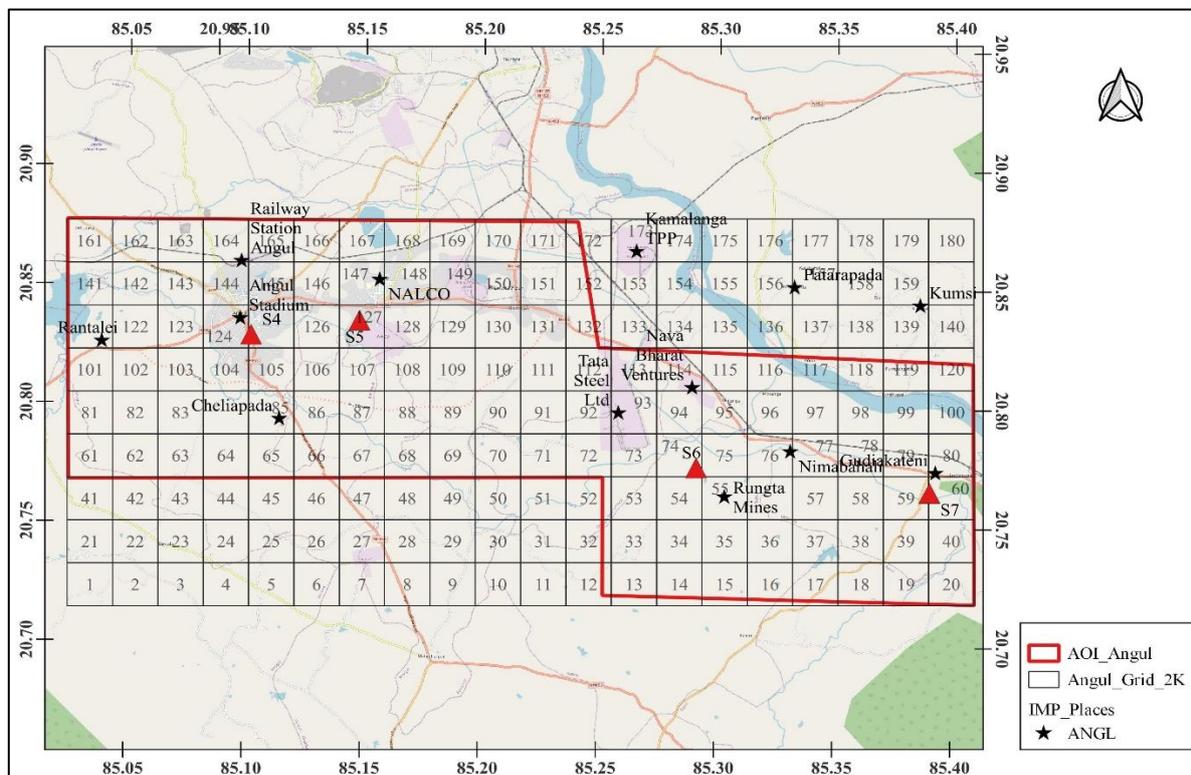


Figure ES-1 Angul region map showing different land-use classes. The red stars show the location of five sampling sites selected for source apportionment study

The winter-season mean PM_{2.5} and PM₁₀ mass concentrations over all sites were 76.8 and 179.8 µg/m³, respectively. The highest seasonal mean PM_{2.5} concentrations were observed at NALCO CISF headquarters i.e. S5 (108.7 µg/m³) while the lowest were recorded at Gudiakateni i.e. S7 (58.8 µg/m³). Similarly, the highest seasonal mean PM₁₀ concentrations were observed at Govt. College, Angul i.e. S4 (217.0 µg/m³) while the lowest were recorded at Galapada i.e. S6 (138.5 µg/m³). The mean value of PM_{2.5} to PM₁₀ ratios during the study period over all sites was found to be 0.44, varying from 0.33 to 0.55, which in turn indicates a mix of dusty and combustion sources.

The summer-season mean PM_{2.5} and PM₁₀ mass concentrations over all sites were 33.3 and 107.2 µg/m³, respectively. The highest seasonal mean PM_{2.5} concentration was observed at NALCO CISF headquarters i.e. S5 (39.8 µg/m³) while the lowest was recorded at

Gudiakatani i.e. S7 ($25.5 \mu\text{g}/\text{m}^3$). Similarly, the highest seasonal mean PM_{10} concentration was observed at NALCO CISF headquarters i.e. S5 ($129.0 \mu\text{g}/\text{m}^3$) while the lowest was recorded at Gudiakatani i.e. S7 ($92.7 \mu\text{g}/\text{m}^3$). The mean value of $\text{PM}_{2.5}$ to PM_{10} ratios during the summer season over all sites was found to be 0.32, varying from 0.29 to 0.35, which in turn indicates dominance of dusty sources.

Based on the chemical speciation analysis, the PM chemical components were grouped into six categories i.e. organic matter (OM), elemental carbon (EC), sulphate, nitrate and ammonium ions (together referred to as SNA), chloride ions, crustal materials (CM) and other trace elements (TE). The reconstructed PM mass is then calculated and compared with observed gravimetric mass. The reconstructed mass was significantly related to gravimetric mass in both winter and summer seasons. The squared correlation coefficient, R^2 is found to be 0.85 (winter) and 0.70 (summer) for $\text{PM}_{2.5}$ whereas it is found to be 0.72 (winter) and 0.96 (summer) for PM_{10} , respectively. During the winter season, the fractions of major chemical compositions followed the order of $\text{OM} > \text{SNA} > \text{EC} > \text{CM} > \text{TE} > \text{SS}$ in both $\text{PM}_{2.5}$ whereas this order changed to $\text{OM} > \text{SNA} > \text{CM} > \text{EC} > \text{TE} > \text{SS}$ in PM_{10} . Similarly, during the summer season, the fractions of major chemical compositions followed the order of $\text{OM} > \text{SNA} > \text{EC} > \text{CM} > \text{TE} > \text{SS}$ in $\text{PM}_{2.5}$ whereas this order changed to $\text{OM} > \text{CM} > \text{SNA} > \text{EC} > \text{TE} > \text{SS}$ in PM_{10} . Additionally, chemical ratios such as OC/EC , Cl^-/Na^+ , K^+/OC , K^+/EC , $\text{NO}_3^-/\text{SO}_4^{2-}$ 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 Angul region, during the winter season sampling period i.e. December 7-26, 2021. The winter season mean concentrations of SO_2 are observed to be $45.3 \mu\text{g}/\text{m}^3$ at Govt. College, Angul (S4), $39.7 \mu\text{g}/\text{m}^3$ at NALCO CISF Headquarters (S5), $26.1 \mu\text{g}/\text{m}^3$ at Galapada (S6) and $21.7 \mu\text{g}/\text{m}^3$ at Gudiakatani (S7). Similarly, the winter season mean concentrations of NO_2 are observed to be $18.8 \mu\text{g}/\text{m}^3$ at Govt. College, Angul (S4), $24.4 \mu\text{g}/\text{m}^3$ at NALCO CISF Headquarters (S5), $20.9 \mu\text{g}/\text{m}^3$ at Galapada (S6) and $22.6 \mu\text{g}/\text{m}^3$ at Gudiakatani (S7). In case of VOCs, the winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites ranged from 1.3 to $3.8 \text{ ng}/\text{m}^3$, 3.8 to $15.9 \text{ ng}/\text{m}^3$, 4.3 to $45.5 \text{ ng}/\text{m}^3$ and 6.0 to $67.3 \text{ ng}/\text{m}^3$, 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 PM₁₀ particles in Angul 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 PM₁₀ were calculated with the CMB model for the individual daily samples for four sampling sites in Angul 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 Angul (Fig. ES-2 - A) are found to be dominated by dust and industrial sectors with contribution of 29.9% and 25.2%, respectively. The other sources of PM_{2.5} at Angul are identified as transport (11.1%), biomass and solid waste combustion (9.6%), secondary aerosols (4.9%), and mining activities (2.8%). Similarly, the winter-time PM₁₀ mass at Angul is also found to be dominated by industries and powerplants (36.8%), followed by road and construction dust (30.7%), mining activities (8.3%), transport (6.3%), biomass and solid waste combustion (5.2%), and secondary aerosols (4.0%). Additionally, about 16.7% and 8.7% mass of PM_{2.5} and PM₁₀ 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 Angul region (Fig. ES-2 - B) is found to be dominated by dust with highest contribution of 22.8%. The other summer-time sources of PM_{2.5} in Angul region are identified as secondary aerosols (22.1%), industries and powerplants (19.1%), transport (8.6%), biomass and solid waste combustion (6.6%) and mining activities (2.6%). The summer-time PM₁₀ mass in Angul Region is found to be dominated by industries and powerplants (35.1%), followed by road and construction dust (28.0%), secondary aerosols (12.1%). The transport, biomass and solid waste combustion and mining activities were found

to be minor contributors with a contribution of 3% each. Additionally, about 18.3% and 15.8% mass of PM_{2.5} and PM₁₀ remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

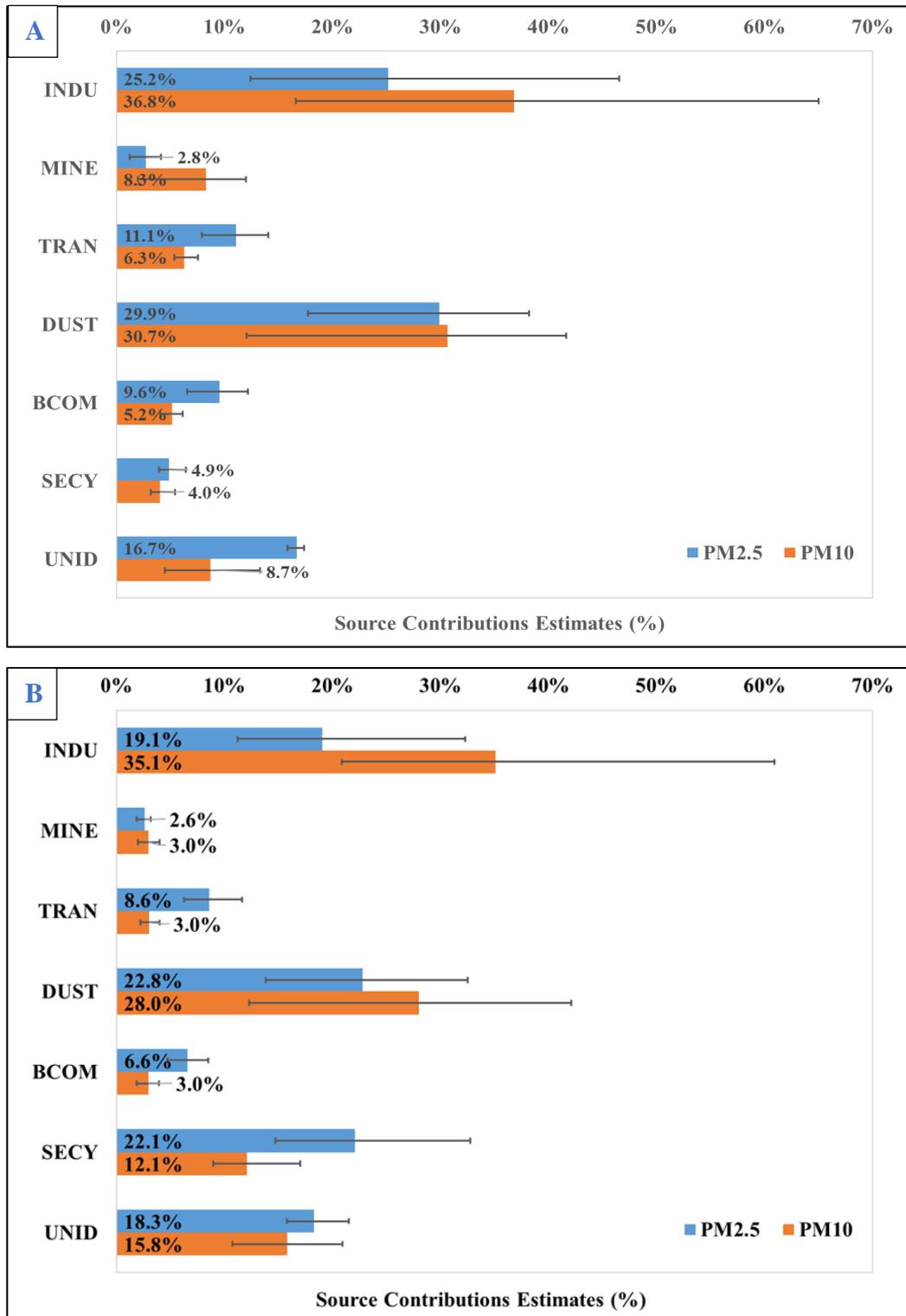


Figure ES-2 City-level source contribution estimates (SCE) for Angul region using CMB receptor model during winter (A) and summer (B) seasons

Emission Inventory

The development of emission inventory for Angul region involved quantification of emission loads originating from sectors including: Industries, 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 (PM₁₀), particulate matter having aerodynamic diameter less than or equal to 2.5 microns (PM_{2.5}), sulfur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). The spatial resolution of emission inventory is: 2 x 2 km² 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 Angul region is presented in Table ES-2, while the pollutant wise contribution is shown in Fig. ES-3. The Angul regional spatial distribution of the pollutants is provided in Fig. ES-4, ES-5 and ES-6. The total PM₁₀ emission load in the Angul region is estimated to be 24,124 tonnes per year. The top four contributors to PM₁₀ emissions are fugitive emissions (39.5%), followed by thermal powerplants (27.2%), industries (15.3%), and resuspended road dust (12.8%). Similarly, PM_{2.5} emission load in the Angul region is estimated to be 7,241 tonnes per year. The top four contributors to PM_{2.5} emissions are thermal powerplants (40.2%), industries (25.5%), fugitive emissions (11.7%), and re-suspended road dust (10.4%). Other PM_{2.5} contributors include

transport (4.6%), residential (3.3%), and waste burning (2.3%). 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 Angul Region in year 2021

Sector	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO	NM VOC
Industries	3696 ± 762	1847 ± 381	36946 ± 4131	15405 ± 3176	797 ± 164	108 ± 22
Thermal powerplants	6576 ± 1356	2908 ± 600	88863 ± 9935	44998 ± 9279	2307 ± 476	185 ± 38
Fugitive emissions	9548 ± 4868	847 ± 432	NA	NA	NA	NA
Residential	361 ± 184	240 ± 122	100 ± 14	122 ± 62	3427 ± 1747	1011 ± 516
Transport	371 ± 97	334 ± 88	7 ± 1	2199 ± 1161	6282 ± 3317	6282 ± 3317
Road dust	3103 ± 694	751 ± 168	NA	NA	NA	NA
Open waste burning	179 ± 97	167 ± 90	11 ± 6	26 ± 14	859 ± 463	186 ± 100
Construction	136 ± 28	23 ± 5	NA	NA	NA	NA
Brick Kilns	128 ± 69	91 ± 49	36 ± 19	0 ± 0	927 ± 499	15 ± 8
Industrial DG	10 ± 5	8 ± 4	9 ± 2	139 ± 71	30 ± 15	199 ± 102
Crematoria	17 ± 9	8 ± 4	0 ± 0	2 ± 1	87 ± 44	48 ± 25
Hotels, Restaurants, Bakeries and Open eateries	27 ± 15	17 ± 9	23 ± 5	9 ± 5	48 ± 26	26 ± 14
Total	24152 ± 8184	7241 ± 1951	125996 ± 14114	62900 ± 13769	14764 ± 6752	8060 ± 4142

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 SO₂, NO_x, CO and NMVOC. The SO₂, NO_x, CO and NMVOC emission loads for year 2021 in the study domain are estimated to be 125996, 62900, 14764 and 8060 tonnes per year, respectively.

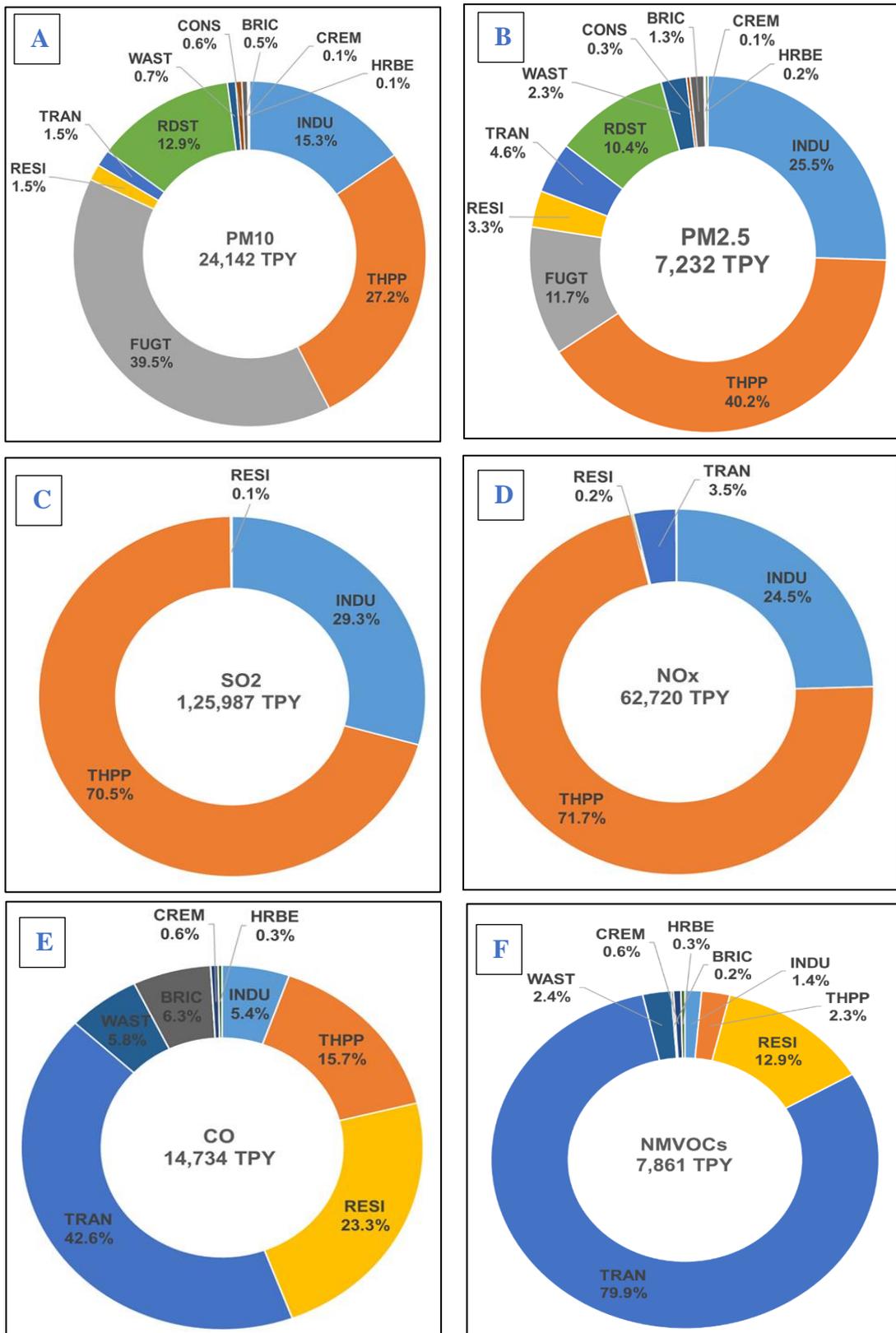


Figure ES-3 Sector-wise contribution to air pollutant emissions of A) PM₁₀, B) PM_{2.5}, C) SO₂, D) NO_x, E) CO and F) NMVOC in Angul region in 2021

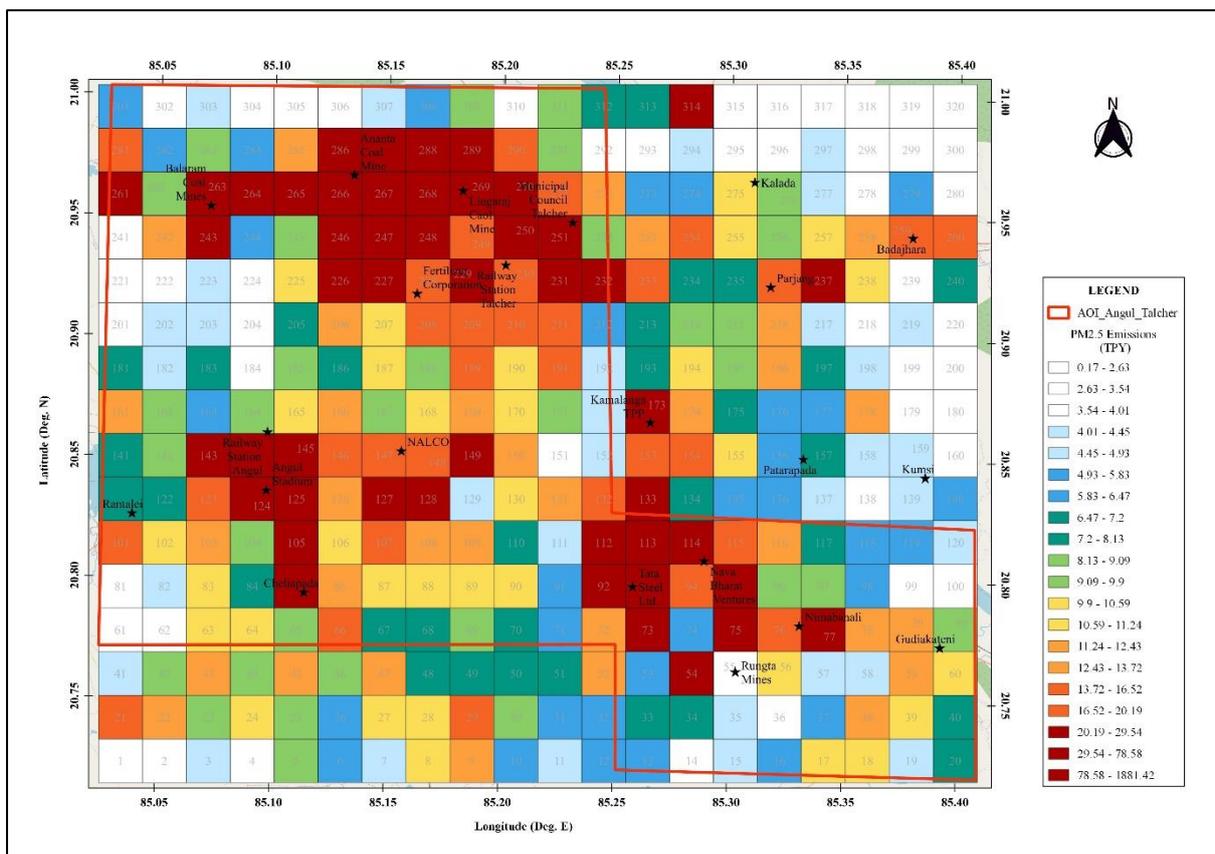
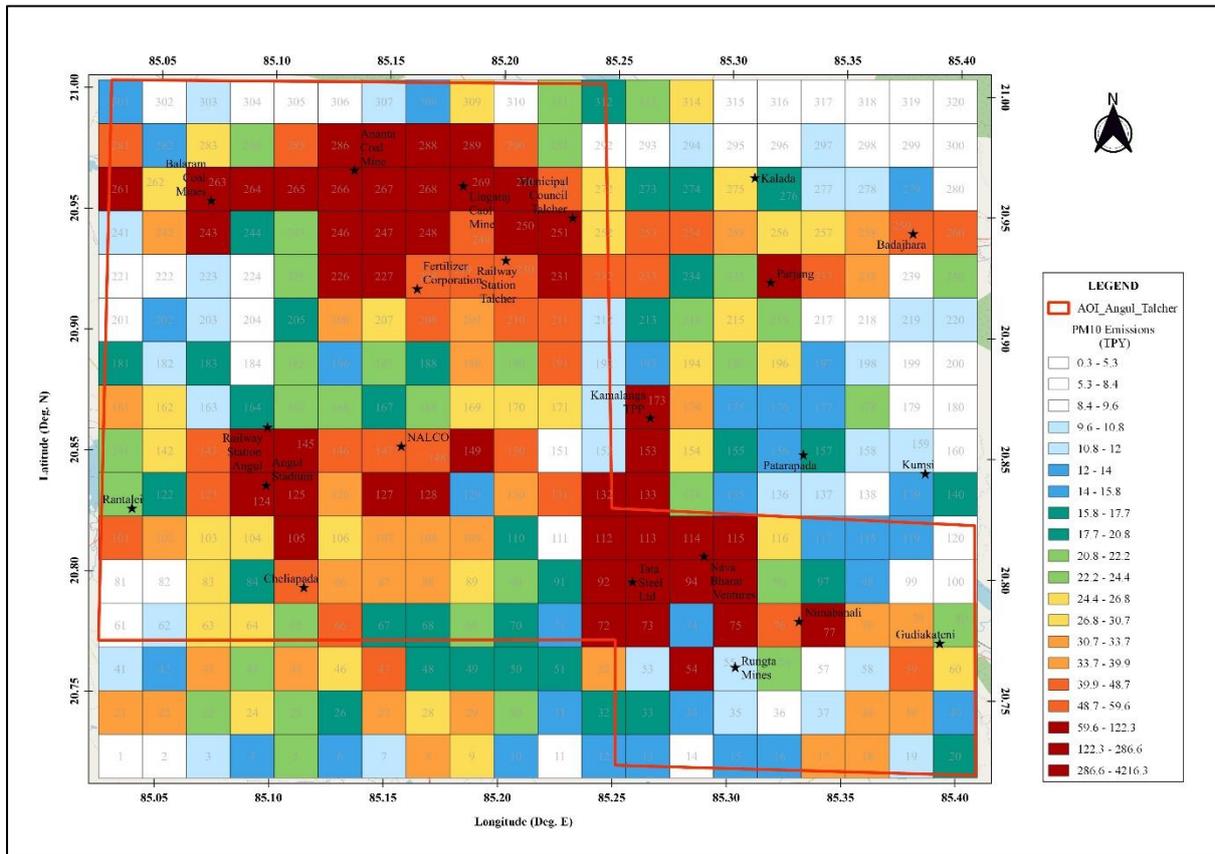


Figure ES-4 Spatial distribution of air pollutant emissions A) PM₁₀, B) PM_{2.5} (tonnes per year) in Angul-Talcher region in 2021.

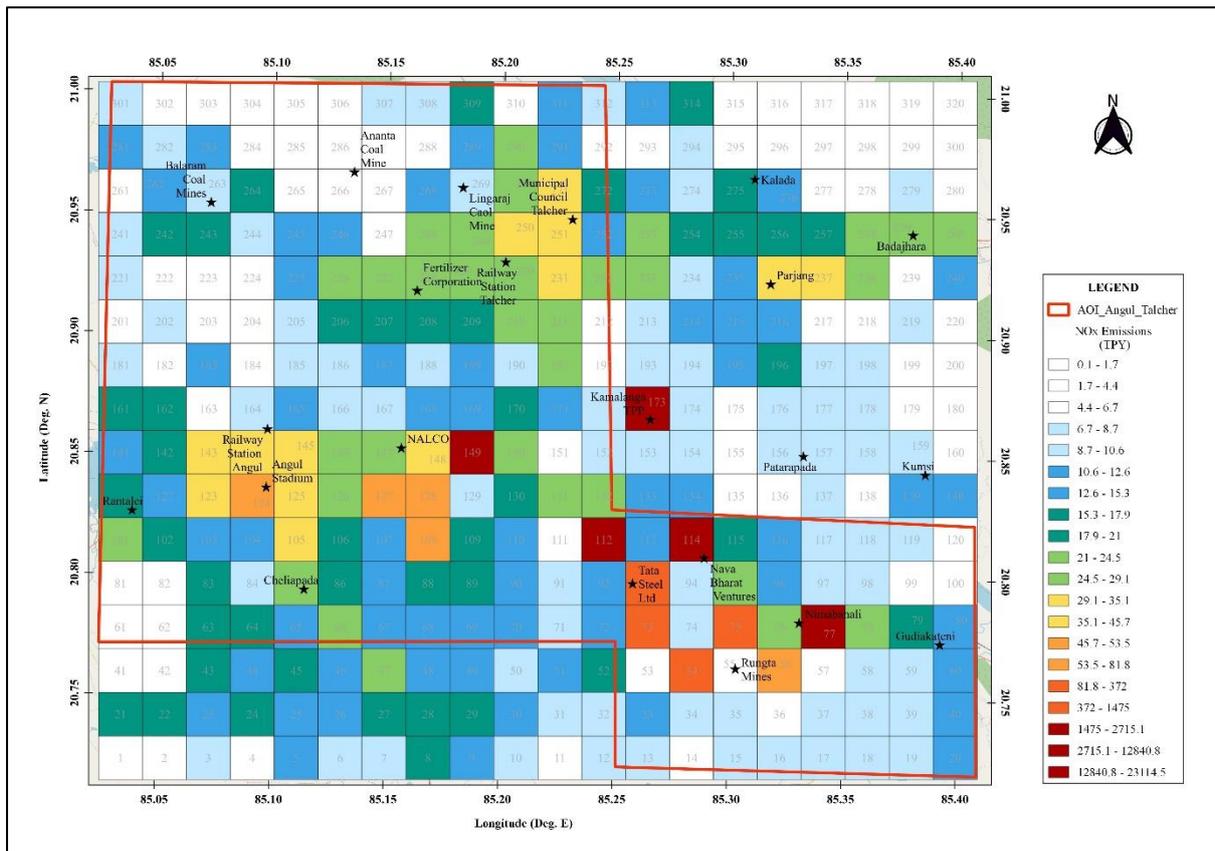
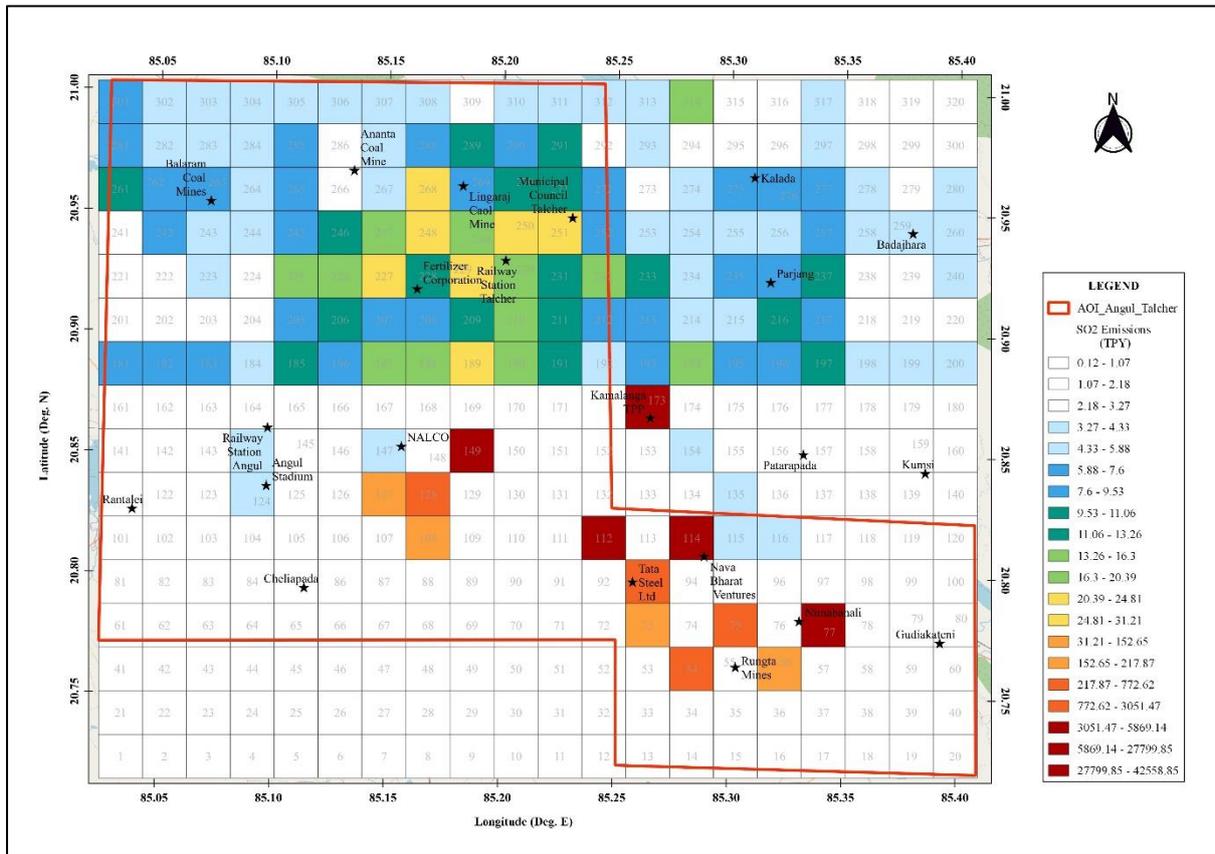


Figure ES-5 Spatial distribution of air pollutant emissions C) SO₂, D) NO_x (tonnes per year) in Angul-Talcher region in 2021.

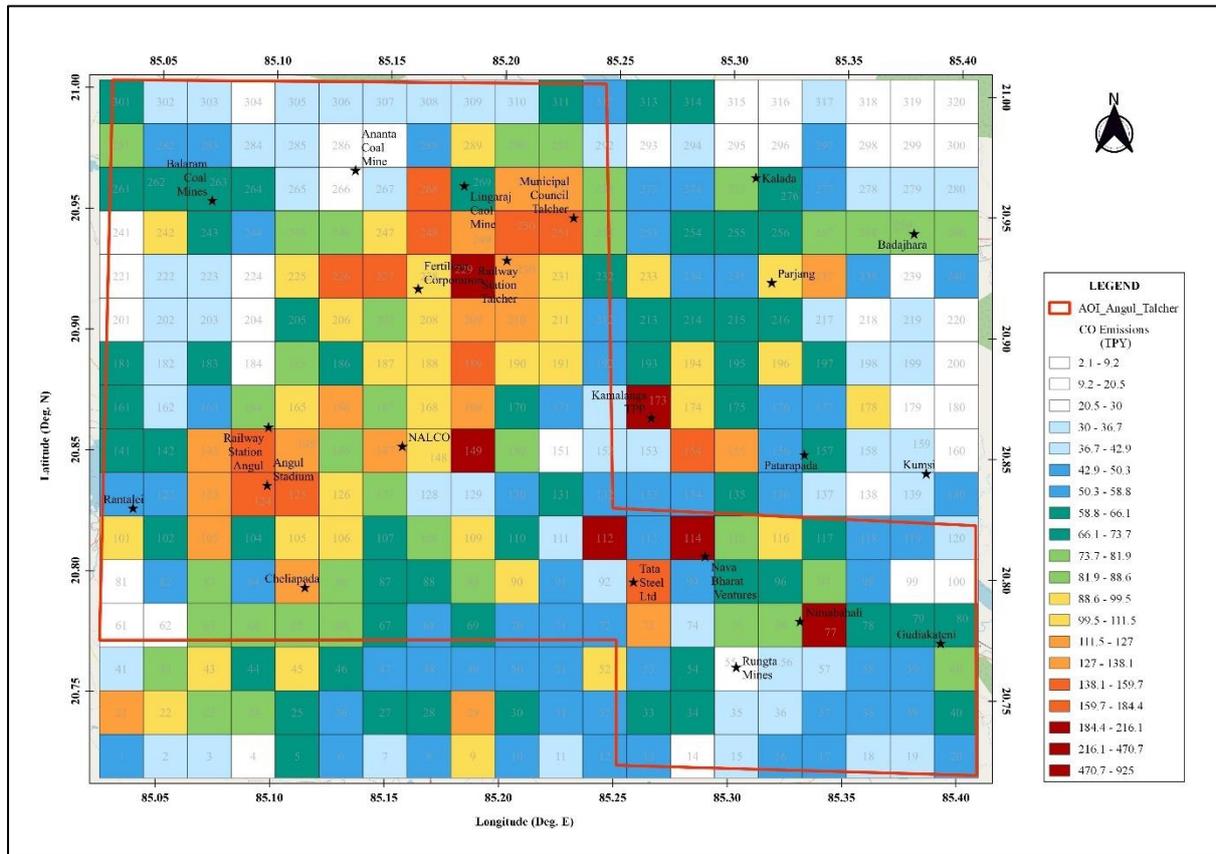


Figure ES-6 Spatial distribution of air pollutant emissions E) CO (tonnes per year) in Angul-Talcher region in 2021.

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 $2 \times 2 \text{ km}^2$, except industries and thermal powerplants, crematoria and brick kilns. The stack emissions from industries and thermal powerplants, industrial DG sets, and FCBTK brick kilns are modelled as point sources. Mines and 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 357 gridded receptors (refer Fig. ES-7). Additionally, eight discrete receptors are also configured at Talcher Coal Fields CAAQM station (operated by OSPCB and in this study used for model validation purpose) and seven 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, the lowest seasonal concentration of a pollutants reported, in a particular month, at Talcher Coal Fields CAAQM station are used to derive the seasonal background concentration to reflect the regional-scale contributions from distant sources.

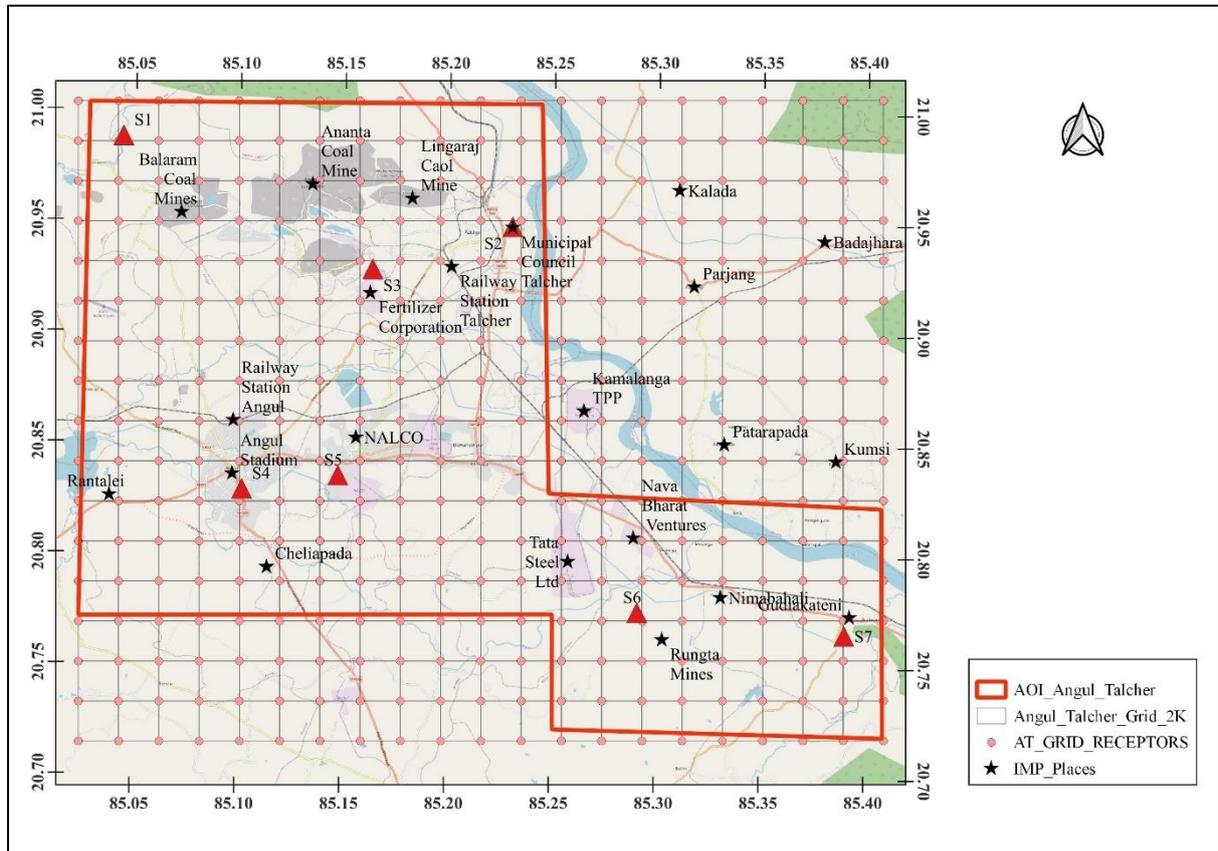


Figure ES-7 Map showing AERMOD modelling domain overlaid by gridded and discrete receptors configured in this study.

In order to validate the dispersion modelling set-up, the AERMOD simulated daily averaged concentrations of pollutants including PM_{2.5}, PM₁₀, SO₂, NO₂, and CO are compared against observations at CAAQM observations at Talcher Coal Fields for year 2022. The model performance is evaluated using six statistical measures including: mean, Pearson correlation coefficient (R), Mean Bias (MB), Factor of two (FAC2) envelope and Mean Fractional bias (MFB) and Mean Fractional Error (MFE). Based on the statistical analysis, the AERMOD model has been found to estimate the pollutant concentrations in Angul region, with a reasonable accuracy. Fig. ES-8 shows the spatial distribution of AERMOD simulated PM₁₀ and PM_{2.5} concentrations during baseline year, respectively

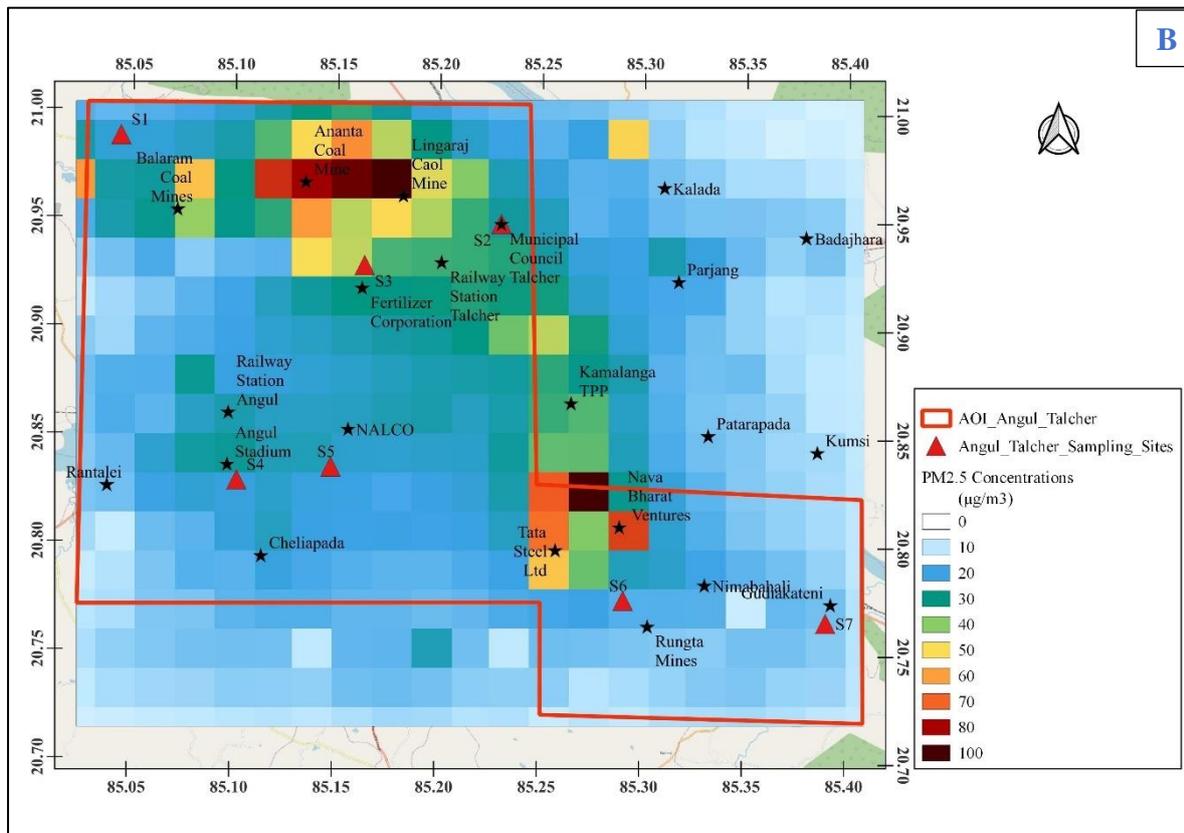
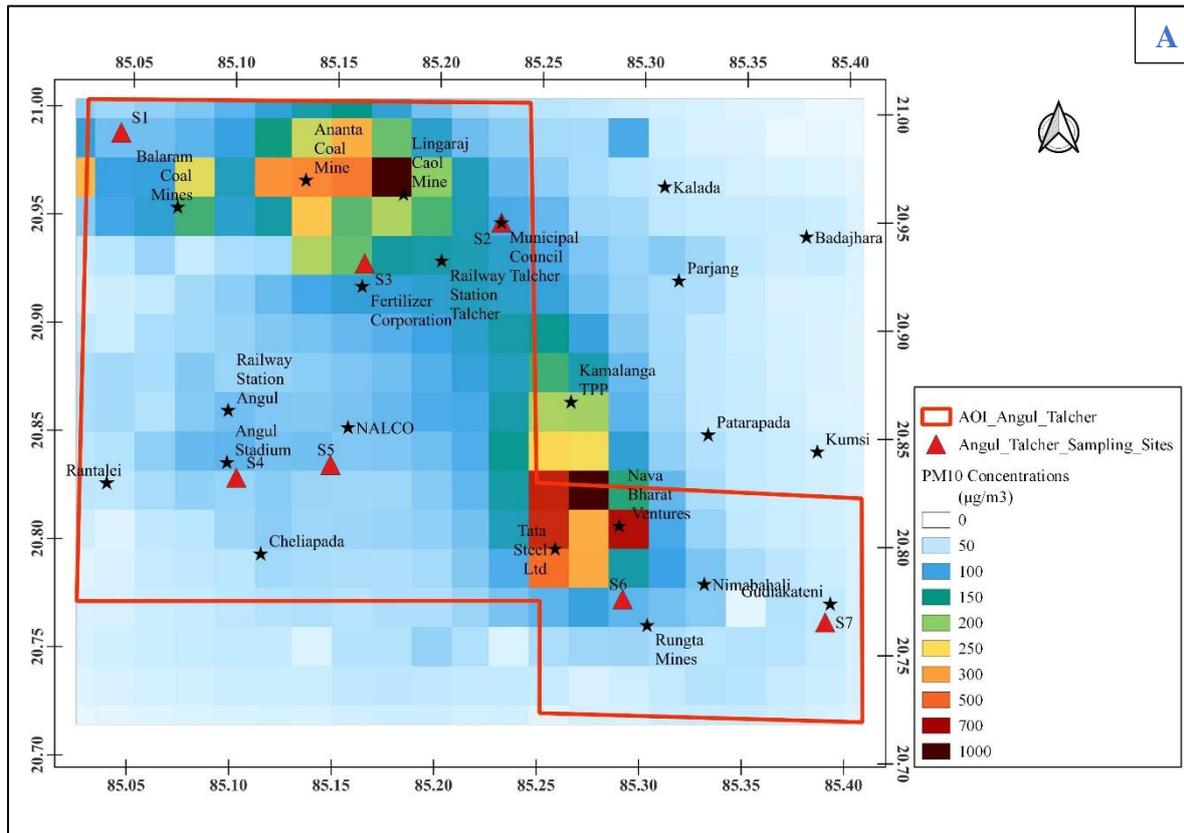


Figure ES-8 Map showing spatial distribution of PM₁₀ (A) and PM_{2.5} (B) annual mean concentrations (µg/m³) over Angul region for year 2022

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 Angul 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 Angul region for years 2021, 2026 and 2031.

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

Year	Scenario	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO
2021	BASE	24,152	7,241	1,25,996	62,900	14,764
2026	NFC	28,387	8,669	1,40,766	69,320	18,447
	BAU	27,008	8,390	91,700	69,316	17,305
	SC_I	23,906	7,401	78,747	59,406	15,565
	SC_II	20,938	6,530	70,905	53,836	13,343
2031	NFC	35,054	10,504	1,54,661	75,411	20,851
	BAU	29,997	9,287	89,379	68,915	19,622
	SC_I	22,390	7,172	72,932	50,544	15,665
	SC_II	11,385	4,368	56,497	32,061	10,478

The NFC scenario projections in Angul region indicate a potential increase in PM₁₀ emissions to 28,830 tonnes per year in 2026 i.e. an increase of 19.4% w.r.t. baseline year 2021 and to 35,054 tonnes per year in 2031 i.e. an increase of 45.1% w.r.t. baseline year 2021. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to reach to 8,669 (19.7%) and 10,504 tonnes per year (i.e. 45.1%) in 2026 and 2031, respectively. The BAU projections in Angul indicate a potential decrease of PM₁₀ emissions to 27,008 tonnes per year in 2026 i.e. a decrease of 6.3 % w.r.t. NFC_2026 and to 29,997 tonnes per year in 2031 i.e. a decrease of 14.4% w.r.t. NFC 2031. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 8,390 (-3.2%) and 9,287 tonnes per year (i.e. -11.6%) in 2026 and 2031, respectively.

The SC-I projections in Angul region indicate a potential decrease of PM₁₀ emissions to 23,906 tonnes per year in 2026 i.e. a decrease of 17.1% w.r.t. NFC 2026 and to 22,700 tonnes per year in 2031 i.e. a decrease of -35.2% w.r.t. NFC 2031. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 7,401 (-14.6%) and 7,357 tonnes per year (i.e. -30.0%) in 2026 and 2031, respectively. The SC-II projections in Angul region indicate a potential decrease of PM₁₀ emissions to 21,270 tonnes per year in 2026 i.e. a decrease of 26.2% w.r.t. NFC 2026 and to 11,385 tonnes per year in 2031 i.e. a decrease of 67.5% w.r.t. NFC 2031. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 6,728 (i.e. -22.4%) and 4,368 tonnes per year (i.e. -58.4%) in 2026 and 2031, respectively.



Figure ES-9 Estimated PM₁₀ (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 Angul-Talcher 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, the ambient PM₁₀ concentrations are estimated to reduce 8.9%, 18.3%, and 30.5% in 2026 and 18.3%, 40.2%, and 75.3% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively, compared to corresponding NFC scenarios. In case of PM_{2.5}, with implementation of control measures considered in different scenarios, an estimated reduction of 7.2%, 13.3%, and 23.0% in 2026 and 12.2%, 26.0%, and 44.1% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively compared to corresponding NFC scenarios.

This study also extracted location -specific air quality benefits due to implementation of different scenarios in 2026 and 2031. Eight representative locations, i.e. Talcher Coalfields CAAQMS and seven ARAI sampling locations, were selected to understand the impact of controls measures on air quality. Tables ES-4 presents the Percentage change in predicted

ambient air quality concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at Talcher Coalfields CAAQMS location in Angul-Talcher.

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

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-8.4%	-17.5%	-28.5%	-18.9%	-40.7%	-74.8%
PM _{2.5}	-7.4%	-15.4%	-25.6%	-15.9%	-36.7%	-67.3%
SO ₂	-26.0%	-28.5%	-30.2%	-30.8%	-47.1%	-57.8%
NO ₂	0.0%	-3.6%	-5.8%	3.2%	-7.6%	-18.0%
CO	-1.0%	-2.2%	-3.8%	-0.6%	-8.6%	-16.1%

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 21% and 16% in 2026 and 2031, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 22% and 19% in 2026 and 2031, respectively under BAU scenario, to 24% and 25% in 2026 and 2031, respectively under SC-I, to 29% and 47% in 2026 and 2031, respectively under SC-II scenario.

It is important to note that, the AQI changes presented here are location specific and a similar improvement is expected in other locations of Angul-Talcher 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) and aimed at reducing the national level PM_{2.5} and PM₁₀ concentrations.

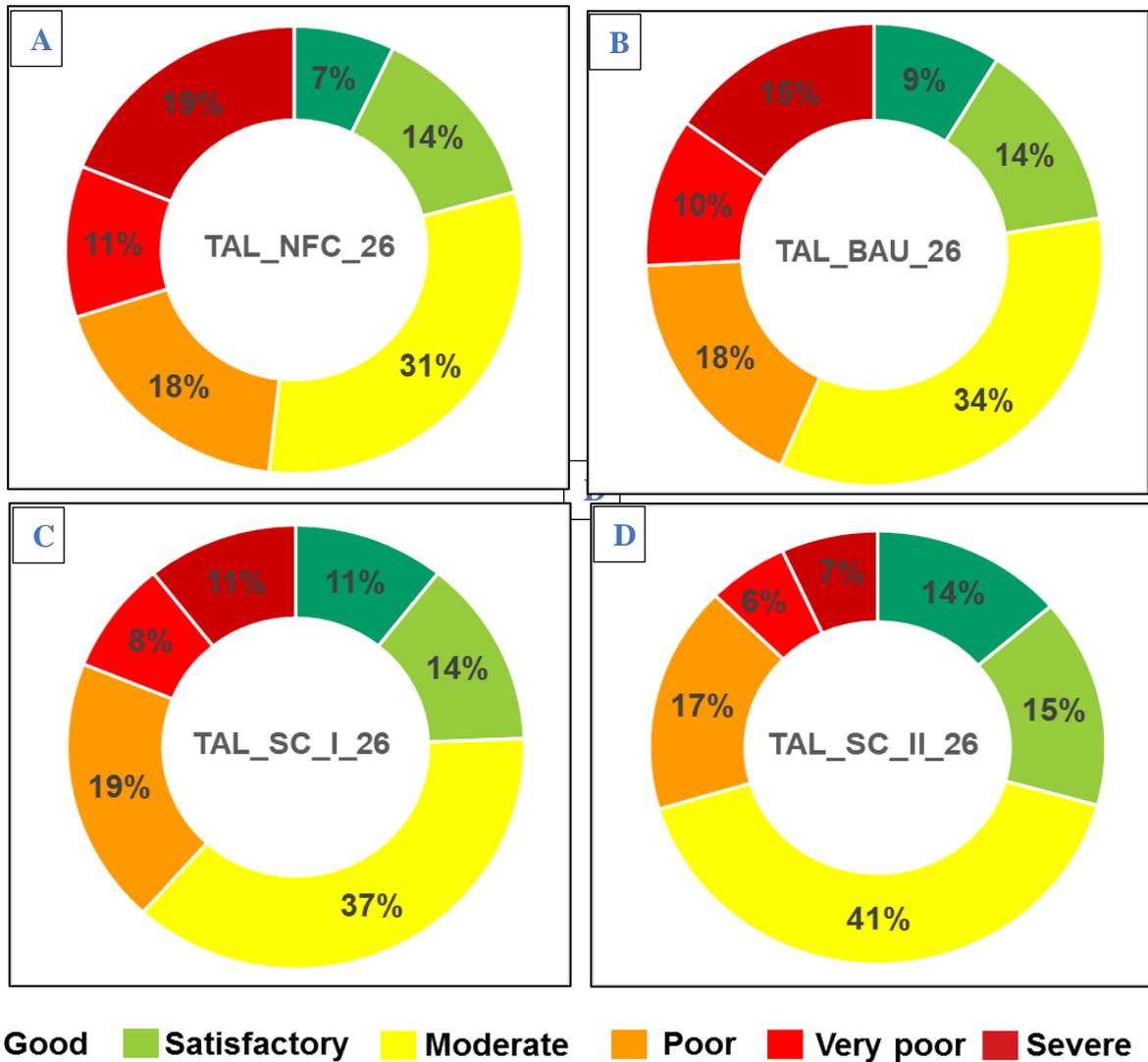
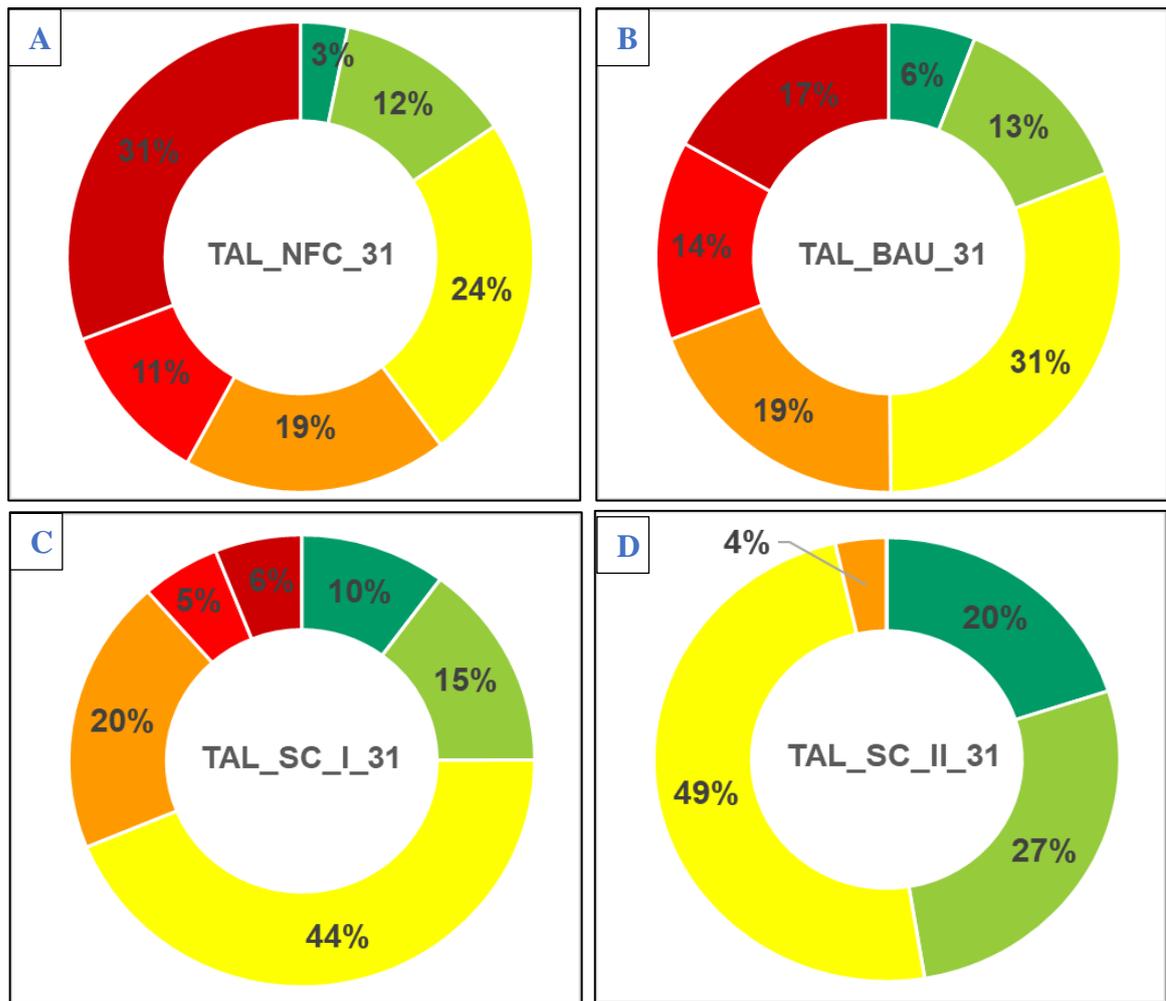


Figure ES-10 Distribution of six AQI categories at Talcher Coalfields CAAQMS location in Angul for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2026



■ Good
 ■ Satisfactory
 ■ Moderate
 ■ Poor
 ■ Very poor
 ■ Severe

Figure ES-11 Distribution of six AQI categories at Talcher Coalfields CAAQMS location in Angul 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 Angul 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 Angul 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 kerb side, especially small ones to avoid traffic congestions.	RTO, Angul	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.	RMC / RTO, Angul	6 months
	Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses).	RMC	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	RMC	1 -2 years
	Declare NO-vehicle zones in hot-spots, university / school premises.	RMC / 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, Angul	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, Angul	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
	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 suppress 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: <ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> • Cleaner fuel implementation to be encouraged and incentivized. 	OSPCB	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	<ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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
	<p>Iron and Steel Industry:</p> <ul style="list-style-type: none"> • 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
	<p>Thermal Power Plants</p> <ul style="list-style-type: none"> • 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
	<ul style="list-style-type: none"> Installation of Flue Gas Desulfurization (FGD) units to reduce the SO₂ 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 <i>Chullahs</i> (low emission <i>Chullahs</i>) 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

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Contents

Executive Summary	i-xxix
Chapter 1: Introduction	7
1.1. Background	7
1.2. Brief Description of the study area.....	9
1.2.1. Geography	10
1.2.2. Weather and Climate.....	10
1.2.3. Demography	10
1.3. Objectives of the Project.....	11
1.4. Scope of Work	11
1.5. Integrated framework for source apportionment study.....	12
1.6. Organization of the Report	14
Chapter 2: Air Quality Monitoring, Chemical Analysis & Receptor Modelling	17
2.1. Introduction.....	17
2.2. Methodology	17
2.2.1. Sampling sites selection	17
2.2.2. Sampling schedule.....	18
2.2.3. Sampling and gravimetric analysis.....	19
2.2.4. Chemical analysis of PM	20
2.2.4.1. Elements.....	20
2.2.4.2. Ions	20
2.2.4.3. Elemental/Organic Carbon	20
2.2.4.4. Molecular Markers	21
2.2.5. Gases and Volatile Organic Compounds (VOCs)	21
2.3. Quality Assurance/Quality Control.....	22
2.4. Chemical Mass Reconstruction.....	23
2.5. Receptor Modelling: Chemical Mass Balance (CMB) Model	24
2.6. Results and discussions.....	25
2.6.1. Winter season	25
2.6.1.1. PM mass concentrations.....	25
2.6.1.2. Spatial variability	25
2.6.1.3. Temporal variability	27
2.6.1.4. PM _{2.5} to PM ₁₀ ratios	28
2.6.1.5. Chemical composition of PM _{2.5} and PM ₁₀	29

2.6.1.6.	Molecular Markers in PM _{2.5} and PM ₁₀	18
2.6.1.7.	Gaseous pollutants and VOCs	19
2.6.2.	Summer season.....	21
2.6.2.1.	PM mass concentrations.....	21
2.6.2.2.	Spatial variability.....	22
2.6.2.3.	Temporal variability.....	24
2.6.2.4.	PM _{2.5} to PM ₁₀ ratios	25
2.6.2.5.	Chemical composition of PM _{2.5} and PM ₁₀	26
2.6.2.6.	Molecular Markers in PM _{2.5} and PM ₁₀	30
2.7.	Mass reconstruction of Particulate Matter (PM _{2.5} and PM ₁₀).....	32
2.7.1.	Validation of mass reconstruction methodology	32
2.7.2.	Winter Season: Reconstructed chemical mass	34
2.7.3.	Summer Season: Reconstructed chemical mass.....	40
2.8.	Chemical Ratios Analysis in PM _{2.5} and PM ₁₀	46
2.9.	Source apportionment of PM _{2.5} and PM ₁₀	49
2.9.1.	WINTER SEASON.....	50
2.9.1.1.	Site 4: Govt. College, Angul	50
2.9.1.2.	Site 5: NALCO CISF headquarters (S5).....	51
2.9.1.3.	Site 6: Galapada (S6)	52
2.9.1.4.	Site 7: Gudiakateni (S7).....	53
2.9.2.	SUMMMER SEASON.....	54
2.9.2.1.	Site 4: Govt. College, Angul	54
2.9.2.2.	Site 5: NALCO CISF Headquarters (S5).....	55
2.9.2.3.	Site 6: Galapada (S6)	56
2.9.2.4.	Site 7: Gudiakateni (S7).....	57
2.9.3.	City-level source contribution analysis	58
Chapter 3: Emission Inventory.....		60
3.1.	Introduction.....	60
3.2.	Objectives and Scope of Work.....	60
3.3.	Approach to the EI development.....	61
3.4.	Methodology	62
3.4.1.	Primary and secondary data collection.....	64
3.4.2.	Industries and thermal powerplants	65
3.4.3.	Fugitive dust	66
3.4.4.	Residential	67
3.4.5.	Transport	68

3.4.5.1.	Road network digitization	69
3.4.5.2.	Reconnaissance survey	69
3.4.5.3.	Traffic counts and vehicle fleet characteristics	69
3.4.6.	Road Dust	77
3.4.7.	Open Waste Burning	78
3.4.8.	Construction	79
3.4.9.	Brick Kilns	80
3.4.10.	Industrial Diesel Generators	81
3.4.11.	Crematoria.....	82
3.4.12.	Hotels, Restaurants and Bakeries	82
3.5.	Uncertainty in Emission Estimates	84
3.6.	Exclusion of sectors in emission inventory.....	85
3.6.1.	Agricultural burning and forest fires.....	85
3.6.2.	Rail transport	85
3.7.	Sectorial Emission Inventory	86
3.7.1.	Industries	86
3.7.2.	Thermal powerplants.....	87
3.7.3.	Industrial Fugitive Emissions	88
3.7.4.	Residential	89
3.7.5.	Transport	90
3.7.6.	Road dust resuspension	91
3.7.7.	Open waste burning	92
3.7.8.	Construction	93
3.7.9.	Brick Kilns.....	94
3.7.10.	Industrial diesel generators.....	95
3.7.11.	Crematoria.....	96
3.7.12.	Hotels, restaurants and bakeries	97
3.6.	Regional Emission Inventory	98
Chapter 4: Dispersion Modelling.....		108
4.1.	Background	108
4.2.	Meteorological Data.....	110
4.3.	Terrain Data	111
4.4.	Source Configurations	112
4.5.	Receptor Configurations	113
4.6.	Background Concentrations	115
4.7.	Dispersion Model Validation.....	115

4.8. Spatial Distribution of Modelled Pollutants	117
Chapter 5: Future Projections	124
5.1. Future Projections of Emissions and Air Quality Benefits	124
5.2. Transport Sector	125
5.2.1. Increased penetration of Bharat Stage (BS) – VI vehicles	125
5.2.2. Roll-out of Ethanol blended Gasoline (E20) fuel	125
5.2.3. Increased Penetration of Electric Vehicles (EV)	126
5.2.4. Non-Motorised Transport (NMT) Share	126
5.2.5. Public Transport Improvement (PTI).....	128
5.3. Re-suspended Road Dust.....	128
5.4. Industrial Sector.....	128
5.5. Thermal Powerplants	129
5.6. Fugitive emissions	129
5.7. Residential, HRBE and Open Waste Burning Sectors	129
5.8. Brick Kilns Sector	130
5.9. Construction Sector	130
5.10. Crematoria Sector	130
5.11. No Further Control (NFC) Scenario	131
5.12. Business-As-Usual (BAU) Scenario	133
5.13. Scenario – I (SC-I)	136
5.14. Scenario – II (SC-II)	139
5.15. Projected Emissions for 2026 and 2031.....	142
5.15.1. Sector-wise emission reduction potentials	147
5.16. Air Quality Benefits	151
5.16.1. Air quality benefits in terms of Air Quality Indices	166
Chapter 6: Action Plan.....	172
6.1. Air Quality Action Plan for Angul Region	172
Chapter 7: Future Research Work.....	144
7.1. Suggestions for future research work in non-attainment cities	144
References.....	146
Annexures	152
Annexure-A: Air Quality Monitoring	152
Annexure-B: Filter sample preparation, handling and weighing.....	156
Annexure-C: Analysis of Ions	159
Annexure-D: Analysis of Elements.....	166
Annexure-E: Carbon Analysis.....	169

Annexure-F: QA/QC	174
Annexure-G: Emission Inventory Activities.....	175
Annexure-H: Break-up of Emissions originating from the Industrial Sectors	181
Annexure-I: Assumptions for Transport Sector	182
ANNEXURE – J.....	190
Compilation of Best Available Techniques (BAT) for Iron and Steel and Allied Industries	190
I.1 Sinter plants.....	190
I.2 Pelletisation Plants	192
I.3 Coke Oven Plants	193
I.4 Blast Furnaces	197
I.5 Basic Oxygen Steelmaking and Casting.....	199
I.6 Electric Arc Furnace Steelmaking and Casting	201
Annexure-J: Breakpoints for AQI.....	202

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Chapter 1: Introduction

1.1. Background

Air pollution has become a serious problem in recent years with PM_{2.5} i.e. particles with aerodynamic diameter less than or equal to 2.5 µm, accounting for about 4.9 million deaths worldwide and ~1.2 million deaths in India in the year 2017 (HEI, 2019) and it is considered as a major challenge for air pollution and health regulatory agencies around the world. Similarly, PM₁₀ 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 PM₁₀ 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 PM₁₀ 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 PM₁₀ 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 PM₁₀. 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 Angul Region in Odisha”.

1.2. Brief Description of the study area

Situated in the heart of Odisha, the Angul region stands as one of India's oldest and most historically significant industrial zones. Spanning latitudes, 20.71427⁰N to 20.88076⁰N and longitudes 85.02578⁰E to 85.40797⁰E, this area, located just 120 km from Bhubaneswar, the capital city of Odisha, has been a key player in India's industrial evolution since the early 19th century. Divided by the Brahmani River, which flows directly into the Bay of Bengal, the region hosts a diverse array of industries. However, this industrial activity has come with its challenges, as the region is among the 43 most polluted industrial clusters in India, and ranks 7th among critically polluted zones according to the Central Pollution Control Board (Mohan et al., 2020). Notable among its industrial landscape are thermal power plants such as the Talcher Thermal Power Station and NTPC Kaniha, along with iron, steel and aluminium giants like Jindal Steel and Power Ltd. (JSPL) and Jindal India Thermal Power Ltd. (JITPL). The adjacent Talcher area also boasts significant mining industries, including Mahanadi Coal Field Ltd. and Lingaraj coal mines, contributing to its industrial heritage.

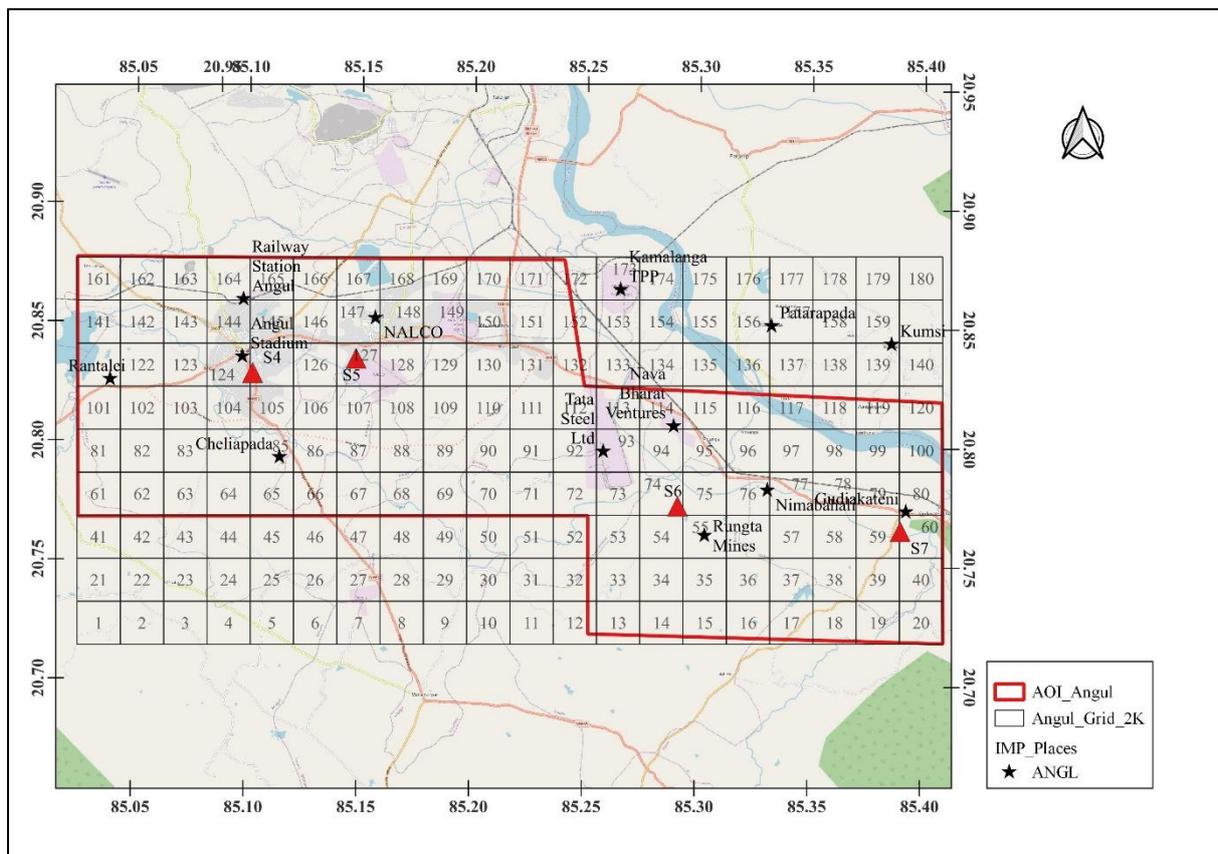


Figure 2 Map showing study area i.e. Angul region

1.2.1. Geography

The study area of Angul lies in between geographic coordinates from 85.02578, 20.71427 to 85.40797, 20.88076 in the Angul district of Odisha at a mean elevation of about 195 m above mean sea level. A river called Brahmani flows through nearby and give this region water resources. It is important to note that, the study area for this study extends beyond the municipal limits of Angul and covers an area of 720 km². Fig. 2, shows the study area divided into grids of size 2 x 2 km² for the emission inventory purpose.

1.2.2. Weather and Climate

Angul exhibits a tropical climate and receives abundant rainfall during Southwest monsoon (June – September). The mean annual temperature in Angul district is ~20.0 to 33.0 0C and the highest and lowest temperatures are generally observed in the months of May and January, respectively. Angul district receives an annual mean rainfall of about ~1277 mm, with highest rainfall in the month of August.

1.2.3. Demography

According to Census of India 2011, the total population of Angul and Talcher towns was 85,231. 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 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 4,45,359 for year 2021. Fig. 3 shows the gridded population of the study area for year 2021.

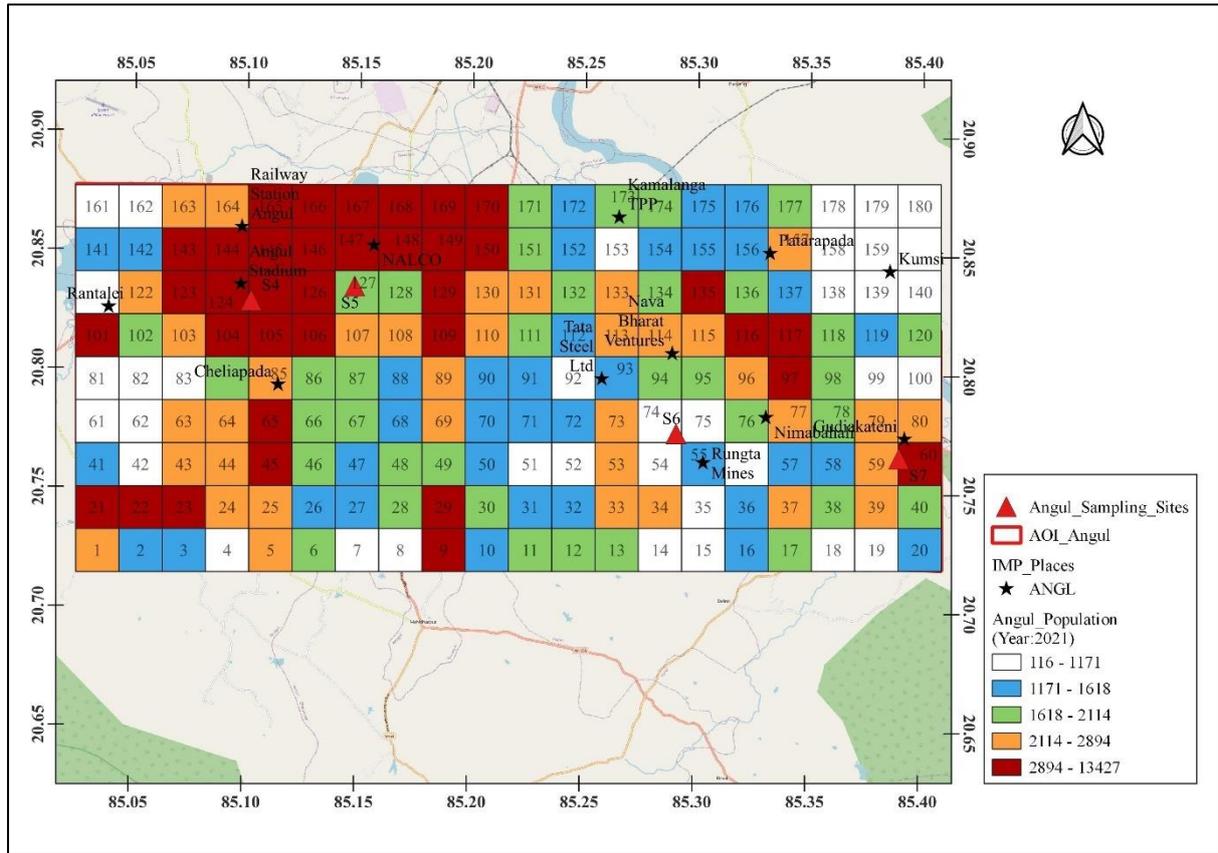


Figure 3: The estimated gridded population of the study area for year 2021.

1.3. Objectives of the Project

The main aim of this study is to identify and characterize various emission sources in Angul 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 (PM₁₀ & PM_{2.5}) source apportionment using receptor modelling approach for Angul region.
- ii) To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Angul region.

1.4. Scope of Work

1.1. Sampling of Particulate Matter (PM₁₀ & PM_{2.5}) using speciation samplers at identified sites (5 locations in Angul 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 SO₂, NO₂, Benzene, Toulene, Ethyl Benzene and Xylene identified locations during winter season only.

- 1.2. Analysis of collected Particulate Matter (PM₁₀ & PM_{2.5}) samples for ions, elements, carbon fractions (organic and elemental carbon) and molecular markers (PAHs, alkanes, hopanes).
- 1.3. To carry out PM₁₀ & 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: PM₁₀, PM_{2.5}, SO₂, NO_x, CO and NMVOCs originating from various sources for Angul 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 PM₁₀ & PM_{2.5} concentrations using AERMOD dispersion model.
- 1.7. To prepare a comprehensive action plan for reducing, control and abatement of PM₁₀ & 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).

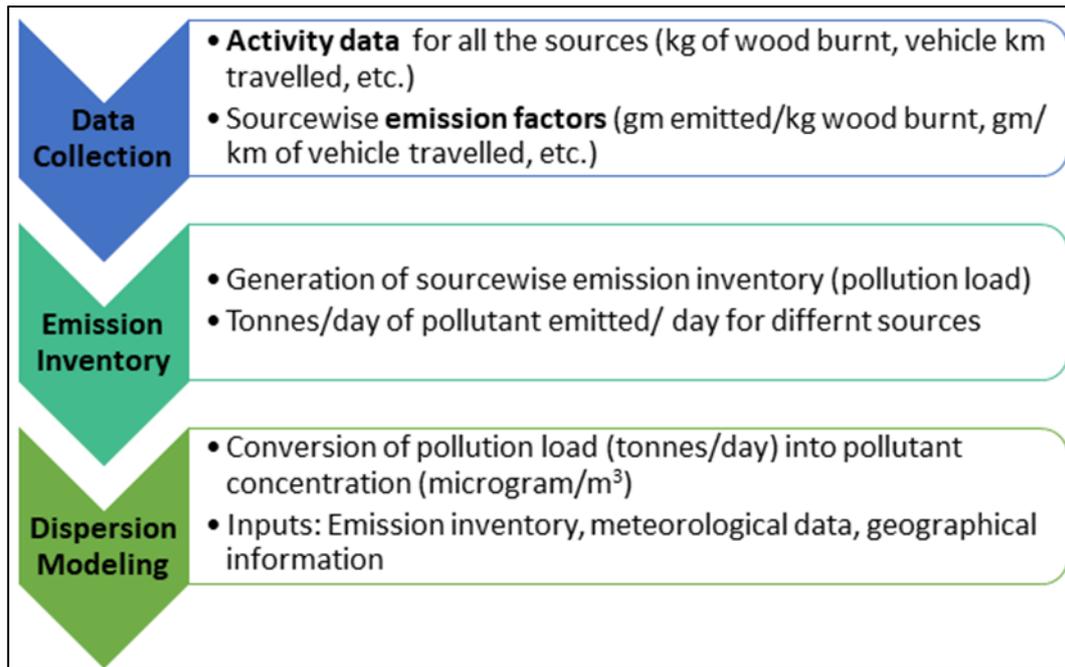


Figure 4 Bottom-up approach for Particulate Matter Source Apportionment

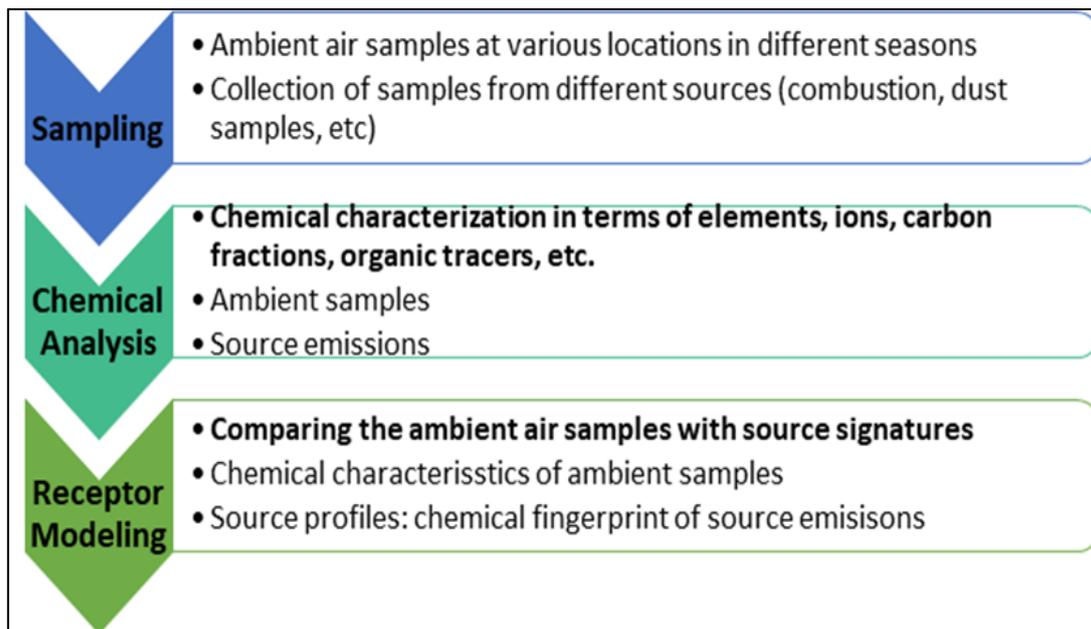


Figure 5 Top-down approach for Particulate Matter Source Apportionment

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 Angul region in Odisha.

1.6. Organization of the Report

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

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

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

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

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

Chapter 5 describes the various emission control scenarios designed for Angul 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.

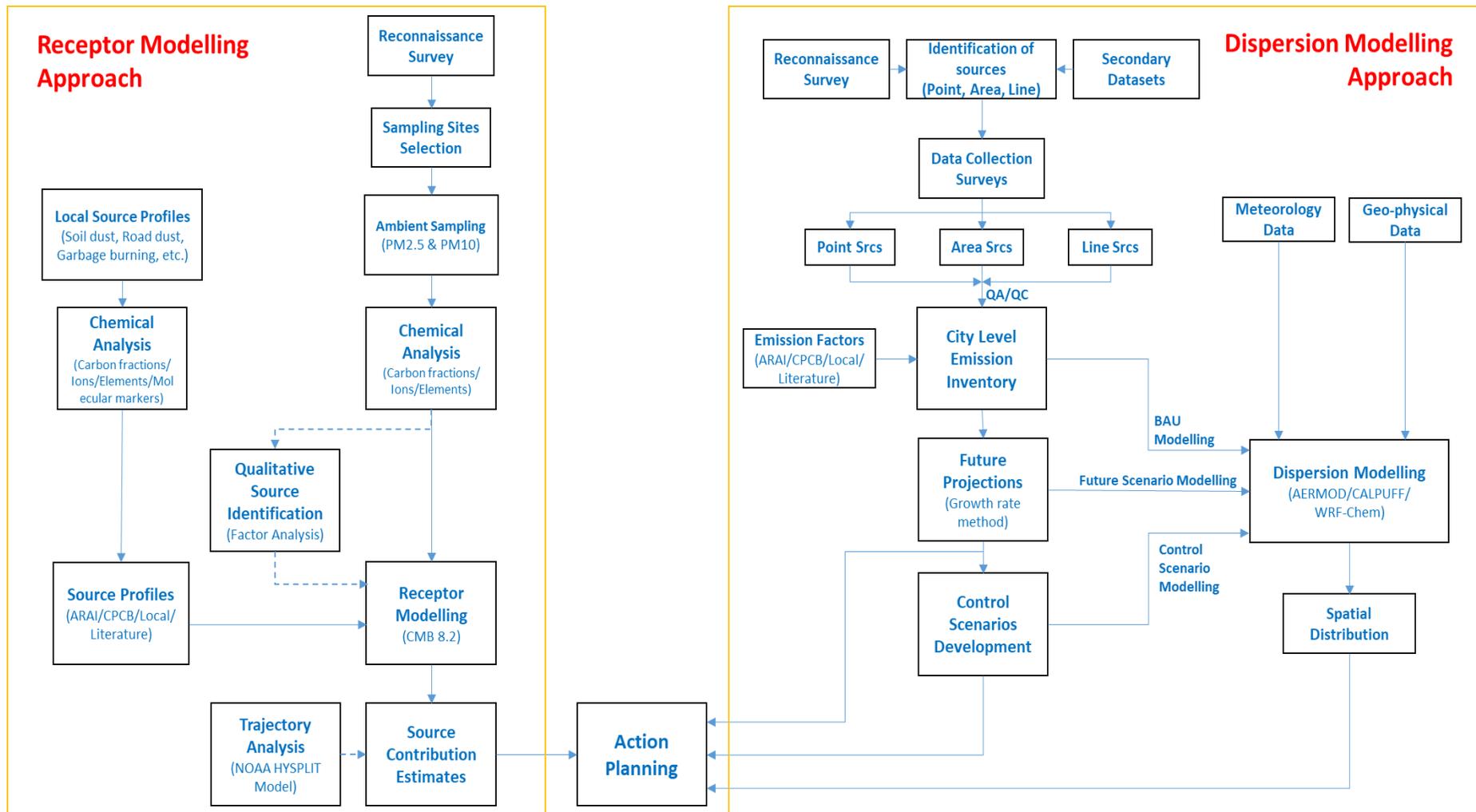


Figure 6 Framework for integrated emission inventory and source apportionment study of Angul region in Odisha

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 PM₁₀ 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. December 7 to 26, 2021 and summer season i.e. May 21 to June 7, 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 Angul region. Figure 7 and Table 1, show the geographic distribution and details of the sampling sites, respectively. The sites include 1 mixed 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 PM₁₀ over Angul. For example, the residential sites, such as those at Galpada (S6) and Gudiakateni (S7), are surrounded by typical residential areas with low to middle income group households, respectively. The Angul Government College site (S4) is of mixed type and located at the city centre. The other site i.e. NALCO CISF quarters (S5) typically represents the industrial site. It is important to note that, this study was undertaken together for Angul and Talcher regions. Considering the geographical settings and meteorology, background site is only considered in the Talcher region and not in the Angul region.

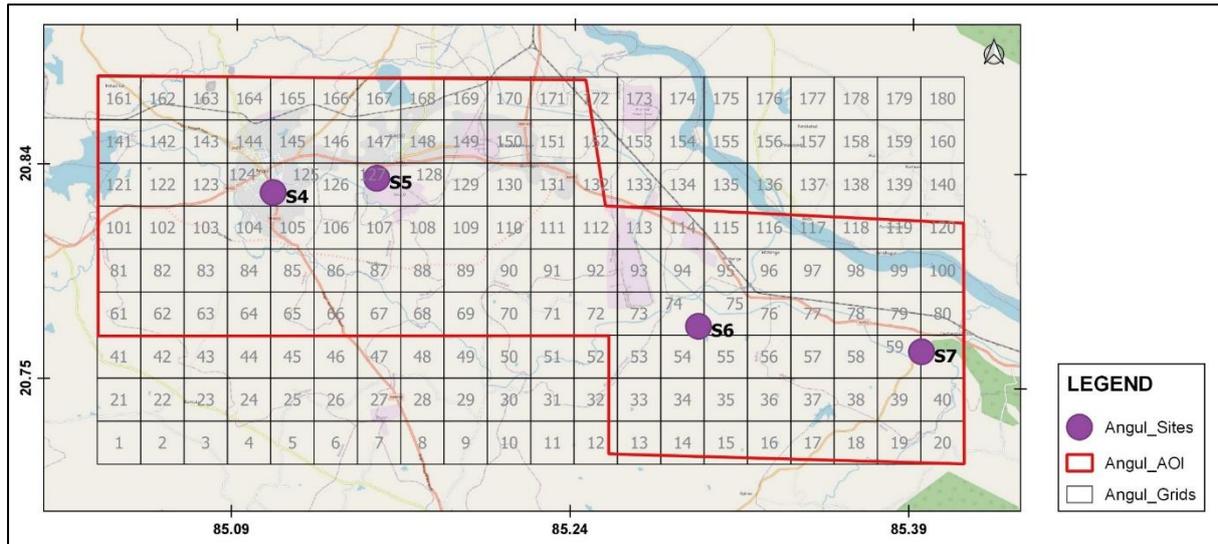


Figure 7 Angul region map showing location of four sampling sites selected for source apportionment study

Table 1 Geographic information of the selected sampling sites in Angul region

Code	Location	Latitude	Longitude	Category
S4	Government College Angul	20.829118	85.102152	Mixed
S5	Nalco CISF Quarters	20.835580	85.148018	Industrial
S6	Galapada	20.774936	85.291356	Residential (LIG) + Others
S7	Gudiakateni	20.765197	85.390308	Residential (LIG) + Others

2.2.2. Sampling schedule

The ambient PM_{2.5} and PM₁₀ 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 December 7 to 26, 2021 while summer season sampling was conducted from May 21 to June 7, 2022. The summer season sampling could not be conducted in 2021 due to the COVID-19 lockdown. There were restrictions on movement of people as well polluting sources activities were also well below normal. Hence, it was decided to conduct summer season sampling in 2022, upon normalization of activities and movement of people.

W I N T E R	SITE	Dec-21																			
		7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	GOVERNMENT COLLEGE ANGUL																				
	NALCO CISF QUARTERS																				
	GALPADA																				
	GUDIAKATANI																				

S U M M E R	SITE	May-22										Jun-22									
		21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9
	GOVERNMENT COLLEGE ANGUL																				
	NALCO CISF QUARTERS																				
	GALPADA																				
	GUDIAKATANI																				

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

2.2.3. Sampling and gravimetric analysis

PM_{2.5} and PM₁₀ 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 PM₁₀. 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 stigmaterol. 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 °C) and relative humidity (20 – 35%) for 24 hours. Additionally, the quartz-fiber filter papers were pre-baked at 900 °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 °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 Angul 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 PM₁₀ 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 PM₁₀ 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-Docosane, 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 SO₂ and NO₂ 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 SO₂ and NO₂ determination, were collected at four sampling sites, on daily basis during the winter season sampling period i.e. December 7 – 26, 2021. 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 SO₂ and NO₂. The ambient SO₂ and NO₂ 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):

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

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 .

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

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

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

The chemical reconstruction method explained above was applied to all 4 sites over Angul 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 PM₁₀ particles in Angul 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.

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

In this equation, C_i is the ambient concentrations of the species i measured at the receptor site, P is the number of contributing sources, F_{ij} is the fraction of the emissions of the species i starting from the source j , and S_j 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 PM₁₀ concentrations observed at four sampling locations in Angul region during the winter season i.e. December 7 – 26, 2021. The mean PM_{2.5} and PM₁₀ mass concentrations during the entire sampling period over all sites were 76.8 and 179.8 µg/m³, respectively. The mean PM_{2.5} concentrations exhibited a 5-fold range and ranged from a minimum of 31.7 µg/m³ (at Gudiakatani i.e. S7) to a maximum of 148.4 µg/m³ (at NALCO CISF headquarters i.e. S5). Similarly, the mean PM₁₀ concentrations exhibited a 3-fold range and ranged from 81.4 µg/m³ (at Galapada i.e. S6) to 291.6 µg/m³ (at NALCO CISF headquarters i.e. S5). The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 µg/m³ for PM_{2.5} and PM₁₀, respectively. The winter-time PM_{2.5} concentrations were observed to exceed the daily NAAQS limit at all sites (47 to 87% of sampling days) with minimum exceedance at Gudiakatani i.e. S7 (47%) and maximum exceedance at NALCO CISF headquarters i.e. S5 (87%). The daily averaged PM₁₀ concentrations exceeded the NAAQS limit at all sites (88-100% of sampling days) with minimum exceedance at Galapada i.e. S6 (88%). All other sites i.e. Govt. College, Angul (S4), NALCO CISF headquarters (S5) and Gudiakatani (S7) violated the PM₁₀ limit value for all sampling days (100%) during winter season.

2.6.1.2. Spatial variability

The highest seasonal mean PM_{2.5} concentrations were observed at NALCO CISF headquarters i.e. S5 (108.7 µg/m³) while the lowest were recorded at Gudiakatani i.e. S7 (58.8 µg/m³). 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 51.5 to 148.4 µg/m³ at NALCO CISF headquarters i.e. S5 while it ranged from 31.7 to 81.4 µg/m³ at Gudiakatani i.e. S7.

The highest seasonal mean PM₁₀ concentrations were observed at Govt. College, Angul i.e. S4 (217.0 µg/m³) while the lowest were recorded at Galapada i.e. S6 (138.5 µg/m³). The daily

PM₁₀ concentrations showed highest and lowest variability at NALCO CISF headquarters i.e. S5 and Gudiakatani i.e. S7 sites, respectively. For example, daily PM₁₀ concentrations ranged from a minimum of 114.0 to a maximum of 291.6 µg/m³ at NALCO CISF headquarters i.e. S5 while it ranged between 107.2 and 211.8 µg/m³ at Gudiakatani i.e. S7.

These concentration levels can be attributed to air polluting activities around each site. For example, NALCO CISF headquarters i.e. S5 is located in the Industrial area of NALCO. 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.

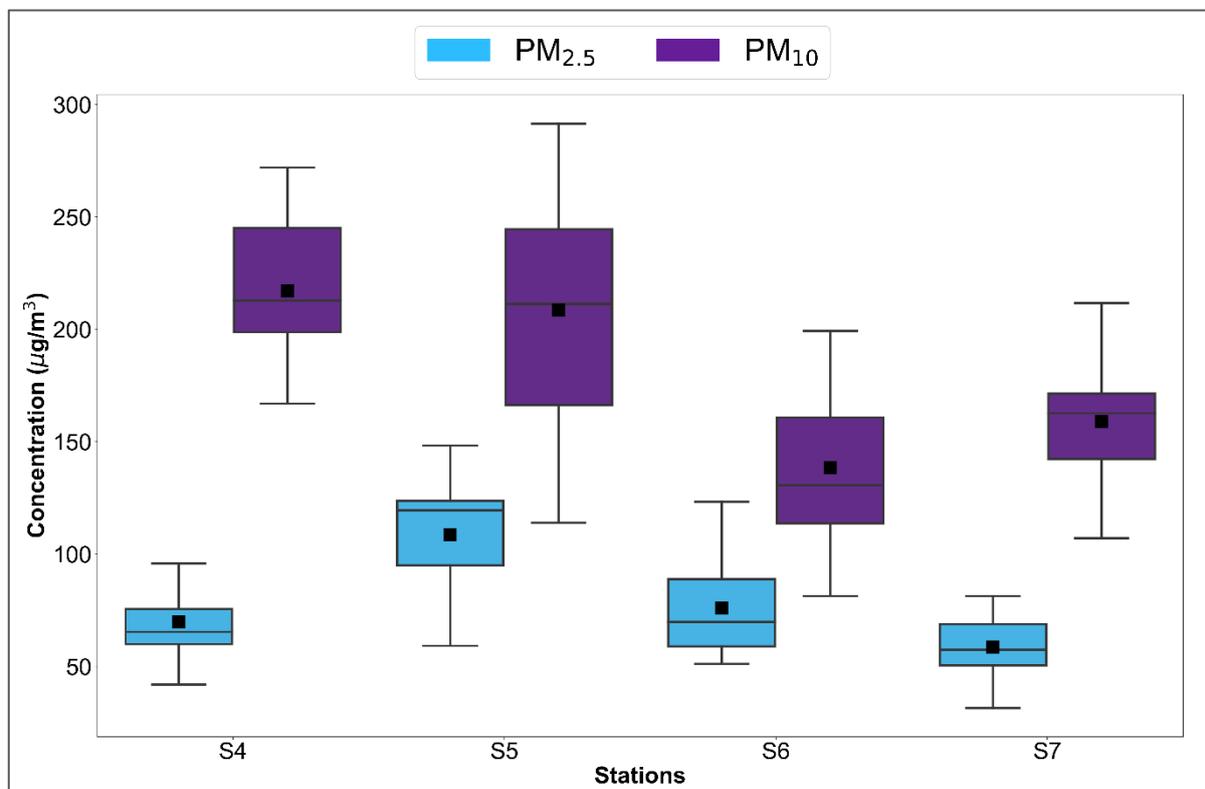


Figure 9 Boxplot showing distribution of daily PM_{2.5} (blue colored boxes) and PM₁₀ (violet colored boxes) concentrations observed at four sampling sites in Angul region during the winter season sampling period (December 7 – 26, 2021).

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 PM₁₀ observed at four selected sampling locations in Angul region during the winter season sampling period. Only valid samples between December 7 – 26, 2021 are considered for this analysis. Overall, the PM concentrations showed an increasing trend from December 7 to 24, 2021 at all sites. This could be attributed to the meteorological conditions over Angul region during the winter season.

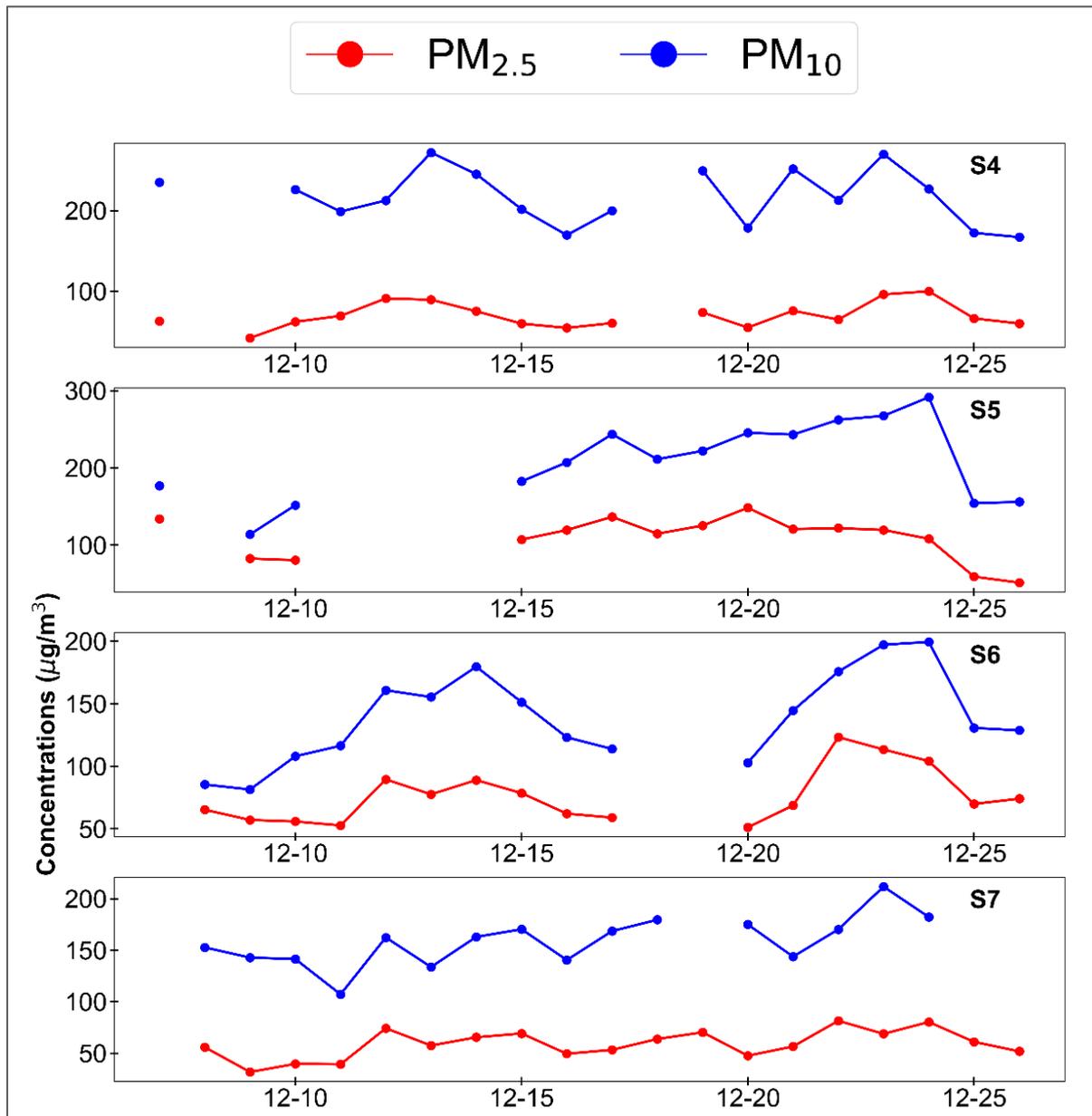


Figure 10 Daily time-series of PM_{2.5} (red) and PM₁₀ (blue) concentrations observed at four sites in Angul region during the winter season sampling (December 7 – 26, 2021)

2.6.1.4. PM_{2.5} to PM₁₀ ratios

Fig. 11 shows distribution of daily PM_{2.5} to PM₁₀ ratios observed at four sampling sites during the winter season. The mean value of PM_{2.5} to PM₁₀ ratios during the study period over all sites was found to be 0.44, varying from 0.33 to 0.55. The highest winter season mean PM_{2.5} to PM₁₀ ratio was observed at Galapada i.e. S6 (0.55) while the lowest was observed at Govt. College, Angul i.e. S4 (0.33). 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.

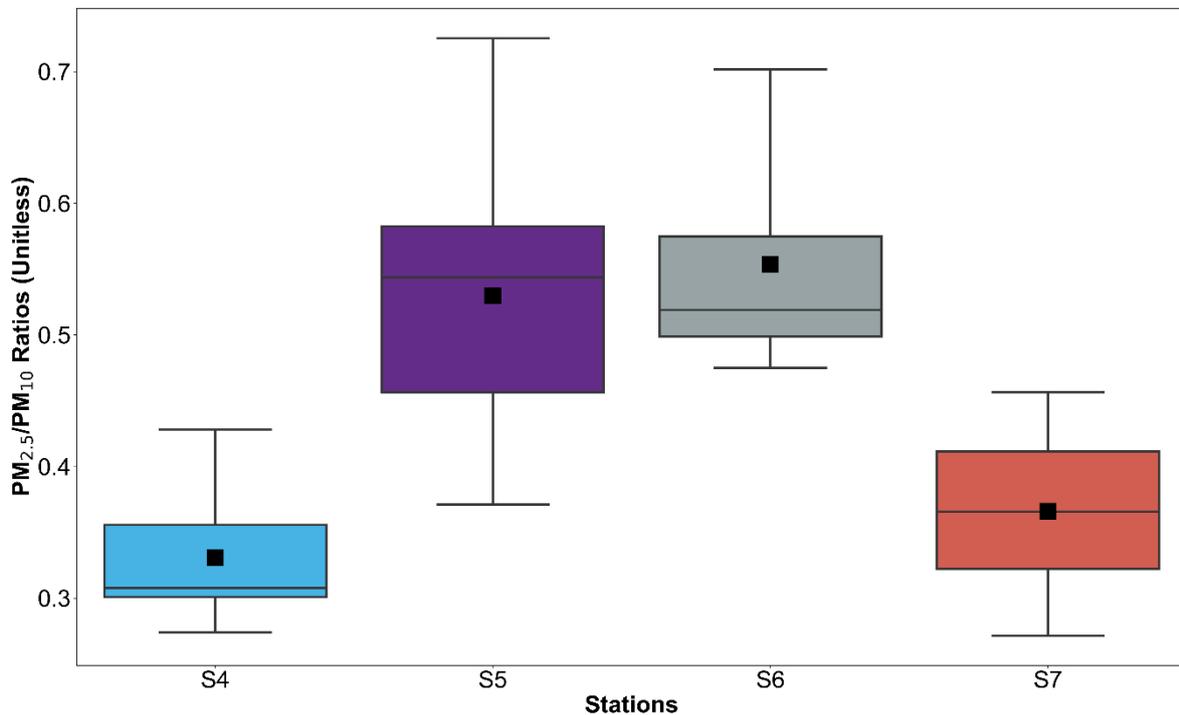


Figure 11 Boxplot showing distribution of PM_{2.5} to PM₁₀ ratios at four sampling sites in Angul region during the winter season (December 7 – 26, 2021)

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 PM₁₀

2.6.1.5.1. Site 4: Govt. College, Angul (S4)

Fig. 12 shows the frequency distribution of different species observed in PM_{2.5} and PM₁₀ at Govt. College, Angul i.e. S4 in Angul region during the winter season. OC, EC, NH₄⁺, and SO₄²⁻ in PM_{2.5} and OC, EC, NH₄⁺, SO₄²⁻, NO₃⁻, Fe, and Si in PM₁₀ are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m³. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

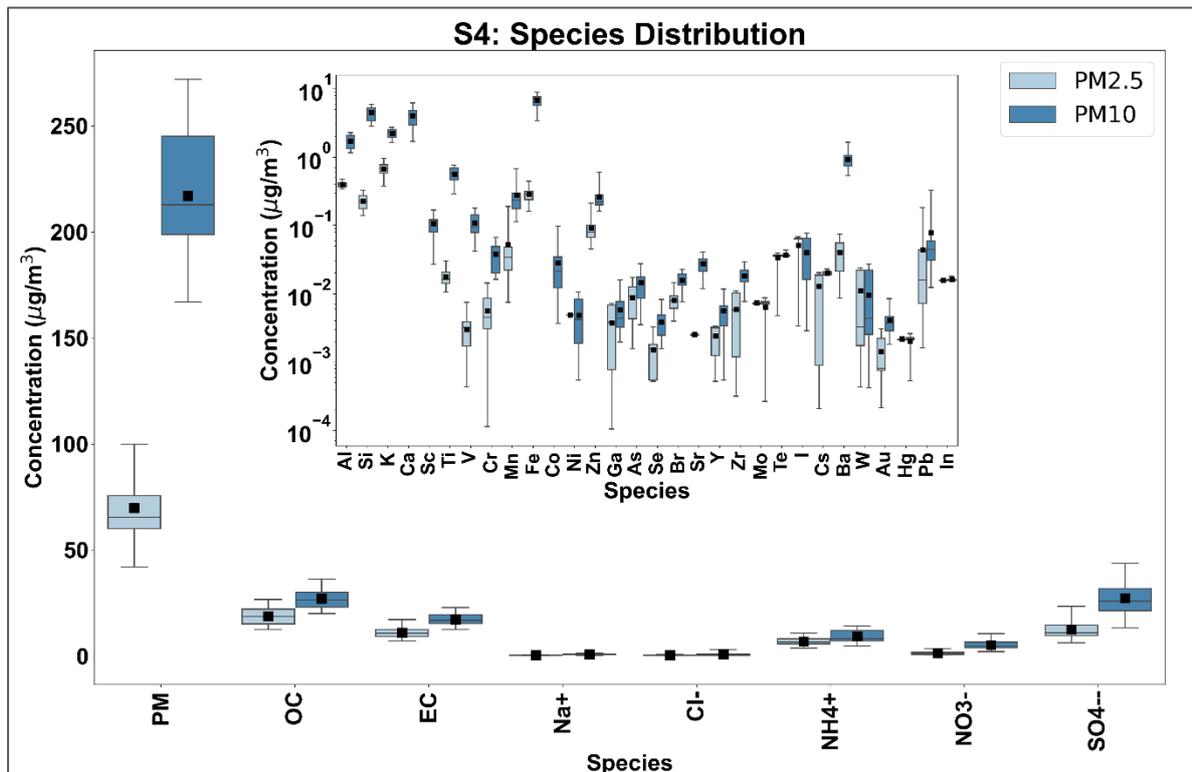


Figure 12 Box plots showing distribution of different species observed in PM_{2.5} and PM₁₀ at Govt. College, Angul (S4) in Angul region during the winter season

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 5: NALCO CISF headquarters (S5)

Fig. 13 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , NO_3^- , and SO_4^{--}) 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 $\text{PM}_{2.5}$ and PM_{10} observed at NALCO CISF HQ Site (S5) during winter season (December 7-27, 2021). OC, EC, NH_4^+ , and SO_4^{--} in $\text{PM}_{2.5}$ and PM_{10} are the most abundant species having seasonal mean concentrations greater than $5.0 \mu\text{g}/\text{m}^3$. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

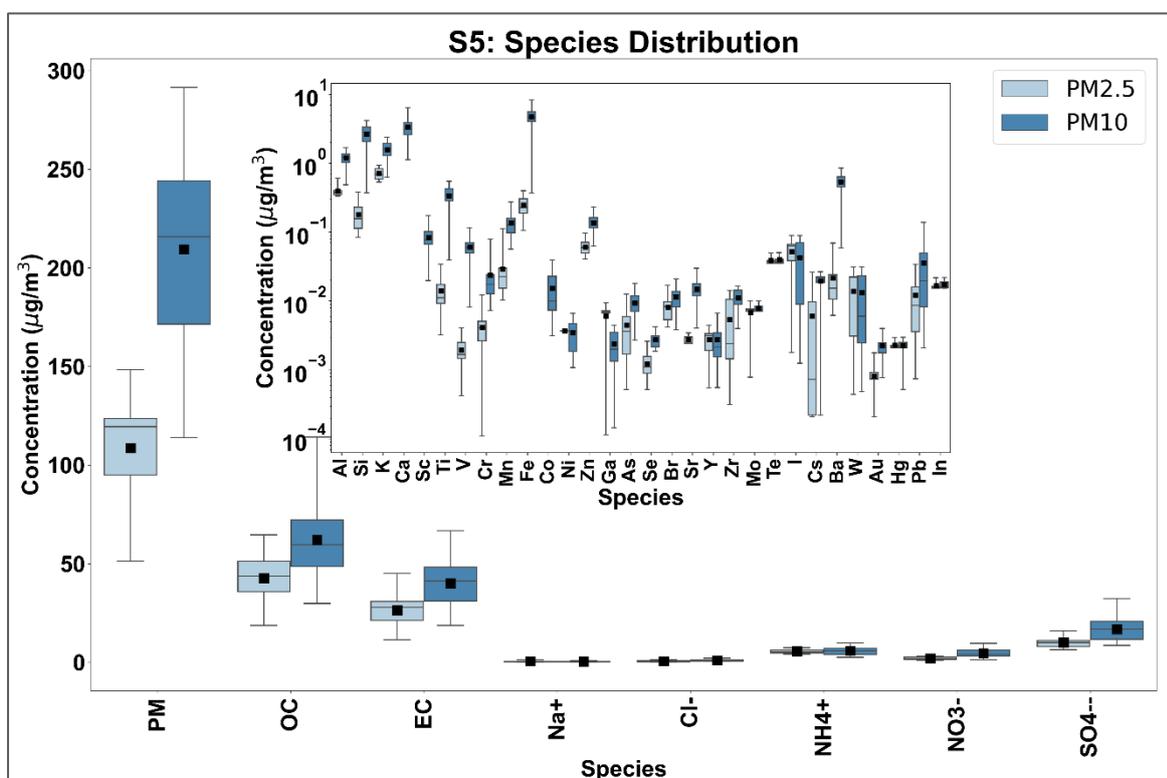


Figure 13 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at NALCO CISF headquarters (S5) in Angul region during the winter season

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 6: Galapada (S6)

Fig. 14 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , NO_3^- , and SO_4^{--}) 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 $\text{PM}_{2.5}$ and PM_{10} observed at Galapada site (S6) during winter season (December 7-27, 2021). OC, EC, NH_4^+ and SO_4^{--} in $\text{PM}_{2.5}$ and OC, EC, NH_4^+ , NO_3^- , and SO_4^{--} in PM_{10} are the most abundant species having seasonal mean concentrations greater than $5.0 \mu\text{g}/\text{m}^3$. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

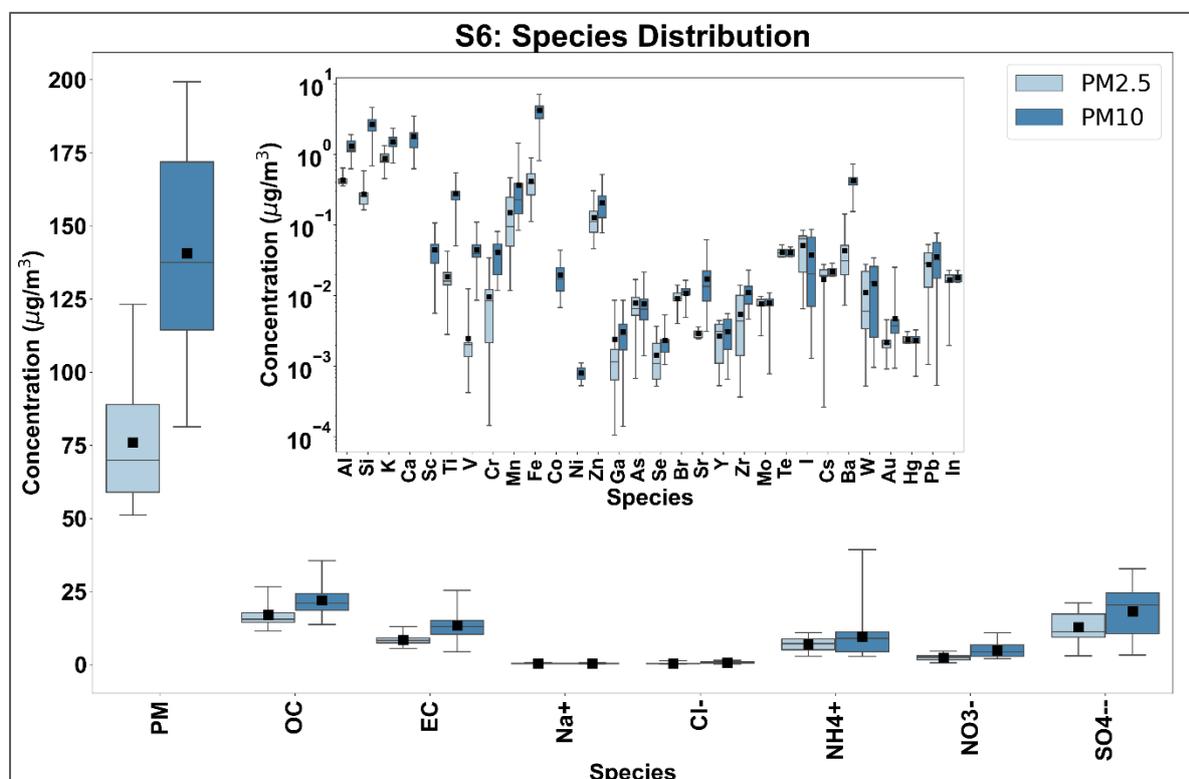


Figure 14 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at Galapada (S6) in Angul region during the winter season

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 7: Gudiakateni (S7)

Fig. 15 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na⁺, NH₄⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, NO₃⁻, and SO₄²⁻) 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 PM₁₀ observed at Gudiakateni site (S7) during winter season (December 7-27, 2021). OC, EC, NH₄⁺, and SO₄²⁻ in PM_{2.5} and OC, EC, SO₄²⁻, NH₄⁺, Si and Fe in PM₁₀ are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m³. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

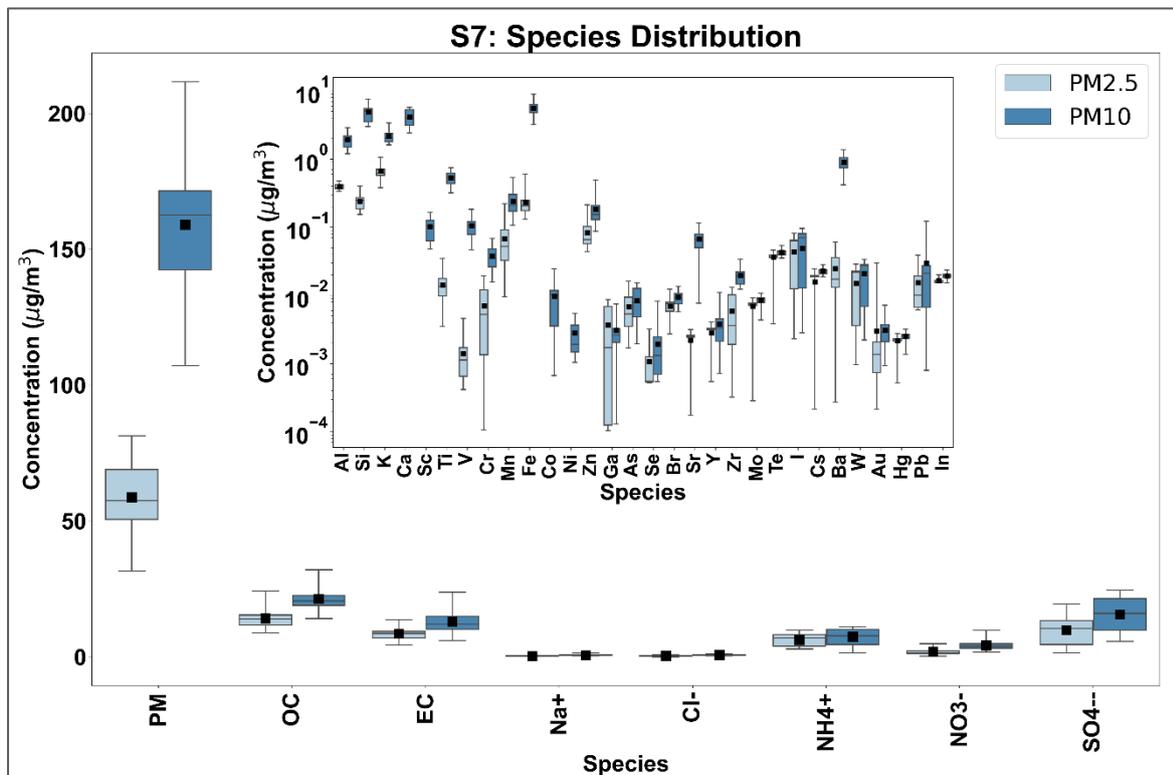


Figure 15 Box plots showing distribution of different species observed in PM_{2.5} and PM₁₀ at Gudiakateni (S7) in Angul region during the winter season

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 PM₁₀

Fig. 16 and 17, represents the seasonal mean concentrations of molecular markers observed at four sampling locations in Angul region, during the winter season sampling period i.e. December 7-26, 2021. Alkane group is found to dominate the molecular markers mass, with contributions > 80% of the total measured species, during the winter season over Angul region. Besides Alkanes, Levoglucosan, Amides and Stigmasterol, which are considered as tracers for biomass burning emissions (CPCB, 2010), are also detected in significant amounts, in PM samples collected over Angul region during winter season.

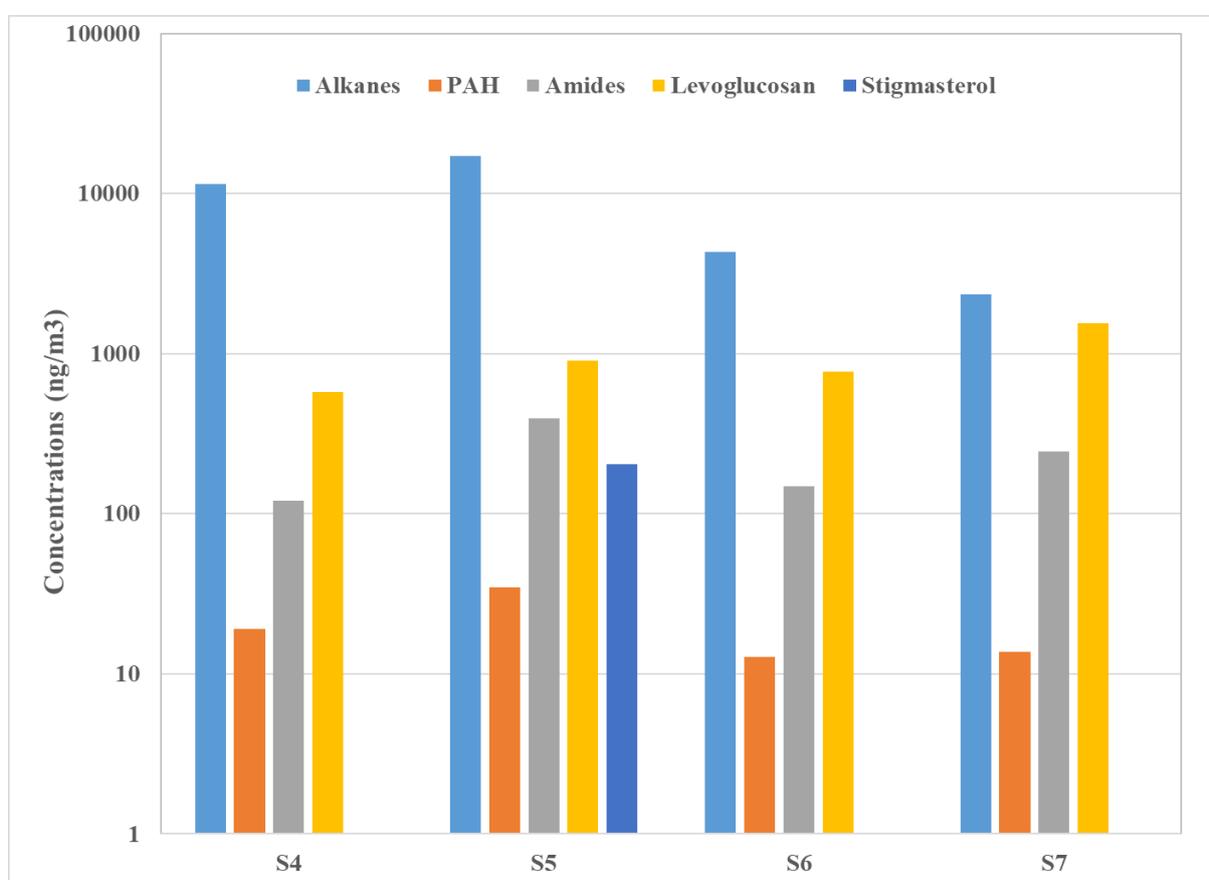


Figure 16: The seasonal mean concentrations of molecular marker species in PM_{2.5} (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Angul region during the winter season sampling period (December 7-26, 2021).

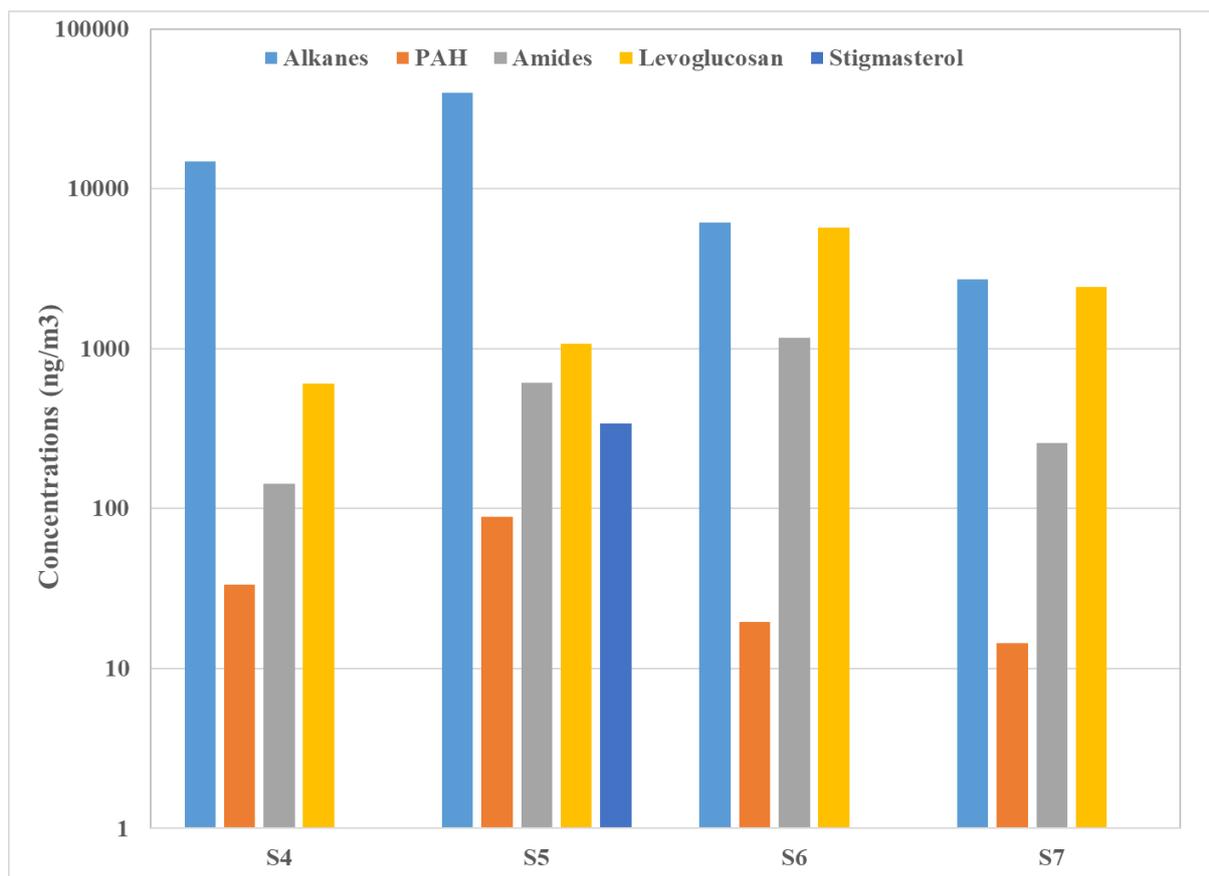


Figure 17: The seasonal mean concentrations of molecular marker species in PM₁₀ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Angul region during the winter season sampling period (December 7-26, 2021).

2.6.1.7. Gaseous pollutants and VOCs

Fig. 18, represents the seasonal mean concentrations of gaseous pollutants i.e. SO₂ and NO₂ observed at four sampling locations in Angul region, during the winter season sampling period i.e. December 7-26, 2021.

The winter season mean concentrations of SO₂ are observed to be 45.3 µg/m³ at Govt. College, Angul (S4), 39.7 µg/m³ at NALCO CISF Headquarters (S5), 26.1 µg/m³ at Galapada (S6) and 21.7 µg/m³ at Gudiakatani (S7). Similarly, the winter season mean concentrations of NO₂ are observed to be 18.8 µg/m³ at Govt. College, Angul (S4), 24.4 µg/m³ at NALCO CISF Headquarters (S5), 20.9 µg/m³ at Galapada (S6) and 22.6 µg/m³ at Gudiakatani (S7).

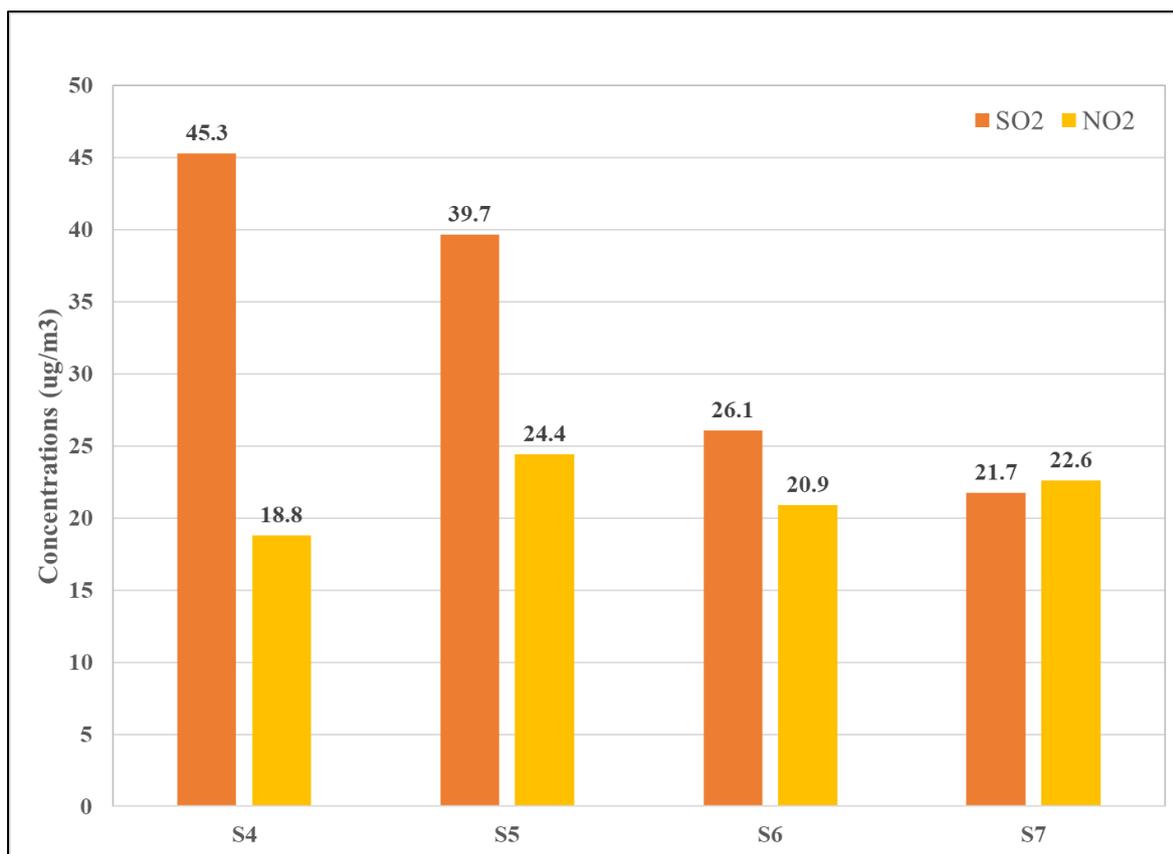


Figure 18: The seasonal mean concentrations of SO₂ and NO₂ observed at four sampling sites in Angul region during the winter season sampling period (December 7-26, 2021).

Fig. 19, represents the seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX), observed at four sampling locations in Angul region, during the winter season sampling period i.e. December 7-26, 2021. The winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites range from 1.3 to 3.8 ng/m³, 3.8 to 15.9 ng/m³, 4.3 to 45.5 ng/m³ and 6.0 to 67.3 ng/m³, respectively. In general, the lowest concentrations were observed at Galapada (S6) while the highest concentrations were observed at Govt. College, Angul (S4). 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.

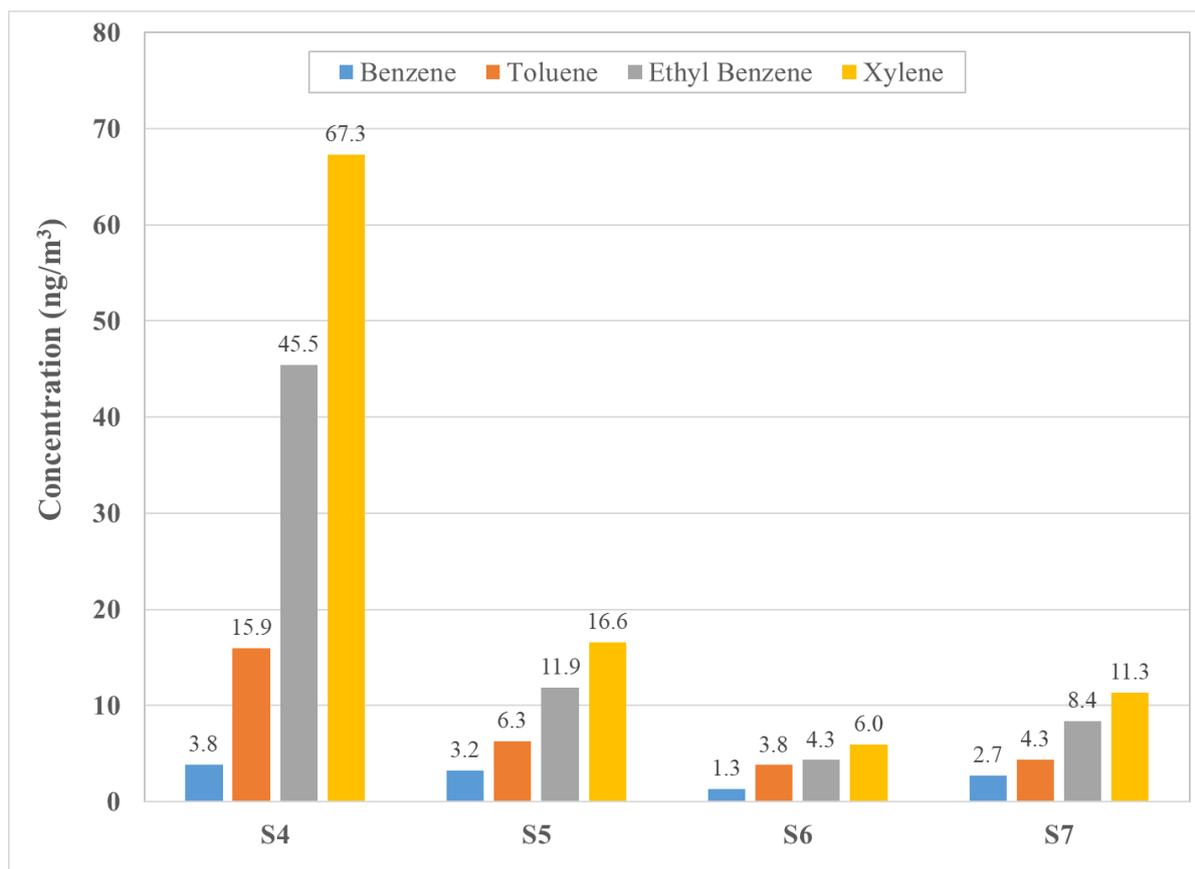


Figure 19: The seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) observed at four sampling sites in Angul region during the winter season sampling period (December 7-26, 2021).

2.6.2. Summer season

2.6.2.1. PM mass concentrations

Fig. 20, presents the distribution of daily PM_{2.5} and PM₁₀ concentrations observed at four sampling locations in Angul region during the summer season i.e. May 21 – June 7, 2022. The mean PM_{2.5} and PM₁₀ mass concentrations during the entire sampling period over all sites were 33.3 and 107.2 µg/m³, respectively. The daily mean PM_{2.5} concentrations exhibited a 5-fold range and ranged from a minimum of 15.7 µg/m³ (at Gudiakatani i.e. S7) to a maximum of 83.9 µg/m³ (at NALCO CISF headquarters i.e. S5). Similarly, the mean PM₁₀ concentrations exhibited a 4-fold range and ranged from 58.3 µg/m³ (at Gudiakatani i.e. S7) to 226.5 µg/m³ (at NALCO CISF headquarters i.e. S5). The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 µg/m³ for PM_{2.5} and PM₁₀, respectively. The summer-time PM_{2.5} concentrations were observed to comply with the daily NAAQS limit at all sites, with only single day exceedance at NALCO

CISF headquarters i.e. S5. The daily averaged PM₁₀ concentrations exceeded the NAAQS limit at all sites (31-67% of sampling days) with minimum exceedance at Gudiakateni i.e. S7 (31%) and maximum exceedance at NALCO CISF headquarters i.e. S5 (67% of sampling days) during summer season.

2.6.2.2. Spatial variability

The highest seasonal mean PM_{2.5} concentrations were observed at NALCO CISF headquarters i.e. S5 (39.8 µg/m³) while the lowest were recorded at Gudiakateni i.e. S7 (25.5 µg/m³). 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 24.3 to 83.9 µg/m³ at NALCO CISF headquarters i.e. S5 while it ranged from 15.7 to 38.2 µg/m³ at Gudiakateni i.e. S7.

The highest seasonal mean PM₁₀ concentrations were observed at NALCO CISF headquarters i.e. S5 (129.0 µg/m³) while the lowest were recorded at Gudiakateni i.e. S7 (92.7 µg/m³). The daily PM₁₀ concentrations showed highest and lowest variability at NALCO CISF headquarters i.e. S5 and Govt. College, Angul i.e. S4 sites, respectively. For example, daily PM₁₀ concentrations ranged from a minimum of 73.8 to a maximum of 226.5 µg/m³ at NALCO CISF headquarters i.e. S5 while it ranged between 67.3 and 125.6 µg/m³ at Govt. College, Angul i.e. S4.

These concentration levels can be attributed to air polluting activities around each site. For example, NALCO CISF headquarters i.e. S5 is located in the Industrial area of NALCO. 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.

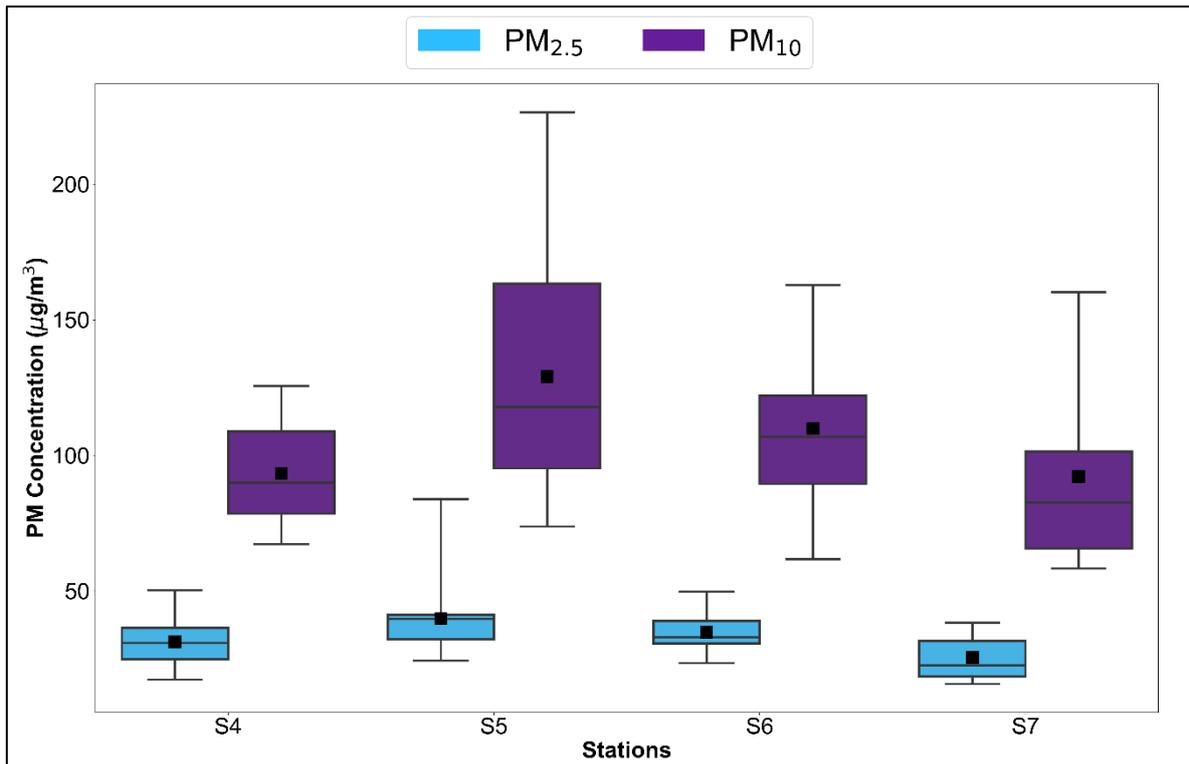


Figure 20 Boxplot showing distribution of daily PM_{2.5} (blue colored boxes) and PM₁₀ (violet colored boxes) concentrations observed at four sampling sites in Angul region during the summer season sampling period (May 21 – June 7, 2022).

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 PM₁₀ observed at four selected sampling locations in Angul region during the summer season sampling period. Only valid samples between May 21 and June 7, 2022 are considered for this analysis. Overall, the PM concentrations did not any significant trend from May 21 to June 7, 2022 at all sites. This could be attributed to the unstable meteorological conditions over Angul region during the summer season.

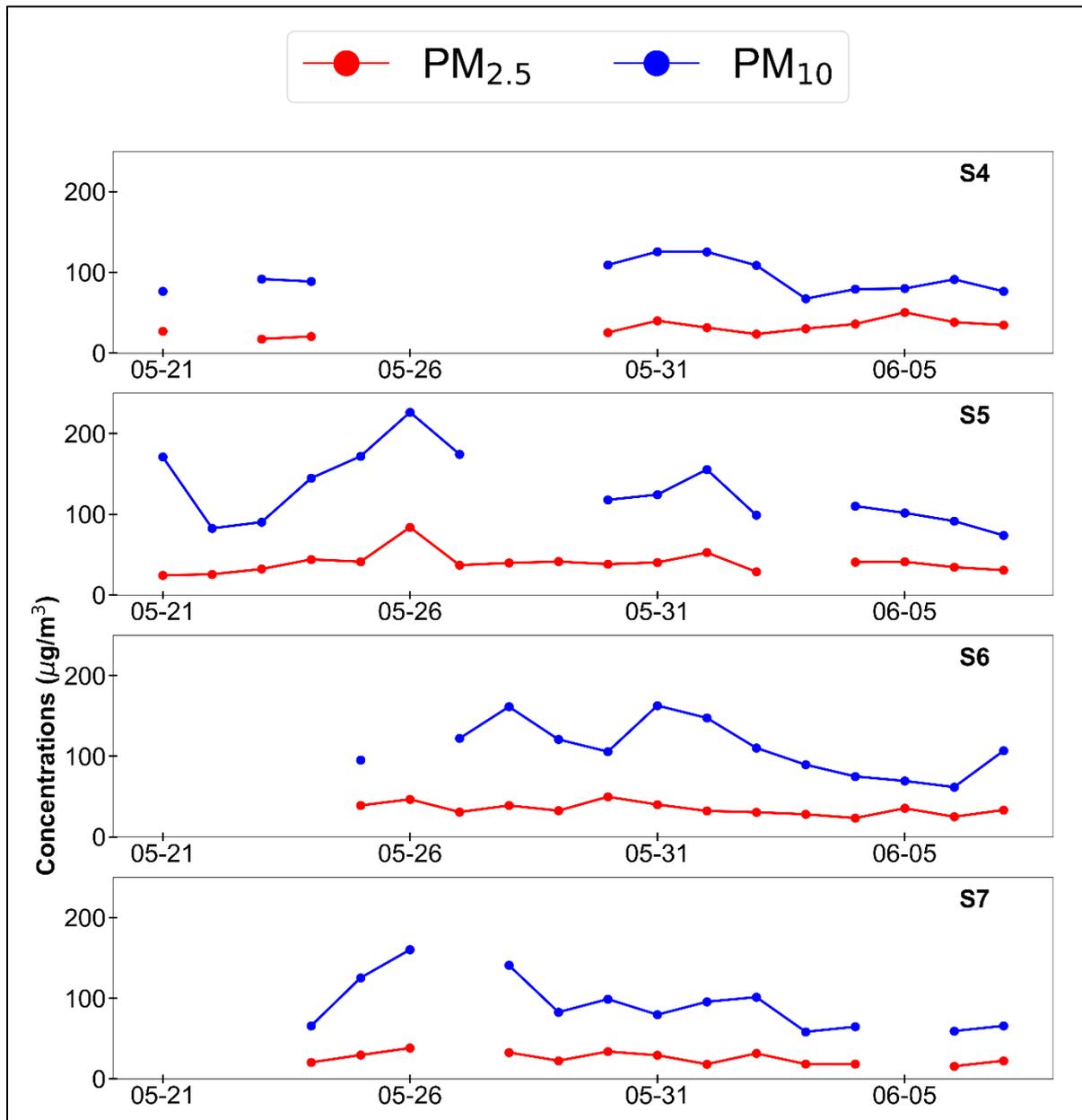


Figure 21 Daily time-series of PM_{2.5} (red) and PM₁₀ (blue) concentrations observed at four sites in Angul region during the summer season sampling (May 21 – June 7, 2022)

2.6.2.4. PM_{2.5} to PM₁₀ ratios

Fig. 22 shows distribution of daily PM_{2.5} to PM₁₀ ratios observed at four sampling sites during the summer season. The mean value of PM_{2.5} to PM₁₀ ratios during the summer season over all sites was found to be 0.32, varying from 0.29 to 0.35. The highest summer season mean PM_{2.5} to PM₁₀ ratio was observed at Govt. College, Angul i.e. S4 (0.35) while the lowest was observed at Gudiakatani i.e. S7 (0.29). 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.

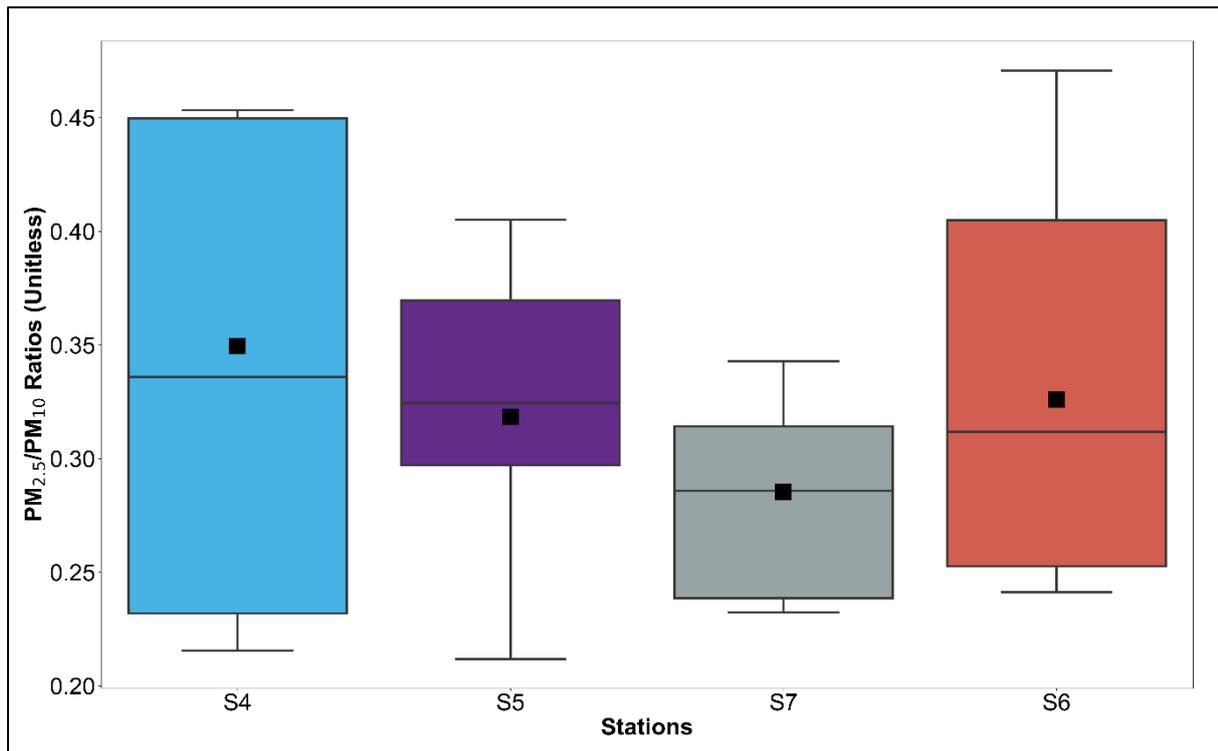


Figure 22 Boxplot showing distribution of PM_{2.5} to PM₁₀ ratios at four sampling sites in Angul region during the winter season (May 21 – June 7, 2022)

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 PM₁₀

2.6.2.5.1. Site 4: Govt. College, Angul (S4)

Fig. 23 shows the frequency distribution of different species observed in PM_{2.5} and PM₁₀ at Govt. College, Angul i.e. S4 in Angul region during the summer season. OC in PM_{2.5} and OC, EC, and SO₄²⁻ in PM₁₀ are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m³. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

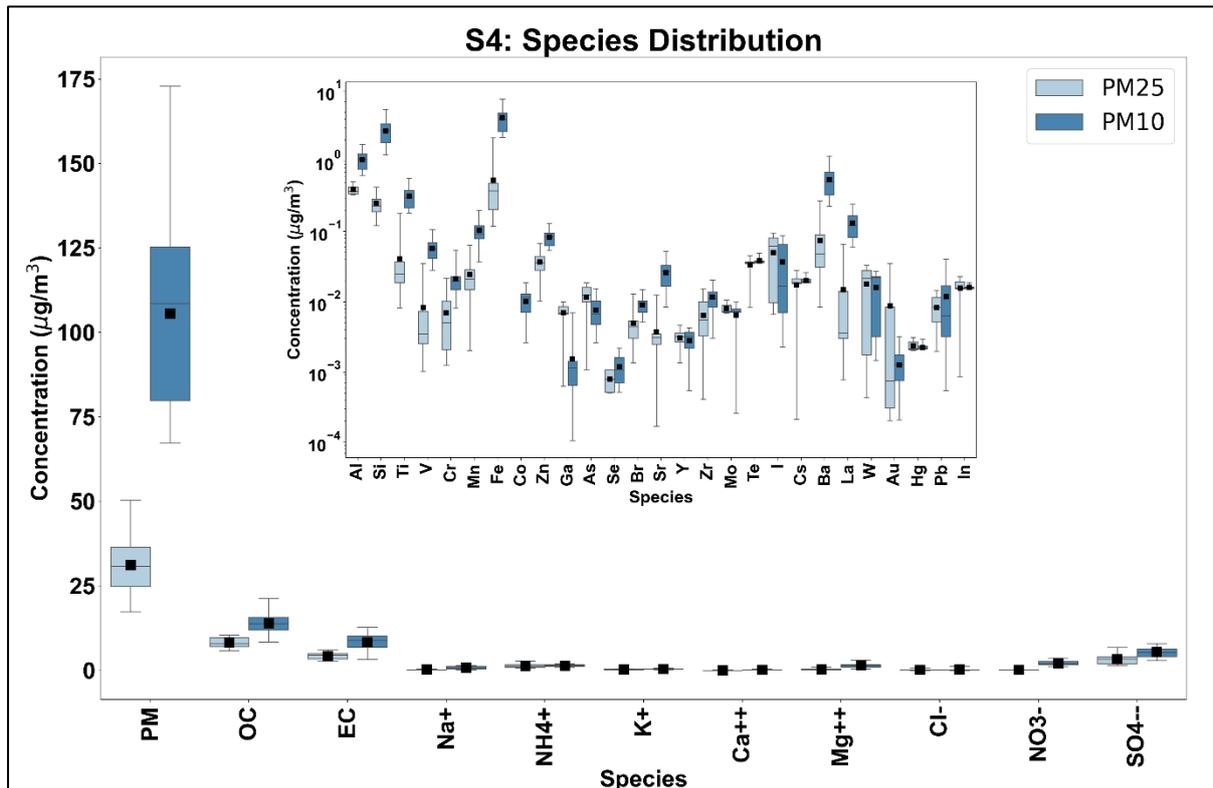


Figure 23 Box plots showing distribution of different species observed in PM_{2.5} and PM₁₀ at Govt. College, Angul (S4) in Angul region during the summer season

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 5: NALCO CISF headquarters (S5)

Fig. 24 shows the frequency distribution of chemical constituents carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , NO_3^- , and SO_4^{--}) 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 $\text{PM}_{2.5}$ and PM_{10} observed at NALCO CISF HQ Site (S5) during summer season (May 21 – June 7, 2022). OC and EC in $\text{PM}_{2.5}$ and OC, EC and Fe in PM_{10} are the most abundant species having seasonal mean concentrations greater than $5.0 \mu\text{g}/\text{m}^3$. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

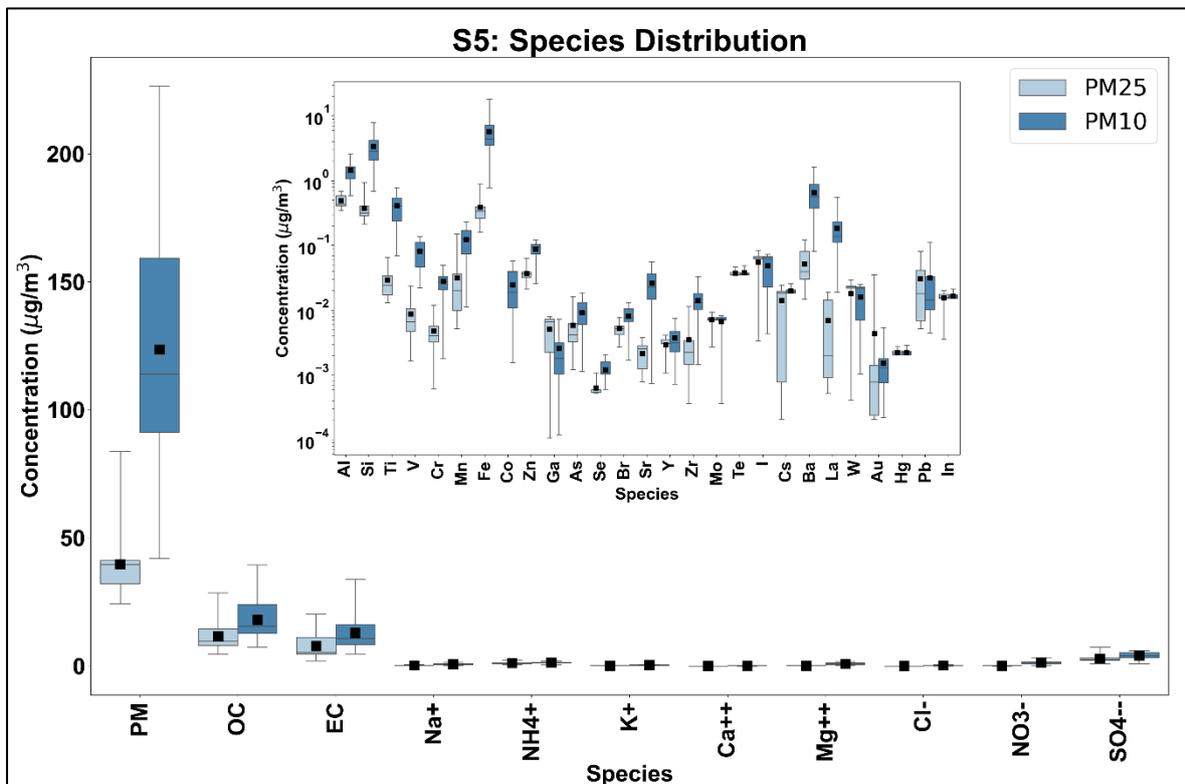


Figure 24 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at NALCO CISF headquarters (S5) in Angul region during the summer season

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 6: Galapada (S6)

Fig. 25 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , NO_3^- , and SO_4^{--}) 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 $\text{PM}_{2.5}$ and PM_{10} observed at Galapada site (S6) during summer season (May 21 – June 7, 2022). OC and SO_4^{--} in $\text{PM}_{2.5}$ and OC, EC, and SO_4^{--} in PM_{10} are the most abundant species having seasonal mean concentrations greater than $5.0 \mu\text{g}/\text{m}^3$. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

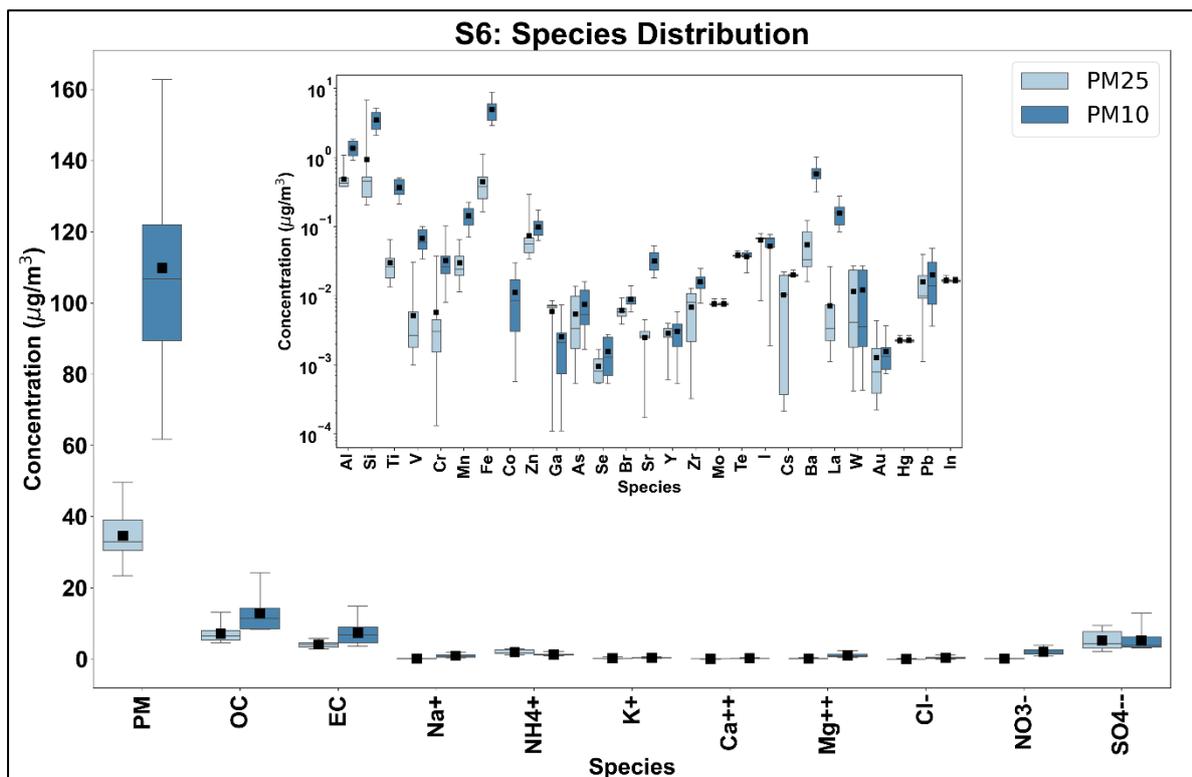


Figure 25 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at Galapada (S6) in Angul region during the summer season

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 7: Gudiakatani (S7)

Fig. 26 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na⁺, NH₄⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, NO₃⁻, and SO₄²⁻) 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 PM₁₀ observed at Gudiakatani site (S7) during summer season (May 21 – June 7, 2022). OC in PM_{2.5} and OC and SO₄²⁻ in PM₁₀ are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m³. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

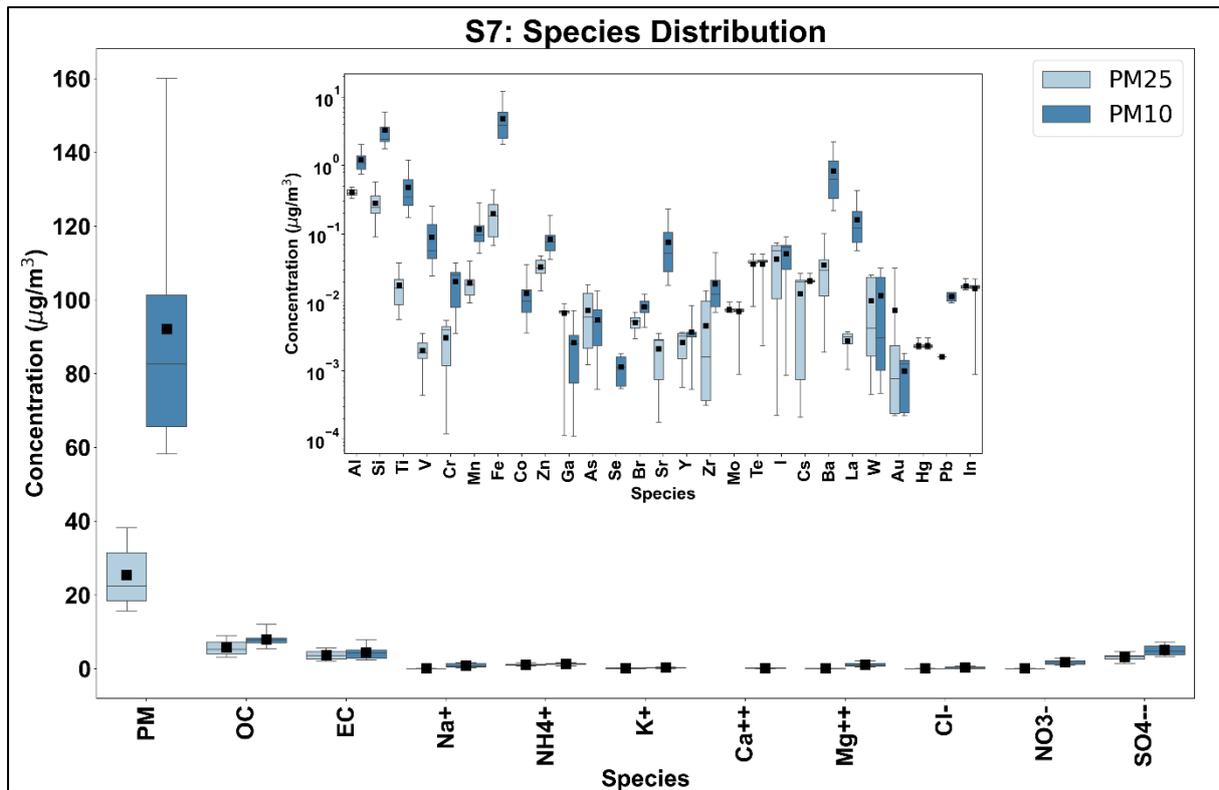


Figure 26 Box plots showing distribution of different species observed in PM_{2.5} and PM₁₀ at Gudiakatani (S7) in Angul region during the summer season

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 PM₁₀

Fig. 27 and 28, represents the seasonal mean concentrations of molecular markers observed at four sampling locations in Angul region, during the summer season sampling period i.e. May 21 -June 7, 2022. Levoglucosan, a biomass burning tracer (CPCB, 2010), is found to dominate the molecular markers mass, during the summer season in Angul region. Apart from Levoglucosan, Alkanes, and Amides are also detected in trace amounts, in PM samples collected over Angul region during summer season. The summer-season concentrations of molecular markers over Angul region, is significantly lower compared to winter season, indicating the dominance of biomass burning emissions in winter season.

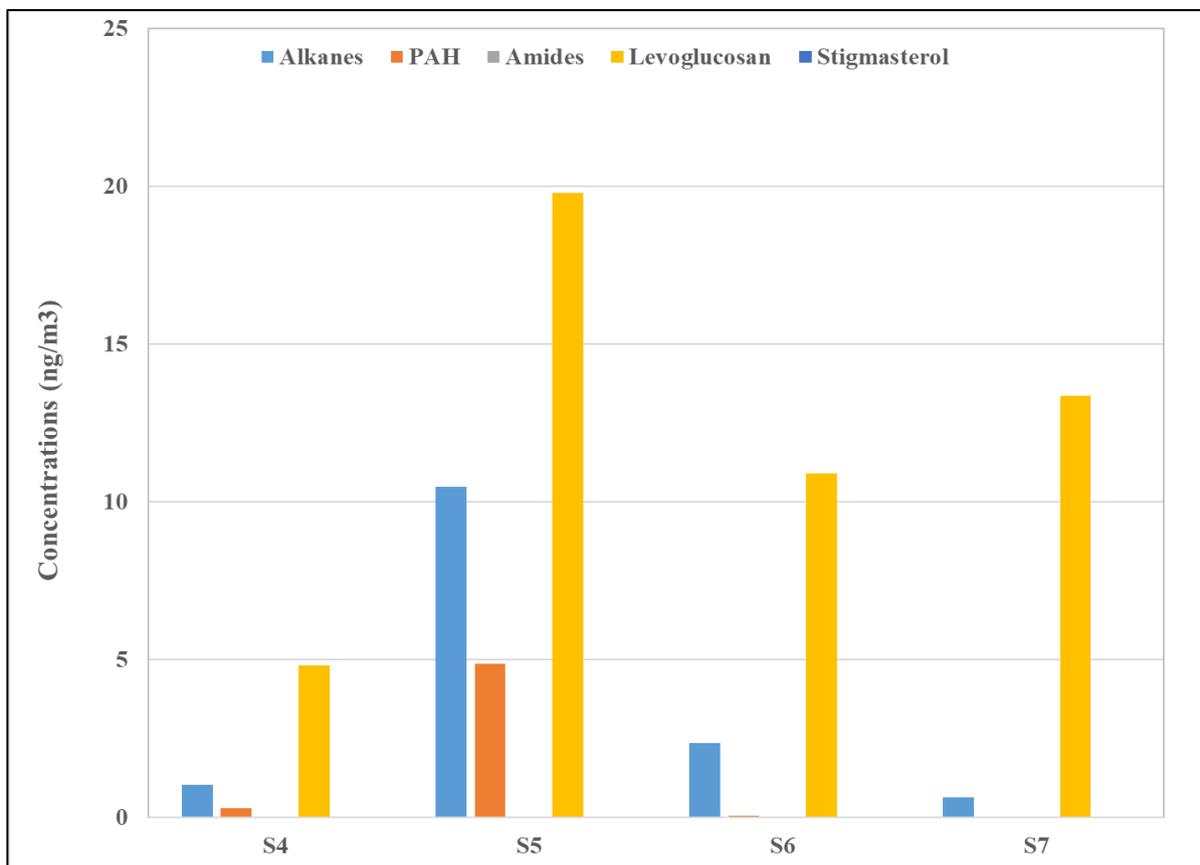


Figure 27: The seasonal mean concentrations of molecular marker species in PM_{2.5} (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Angul region during the summer season sampling period (May 21 -June 7, 2022).

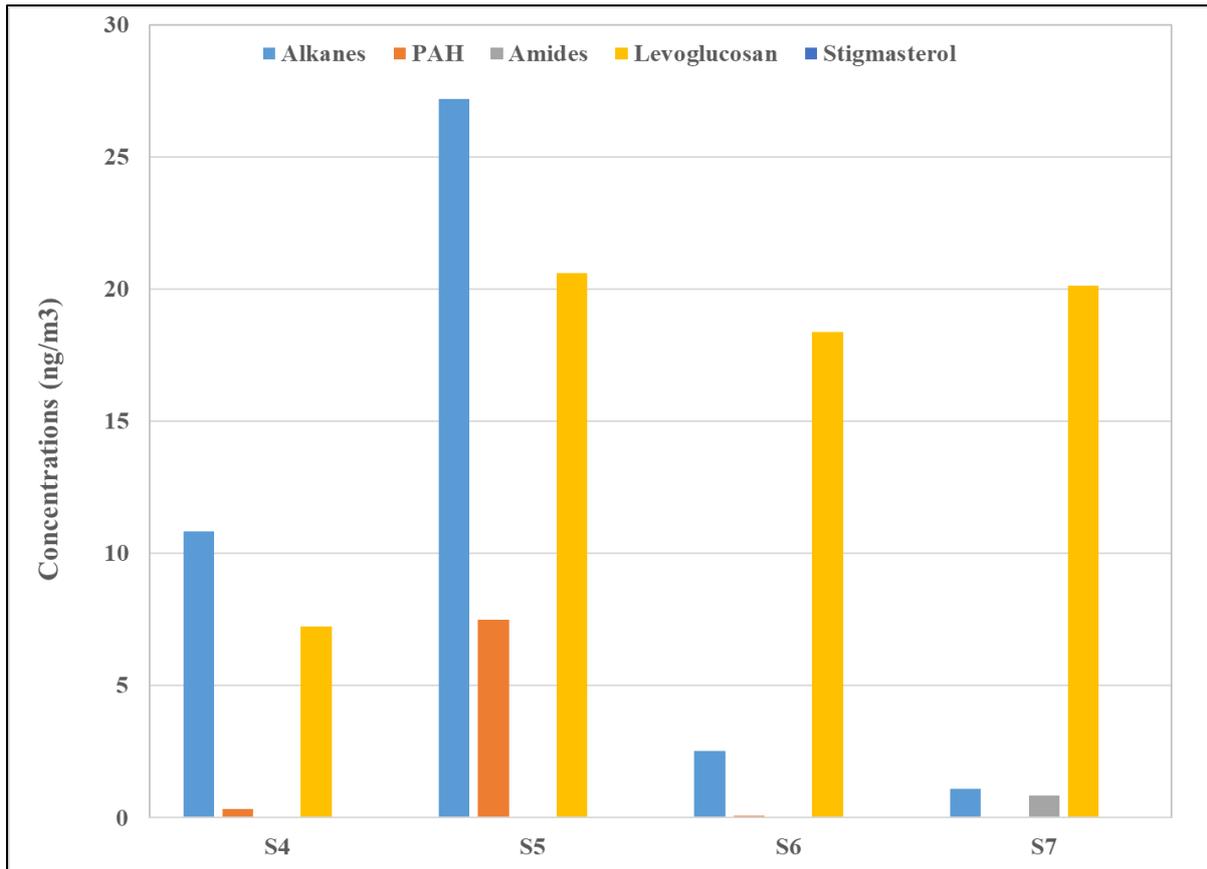


Figure 28: The seasonal mean concentrations of molecular marker species in PM₁₀ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at four sampling sites in Angul region during the summer season sampling period (May 21 -June 7, 2022).

2.7. Mass reconstruction of Particulate Matter (PM_{2.5} and PM₁₀)

2.7.1. Validation of mass reconstruction methodology

As discussed in section 2.6.1.1, PM_{2.5} and PM₁₀ 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 0.85 (winter) and 0.70 (summer) for PM_{2.5} whereas it is found to be 0.72 (winter) and 0.96 (summer) for PM₁₀, 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).

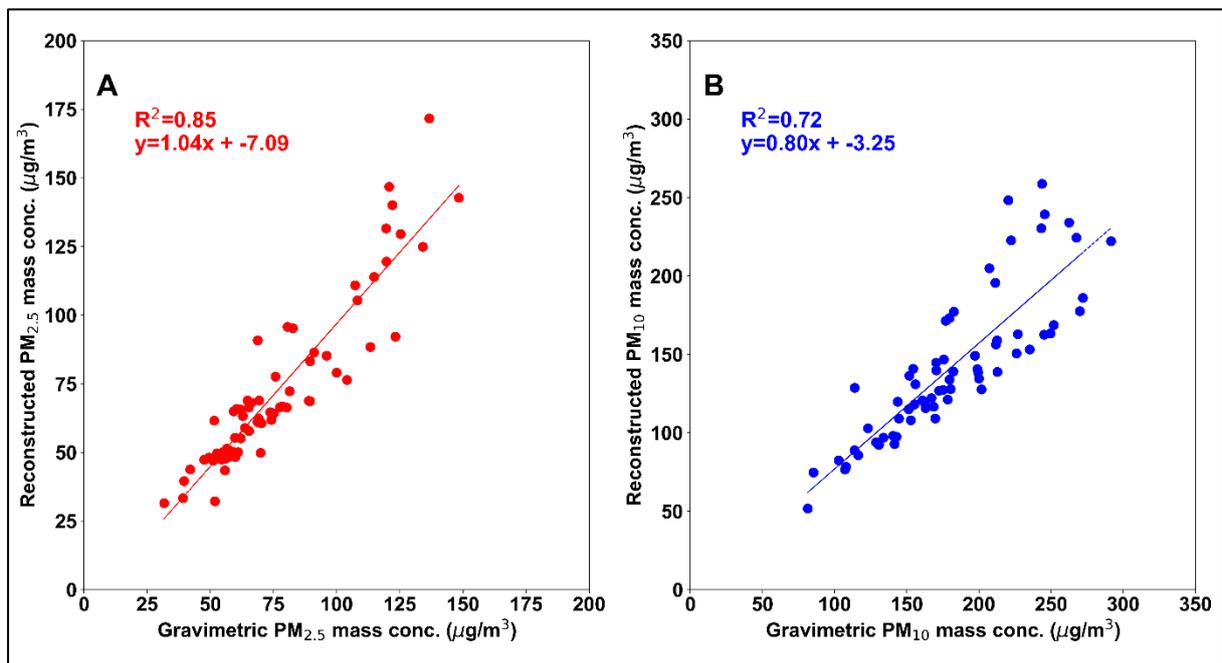


Figure 29 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) PM_{2.5} and (B) PM₁₀ in Angul region during the winter season sampling period (Dec 07-26, 2021)

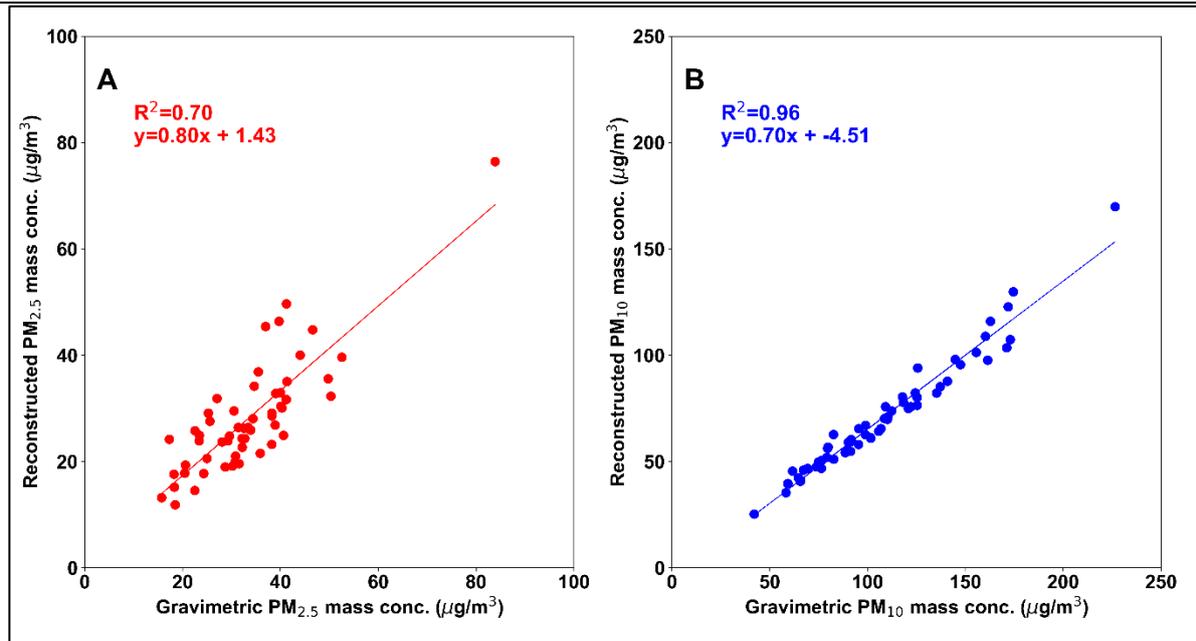


Figure 30 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) PM_{2.5} and (B) PM₁₀ in Angul region during the summer season sampling period (May 21 - Jun 7, 2022)

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 PM₁₀ during the winter season at four sampling locations in Angul 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 PM₁₀.

The Organic mass (OM) was the most abundant component in PM_{2.5} during the winter season, with seasonal mean contribution ranging from 35.9 to 62.8% in PM_{2.5} and 20.0 to 47.5% in PM₁₀. The seasonal mean OM concentrations among the four sites in the winter season ranged from 22.7 to 68.3 µg/m³ in PM_{2.5} while it ranged from 34.2 to 99.4 µg/m³ in PM₁₀.

Secondary inorganic aerosols, represented as SNA, are the second major component observed in PM_{2.5} and PM₁₀ fractions during the winter season in Angul region. The seasonal mean contributions from SNA varied from 16.5 to 30.7% in PM_{2.5} while it varied from 13.1 to 23.3% in PM₁₀. The seasonal mean SNA concentrations among the four sites ranged from 18.0 to 22.1 µg/m³ in PM_{2.5} whereas it ranged from 27.3 to 41.8 µg/m³ in PM₁₀. 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 SO₂ and NO_x to sulfate and nitrate particles.

Crustal Mass (CM) is the most important contributor to coarse fraction i.e. PM₁₀ during winter season, besides OM and SNA. The seasonal mean contributions from CM varied from 1.8 to 3.5% in PM_{2.5} while it varied from 12.7 to 23.8% in PM₁₀. The seasonal mean CM concentrations in PM₁₀ varied from a minimum of 23.1 to 39.0 µg/m³ in PM₁₀. In contrast, the CM concentrations in fine fraction i.e. PM_{2.5} were relatively lower and ranged from 1.9 to 2.7 µg/m³.

The seasonal mean contributions from EC ranged between 11.2 and 24.3% in PM_{2.5} while it ranged between 7.9 and 19.1% in PM₁₀. The seasonal mean elemental carbon (EC) concentrations during winter season varied from 8.5 to 26.4 µg/m³ in PM_{2.5} whereas it ranged from 13.0 to 40.0 µg/m³ in PM₁₀.

Trace elements (TE) also form an important part of the reconstructed mass in coarse fraction i.e. PM₁₀ during the winter season, with contributions ranging from 1.4 to 2.6%. The seasonal

mean TE concentrations ranged from 1.0 to 1.4 $\mu\text{g}/\text{m}^3$ and 2.9 to 4.4 $\mu\text{g}/\text{m}^3$ in $\text{PM}_{2.5}$ and PM_{10} , respectively.

The Sea salt (SS) represented by a sum of Na^+ and Cl^- ions, are the minor contributors to $\text{PM}_{2.5}$ and PM_{10} masses during the winter season over Angul, with contributions ranging from 0.8 to 1.2%. The seasonal mean SS concentrations ranged from 0.7 to 1.3 $\mu\text{g}/\text{m}^3$ in $\text{PM}_{2.5}$ while it ranged from 1.1 to 1.7 $\mu\text{g}/\text{m}^3$ in PM_{10} .

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

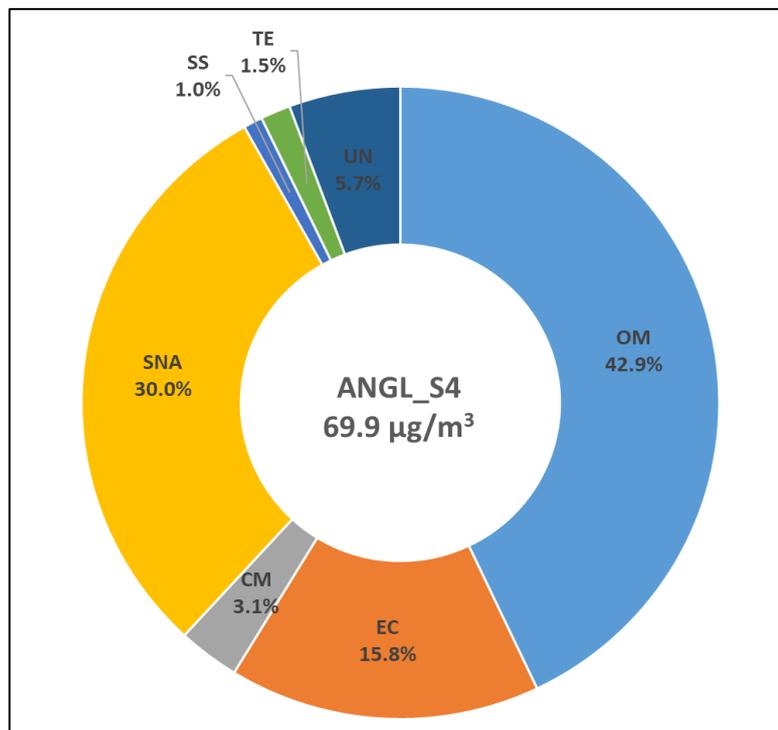


Figure 31: The reconstructed mass of $\text{PM}_{2.5}$ at S4 i.e. Govt. College, Angul in Angul region during the winter season

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.

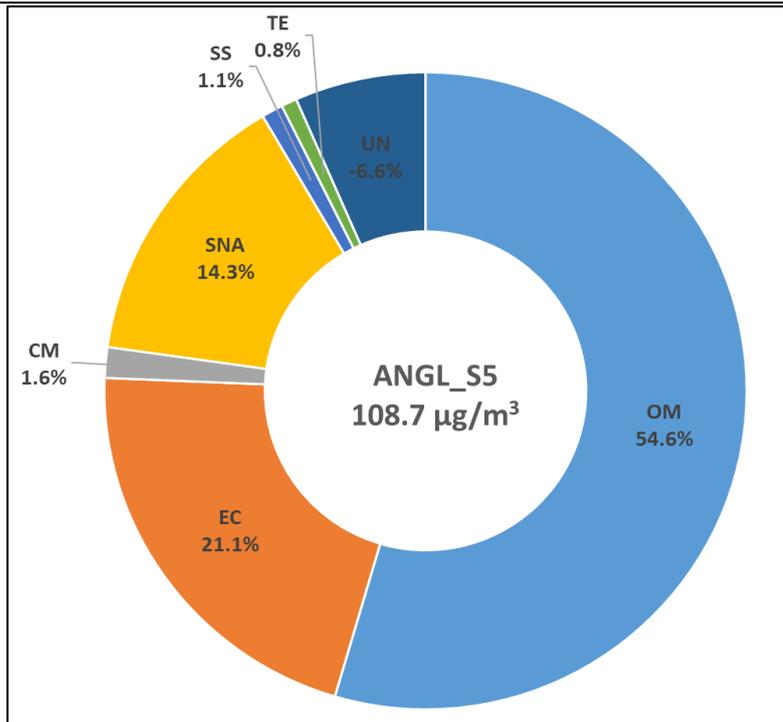


Figure 32: The reconstructed mass of PM_{2.5} at S5 i.e. NALCO CISF headquarters in Angul region during the winter season

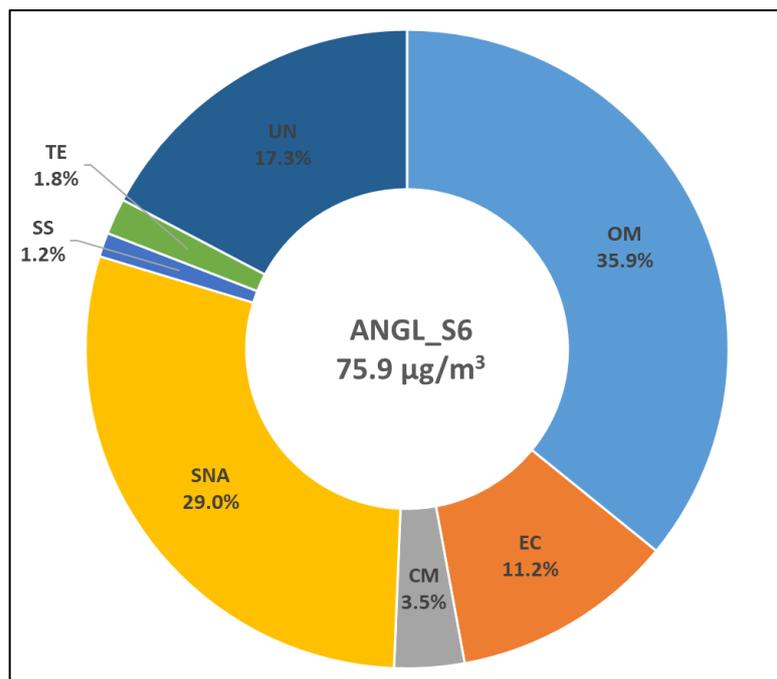


Figure 33: The reconstructed mass of PM_{2.5} at S6 i.e. Galapada in Angul region during the winter season

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.

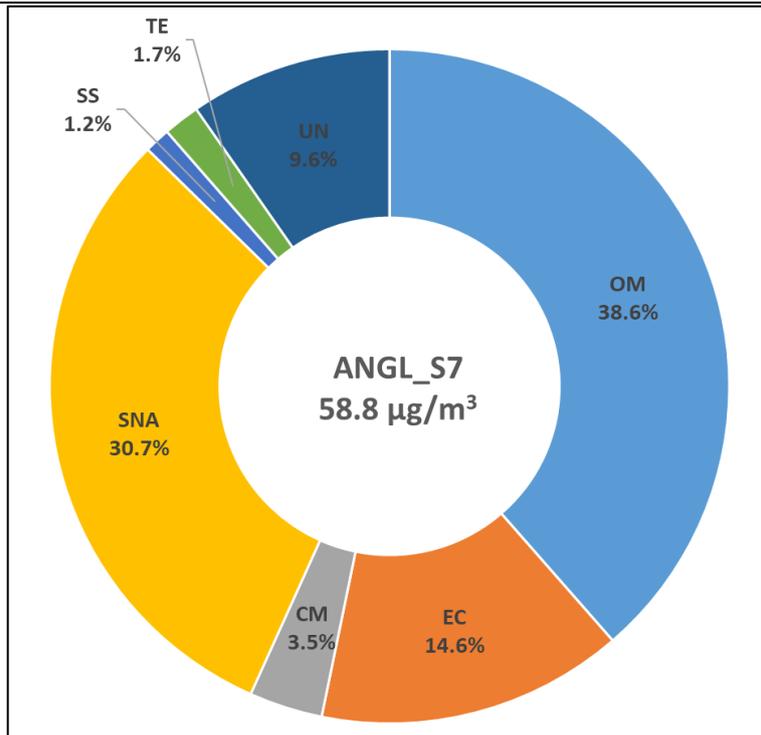


Figure 34: The reconstructed mass of PM_{2.5} at S7 i.e. Gudiakateni in Angul region during the winter season

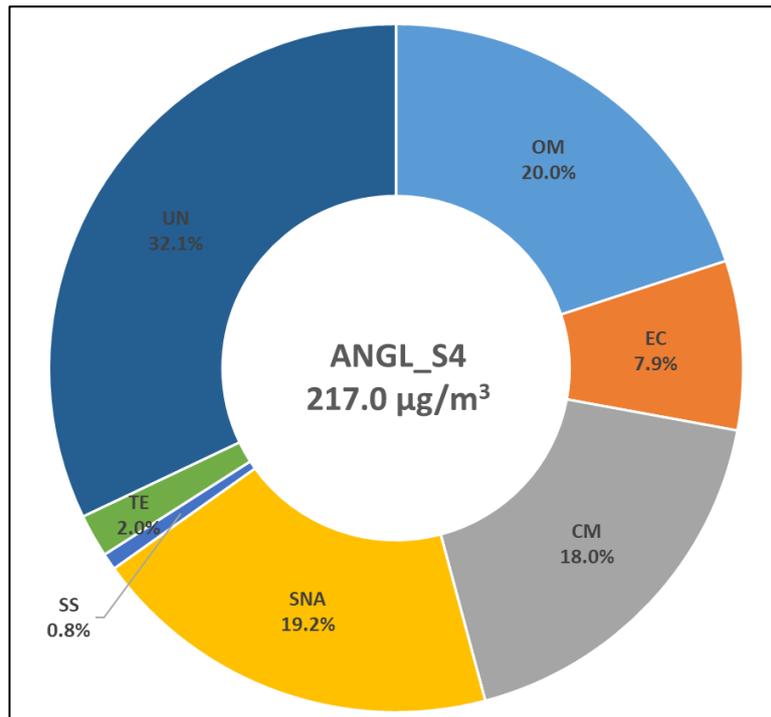


Figure 35: The reconstructed mass of PM₁₀ at S4 i.e. Govt. College, Angul in Angul region during the winter season

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.

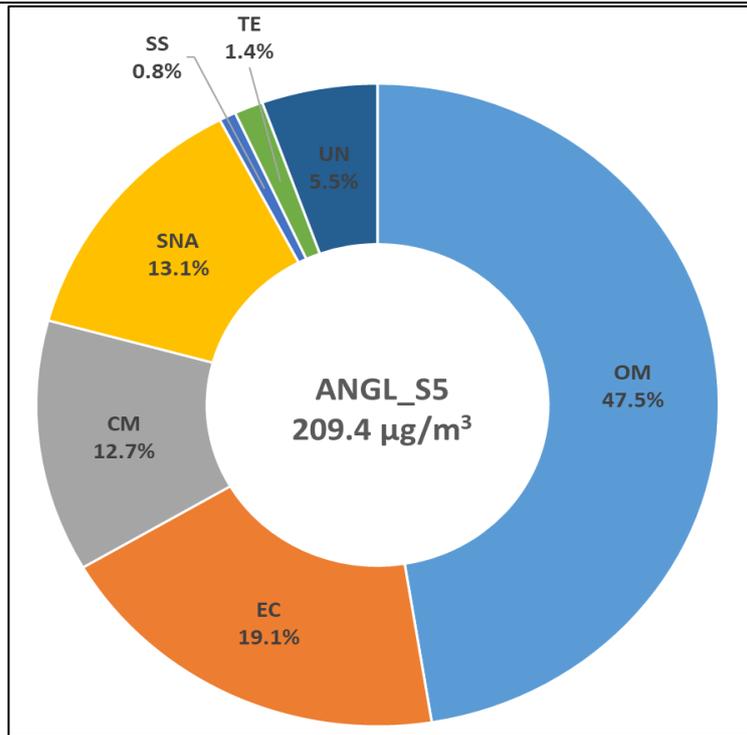


Figure 36: The reconstructed mass of PM₁₀ at S5 i.e. NALCO CISF headquarters in Angul region during the winter season

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

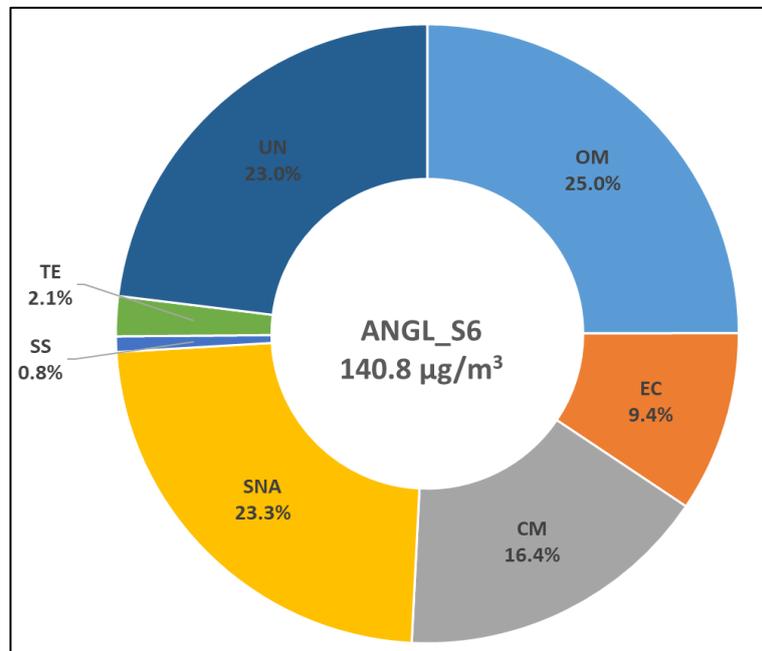


Figure 37: The reconstructed mass of PM₁₀ at S6 i.e. Galapada in Angul region during the winter season

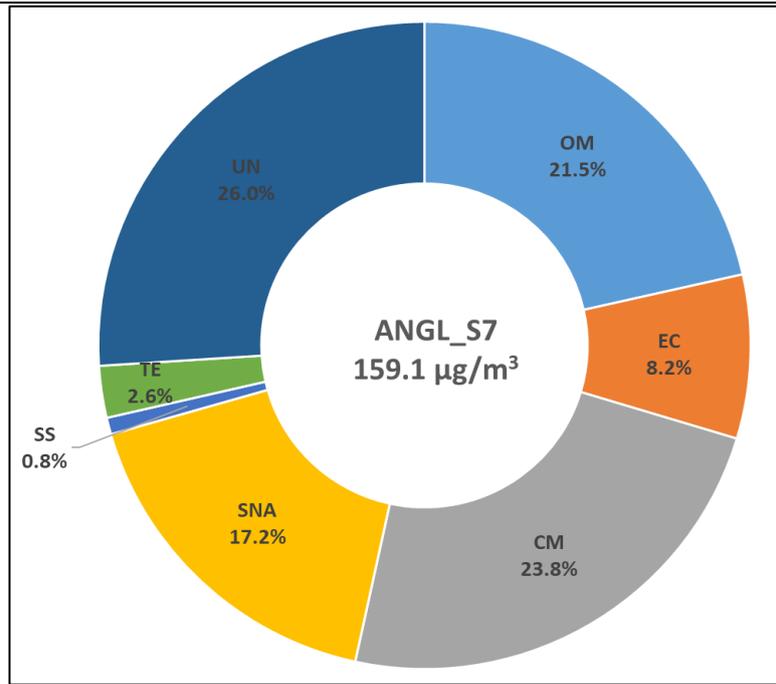


Figure 38: The reconstructed mass of PM₁₀ at S7 i.e. Gudiakateni in Angul region during the winter season

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 PM₁₀ during the summer season at four sampling locations in Angul 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 > CM > SNA > EC > TE > SS in PM₁₀.

The Organic mass (OM) was the most abundant component in both PM_{2.5} and PM₁₀ during the summer season, with seasonal mean contribution of 25.1 to 31.2% in PM_{2.5} and 13.9 to 23.4%. The seasonal mean OM concentrations in the summer season ranged from 9.3 to 18.4 µg/m³ in PM_{2.5} while it ranged from 12.8 to 28.9 µg/m³ in PM₁₀.

Crustal Mass (CM) is the second most important contributor to coarse fraction i.e. PM₁₀ during summer season. The seasonal mean contributions from CM varied from 7.7 to 13.2% in PM_{2.5} while it varied from 23.8 to 32.7% in PM₁₀. The seasonal mean CM concentrations in PM₁₀ varied from a minimum of 25.1 to 31.2 µg/m³ in PM₁₀. In contrast, the CM concentrations in fine fraction i.e. PM_{2.5} were relatively lower and ranged from 2.1 to 4.6 µg/m³.

Secondary inorganic aerosols, represented as SNA, is the third major component observed in PM_{2.5} and PM₁₀ fractions during the summer season in Angul region. The seasonal mean contributions from SNA varied from 10.6 to 21.4% in PM_{2.5} while it varied from 5.4 to 8.9% in PM₁₀. The seasonal mean SNA concentrations ranged from 4.2 to 7.4 µg/m³ in PM_{2.5} whereas it ranged from 6.7 to 9.1 µg/m³ in PM₁₀. The relative contributions indicate significant share of SNA in PM_{2.5} during the summer season.

The seasonal mean contributions from EC ranged between 11.9 and 19.5% in PM_{2.5} while it ranged between 4.9 and 10.5% in PM₁₀. The daily averaged elemental carbon (EC) concentrations during summer season varied from 3.7 to 7.7 µg/m³ in PM_{2.5} whereas it ranged from 4.5 to 13.0 µg/m³ in PM₁₀.

Trace elements (TE) form an important part of the reconstructed mass in coarse fraction i.e. PM₁₀ during the summer season, with contributions ranging from 2.4 to 3.0%. The seasonal mean TE concentrations ranged from 0.6 to 0.9 µg/m³ and 2.4 to 3.0 µg/m³ in PM_{2.5} and PM₁₀, respectively.

The Sea salt (SS) represented by a sum of Na⁺ and Cl⁻ ions, are the minor contributors to PM_{2.5} and PM₁₀ masses during the summer season over Angul region, with contributions ranging from 0.5 to 1.3%. The seasonal mean SS ranged from 0.1 to 0.4 µg/m³ in PM_{2.5} while it ranged from 0.9 to 1.3 µg/m³ in PM₁₀.

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

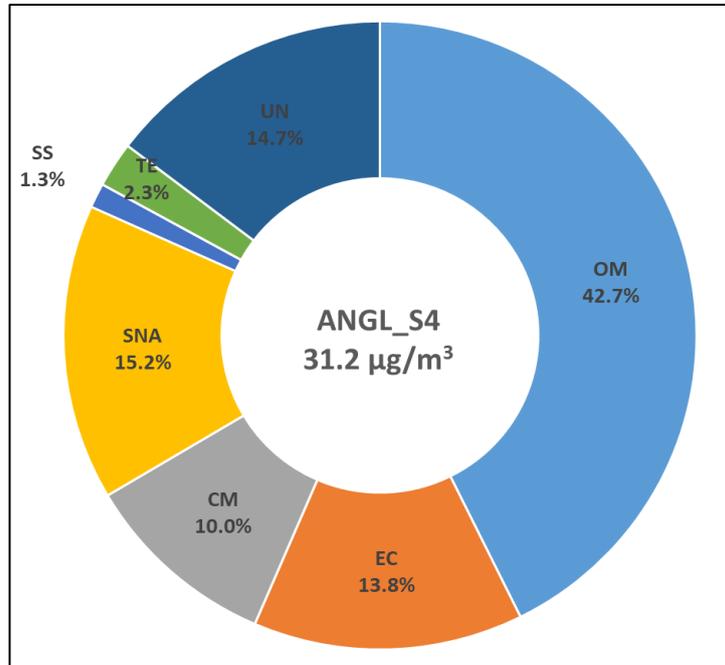


Figure 39: The reconstructed mass of PM_{2.5} at S4 i.e. Govt. College, Angul in Angul region during the summer season

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.

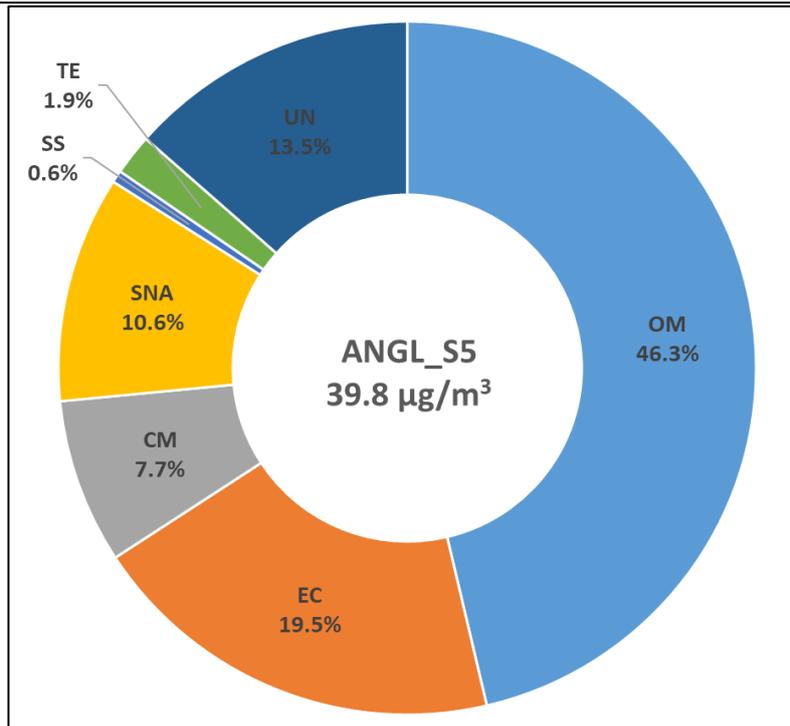


Figure 40: The reconstructed mass of PM_{2.5} at S5 i.e. NALCO CISF headquarters in Angul region during the summer season

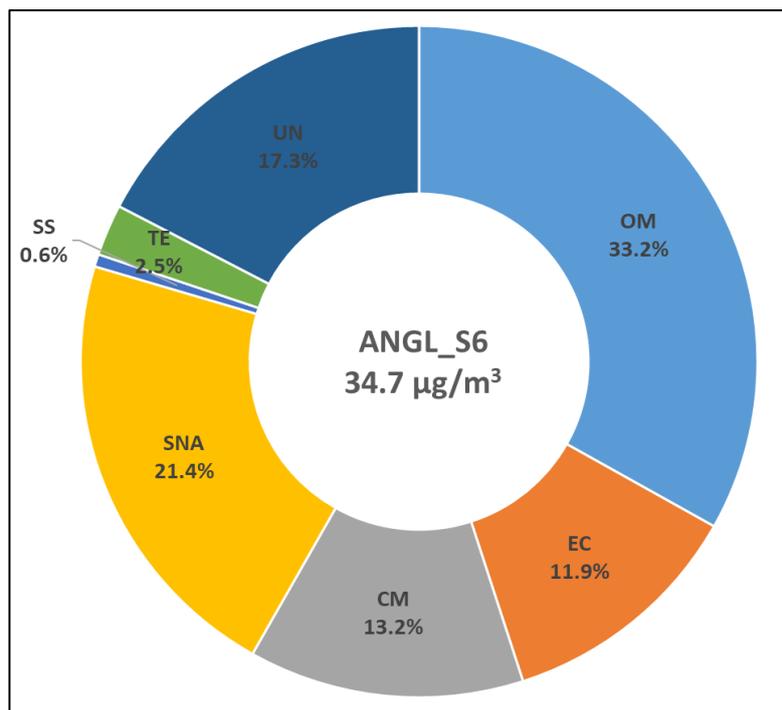


Figure 41: The reconstructed mass of PM_{2.5} at S6 i.e. Galapada in Angul region during the summer season

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.

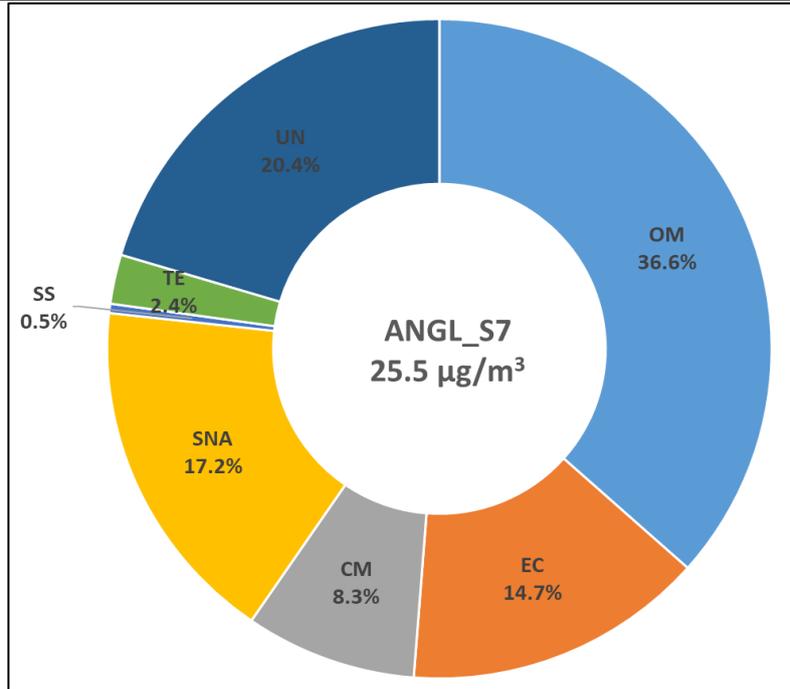


Figure 42: The reconstructed mass of PM_{2.5} at S7 i.e. Gudiakateni in Angul region during the summer season

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.

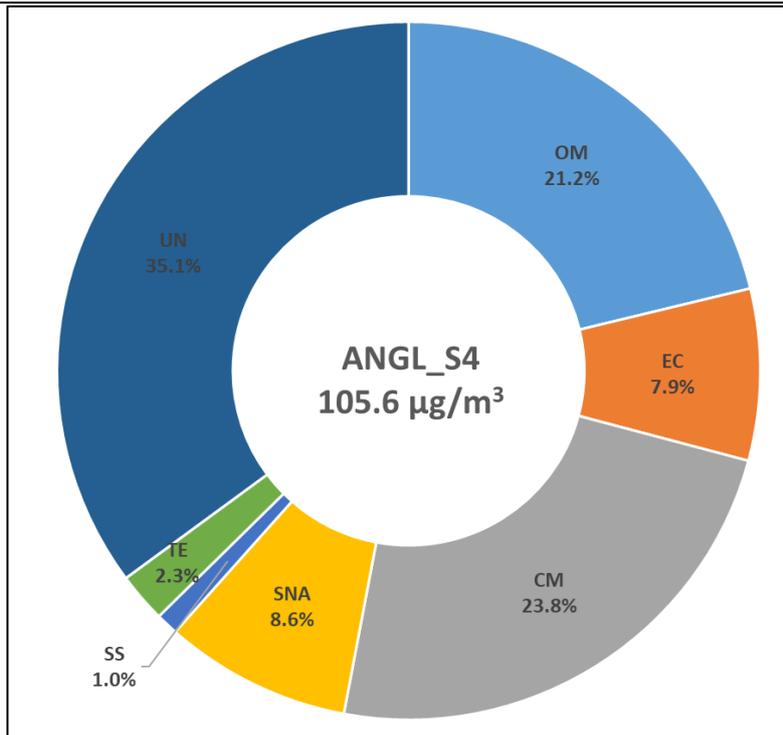


Figure 43: The reconstructed mass of PM₁₀ at S4 i.e. Govt. College, Angul in Angul region during the summer season

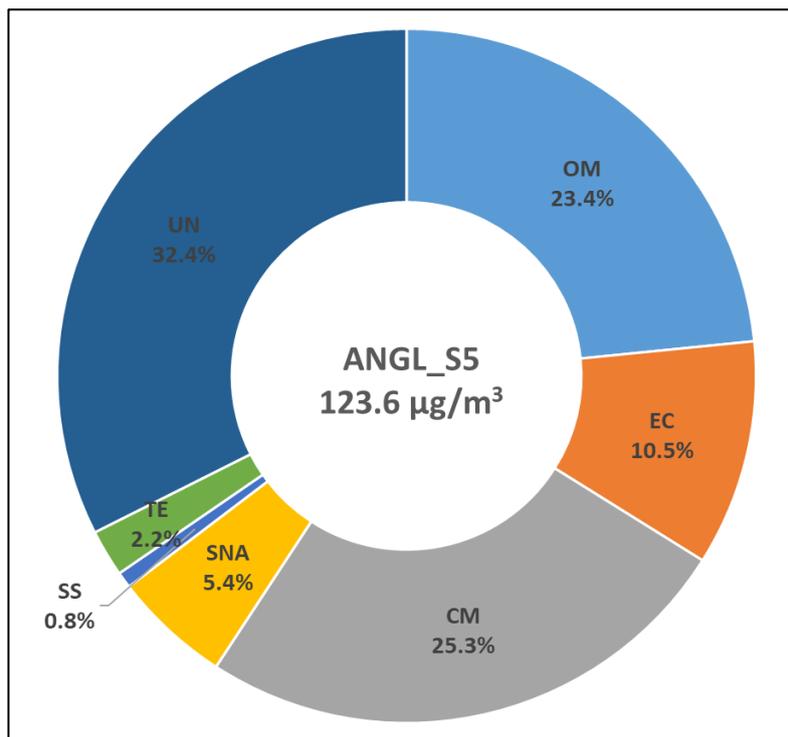


Figure 44: The reconstructed mass of PM₁₀ at S5 i.e. NALCO CISF headquarters in Angul region during the summer season

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.

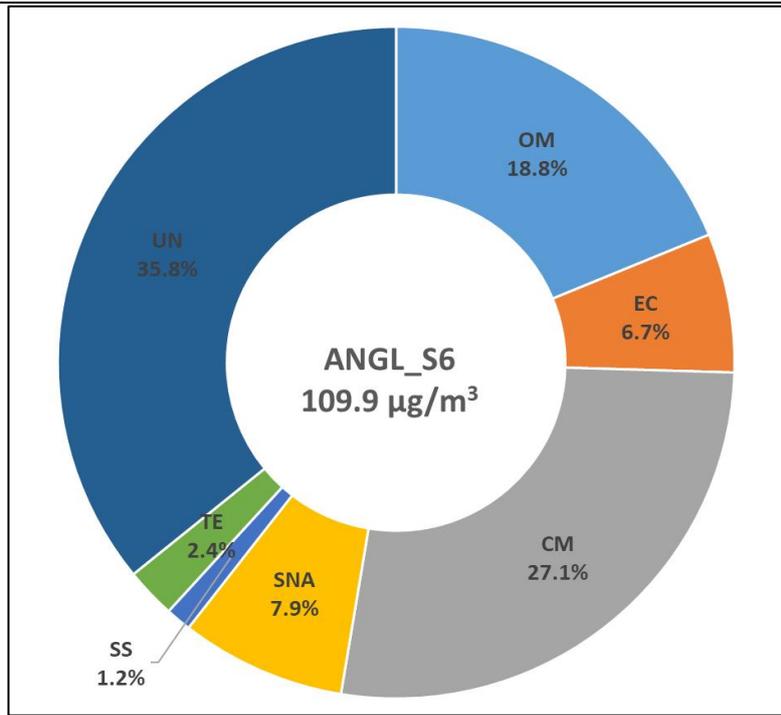


Figure 45: The reconstructed mass of PM₁₀ at S6 i.e. Galapada in Angul region during the summer season

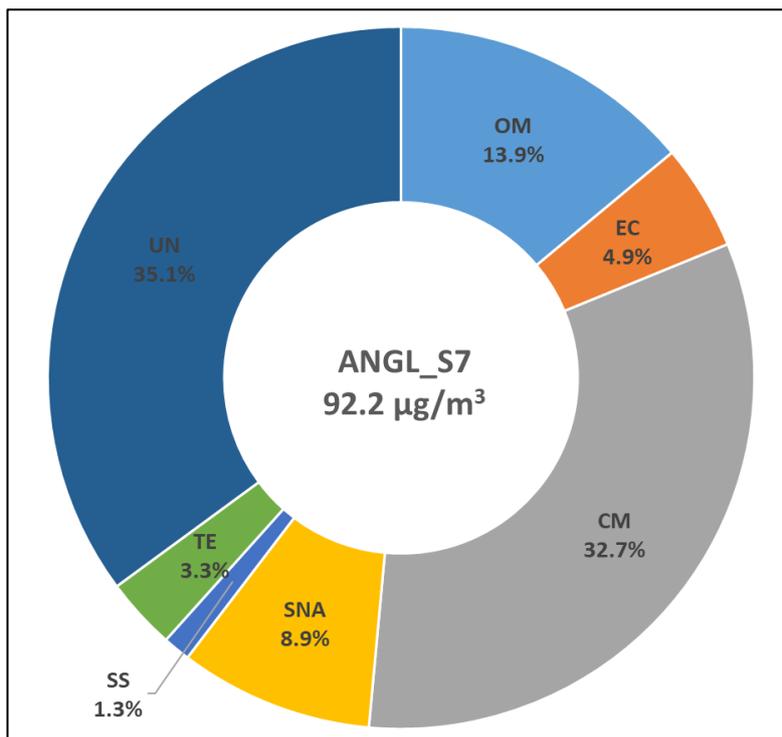


Figure 46: The reconstructed mass of PM₁₀ at S7 i.e. Gudiakateni in Angul region during the summer season

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 PM₁₀

The chemical ratios of OC/EC, Cl⁻/Na⁺, K⁺/OC, K⁺/EC, NO₃⁻/SO₄⁻ 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) NO₃⁻ to SO₄⁻ ratio, and vi) degree of neutralization (DON) in PM_{2.5} and PM₁₀ observed at four sampling locations in Angul 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 PM₁₀ at sampling sites implies their primary source signature (Srinivas and Sarin, 2014). A relatively lower OC/EC ratio at S5 i.e. NALCO CISF Headquarters, 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 0.07 in PM_{2.5} and PM₁₀. Similarly, K⁺/EC ratios ranged from 0.04 to 0.13 in PM_{2.5} and PM₁₀. The summer season K⁺/OC ratios ranged from 0.02 to 0.04 PM_{2.5} and PM₁₀. Similarly, K⁺/EC ratios ranged from 0.03 to 0.08 in PM_{2.5} and PM₁₀. These ratios suggest possibility of biomass burning in the region.

The NO₃⁻/SO₄⁻ 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 NO₃⁻/SO₄⁻ ratios varied from 0.12 to 0.22 in PM_{2.5} whereas it varied from 0.20 to 0.30 PM₁₀. Similarly, summer-time NO₃⁻/SO₄⁻ ratios varied from 0.04 to 0.06 in PM_{2.5} whereas it varied from 0.34 to 0.42 in PM₁₀. The ratios much lesser than unity indicates the dominance of stationary sources over mobile sources in Angul 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 1.22 in $\text{PM}_{2.5}$ whereas it ranged from 1.16 to 2.09 in PM_{10} . The summer season mean Cl^-/Na^+ ratio ranged from 0.05 to 0.56 in $\text{PM}_{2.5}$ whereas it ranged from 0.26 to 0.41 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 $\text{PM}_{2.5}$ and PM_{10} samples. In Eq. 5, $[\text{NH}_4^+]$, $[\text{SO}_4^{2-}]$ and $[\text{NO}_3^-]$ represents the molar concentrations of ammonium, sulfate and nitrate ions, respectively observed over 24-h sampling. A $\text{DON} < 1$ indicates an ammonium deficiency; $\text{DON} = 1$ indicates complete neutralization whereas $\text{DON} > 1$ 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.

$$\text{DON} = \frac{[\text{NH}_4^+]}{2[\text{SO}_4^{2-}] + [\text{NO}_3^-]} \dots \dots \dots \text{Eq. (5)}$$

In winter season, the mean DON values ranged from 1.27 to 1.91 in $\text{PM}_{2.5}$ and 0.78 to 1.10 in PM_{10} at four sampling locations in Angul 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 0.9 to 1.10 in $\text{PM}_{2.5}$ and 0.53 to 0.74 in PM_{10} at four sampling locations in Angul 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.

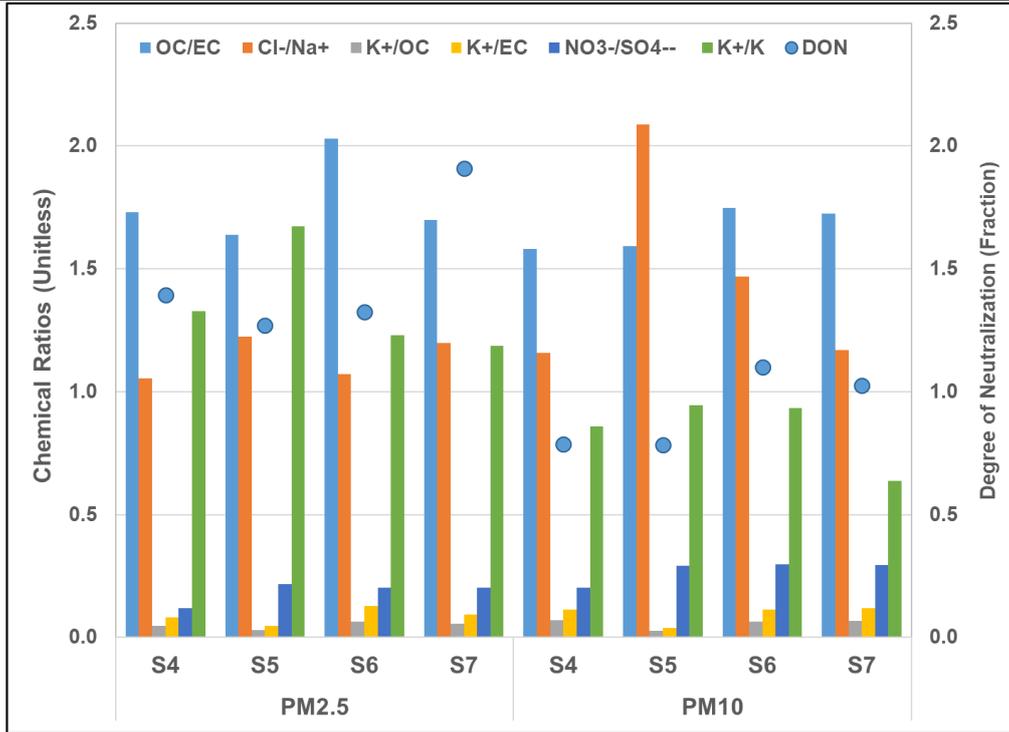


Figure 47: Chemical ratios i.e. OC to EC ratio, Cl⁻ to Na⁺ ratio, K⁺ to OC ratio, K⁺ to EC, NO₃⁻ to SO₄⁻⁻ ratio, and degree of neutralization (DON) observed at four sampling locations during the winter season in Angul region.

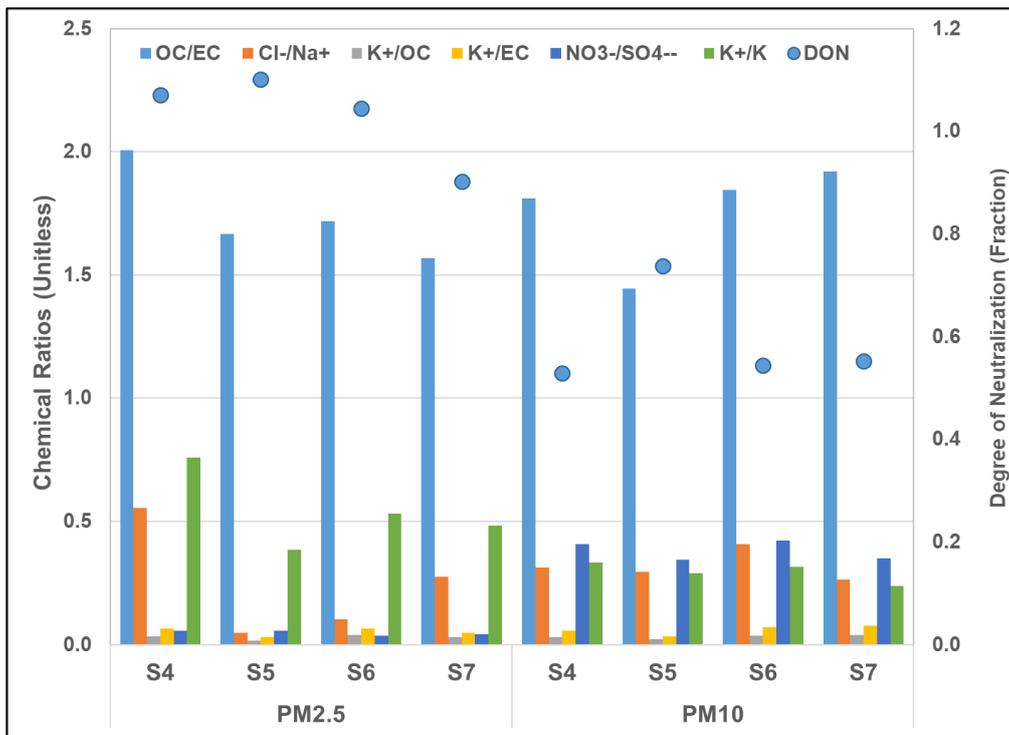


Figure 48: Chemical ratios i.e. OC to EC ratio, Cl⁻ to Na⁺ ratio, K⁺ to OC ratio, K⁺ to EC, NO₃⁻ to SO₄⁻⁻ ratio, and degree of neutralization (DON) observed at four sampling locations during the summer season in Angul region.

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

Fraction	Site	OC/EC	Cl ⁻ /Na ⁺	K ⁺ /OC	K ⁺ /EC	NO ₃ ⁻ / SO ₄ ²⁻	DON
Winter PM _{2.5}	S4	1.73	1.05	0.05	0.08	0.12	1.33
	S5	1.64	1.22	0.03	0.05	0.22	1.67
	S6	2.03	1.07	0.06	0.13	0.20	1.23
	S7	1.70	1.20	0.06	0.09	0.20	1.19
Winter PM ₁₀	S4	1.58	1.16	0.07	0.11	0.20	0.86
	S5	1.59	2.09	0.03	0.04	0.29	0.95
	S6	1.75	1.47	0.06	0.11	0.30	0.93
	S7	1.73	1.17	0.07	0.12	0.29	0.64
Summer PM _{2.5}	S4	2.01	0.56	0.03	0.06	0.06	0.76
	S5	1.67	0.05	0.02	0.03	0.06	0.39
	S6	1.72	0.10	0.04	0.06	0.04	0.53
	S7	1.57	0.27	0.03	0.05	0.04	0.48
Summer PM ₁₀	S4	1.81	0.31	0.03	0.06	0.41	0.33
	S5	1.44	0.29	0.02	0.03	0.34	0.29
	S6	1.85	0.41	0.04	0.07	0.42	0.32
	S7	1.92	0.26	0.04	0.08	0.35	0.24

2.9. Source apportionment of PM_{2.5} and PM₁₀

Source contributions to fine and coarse particulate matter i.e. PM_{2.5} and PM₁₀ were calculated with the CMB model for the individual daily samples for four sampling sites in Angul 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 4: Govt. College, Angul

Fig. 49 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at Govt. College, Angul i.e. S4 during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 69.9 µg/m³ and 217.0 µg/m³, respectively. Dusty sources, particularly road and construction dust, dominated PM_{2.5} at Site 4, contributing the highest proportion at 37.8%, Transport (14.0%), biomass and solid waste combustion (12.9%), industries and power plants (10.5%), mining activities (5.7%), and secondary aerosols (4.3%) were also identified as significant contributors. At Site 4, road and construction dust was the primary contributor to PM₁₀, with a substantial contribution of 47.5%. Mines followed at 18.5%, while industries and power plants constituted 14.4%. Biomass and solid waste combustion accounted for 5.5%, transport for 4.5%, and secondary aerosols for 3.8%. About 14.9% and 5.7% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

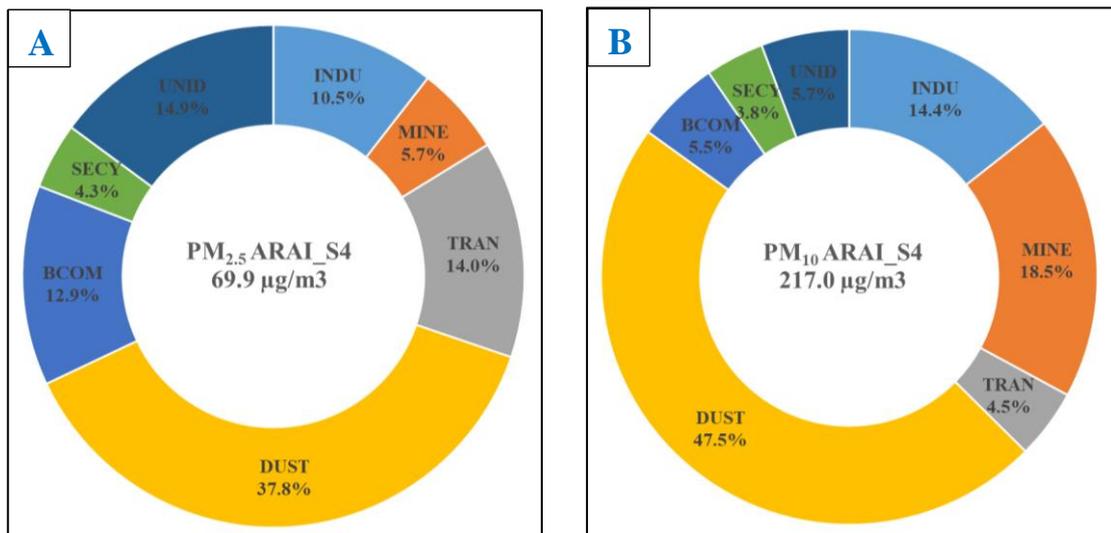


Figure 49 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S4 i.e. Govt. College, Angul during the winter season in Angul region

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 5: NALCO CISF headquarters (S5)

Fig. 50 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at NALCO CISF headquarters i.e. S5 during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 108.7 µg/m³ and 209.4 µg/m³, respectively.

Road and construction dust were the primary contributors to PM_{2.5} at Site 5, with a substantial contribution of 38.2%. Industries and power plants followed at 12.4%, while transport accounted for 14.0%. Other contributors included biomass and solid waste combustion (9.9%), mines (4.1%), secondary aerosols (4.0%), and unidentified sources (17.4%). Road and construction dust dominated PM₁₀ concentrations at Site 5, contributing the highest proportion at 41.6%. Industries and power plants followed at 16.6% while Mines constituted 12.1%. Transport contributed 7.6%, biomass and solid waste combustion 5.4%, and secondary aerosols 3.5%. About 17.4% and 13.3% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

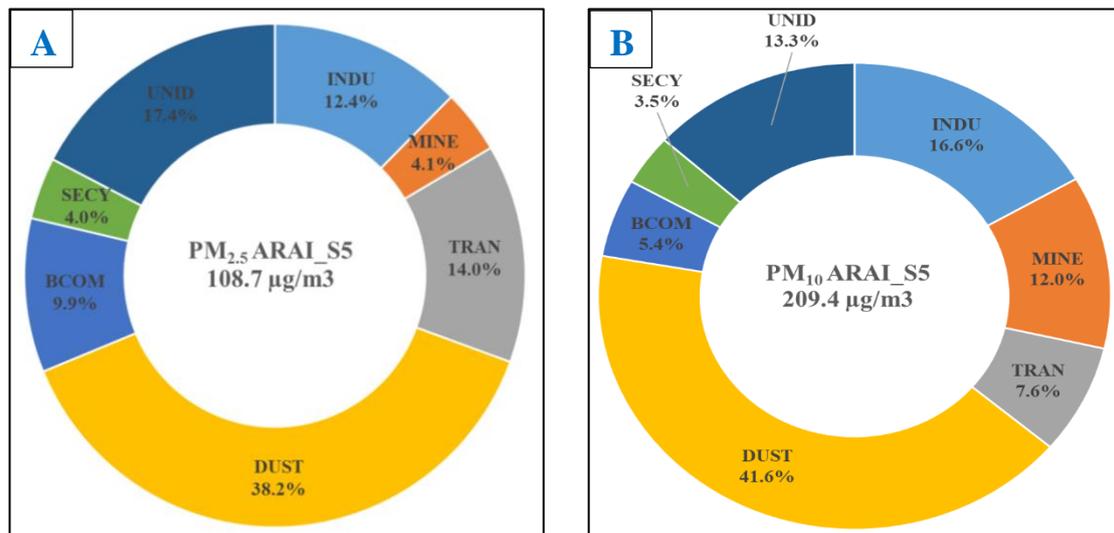


Figure 50 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S5 i.e. NALCO CISF headquarters during winter season in Angul region

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 6: Galapada (S6)

Fig. 51 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at Galapada (S6) during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 75.9 µg/m³ and 140.8 µg/m³, respectively. Industries and power plants had the highest contribution to PM_{2.5} at Site 6, with a significant proportion of 46.6%. Road and construction dust followed at 17.8%, while transport accounted for 7.9%. Biomass and solid waste combustion contributed 6.6%, secondary aerosols 4.2%, and mines 1.2%. Similar to PM_{2.5}, Industries and power plants also had the highest contribution to PM₁₀ at Site 6, with a significant proportion of 65.0%, followed by Road and construction dust at 12.1%. Transport contributed 5.4%, biomass and solid waste combustion 4.0%, secondary aerosols 3.2%, and mines 2.0%. About 15.8% and 8.4% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

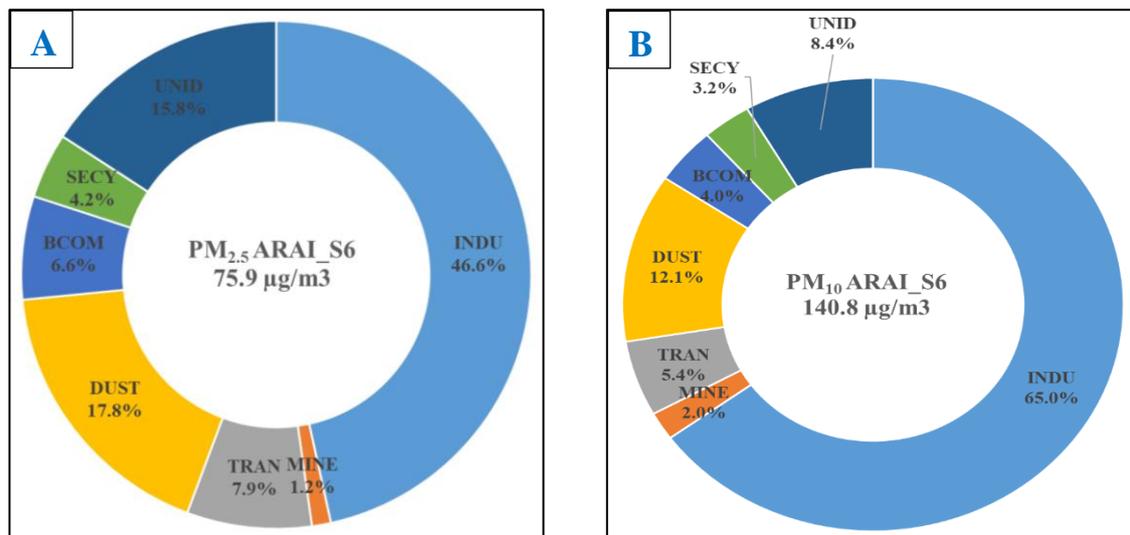


Figure 51 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S6 i.e. Galpada during winter season in Angul region

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 7: Gudiakatani (S7)

Fig. 52 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at Gudiakatani (S7) site during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 58.8 µg/m³ and 159.1 µg/m³, respectively. During the winter season, Road and construction dust were the leading contributors to PM_{2.5} at Site 7, accounting for 33.7%. Industries and power plants followed closely at 16.5%, while biomass and solid waste combustion accounted for 12.2%. Other contributors included transport (11.3%), secondary aerosols (6.4%), and mines (3.0%). The winter-season PM₁₀ concentrations at Site 7 were primarily influenced by road and construction dust, contributing the highest proportion at 38.3%. Industries and power plants followed closely at 28.9%, while mines constituted 10.9%. Biomass and solid waste combustion contributed 6.1%, transport 5.9% and secondary aerosols 5.4%. About 16.9% and 4.5% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

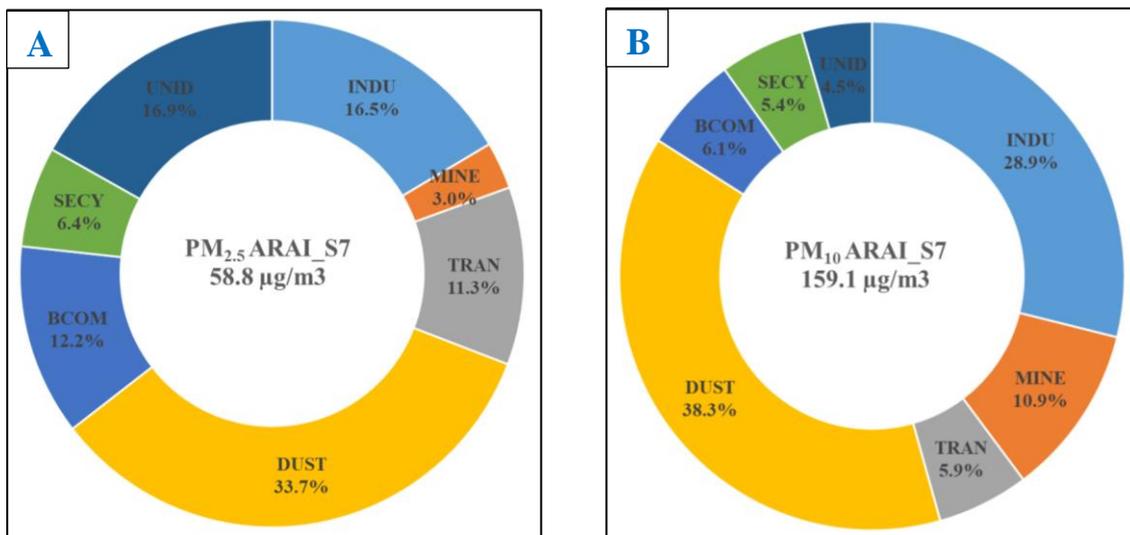


Figure 52 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S7 i.e. Gudiakatani during winter season in Angul region

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 4: Govt. College, Angul

Fig. 53 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at Govt. College, Angul (S4) during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 31.2 µg/m³ and 105.6 µg/m³, respectively. Road and construction dust were the largest contributor to PM_{2.5} levels at Site 4, accounting for 31.4%. Secondary aerosols follow closely, contributing 15.5%. Transport emissions contribute 11.8%, while industries and power plants, biomass combustion, and mining activities contribute 10.1%, 9.1%, and 5.0%, respectively. Similar to PM_{2.5}, the road and construction dust were the largest contributor to PM₁₀ levels at Site 4, constituting the highest contribution at 43.4%. Industries and power plants and Secondary aerosols follow closely, contributing 15.3% and 11.2% of the total, respectively. Mining activities, transport emissions and biomass combustion make smaller contributions at this site, with 6.0%, 4.2% and 4.2% respectively. About 17.1% and 15.7% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

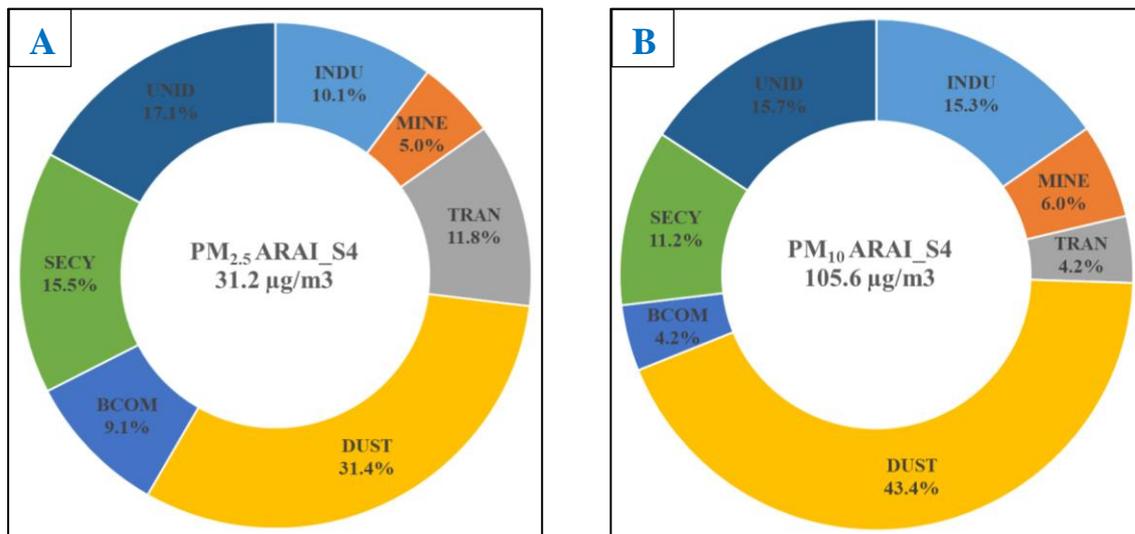


Figure 53 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S4 i.e. Govt. College, Angul during the summer season in Angul region

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 5: NALCO CISF Headquarters (S5)

Fig. 54 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at NALCO CISF Headquarters (S5) during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 39.8 µg/m³ and 123.6 µg/m³, respectively.

PM_{2.5} levels at Site 5 are primarily influenced by road and construction dust, contributing 32.5%. Secondary aerosols and Industries and power plants unidentified sources follow closely, contributing 14.7% and 13.7%, respectively, while transport emissions, biomass and solid waste combustion, and mining activities contribute 11.7%, 6.5%, and 3.2%, respectively. Similar to PM_{2.5}, the summer season, PM₁₀ concentrations at Site 5 are also primarily influenced by road and construction dust, constituting the highest contribution at 42.1%. Industries and power plants follow closely, contributing 20.9% of the total PM₁₀ levels. Secondary aerosols also make notable contributions, accounting for 10.2%. Transport emissions and mining activities make smaller contributions at this site, with 4.0% each. Biomass and solid waste combustion contribute 3.0% to the total PM₁₀ levels. About 17.7% and 15.8% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

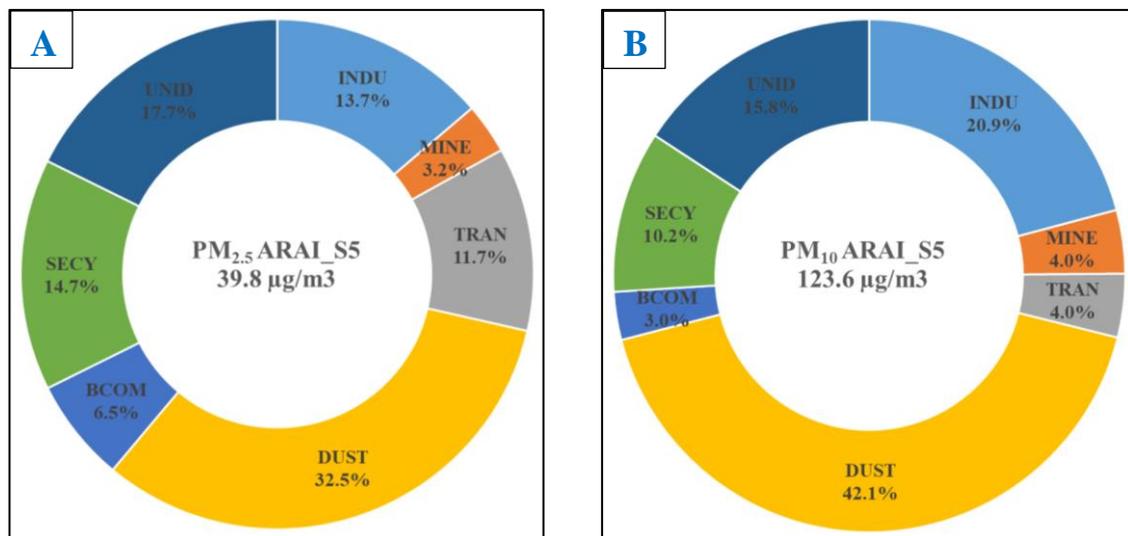


Figure 54 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S5 i.e. NALCO CISF Headquarters during summer season in Angul region

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 6: Galapada (S6)

Fig. 55 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at Galapada (S6) during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 34.7 µg/m³ and 109.9 µg/m³, respectively. Industries and power plants are the main contributors to summer season PM_{2.5} levels at Site 6, accounting for 32.3%. Secondary aerosols and road and construction dust follow closely, contributing 18.7% and 13.8%, respectively. Transport emissions contribute 6.3%, while biomass combustion, and mining activities contribute 4.7%, and 2.7%, respectively. Similar to PM_{2.5}, industries and power plants are also the top contributors to summer season PM₁₀ levels at Site 6, accounting for the highest proportion at 60.9%. Road and construction dust follow at a distant second, constituting 12.3% of the particulate matter. Secondary aerosols also make significant contribution, accounting for 9.0% of the total PM₁₀ levels. Mines contribute 3.0% to the total, while transport emissions and biomass and solid waste combustion make smaller contributions at this site, with 2.2% and 1.9%, respectively. About 21.5% and 10.7% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

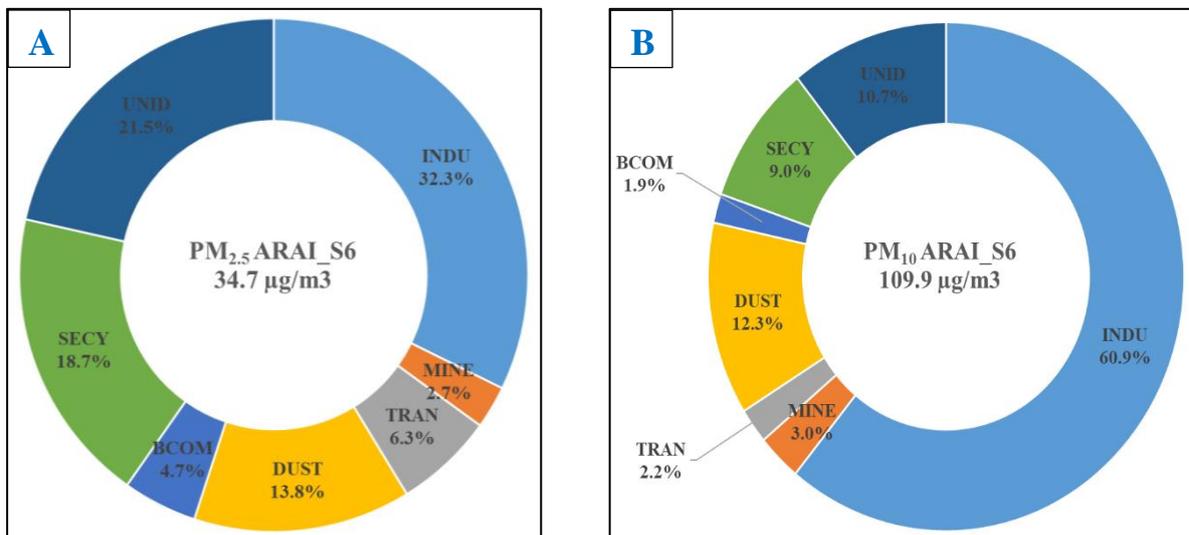


Figure 55 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S6 i.e. Galpada during summer season in Angul region

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 7: Gudiakatani (S7)

Fig. 56 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at Gudiakatani (S7) site during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 25.5 µg/m³ and 92.2 µg/m³, respectively. Secondary aerosols are the largest contributor to PM_{2.5} levels at Site 7, accounting for 32.8%. Road and construction dust follow closely, contributing 22.1%, while industries and power plants contribute 11.2%. The other sources biomass combustion, transport emissions, and mining activities contribute to 8.5%, 7.8%, and 1.9% of the total PM_{2.5} levels, respectively. Similar to PM_{2.5}, road and construction dust are the primary contributors to summer season PM₁₀ levels, constituting the highest contribution at 29.7%. Industries and power plants follow closely, contributing 23.6% of the total PM₁₀ levels. Secondary aerosols make a significant contribution of 17.0% to the total, while biomass and solid waste combustion, transport emissions and mining activities make smaller contributions at this site, with 4.0%, 2.8% and 2.0%, respectively. About 15.8% and 20.9% in PM_{2.5} and PM₁₀ mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

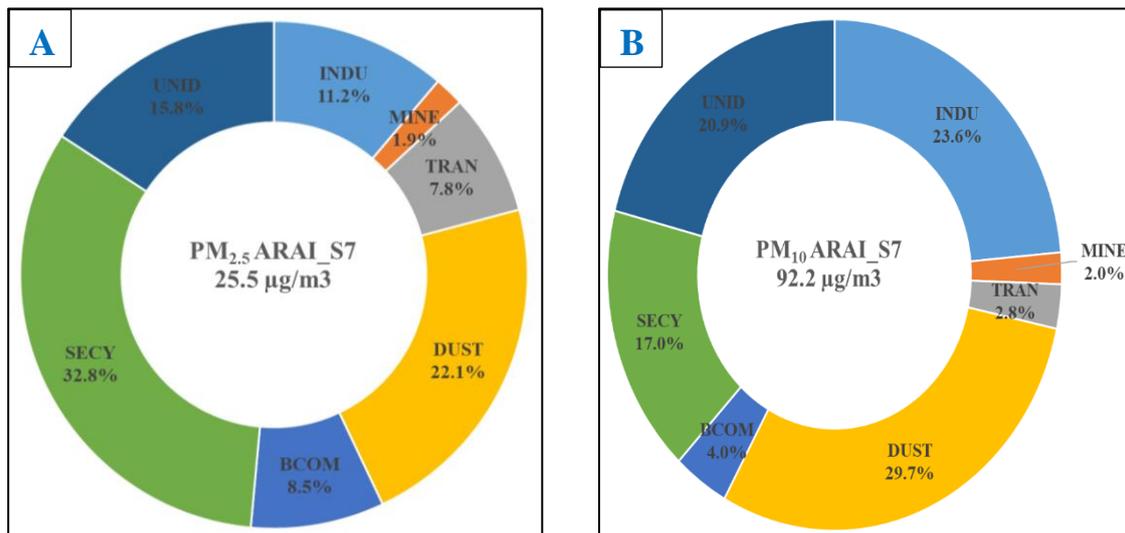


Figure 56 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S7 i.e. Gudiakatani during summer season in Angul region

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 PM₁₀ at Angul during winter and summer seasons, respectively. Overall, the winter-time PM_{2.5} mass at Angul (Fig. 57) are found to be dominated by dust and industrial sectors with contribution of 29.9% and 25.2%, respectively. The other sources of PM_{2.5} at Angul are identified as transport (11.1%), biomass and solid waste combustion (9.6%), secondary aerosols (4.9%), and mining activities (2.8%). Similarly, the winter-time PM₁₀ mass at Angul is also found to be dominated by industries and powerplants (36.8%), followed by road and construction dust (30.7%), mining activities (8.3%), transport (6.3%), biomass and solid waste combustion (5.2%), and secondary aerosols (4.0%). Additionally, about 16.7% and 8.7% mass of PM_{2.5} and PM₁₀ remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

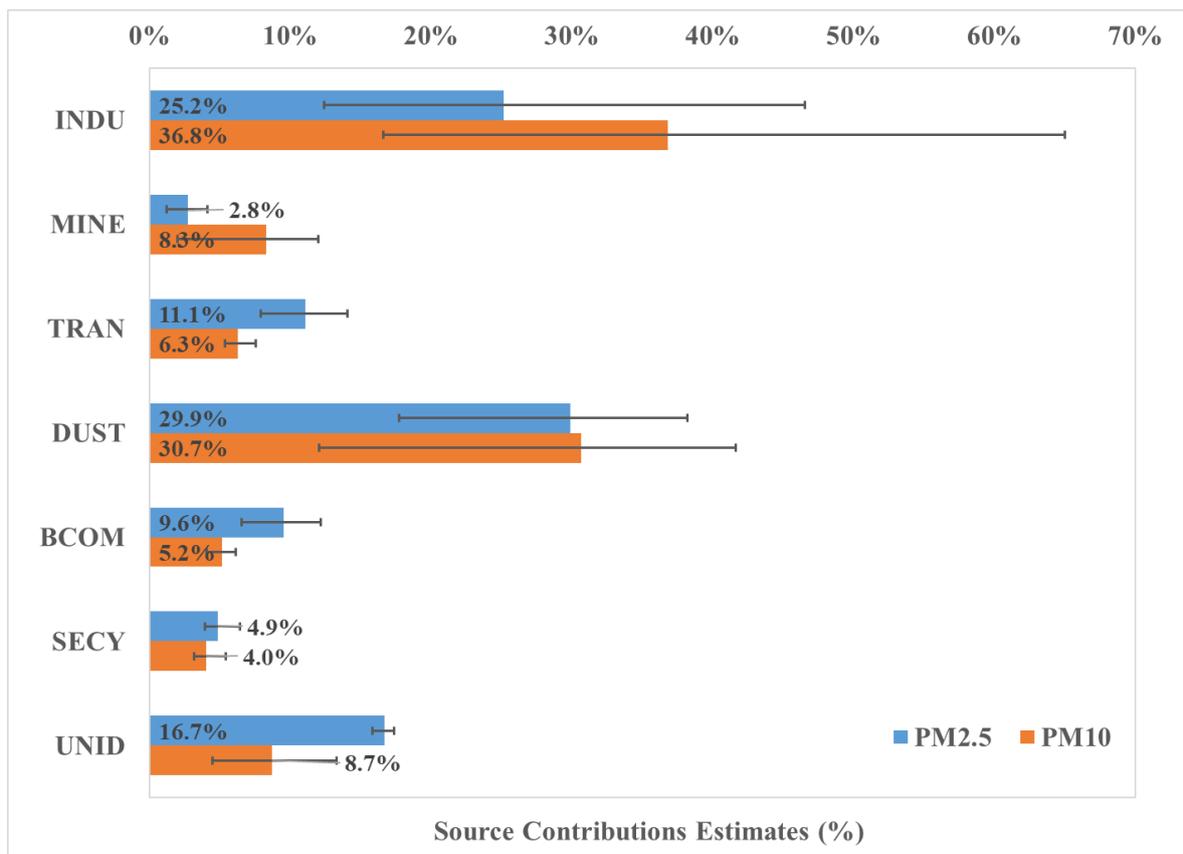


Figure 57 City-level source contribution estimates (SCE) for Angul region using CMB receptor model during winter season (December 7 – 26, 2021)

The summer-time PM_{2.5} mass in Angul region (Fig. 58) is found to be dominated by dust with highest contribution of 22.8%. The other summer-time sources of PM_{2.5} in Angul region are identified as secondary aerosols (22.1%), industries and powerplants (19.1%), transport (8.6%), secondary aerosols (12.0%), biomass and solid waste combustion (6.6%) and mining activities (2.6%). The summer-time PM₁₀ mass in Angul Region is found to be dominated by industries and powerplants (35.1%), followed by road and construction dust (28.0%), secondary aerosols (12.1%). The transport, biomass and solid waste combustion and mining activities were found to be minor contributors with a contribution of 3% each. Additionally, about 18.3% and 15.8% mass of PM_{2.5} and PM₁₀ remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

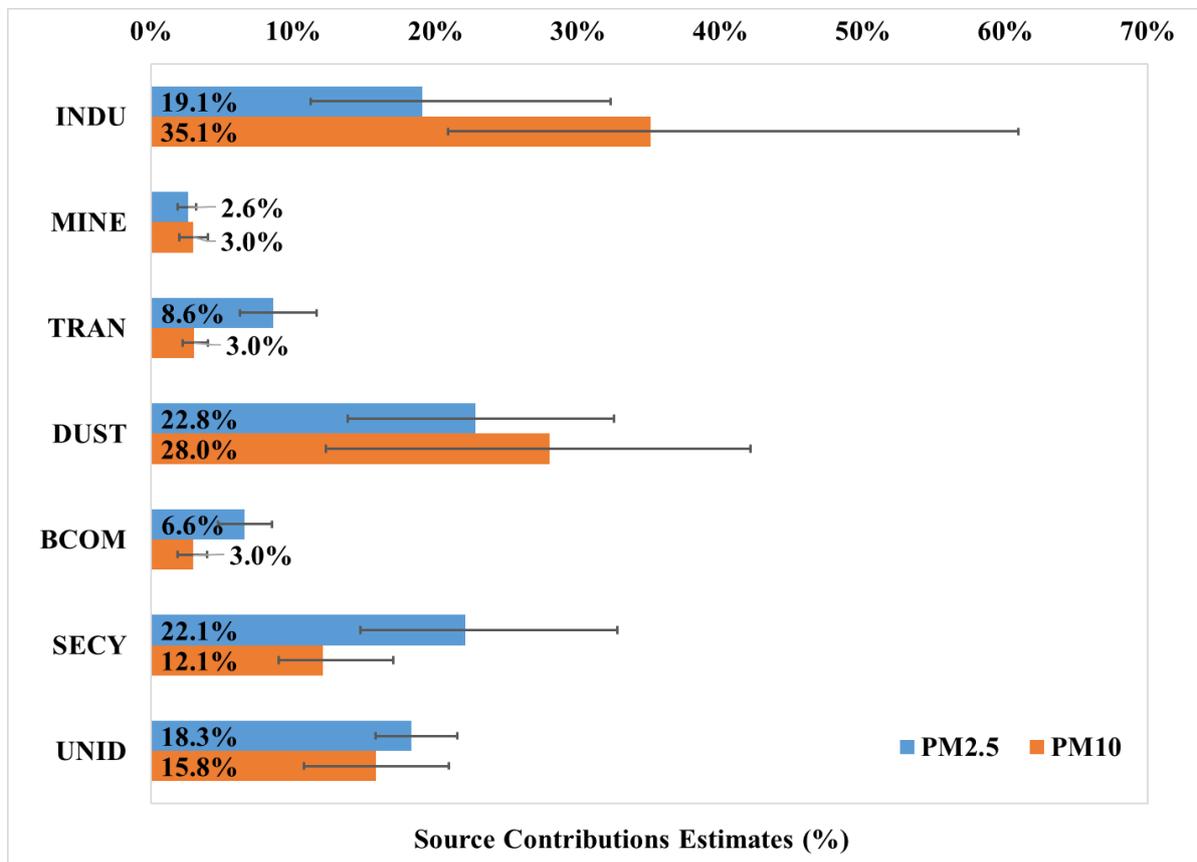


Figure 58 City-level source contribution estimates (SCE) for Angul region using CMB receptor model during summer season (May 21 – June 07, 2022)

(Note: The horizontal blue and orange coloured bars in Fig 57 and 58 represent the mean SCE percentage in PM_{2.5} and PM₁₀, 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 Angul region. The scope of this study includes:

- Quantification of emission loads originating from sectors including: Industries, Thermal powerplants, Transport, Re-suspended road dust, Open Waste Burning, Residential, Diesel generators, Hotels, Restaurants and Bakeries, Crematoria, Brick kilns, Fugitive emissions and Construction activities in Angul region.
- Air pollutants considered in this research includes: particulate matter having aerodynamic diameter less than or equal to 10 microns (PM₁₀), particulate matter having aerodynamic diameter less than or equal to 2.5 microns (PM_{2.5}), sulfur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs).
- The spatial resolution of emission inventory is: 2 x 2 km² 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 Angul 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.

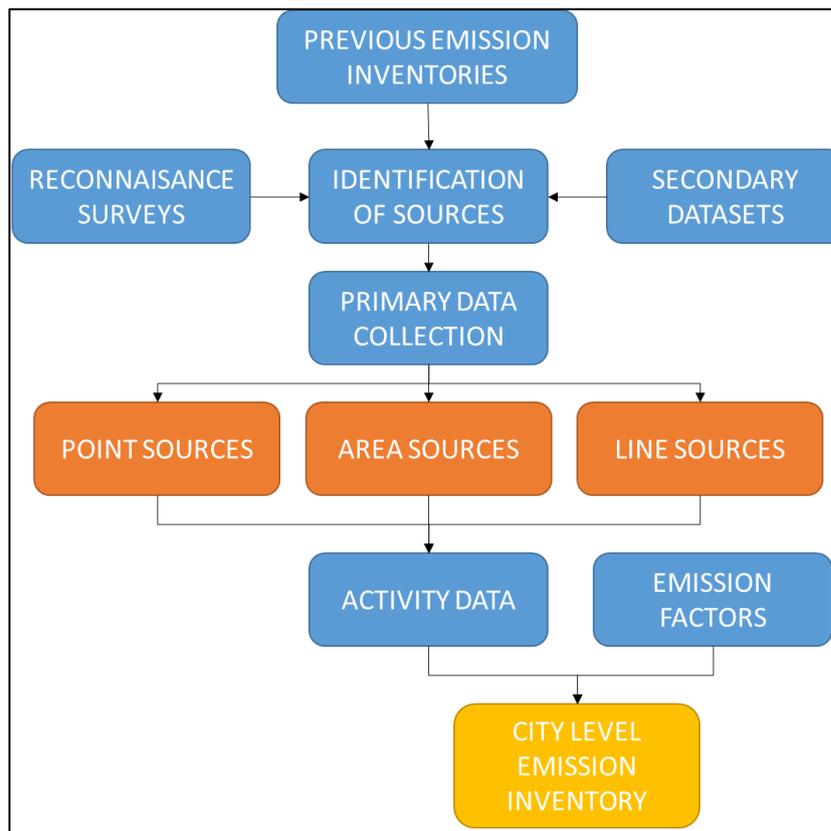


Figure 59: Approach adopted for emission inventory development at city level

The study area was divided into high resolution grid cells at 2 X 2 km² grids using GIS tools. A total 180 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 km²). The methodologies followed for estimation of emissions from different sectors are described in subsequent sections.

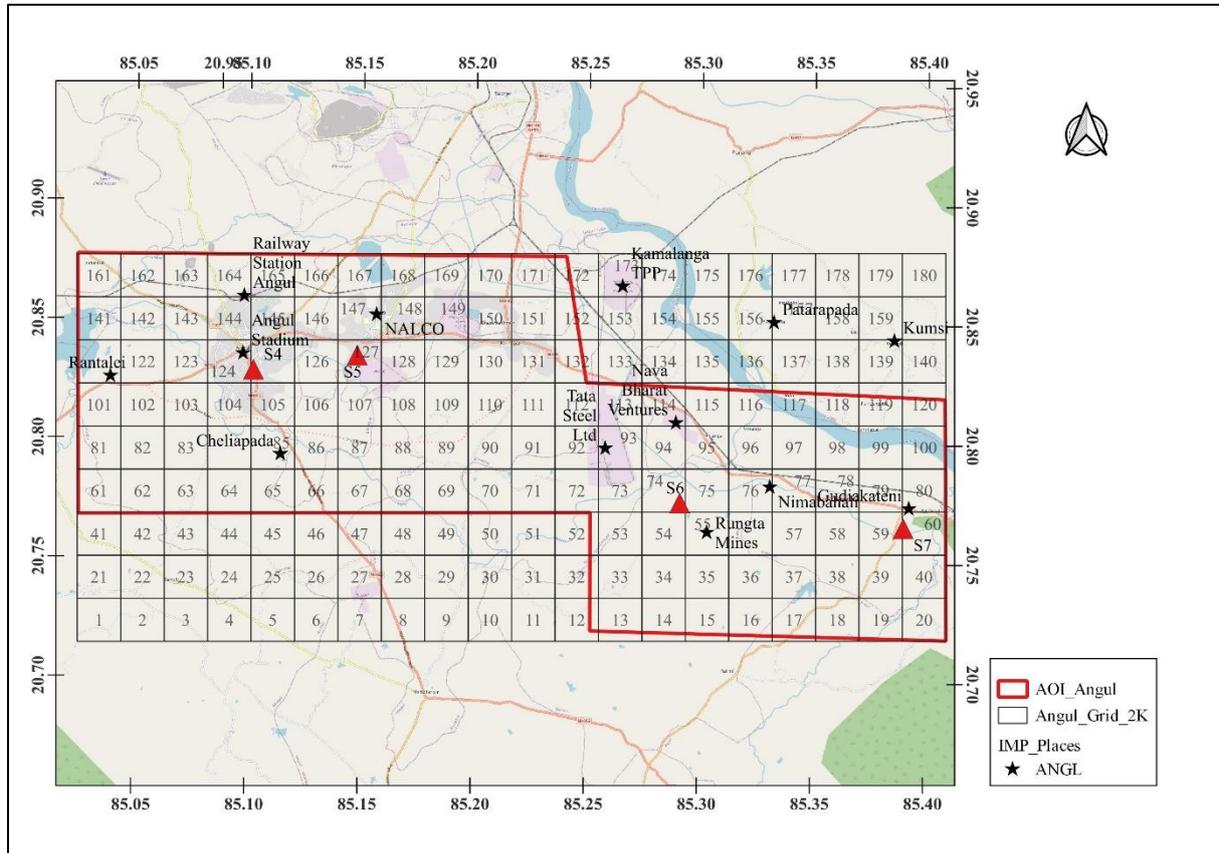


Figure 60: Map showing study area overlaid with emission inventory grids with horizontal spacing of 2 x 2 km²

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):

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

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 Angul region

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

Details of primary and secondary data collection surveys are provided in sectoral manner in subsequent sections. Air pollution sources were categorized into three main types i.e. point, area and line sources and details of sectors included in each type are provided in Table 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	<ul style="list-style-type: none"> • Classified vehicle counts • Parking lot / Fuel station surveys
2.	Re-suspended road dust	<ul style="list-style-type: none"> • On -road dust sampling to determine the silt loading rates
3.	Residential	<ul style="list-style-type: none"> • Fuel consumption surveys
4.	Hotels, Restaurants. Bakeries and Open eateries	<ul style="list-style-type: none"> • Fuel consumption surveys
5	Diesel Generators	<ul style="list-style-type: none"> • Fuel consumption surveys

Table 5 Summary of secondary data sources used in this study

Sr. No.	Sector	Secondary Data Sources
1.	Transport	<ul style="list-style-type: none"> • VAHAN database • MoRTH Annual Reports • Road network from Openstreetmap and Google Inc.
2.	Construction	<ul style="list-style-type: none"> • Google Earth Inc.
3.	Hotels, Restaurants, Bakeries and Open eateries	<ul style="list-style-type: none"> • Numbers, types, and locations of facilities through online food delivery portals
4.	Open waste burning	<ul style="list-style-type: none"> • Solid waste generation, processing and disposal statistics
5.	DG Sets	<ul style="list-style-type: none"> • Numbers, types, and locations of facilities through open street map, wherever applicable.
6.	Brick Kilns	<ul style="list-style-type: none"> • Google Earth Inc.
7.	Industry	<ul style="list-style-type: none"> • OSPCB database
8.	Residential	<ul style="list-style-type: none"> • National Family Health Survey (NFHS) 2019-2021

3.4.2. Industries and thermal powerplants

Angul is one of the oldest industrial zones of the country. The major industries in Angul region are Iron & Steel plants, Cement Industry, Sponge and Power Industry, Detonators, Chemical Plants etc. The major industries and thermal powerplants in Angul region include: National Aluminium Company Limited (NALCO), Jindal Steel & Power Limited, Tata Steel BSL Ltd., Rungta Mines Ltd. (Dhenkanal Steel Plant), M. G. M. Minerals Ltd. (Steel Division), BRG Iron & Steel, GMR Angul, Navabharat Ventures Ltd. For the steel industries, raw materials like coal, haematite, limestone, dolomite etc. are available within a short radius of the plant itself. Besides these, bulk of raw materials comes from its own captive mines. Generally, coal is the dominant fuel used by these industries (OSPCB, 2019).

Figure 61 shows the major industrial areas and stack locations in the Angul region. It is important to note that, important major industries and thermal powerplants which are outside the gridded study domain, but can influence the regional air quality are also considered in this assessment.

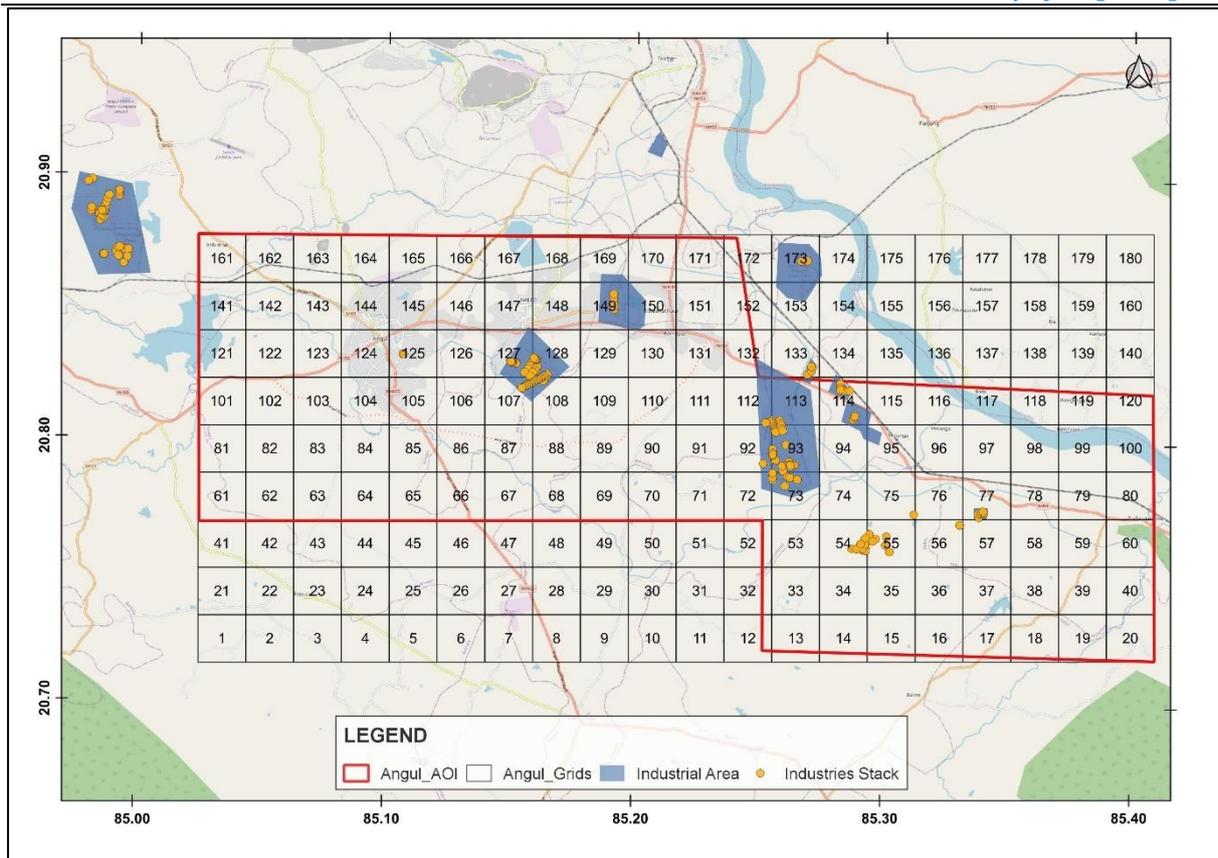


Figure 61: Map showing major industrial areas and stack locations in the Angul region

The emissions from major industries in Angul 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 Angul Regional office of State pollution control board, Odisha (OSPCB). This included data on manufacturing process, stack dimensions, installed control equipment and stack emissions of pollutants (PM, NO₂, and SO₂). As CO and NMVOC emissions from industrial stacks are not routinely monitored, these emissions are estimated based on the production capacity.

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 6 provides the emission factors for material handling used in this study.

Table 6: Emission factors of PM₁₀ 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. Residential

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

$$E_p = \sum_{f=1}^6 \text{Pop}_f \times C_f \times \text{EF}_{f,p} \dots \dots \dots (7)$$

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 Angul region is available for year 2011 but Angul 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. 62) 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 Angul region as a part of this study. The emission factors for residential sector used in this study are summarized in Table 7.

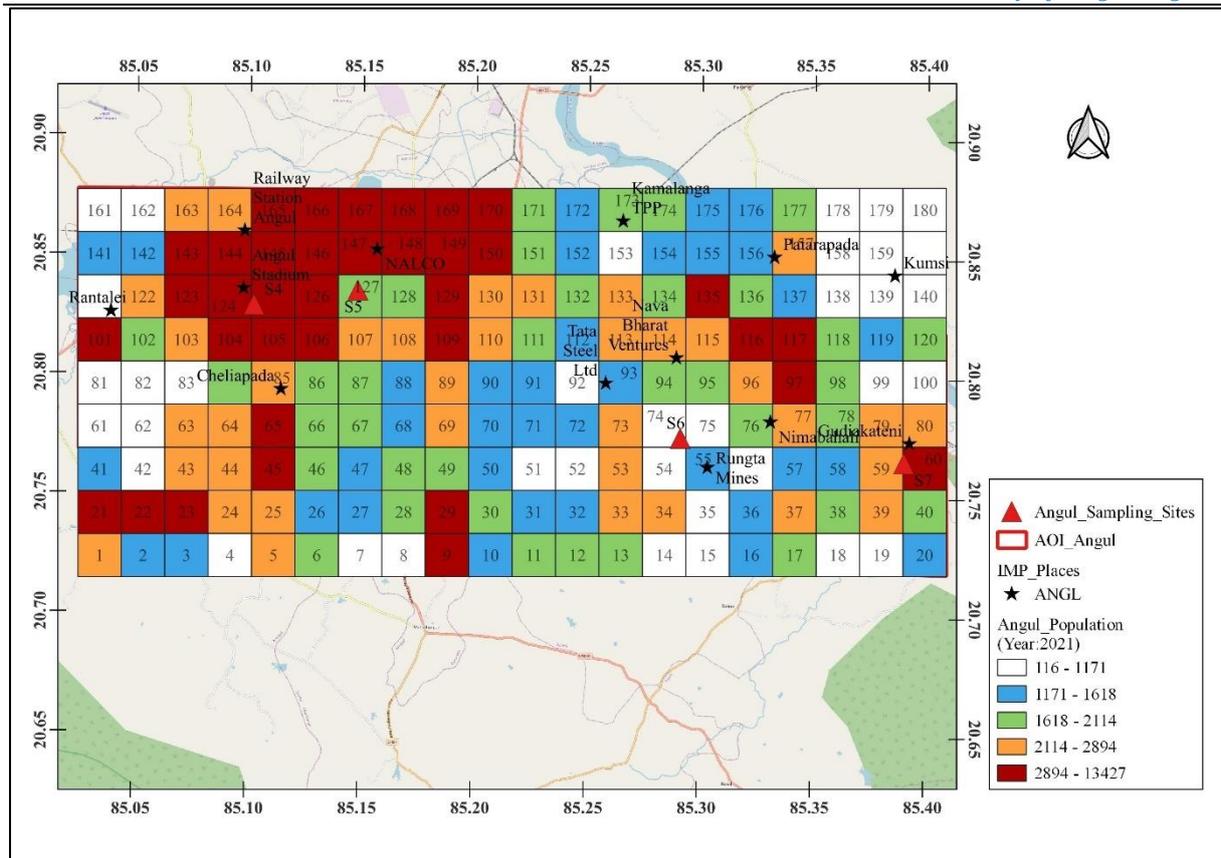


Figure 62 Map showing the estimated gridded population of the study area in year 2021

Table 7: 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)

3.4.5. 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):

$$\text{Transport Emissions} = \text{VKT} \times \text{EF}_{EX} \dots \dots \dots (8)$$

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.

3.4.5.1. Road network digitization

Road network in the study area was digitized using Google Earth application (Fig. 63). Roads in Angul region are classified into six categories viz. i) highways, ii) major roads, iii) intermediate roads, iv) minor roads v) residential roads and vi) industrial roads. After complete digitization, road lengths were calculated for each link in the network using GIS software. Category-wise gridded road lengths were also computed using GIS software.

3.4.5.2. Reconnaissance survey

A Reconnaissance survey was conducted in the Angul 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 Angul region to perform the classified vehicle count surveys and 4 areas/localities were selected for Parking lot surveys.

3.4.5.3. 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 Angul 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. 64 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 May to June, 2022 (Talcher Region) and December, 2022 to January, 2023 (Angul Region). 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 7 areas/localities around the selected sampling sites (S1-S7) in Angul-Talcher region during May to June, 2022 (Talcher Region) and December, 2022 to January, 2023 (Angul Region). Table 8 and 9 shows the details of locations of vehicle count surveys and parking lot surveys respectively.

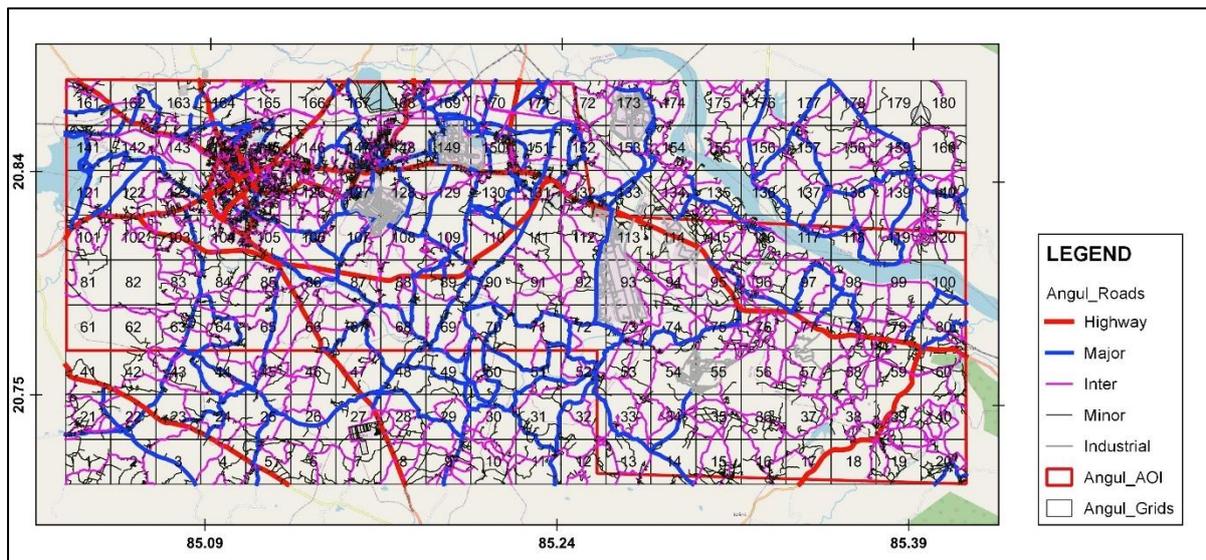


Figure 63: Map showing road network in Angul region and surrounding areas digitized using OpenStreetMap and Google Earth Applications

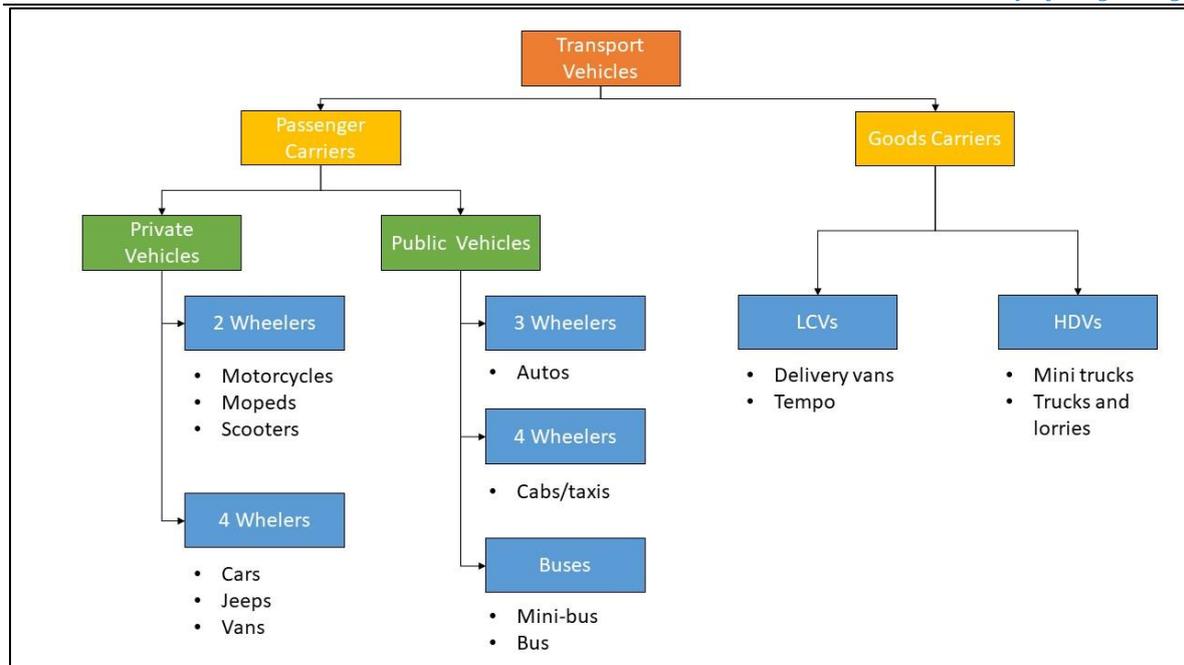


Figure 64: Vehicle categories used in this study

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 Angul 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 Angul region

Code	Road Name	Road Type	Latitude	Longitude	Direction
VC1	Angul-Athgarh Road	Major	20.8302	85.1005	
VC2	Sambalpur-Cuttack Highway	Highway	20.8321	85.0870	Towards Cuttack
VC3	Mishrapada	Intermediate	20.8266	85.0937	Towards Govt College, Angul
VC4	Banapal - Pallaharra Road	Highway	20.8529	85.2138	Towards Banarpal Chowk
VC5	Nalco Nagar	Intermediate	20.8506	85.1619	Towards Talcher
VC6	Jagannath Temple Road	Minor	20.8539	85.1602	Towards Jagannath Temple
VC7	Sambalpur-Cuttack Highway	Highway	20.7877	85.3130	Towards Angul
VC8	Galapada-Nimabahali Chowk	Intermediate	20.7814	85.3091	Both way
VC9	Banarpal - Hindol Road	Major	20.8108	85.2140	Towards Banarpal Chowk
VC10	Uparbaghalunda	Major	20.7684	85.3880	Towards Gudiakteni Chowk
VC11	Thana Road	Major	20.9488	85.2329	Police station to Rajbati (Talcher Town Road)
VC12	Green Park Road	Highway	20.9508	85.2247	Bus Stand To Banarpal
VC13	Talcher Town Road	Intermediate	20.9495	85.2339	Talcher To Angul
VC14	B.P School Road	Intermediate	20.9870	85.0427	Gopal Prasad Road
VC15	Balanda bus Stand	Major	20.9297	85.1579	Moten Market
VC16	Jatra Padia Road	Minor	20.9339	85.1619	Ganesh Market To Talcher
VC17	Karigarapada	Minor	20.9472	85.2297	Karigarapada To Bus Stand

Table 9 Locations of Parking Lot Surveys in Angul region

Location No.	Area Name	Location No.	Area Name
P1	Banbaspur	P4	Angul Town
P2	Talcher Municipality Area	P5	NALCO Area
P3	Talcher Coalfields	P6	Galapada
		P7	Gudikateni

Figure 65 shows the yearly and cumulative vehicle registrations in Angul-Talcher region starting year 2000 till 2021. The total cumulative vehicle registrations reached 4.51 lakhs till 2021. The yearly registration showed a significant decline in vehicle registrations during year 2020- and 2021, mainly due to the COVID-19 pandemic.

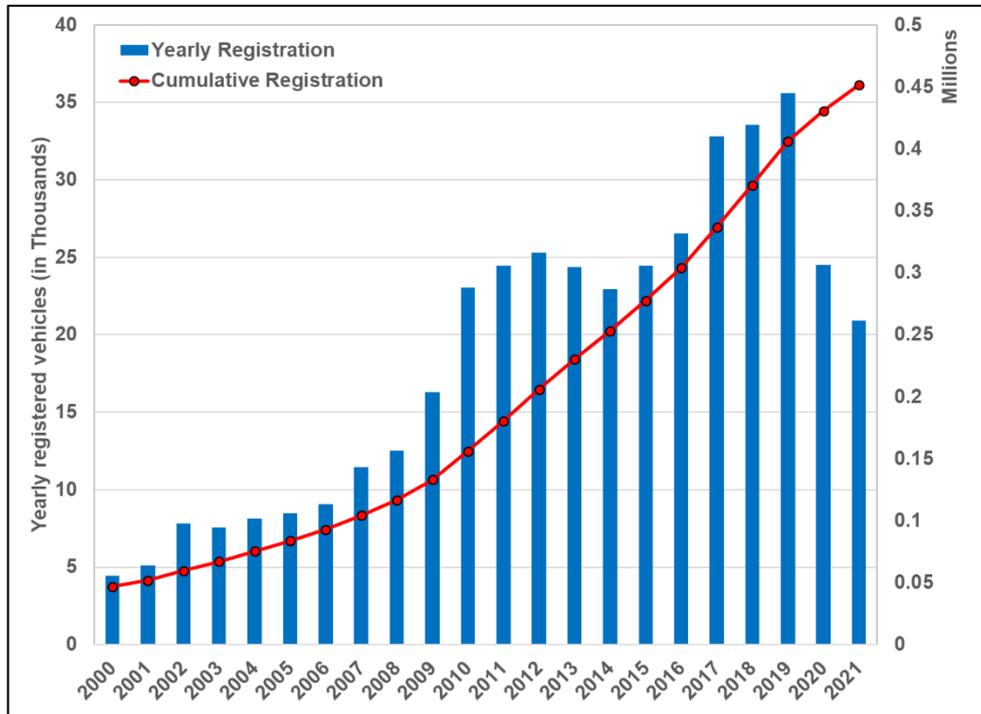


Figure 65: The number of vehicles registered by year (blue bars) and cumulative (red line) in Angul-Talcher region from 2000 to 2021.

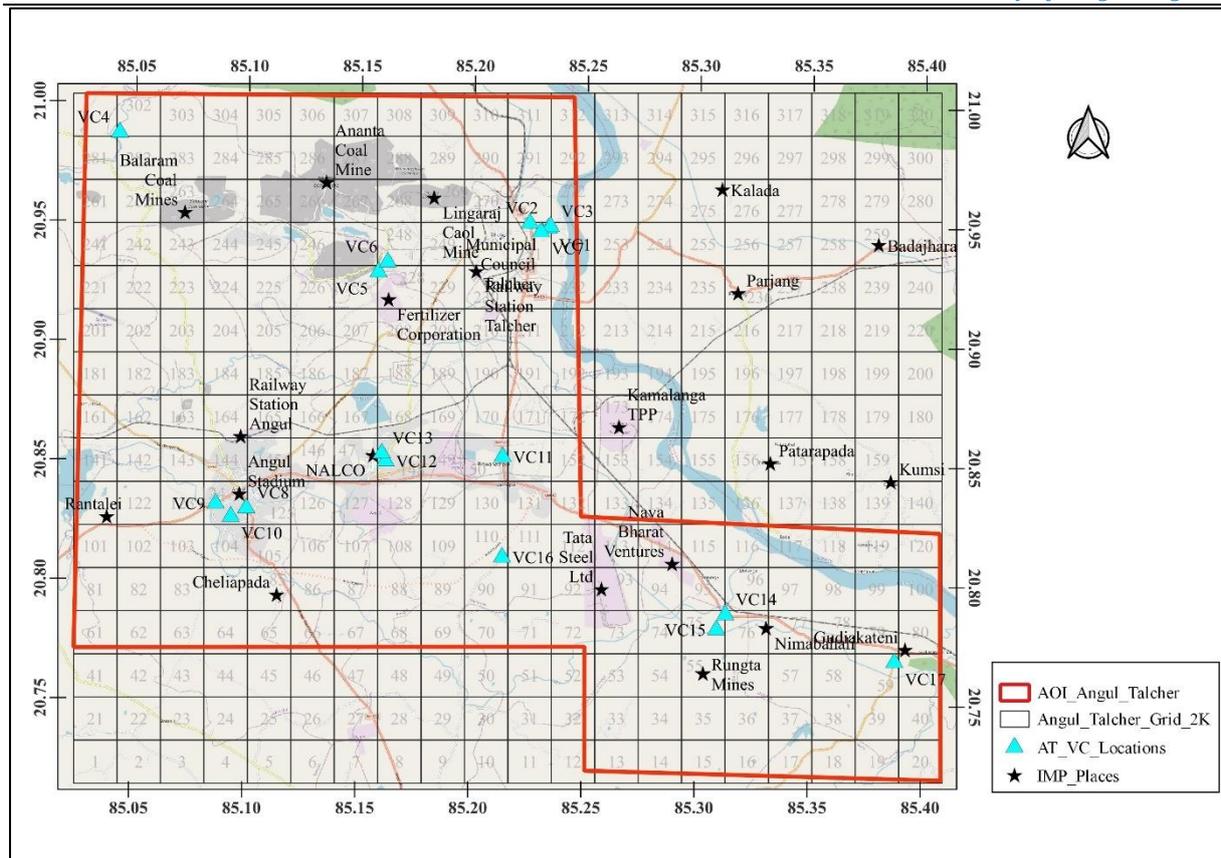


Figure 66: Map showing selected locations in Angul-Talcher region for vehicle counting surveys.

Fig. 67 presents the classified vehicle count observed at different types of roads in Angul region. Highways and Major roads such as VC1, VC7, VC12 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 VC12 location, which exhibited a significant contrast in vehicular population. This can be attributed to regular traffic during office hours on weekdays.

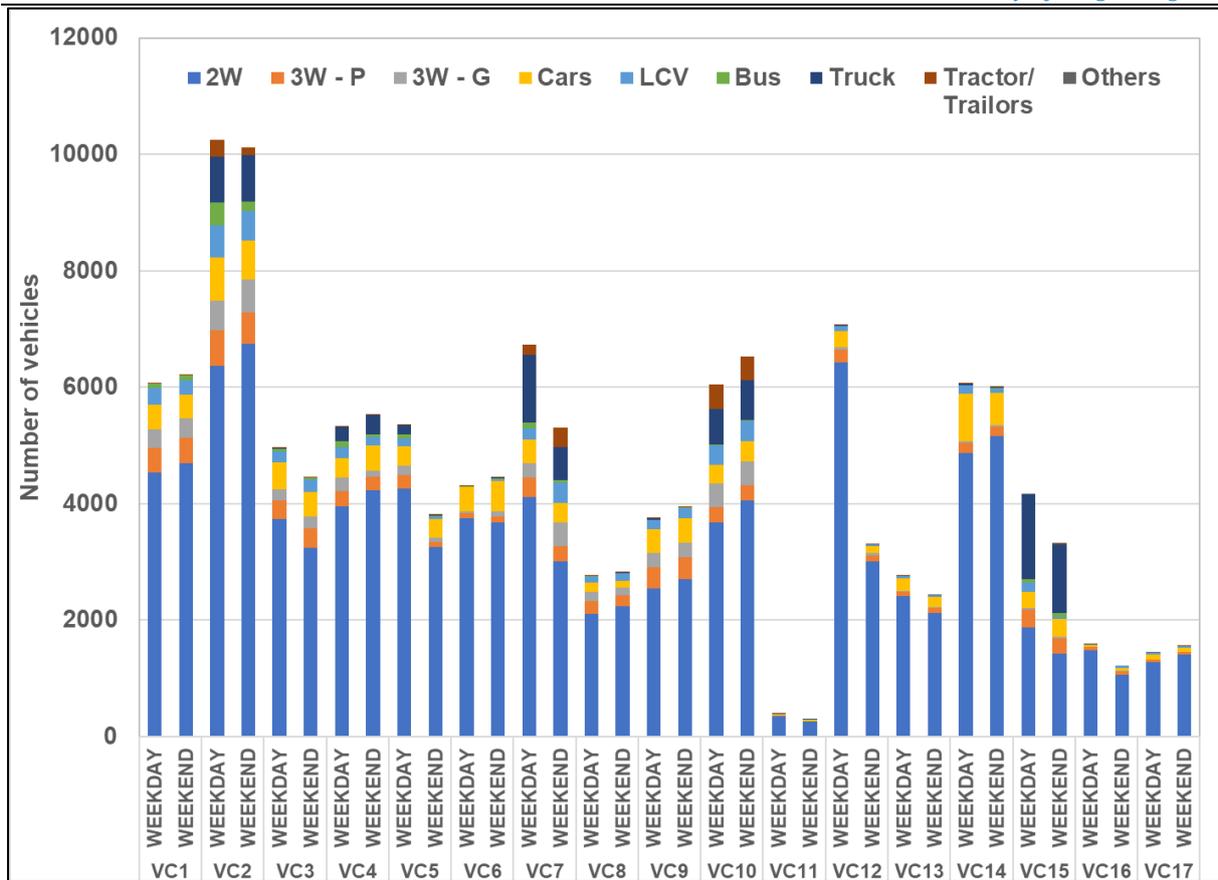


Figure 67: Classified vehicle counts observed at selected locations in Angul-Talcher region during the primary surveys.

Fig. 68 depicts the observed percentage distribution of vehicles according to Bharat standards in Angul-Talcher region. A total of 708 vehicles were surveyed in the region during the primary surveys. The BS-III category vehicles are observed to be maximum (45.4%) followed by BS-IV (29.5%), BS-VI (18.2%), BS-II (5.7%), and BS-I (1.2%).

Fig. 69 shows the estimated daily vehicle kilometres travelled by each category of vehicles in the Angul-Talcher region. The daily VKT is estimated to be 2.77 Cr km and is dominated by two wheelers (76.5%) followed by private cars (6.4%), and passenger three wheelers (6.1%). Other vehicle categories together constitute about 11% of the daily VKT in Angul region.

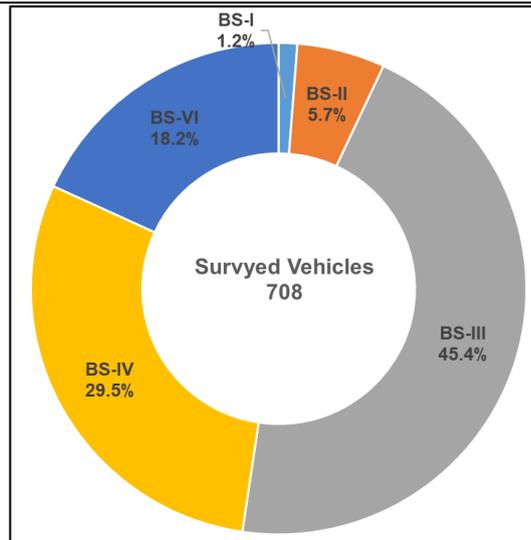


Figure 68: Distribution of vehicles as per different Baharat standards (BS) in Angul-Talcher region obtained through parking lot surveys.

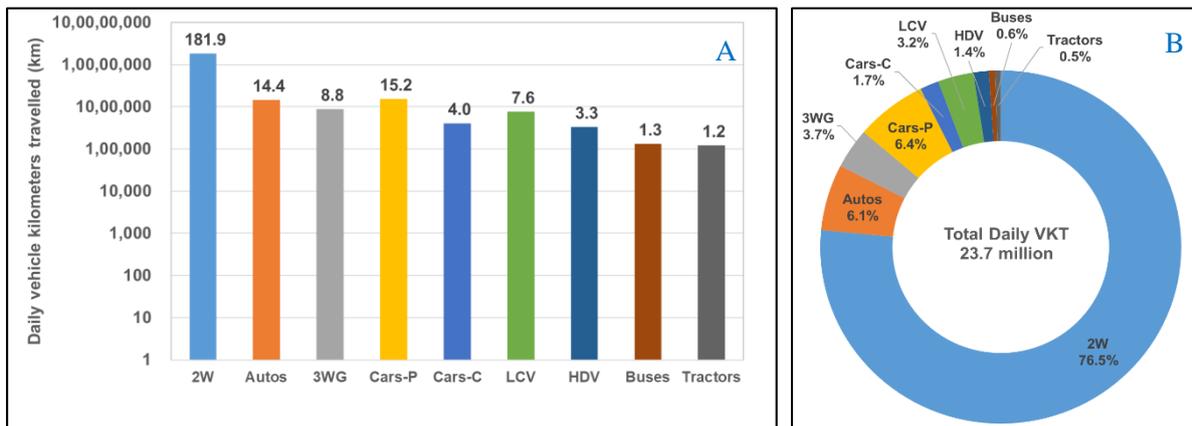


Figure 69: Daily vehicle kilometres travelled (A) and percent distribution (B) by different category of vehicles in Angul-Talcher region.

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.

3.4.6. 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:

$$\text{Emissions load} = \text{VKT} \times \text{EF}_{RD} \dots \dots \dots (9)$$

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

$$\text{EF}_{RD} = k \times w^{1.02} \times (\text{sL})^{0.91} \times \left(1 - \frac{P}{4N}\right) \dots \dots \dots (10)$$

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 PM₁₀ 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 Angul-Talcher 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 PM₁₀ 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	2.17	0.94	0.50	0.34	0.30
PM _{2.5}	Rural	2.17	0.94	0.50	0.34	0.30
PM _{2.5}	Industrial	3.25	1.41	0.75	0.51	0.45
PM _{2.5}	Mining	6.50	2.82	1.50	1.02	0.90
PM _{2.5}	Forest	1.63	0.70	0.37	0.26	0.22
PM ₁₀	Urban	8.96	3.88	2.07	1.41	1.24
PM ₁₀	Rural	8.96	3.88	2.07	1.41	1.24
PM ₁₀	Industrial	13.44	5.82	3.10	2.11	1.86
PM ₁₀	Mining	26.87	11.64	6.20	4.22	3.71
PM ₁₀	Forest	6.72	2.91	1.55	1.05	0.93

3.4.7. Open Waste Burning

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

$$E_p = W_b \times EF_p \dots \dots \dots (11)$$

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. 11 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).

$$W_b = (MSW_P - MSW_C - MSW_R - MSW_F) \times (1 - f_i) \times 0.6 \dots \dots \dots (12)$$

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 11.

Table 11: 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. 70 shows the map of construction locations identified using the satellite imagery. The emissions are obtained by using equation 17.

$$E = A_s \times EF \dots \dots \dots \text{Eq. (13)}$$

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, PM₁₀ and PM_{2.5} emissions from construction areas are approximately 25% and 6% of the total PM mass.

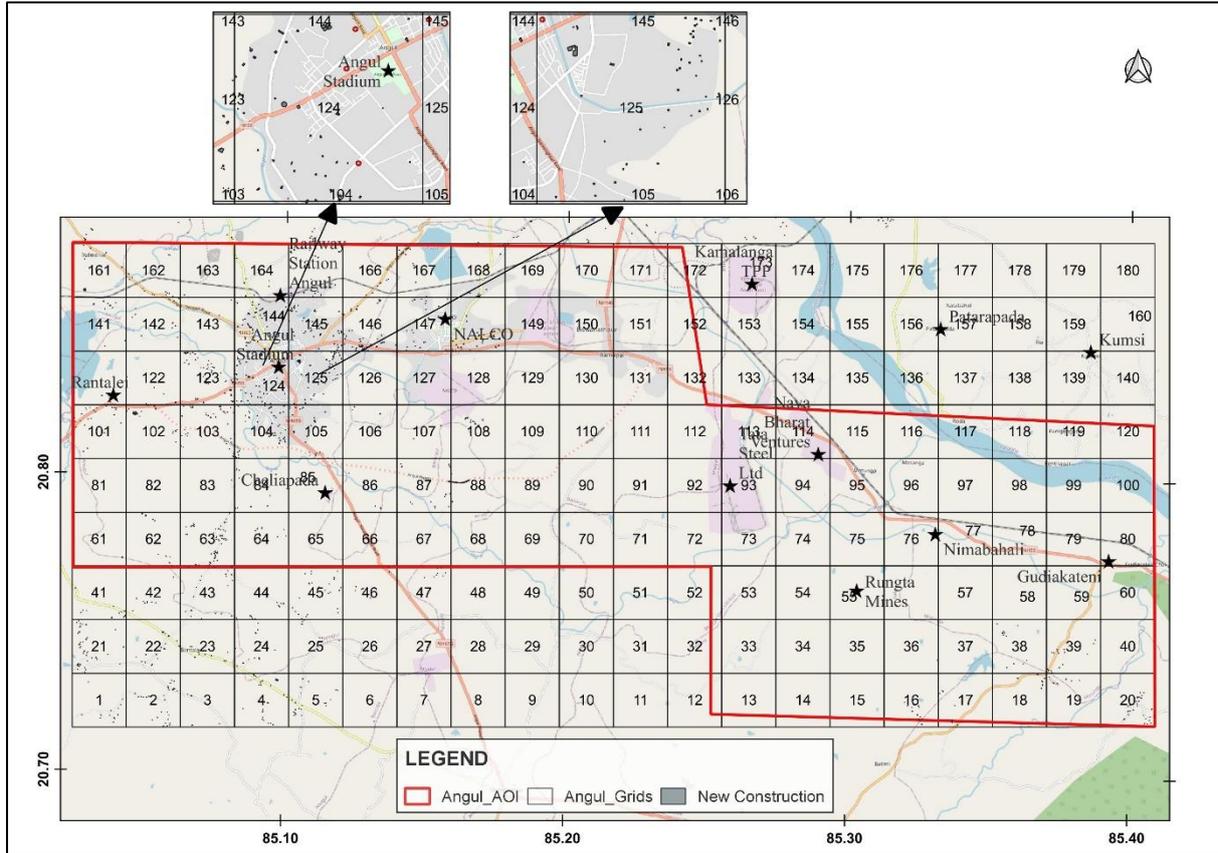


Figure 70 Map showing construction areas identified using the satellite imagery in Angul region. The inset view shows zoomed in view of new construction activities in grid no. 124 and 125 of the study domains.

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 53 number of brick kilns. Most of the brick kilns are of traditional clamp type brick kilns whereas a few are of Fixed Chimney Bull’s Trench Kiln (FCBTK). Fig. 71 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 12. The total emissions from brick kilns calculated using Eq. 15

$$E_p = W_b \times EF \dots \dots \dots (14)$$

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.

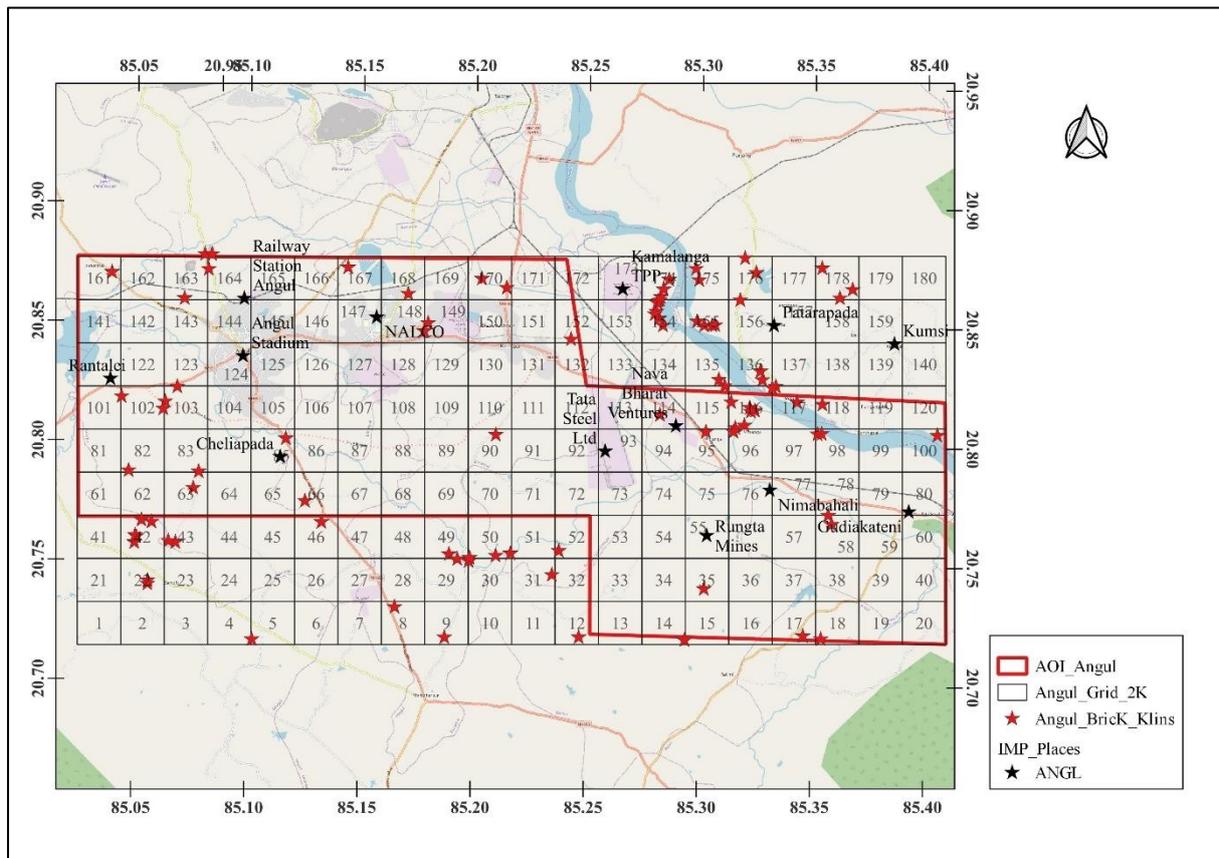


Figure 71 Map showing locations of brick kilns in the Angul study domain identified using satellite imagery

Table 12 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 Angul 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 13.

Table 13 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. 14.

$$E_p = F_b \times EF_{f,p} \dots \dots \dots (15)$$

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 locations of crematoria are marked and average number of dead bodies cremated each month is calculated based on crude death rate of Angul 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 14. The emissions are quantified using equation 14.

Table 14: Emission Factors for crematoria

Fuel	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO	NMVOCs
Wood (g/body)	5550.0	2730.0	120.0	750.0	27900.0	15,570.0
Electricity (g/body)	3.60	2.25	3.60	26.1	18.0	171.0

3.4.12. 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 Angul region are LPG, coal and wood. The equation (13) used for calculating emissions by this sector:

$$E_p = C_f \times EF_{f,p} \dots \dots \dots (16)$$

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 Angul region to understand the fuel usage pattern in hotels, restaurants, bakeries and 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 15). It is also assumed that no control devices are installed in the restaurants to control the emissions.

Table 15 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).

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

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 14, 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

As discussed earlier, Angul region is home to large industrial units including iron and steel plants, aluminium smelters, and a few sponge iron units. All these industries mainly use coal as the primary fuel. Figure 72, shows the stack emissions originating from these industries. Due to large usage of coal in industries, SO₂ emerged as a major pollutant in the region, emitting 36,946 tonnes per year in the base year i.e. 2021. This is followed by NO_x (15,405 tonnes per year), PM₁₀ (3,696 tonnes per year) and PM_{2.5} (1847 tonnes per year). As industrial boilers are designed for efficient combustion, CO is not a major contributor (797 tonnes per year) in Angul region.

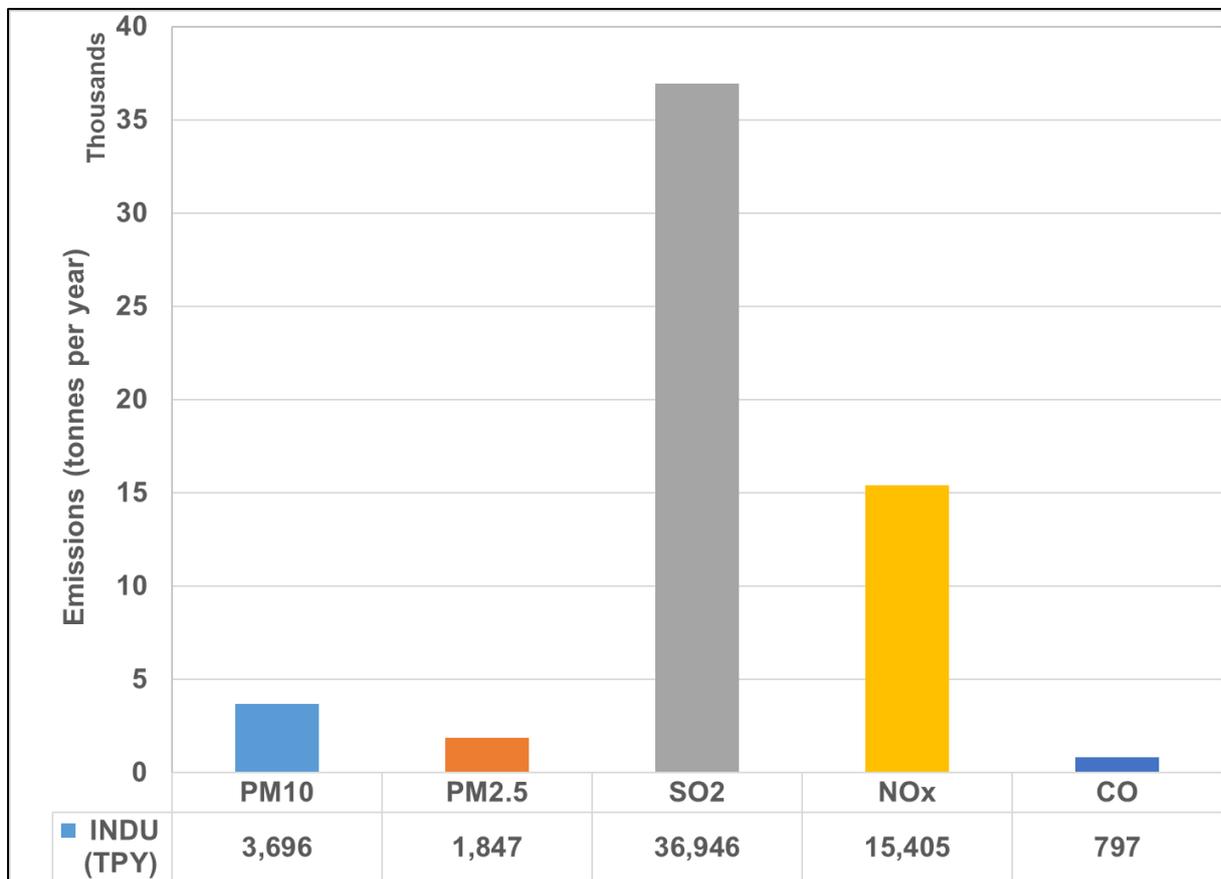


Figure 72: Emissions load (tonnes per year) of pollutants originating from industrial sector in Angul region

3.7.2. Thermal powerplants

Due to abundance of coal in the region, Angul region hosts a number of coal-based thermal powerplants which includes captive powerplants operated by large industries. Figure 73, shows the stack emissions originating from these industries. With huge amount of coal consumption in thermal powerplants, SO₂ emerged as a major pollutant in the region, emitting 88,863 tonnes per year in the base year i.e. 2021. This is followed by NO_x (44,998 tonnes per year), PM₁₀ (6,576 tonnes per year) and PM_{2.5} (2,908 tonnes per year). As powerplant boilers are designed for efficient combustion, CO emissions are relatively lower (2,307 tonnes per year) in Angul region.

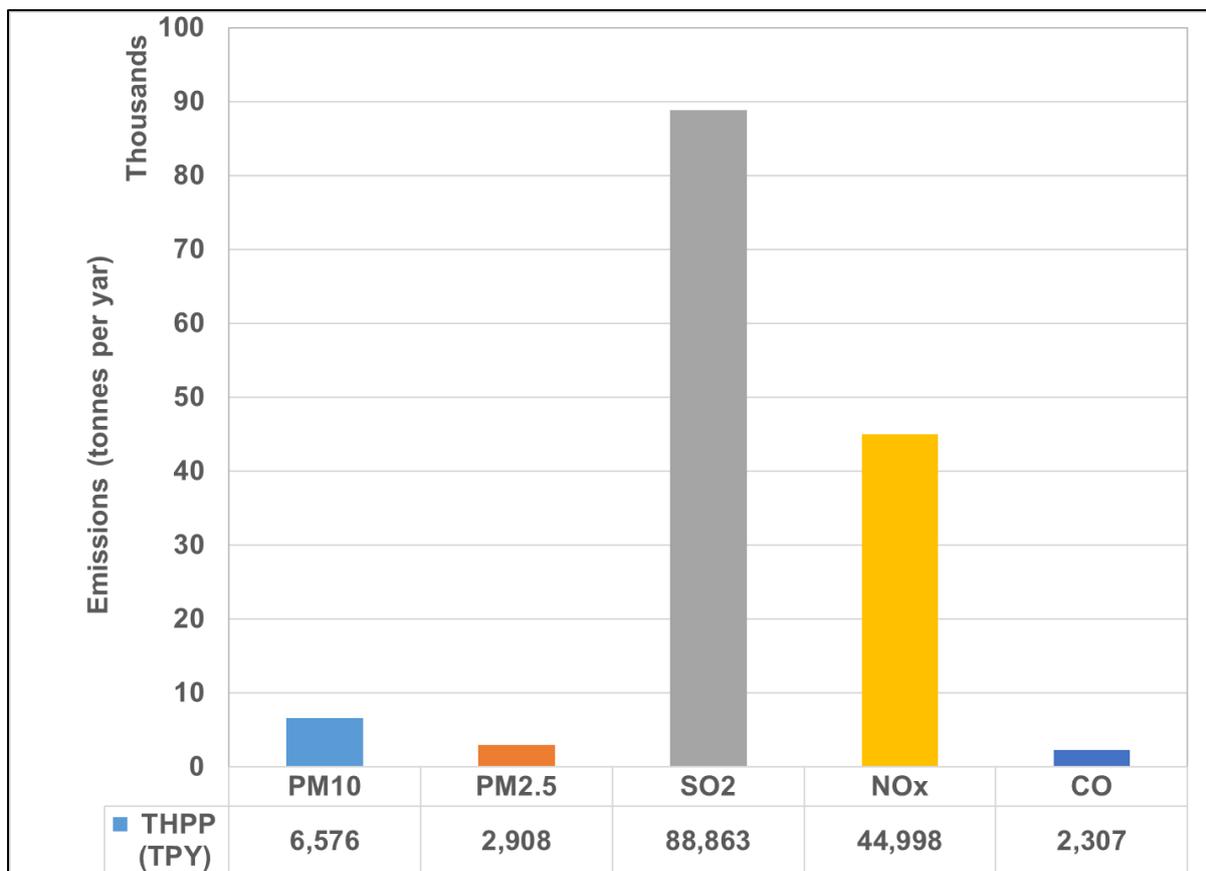


Figure 73: Emissions load (tonnes per year) of pollutants originating from industrial sector in Angul region

3.7.3. 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 74 shows the fugitive emissions load originating from different industrial operations in Angul region. PM₁₀ was estimated to be 9,548 tonnes per year, followed by PM_{2.5} (847 tonnes per year).

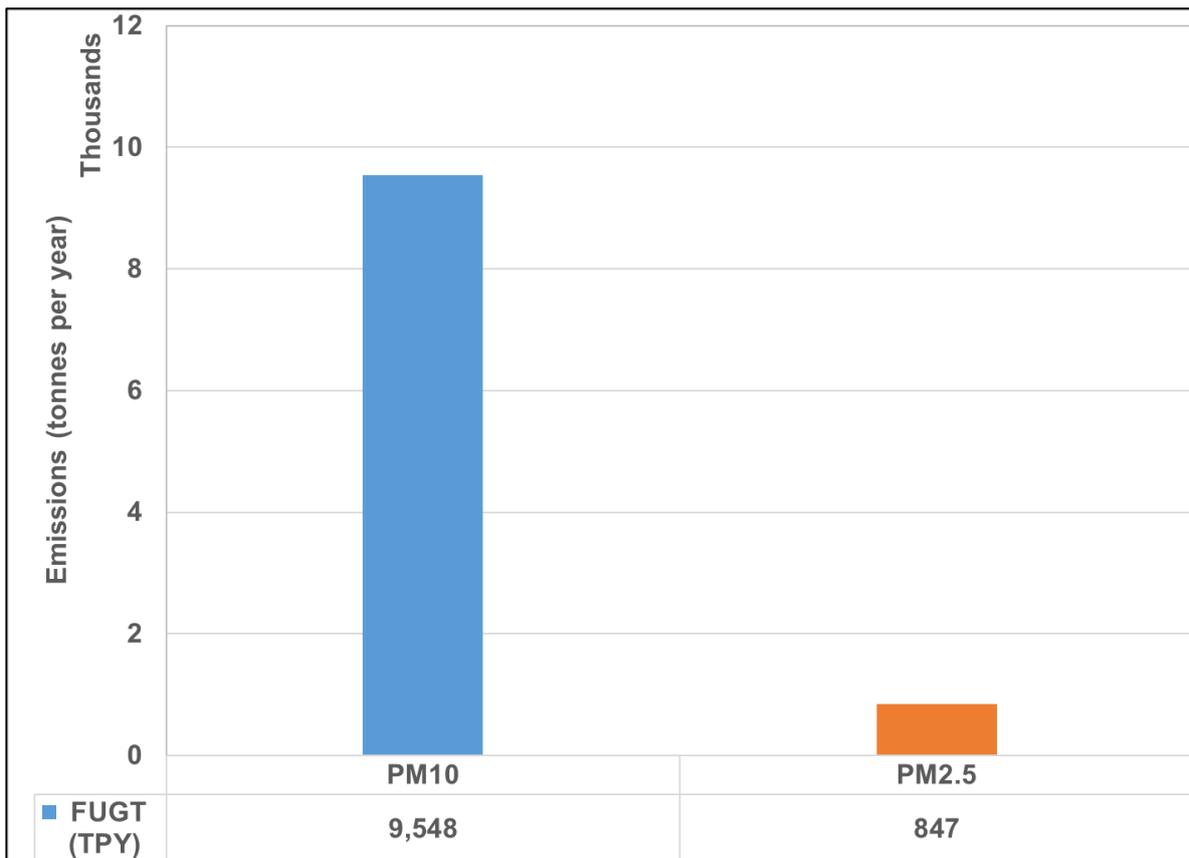


Figure 74: Emissions load (tonnes per year) of pollutants originating from fugitive operations in Angul region

3.7.4. Residential

Figure 75 depicts the emission loads originating from residential sector in Angul 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 3,427 tonnes per year, followed by NMVOCs (1,011 tonnes per year), PM₁₀ (361 tonnes per year), PM_{2.5} (240 tonnes per year), NO_x (122 tonnes per year) and SO₂ (100 tonnes per year).

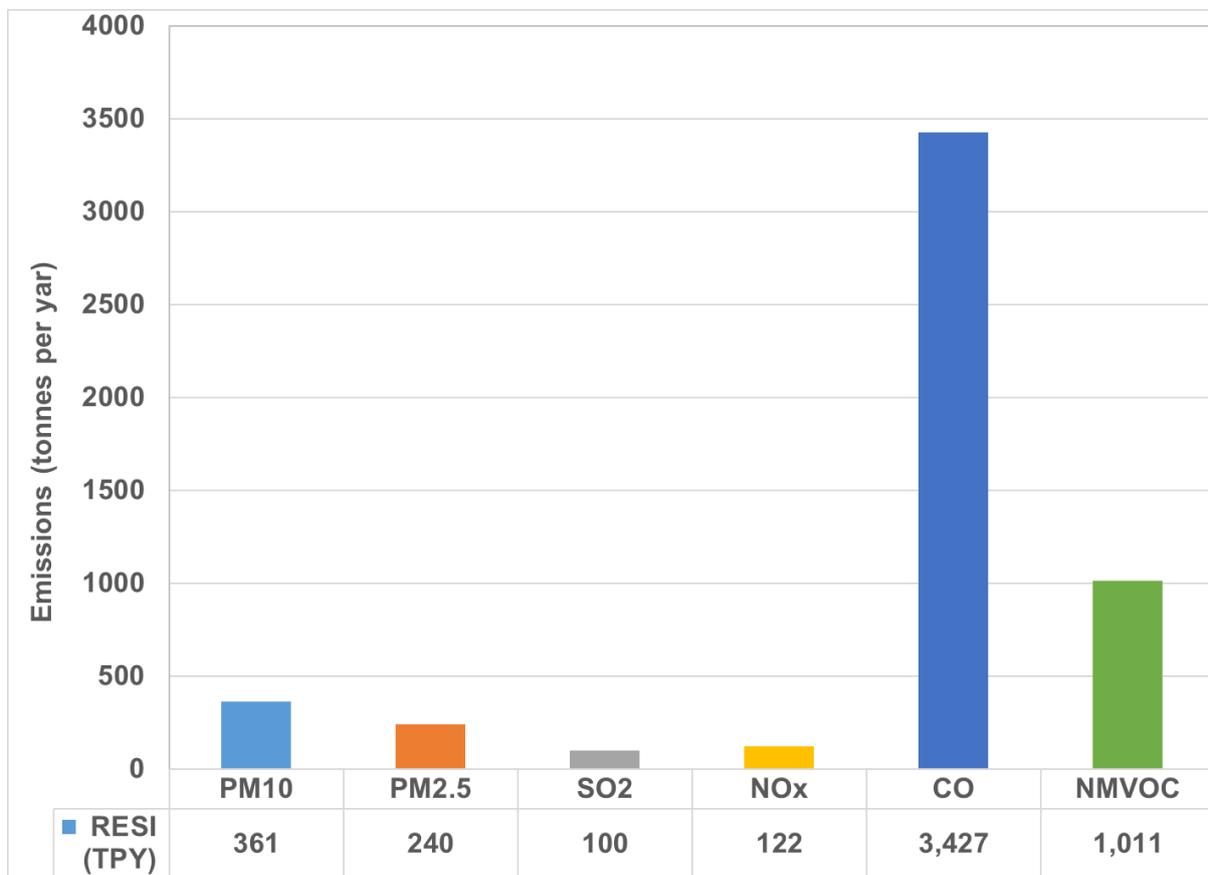


Figure 75: Emissions load (tonnes/year) of pollutants originating from residential sector in Angul region

3.7.5. Transport

Figure 76 shows the emissions of pollutants originating from transport sector in Angul region. It can be seen that CO and NMVOCs are the maximum contributing pollutants from transport sector in Angul with emissions of 6282 tonnes per year, followed by NO_x (2199 tonnes per year). Transport sector contribution to regional PM₁₀ and PM_{2.5} emissions was found to be 371 and 334 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 (Ketzell et al., 2007). Following the approach suggested by Sharma and Dikshit (2016), PM vehicular exhaust emission factors are used directly for quantifying PM₁₀ while PM_{2.5} fraction is assumed to be 90% of PM₁₀ emissions.

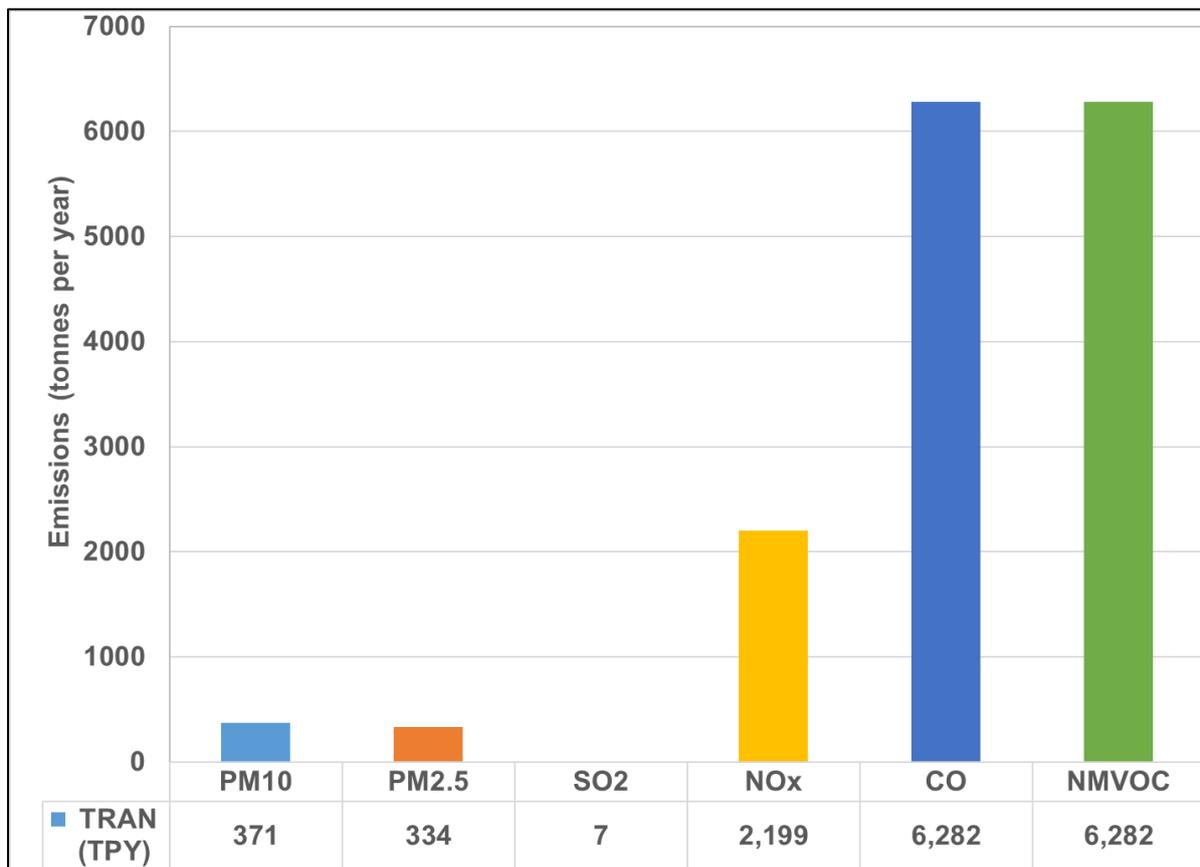


Figure 76: Emission loads (tonnes per year) of pollutants originating from the transport in Angul region

3.7.6. Road dust resuspension

The PM emissions generated due to road dust re-suspension in Angul region are depicted in Fig. 77. 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. PM₁₀ and emissions are estimated to be 3,103 tonnes per year and 751 tonnes per year in 2021. PM_{2.5} emissions from road dust re-suspension are about four times lower than PM₁₀ emissions

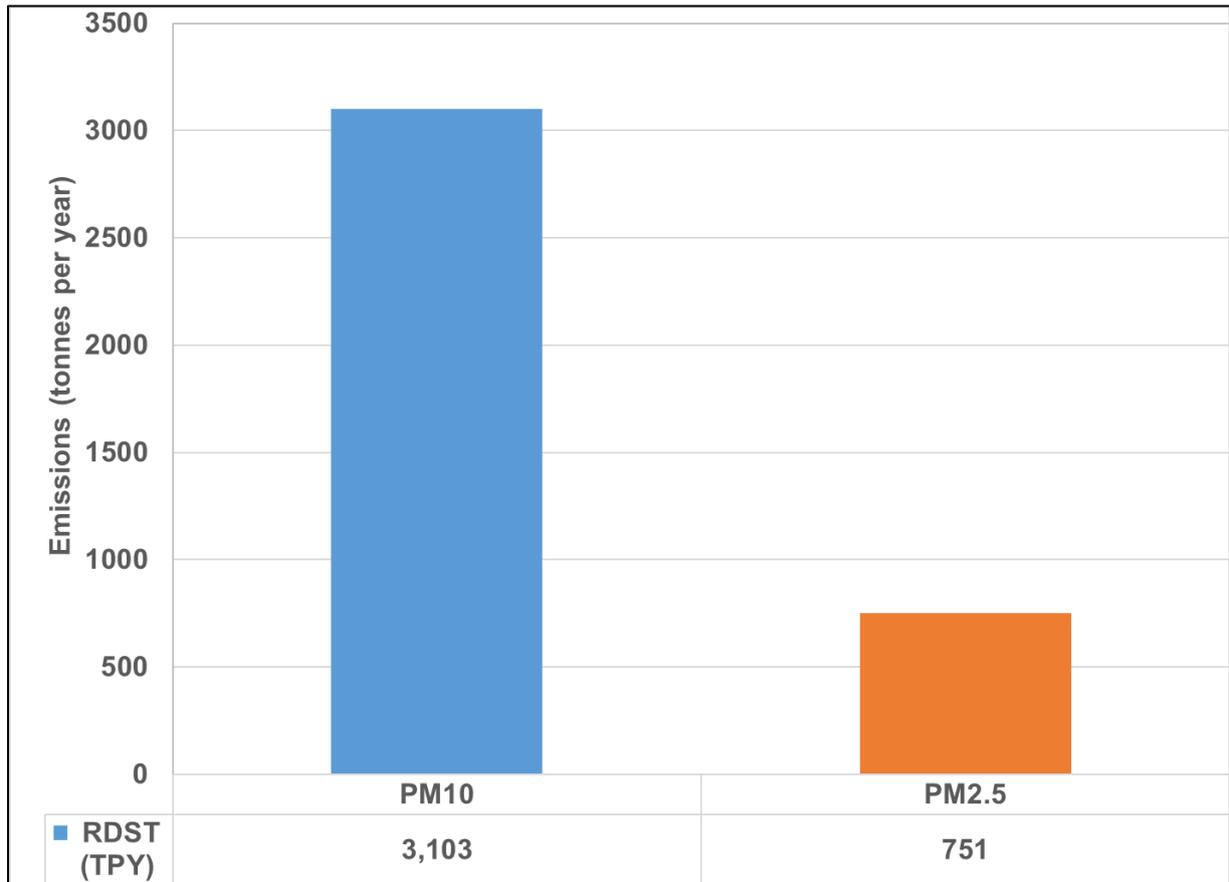


Figure 77: Emission load (tonnes per year) of pollutants originating from the road dust resuspension sector in Angul region

(Note: Emission loads for pollutants other than PM₁₀ and PM_{2.5} are “NOT APPLICABLE”)

3.7.7. Open waste burning

Figure 78 presents the emissions of air pollutants originating from open waste burning in Angul region. It is observed that, due to incomplete combustion of the waste a large amount of CO would be introduced into the atmosphere (859 tonnes per year) followed by NMVOCs (186 tonnes per year), PM₁₀ (179 tonnes per year) PM_{2.5} (167 tonnes per year), NO_x (26 tonnes per year) and SO₂ (11 tonnes per year).

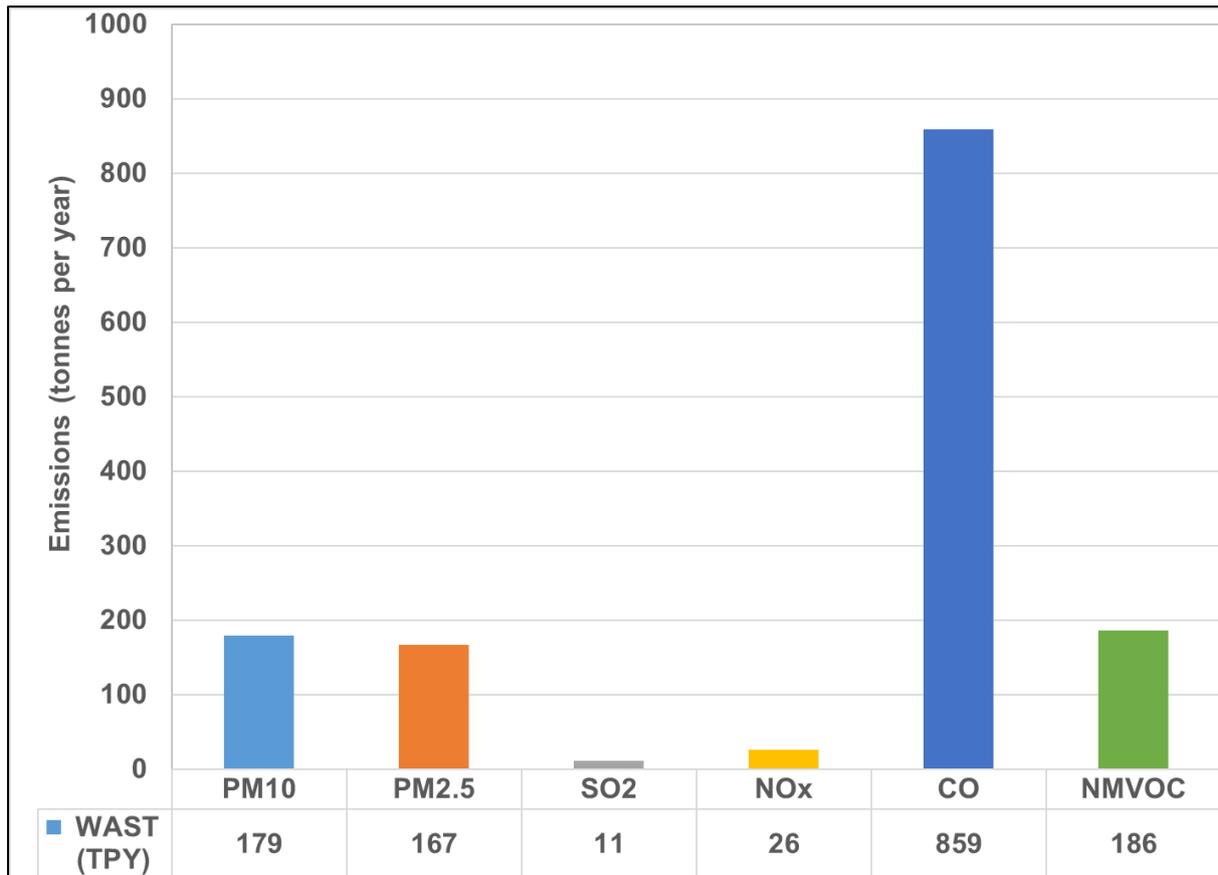


Figure 78 Emission load (tonnes per year) of pollutants originating from the open waste burning sector in Angul region

3.7.8. Construction

Figure 79 shows the PM₁₀ and PM_{2.5} emissions originating from construction activities in Angul region. Construction sector is estimated to contribute about 136 tonnes per year of PM₁₀ and 23 tonnes per year of PM_{2.5}.

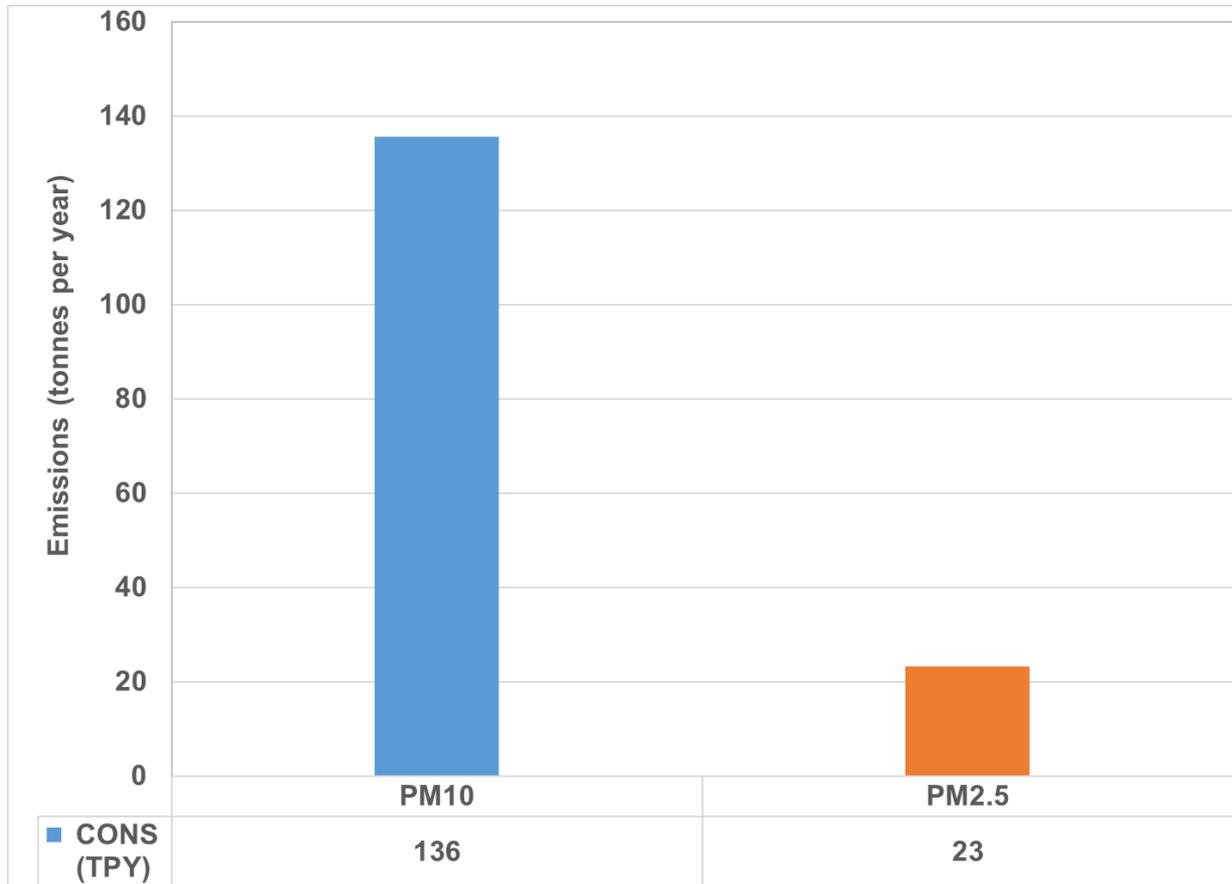


Figure 79: Emissions load (tons/year) of pollutants originating from construction activities in Angul region

(Note: Emission loads for pollutants other than PM₁₀ and PM_{2.5} are “NOT APPLICABLE”)

3.7.9. Brick Kilns

Figure 80 shows the emissions of pollutants originating from brick kilns in Angul region. CO is the maximum contributor with emissions of 927 tonnes per year, followed by PM₁₀ (128 tonnes per year), PM_{2.5} (91 tonnes per year), SO₂ (36 tonnes per year), and NMVOC (15 tonnes per year). NO_x was found to be lowest contributor with emission of less than 0.5 tonnes per year.

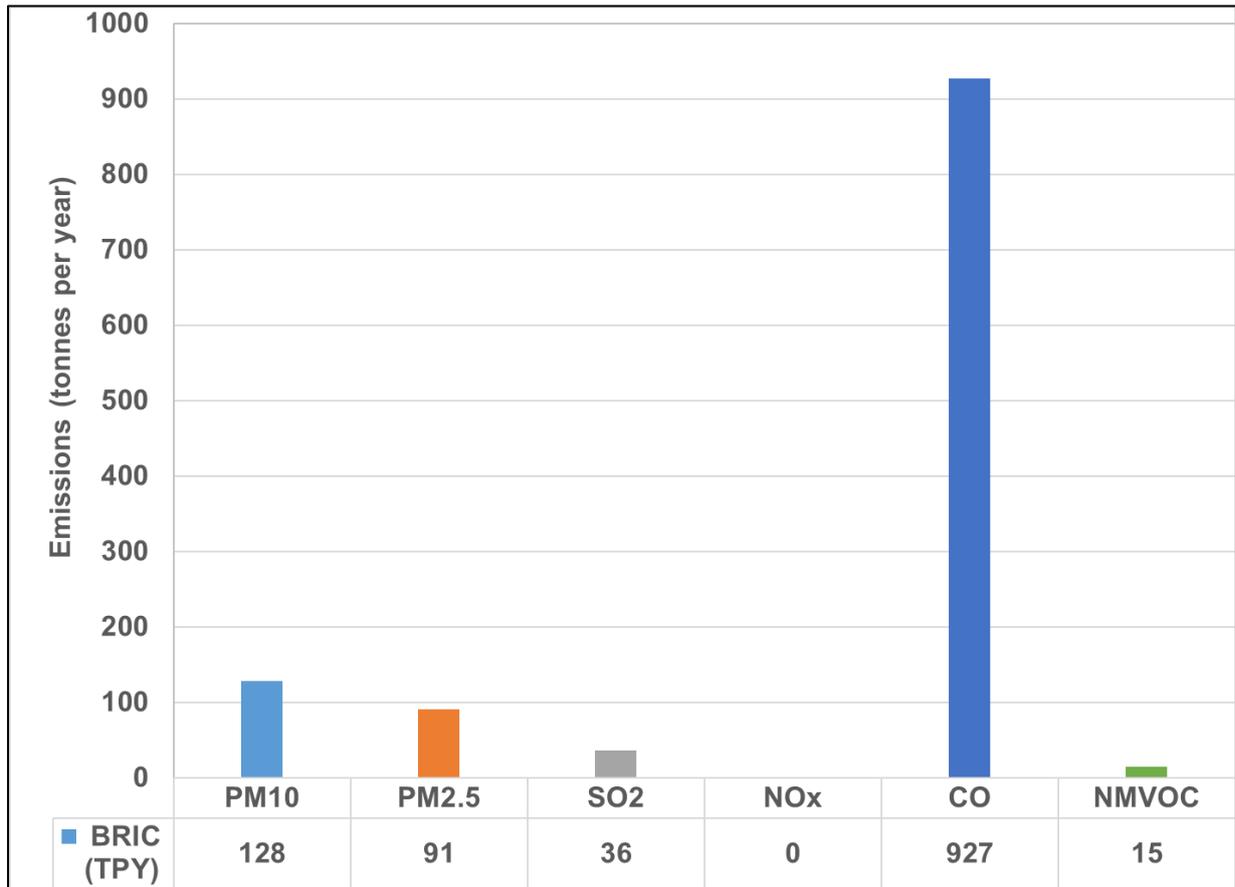


Figure 80 Emissions loads (tonnes per year) of pollutants originating from brick kilns in Angul region

3.7.10. Industrial diesel generators

As discussed earlier, industrial diesel generators are only used during the power failure emergency, they have very lesser emissions. Figure 81 shows emissions of pollutants originating from diesel generators usage. NMVOC is the major contributor (199 tonnes per year) from industrial diesel generators, in Angul region. Followed by NO_x (139 tonnes per year), CO (30 tonnes per year), PM₁₀ (10 tonnes per year), SO₂ (9 tonnes per year) and PM_{2.5} (8 tonnes per year).

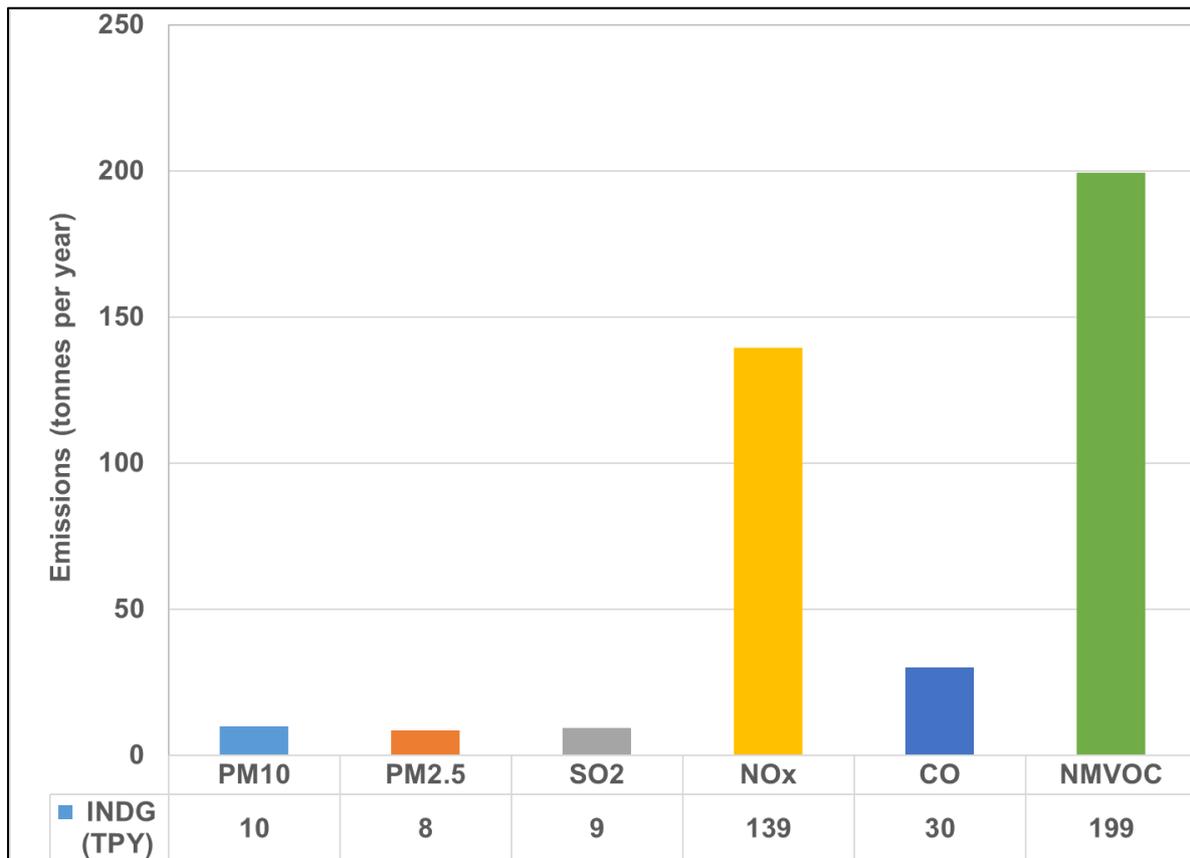


Figure 81 Emissions load (tonnes per year) of pollutants originating from industrial diesel generators usage in Angul region

3.7.11. Crematoria

Figure 82 shows the emissions of pollutants originating from cremation activities in Angul region. Due to incomplete combustion of wood in wood pyres, CO is the maximum contributor with emissions of 87 tonnes per year, followed by NMVOCs (48 tonnes per year), PM₁₀ (17 tonnes per year) and PM_{2.5} (8 tonnes per year). NO_x was found to contribute 2 tonnes per year of emissions, while SO₂ was found to be the lowest among all pollutants with less than 0.5 tonnes per year of emissions.

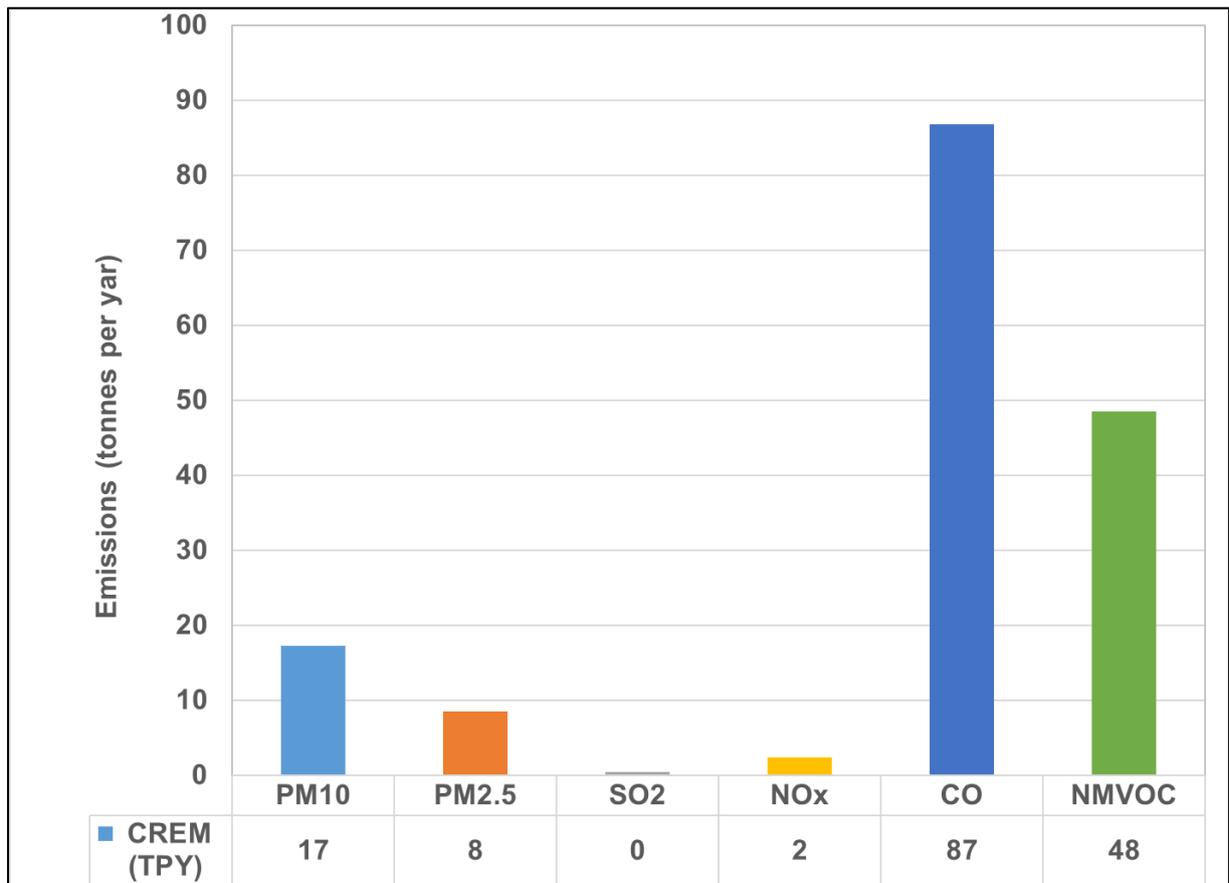


Figure 82 Emissions loads (tonnes per year) of pollutants originating from crematoria in Angul region

3.7.12. Hotels, restaurants and bakeries

Figure 83 presents the emissions load contributed by hotels, restaurants, bakeries and open eateries in Angul region. CO has been found to be the major contributor 48 tonnes per year, followed by, PM₁₀ (27 tonnes per year), NMVOC (26 tonnes per year), SO₂ (23 tonnes per year), PM_{2.5} (17 tonnes per year), and NO_x (9 tonnes per year).

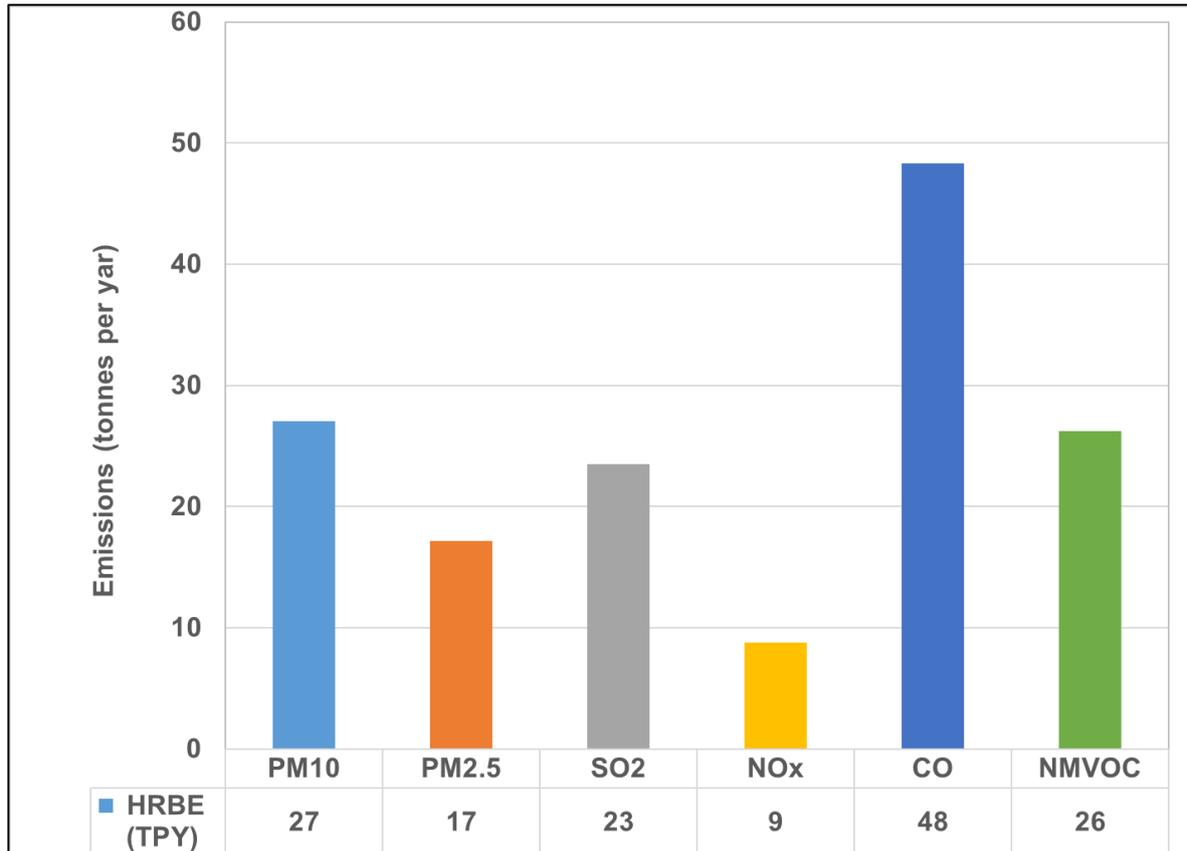


Figure 83: Emissions load (tonnes per year) of pollutants originating from hotels, restaurants and bakeries in Angul region

3.6. Regional Emission Inventory

The overall baseline emission inventory (Year 2021) for the Angul region is presented in Table 16. The sectoral contribution to pollutants is provided in Fig. 84 to 89.

The total PM₁₀ emission load in the Angul region is estimated to be 24,124 tonnes per year. The top four contributors to PM₁₀ emissions are fugitive emissions (39.5%), followed by thermal powerplants (27.2%), industries (15.3%), and resuspended road dust (12.8%). 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 Angul region is estimated to be 7,241 tonnes per year. The top four contributors to PM_{2.5} emissions are thermal powerplants (40.2%), industries (25.5%), fugitive emissions (11.7%), and re-suspended road dust (10.4%). Other PM_{2.5} contributors include transport (4.6%), residential (3.3%), and waste burning (2.3%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

SO₂ emission load in the Angul region is estimated to be 1,25,996 tonnes per year. Due to large coal usage, thermal powerplants (70.5%) and Industries (29.3%), constitute more than 99% emissions of SO₂ in the region. All other sectors together contribute less than 1% of the SO₂ emissions.

The annual NO_x emission load in the Angul region is estimated to be 62,900 tonnes per year. Similar to SO₂, thermal powerplants (70.5%) and Industries (24.5%) are the largest contributors to NO_x emissions, followed by transport sector (3.5%). Remaining sectors such as open waste burning, residential together contributes less than 1%.

The total annual CO emissions in the Angul region are estimated to be 14,764 tonnes per year. Transport sector is the major contributor to CO emissions i.e. 42.5%, followed by Residential (23.2%), thermal powerplants (15.6%), brick kilns (6.3%), open waste burning (5.8%), and industries (5.4%).

Fig. 90-94 shows the spatial distribution of pollutants over Angul-Talcher region for baseline year 2021. Considering the importance of the emission sources in surrounding region, the spatial distribution provides an overview of annual pollutant emissions in Angul and Talcher regions combined.

Table 16: Baseline (Year 2021) Emission Inventory for the Angul region (tonnes per year) of Odisha

Sector	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO	NM VOC
Industries	3696 ± 762	1847 ± 381	36946 ± 4131	15405 ± 3176	797 ± 164	108 ± 22
Thermal powerplants	6576 ± 1356	2908 ± 600	88863 ± 9935	44998 ± 9279	2307 ± 476	185 ± 38
Fugitive emissions	9548 ± 4868	847 ± 432	NA	NA	NA	NA
Residential	361 ± 184	240 ± 122	100 ± 14	122 ± 62	3427 ± 1747	1011 ± 516
Transport	371 ± 97	334 ± 88	7 ± 1	2199 ± 1161	6282 ± 3317	6282 ± 3317
Road dust	3103 ± 694	751 ± 168	NA	NA	NA	NA
Open waste burning	179 ± 97	167 ± 90	11 ± 6	26 ± 14	859 ± 463	186 ± 100
Construction	136 ± 28	23 ± 5	NA	NA	NA	NA
Brick Kilns	128 ± 69	91 ± 49	36 ± 19	0 ± 0	927 ± 499	15 ± 8
Industrial DG	10 ± 5	8 ± 4	9 ± 2	139 ± 71	30 ± 15	199 ± 102
Crematoria	17 ± 9	8 ± 4	0 ± 0	2 ± 1	87 ± 44	48 ± 25
Hotels, Restaurants, Bakeries and Open eateries	27 ± 15	17 ± 9	23 ± 5	9 ± 5	48 ± 26	26 ± 14
Total	24152 ± 8184	7241 ± 1951	125996 ± 14114	62900 ± 13769	14764 ± 6752	8060 ± 4142

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

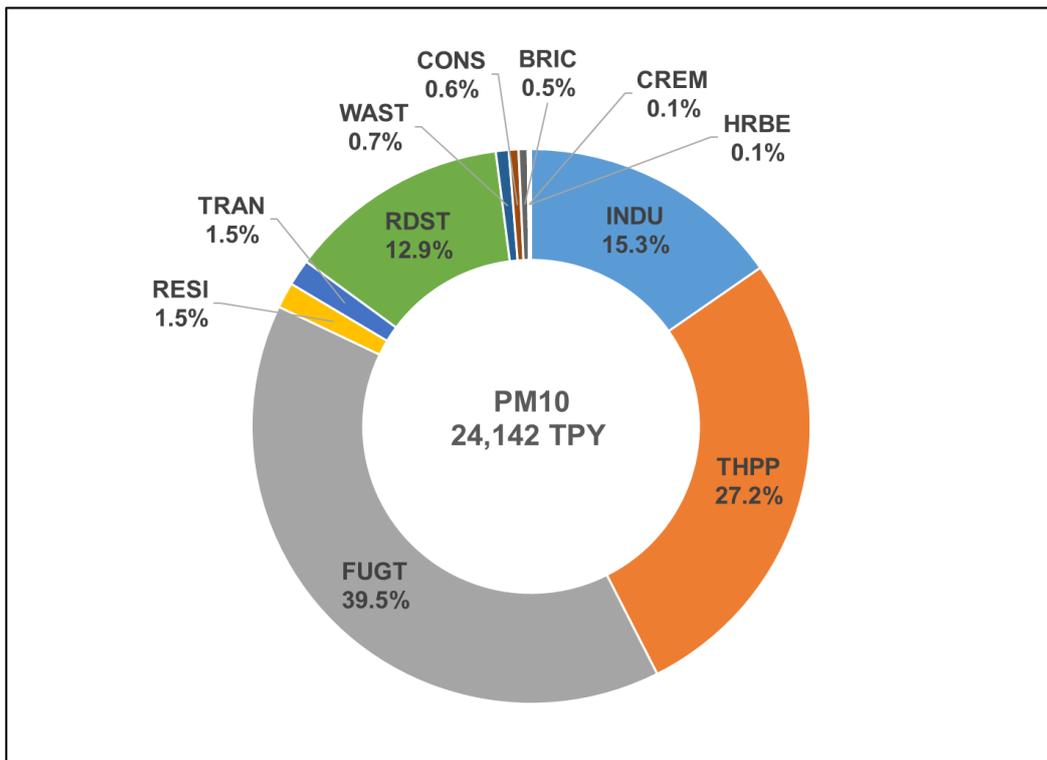


Figure 84 Sectoral contribution to annual PM₁₀ emissions in Angul Region

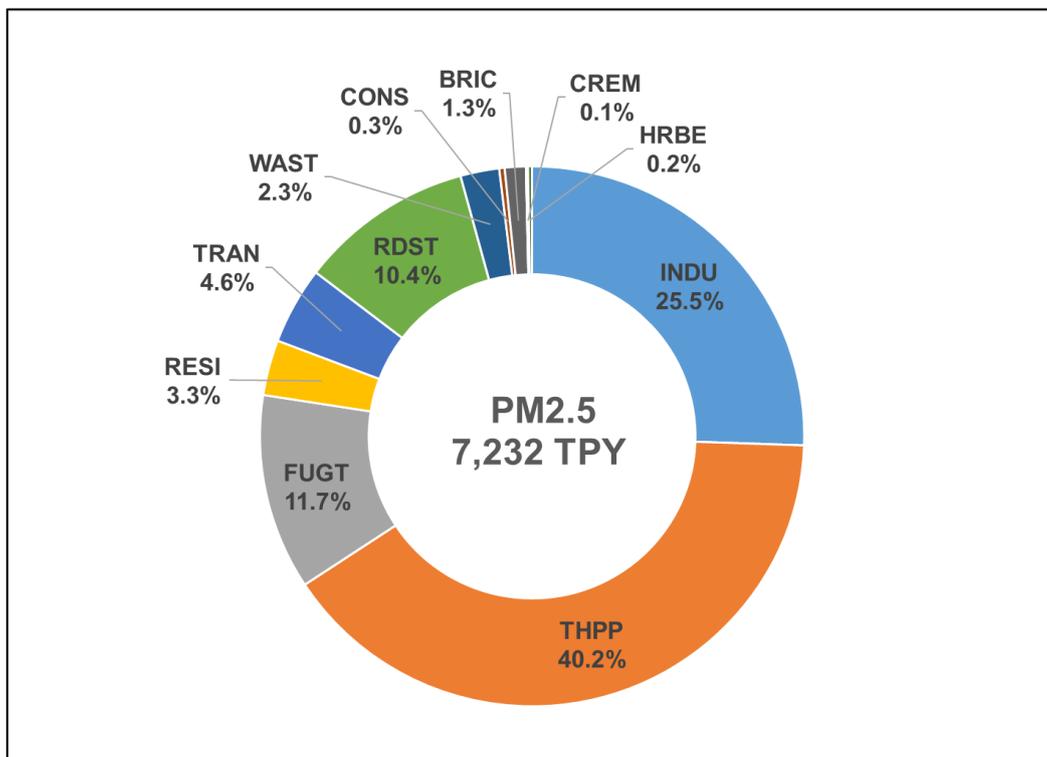


Figure 85 Sectoral contribution to annual PM_{2.5} emissions in Angul region

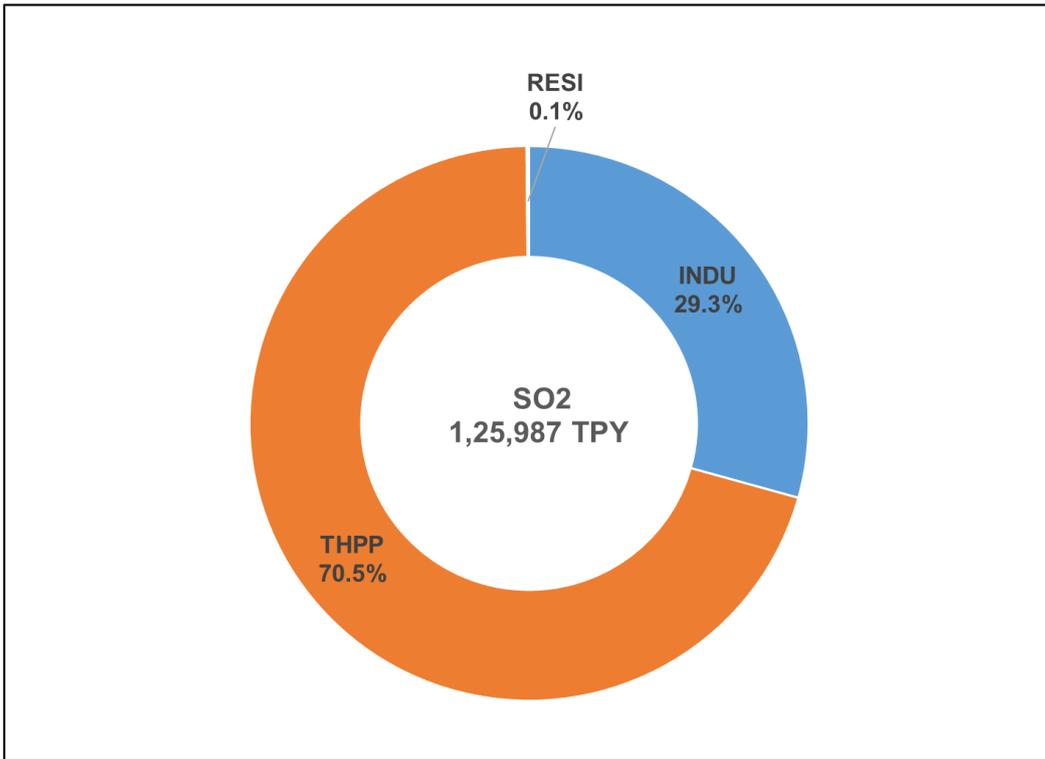


Figure 86 Sectoral contribution to annual SO₂ emissions in Angul region

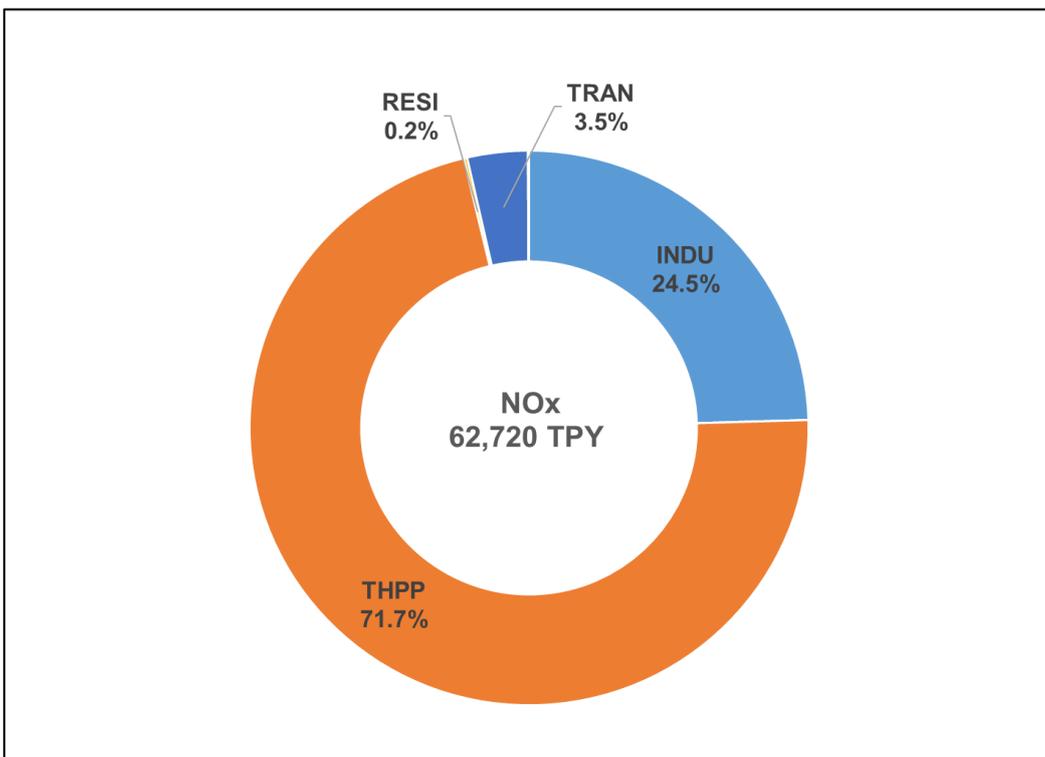


Figure 87 Sectoral contribution to annual NO_x emissions in Angul region

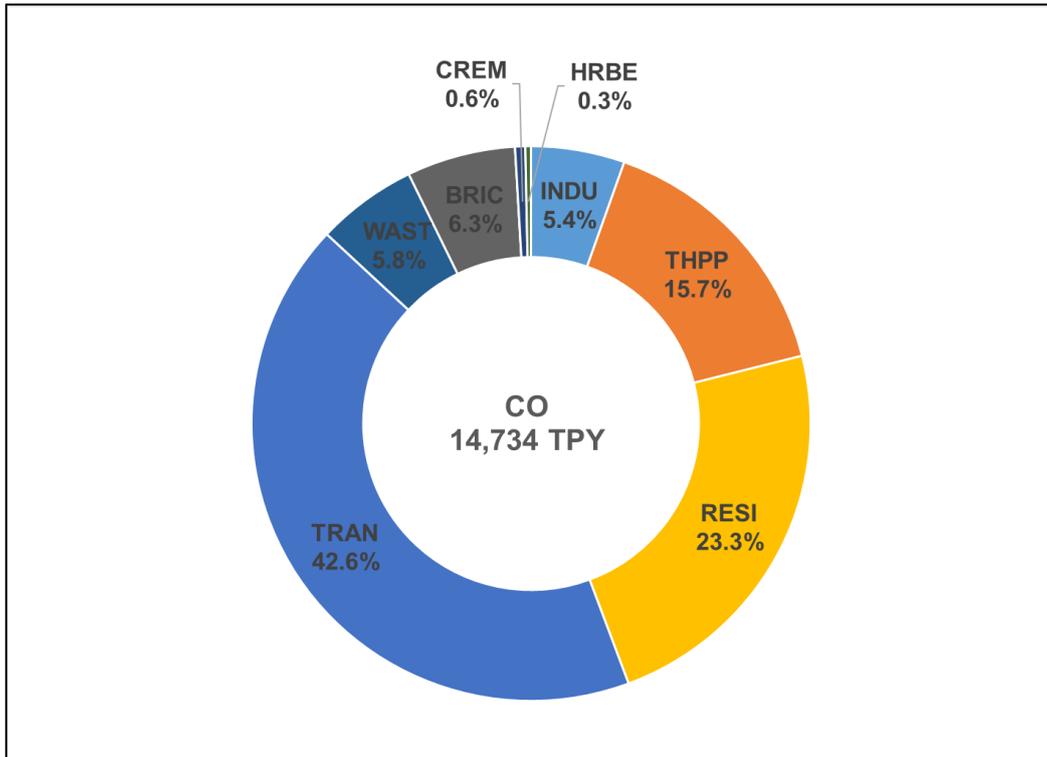


Figure 88 Sectoral contribution to annual CO emissions in Angul region

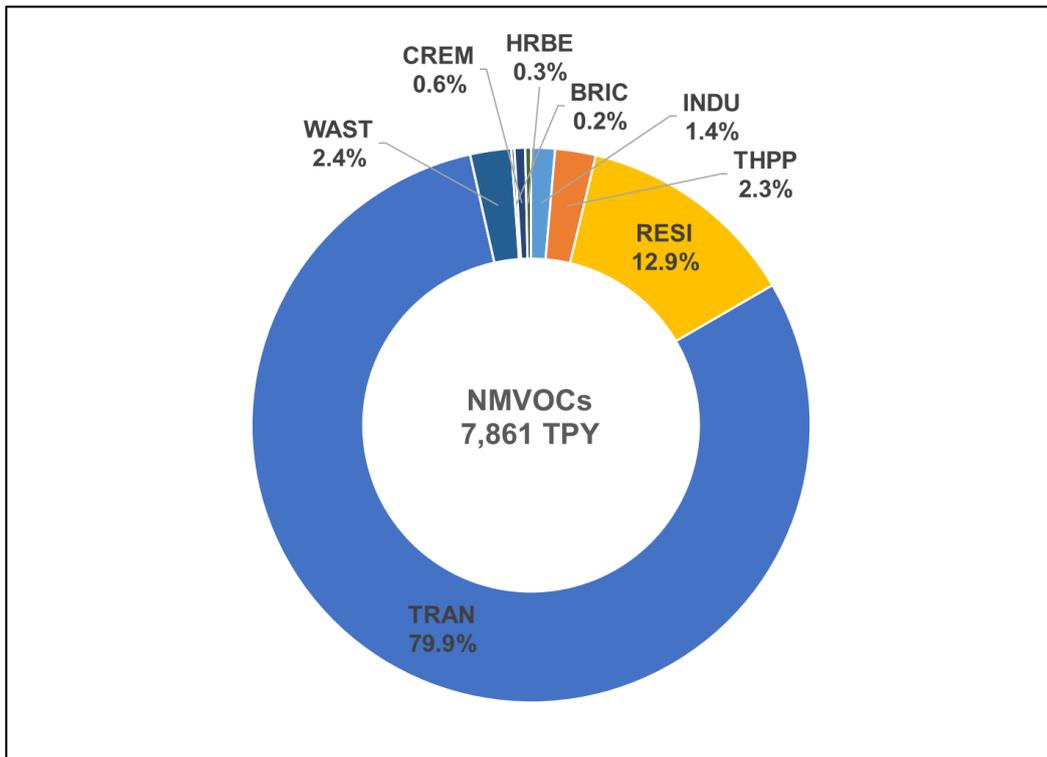


Figure 89 Sectoral contribution to annual NMVOC emissions in Angul region

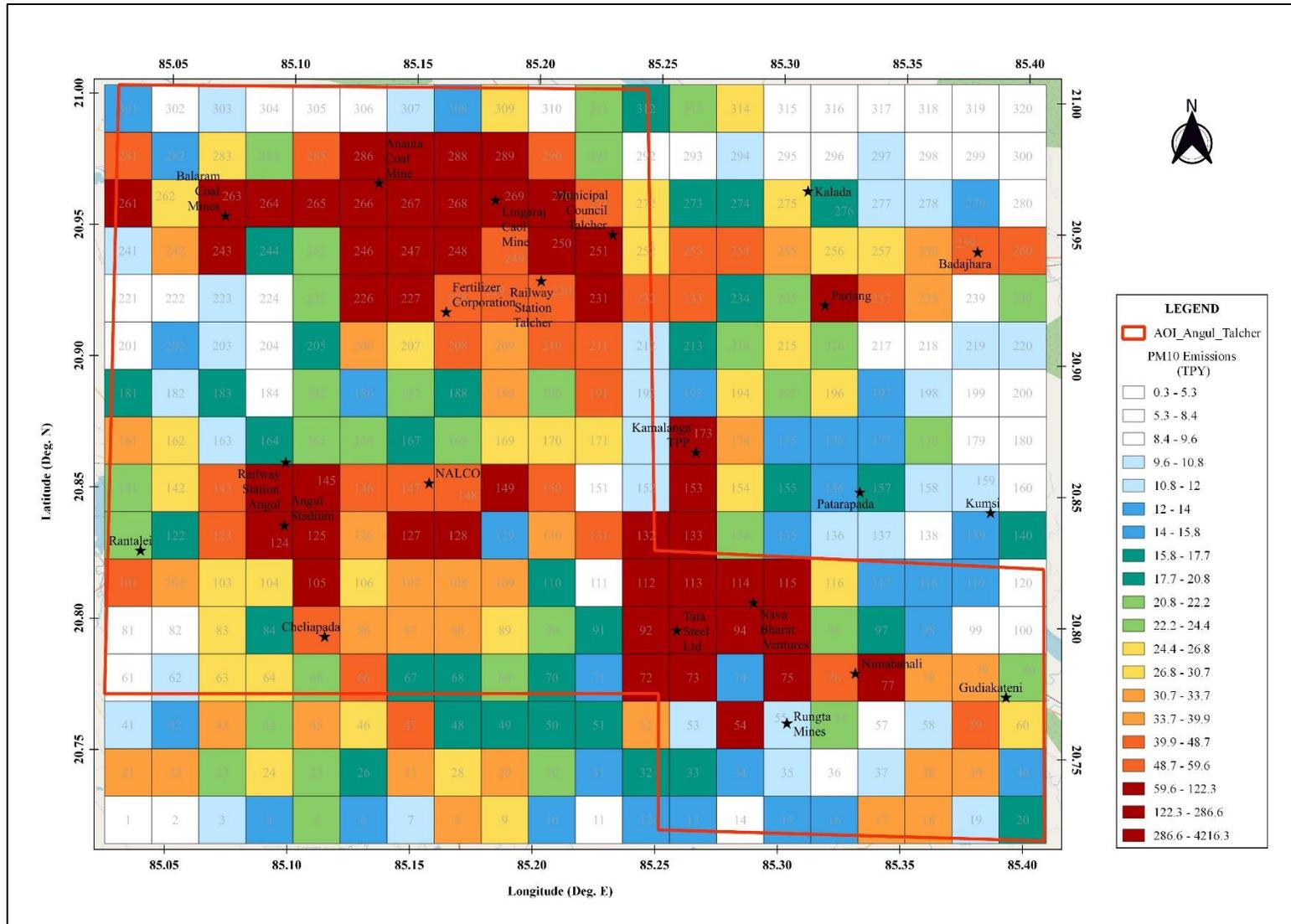


Figure 90: Spatial distribution of PM₁₀ emissions (tonnes per year) in Angul-Talcher region for year 2021

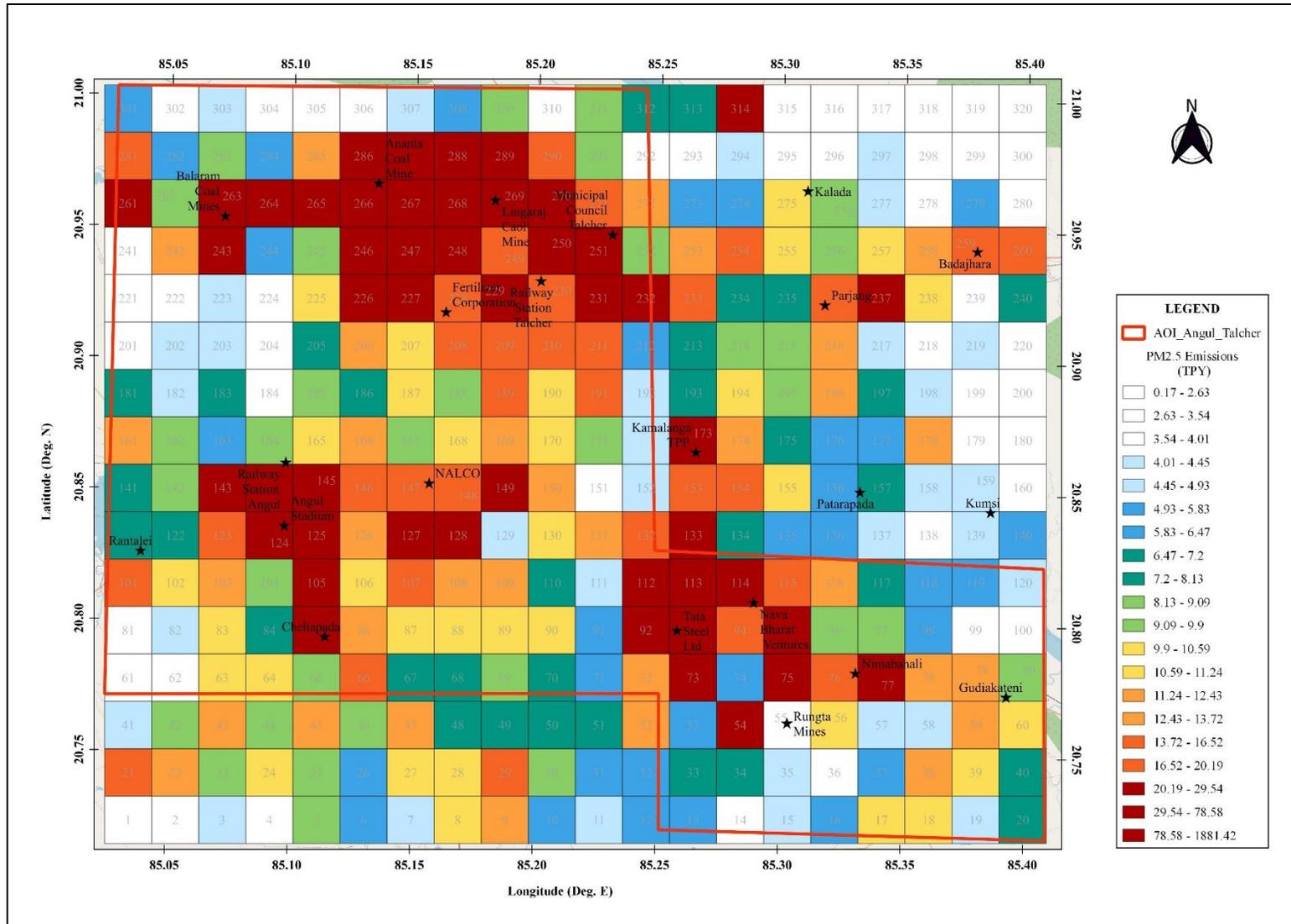


Figure 91: Spatial distribution of PM_{2.5} emissions (tonnes per year) in Angul-Talcher region for year 2021

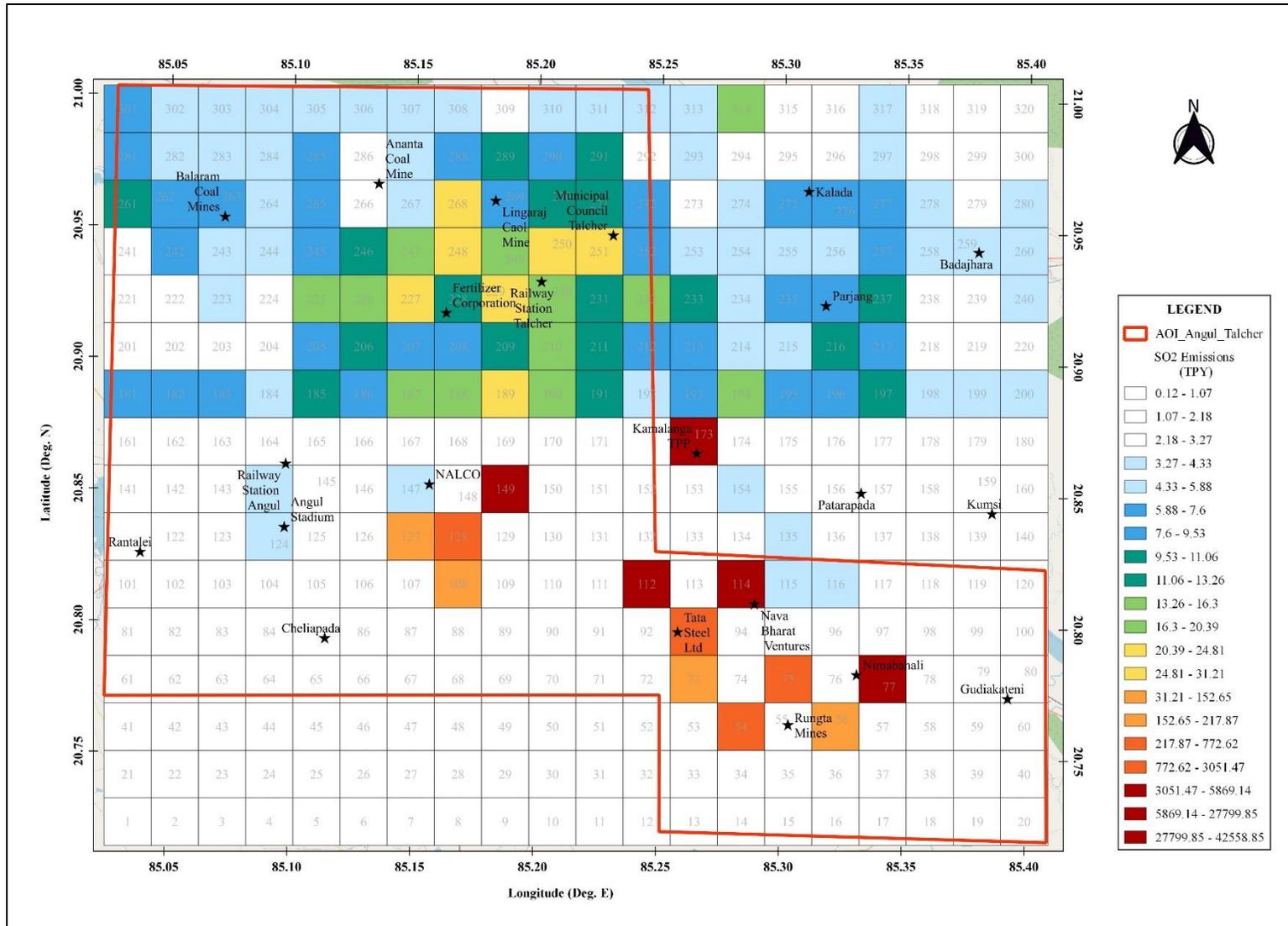


Figure 92 Spatial distribution of SO₂ emissions (tonnes per year) in Angul-Talcher region for year 2021

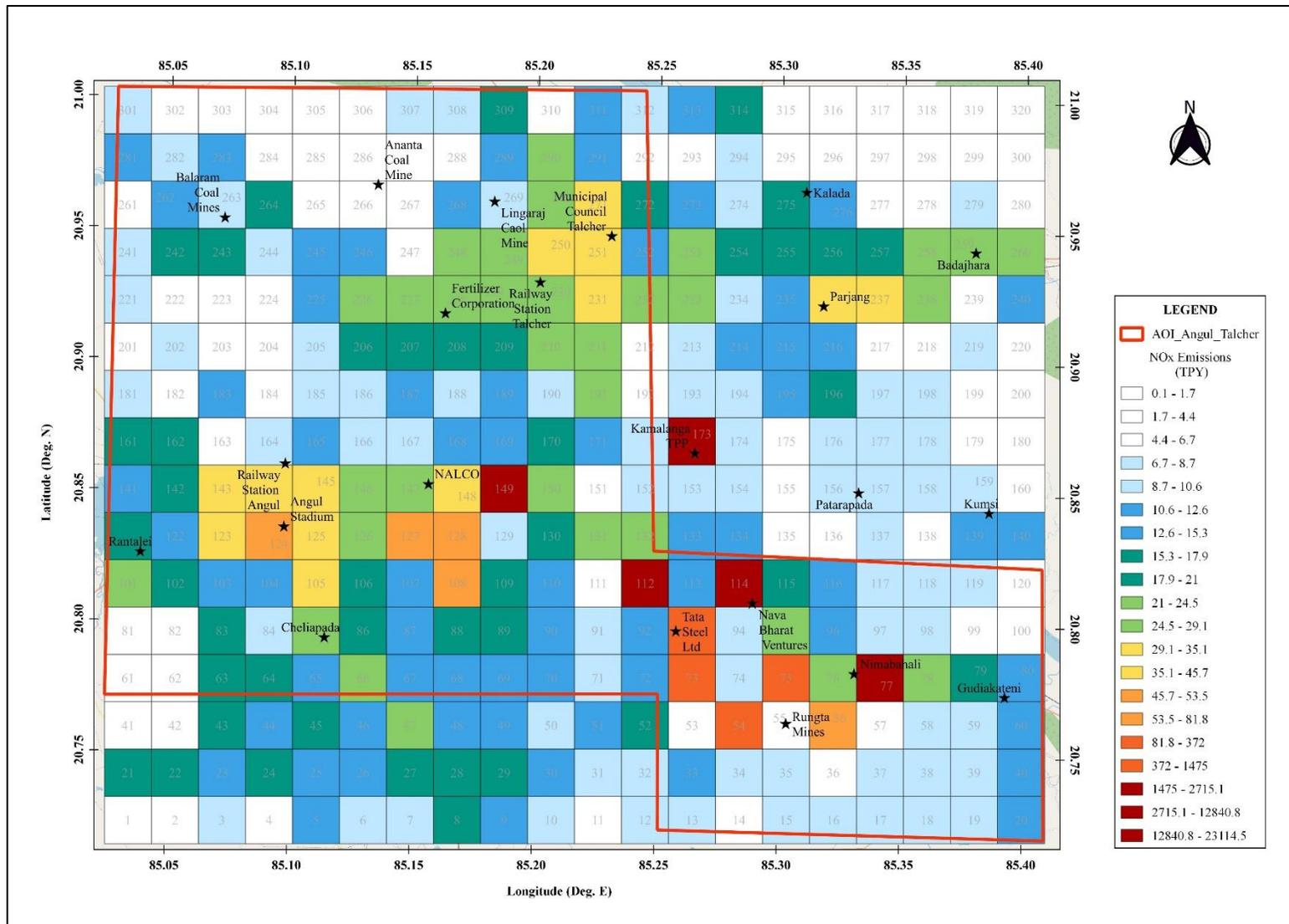


Figure 93 Spatial distribution of NO_x emissions (tonnes per year) in Angul-Talcher region for year 2021

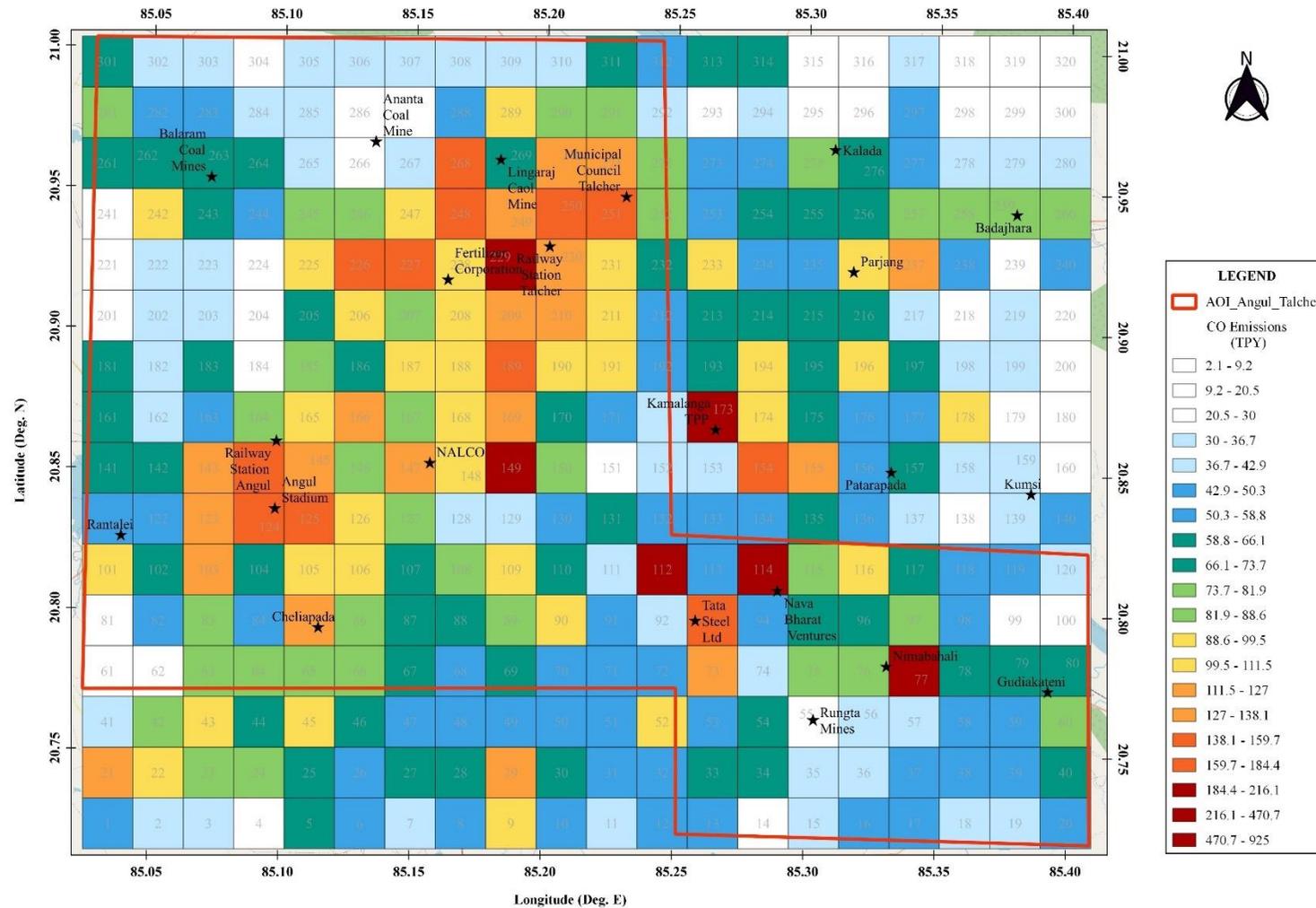


Figure 94 Spatial distribution of CO emissions (tonnes per year) in Angul-Talcher region for year 2021

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 (AMS/EPA **R**egulatory **M**ODEl), 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).

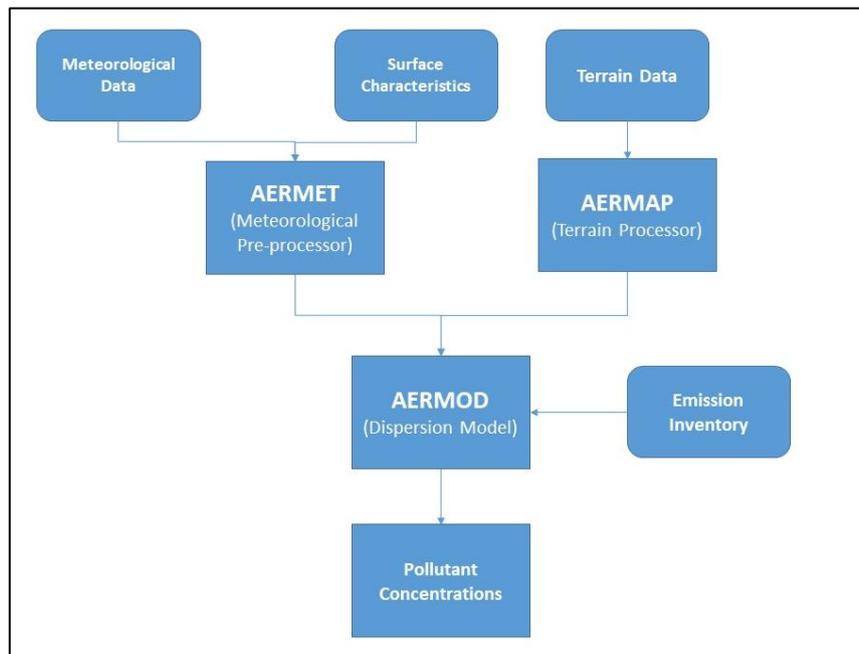


Figure 95 Flow diagram of AERMOD Modelling System used in this study to simulate the air pollutant concentrations

Fig. 95 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 (z_i), 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.

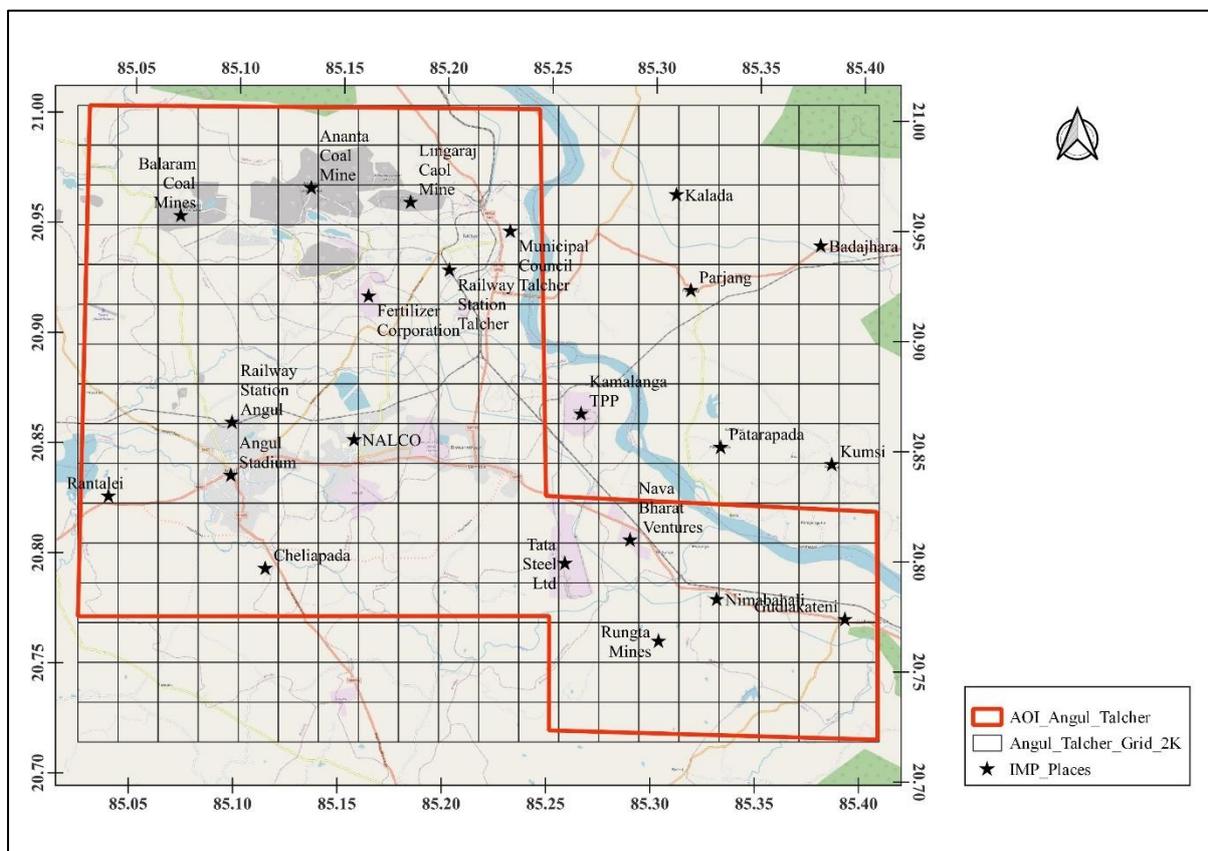


Figure 96 Map showing dispersion modelling domain i.e. Angul-Talcher region and surrounding areas

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 96). Due to proximity and importance of regional sources, Angul and Talcher 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 Angul-Talcher 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 17 provides summary of ERA5 reanalysis dataset.

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

Table 17 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

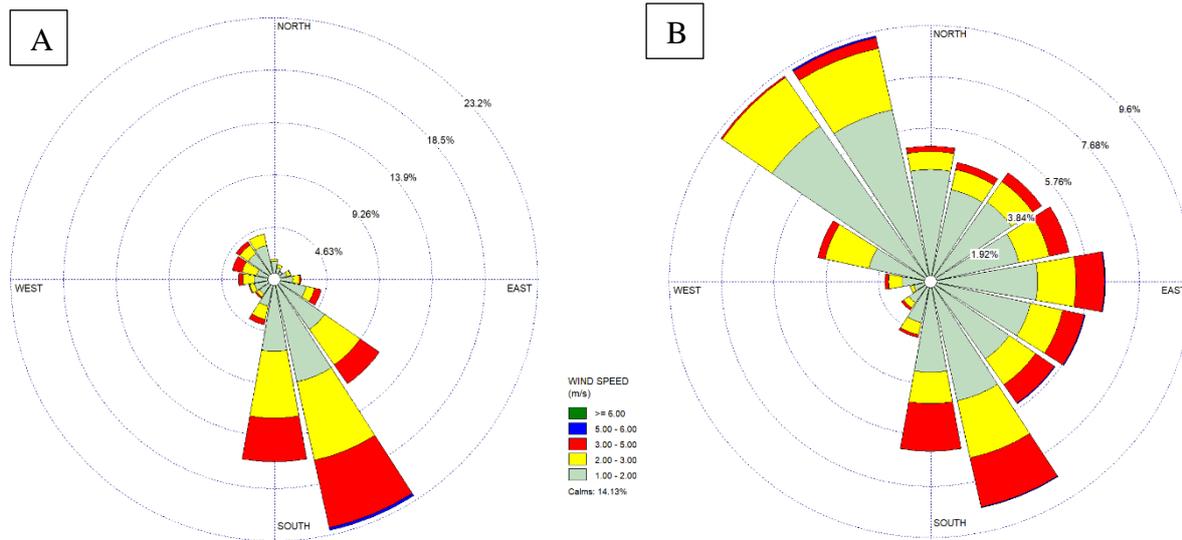


Figure 97 Windrose diagrams showing the wind speed and direction frequency distribution over Angul-Talcher region during summer (A) and winter (B) seasons of year 2022

Fig. 97 shows the wind speed and direction frequency distribution over Angul-Talcher 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 (~14%) of calm winds i.e. < 1 m/s. The predominant wind directions during the summer season over Angul-Talcher region are observed to be from south of south-west (SSW) (~23%); followed by south (S, >14%), and east of south-west (ESW) (frequencies > 5%).

In the winter season, lesser wind variations were observed with slightly higher frequencies of (~18%) calm winds (i.e. < 1 m/s) indicating stable atmospheric conditions. The predominant winds are observed to be blowing from north-west (NW, ~10%) and north of north-west (NNW, ~10%) followed by south of south-west (SSW) (~8%), east (E, ~6%) and south (S, >5%).

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 Angul-Talcher region was downloaded and processed using AERMAP processor.

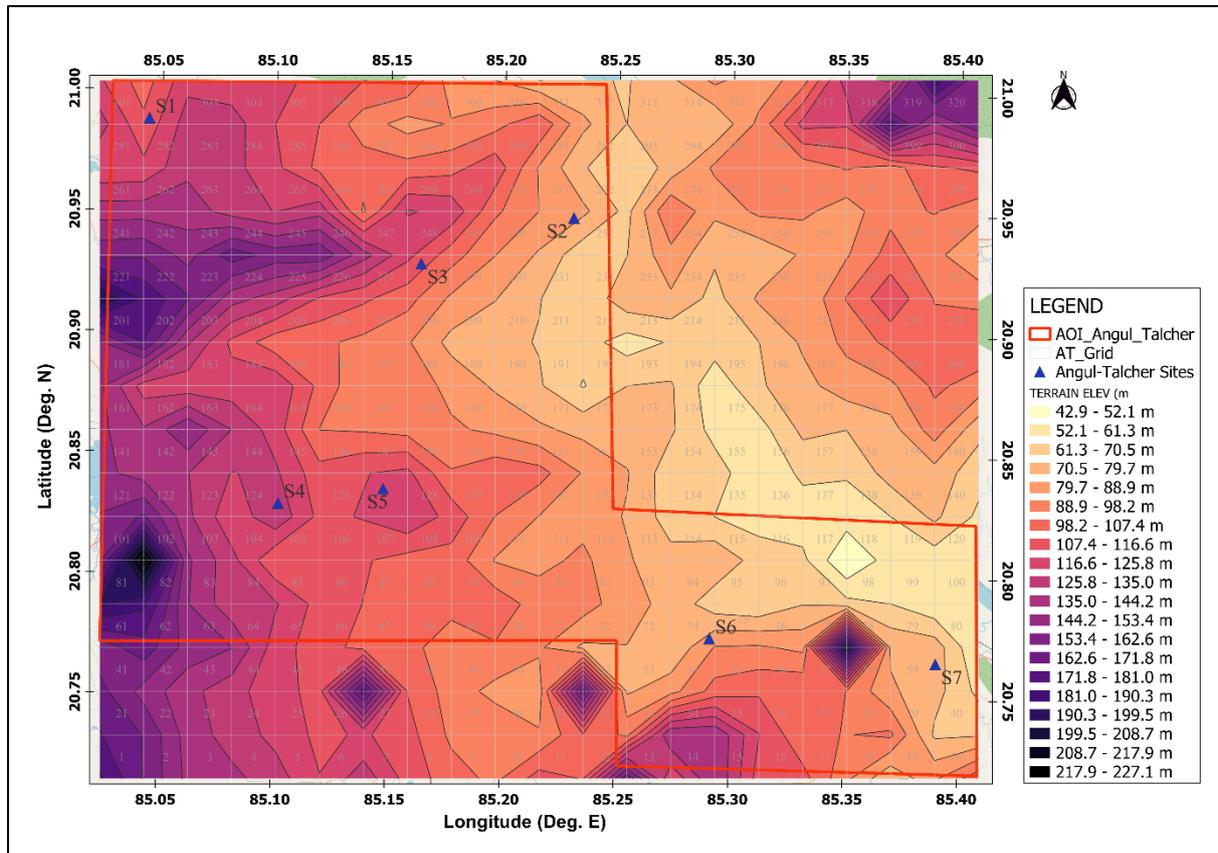


Figure 98 Contour map showing terrain elevations extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m)

Fig. 98 shows the contour map showing terrain elevations over Angul-Talcher 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 ~42.9 m (above MSL) towards eastern part i.e. near the river channel, to a maximum of ~227.1 m (above MSL) towards 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, mines, 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. Mines and 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 357 gridded receptors. Additionally, seven discrete receptors are also configured to represent one CAAQM station operated by OSPCB at Talcher Coal Fields and seven sampling locations for ARAI sampling sites. The AERMOD predicted concentrations at Talcher Coal Fields were used for model validation purpose. The height of each receptor is set to 1.5 m above ground level i.e. mean breathing level for humans. Figure 99 shows map of the modelling domain overlaid by gridded and discrete receptors configured in this study.

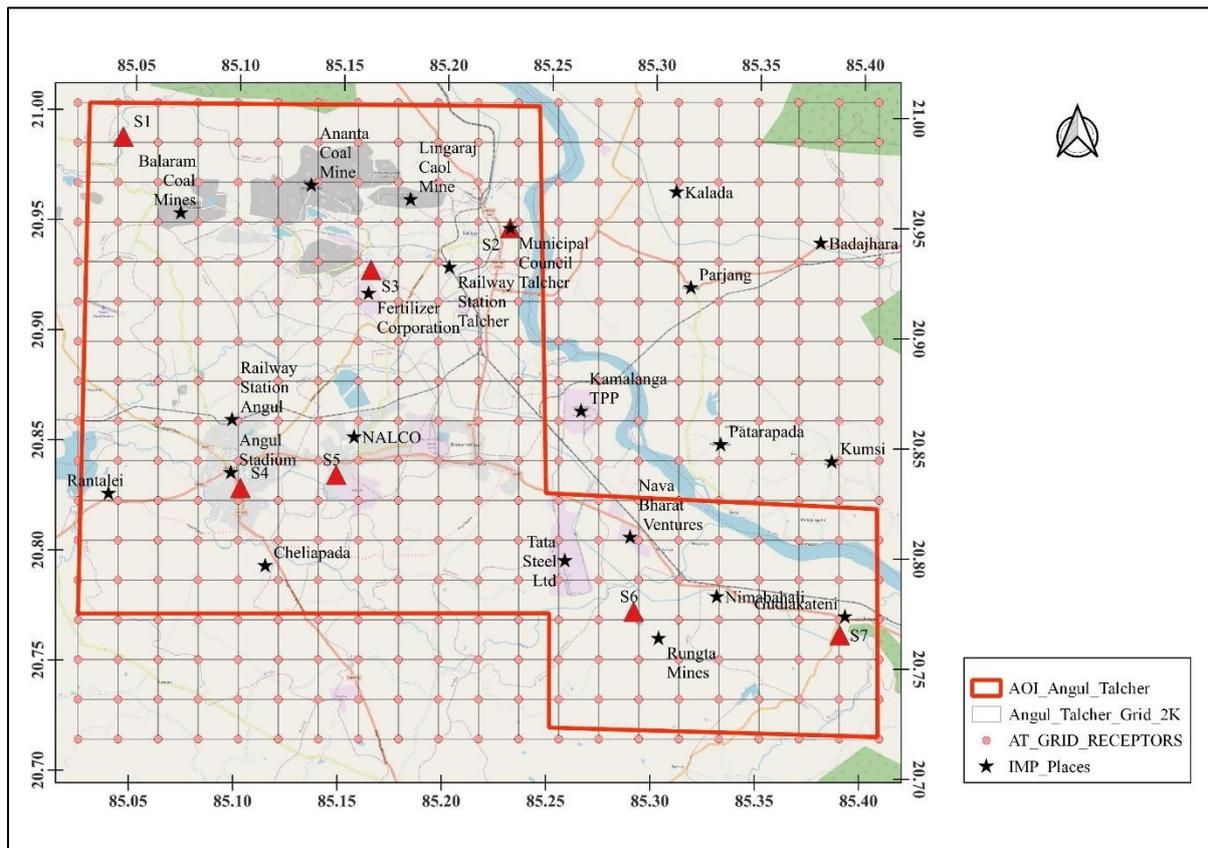


Figure 99 Map showing modelling domain overlaid by gridded and discrete receptors configured in this study.

Table 18 summarizes the details of dispersion model, source and receptor configurations, meteorology and geophysical data used for dispersion modelling simulations.

Table 18 Summary of AERMOD dispersion modelling setup used in this study

S. No.	Description	Symbol	Details
1.	Length of modelling domain in X-direction	X	40 km
2.	Length of modelling domain in Y-direction	Y	32 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}	357
7.	Total number of discrete receptors	N_{DISC}	7
8.	Source configuration in AERMOD	--	<ul style="list-style-type: none"> • Industries, TPP, DG, FCBTK: Point source • Clamp Brick kilns: Volume source • Mines, 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: <ul style="list-style-type: none"> • Dry bulb temperature • Wet bulb temperature • Cloud cover • Wind speed • Wind direction
10.	Meteorology: Upper air soundings	--	ERA5 fifth generation ECMWF reanalysis <ul style="list-style-type: none"> • Dry bulb temperature • Wet bulb temperature • Wind speed • Wind direction
11.	Terrain data	--	NASA's Shuttle Radar Topography Mission (SRTM) global product having 1 arc second (~30 meter) spatial resolution

4.6. Background Concentrations

The background pollutant concentrations play an important role in dispersion model validation. In this study, the lowest daily concentration of a pollutant reported, in a particular season, at Talcher Coalfields CAAQM station is used as the daily background concentration to reflect the regional-scale contributions from distant sources. A similar approach, has been successfully used in the earlier AERMOD validation studies (Dresser and Huizer, 2011). The minimum daily observed concentration in a season at Talcher Coalfields CAAQM station i.e. seasonal background, is added to the daily averaged concentrations estimated by AERMOD to get total daily concentration of pollutant under consideration.

4.7. Dispersion Model Validation

The AERMOD simulated daily averaged concentrations of pollutants including PM_{2.5}, PM₁₀, SO₂, NO₂, and CO are compared against observations at CAAQM observations at Talcher Coalfields for year 2022. The model performance is evaluated using six statistical measures including: mean, pearson correlation coefficient (R), Mean Bias (MB), Factor of two (FAC2) envelope and Mean Fractional bias (MFB) and Mean Fractional Error (MFE).

$$R = \frac{(\overline{C_o} - \overline{C_o}) (\overline{C_p} - \overline{C_p})}{\sigma_{C_o} \sigma_{C_p}} \dots \dots \dots \text{Eq. (17)}$$

$$MB = \frac{1}{N} \sum_{i=1}^N (C_{pi} - C_{oi}) \dots \dots \dots \text{Eq. (18)}$$

$$FAC2 = \text{Fraction of data that satisfy } 0.5 < \frac{C_p}{C_o} < 2.0 \dots \dots \dots \text{Eq. (19)}$$

$$MFB = \frac{2}{n} \sum_{i=1}^N \frac{(C_{pi} - C_{oi})}{(C_{pi} + C_{oi})} \dots \dots \dots \text{Eq. (20)}$$

$$MFE = \frac{2}{n} \sum_{i=1}^N \frac{|(C_{pi} - C_{oi})|}{(C_{pi} + C_{oi})} \dots \dots \dots \text{Eq. (21)}$$

Table 19 presents the summary of statistical measures obtained by comparing AERMOD simulated daily mean concentrations against the respective in-situ observations at Talcher Coalfields CAAQM location in Angul - Talcher region. Overall, the AERMOD model is found

to simulate the daily mean concentrations of the pollutants with a good accuracy compared to observations.

Table 19 Statistical summary of model performance for monthly simulated AERMOD concentrations

Parameter	Unit	Benchmark	PM _{2.5}	PM ₁₀	SO ₂	NO ₂	CO
Mean Obs	µg/m ³	-	40.01	76.51	28.88	19.53	1.19
Mean Mod	µg/m ³	-	41.21	115.65	24.59	16.54	0.43
Pearson R	Unitless	1	0.54	0.47	0.54	0.33	0.30
Mean Bias	µg/m ³	0	1.75	39.14	0.46	-2.99	-0.77
FAC2	%	100%	68%	42%	40%	64%	45%
MFB	µg/m ³	<= ±0.6	-0.13	-0.58	-0.48	-0.20	0.65
MFE	µg/m ³	<= ±0.75	0.52	0.74	0.93	0.64	0.71

The difference between seasonal mean modelled and observed values is less than 50% except CO. The negative values of mean bias (MB) for NO₂ and CO indicate under-estimation by AERMOD whereas positive MB values for PM_{2.5}, PM₁₀, and SO₂ indicates slight over-estimation of daily modelled values. This can be attributed to the uncertainties in emissions, source types and meteorology. The correlation coefficient (R) ranges between 0.30 to 0.54 for different pollutants indicates the model is able to reasonably capture temporal evolution of these pollutants.

FAC2 values greater than 40% for all pollutants indicate that predicted values are within factor of two envelop for more than 40% of time. The mean fractional bias (MFB) and mean fractional error (MFE) are less than ±0.6 and ±0.75, respectively, for all pollutants except CO, indicating a reasonable model performance.

4.8. Spatial Distribution of Modelled Pollutants

Fig. 100 - 104 shows the spatial distribution of modelled pollutant annual mean concentrations of PM₁₀, PM_{2.5}, SO₂, NO₂ 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. PM₁₀ and PM_{2.5} are observed towards the north and north western part of the study domain, followed by central part. These highest concentrations can be attributed to the air polluting sources such mining activities towards north and presence of industries and powerplants such as Bhushan Steel, Navbharat, BRG, GMR (central part). 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. north-eastern (NE) and south-western (SW), 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 SO₂ and NO₂ (Refer Fig. 102 - 103) is mainly governed by the stack emissions from industries and thermal powerplants followed by vehicular exhaust emissions, upto a certain extent. The CO concentrations are found to be distributed across the domain. The vehicular exhaust emissions and 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-western (NW) and south-eastern (SE) 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 mining activities and 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.

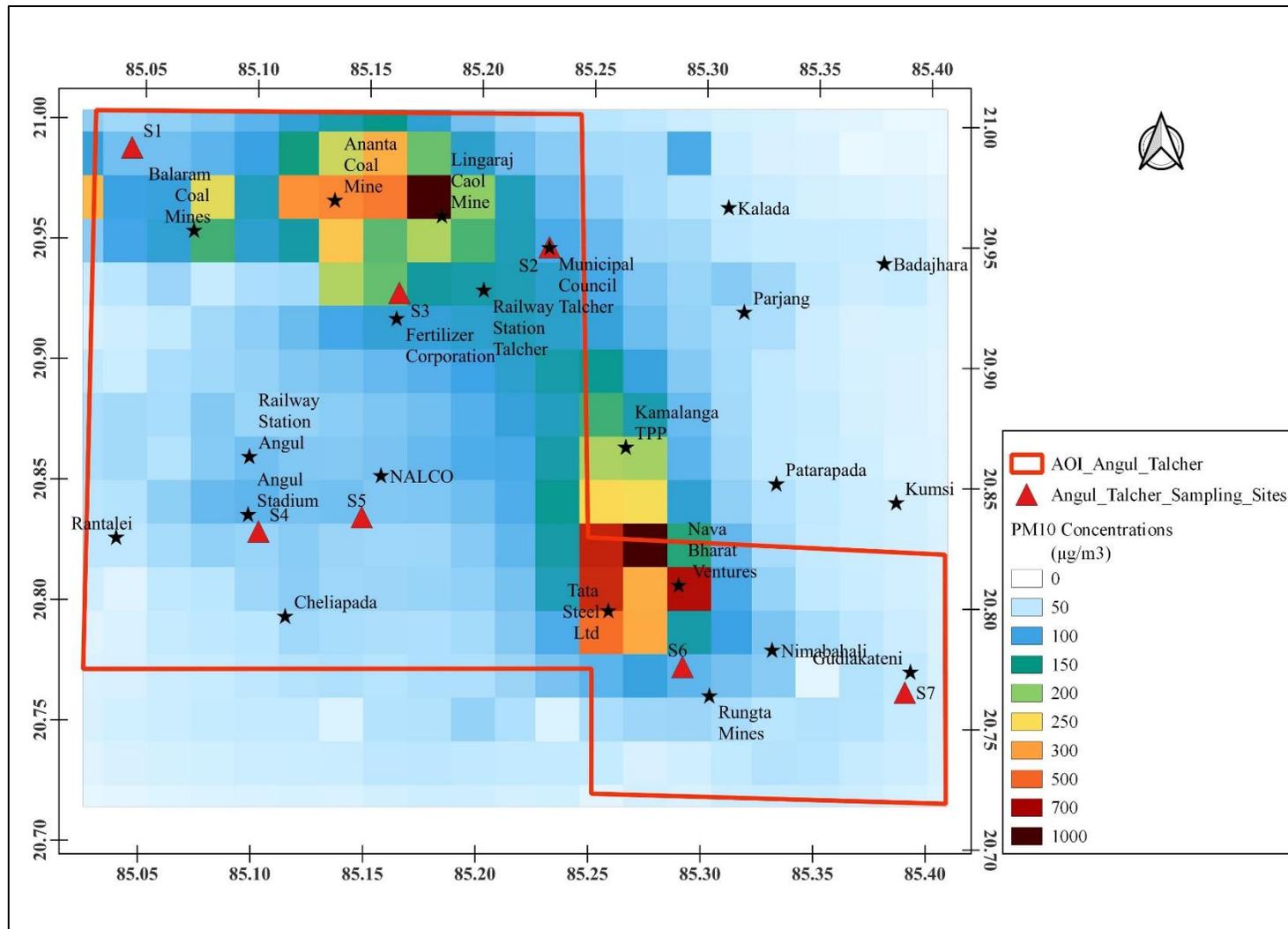


Figure 100 Map showing spatial distribution of annual mean PM₁₀ concentrations ($\mu\text{g}/\text{m}^3$) over Angul - Talcher region for year 2021

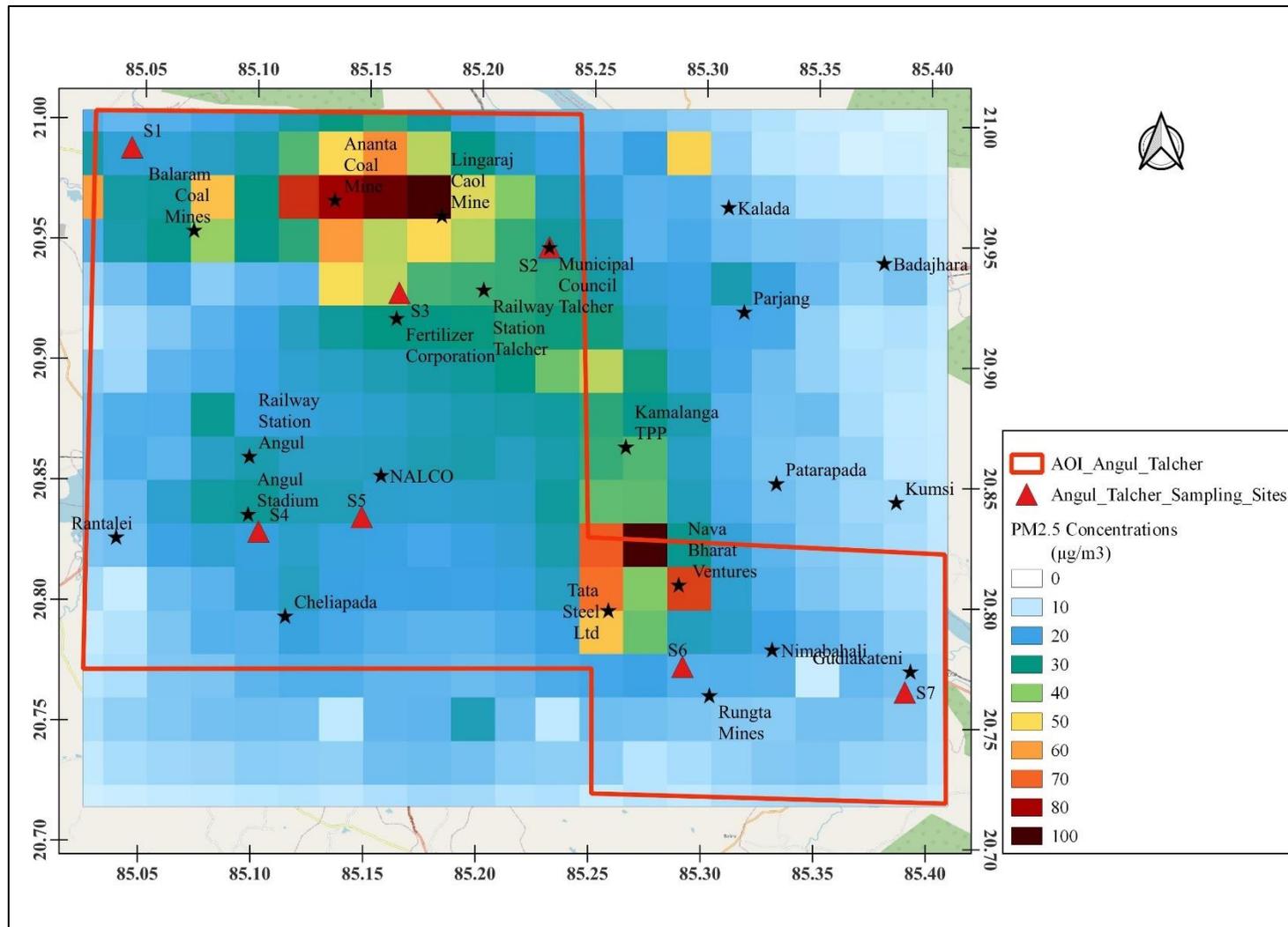


Figure 101 Map showing spatial distribution of annual mean PM_{2.5} concentrations (µg/m³) over Angul - Talcher region for year 2021

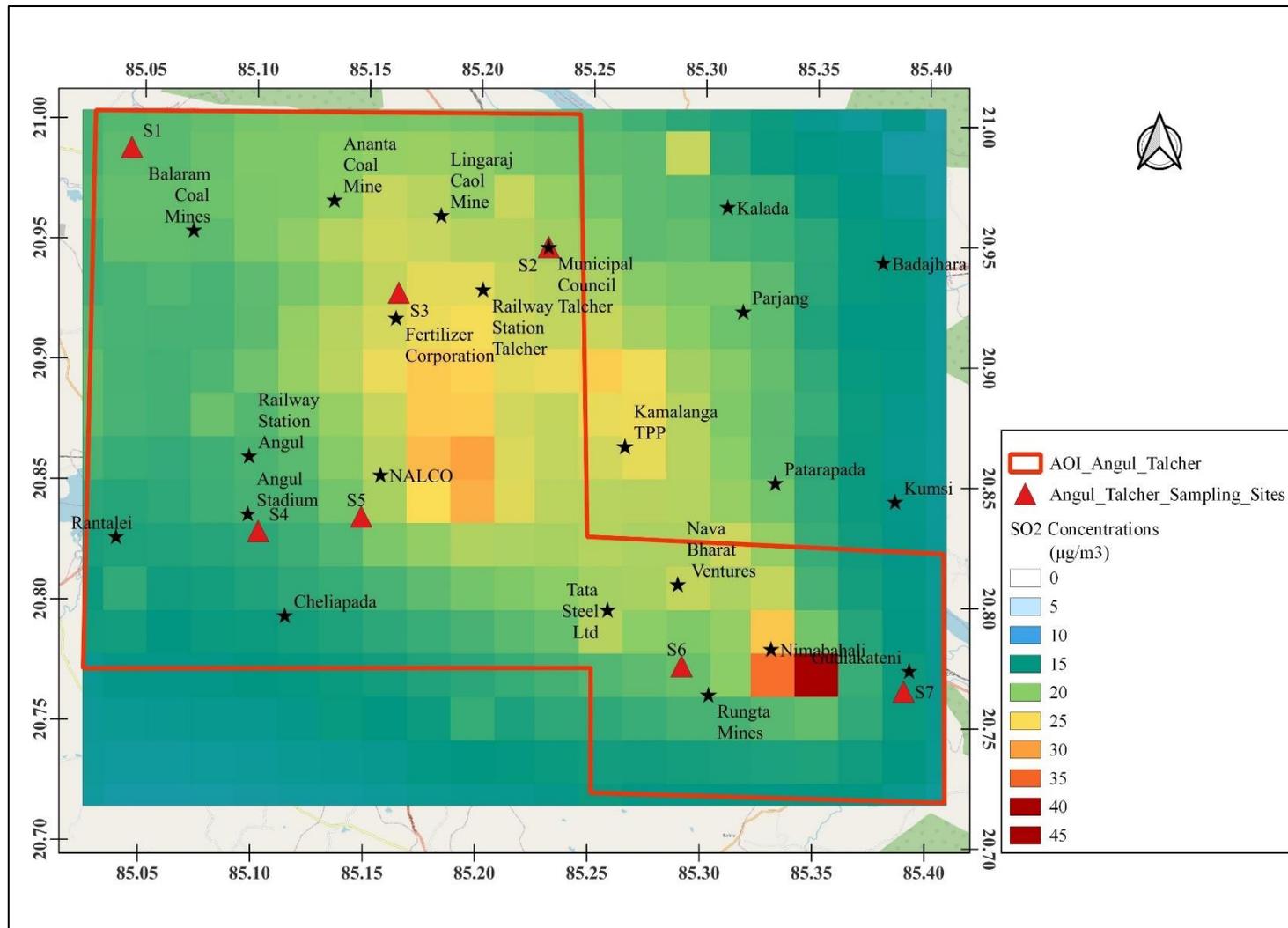


Figure 102 Map showing spatial distribution of annual mean SO₂ concentrations ($\mu\text{g}/\text{m}^3$) over Angul - Talcher region for year 2021

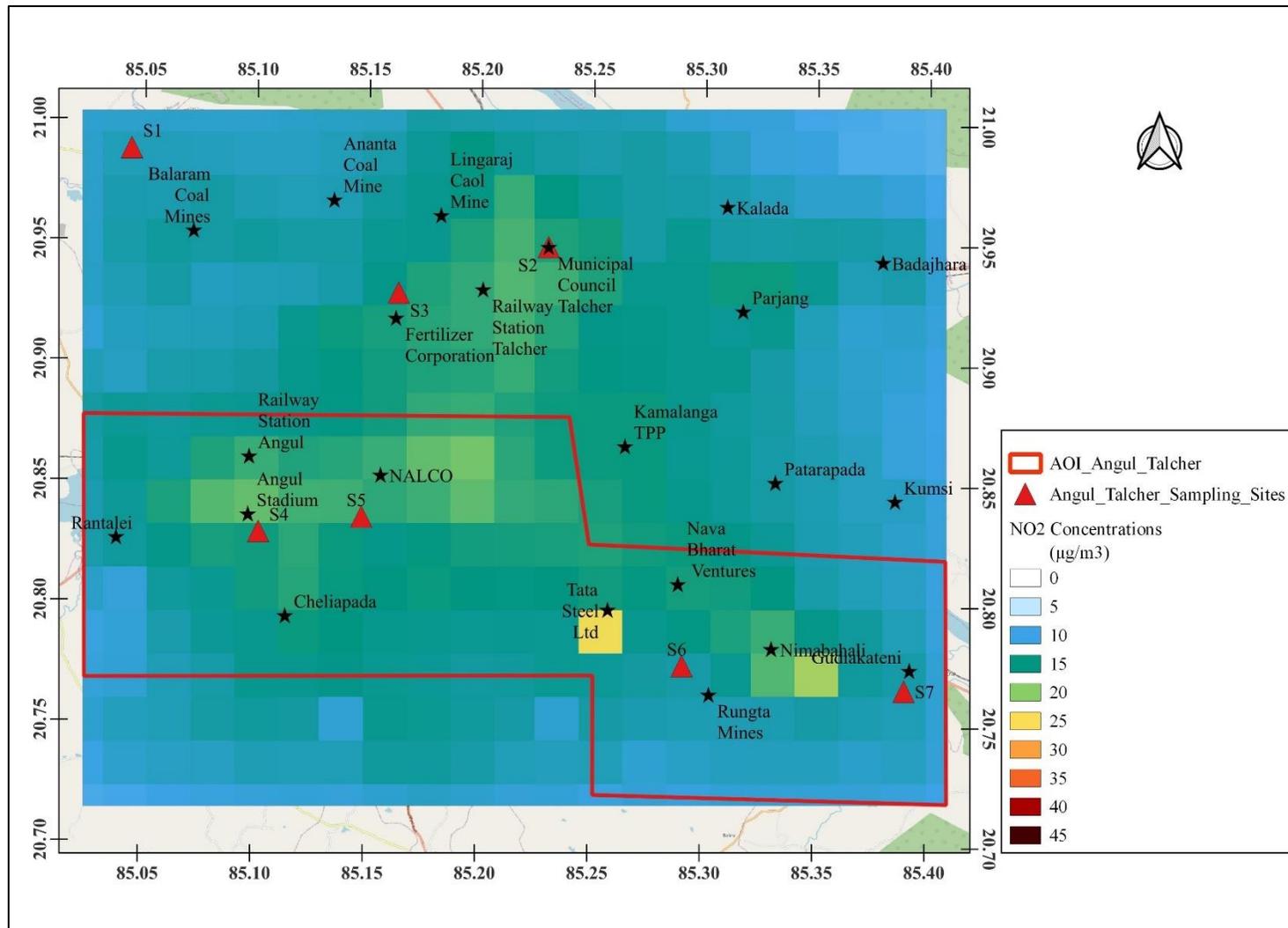


Figure 103 Map showing spatial distribution of annual mean NO₂ concentrations (µg/m³) over Angul - Talcher region for year 2021

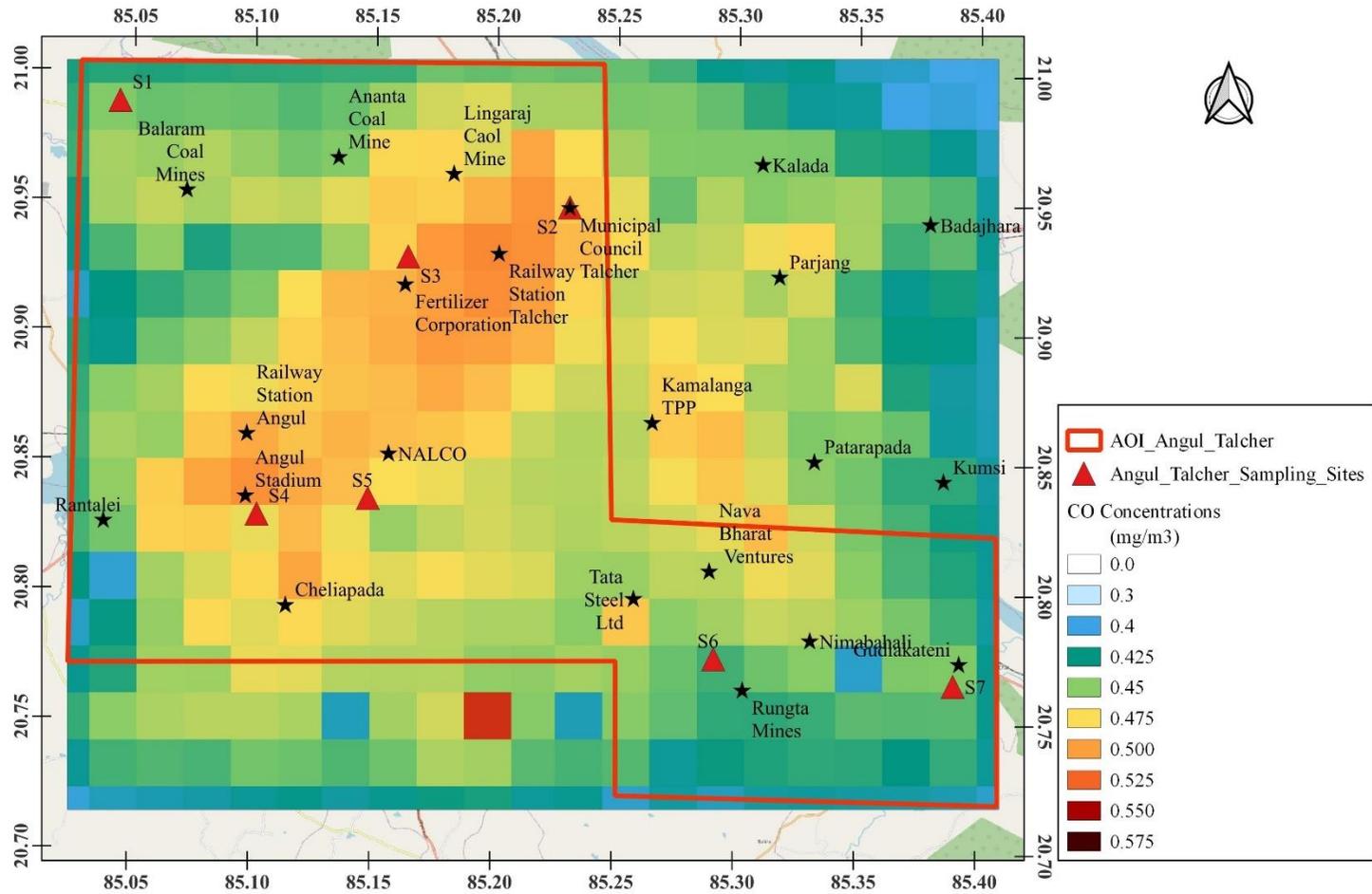


Figure 104 Map showing spatial distribution of annual mean CO concentrations (mg/m³) over Angul - Talcher region for year 2021

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Chapter 5: Future Projections

5.1. Future Projections of Emissions and Air Quality Benefits

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 2021. Four hypothetical emission scenarios viz. i) No further control (NFC), ii) Business-as-usual (BAU), iii) Scenario – I (SC-I) and iv) Scenario – II (SC-II); are developed for Angul 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 Angul 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 Angul 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 Angul region as well, which will in turn lead to significant reduction in vehicular exhaust emissions. The effect of increased EV penetration in Angul 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 Angul 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 Angul 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). Angul region has also taken several steps to improve the public transportation system such as phase-out of older buses, and procurement of CNG and electric buses. The VKT shift approach used by Sharma et al. (2010 and 2014) is adopted to calculate the VKT shifted to buses and emission reductions achieved.

5.3. Re-suspended Road Dust

As discussed earlier, road dust re-suspension is a major source of PM emissions in Angul 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

Angul 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. Thermal Powerplants

Coal-based thermal powerplants are a key contributor to emissions in Angul-Talcher region. Hence, it is crucial to reduce, control and abate emissions originating from thermal powerplants in the region with latest available technologies.

For compliance to Sulphur dioxide (SO₂) emission norms, all Thermal Power Plants within 10 km radius of the Non-attainment cities are directed to install Flue Gas Desulphurisation (FGD) control equipment by 31st December, 2025 vide MoEF&CC notification dated 05.09.2022. Considering these timelines, in the present study, it is assumed that Flue gas desulphurization (FGD) systems will be in-place by start year 2026 for control of SO₂ emissions in all thermal powerplants in the Angul region.

Apart from SO₂, it is important to reduce the emissions of other pollutants as well. The present study assesses the air quality improvement in the region by assuming reduction in other pollutant emissions ranging from 10% (intermediate scenarios) to 50% (under the highest aggressive scenario).

5.6. Fugitive emissions

As discussed earlier, fugitive dust emissions are an important source of air pollution in the Angul 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 assess the impact of controlling the fugitive sources by 10% to 75% compared to No Further Control (NFC) scenario, in future years.

5.7. 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 Angul 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.

5.8. Brick Kilns Sector

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

5.9. Construction Sector

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

5.10. 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.

5.11. 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	<ul style="list-style-type: none"> • The vehicles in Angul region are estimated to grow at a CAGR of 6.9% till 2031. • The major control measures considered for the transport sector include: <ul style="list-style-type: none"> ○ Increased penetration of BS-VI vehicles • Refer Annexure-H for more details on penetration and applicability of each control measure listed above. 	VAHAN database, Odisha EV Policy, 2019 Assumptions
2.	RDST	<ul style="list-style-type: none"> • The vehicles in Angul 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	<ul style="list-style-type: none"> • Industrial sector is expected to grow at an annual growth rate of 7.73% • No additional emission reduction measures in-place i.e. same as baseline year 2021 	Odisha Economic Survey 2022-23, Assumptions
4.	THPP	<ul style="list-style-type: none"> • Thermal powerplant emissions are assumed to equal to baseline year 2021 • Controls are same as baseline year 	Assumptions
5..	FUGT	<ul style="list-style-type: none"> • Fugitive emissions are assumed to increase similar to Industrial growth rate i.e. 7.73% • No control in-place 	Assumptions
6.	WAST	<ul style="list-style-type: none"> • The population is estimated based on historic population growth rate. 	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> The MSW collection efficiency in the study area for years 2026 and 2031 would remain same as baseline. 	
7.	HRBE	<ul style="list-style-type: none"> The hotel and restaurants are assumed to follow an annual growth rate of 9.93%. The fuel usage characteristics and technology would remain same as the baseline inventory. 	Odisha Economic Survey 2022-23, Assumptions
8.	BRIC	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> The construction activities are assumed to increase at an annual growth rate of 5.0% till 2031 No reduction in PM. 	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
10.	CREM	<ul style="list-style-type: none"> 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

5.12. 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	<ul style="list-style-type: none"> • The vehicles in Angul region are estimated to grow at a CAGR of 6.9% till 2031. • The major control measures considered for the transport sector include: <ul style="list-style-type: none"> ○ 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	<ul style="list-style-type: none"> • The vehicles in Angul region are estimated to grow at a CAGR of 6.9% till 2031. • The silt loading on different road types calculated by assuming following: <ul style="list-style-type: none"> ○ Year 2026: 15% silt load reduction @ Highways and Major roads and 5% silt load reduction @ Inter, Minor and residential roads 	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> ○ Year 2031: 25% silt load reduction @ Highways and Major roads and 10% silt load reduction @ Inter, Minor and residential roads 	
3.	INDU	<ul style="list-style-type: none"> ● Industrial sector is expected to grow at an annual growth rate of 7.73% ● Ensuring the PM control equipment are operating at minimum 99% control efficiency. ● Adoption of suggested Best Available Technologies and Practices for Iron and Steel Industries (Refer Annexure – XX). ● Assumed an emission reduction (in addition to NFC scenarios) from Industries: <ul style="list-style-type: none"> ○ 2026: No reduction ○ 2031: 15% reduction in PM and 25% reduction in gaseous pollutants 	Assumptions
4.	THPP	<ul style="list-style-type: none"> ● Thermal powerplant emissions are assumed to equal to baseline year 2021 ● Flue Gas Desulphurization (FGD) systems in place for SO₂ emission controls ● Other emission controls are same as baseline year 	Assumptions
5..	FUGT	<ul style="list-style-type: none"> ● Fugitive emissions are assumed to increase similar to Industrial growth rate i.e. 7.73% ● 10% and 25% reduction in fugitive emissions by 2026 and 2031, respectively, compared to NFC scenario 	Assumptions
6.	RESI	<ul style="list-style-type: none"> ● The population is estimated based on historic population growth rate. ● The assumed LPG penetration in study area: <ul style="list-style-type: none"> ○ Year 2026: <ol style="list-style-type: none"> 1. Urban HH: 90% 2. Rural HH: 50% ○ Year 2031: 	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ol style="list-style-type: none"> 1. Urban HH: 100% 2. Rural HH: 50% 	
7.	WAST	<ul style="list-style-type: none"> • The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency: <ul style="list-style-type: none"> ○ Year 2026: <ol style="list-style-type: none"> 1. Rural areas: 65% 2. Urban Areas: 90% ○ Year 2031: <ol style="list-style-type: none"> 1. Rural areas: 70% 2. Urban areas: 90% 	Assumptions
8.	HRBE	<ul style="list-style-type: none"> • The hotel and restaurants are assumed to follow an annual growth rate of 9.93%. • 5% and 10% 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	<ul style="list-style-type: none"> • The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. • All brick kilns within 5 km radius from the Angul city centre will be converted to Zig-Zag kilns by 2031 	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
10.	CONS	<ul style="list-style-type: none"> • The construction activities are assumed to increase at growth rate of 5.0% 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	<ul style="list-style-type: none"> • 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

5.13. 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	<ul style="list-style-type: none"> • The vehicles in Angul region are estimated to grow at a CAGR of 6.9% till 2031. • The major control measures considered for the transport sector include: <ul style="list-style-type: none"> ○ 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	<ul style="list-style-type: none"> • The vehicles in Angul region are estimated to grow at a CAGR of 6.9% till 2031. • The silt loading on different road types calculated by assuming following: <ul style="list-style-type: none"> ○ Year 2026: 25% silt load reduction @ Highways and Major roads and 15% silt load reduction @ Inter, Minor and residential roads ○ Year 2031: 50% silt load reduction @ Highways and Major roads and 25% silt load reduction @ Inter, Minor and residential roads 	Assumptions
3.	INDU	<ul style="list-style-type: none"> • Industrial sector is expected to grow at an annual growth rate of 7.73% • Ensuring the PM control equipment are operating at minimum 99% control efficiency. 	

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> • Adoption of suggested Best Available Technologies and Practices for Iron and Steel Industries (Refer Annexure – XX). • Assumed PM emission reduction (in addition to NFC scenarios) from Industries: <ul style="list-style-type: none"> ○ 2026: 15% for PM and 25% for Gaseous pollutants ○ 2031: 30% for PM and 50% for Gaseous pollutants 	
4.	THPP	<ul style="list-style-type: none"> • Thermal powerplant emissions are assumed to equal to baseline year 2021 • Flue Gas Desulphurization (FGD) systems in place for SO₂ emission controls • Additional 10% and 25% reduction in PM, NO_x, CO, VOC for year 2026 and 2031, respectively, compared to corresponding NFC scenario 	Assumptions
5.	FUGT	<ul style="list-style-type: none"> • Fugitive emissions are assumed to increase similar to Industrial growth rate i.e. 7.73% • 20% and 50% reduction in fugitive emissions by 2026 and 2031, respectively, compared to NFC scenario 	Assumptions
6.	RESI	<ul style="list-style-type: none"> • The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: <ul style="list-style-type: none"> ○ Year 2026: <ol style="list-style-type: none"> 1. Urban HH: 85% 2. Rural HH: 70% ○ Year 2031: <ol style="list-style-type: none"> 1. Urban HH: 95% 2. Rural HH: 80% 	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
7.	WAST	<ul style="list-style-type: none"> • The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency: <ul style="list-style-type: none"> ○ Year 2026: <ol style="list-style-type: none"> 1. Rural areas: 75% 2. Urban Areas: 90% ○ Year 2031: <ol style="list-style-type: none"> 1. Rural areas: 80% 2. Urban areas: 90% 	Assumptions
8.	HRBE	<ul style="list-style-type: none"> • The hotel and restaurants are assumed to follow an annual growth rate of 9.93%. 	Based on growth rate acquired from FICCI report 2022

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> 10 and 20% facilities would be converted from wood/coal to LPG in years 2026 and 2031, respectively. 	
9.	BRIC	<ul style="list-style-type: none"> The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. All brick kilns within 2 km and 10 km radius from the Angul city centre will be converted to Zig-Zag kilns by 2026 and 2031, respectively. 	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
10.	CONS	<ul style="list-style-type: none"> The construction activities are assumed to increase at growth rate of 5.0% 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	<ul style="list-style-type: none"> 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

5.14. 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	<ul style="list-style-type: none"> • The vehicles in Angul region are estimated to grow at a CAGR of 6.9% till 2031. • The major control measures considered for the transport sector include: <ul style="list-style-type: none"> ○ 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	<ul style="list-style-type: none"> • The vehicles in Angul region are estimated to grow at a CAGR of 6.9% till 2031. • The silt loading on different road types calculated by assuming following: <ul style="list-style-type: none"> ○ 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	<ul style="list-style-type: none"> • Industrial sector is expected to grow at an annual growth rate of 7.73% • Ensuring the PM control equipment are operating at minimum 99% control efficiency. 	

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> • Adoption of suggested Best Available Technologies and Practices for Iron and Steel Industries (Refer Annexure – XX). • Assumed PM emission reduction (in addition to NFC scenarios) from Industries: <ul style="list-style-type: none"> ○ 2026: 25% for PM and 40% for Gaseous pollutants ○ 2031: 50% for PM and 75% for Gaseous pollutants 	
4.	THPP	<ul style="list-style-type: none"> • Thermal powerplant emissions are assumed to equal to baseline year 2021 • Flue Gas Desulphurization (FGD) systems in place for SO₂ emission controls • Additional 15% and 50% reduction in PM, NO_x, CO, VOC for year 2026 and 2031, respectively, compared to corresponding NFC scenario 	Assumptions
5.	FUGT	<ul style="list-style-type: none"> • Fugitive emissions are assumed to increase similar to Industrial growth rate i.e. 7.73% • 30% and 75% reduction in fugitives emissions by 2026 and 2031, respectively, compared to NFC scenario 	Assumptions
6.	RESI	<ul style="list-style-type: none"> • The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: <ul style="list-style-type: none"> ○ Year 2026: <ol style="list-style-type: none"> 1. Urban HH: 95% 2. Rural HH: 90% ○ Year 2031: <ol style="list-style-type: none"> 1. Urban HH: 100% 2. Rural HH: 100% 	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
7.	WAST	<ul style="list-style-type: none"> • The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency: <ul style="list-style-type: none"> ○ Year 2026: <ol style="list-style-type: none"> 1. Rural areas: 90% 2. Urban Areas: 95% ○ Year 2031: <ol style="list-style-type: none"> 1. Rural areas: 95% 2. Urban areas: 98% 	Assumptions
8.	HRBE	<ul style="list-style-type: none"> • The hotel and restaurants are assumed to follow an annual growth rate of 9.93%. 	Based on growth rate acquired

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> 20 and 25% facilities would be converted from wood/coal to LPG in years 2026 and 2031, respectively. 	from FICCI report 2022
9.	BRIC	<ul style="list-style-type: none"> The brick kilns are estimated to follow a growth rate of 6% till 2031, respectively. All brick kilns within 10 km radius from the Angul city centre will be converted to Zig-Zag kilns by 2026 and all brick kilns within study domain would be converted to Zig-Zag kilns by 2031. 	Based on the gross domestic product of construction activities in Odisha during the year 2017-2022, RBI Handbook, 2022 Assumptions
10.	CONS	<ul style="list-style-type: none"> The construction activities are assumed to increase at growth rate of 5.0% 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	<ul style="list-style-type: none"> 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

5.15. 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 Angul region. As discussed earlier, these scenarios consider implementation of various control measures explained in Section 5.12 in Angul region with varying factors for 2026 and 2031. Table 25 and Figures 105 to 109 presents the summary of estimated emissions (tonnes per year) of selected pollutants for four scenarios in Angul 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 Angul region indicate a potential increase in PM₁₀ emissions to 28,830 tonnes per year in 2026 i.e. an increase of 19.4% w.r.t. baseline year 2021 and to 35,054 tonnes per year in 2031 i.e. an increase of 45.1% w.r.t. baseline year 2021. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to reach to 8,669 (19.7%) and 10,504 tonnes per year (i.e. 45.1%) in 2026 and 2031, respectively. As this is an industrial region, the SO₂ emissions are of particular interest. The projected emissions of SO₂ indicate a potential increase to 1,40,766 tonnes per year in 2026 i.e. an increase of 11.7% w.r.t. baseline year 2021 and to 1,54,661 tonnes per year in 2031 i.e. an increase of 22.8% w.r.t. baseline year 2021. The projected emissions of NO_x indicate a potential increase to 69,320 tonnes per year in 2026 i.e. an increase of 10.2% w.r.t. baseline year 2021 and to 75,411 tonnes per year in 2031 i.e. an increase of 19.9% w.r.t. baseline year 2021. The CO emissions are expected to increase to 18,447 tonnes per year in 2026 i.e. a decrease of 24.9% and 20,851 tonnes per year in 2031 i.e. an increase of 41.2% w.r.t. baseline year 2021.

The BAU projections in Angul indicate a potential decrease of PM₁₀ emissions to 27,008 tonnes per year in 2026 i.e. a decrease of 6.3 % w.r.t. NFC_2026 and to 29,997 tonnes per year in 2031 i.e. a decrease of 14.4% w.r.t. NFC 2031. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 8,390 (-3.2%) and 9,287 tonnes per year (i.e. -11.6%) in 2026 and 2031, respectively. Sulphur dioxide (SO₂) emissions are also projected to decline by 11.7% (i.e. 91,700 tonnes per year) and 42.2% (i.e. 89,379 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 69,316 tonnes per year in 2026 i.e. a decrease of 0.01% w.r.t. NFC_2026 and to 68,915 tonnes per year in 2031 i.e. a decrease of 8.6% w.r.t. NFC 2031. The CO emissions are expected to decrease to 17,305 tonnes per year in 2026 i.e. a decrease

of 6.2% w.r.t. NFC_2026 and 19,622 tonnes per year in 2031 i.e. a decrease of 5.9% w.r.t. NFC 2031.

The SC-I projections in Angul region indicate a potential decrease of PM₁₀ emissions to 23,906 tonnes per year in 2026 i.e. a decrease of 17.1% w.r.t. NFC 2026 and to 22,700 tonnes per year in 2031 i.e. a decrease of -35.2% w.r.t. NFC 2031. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 7,401 (-14.6%) and 7,357 tonnes per year (i.e. -30.0%) in 2026 and 2031, respectively. Sulphur dioxide emissions are projected to decline by 44.1% (i.e. 78,747 tonnes per year) and 52.8% (i.e. 72,942 tonnes per year) in 2026 and 2031, respectively, relative to their respective NFC scenarios. Similarly, projected emissions of NO_x indicate a potential reduction to 59,406 tonnes per year in 2026 i.e. a decrease of 14.3% w.r.t. NFC 2026 and to 50,544 tonnes per year in 2031 i.e. a decrease of 33% w.r.t. NFC 2031. The CO emissions are expected to decrease to 15,565 tonnes per year in 2026 i.e. a decrease of 15.6% w.r.t. NFC 2026 and 15,665 tonnes per year in 2031 i.e. a decrease of 24.9% w.r.t. NFC 2031.

The SC-II projections in Angul region indicate a potential decrease of PM₁₀ emissions to 21,270 tonnes per year in 2026 i.e. a decrease of 26.2% w.r.t. NFC 2026 and to 11,385 tonnes per year in 2031 i.e. a decrease of 67.5% w.r.t. NFC 2031. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 6,728 (i.e. -22.4%) and 4,368 tonnes per year (i.e. -58.4%) in 2026 and 2031, respectively. Sulphur dioxide (SO₂) emissions are projected to decline by 49.6% (i.e. 70,915 tonnes per year) and 63.5% (i.e. 56,497 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 53,836 tonnes per year in 2026 i.e. a decrease of 22.3% w.r.t. NFC 2026 and to 32,061 tonnes per year in 2031 i.e. a decrease of 57.5% w.r.t. NFC 2031. The CO emissions are expected to decrease to 16,096 tonnes per year in 2026 i.e. a decrease of 12.7% w.r.t. NFC 2026 and 10,478 tonnes per year in 2031 i.e. a decrease of 49.7% w.r.t. NFC 2031.

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

Year	Scenario	PM₁₀	PM_{2.5}	SO₂	NO_x	CO
2021	BASE	24,152	7,241	1,25,996	62,900	14,764
2026	NFC	28,387	8,669	1,40,766	69,320	18,447
	BAU	27,008	8,390	91,700	69,316	17,305
	SC_I	23,906	7,401	78,747	59,406	15,565
	SC_II	20,938	6,530	70,905	53,836	13,343
2031	NFC	35,054	10,504	1,54,661	75,411	20,851
	BAU	29,997	9,287	89,379	68,915	19,622
	SC_I	22,390	7,172	72,932	50,544	15,665
	SC_II	11,385	4,368	56,497	32,061	10,478

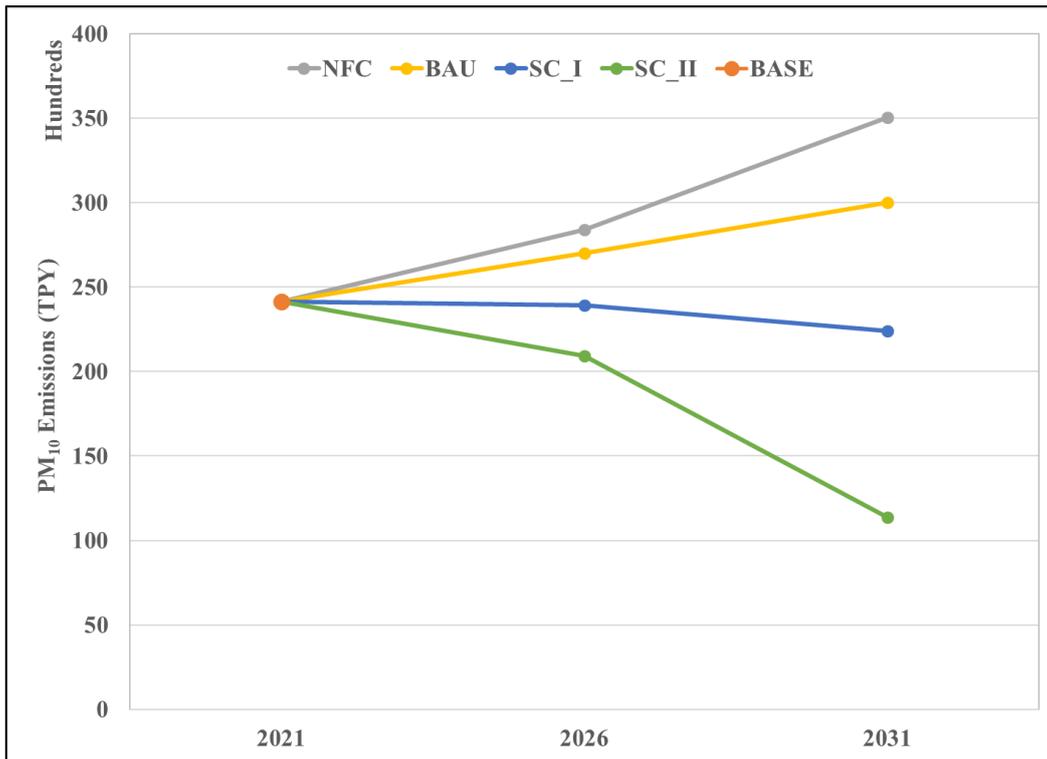


Figure 105 PM₁₀ Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

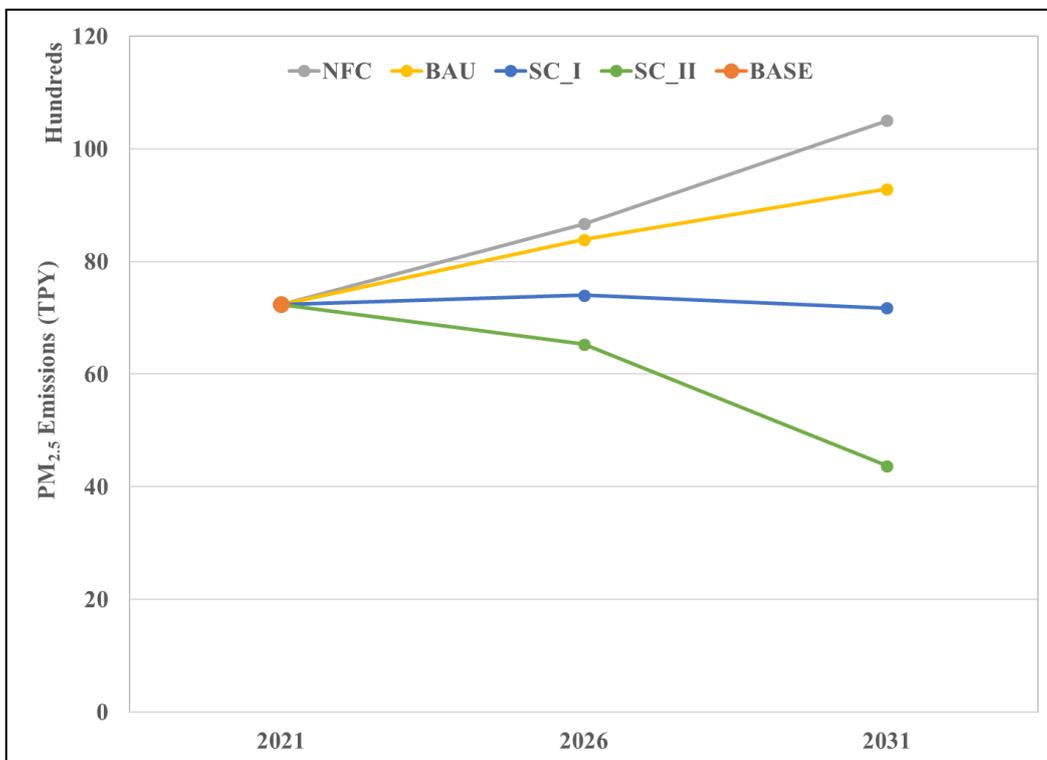


Figure 106 PM_{2.5} Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

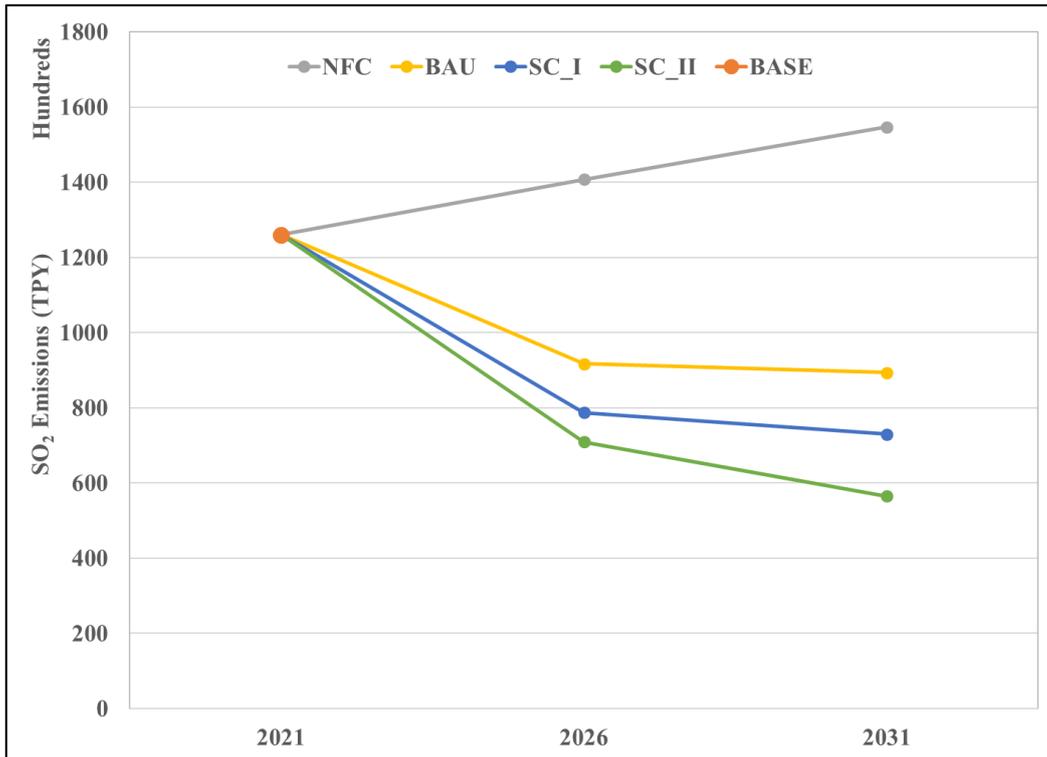


Figure 107 SO₂ Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

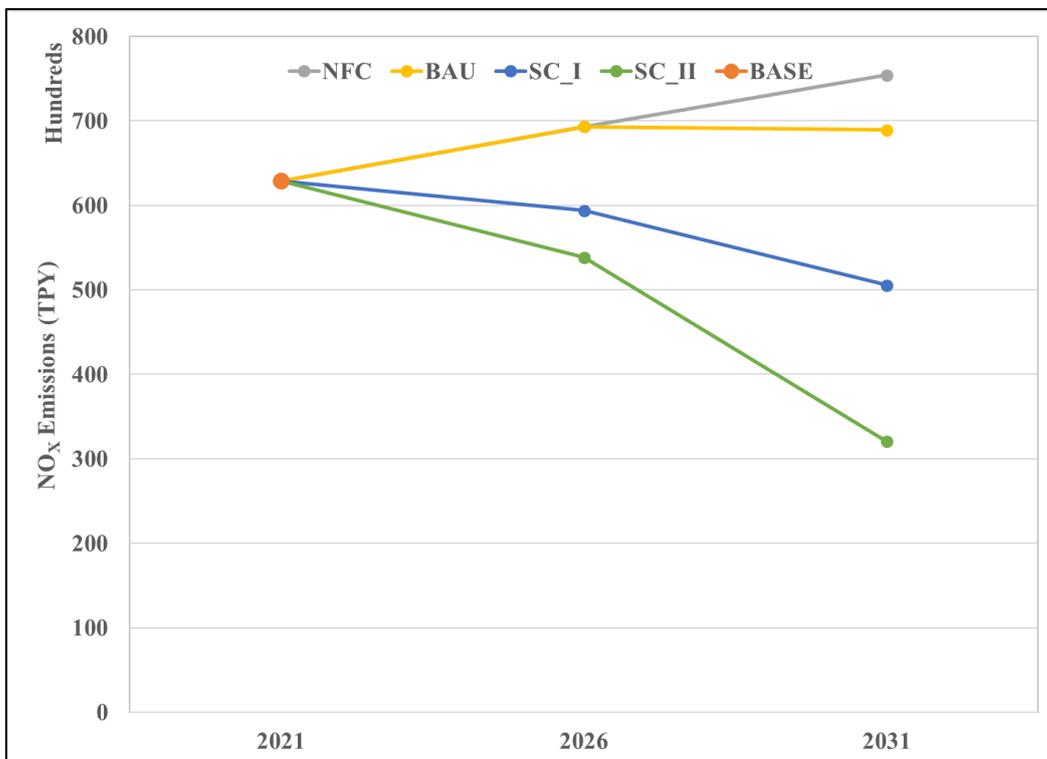


Figure 108 NO_x Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

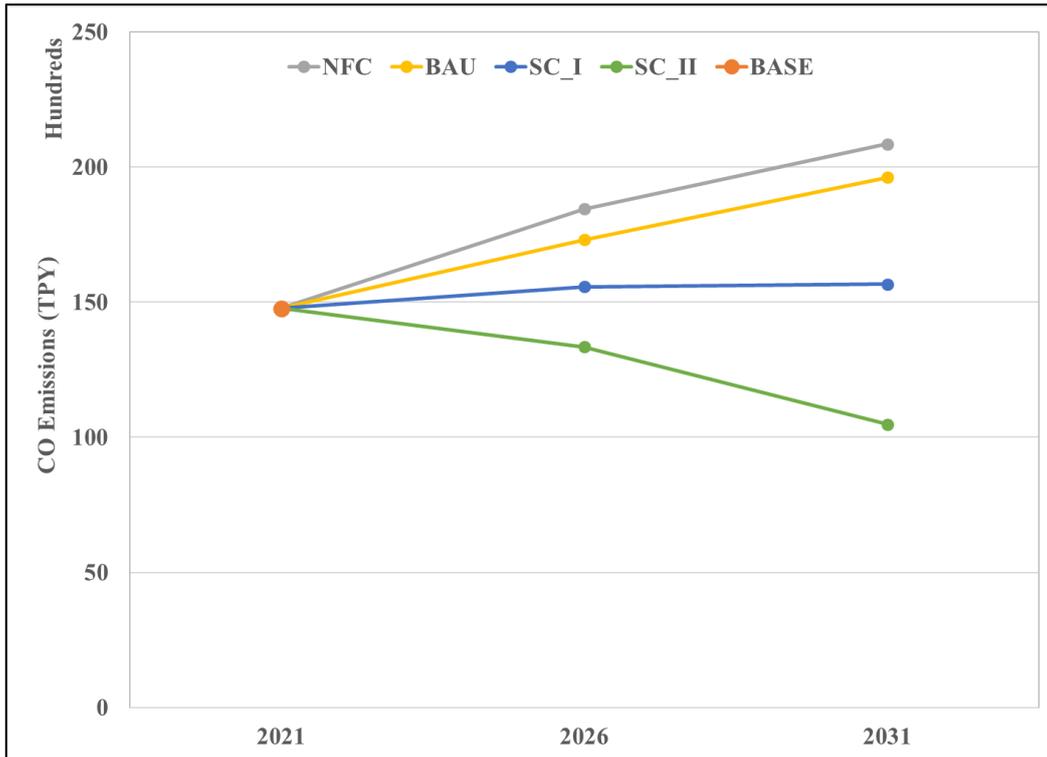


Figure 109 CO Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2026 and 2031

5.15.1. Sector-wise emission reduction potentials

Table 26 and Fig. 110-114 shows sector-wise and total estimated emission reduction potential (%) of pollutants w.r.t. respective NFC scenarios in Angul region for years 2026 and 2031. The total particulate matter emissions in 2026 can be reduced upto maximum 26.2% and 24.7% in PM₁₀ and PM_{2.5}, respectively w.r.t. NFC 2026 scenario. Similarly, total particulate matter emissions in 2031 can be reduced upto maximum 67.5% and 58.4% in PM₁₀ and PM_{2.5}, respectively w.r.t. NFC 2031 scenario. In year 2031 the sectoral emission reduction potential in decreasing order of reduction are fugitive sources (upto 29.8%), road dust (upto 15.9%), thermal powerplants (upto 9.4%), industries (upto 9.3%), residential (upto 1.2%). Remaining PM₁₀ emission sources contribute less than 1% reduction in PM₁₀. Similarly, for PM_{2.5} significant emission reductions can be obtained in industrial (upto 15.6%), thermal powerplants (upto 13.8%), re-suspended road dust (upto 12.9%), fugitive dust (upto 8.9%), residential (upto 2.7%), brick kilns (upto 1.3%) and transport (upto 1%).

Table 26 Sector-wise estimated emission reduction potential (%) for PM₁₀ and PM_{2.5} w.r.t. respective NFC scenarios in Angul region

Year	Sector	PM ₁₀			PM _{2.5}		
		BAU	SC-I	SC-II	BAU	SC-I	SC-II
2026	TOTAL	-4.9%	-15.8%	-26.2%	-3.2%	-14.6%	-24.7%
	INDU	< 0.1%	-2.7%	-4.5%	< 0.1%	-4.4%	-7.4%
	THPP	< 0.1%	-2.3%	-3.5%	< 0.1%	-3.4%	-5.0%
	TRAN	< 0.1%	-0.1%	-0.2%	-0.1%	-0.3%	-0.5%
	RDST	-1.6%	-3.3%	-6.3%	-1.3%	-2.6%	-5.0%
	WAST	-0.1%	-0.3%	-0.6%	-0.4%	-0.9%	-1.7%
	CONS	< 0.1%	-0.1%	-0.3%	< 0.1%	-0.1%	-0.2%
	DSGN	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
	RESI	-0.4%	-0.7%	-1.1%	-0.6%	-1.1%	-1.8%
	BRIC	< 0.1%	< 0.1%	-0.1%	< 0.1%	< 0.1%	-0.1%
	HRBE	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	-0.1%
	CREM	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	-0.1%
	FUGT	-2.6%	-6.2%	-9.8%	-0.8%	-1.8%	-2.9%
2031	TOTAL	-14.4%	-36.1%	-67.5%	-11.6%	-31.7%	-58.4%
	INDU	-2.8%	-5.6%	-9.3%	-4.7%	-9.4%	-15.6%
	THPP	< 0.1%	-4.7%	-9.4%	< 0.1%	-6.9%	-13.8%
	TRAN	-0.1%	-0.2%	-0.3%	-0.3%	-0.6%	-1.0%
	RDST	-3.8%	-8.3%	-15.9%	-3.0%	-6.7%	-12.9%
	WAST	-0.2%	-0.3%	-0.6%	-0.6%	-1.1%	-1.9%
	CONS	< 0.1%	-0.1%	-0.2%	< 0.1%	-0.1%	-0.1%
	DSGN	< 0.1%	< 0.1%	< 0.1%	< 0.1%	-0.1%	-0.1%
	RESI	-0.3%	-0.8%	-1.2%	-0.6%	-1.7%	-2.7%
	BRIC	-0.1%	-0.2%	-0.5%	-0.2%	-0.4%	-1.3%
	HRBE	< 0.1%	< 0.1%	< 0.1%	< 0.1%	-0.1%	-0.1%
	CREM	< 0.1%	< 0.1%	-0.1%	< 0.1%	< 0.1%	-0.1%
	FUGT	-7.2%	-15.9%	-29.8%	-2.1%	-4.7%	-8.9%

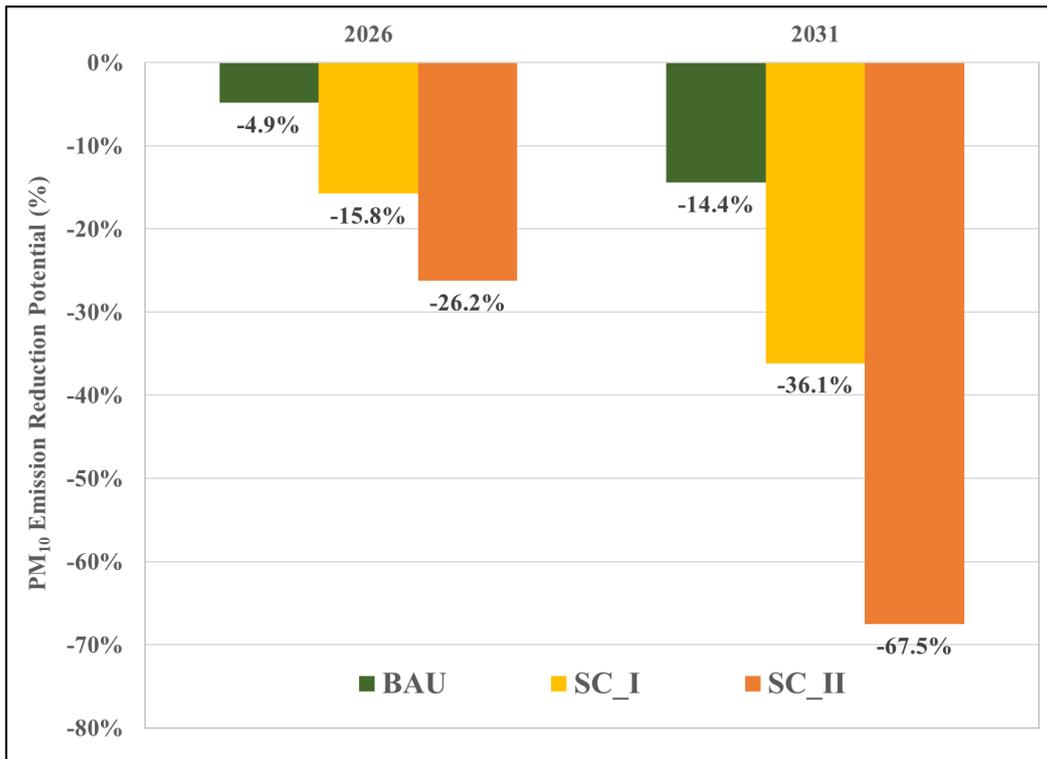


Figure 110 PM₁₀ Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

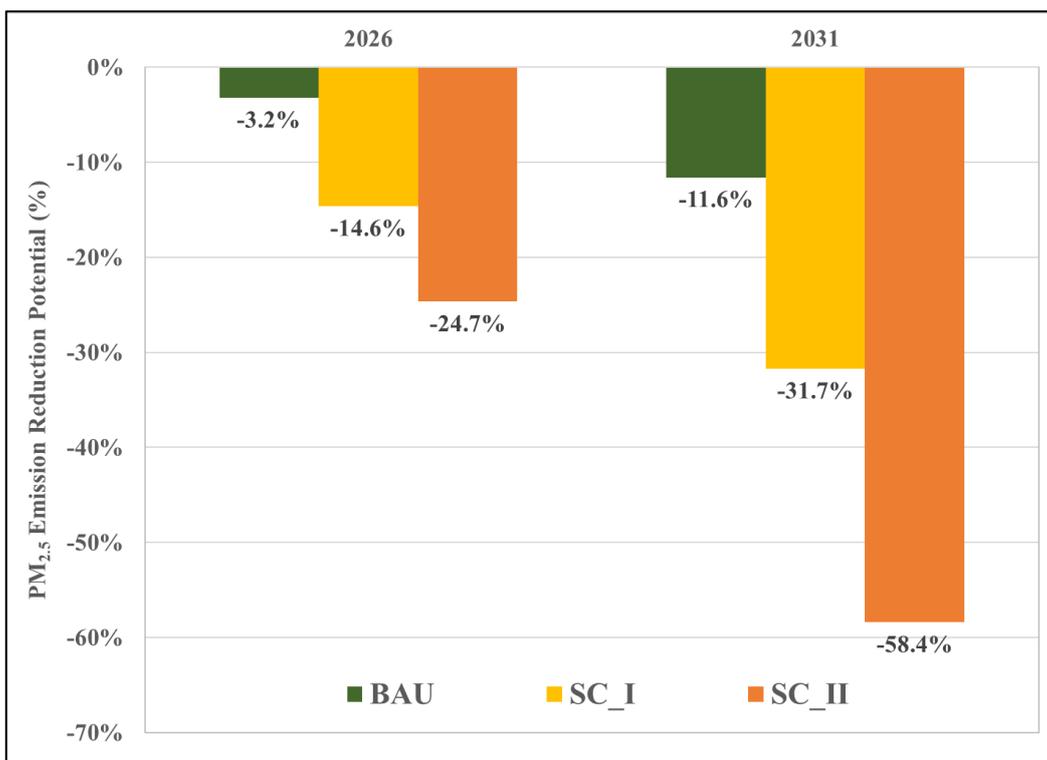


Figure 111 PM_{2.5} Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

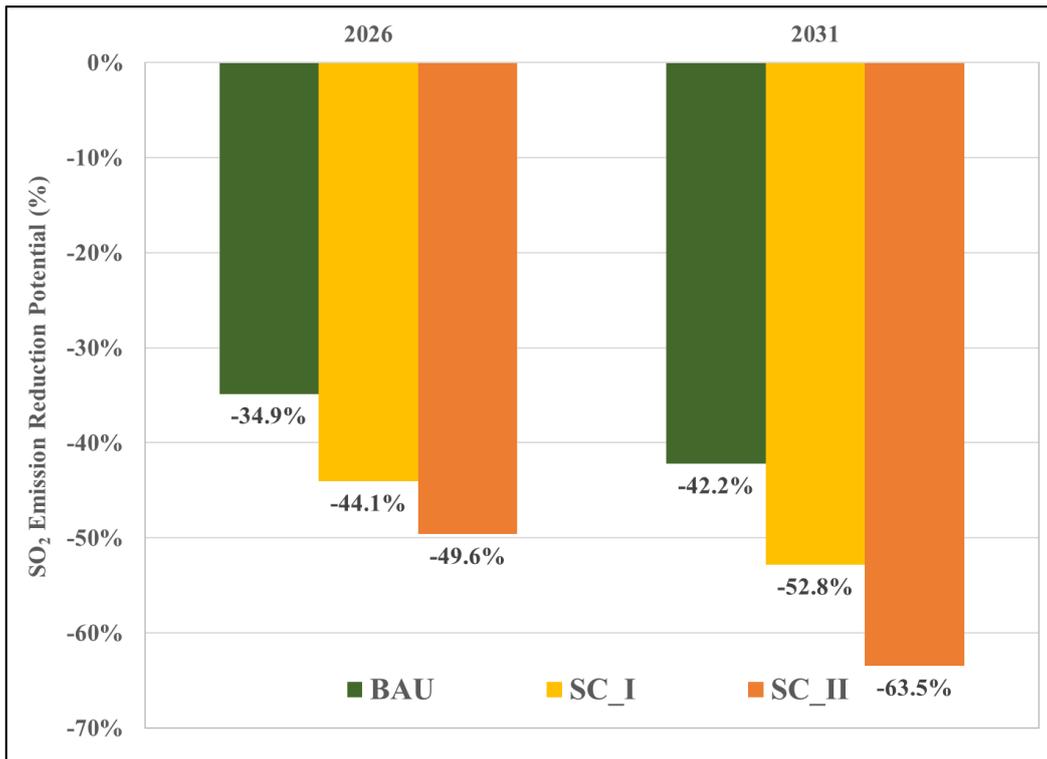


Figure 112 SO₂ Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

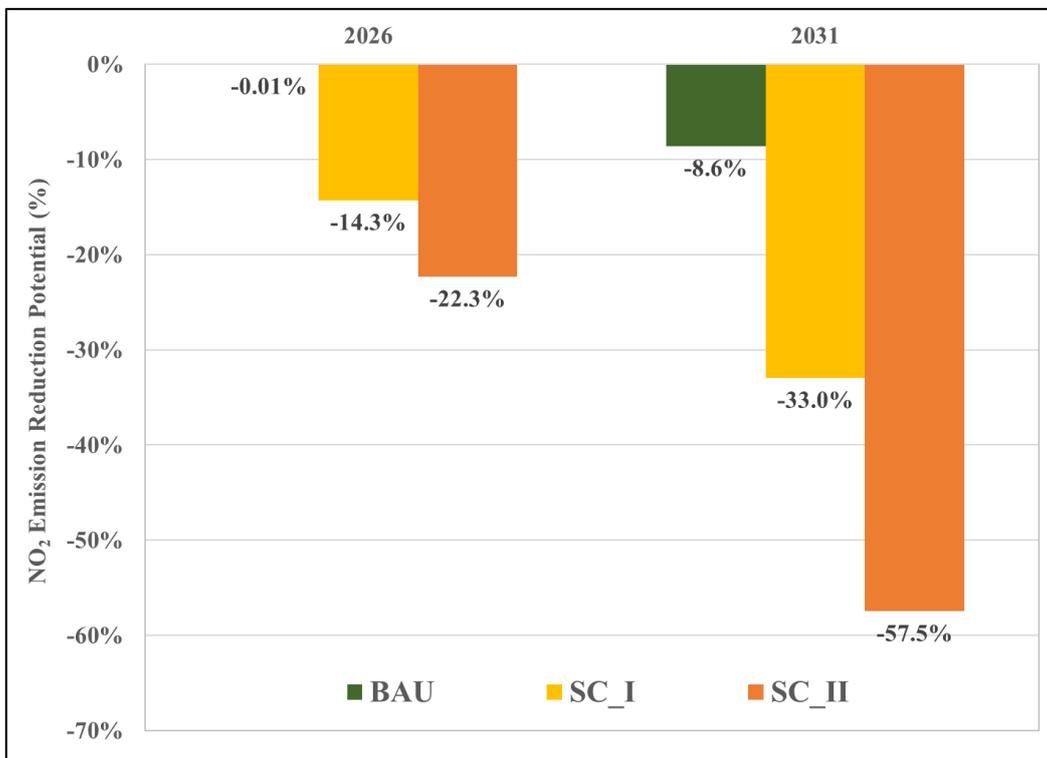


Figure 113 NO_x Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

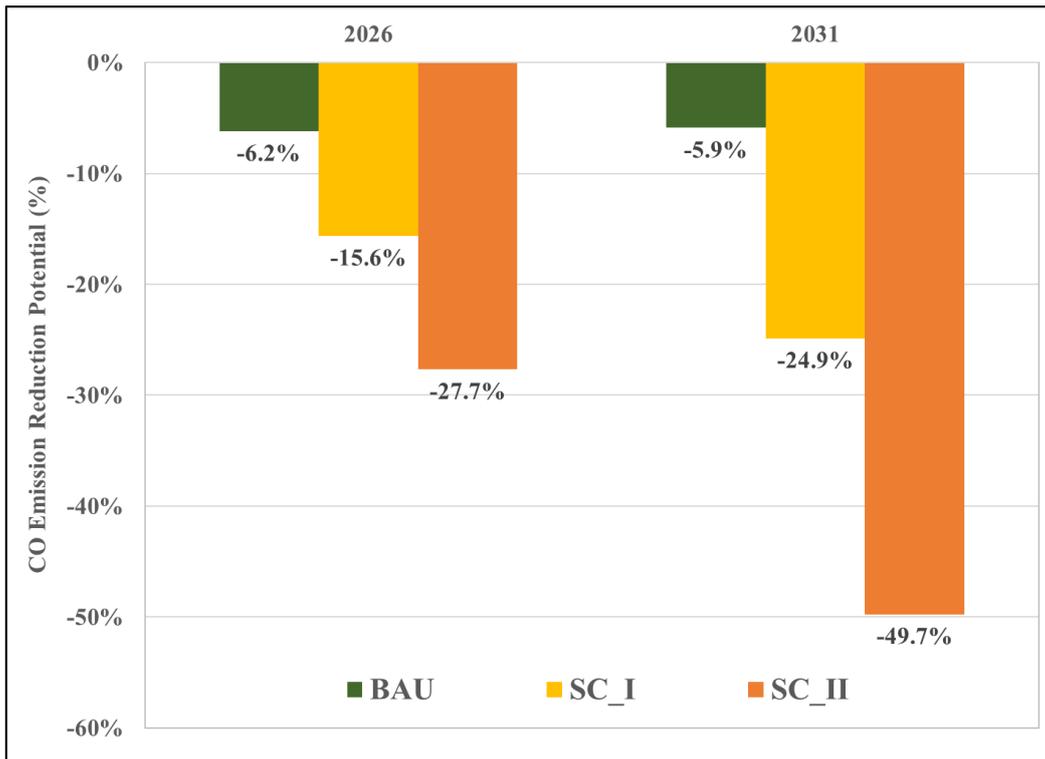


Figure 114 CO Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

5.16. Air Quality Benefits

Angul and Talcher regions are very close to each other, and air pollution sources can influence air quality in the region, hence AERMOD simulations were conducted together for Angul-Talcher regions. Air quality benefits of four designed scenarios were assessed for years 2026 and 2031 using AERMOD modelled annual mean pollutant concentrations in Angul-Talcher region. The spatial distribution of pollutant (PM₁₀, PM_{2.5}, SO₂, NO₂, CO) concentration levels over Angul-Talcher 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 north-western part of the study domain. This spatial distribution can be mainly attributed to the mining operations, fugitive dust and industrial activities in these areas. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2026 and 2031 due to proposed mining dust control, fugitive dust control measures, adoption of best available technologies in iron steel plants and sponge iron industries, changes in technology and fuels of vehicles such as EV adoption, implementation of BS VI, increase in penetration of natural gas

based vehicles, reduction in silt loading on road surfaces, improvement in NMT & public transport, usage of clean fuel for cooking, improved waste collection efficiency, adoption of Zig-zag type brick kilns and various other control strategies considered in different scenarios.

As shown in Fig 115-116, the PM₁₀ concentrations for NFC scenario in 2026 and 2031, are mainly concentrated in the central part and the north-western part of the study domain. The domain-averaged annual PM₁₀ concentrations (i.e. mean of annual concentrations of 357 receptors in the study domain) estimated by AERMOD during four scenarios are 119.9, 109.6, 99.0, and 86.2 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The domain-averaged annual PM₁₀ concentrations during year 2031 are estimated to be 147.6, 119.6, 88.1, and 37.7 µg/m³ for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 8.9%, 18.3%, and 30.5% in 2026 and 18.3%, 40.2%, and 75.3% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 117-118, the PM_{2.5} concentrations, are also concentrated in the central part and the north-western part of the study domain. The domain-averaged annual PM_{2.5} concentrations (i.e. mean of annual concentrations of 357 receptors in the study domain) estimated by AERMOD during four scenarios are 89.1, 82.1, 76.1, and 66.5 µg/m³ 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 90.9, 78.7, 64.6, and 46.4 µg/m³ for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 7.2%, 13.3%, and 23.0% in 2026 and 12.2%, 26.0%, and 44.1% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 119-120, the SO₂ concentrations, are also concentrated in the central and south-eastern part of the study domain. The domain-averaged annual SO₂ concentrations (i.e. mean of annual concentrations of 357 receptors in the study domain) estimated by AERMOD during four scenarios are 21.6, 16.5, 15.5, and 14.7 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The domain-averaged annual SO₂ concentrations (i.e. mean of annual concentrations of 357 receptors in the study domain) are estimated to be 21.7, 16.0, 13.8, and 12.1 µg/m³ for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 23.2%, 27.9%, and 31.2% in 2026 and 25.7%, 35.3% and 42.7% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 121-122, the NO₂ concentrations, are also concentrated in central and south-eastern part of the study domain. The domain-averaged annual SO₂ concentrations (i.e. mean of annual concentrations of 357 receptors in the study domain) estimated by AERMOD during four scenarios are 15.4, 15.4, 14.8, and 14.5 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2026, respectively. The highest annual NO₂ concentrations during year 2031 are estimated to be 15.4, 15.8, 14.3, 12.9 µg/m³ for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 0.1%, 3.5%, and 5.7% in 2026 and 2.5%, 6.9%, and 15.5% in 2031, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 123-124, the CO concentrations, are also concentrated in the central, and southern part of the study domain. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 357 receptors in the study domain) estimated by AERMOD during four scenarios are 0.48, 0.47, 0.47, and 0.46 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 357 receptors in the study domain) estimated to be 0.48, 0.48, 0.47, and 0.44 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 1.2%, 2.1% and 3.5% in 2026 and 0.2%, 3.7% and 8.9% 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.

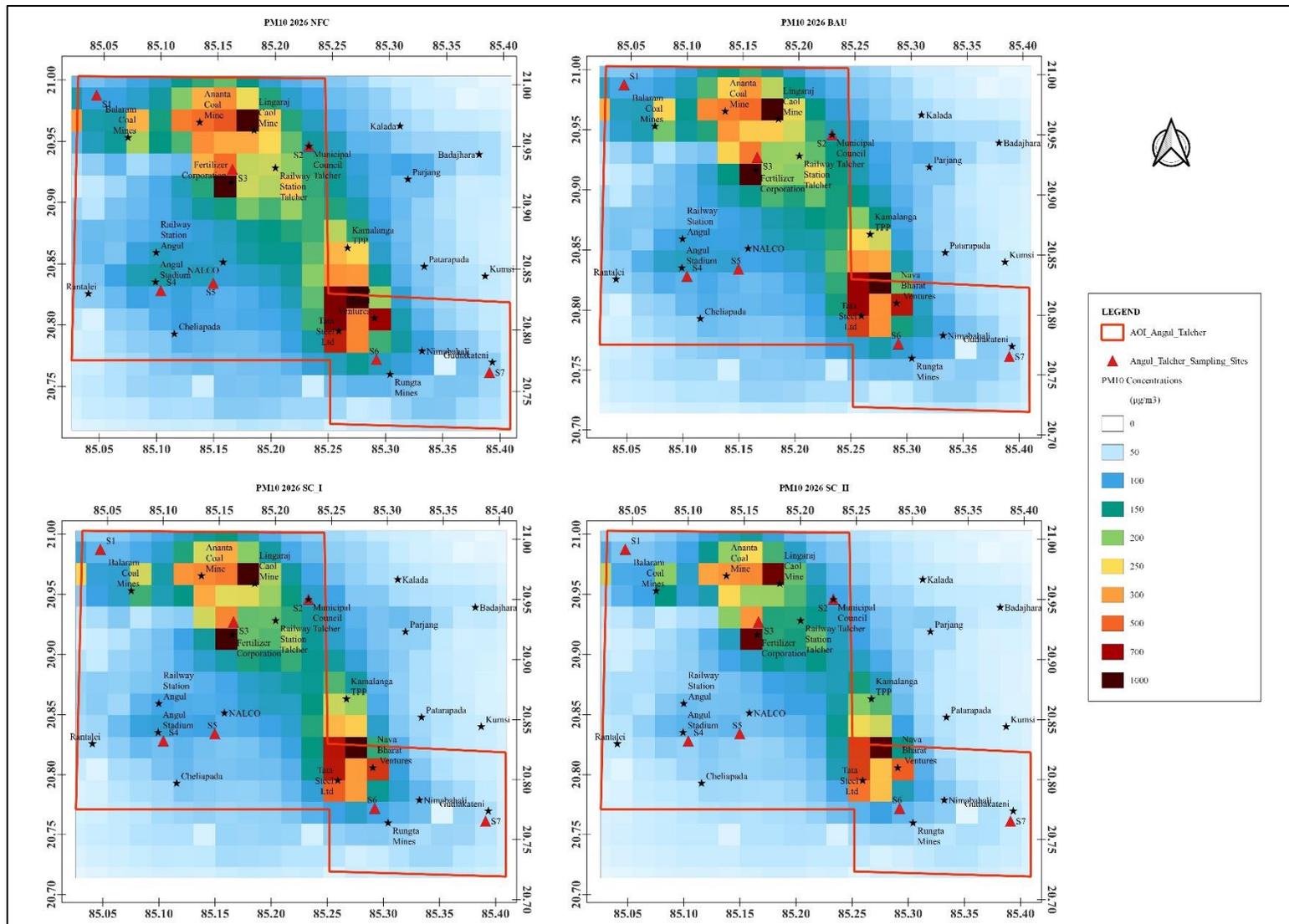


Figure 115 Spatial distribution of annual mean PM₁₀ concentrations (µg/m³) for four scenarios in year 2026 over Angul-Talcher region

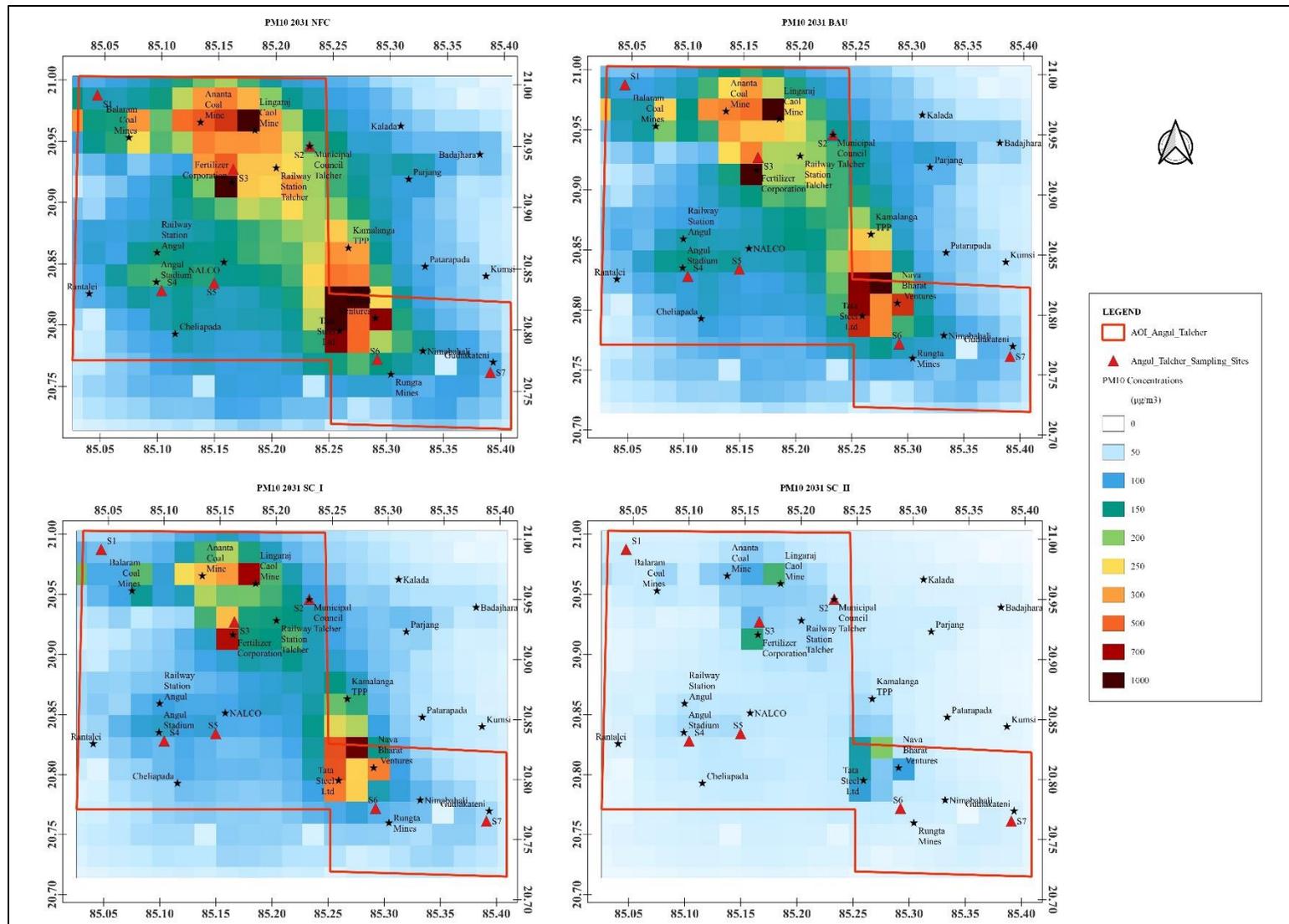


Figure 116 Spatial distribution of annual mean PM₁₀ concentrations (µg/m³) for four scenarios in year 2031 over Angul-Talcher region

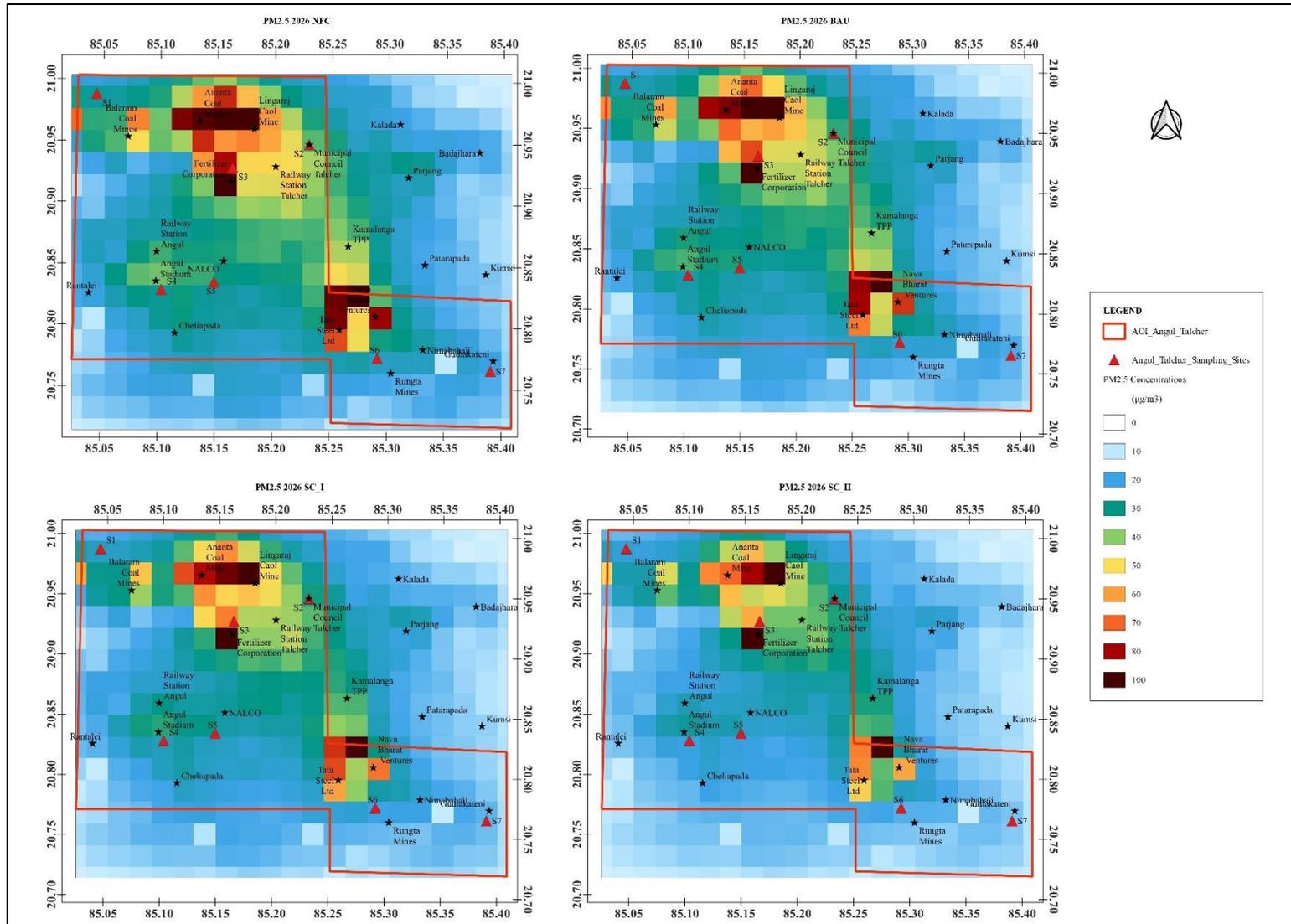


Figure 117 Spatial distribution of annual mean PM_{2.5} concentrations (µg/m³) for four scenarios in year 2026 over Angul-Talcher region

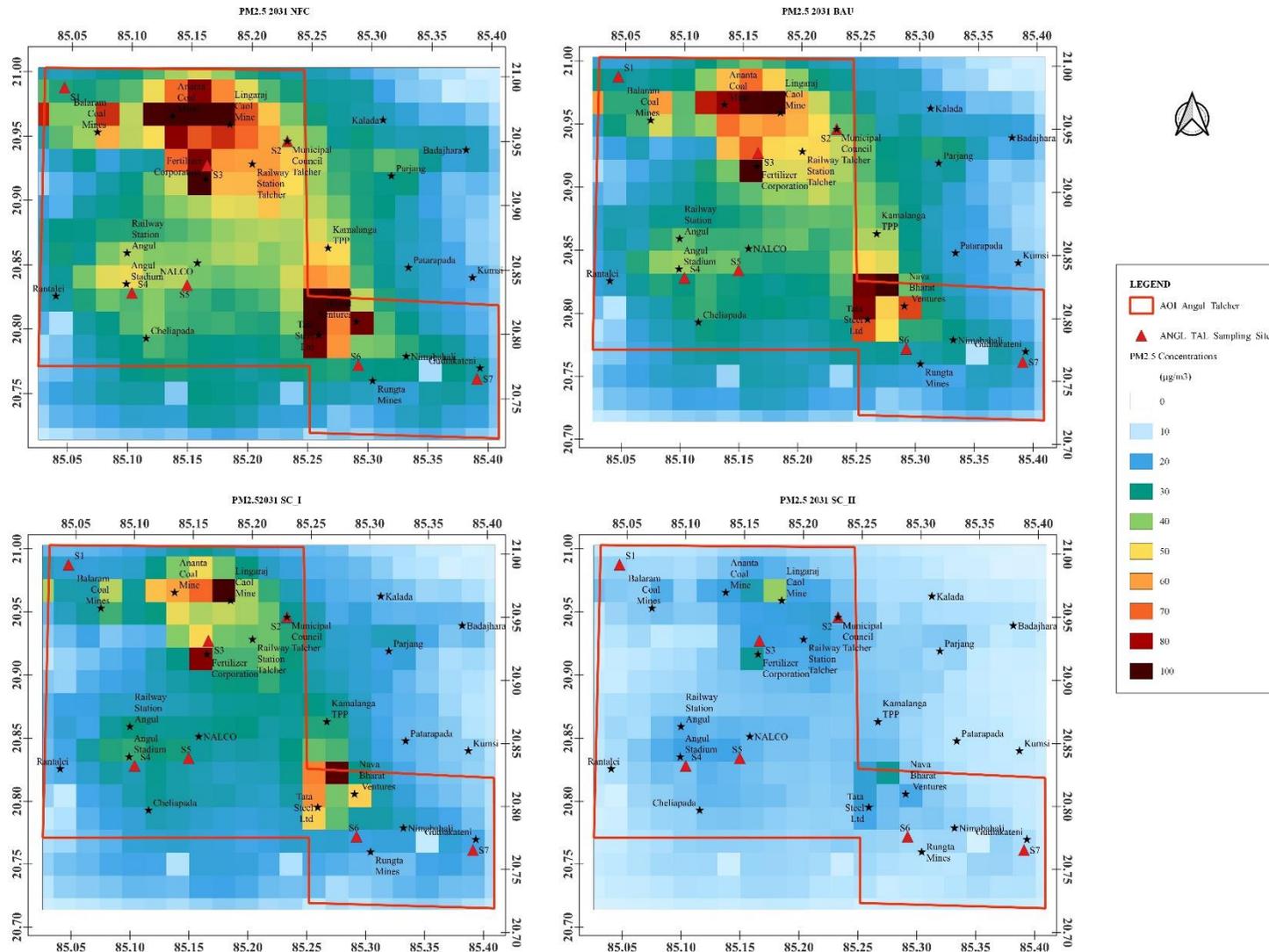


Figure 118 Spatial distribution of annual mean PM_{2.5} concentrations (µg/m³) for four scenarios in year 2031 over Angul-Talcher region

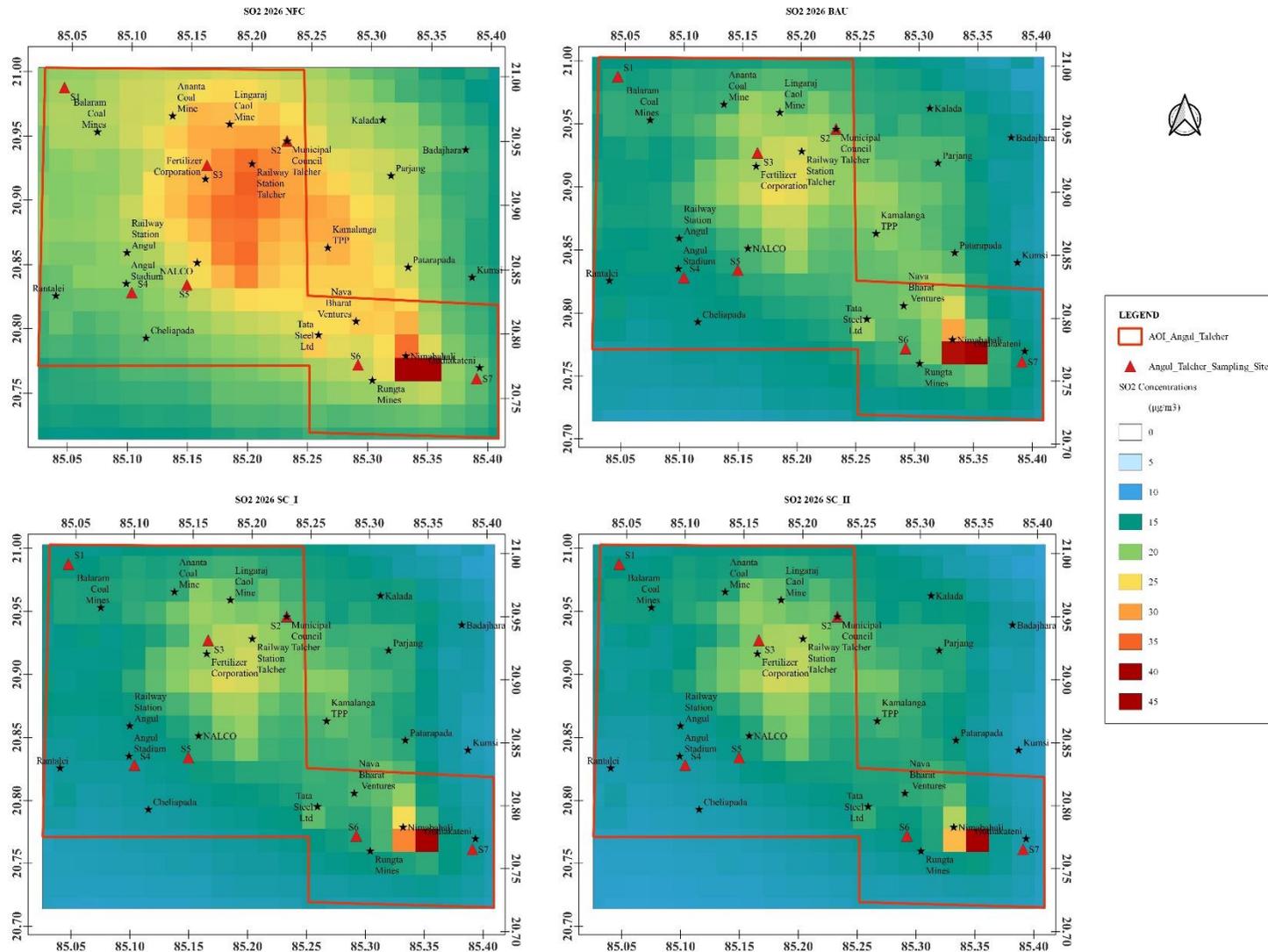


Figure 119 Spatial distribution of annual mean SO₂ concentrations (µg/m³) for four scenarios in year 2026 over Angul-Talcher region

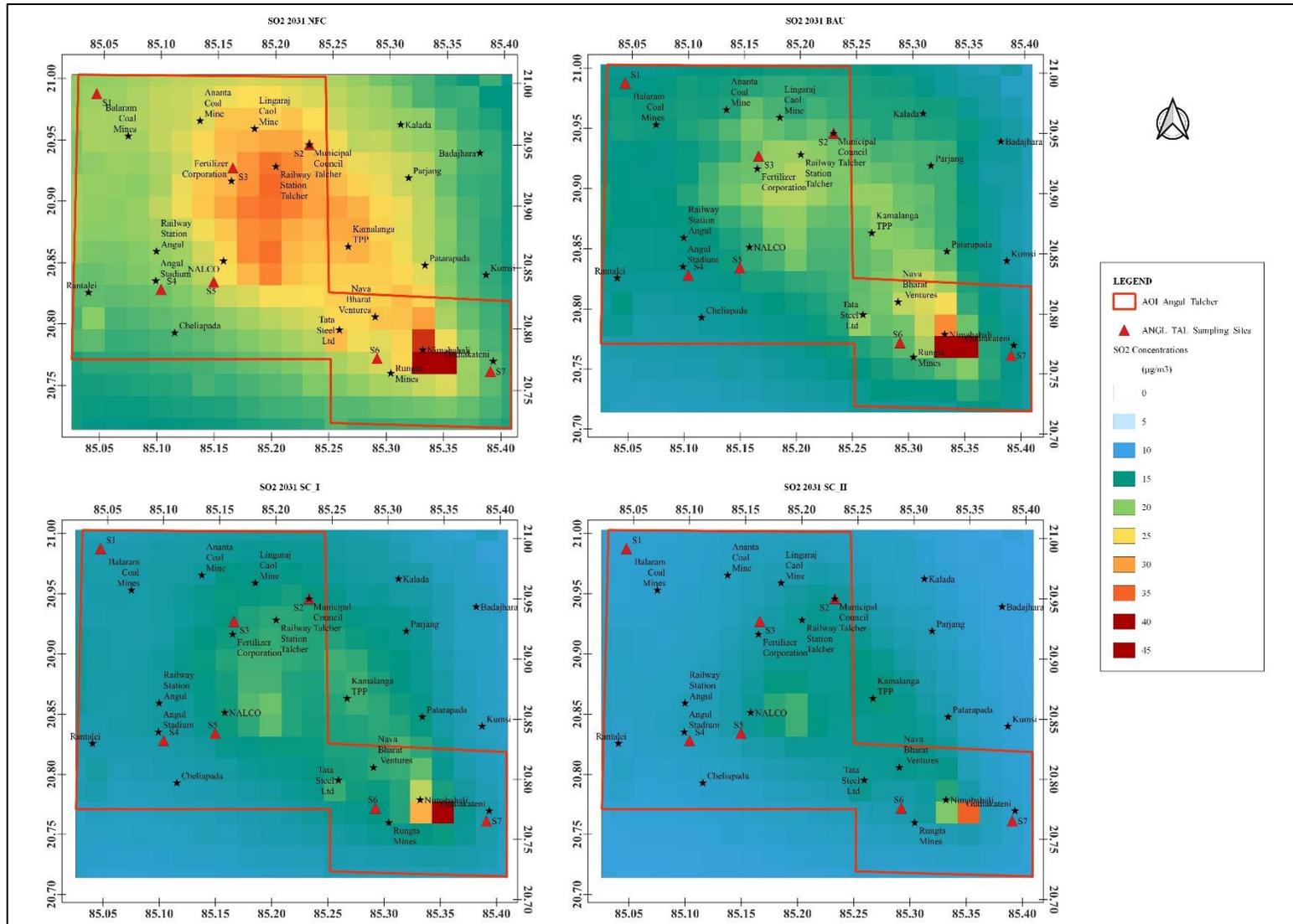


Figure 120 Spatial distribution of annual mean SO₂ concentrations (µg/m³) for four scenarios in year 2031 over Angul-Talcher region

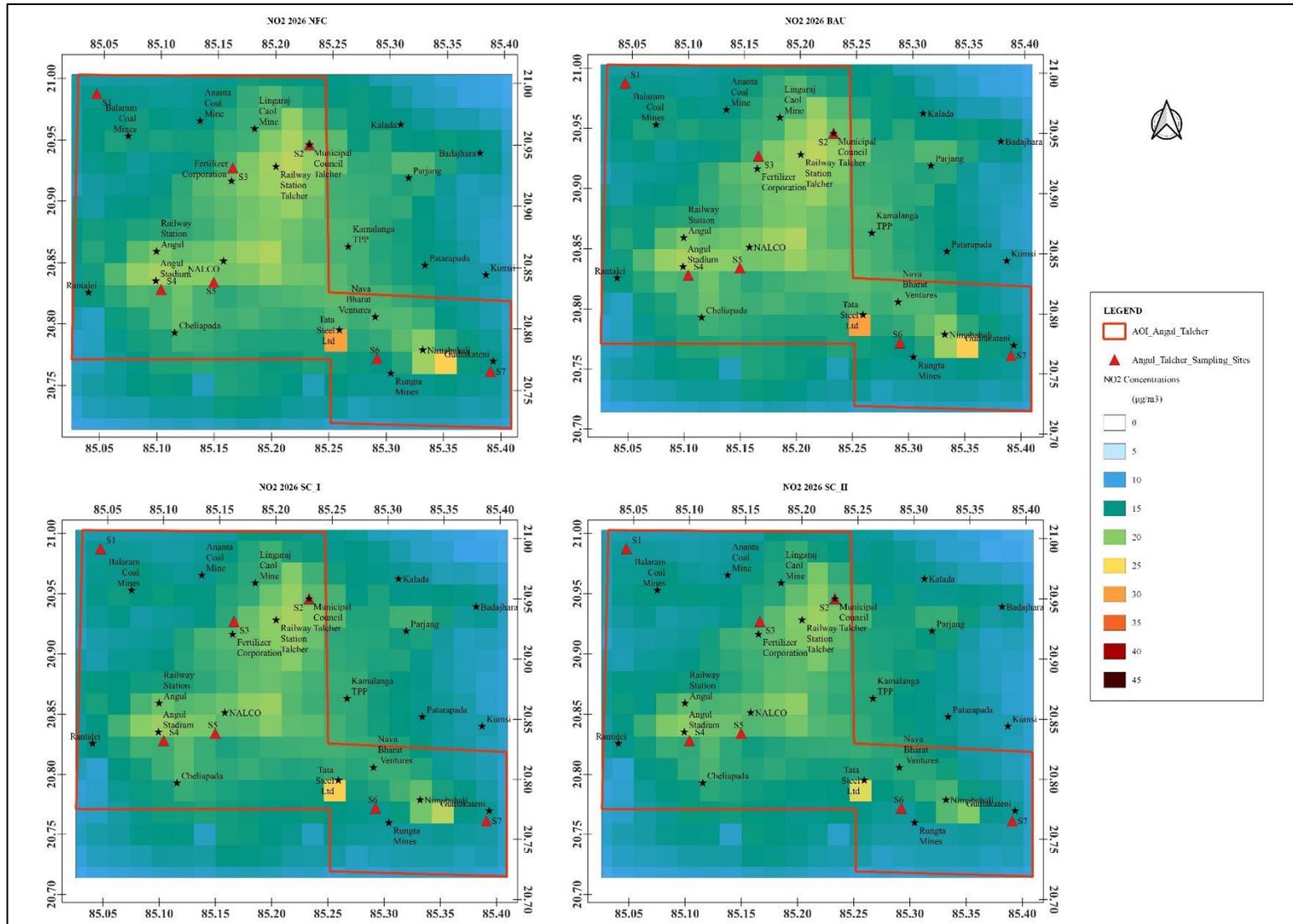


Figure 121 Spatial distribution of annual mean NO₂ concentrations (µg/m³) for four scenarios in year 2026 over Angul-Talcher region

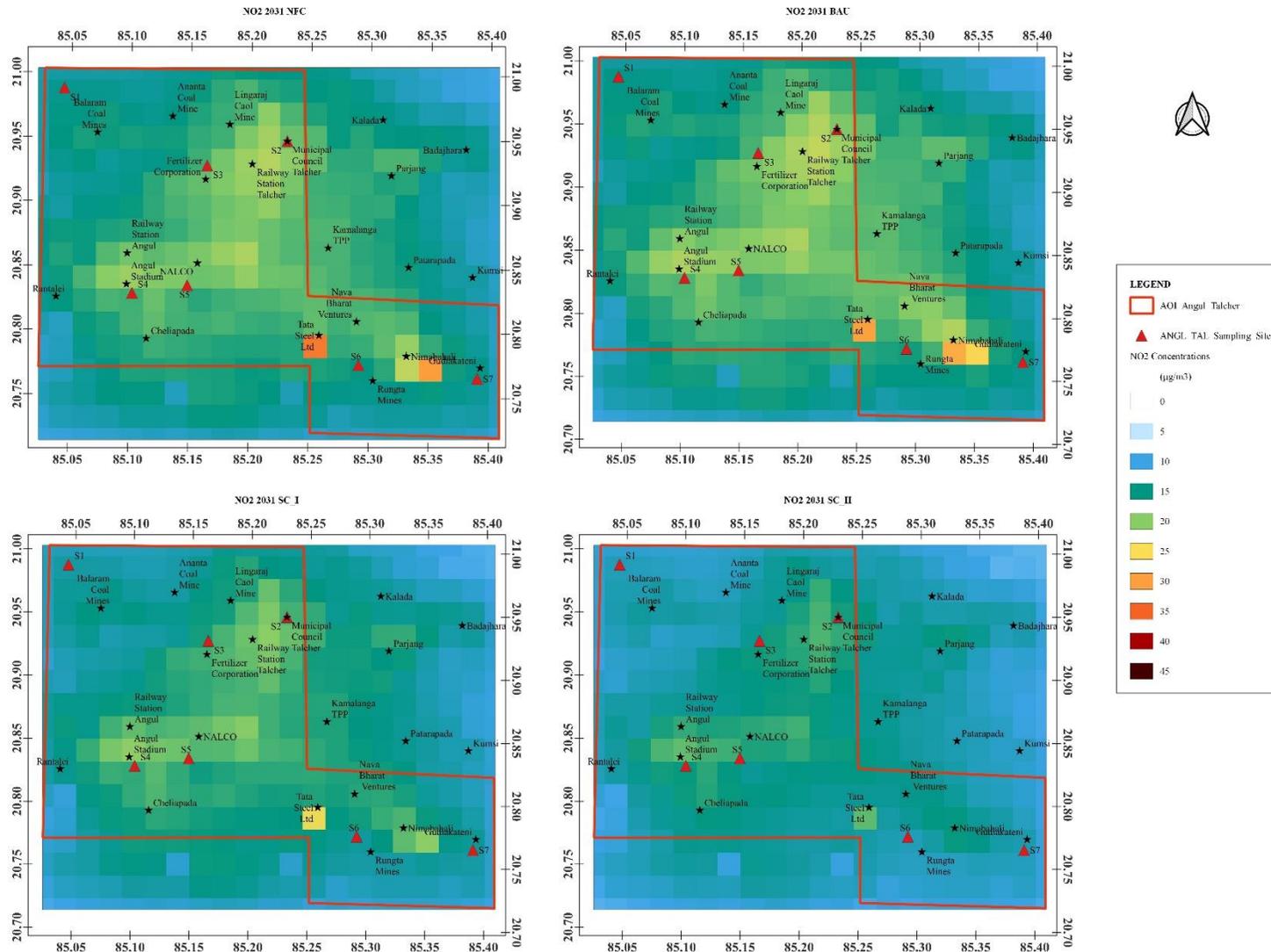


Figure 122 Spatial distribution of annual mean NO₂ concentrations (µg/m³) for four scenarios in year 2031 over Angul-Talcher region

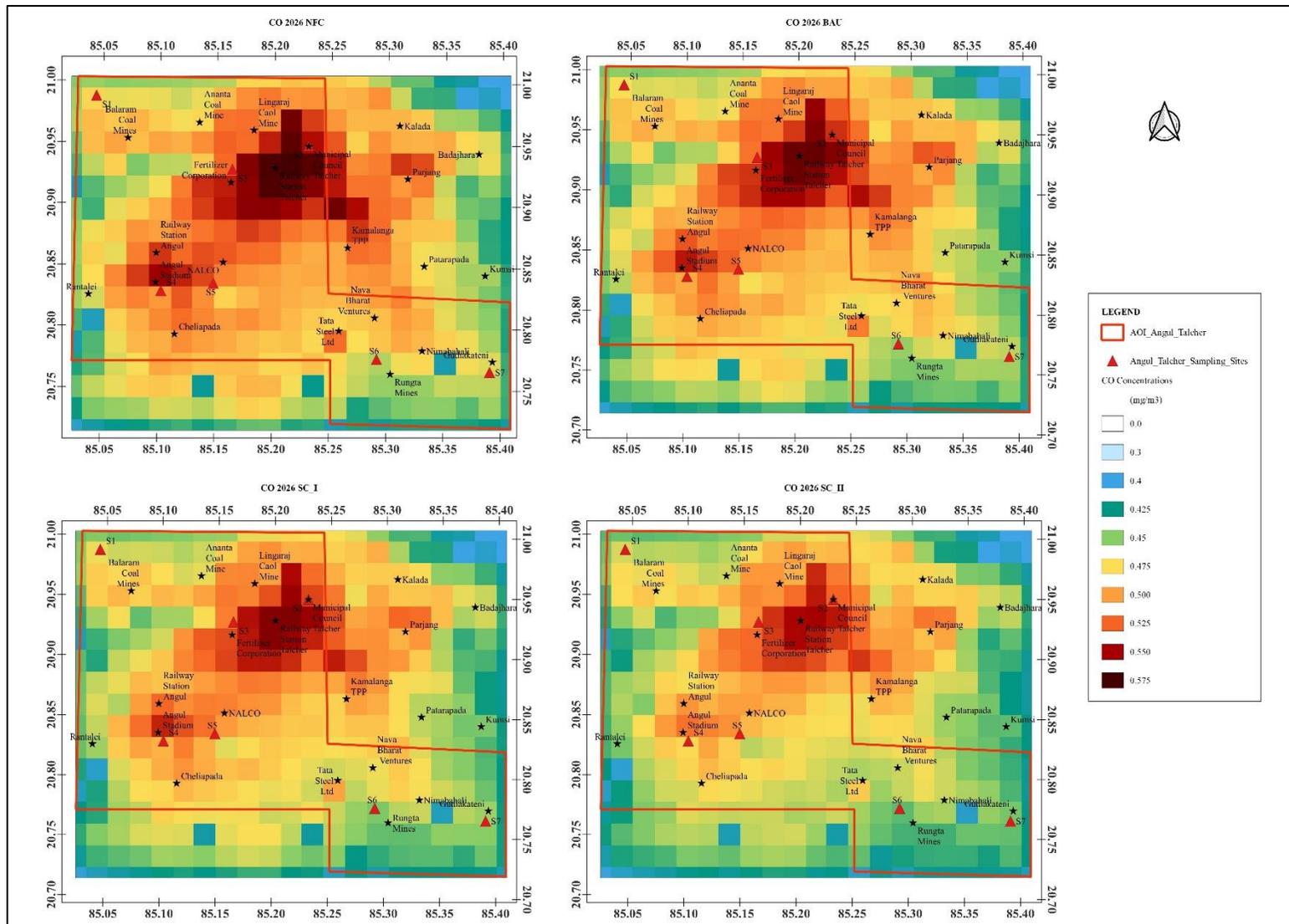


Figure 123 Spatial distribution of annual mean CO concentrations (mg/m³) for four scenarios in year 2026 over Angul-Talcher region

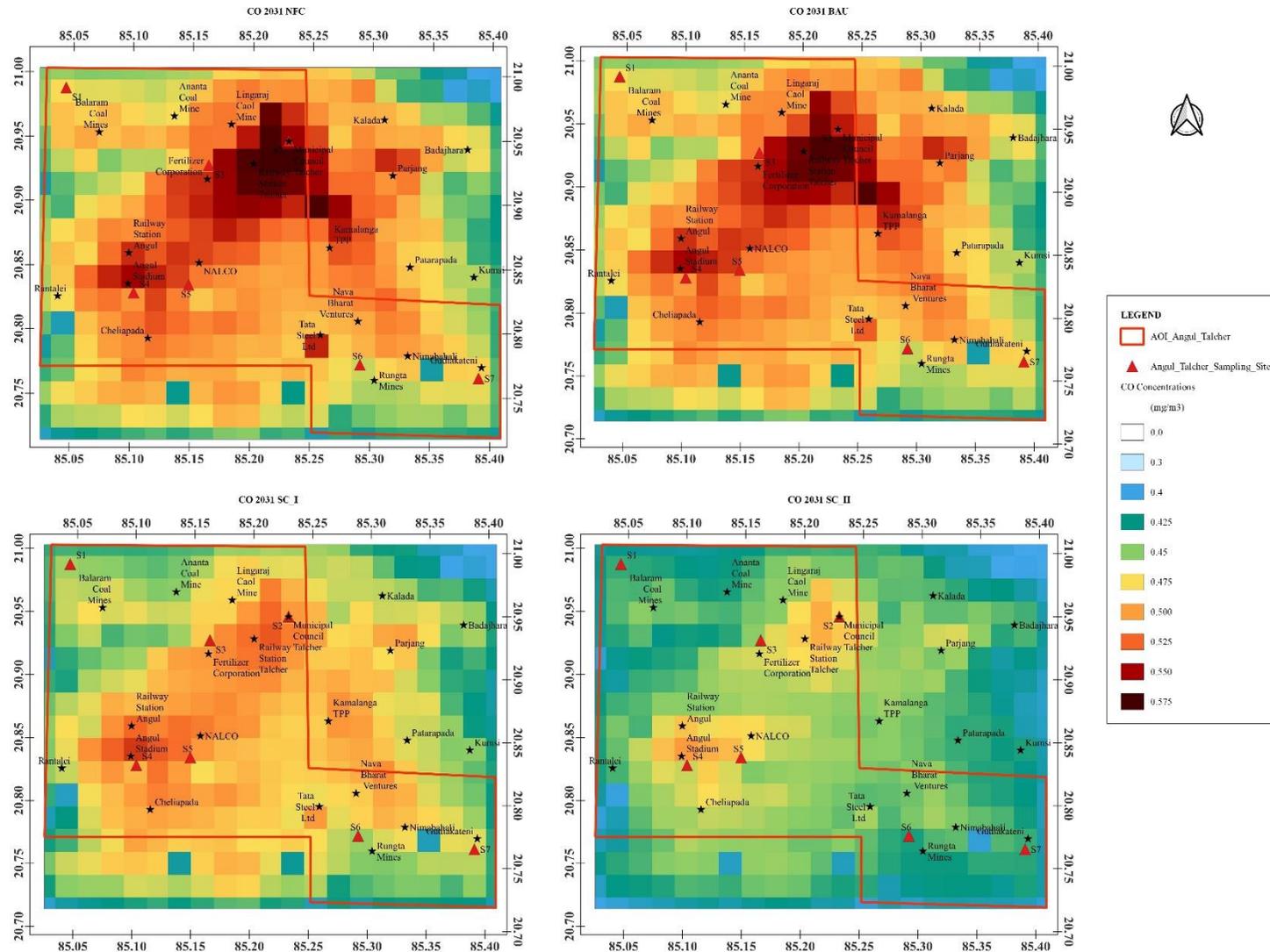


Figure 124 Spatial distribution of annual mean CO concentrations (mg/m³) for four scenarios in year 2031 over Angul-Talcher region

This study also assessed location -specific air quality benefits due to implementation of different scenarios in 2026 and 2031. Eight representative locations, i.e. Talcher coalfields CAAQMS and seven ARAI sampling locations, were selected to understand the impact of control measures on air quality. Tables 27 to 34 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 Angul-Talcher region.

Table 27 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at Talcher coalfields CAAQMS location

Year/Scenario	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-8.4%	-17.5%	-28.5%	-18.9%	-40.7%	-74.8%
PM _{2.5}	-7.4%	-15.4%	-25.6%	-15.9%	-36.7%	-67.3%
SO ₂	-26.0%	-28.5%	-30.2%	-30.8%	-47.1%	-57.8%
NO ₂	0.0%	-3.6%	-5.8%	3.2%	-7.6%	-18.0%
CO	-1.0%	-2.2%	-3.8%	-0.6%	-8.6%	-16.1%

Table 28 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S1 i.e. Banbaspur sampling location

Year/Scenario	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-7.4%	-15.9%	-25.5%	-17.1%	-37.7%	-69.7%
PM _{2.5}	-6.1%	-13.1%	-21.3%	-13.8%	-32.3%	-59.4%
SO ₂	-24.8%	-27.7%	-29.7%	-28.7%	-39.1%	-46.9%
NO ₂	0.1%	-3.2%	-5.2%	2.3%	-7.1%	-15.5%
CO	-0.6%	-1.3%	-2.3%	-0.2%	-4.0%	-8.2%

Table 29 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S2 i.e. Talcher Municipality sampling location

Year/Scenario	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-8.8%	-17.3%	-29.4%	-17.7%	-39.1%	-70.6%
PM _{2.5}	-8.2%	-15.1%	-25.4%	-14.2%	-35.9%	-61.6%
SO ₂	-26.7%	-30.7%	-33.8%	-33.1%	-43.3%	-49.8%
NO ₂	-0.1%	-3.5%	-5.8%	3.6%	-6.1%	-15.3%
CO	-1.9%	-3.2%	-4.9%	-1.6%	-9.8%	-15.2%

Table 30 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S3 i.e. Maa Automotives sampling location

Year/Scenario	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-9.2%	-18.8%	-29.1%	-22.2%	-45.7%	-83.1%
PM _{2.5}	-8.2%	-16.8%	-26.7%	-18.9%	-40.8%	-74.3%
SO ₂	-28.6%	-31.3%	-33.3%	-32.9%	-44.6%	-53.0%
NO ₂	0.1%	-3.8%	-6.0%	2.6%	-7.9%	-18.0%
CO	-0.9%	-1.9%	-3.3%	-0.3%	-6.0%	-11.9%

Table 31 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S4 i.e. Govt. College, Angul sampling location

Year/Scenario	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-8.4%	-16.5%	-30.9%	-16.3%	-34.8%	-65.9%
PM _{2.5}	-7.8%	-14.0%	-27.6%	-14.7%	-30.3%	-57.5%
SO ₂	-23.4%	-27.6%	-31.3%	-26.7%	-32.4%	-38.3%
NO ₂	0.1%	-2.6%	-4.9%	3.3%	-3.2%	-11.6%
CO	-1.4%	-2.0%	-5.2%	-0.4%	-2.5%	-7.9%

Table 32 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S5 i.e. NALCO CISF Headquarters sampling location

Year/Scenario	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-7.8%	-16.3%	-28.9%	-15.7%	-33.9%	-64.5%
PM _{2.5}	-6.7%	-13.9%	-25.2%	-13.4%	-29.1%	-55.7%
SO ₂	-26.2%	-31.3%	-34.9%	-30.5%	-37.1%	-43.8%
NO ₂	0.1%	-3.2%	-5.7%	3.1%	-4.5%	-14.2%
CO	-1.2%	-2.2%	-4.4%	0.3%	-2.2%	-7.9%

Table 33 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S6 i.e. Galapada sampling location

Year/Scenario	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-8.7%	-17.8%	-27.8%	-19.7%	-41.2%	-76.1%
PM _{2.5}	-7.2%	-14.6%	-23.3%	-13.8%	-31.3%	-60.0%
SO ₂	-20.7%	-28.3%	-33.2%	-21.7%	-35.6%	-44.9%
NO ₂	0.0%	-4.8%	-7.9%	3.1%	-9.9%	-19.8%
CO	-1.2%	-2.3%	-3.5%	-0.1%	-2.3%	-7.4%

Table 34 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2026 and 2031 at S7 i.e. Gudiakateni sampling location

Year/Scenario	2026			2031		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-8.0%	-16.3%	-27.9%	-14.9%	-32.8%	-63.7%
PM _{2.5}	-7.1%	-14.1%	-24.0%	-11.5%	-26.2%	-53.7%
SO ₂	-18.6%	-25.4%	-30.3%	-20.4%	-29.9%	-38.2%
NO ₂	0.0%	-3.5%	-5.8%	2.1%	-6.2%	-14.3%
CO	-1.4%	-2.6%	-4.0%	-0.2%	-2.1%	-8.2%

5.16.1. Air quality benefits in terms of Air Quality Indices

Air quality index (AQI) is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (*Ott, 1978*). In this study, a two-step methodology recommended by CPCB is used to calculate daily AQI values (*CPCB, 2015*). A sub-index (*CPCB, 2015*; refer Eq. (23)) was first calculated for each pollutant based on its observed and breakpoint concentrations using linear segmented principle. Then the individual sub-indices were aggregated using a maxima function to obtain an overall daily AQI (*CPCB, 2015*; refer Eq. (24)). The AQI values were then categorized into six different classes: Good (AQI ≤50), Satisfactory (50 < AQI ≤100), Moderate (100 < AQI ≤200), Poor (200 < AQI ≤300), Very poor (300 < AQI ≤400) and Severe (400 < AQI ≤500). The breakpoint concentrations used to calculate the AQI are provided in Annexure-J. In this study, we calculated the AQI using 24-hour mean concentrations of PM_{2.5}, PM₁₀, NO₂ and SO₂ and maximum 8-hour concentrations of CO for the corresponding day.

$$I_i = \left[\left\{ \frac{(I_{HI} - I_{LO})}{(B_{HI} - B_{LO})} \right\} * (C_P - B_{LO}) \right] + I_{LO} \dots \dots \dots (22)$$

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.

$$I = \max_{i=1,2,3,\dots,n} (I_i) \dots \dots \dots (23)$$

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 Talcher Coalfields CAAQMS location for different scenarios in 2026 and 2031 and its implication to short and long-term national air quality goals and future directions. It is important to note that, the AQI values are calculated using the AERMOD estimated pollutant concentrations, only.

Fig. 125 shows the distribution of six AQI categories at Talcher Coalfields CAAQMS location in Angul-Talcher for observed and modelled concentrations in year 2022, while Fig. 126 and Fig. 127 shows the distribution of AQI categories for different scenarios in 2026 and 2031 respectively.

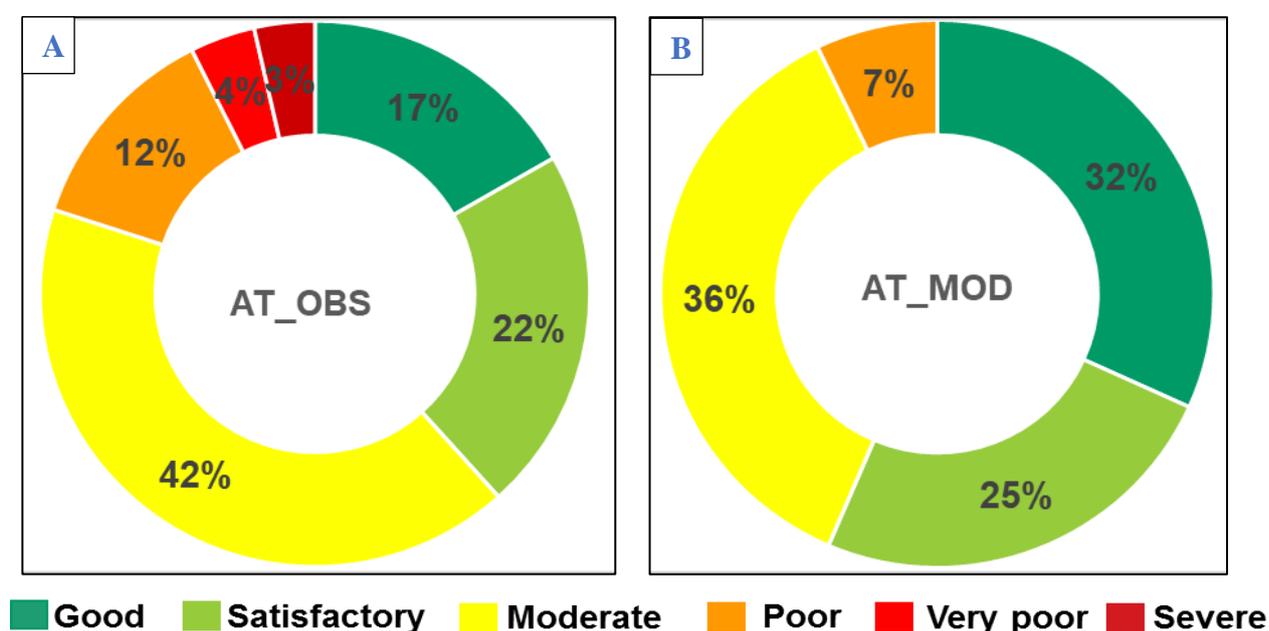


Figure 125 Distribution of six AQI categories at Talcher Coalfields CAAQMS location in Angul-Talcher for observed (A) and modelled (B) pollutant concentrations for baseline year

Initially, the AQI values calculated using modelled concentrations are compared against the AQI values calculated using observed pollutant concentrations. An examination of Fig. 125 (A and B) confirms that AQI values calculated using modelled concentrations reasonably well with observed AQI for year 2022. The AQI at the selected location during baseline scenario in 2022 is mainly driven by PM₁₀ and on several occasions by PM_{2.5}. An examination of observed AQI for the baseline scenario revealed that air quality index, is mainly distributed in Moderate (42%), Satisfactory (22%) and Good (17%) classes while Poor category AQI is reported for approx. 13% of days in a year. It is also important to note that the

very poor and severe category AQI classes together constitute about 8% i.e. 27 days in a year. The modelled AQI values did not capture the very poor and Severe days during baseline year. This is attributed to under-predicted model values of SO₂ and NO₂ on few days, when Observed AQI is mainly driven by gaseous pollutants.

The AQI distribution in NFC scenarios during year 2026 shows degraded air quality compared to baseline year with 7% Good, 14% satisfactory, 31% moderate, 18% poor, 11% very poor and 19% 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 3% Good, 12% satisfactory, 24% moderate, 18% poor, 11% very poor and 31% 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 21% and 16% in 2026 and 2031, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 22% and 19% in 2026 and 2031, respectively under BAU scenario, to 24% and 25% in 2026 and 2031, respectively under SC-I, to 29% and 47% in 2026 and 2031, respectively under SC-II scenario. Fig 126 and 127 represents the distribution of AQI categories in four scenarios at Talcher Coalfields CAAQMS station for year 2026 and 2031 respectively.

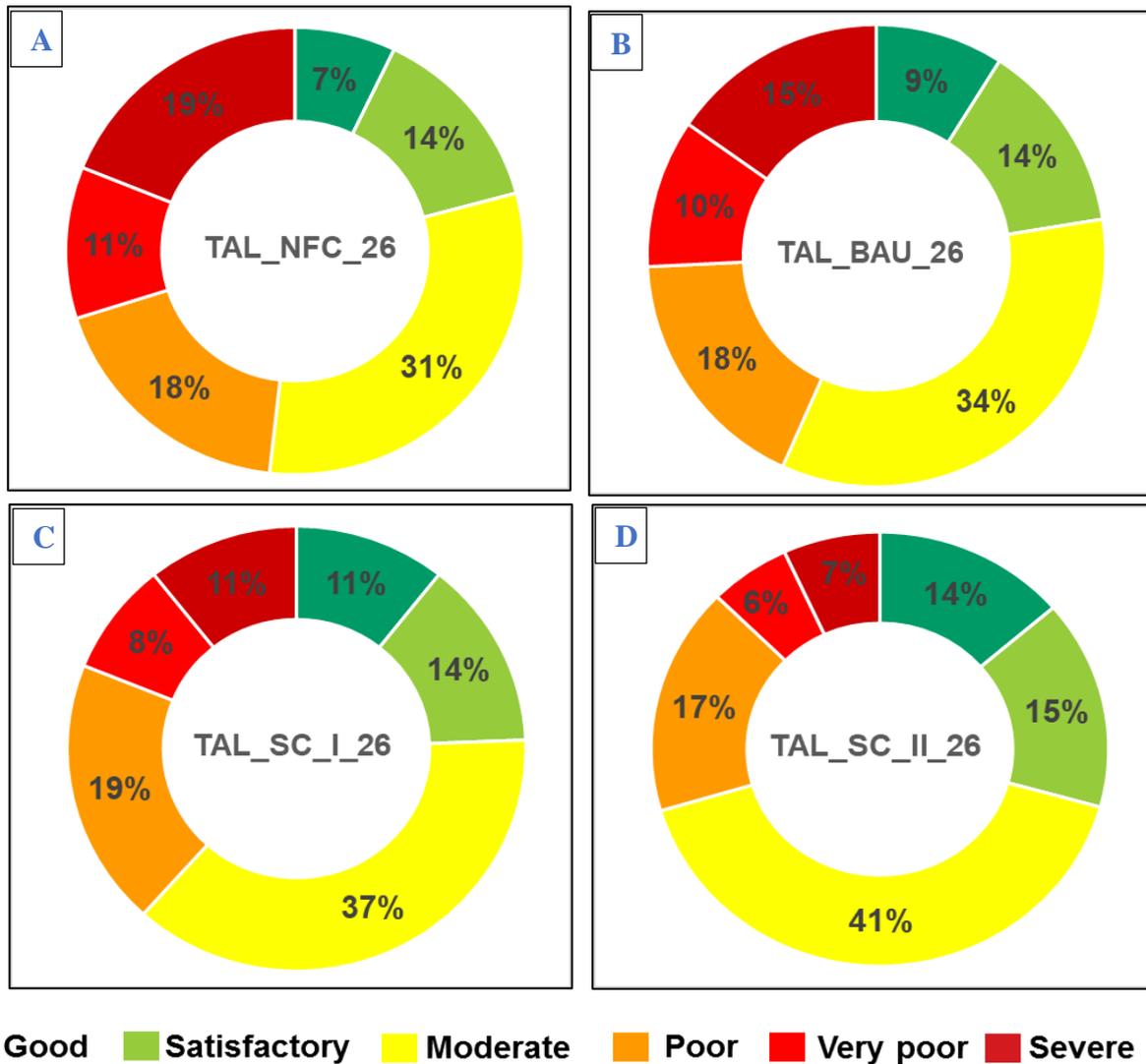


Figure 126 Distribution of six AQI categories at Talcher Coalfields CAAQMS location in Angul-Talcher for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2026

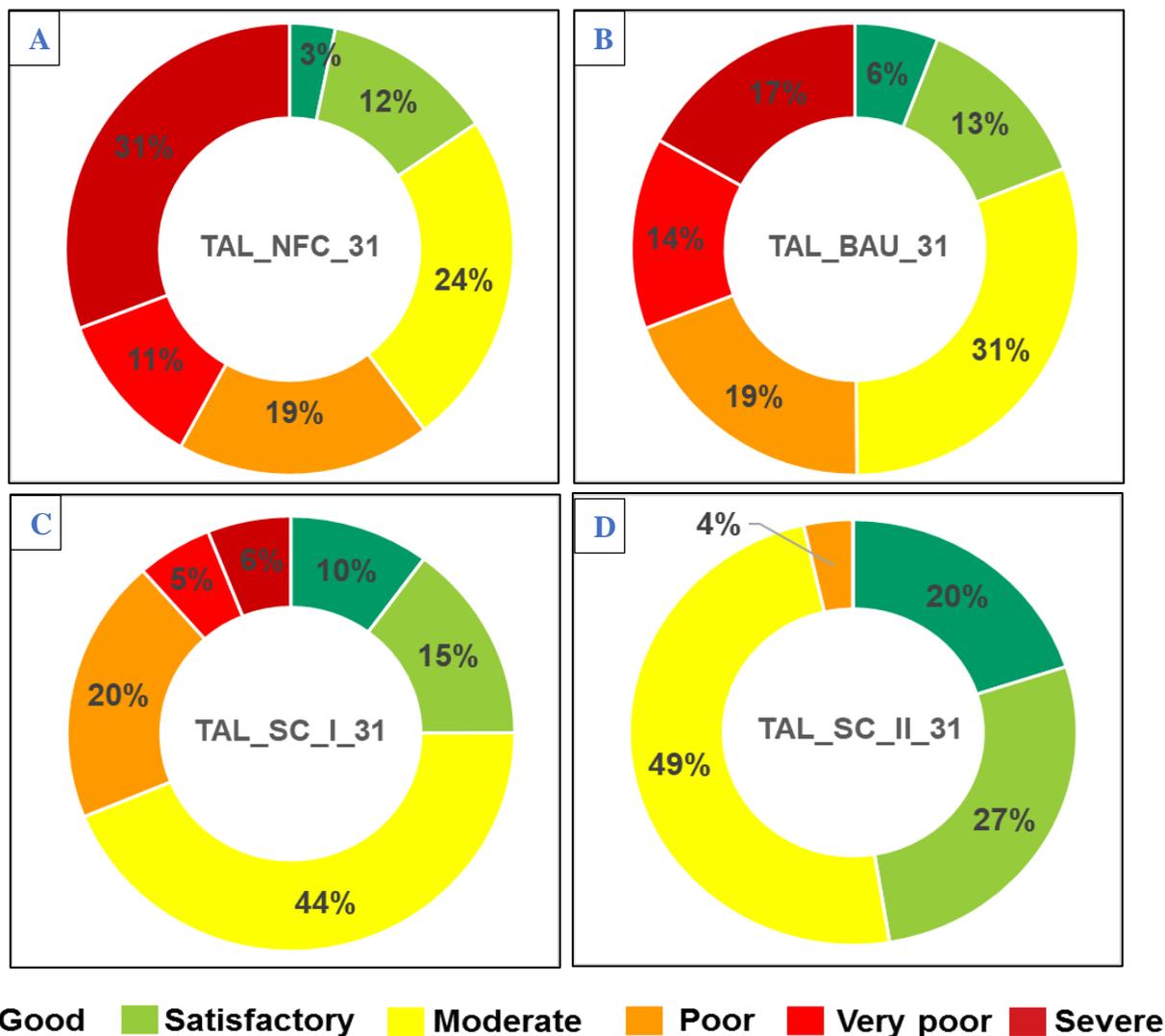


Figure 127 Distribution of six AQI categories at Talcher Coalfields CAAQMS location in Angul-Talcher for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2031

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Angul-Talcher region as well. These findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level PM_{2.5} and PM₁₀ concentrations by 20-30% by the year 2024, as compared to 2017 i.e. base year.

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Chapter 6: Action Plan

6.1. Air Quality Action Plan for Angul Region

Table 35 presents the proposed air quality action plan for Angul region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

Table 35 Proposed Air quality action plan for Angul 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 kerb side, especially small ones to avoid traffic congestions.	RTO, Angul	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.	RMC / RTO, Angul	6 months
	Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses).	RMC	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	RMC	1 -2 years
	Declare NO-vehicle zones in hot-spots, university / school premises.	RMC / 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, Angul	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Road Dust	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, Angul	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 suppress 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: <ul style="list-style-type: none"> • 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
	<ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> • 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 <ul style="list-style-type: none"> • 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
	<ul style="list-style-type: none"> Installation of Flue Gas Desulfurization (FGD) units to reduce the SO₂ 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 <i>Chullahs</i> (low emission <i>Chullahs</i>) 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.)
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 PM_{2.5} 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 (NO_x), supplemented by transport from the stratosphere (e.g. Crutzen, 1974; Atkinson, 2000; Monks et al., 2015). It can be transported over long distances resulting in enhanced concentrations even in areas remote from the sources of precursors (Cox et al., 1975). It is suggested to augment current monitoring network, to include monitoring of VOCs and Ozone in non-attainment cities.
- **Advanced source apportionment:** Near real time advanced source apportionment using set of state-of-the-art equipment. This can typically include an aerosol chemical speciation monitors (ACSM) to monitor organic aerosols and selected ions (such as sulfate, nitrate, ammonium, and chlorides); along with a black carbon and a metals analyzer. This set-up can provide high resolution near real time data

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

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

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Annexures

Annexure-A: Air Quality Monitoring

Air quality monitoring is to be done with the speciation samplers to collect PM₁₀ 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 PM₁₀ and PM_{2.5} from Ambient Air by Speciation Sampler

1.0 Scope

This procedure is applicable to air sampling for PM₁₀ 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 (PM₁₀) 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 PM₁₀ 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°C

6.0 PPEs TO BE USED:

Cotton hand gloves, safety shoes

7.0 Procedure:

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

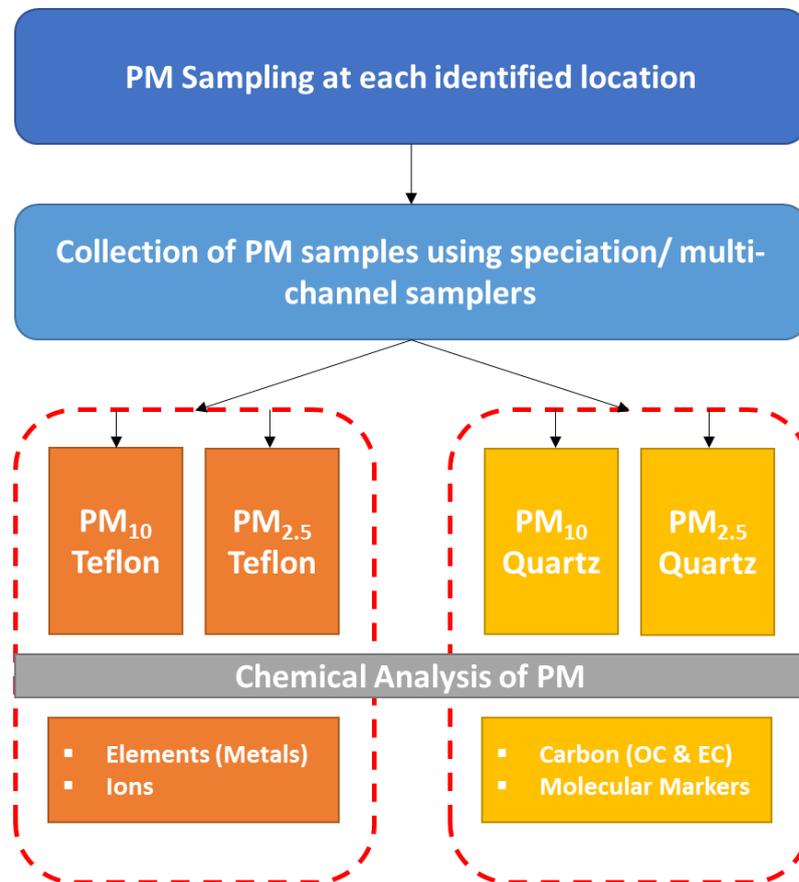
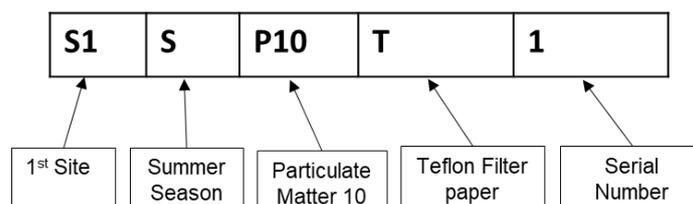


Fig. A-1: Arrangement of filter papers for multi-channel speciation samplers

- 7.2 Check Temperature and Humidity sensor connections.
- 7.3 Filter papers are numbered with Site id, Season, PM type, Filter type, serial number.



Similarly, for Winter Season →“W,” PM_{2.5} →“P2.5” and Quartz filter paper →“Q”

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

7.5 Load filter paper in cartridge as per below table:

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

7.6 Start Speciation sampler as per standard procedure.

Sampling Site photographs





VOC Sampling Collection through Tenax Sorbent Tubes



Gaseous Sampling Collection (SO₂ & NO_x)



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 PM₁₀ 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) tweezers/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 by 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

$1\mu\text{g}/\text{cm}^3$ 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, $\text{PM}_{2.5}$ reference methods require that filters be equilibrated for 24 hours at a constant (within $\pm 5\%$) relative humidity between 30% and 40% and at a constant (within $\pm 2^\circ\text{C}$) temperature between 20°C and 23°C , 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 ($\pm 5\%$) and 15°C to 30°C temperature ($\pm 3^\circ\text{C}$).

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 20°C 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 handling storage use disposal of chemicals for --
 - Sodium Carbonate (Na₂CO₃)
 - Sodium Bi-Carbonate (NaHCO₃)
 - Methane Sulphonic Acid (MSA)

3.0 Summary of Test Procedure

The method determines the anions and cations present in PM e.g. PM₁₀ / 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 software Software Version 7.2.9

- Ions analyzed by Ion chromatograph:
 - Cations: Na⁺, NH₄⁺, K⁺, Mg⁺², Ca⁺²
 - Anions: F⁻, Cl⁻, Br⁻, NO₂⁻, NO₃⁻, SO₄²⁻, PO₄³⁻

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 Columnn
- Suppressor
- Conductivity detector
- Automated Sampler

4.2 IC Operating Conditions:

Sample loop volume:	25 µl for anions and cations
Analytical Columnn:	
Anions	Dionex Ion Pac AS23 Analytical columnn
Cations	Ion Pac SCS1 Separator columnn
Guard Columnn:	
Anions	Dionex Ion Pac AG23 guard columnn
Cations	Dionex Ion Pac SCG1 guard columnn
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	1.5ml/min
Cations	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	AERS type 600 (4mm) suppressor
Suppressor for Cation	CERS type 600 (4mm) suppressor
Analysis Time:	
Anion	20min
Cation	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 (Na₂CO₃)
- Sodium Bi-Carbonate (NaHCO₃)
- Methane Sulphonic Acid (MSA)
- Milli-Q Grade ASTM type 1 deionized water (18.2 Mega Ohm cm⁻¹)
- Anion Standard (F⁻, Cl⁻, Br⁻, NO₂⁻, NO₃⁻, SO₄²⁻, PO₄³⁻)
- Cation Standard (Na⁺, NH₄⁺, 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
<i>Anion Eluent</i>	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)
<i>Cation Eluent</i>	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 1 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 m³

Q = Mean flow rate in m³/minute

T = Total sampling time in minute

7.2 Calculation of Anions and Cations in PM in Ambient Air

$$\text{Concentration of Ion } \mu\text{g/ m}^3 = [(C \times V_1) - B] / (V \times F)$$

Where,

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

V₁ = 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 (m³) of ambient particulate matter.

9.0 Calibration Records:

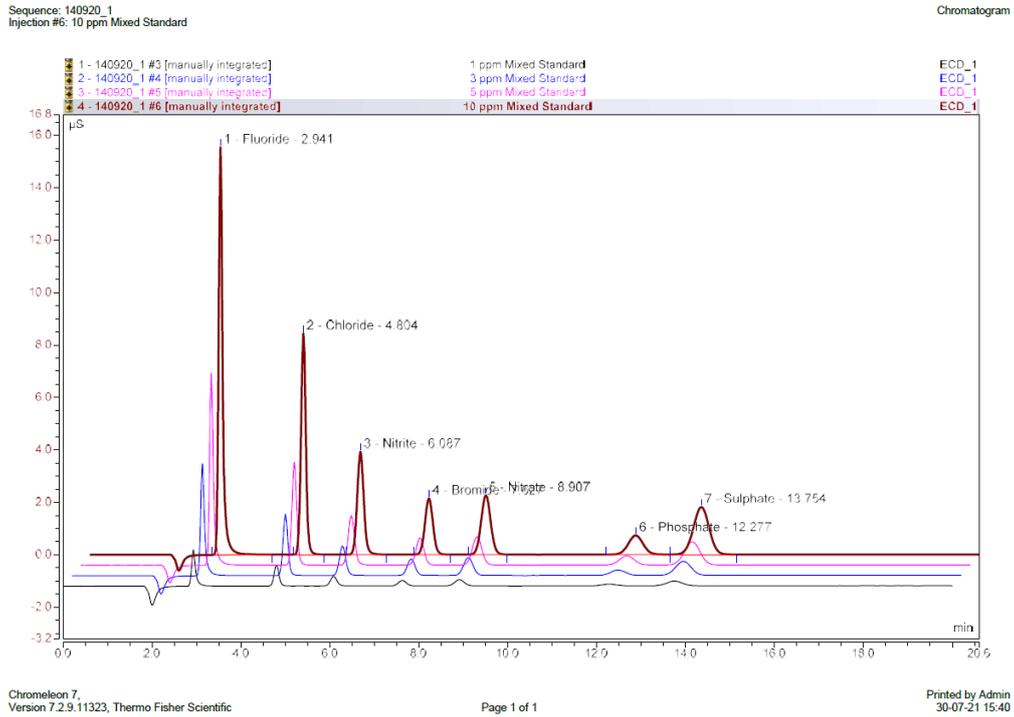


Fig. C-1: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Anion

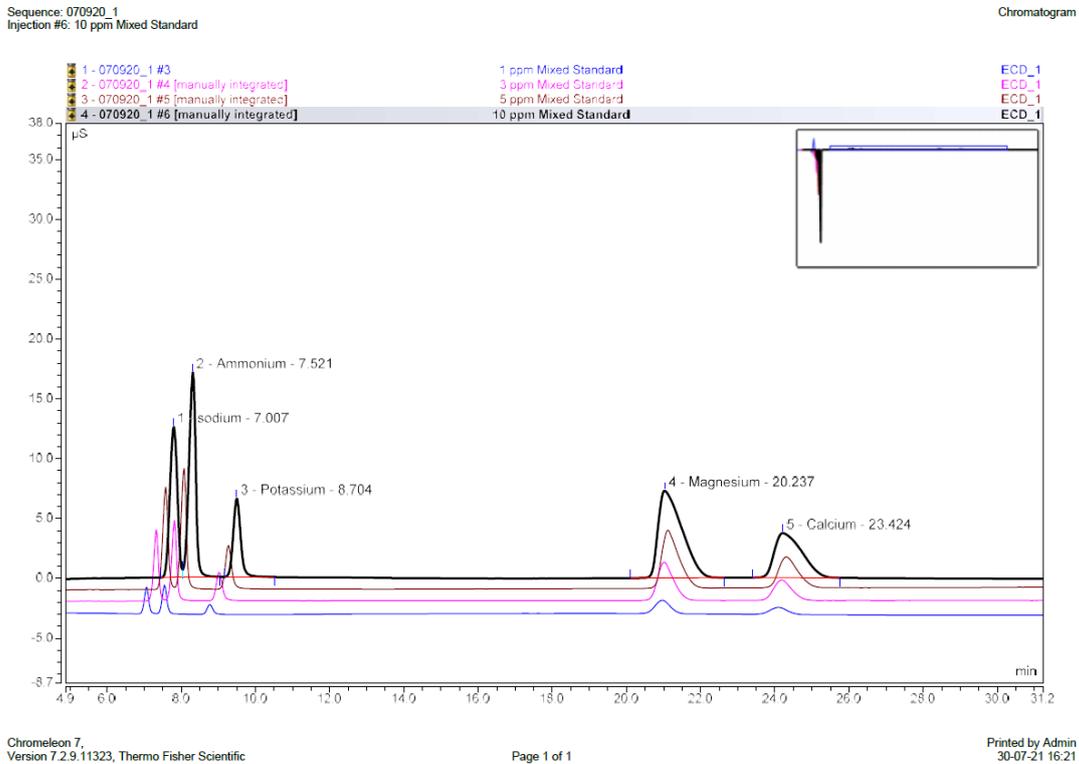


Fig. C-2: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Cation

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 $\mu\text{g}/\text{cm}^2$.

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 $\mu\text{g}/\text{cm}^2$.
- 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 $\mu\text{g}/\text{cm}^2$.
- 7.2 Results are converted to $\mu\text{g}/\text{m}^3$ by using exposed area of filter and volume of air sampled.

8.0 Reporting

- a) Report the result in the desired unit e.g. $\mu\text{g}/\text{cm}^2$ up to 2 decimal places.

Annexure-E: Carbon Analysis

Analysis of Organic Carbon (OC) and Elemental Carbon (EC) in Particulate matter (PM₁₀ and PM_{2.5})

1.0 Scope

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

2.0 Referred Documents

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

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

3.0 Summary of test Procedure

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

4.0 Apparatus

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

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

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

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

- 4.4 Flat-tip tweezers.
- 4.5 Flat glass plate.
- 4.6 Tissue paper
- 4.7 Glassware
- 4.8 **Gases:** All gases are required of high purity grade

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

5.0 Chemicals:

- 5.1 Potassium Hydrogen Phthalate (KHP)
- 5.2 Sucrose
- 5.4 Ultrapure ASTM type 1 deionized water (>16 Mega Ohm-cm).

6.0 Procedure

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

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

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

6.2 Leak Check test

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

6.3 Oven Baking

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

6.4 Auto-calibration

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

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

6.5 Sample analysis

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

6.6 Filter blank

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

6.7 Calibration

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

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

7.0 Calculations

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

8.0 Reporting

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

9.0 Calibration Graphs

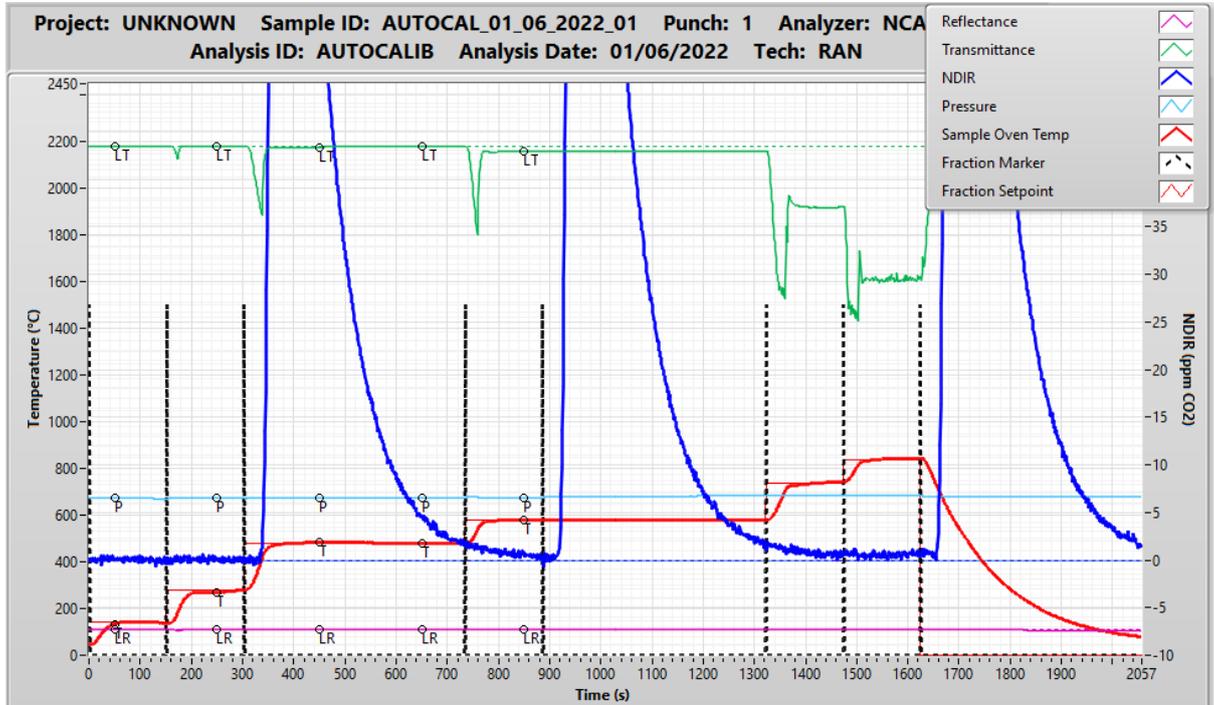


Fig. E-1: Typical example of Auto-calibration run taken on every day before actual testing starts

Annexure-F: QA/QC

Outlines of Field and Laboratory Performance Audits

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

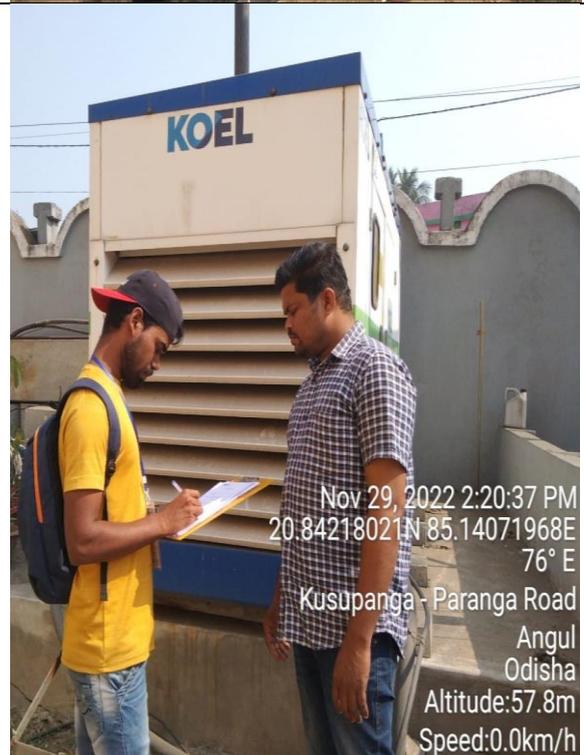
Annexure-G: Emission Inventory Activities



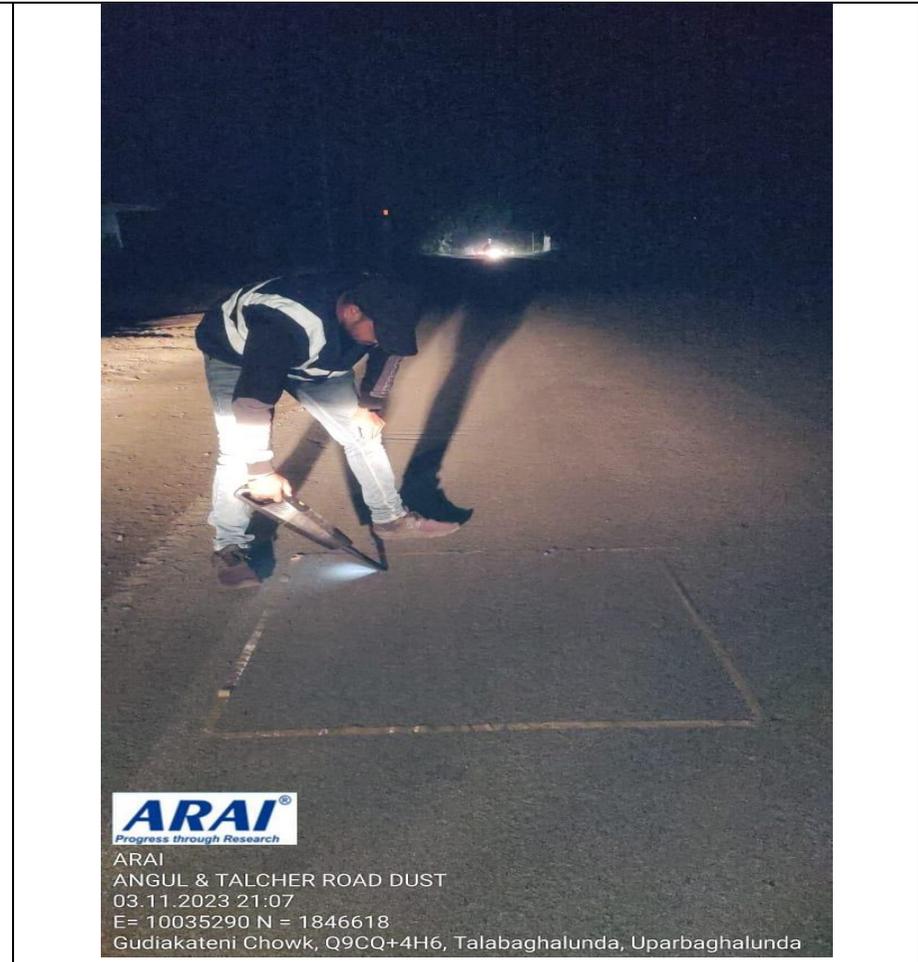
Figure G.128 Construction activity in Angul in March 2021 and December 2021

Photographs taken during primary data collection surveys in Angul region





Photographs taken during road dust sampling at Angul



Photographs showing activities in Angul region



Industrial Pollution



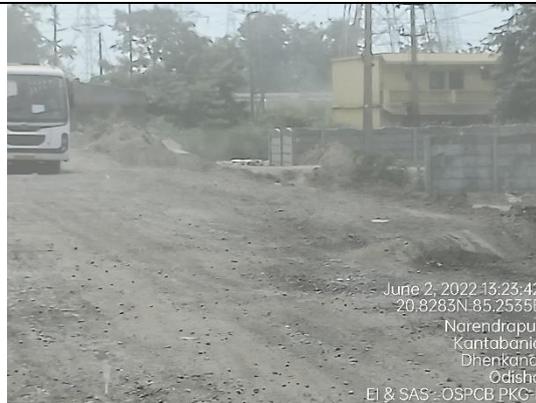
Open Waste Burning



Industrial Pollution



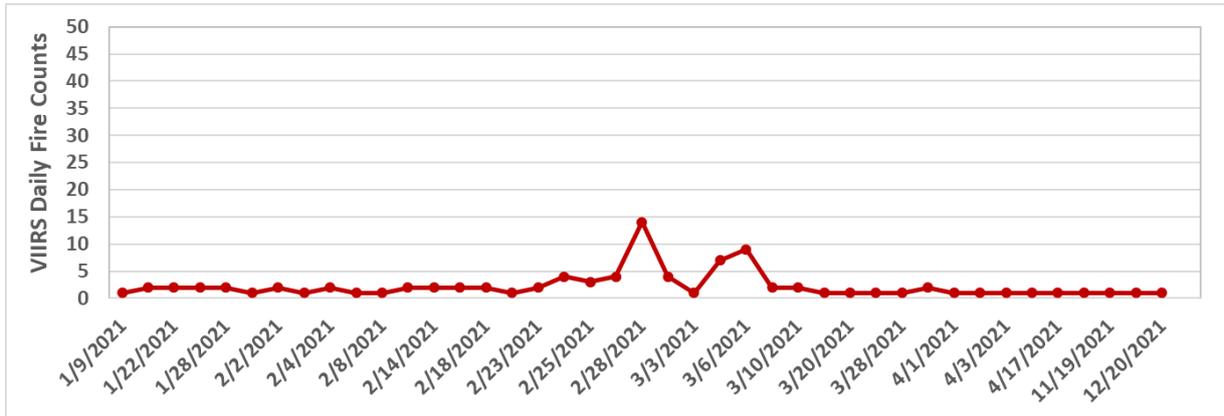
Road Dust



Open Burning



Daily fire counts observed over Angul region in year 2021



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

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

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

Industry Sector	PM10	PM2.5	SO2	NOx
Aluminium Smelter	517.44	274.46	684.48	119.89
Ferro Alloys	9.68	5.13	0.10	0.43
Iron and Steel	3168.79	1567.18	36261.53	15284.58
Thermal Powerplants	6576.00	2908.00	88863.00	44998.00
Fugitive Emissions	9548.00	847.00	-	-
Total	19819.91	5601.77	125809.11	60402.90

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 SO_x emissions from sinter strands	Primary sulphur oxide (SO _x) emissions can be reduced by using one or a combination of the following techniques: <ul style="list-style-type: none"> 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 NO_x emissions from sinter strands	Primary NO _x 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-NO _x 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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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 uninterrupted coke production by using the following techniques:	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		<ol style="list-style-type: none"> I. extensive maintenance of oven chambers, oven doors and frame seals, ascension pipes, charging holes and other equipment (a systematic programme should be carried out by specially-trained detection and maintenance personnel) II. avoiding strong temperature fluctuations III. comprehensive observation and monitoring of the coke oven IV. cleaning of doors, frame seals, charging holes, lids and ascension pipes after handling (applicable at new and, in some cases, existing plants) V. maintaining a free gas-flow in the coke ovens VI. adequate pressure regulation during coking and application of spring-loaded VII. flexible sealing doors or knife-edged doors (in cases of ovens f5 m high and in good working order) VIII. using water-sealed ascension pipes to reduce visible emissions from the whole apparatus which provides a passage from the coke oven battery to the collecting main, gooseneck and stationary jumper pipes IX. luting charging hole lids with a clay suspension (or other suitable sealing material), to reduce visible emissions from all holes X. ensuring complete coking (avoiding green coke pushes) by application of adequate techniques XI. installing larger coke oven chambers (applicable to new plants or in some cases of a complete replacement of the plant on the old foundations) where possible, using variable pressure regulation to oven chambers during coking (applicable to new plants and can be an option for existing plants; the possibility of installing this technique in existing plants should be assessed 	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
		<p>carefully and is subject to the individual situation of every plant).</p> <p>XII. Extract the coke oven gas (COG) during coking as much as possible.</p> <p>XIII. reduce the sulphur content of the coke oven gas (COG) by using one of the following techniques:</p> <ol style="list-style-type: none"> a. desulphurisation by absorption systems b. wet oxidative desulphurisation. 	
5.	Fugitive gaseous emissions from gas treatment plant	<p>The fugitive gaseous emissions from the gas treatment plant can be minimised by using the following techniques:</p> <ol style="list-style-type: none"> 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: <ol style="list-style-type: none"> 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	<p>The emissions from the coke oven under firing can be reduced by using the following techniques:</p> <ol style="list-style-type: none"> I. preventing leakage between the oven chamber and the heating chamber by means of regular coke oven operation II. repairing leakage between the oven chamber and the heating chamber (only applicable to existing plants) III. incorporating low-nitrogen oxides (NOX) techniques in the construction of new batteries, such as staged combustion and the use of thinner bricks and refractory with a better thermal conductivity (only applicable to new plants) IV. using desulphurised coke oven gas (COG) process gases. 	

Sr. No.	Targeted Pollutants and Processes	Techniques/Methods to reduce the targeted pollutant	Remarks
7.	Dust emissions from coke pushing	<p>The dust emissions from coke pushing can be reduced by using the following techniques:</p> <ul style="list-style-type: none"> 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	<p>The dust emissions from coke quenching can be reduced by using the following techniques:</p> <ul style="list-style-type: none"> 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	<p>The dust emissions from coke grading and handling can be reduced by using the following techniques in combination:</p> <ul style="list-style-type: none"> 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
		<ul style="list-style-type: none"> b. dust catchers c. cyclones d. electrostatic precipitators. II. subsequent dust abatement such as: <ul style="list-style-type: none"> 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)	<p>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:</p> <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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. 	
		<p>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:</p> <ul style="list-style-type: none"> 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	<p>The dust emissions from the oxygen lance hole can be minimised by using one or a combination of the following techniques:</p> <ul style="list-style-type: none"> 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	<p>The best technique is secondary dedusting, including the emissions from the different associated processes is to minimise dust emissions</p>	

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	<p>The dust emissions from on-site slag processing can be minimised by using one or a combination of the following techniques:</p> <ul style="list-style-type: none"> 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: <ol style="list-style-type: none"> 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: <ol style="list-style-type: none"> 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	O ₃	CO
	Unit less	µg/m ³	mg/m ³				
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+

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