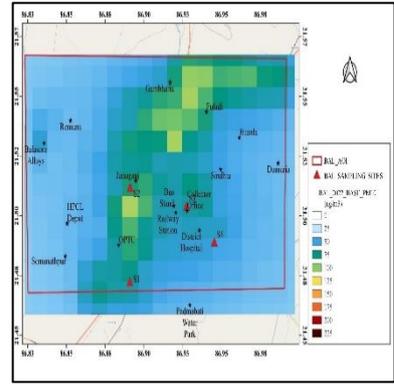
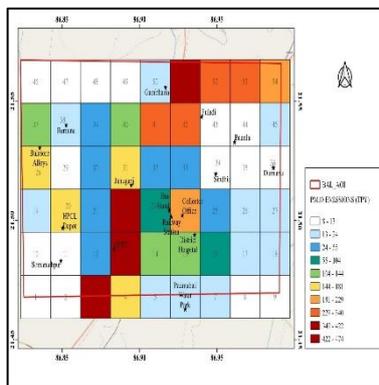
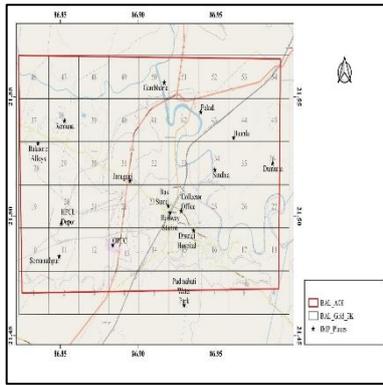
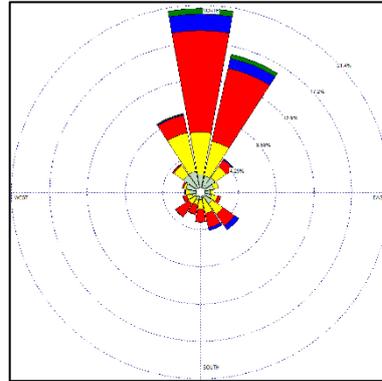


FINAL REPORT

Emission Inventory and Source Apportionment Study of Balasore Region in Odisha



Submitted to



State Pollution Control Board, Odisha

ରାଜ୍ୟ ପ୍ରଦୂଷଣ ନିୟନ୍ତ୍ରଣ ବୋର୍ଡ଼, ଓଡ଼ିଶା

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 Balasore 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 Balasore Region in Odisha”. The main aim of this study is to identify and characterize various emission sources in Balasore 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 Balasore region.
- To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Balasore 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

Balasore, situated at approximately 21.4941° N latitude and 86.9293° E longitude in Odisha, India, holds historical significance dating back to ancient times. It served as a pivotal maritime trade center during the medieval era, influenced by dynasties like the Mughals and Marathas. Strategically located on National Highway 16 (formerly NH-5), connecting Kolkata and Chennai, it functions as a key transportation junction. The city boasts a diverse economy with agriculture, small-scale industries, and trade sectors thriving, alongside defence establishments such as the Integrated Test Range (ITR). Balasore is a hub for education with

institutions like Fakir Mohan University nurturing students from the city and surrounding regions.

Air quality sampling and chemical analysis

Based on the reconnaissance surveys and inputs from OSPCB four sampling locations were identified for this study which represent various land-use patterns, and include 1 background site, 1 mixed site, 1 residential site, and 1 industrial site. These sites are located in different parts of Balasore region and can provide an integrated insight into the characteristics of PM_{2.5} and PM₁₀ over Balasore region. Table ES-1 and Fig. ES-1 provides details of the monitoring locations. The ambient PM_{2.5} and PM₁₀ samples were collected in the study area, during two critical seasons i.e. winter (Winter 1 to 18, 2023) and summer (March 21 to 7 April, 2023).

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

Code	Location	Latitude	Longitude	Category
S1	Jyoti Hospital - Kuruda, Balasore, Odisha 756056	21° 28' 18.61" N	86° 53' 27.07" E	Background
S2	RO Office - Kalidaspur, Balia, Januganj, Baleshwar, Odisha 756019	21° 30' 40.68" N	86° 53' 27.78" E	Industrial
S3	District Collector Office - Kacheri Road, Vivekananda Marg, Manikhamb, Balasore, Odisha 756001	21° 30' 12.63" N	86° 55' 38.81" E	Mixed
S4	Municipality Office - Puruna Balasore Rd, Khaira, Balasore, Gopalgoan, Odisha 756003	21° 29' 18.64" N	86° 56' 43.01" E	Residential

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.

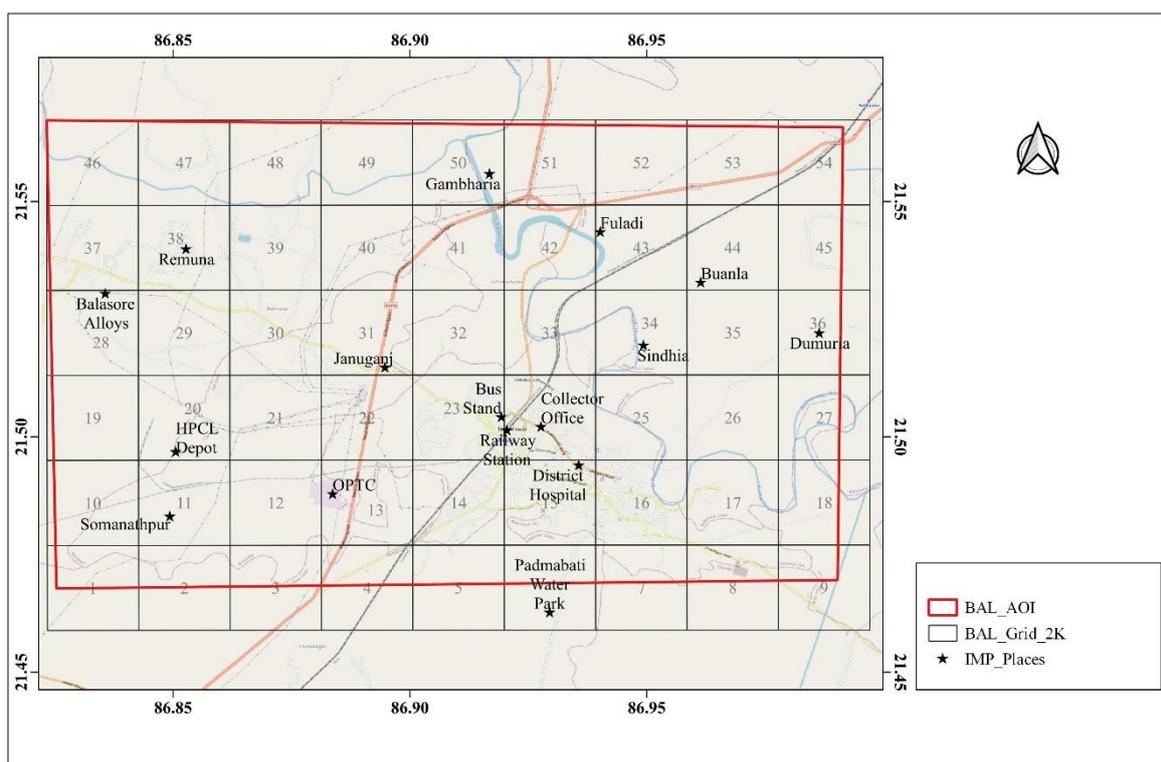


Figure ES-1 Balasore region map. The red coloured triangles show the location of four sampling sites selected for source apportionment study

The winter-season mean PM_{2.5} and PM₁₀ mass concentrations over all sites were 97.7 and 203.7 µg/m³, respectively. The highest seasonal mean PM_{2.5} concentrations were observed at S4 i.e. Municipality Office (103.1 µg/m³) while the lowest were recorded at S3, i.e. District Collector Office (93.3 µg/m³). Similarly, the highest seasonal mean PM₁₀ concentrations were observed at S2 i.e. RO Office (220.2 µg/m³) while the lowest were recorded at S3 i.e. District Collector Office (179.7 µg/m³). The mean value of PM_{2.5} to PM₁₀ ratios during the study period over all sites was found to be 0.48, varying from 0.30 to 0.83, 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 23.9 and 52.6 µg/m³, respectively. The highest seasonal mean PM_{2.5} concentrations were observed

at S2 i.e. RO Office ($27.3 \mu\text{g}/\text{m}^3$) while the lowest was recorded at S1 i.e. Jyoti Hospital ($19.3 \mu\text{g}/\text{m}^3$). Similarly, the highest seasonal mean PM_{10} concentrations were observed at S2 i.e. RO Office ($77.5 \mu\text{g}/\text{m}^3$) while the lowest were recorded at S1 i.e. Jyoti Hospital ($36.1 \mu\text{g}/\text{m}^3$). The mean value of $\text{PM}_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.50, varying from 0.21 to 0.91, 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 0.80 (winter) and 0.89 (summer) for $\text{PM}_{2.5}$ whereas it is found to be 0.90 (winter) and 0.98 (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 $\text{OM} > \text{SNA} > \text{CM} > \text{EC} > \text{TE} > \text{SS}$ 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 Balasore region, during the winter season sampling period i.e. January 1-18, 2023. The winter season SO_2 concentrations were less than $5 \mu\text{g}/\text{m}^3$ at all sites and hence are reported as Below Detection Limit (BDL). The winter season mean concentrations of NO_2 are observed to be $23.6 \mu\text{g}/\text{m}^3$ at Jyoti Hospital (S1), $37.5 \mu\text{g}/\text{m}^3$ at RO Office (S2), $18.7 \mu\text{g}/\text{m}^3$ at Collector Office (S3) and $39.6 \mu\text{g}/\text{m}^3$ at Municipality Office (S4). In case of VOCs, the winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites range from 20.0 to $31.8 \text{ ng}/\text{m}^3$, 41.1 to $198.1 \text{ ng}/\text{m}^3$, 78.3 to $1796.9 \text{ ng}/\text{m}^3$ and 136.0 to $1797.4 \text{ ng}/\text{m}^3$, 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 Balasore 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 Balasore 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 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 Balasore (Fig. ES-2(A)) are found to be dominated by secondary aerosols sector with highest contribution of 40.0%. The other sources of PM_{2.5} at Balasore are identified as dust (24.1%), solid waste and biomass combustion (18.9%), transport (7.6%), and industry (3.6%). Similarly, the winter-time PM₁₀ mass at Balasore is found to be dominated by dust (36.5%), followed by secondary aerosols (30.7%), solid waste and biomass combustion (12.4%), transport (4.5%), and industries (3.1%). Additionally, about 5.8% and 12.9% 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 at Balasore (Fig. ES-2(B)) is found to be dominated by secondary aerosols with highest contribution of 23.9%. The other summer-time sources of PM_{2.5} at Balasore region are identified as solid waste and biomass combustion (19.8%), dust (18.8%), transport (12.7%), and industry (2.3%). Similarly, the summer-time PM₁₀ mass at Balasore is found to be dominated by dust (39.8%), followed by secondary aerosols (20.8%), solid waste and biomass combustion (15.3%), transport (5.0%), and industry (2.3%). Additionally, about 10.7% and 8.0% 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.

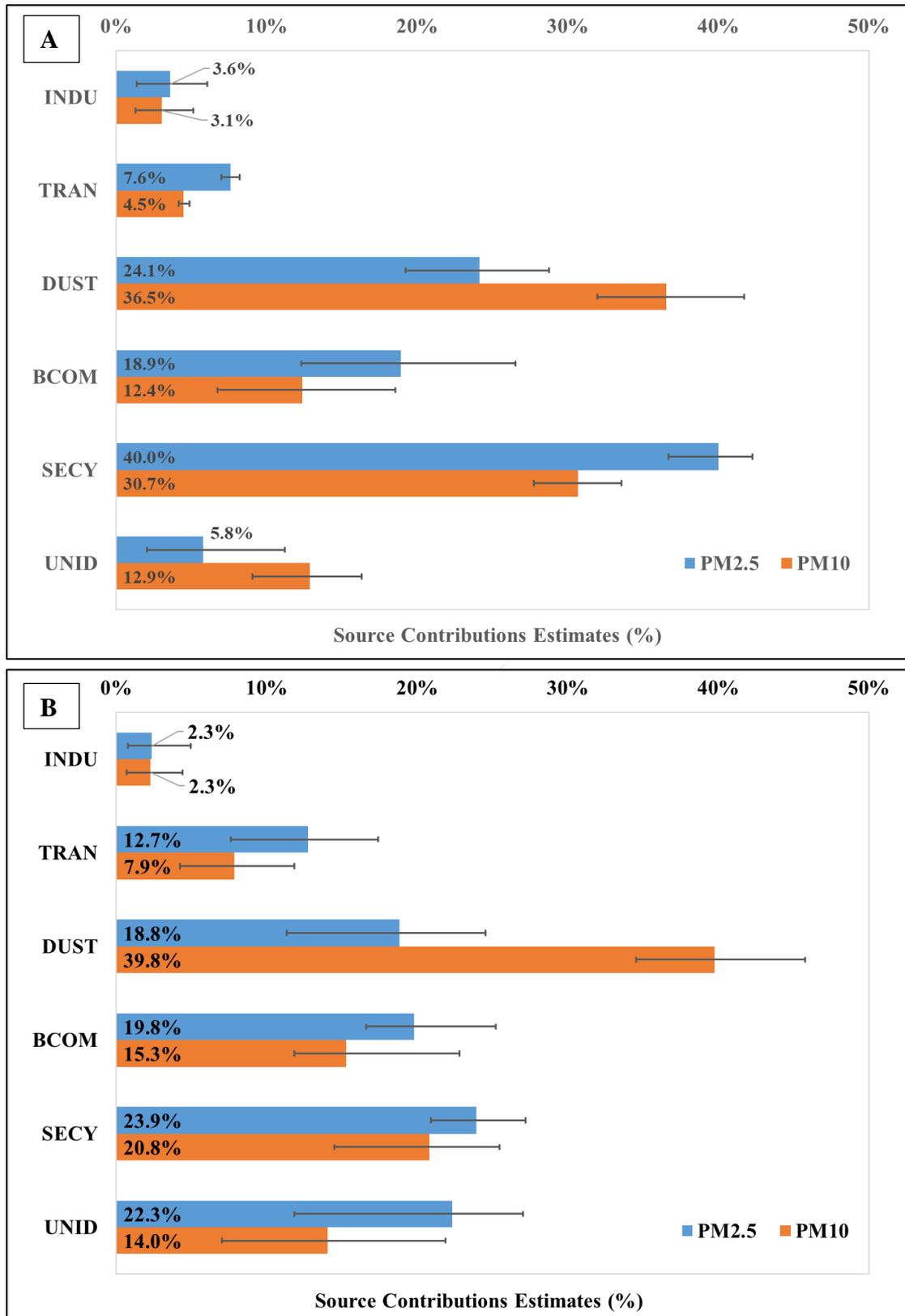


Figure ES-2 City-level source contribution estimates (SCE) for Balasore region using CMB receptor model during winter (A) and summer (B) seasons

Emission Inventory

The development of emission inventory for Balasore region involved quantification of emission loads originating from sectors including: Transport, Re-suspended road dust, Open Waste Burning, Residential, Industries, Diesel generators, Hotels, Restaurants and Bakeries, Crematoria, Brick kilns, Construction, Windblown riverbed erosion dust, and Aviation 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 2022) for the Balasore region is presented in Table ES-2, while the pollutant wise contribution is shown in Fig. ES-3. The spatial distribution of the pollutants over Balasore region is provided in Fig. ES-4, ES-5(A&B) and ES-6(A&B). The total PM₁₀ emission load in the Balasore region is estimated to be 7,711 tonnes per year. The top four contributors to PM₁₀ emissions are resuspended road dust (39.2%), followed by transport (20.4%), open waste burning (11.5%), and hotel, restaurants and bakeries (9.6%). Similarly, PM_{2.5} emission load in the Balasore region is estimated to be 4,356 tonnes per year. The top four contributors to PM_{2.5} emissions are transport (32.5%), open waste burning (18.9%), resuspended road dust (16.8%), and hotel, restaurants and bakeries

(11.3%). 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 Balasore Region in year 2022

Sector	PM10	PM2.5	SO ₂	NO _x	CO	NMVOC
Transport (TRAN)	245 ± 49	221 ± 44	5 ± 0	3135 ± 1248	7533 ± 2450	6350 ± 3353
Road dust re-suspension (RDST)	3572 ± 935	864 ± 226	NA	NA	NA	NA
Residential (RESI)	373 ± 107	253 ± 72	46 ± 5	110 ± 30	3641 ± 1044	979 ± 499
Waste burning (WAST)	448 ± 150	416 ± 140	29 ± 9	64 ± 21	2144 ± 722	464 ± 250
Hotels, Restaurants, Bakeries and Open eateries (HRBE)	201 ± 13	135 ± 9	61 ± 2	30 ± 2	1107 ± 76	52 ± 28
Construction (CONS)	12 ± 0	3 ± 0	NA	NA	NA	NA
Diesel Generators (DSGN)	111 ± 12	96 ± 10	74 ± 3	1128 ± 98	244 ± 21	1506 ± 768
Industries (INDU)	366 ± 75	244 ± 50	1285 ± 143	894 ± 184	358 ± 73	8 ± 2
Fugitive (FUGT)	72 ± 1365	7 ± 558	NA	NA	NA	NA
Brick Kilns (BRIC)	34 ± 18	7 ± 3	23 ± 12	< 0.1	113 ± 61	4 ± 2
Crematoria (CREM)	9 ± 2	4 ± 1	0.2 ± 0	1 ± 0	43 ± 12	24 ± 12
Total	5443 ± 2731	2251 ± 1116	1523 ± 354	5361 ± 3171	15183 ± 8923	9386 ± 4914

NA: indicates the emissions quantification is not applicable for a particular sector. The value after ± indicate 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 2022 in the study domain are estimated to be 1523, 5361, 15183 and 9386 tonnes per year, respectively.

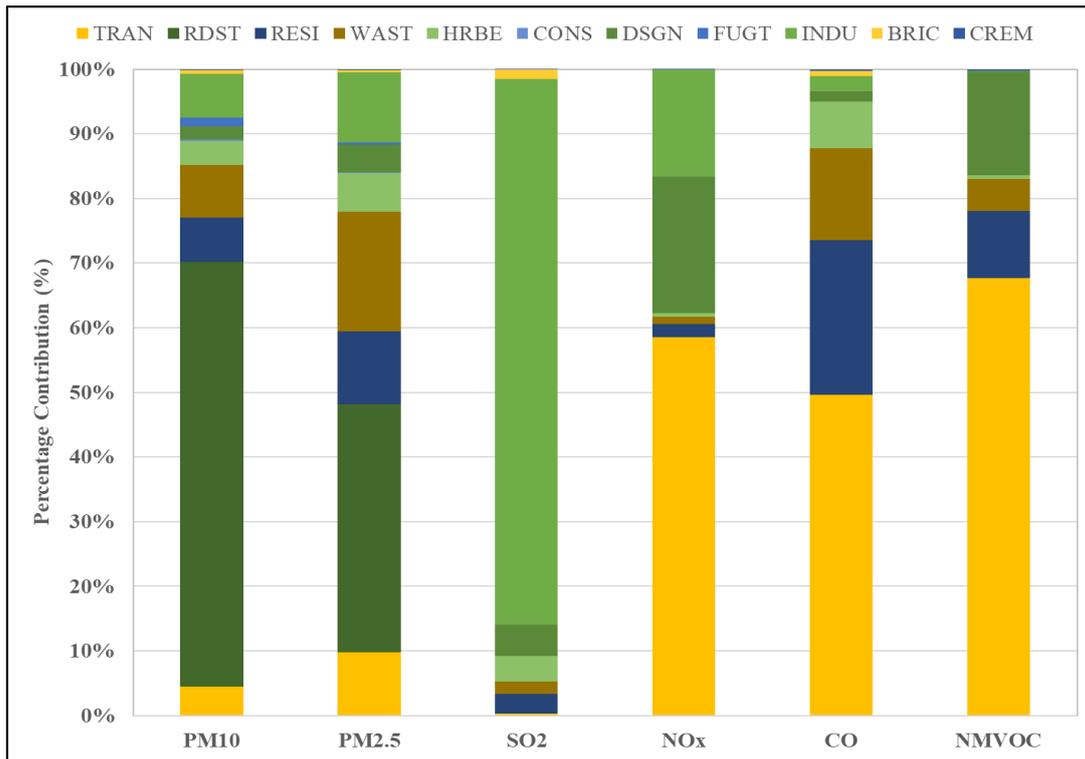


Figure ES-3 Sector-wise contribution to air pollutant emissions of A) PM₁₀, B) PM_{2.5}, C) SO₂, D) NO_x, E) CO and F) NMVOC in Balasore region in 2022

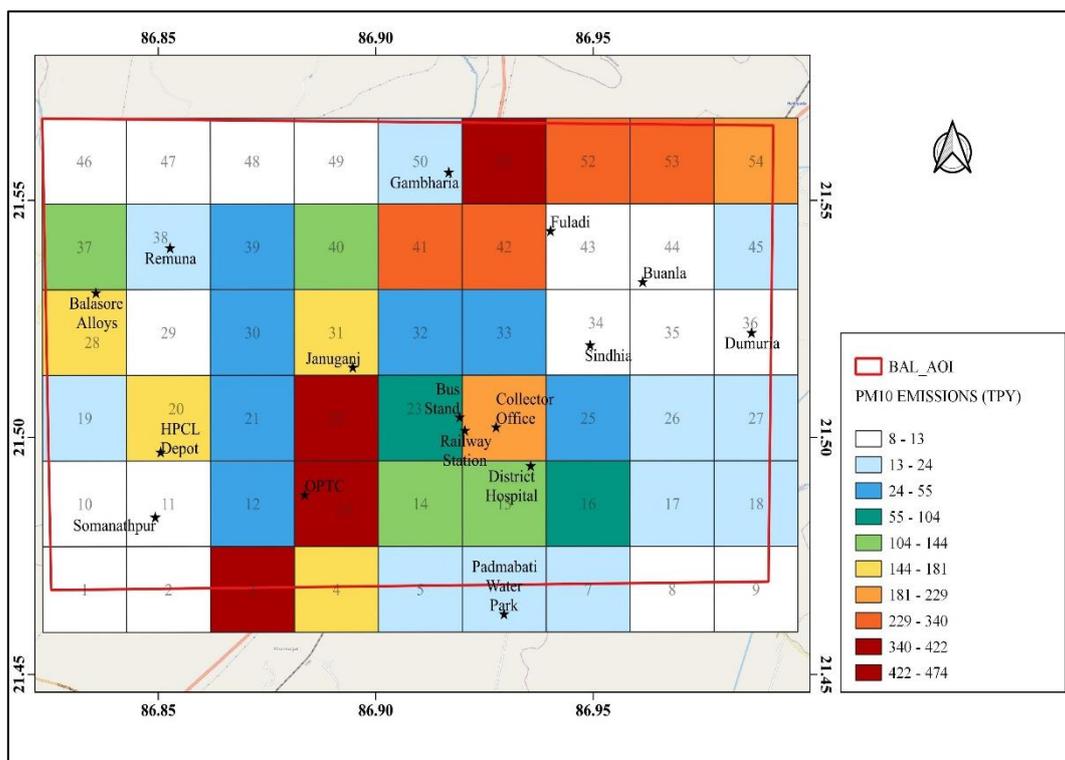


Figure ES-4 Spatial distribution of air pollutant emissions of PM₁₀ (tonnes per year) in Balasore region in 2022.

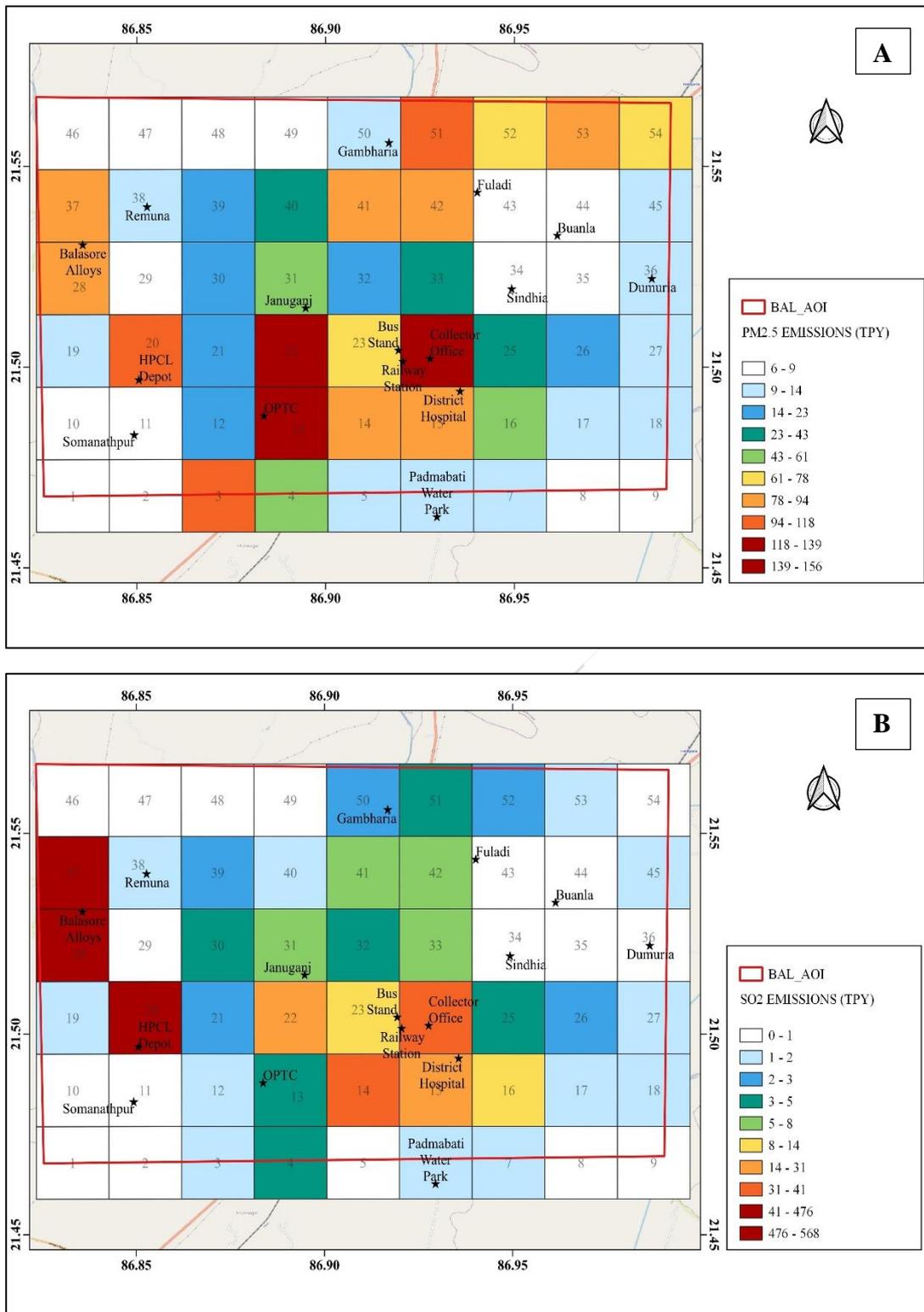


Figure ES-5 Spatial distribution of air pollutant emissions A) PM_{2.5} and B) SO₂ (tonnes per year) in Balasore region in 2022.

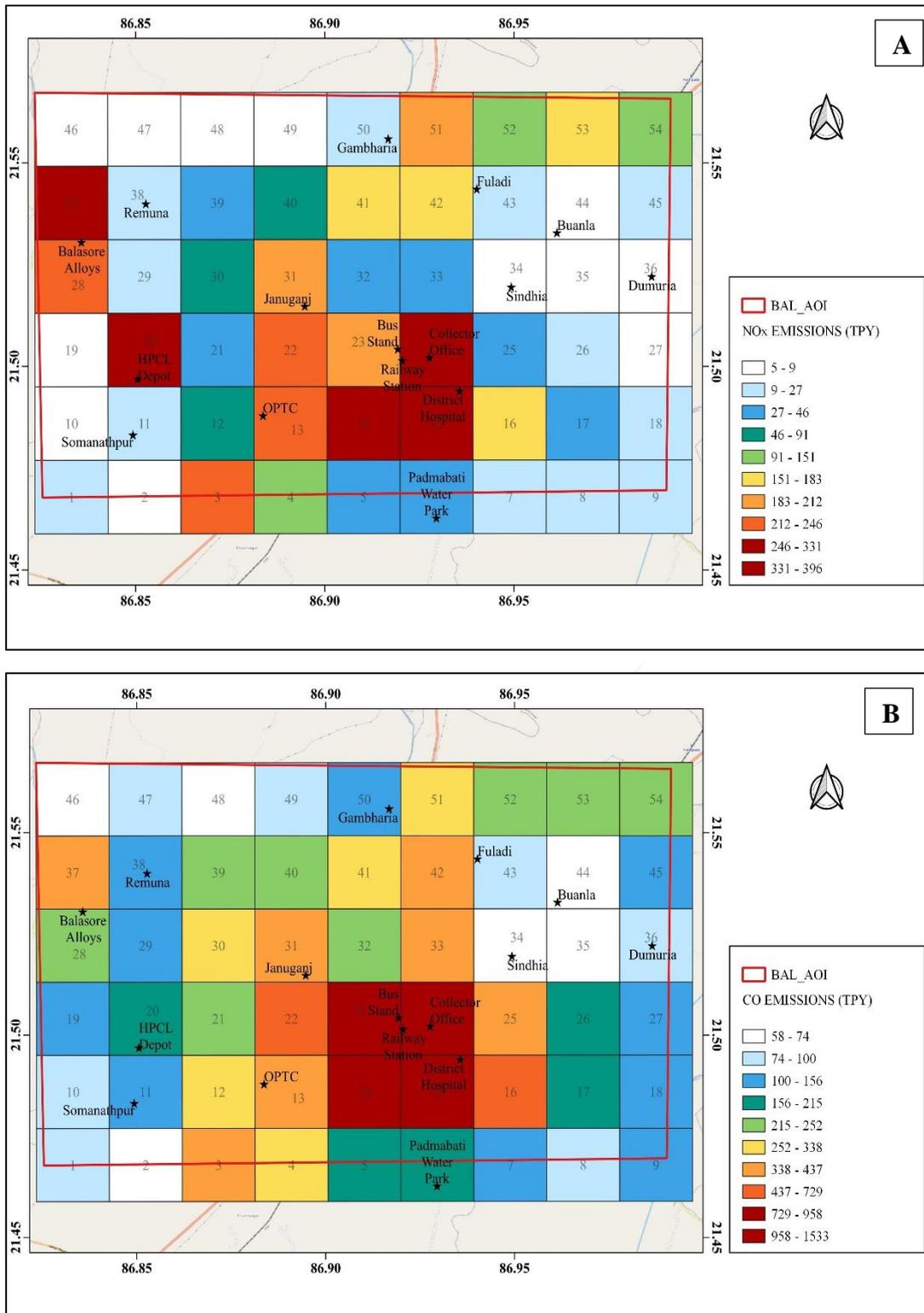


Figure ES-6 Spatial distribution of air pollutant emissions A) NO₂, B) CO (tonnes per year) in Balasore region in 2022.

Dispersion Modelling

In this study the AERMOD model is used to estimate the pollutant concentrations under different emission scenarios. Considering the sources and dependent activities in Balasore region, AERMOD simulations are conducted for the region in a combined manner. AERMOD is configured to consider the local meteorology, emissions and terrain information to simulate the air pollutant concentrations at specified receptors in the study domain. The emissions from different sectors are modelled as area sources having dimensions 2 x 2 km², except the industries and thermal powerplants, crematoria, industrial fugitive dust and brick kilns. The stack emissions from industries, crematoria, and FCBTK brick kilns are modelled as point sources. Industrial fugitive dust sources are modelled as area polygon sources while clamp type brick kilns are modelled as volume sources.

The gridded receptors are placed at the vertex of each grid cell used in the emission inventorization, forming a network of 247 gridded receptors (refer Fig. ES-7). Additionally, four discrete receptors are also configured at ARAI sampling sites locations. The height of each receptor is set to 1.5 m above ground level i.e. mean breathing level for humans. Further, suitable background concentrations are also considered, to reflect the regional-scale contributions from distant sources.

In order to validate the dispersion modelling set-up, the AERMOD simulated average concentrations of pollutants including PM_{2.5}, PM₁₀, SO₂, and NO₂ are compared against NAMP monthly observations during the modelling period. Based on the analysis, the AERMOD model has been found to estimate the pollutant concentrations in Balasore region, with a reasonable accuracy. Fig. ES-8 and ES-9 shows the spatial distribution of AERMOD simulated PM₁₀ and PM_{2.5} concentrations during baseline year, respectively.

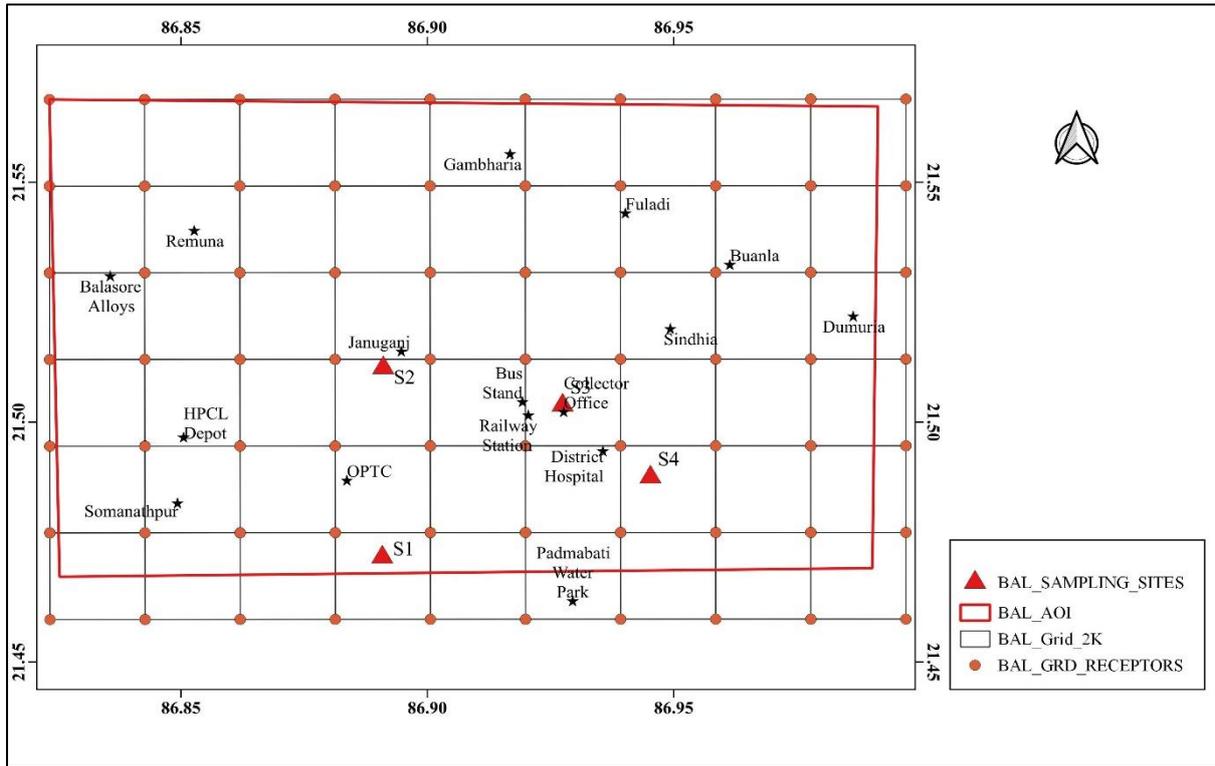


Figure ES-7 Map showing AERMOD modelling domain overlaid by gridded and discrete receptors configured in this study

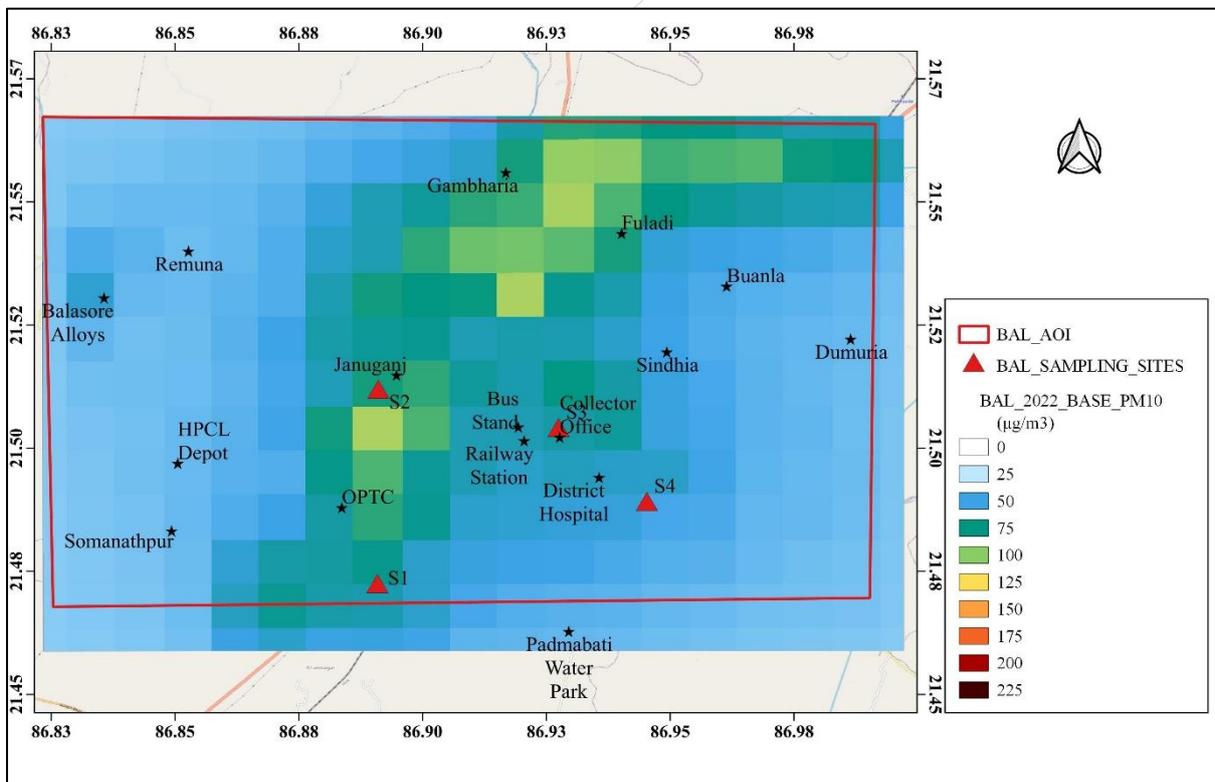


Figure ES-8 Map showing spatial distribution of PM_{10} annual mean concentrations ($\mu g/m^3$) over Balasore region for year 2022

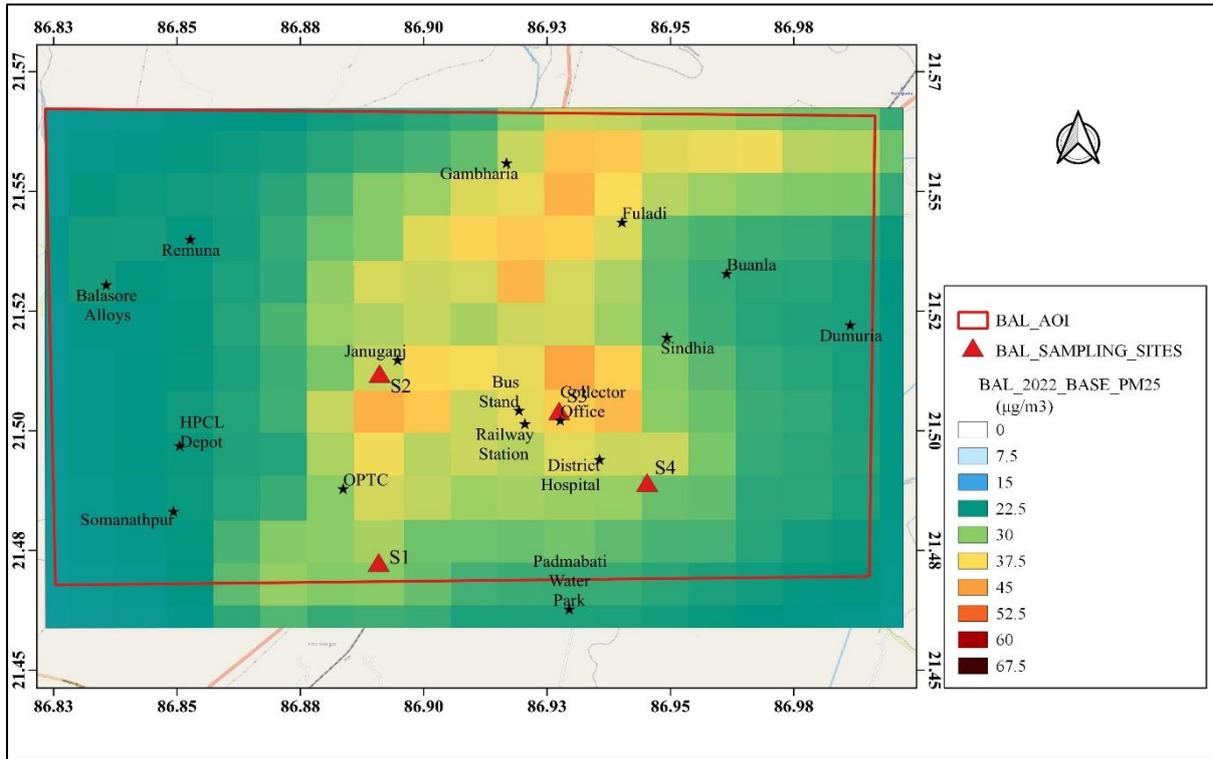


Figure ES-9 Map showing spatial distribution of $PM_{2.5}$ annual mean concentrations ($\mu g/m^3$) over Balasore region for year 2022

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 2022. 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 Balasore 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.
- 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 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 2027 and 2032 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 2027 and 2032 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, operational mass transit system (MRTS), 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 (2027) and long term (2032). 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 Balasore region for years 2022, 2027 and 2032.

Table ES-3 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Balasore region for years 2021, 2027 and 2032

Year	Scenario	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO
2022	BASE	5,443	2,251	1,523	5,361	15,183
2027	NFC	8,938	3,280	2,150	6,384	13,948
	BAU	7,879	2,957	2,026	6,039	13,114
	SC_I	6,703	2,533	1,894	5,611	11,566
	SC_II	5,101	1,977	1,577	5,019	9,955
2032	NFC	13,792	4,632	2,779	7,080	17,322
	BAU	10,346	3,578	2,457	6,126	15,323
	SC_I	6,705	2,454	2,024	5,350	12,704
	SC_II	2,782	1,240	1,366	4,356	10,013

The NFC scenario projections in Balasore region indicate a potential increase in PM₁₀ emissions to 8,938 tonnes per year in 2027 i.e. an increase of 64.2% w.r.t. baseline year 2022 and to 13,792 tonnes per year in 2032 i.e. an increase of 153.4% w.r.t. baseline year 2022. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to reach to 3,280 (45.7%) and 4,632 tonnes per year (i.e. 105.8%) in 2027 and 2032, respectively. The BAU projections in Balasore indicate a potential decrease of PM₁₀ emissions to 7,879 tonnes per year in 2027 i.e. a decrease of 11.9 % w.r.t. NFC_2027 and to 10,346 tonnes per year in 2032 i.e. a decrease of 25.0% w.r.t.

NFC 2032. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 2,957 (-9.8%) and 3,578 tonnes per year (i.e. -22.8%) in 2027 and 2032, respectively.

The SC-I projections in Balasore region indicate a potential decrease of PM₁₀ emissions to 6,703 tonnes per year in 2027 i.e. a decrease of 25.0% w.r.t. NFC 2027 and to 6,705 tonnes per year in 2032 i.e. a decrease of 47.0% w.r.t. NFC 2032. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 2,533 (-22.8%) and 2,454 tonnes per year (i.e. -47.0%) in 2027 and 2032, respectively. The SC-II projections in Balasore region indicate a potential decrease of PM₁₀ emissions to 5,101 tonnes per year in 2027 i.e. a decrease of 42.9% w.r.t. NFC 2027 and to 2,782 tonnes per year in 2032 i.e. a decrease of 79.8% w.r.t. NFC 2032. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 1,977 (i.e. -39.7%) and 1,240 tonnes per year (i.e. -73.2%) in 2027 and 2032, respectively.

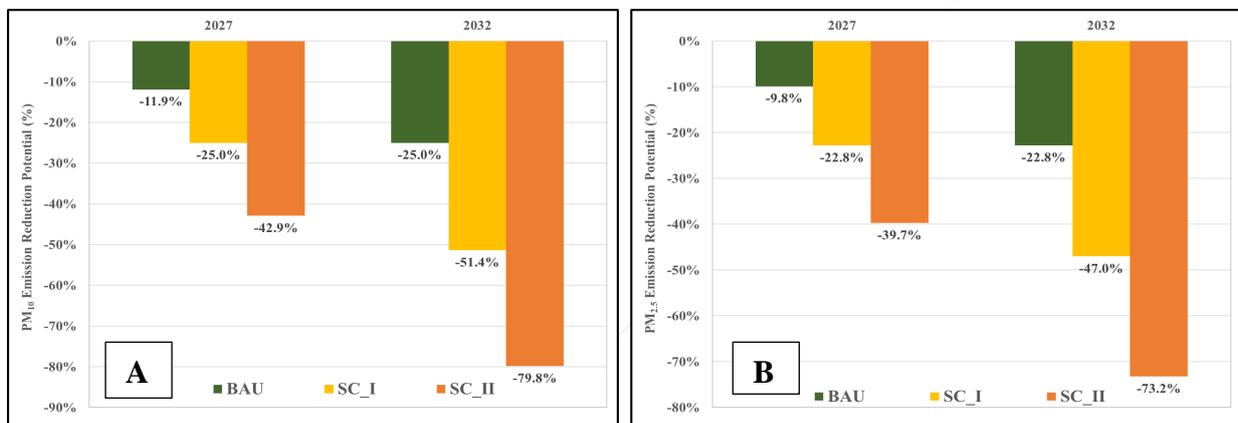


Figure ES-10 Estimated PM₁₀ (A) and PM_{2.5} (B) emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032)

Air quality benefits of four designed scenarios were assessed for years 2027 and 2032 using AERMOD modelled annual mean pollutant concentrations in Balasore region. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2027 and 2032 due to proposed changes in technology and fuels of vehicles such as EV adoption, increased penetration of BS-VI vehicles, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, NMT & improvement in public transport, introduction of mass rapid transit system (MRTS), increasing use of clean fuel for cooking, improved waste collection efficiency, adoption of Zig-zag type brick kilns and various other control strategies considered in different scenarios.

With implementation of control measures considered in different scenarios, an estimated reduction of 11.9%, 25.0%, and 42.9% in 2027 and 25.0%, 51.4%, and 79.8% in

2032, could be achieved in ambient PM10 concentrations for BAU, SC-I and SC-II scenarios, respectively. In case of PM_{2.5}, with implementation of control measures considered in different scenarios, an estimated reduction of 9.8%, 22.8%, and 39.7% in 2027 and 22.8%, 47.0%, and 73.2% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

This study also assessed location -specific air quality benefits due to implementation of different scenarios in 2027 and 2032. Four representative locations, i.e. ARAI sampling locations, were selected to understand the impact of control measures on air quality. Tables ES-4 presents the percentage change in air pollutants annual mean concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at District Collector Office, Balasore site in Balasore region.

Table ES-4 Percentage change in predicted ambient air quality concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at District Collector Office, Balasore(S3) location

Year/Scenario	2027			2032		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-7.0%	-14.8%	-24.6%	-15.9%	-32.1%	-48.8%
PM _{2.5}	-6.2%	-13.5%	-22.2%	-13.8%	-27.4%	-41.2%
SO ₂	-9.4%	-19.4%	-30.0%	-19.1%	-34.3%	-49.9%
NO ₂	-5.8%	-12.4%	-19.8%	-13.0%	-21.5%	-31.2%
CO	-8.6%	-19.8%	-31.9%	-14.5%	-31.3%	-48.5%

The air quality benefits are also translated to improvement in Air quality index (AQI). AQI is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (Ott, 1978). It is important to note that, the AQI values are calculated using the AERMOD estimated pollutant concentrations, only. The air quality situation can gradually improve with implementation of proposed scenarios. The combined proportion of Good and Satisfactory AQI classes are estimated to be substantially higher compared to the corresponding do-nothing or NFC scenario. For example, the combined proportion of Good and Satisfactory AQI classes in NFC is 78% and 71% in 2027 and 2032, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 82% and 82% in 2027 and 2032, respectively under BAU scenario, to 84% and 88% in 2027 and 2032, respectively under SC-I, to 90% and 99% in 2027 and 2032, respectively under SC-II scenario.

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Balasore region as well. These

findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level PM concentrations by 40% by the year 2027, as compared to 2017 i.e. base year.

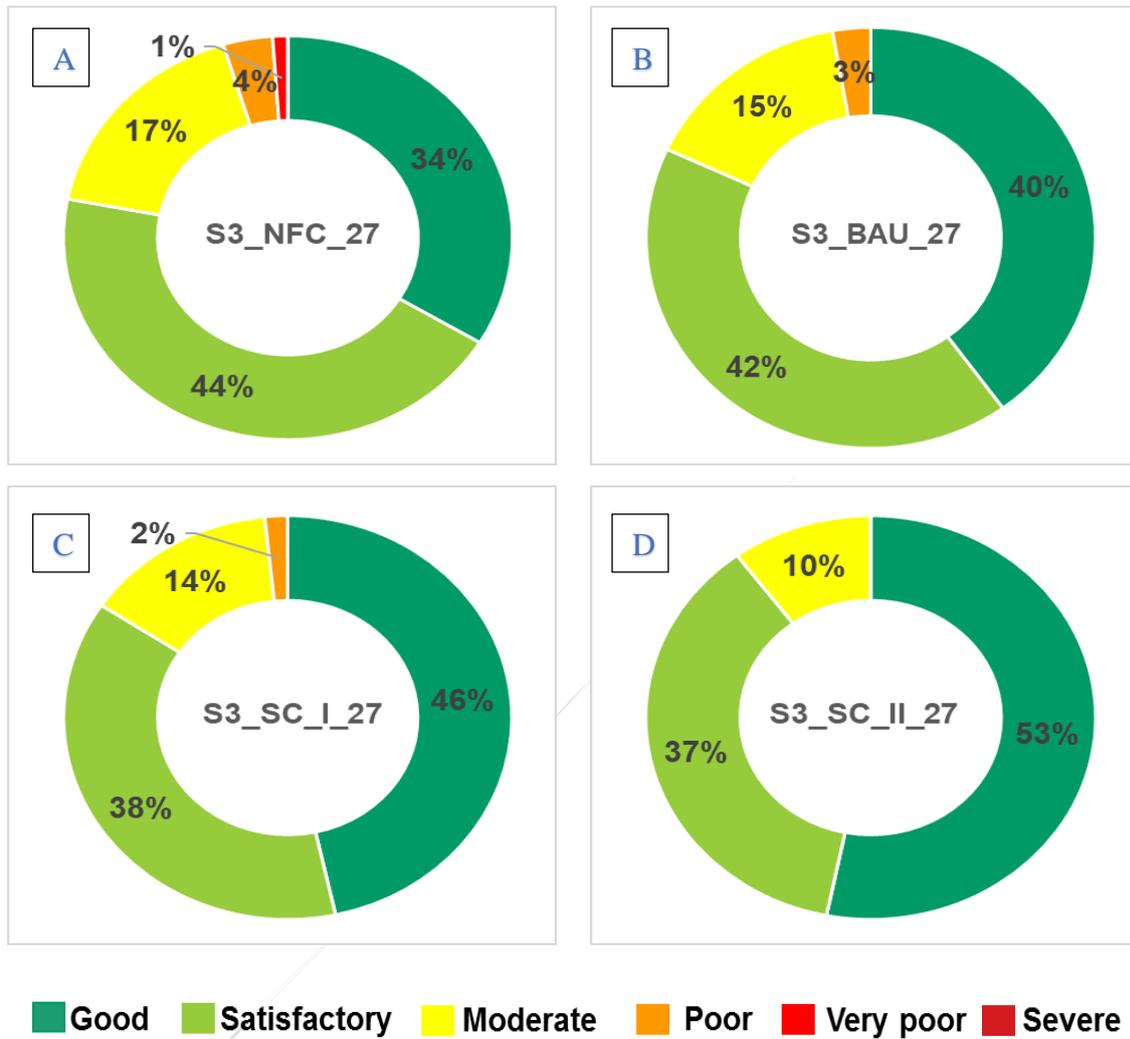


Figure ES-11 Distribution of six AQI categories at OSPCB Head Office, Nayapalli (S2) in Balasore region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2027

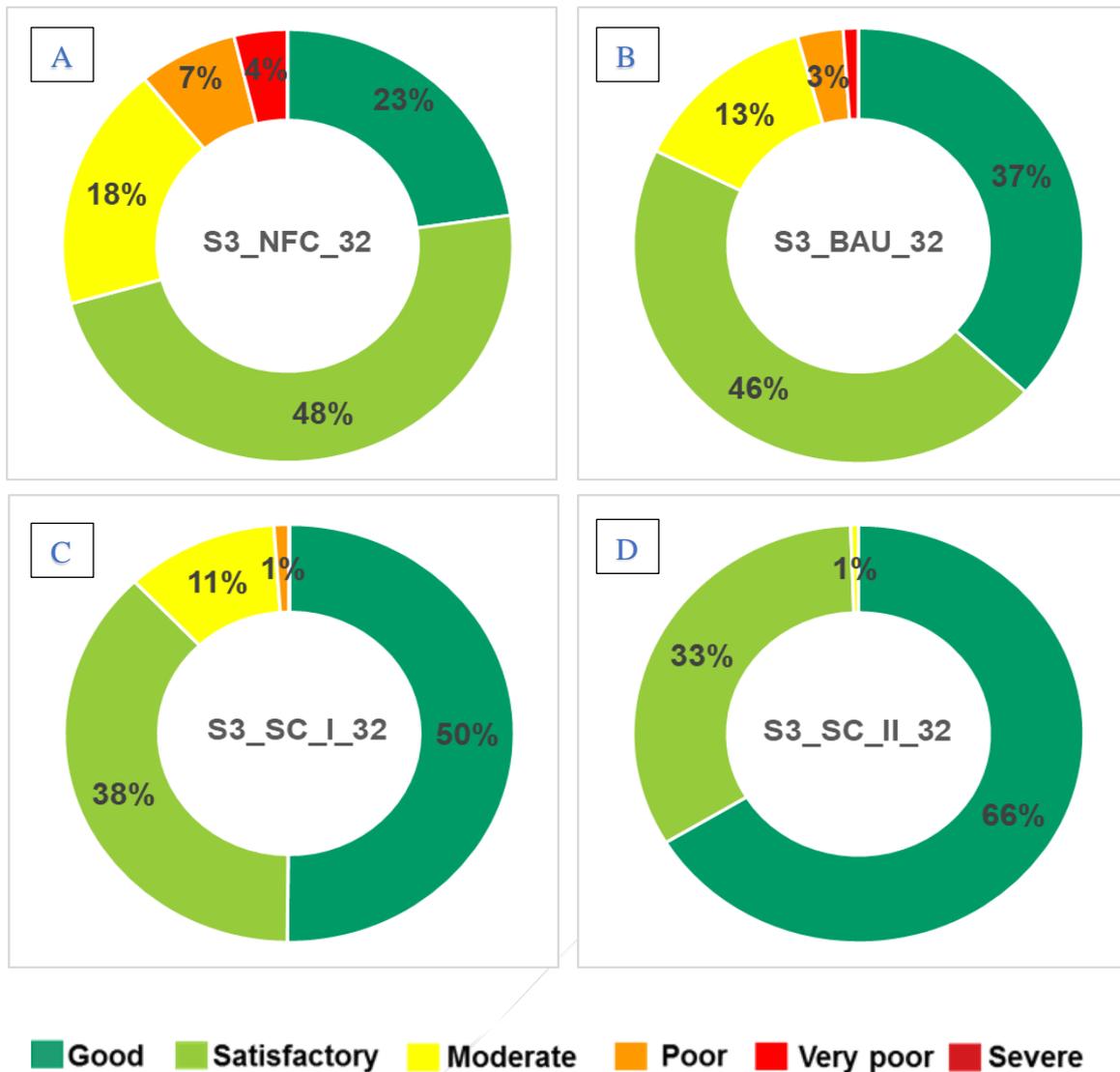


Figure ES-12 Distribution of six AQI categories at OSPCB Head Office, Nayapalli (S2) in Balasore for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2032

Clean Air Action Plan

Table ES-5 presents the proposed air quality action plan for Balasore 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 Balasore Region

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

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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Identify road stretches with high dust generation and use Foggers to 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. • Discourage the fuels with high sulphur content. 	OSPCB	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	<ul style="list-style-type: none"> 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.	OSPCB	6 months
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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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
	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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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
	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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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
	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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
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, as per applicable Govt. guidelines.	OSPCB	1 -2 year

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Chapter 1: Introduction

1.1. Background

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

1.2. Brief Description of the study area

Balasore, situated at approximately 21.4941° N latitude and 86.9293° E longitude in Odisha, India, holds historical significance dating back to ancient times. It served as a pivotal maritime trade center during the medieval era, influenced by dynasties like the Mughals and Marathas. Strategically located on National Highway 16 (formerly NH-5), connecting Kolkata and Chennai, it functions as a key transportation junction. The city boasts a diverse economy with agriculture, small-scale industries, and trade sectors thriving, alongside defence establishments such as the Integrated Test Range (ITR). Balasore is a hub for education with institutions like Fakir Mohan University nurturing students from the city and surrounding regions.

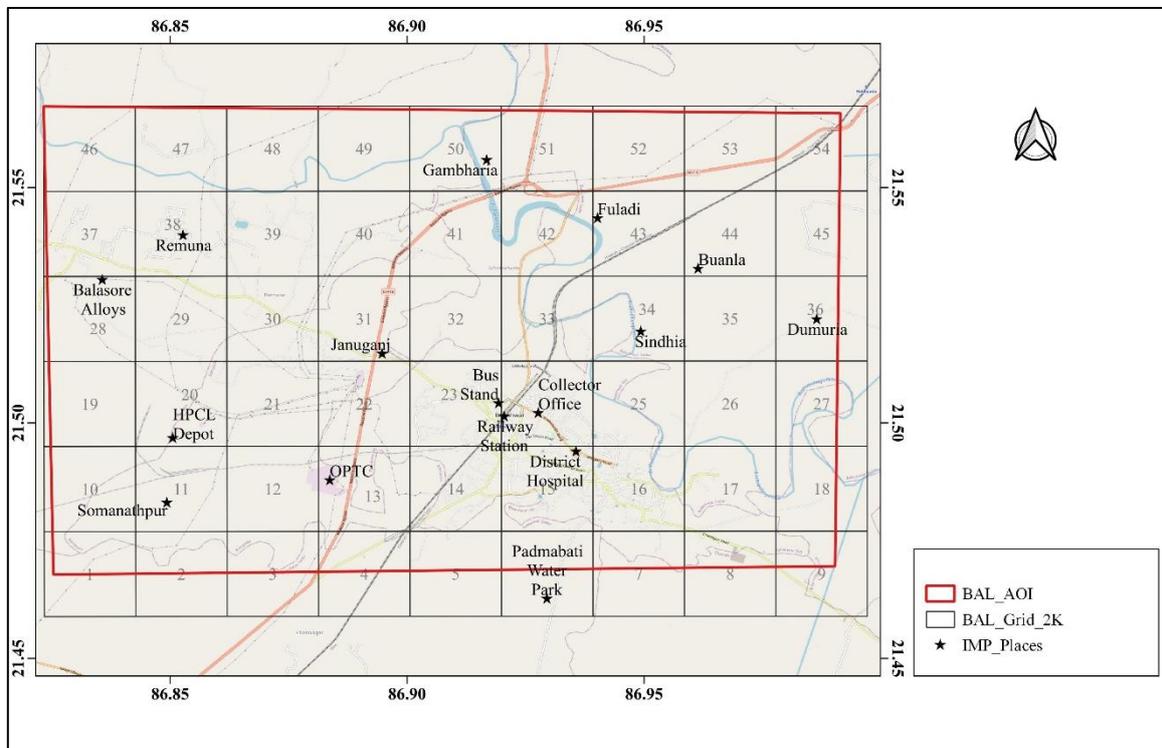


Figure 2 Map showing study area i.e. Balasore region

1.2.1. Geography

Balasore also known as the “Missile City”, due to location of the Indian Ballistic Missile Defence Programme's Integrated Test Range, 18 km south of Balasore. The study area of Balasore region lies in between geographic coordinates from 86.82341, 21.45882 to 86.99713, 21.56734 in the Balasore district of Odisha at an average elevation of about 16 m above mean sea level. It is important to note that, the study area for this study extends beyond the municipal

limits of Balasore and covers an area of 216 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

Balasore experiences hot and humid climate and receives abundant rainfall during Southwest monsoon (June – September). The highest and lowest temperatures are generally observed in the months of May and December, respectively. Balasore district receives an annual average rainfall of about ~1,568 mm, with highest rainfall in the month of August.

1.2.3. Demography

According to Census of India 2011, the total population of Balasore municipal council was 1,44,373. The estimated population for year 2022 is 1,58,632. 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 for year 2022 is 3,32,309 which is estimated considering several factors such as current and proposed land use, land cover, population density, growth directions, and scope for future development. Fig. 3 shows the gridded population map of the study area for year 2022.

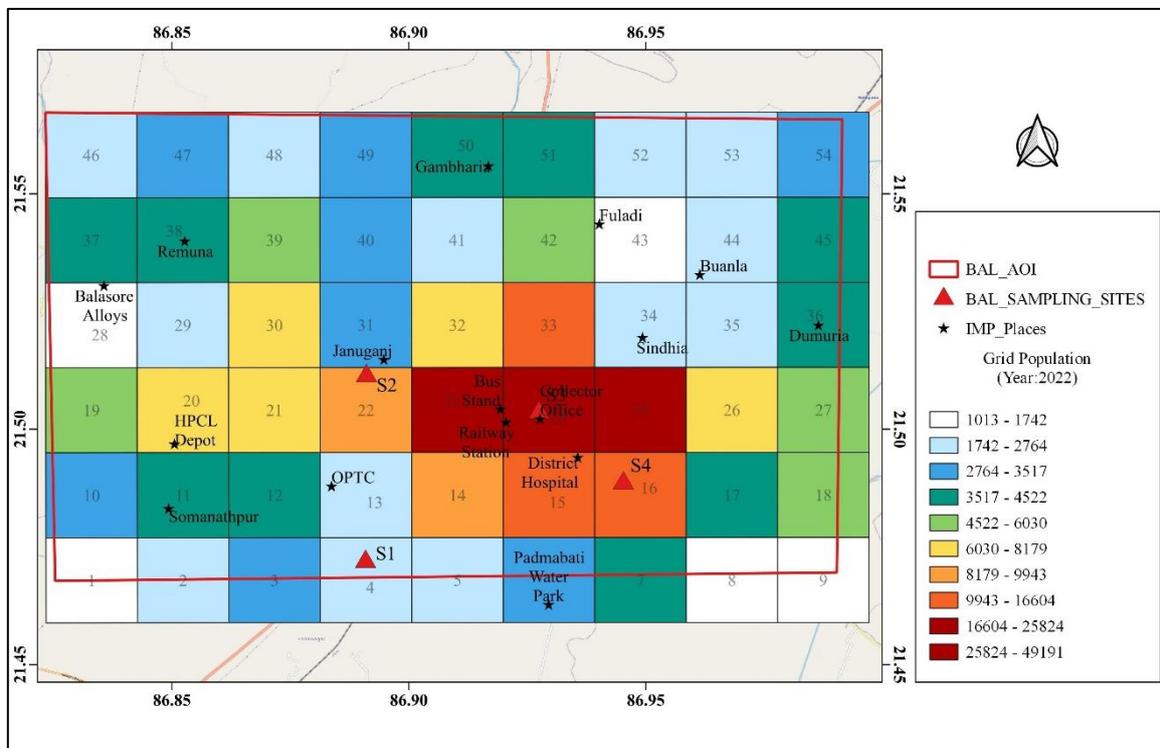


Figure 3: The estimated gridded population of the study area for year 2022.

1.3. Objectives of the Project

The main aim of this study is to identify and characterize various emission sources in Balasore 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 Balasore region.
- ii) To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Balasore region.

1.4. Scope of Work

- 1.1. Sampling of Particulate Matter (PM₁₀ & PM_{2.5}) using speciation samplers at identified sites (4 locations in Balasore 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 at 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 Balasore region for year 2022.
- 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).

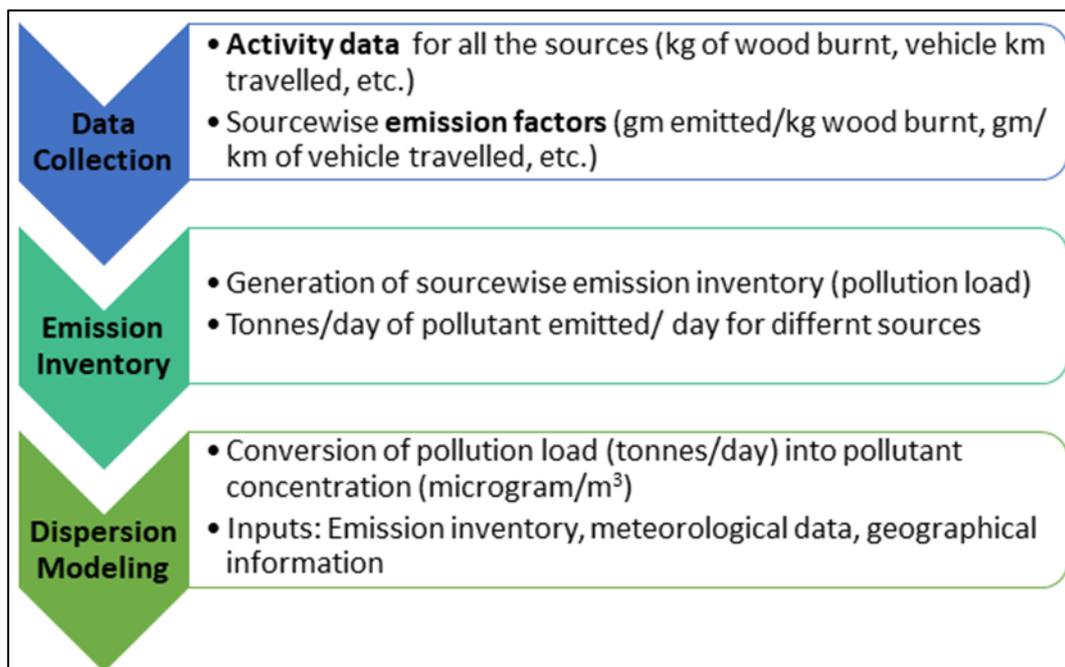


Figure 4 Bottom-up approach for Particulate Matter Source Apportionment

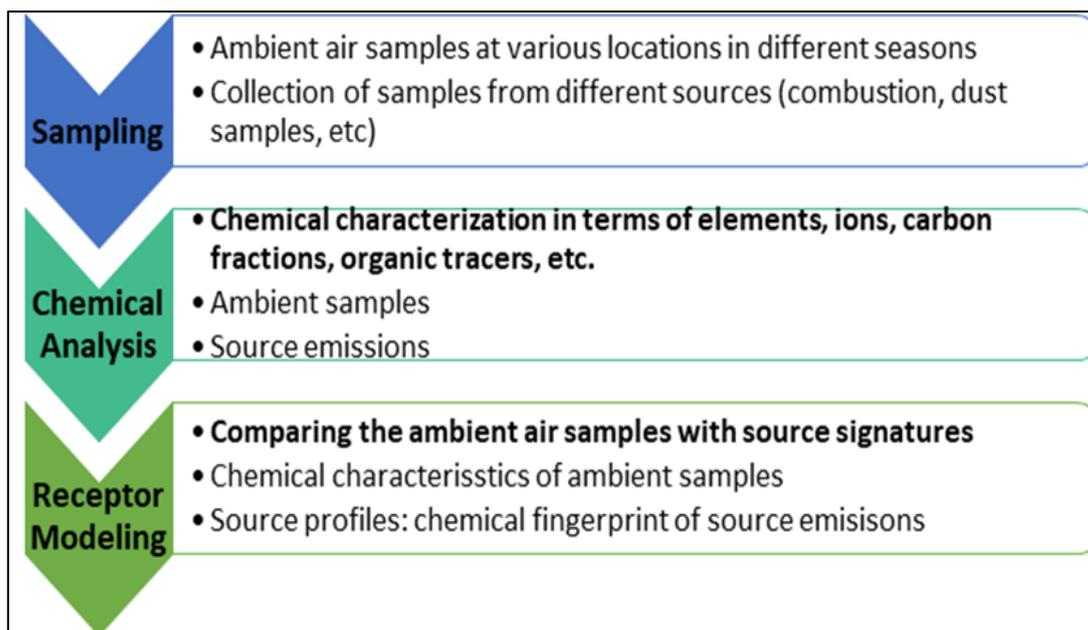


Figure 5 Top-down approach for Particulate Matter Source Apportionment

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 Balasore 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 (PM₁₀ and PM_{2.5}) at four sampling sites for two critical seasons, i.e., winter and summer. This chapter also describes the details of site selection, PM sampling, instrumentation used in laboratory analysis, quality assurance and quality control (QA/QC) protocol, source apportionment using receptor model i.e. CMB. This chapter also discusses the site-wise, seasonal chemical composition of PM₁₀ 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 Balasore 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.

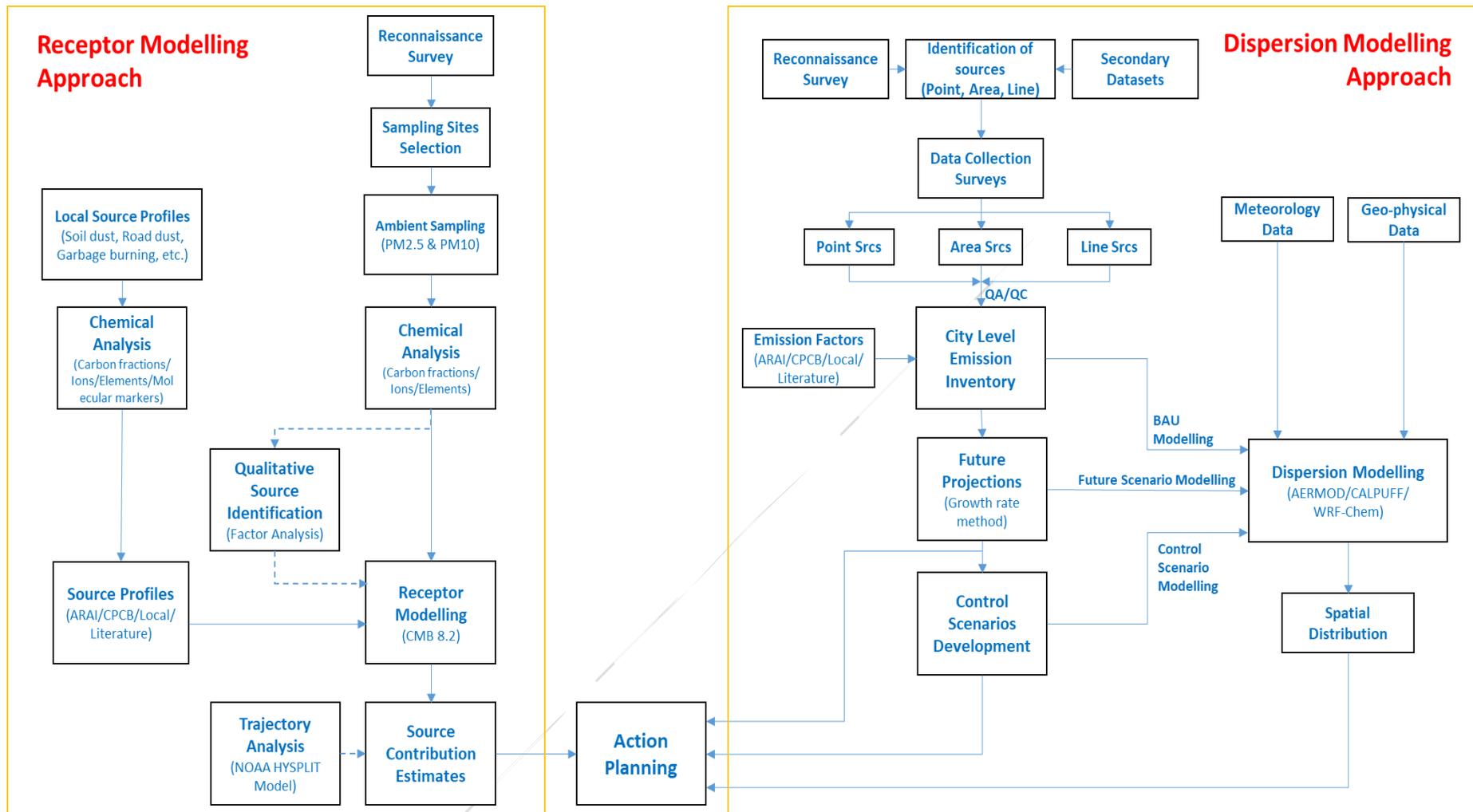


Figure 6 Framework for integrated emission inventory and source apportionment study of Balasore region in Odisha

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. January 1 to 18, 2023 and summer season i.e. March 21 to April 7, 2023 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 Balasore region. Figure 7 and Table 1 respectively show the geographic distribution and details of the sampling sites, which include 1 background site, 1 mixed site, 1 residential site and 1 industrial site. These sites are located in different parts of study domain and can provide an integrated insight into the characteristic of PM_{2.5} and PM₁₀ over Balasore region. For example, the residential site, such as Municipality office (S4) is surrounded by typical residential areas with low and middle-income group households, respectively. The background site such as Jyoti hospital site (S1), is located in predominant wind direction of the city and are less influenced by industrial activities. The other two sites i.e. District Collector Office (S3) and RO Office (S2) typically represent mixed and industrial sites, respectively.

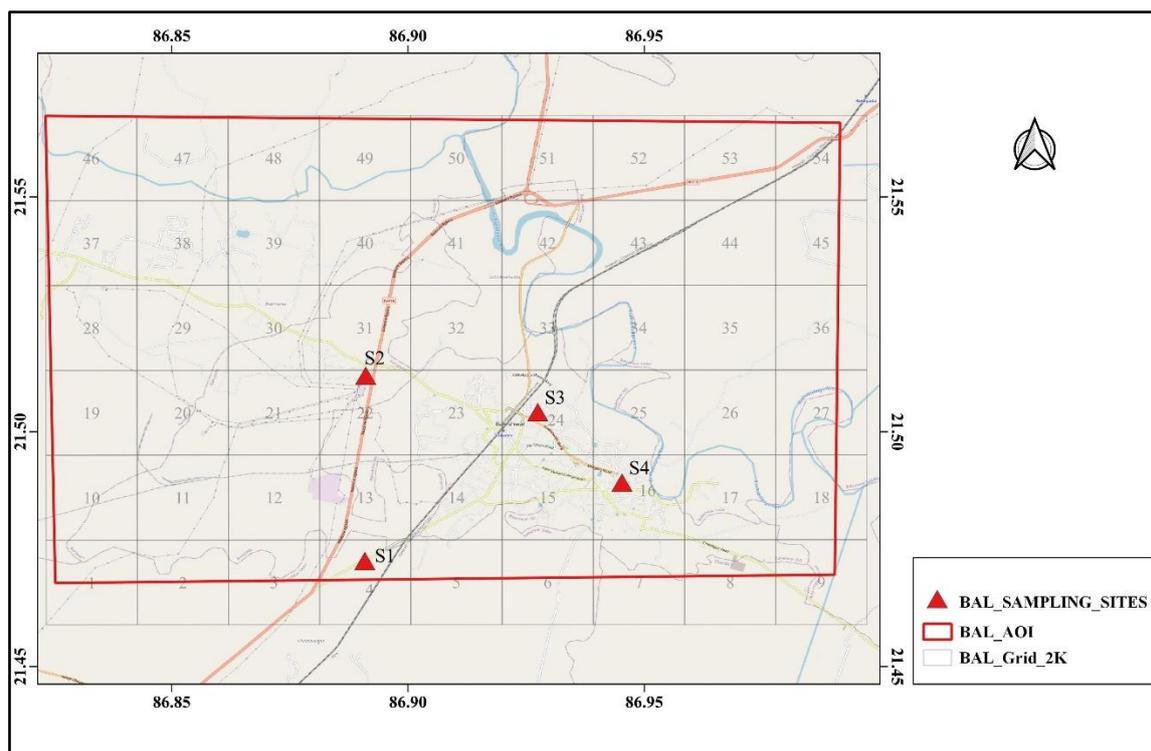


Figure 7 Balasore region map. The red triangles show the location of four sampling sites selected for source apportionment study

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

Code	Location	Latitude	Longitude	Category
S1	Jyoti Hospital - Kuruda, Balasore, Odisha 756056	21° 28' 18.61" N	86° 53' 27.07" E	Background
S2	RO Office - Kalidaspur, Balia, Januganj, Baleshwar, Odisha 756019	21° 30' 40.68" N	86° 53' 27.78" E	Industrial
S3	District Collector Office - Kacheri Road, Vivekananda Marg, Manikhamb, Balasore, Odisha 756001	21° 30' 12.63" N	86° 55' 38.81" E	Mixed
S4	Municipality Office - Puruna Balasore Rd, Khaira, Balasore, Gopalgoan, Odisha 756003	21° 29' 18.64" N	86° 56' 43.01" E	Residential

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 January 1 to 18, 2023 while summer season sampling was conducted from March 21 to April 7, 2023.

W I N T E R	SITE	Jan-23																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	JYOTI HOSPITAL																		
	RO OFFICE																		
	DISTRICT COLLECTOR OFFICE																		
	MUNICIPALITY OFFICE																		

S U M M E R	SITE	Mar-23											Apr-23						
		21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7
	JYOTI HOSPITAL																		
	RO OFFICE																		
	DISTRICT COLLECTOR OFFICE																		
	MUNICIPALITY OFFICE																		

Figure 8 The sampling schedule for collection of PM samples during winter and summer seasons in Balasore 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. 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 Balasore region. The details of the instrumental techniques utilized for analysing PM are given below.

2.2.5. Elemental/Organic Carbon

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

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

2.2.6. Elements

The energy dispersive X-ray fluorescence (ED-XRF) technique was used for the quantification of elements present in PM_{2.5} and 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.

2.2.7. Ions

Ionic species are those that are soluble in water. Anions and cations were analyzed using an ion chromatograph with conductivity detector. In PM_{2.5} and 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.

2.2.7.1. 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 53 molecular marker species listed in Table 2. 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.

Table 2 List of molecular markers species analysed in PM_{2.5} and PM₁₀ fractions

Sr. No.	Class	Species
1.	Alkanes	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
2.	Polycyclic Aromatic Hydrocarbons (PAHs)	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
3.	Alkanoic acids	Hexadecanamide, Octadecanamide
4.	Others	Levoglucosan, Stigmasterol

2.2.8. 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. Jan 1 – 18, 2023. 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):

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

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 Al₂O₃, SiO₂, CaO, TiO₂, and Fe₂O₃.

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

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

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

The chemical reconstruction method explained above was applied to all 4 sites over Balasore city and reconstructed PM mass (PM_{Chem}) was compared against the corresponding observed gravimetric mass (PM_{Grav}).

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

In the present study, the US EPA-Chemical Mass Balance Model (CMB V8.2; Coulter 2004) is used to apportion the sources of PM_{2.5} and PM₁₀ particles in Balasore 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 Balasore region during the winter season i.e. Jan 1 – 18, 2023. The mean PM_{2.5} and PM₁₀ mass concentrations during the entire sampling period over all sites were 97.7 and 203.7 $\mu\text{g}/\text{m}^3$, respectively. The mean PM_{2.5} concentrations exhibited a 3-fold range and ranged from a minimum of 49.1 $\mu\text{g}/\text{m}^3$ (at District Collector Office i.e. S3) to a maximum of 154.5 $\mu\text{g}/\text{m}^3$ (at Municipality Office i.e. S4). Similarly, the mean PM₁₀ concentrations exhibited a 3-fold range and ranged from 113.2 $\mu\text{g}/\text{m}^3$ (at District Collector Office i.e. S3) to 319.4 $\mu\text{g}/\text{m}^3$ (at RO Office i.e. S2). The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 $\mu\text{g}/\text{m}^3$ 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 (73.3 to 100.0%) with minimum exceedance at S1, i.e. Jyoti Hospital (73.3%) and maximum exceedance at S2 i.e. RO Office during winter season. The daily averaged PM₁₀ concentrations exceeded the NAAQS limit at all sites 100%.

2.6.1.2. Spatial variability

The highest seasonal mean PM_{2.5} concentrations were observed at S4 i.e. Municipality Office (103.1 $\mu\text{g}/\text{m}^3$) while the lowest were recorded at S3, i.e. District Collector Office (93.3 $\mu\text{g}/\text{m}^3$). The Municipality Office i.e. S4 and RO Office i.e. S2 locations are reported the highest and lowest variability in PM_{2.5} concentrations. For example, PM_{2.5} concentrations ranged from 54.0 to 154.5 at S4 i.e. Municipality Office while it ranged from 63.7 to 141.3 at S2, i.e. RO Office.

The highest seasonal mean PM₁₀ concentrations were observed at S2 i.e. RO Office (220.2 $\mu\text{g}/\text{m}^3$) while the lowest were recorded at S3 i.e. District Collector Office (179.7 $\mu\text{g}/\text{m}^3$). The

PM₁₀ concentrations showed highest variability at S2 i.e. RO Office ranging from a minimum of 138.0 to a maximum of 319.4 $\mu\text{g}/\text{m}^3$ while it ranged between 134.2 and 283.4 $\mu\text{g}/\text{m}^3$ at S4 i.e. Municipality Office.

These concentration levels can be attributed to air polluting activities around each site. For example, S2 i.e. RO Office is located near the Industrial area. In addition to Industrial stack emissions and fugitive emissions, road dust re-suspension due to movement of heavy vehicles in the region can be one of the major reasons for highest particulate levels. Considering the location, meteorological setting and polluting activities in and around Balasore, the background concentration levels are also expected to play a crucial role in elevated PM concentration levels.

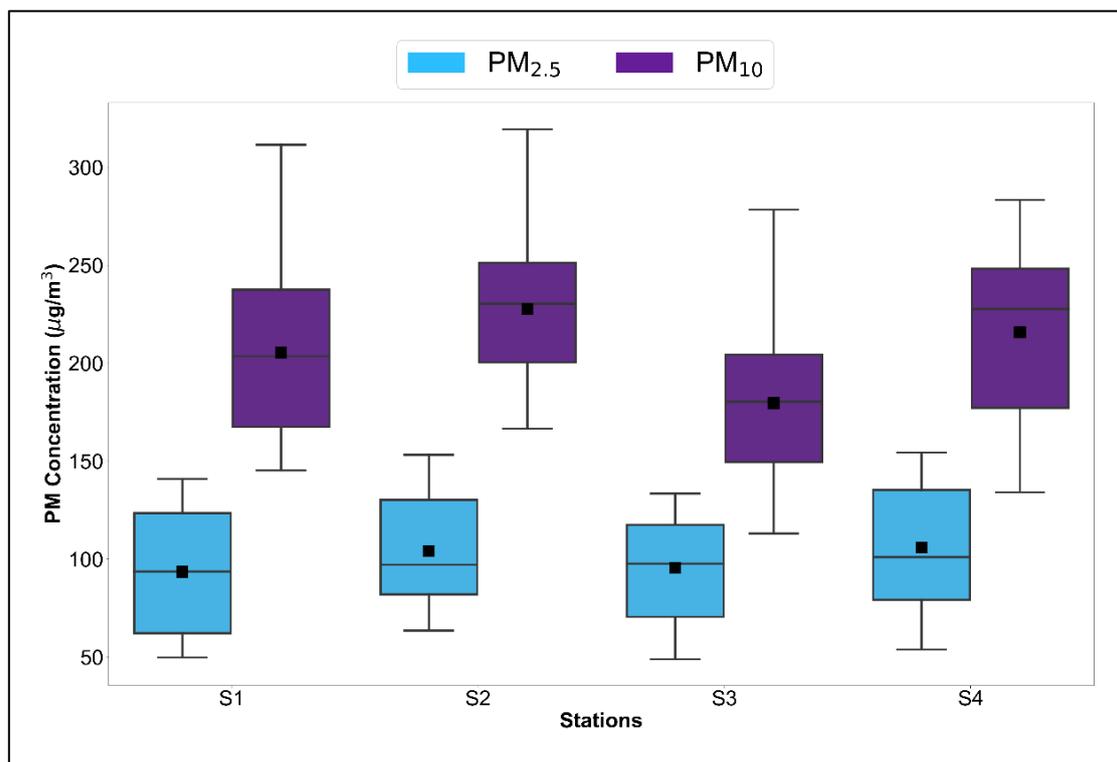


Figure 9 Boxplot showing distribution of daily PM_{2.5} (blue colored boxes) and PM₁₀ (violet colored boxes) concentrations observed at four sampling sites in Balasore region during the winter season sampling period (Jan 1 – 18, 2023).

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

2.6.1.3. Temporal variability

Fig. 10 shows daily time-series of PM_{2.5} and PM₁₀ observed at four selected sampling locations in Balasore region during the winter season sampling period. Only valid samples between Jan 1 - 18, 2023 are considered for this analysis. Overall, the PM concentrations showed mixed trend from January 1 to 18 at all sites. This could be attributed to the meteorological phenomena over Balasore region during the winter season.

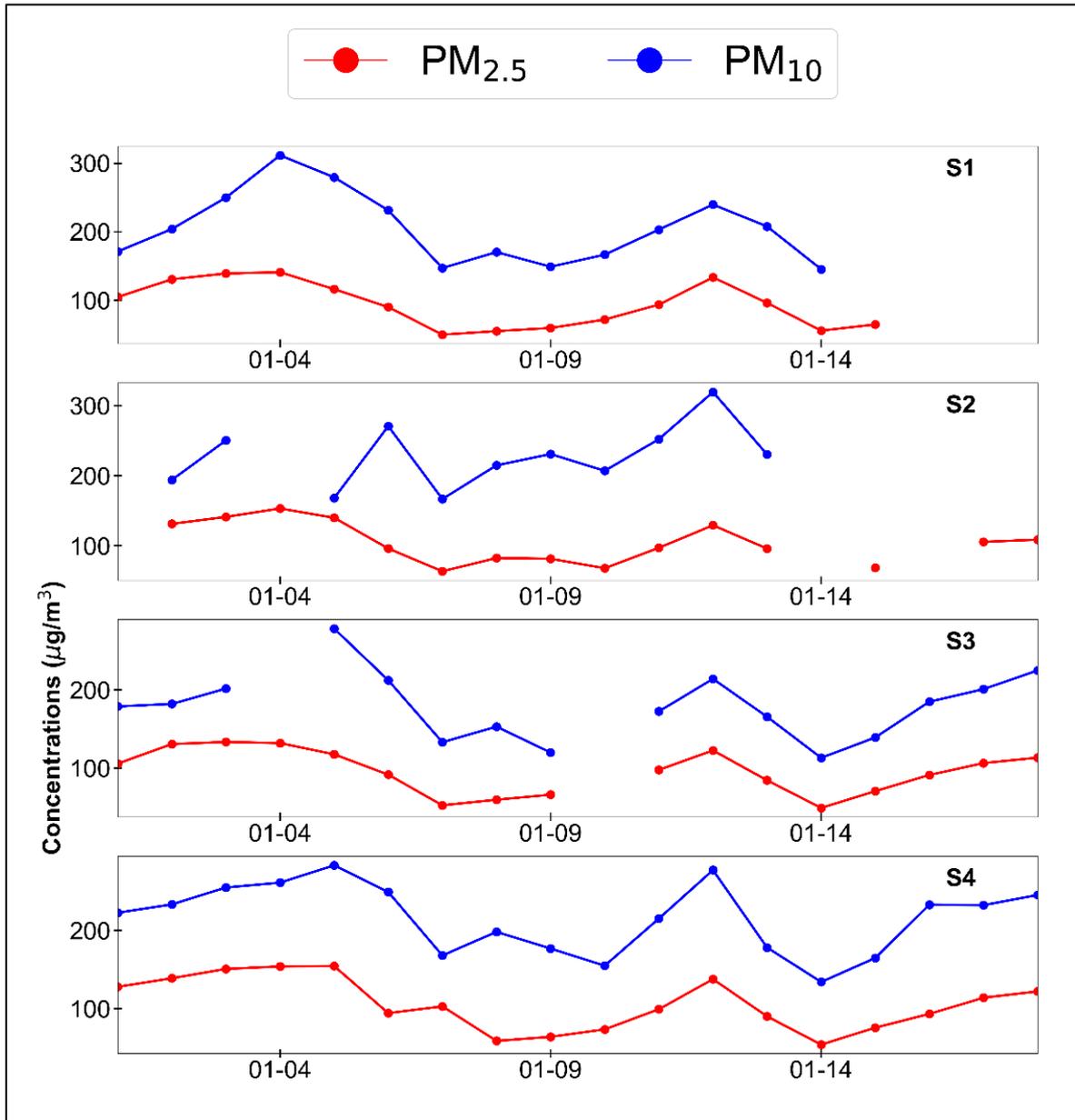


Figure 10 Daily time-series of PM_{2.5} (red) and PM₁₀ (blue) concentrations observed at four sites in Balasore region during the winter season sampling (Jan 1-18, 2023)

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 selected sites during the winter season sampling. The average value of PM_{2.5} to PM₁₀ ratios during the study period over all sites was found to be 0.48, varying from 0.30 to 0.83. The highest winter season mean PM_{2.5} to PM₁₀ ratio was observed at S3 i.e. Collector Office (0.52) while the lowest was observed at S1 i.e. Jyoti Hospital (0.45). 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.

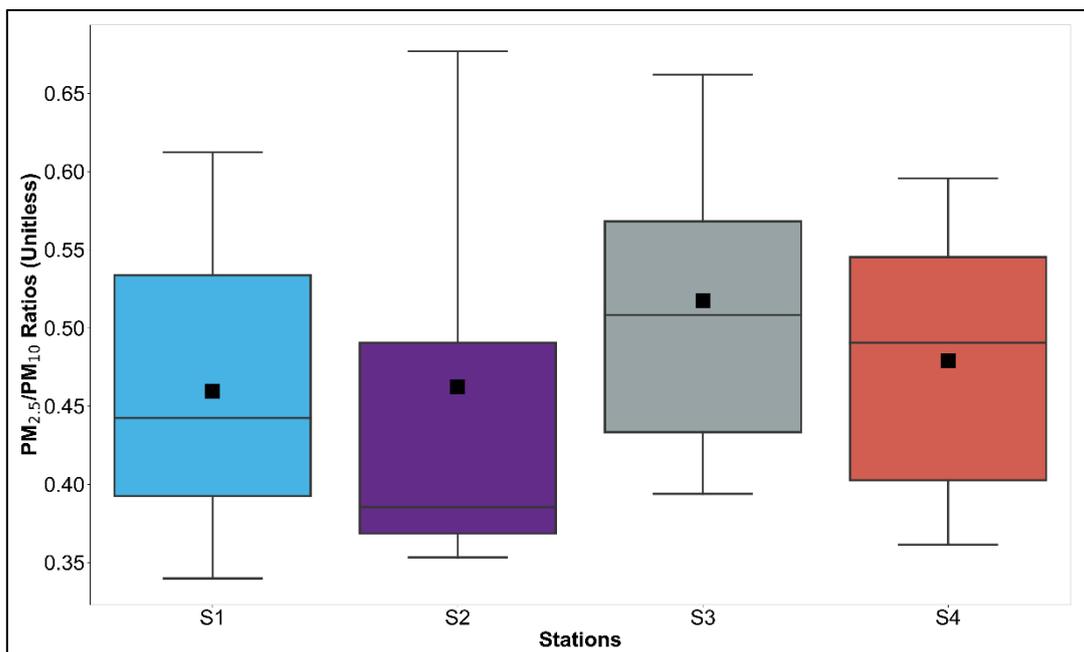


Figure 11 Boxplot showing distribution of PM_{2.5} to PM₁₀ ratios at four selected sites in Balasore region during the winter season (Jan 1-18, 2023)

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

2.6.1.5. Chemical composition of PM_{2.5} and PM₁₀

2.6.1.5.1. Site 1: Jyoti Hospital

Fig. 12 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na⁺, NH₄⁺, K⁺, Ca⁺⁺, Mg⁺⁺, Cl⁻, NO₃⁻, and SO₄⁻) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in PM_{2.5} and PM₁₀ observed at S1 i.e. Jyoti Hospital site in Balasore region during the winter season (January 1-18, 2023). OC, EC, SO₄⁻, NO₃⁻ and NH₄⁺ are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m³ in both PM_{2.5} and PM₁₀. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

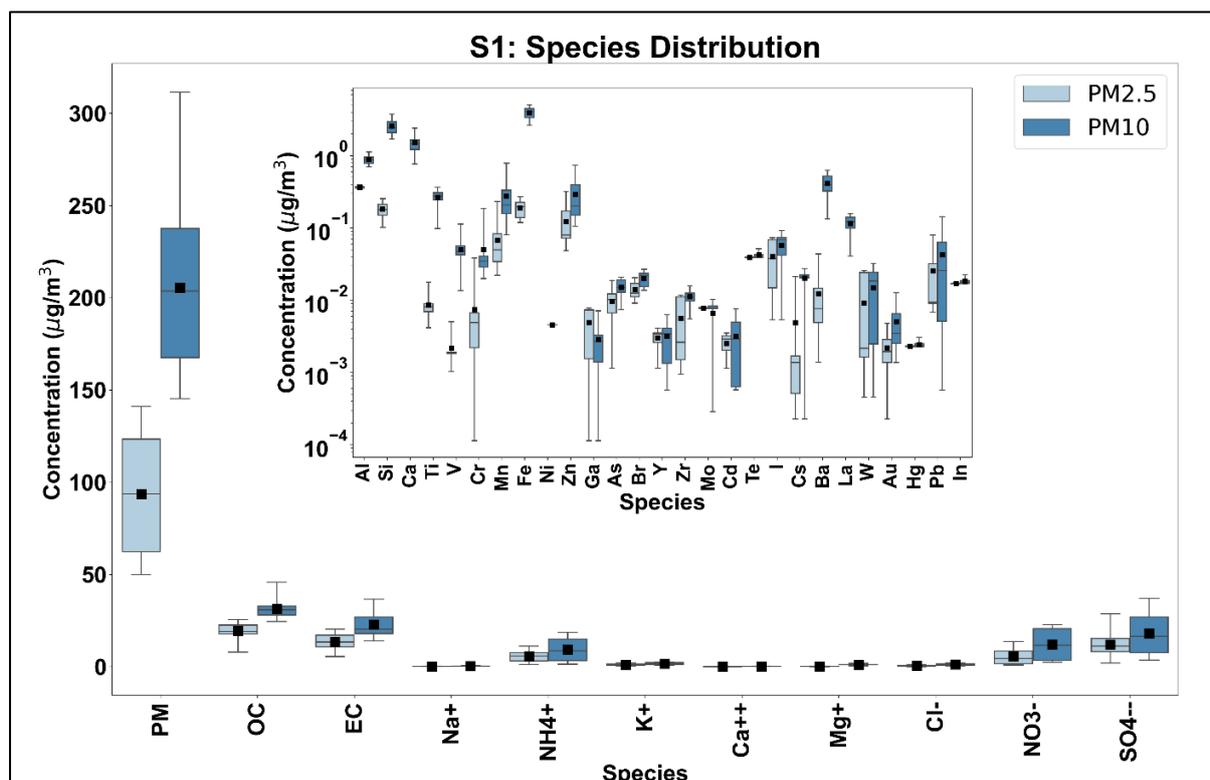


Figure 12 Box plots showing distribution of different species observed in PM_{2.5} and PM₁₀ at Jyoti Hospital site (S1) in Balasore region during the winter season

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

2.6.1.5.2. Site 2: RO Office (S2)

Fig. 13 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , NO_3^- , and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $\text{PM}_{2.5}$ and PM_{10} observed at S2 i.e. RO Office site in Balasore region during winter season (January 1-18, 2023). OC, EC, SO_4^{--} and NO_3^- in $\text{PM}_{2.5}$ and OC, EC, SO_4^{--} , NO_3^- 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.

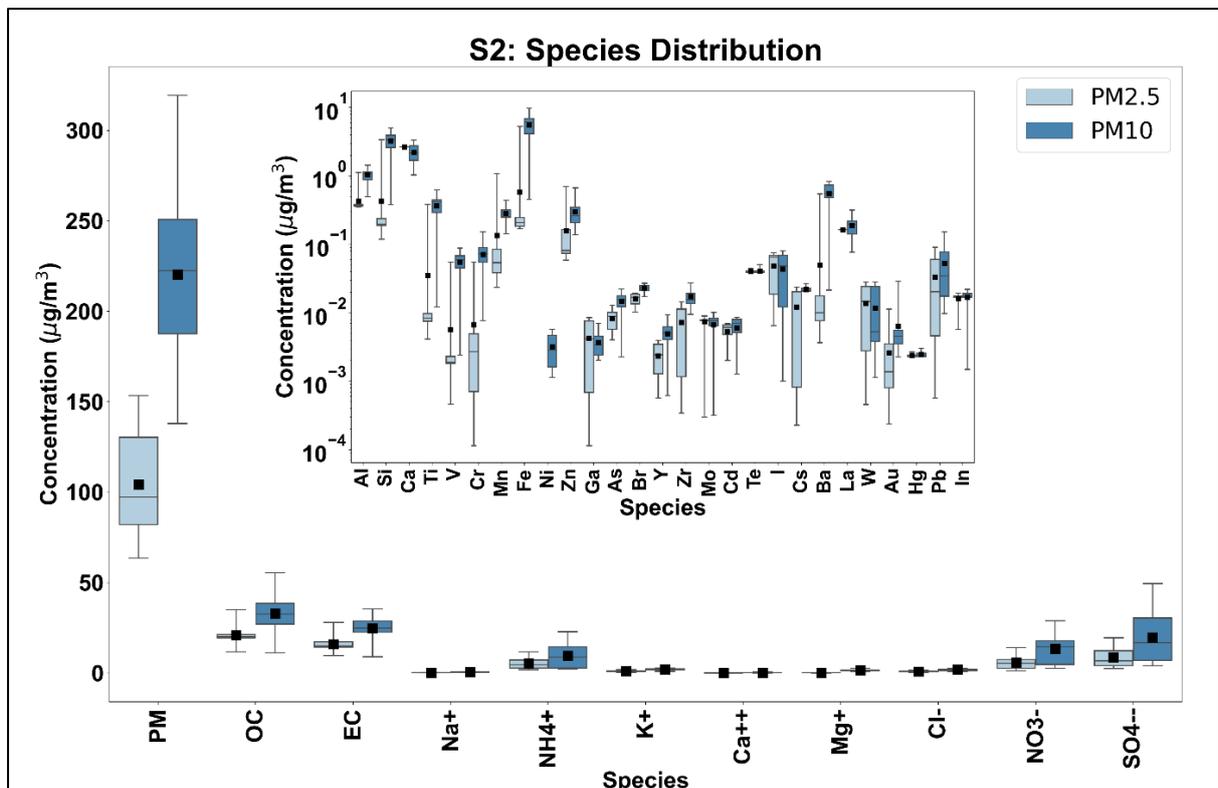


Figure 13 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at RO Office site (S2) in Balasore region during the winter season

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

2.6.1.5.3. Site 3: District Collector Office (S3)

Fig. 14 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , NO_3^- , and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $\text{PM}_{2.5}$ and PM_{10} observed at S3 i.e. District Collector Office site in Balasore region during winter season (January 1-18, 2023). OC, EC, SO_4^{--} , NO_3^- and NH_4^+ are the most abundant species having seasonal mean concentrations greater than $5.0 \mu\text{g}/\text{m}^3$ in both $\text{PM}_{2.5}$ and PM_{10} , respectively. Trace elements concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

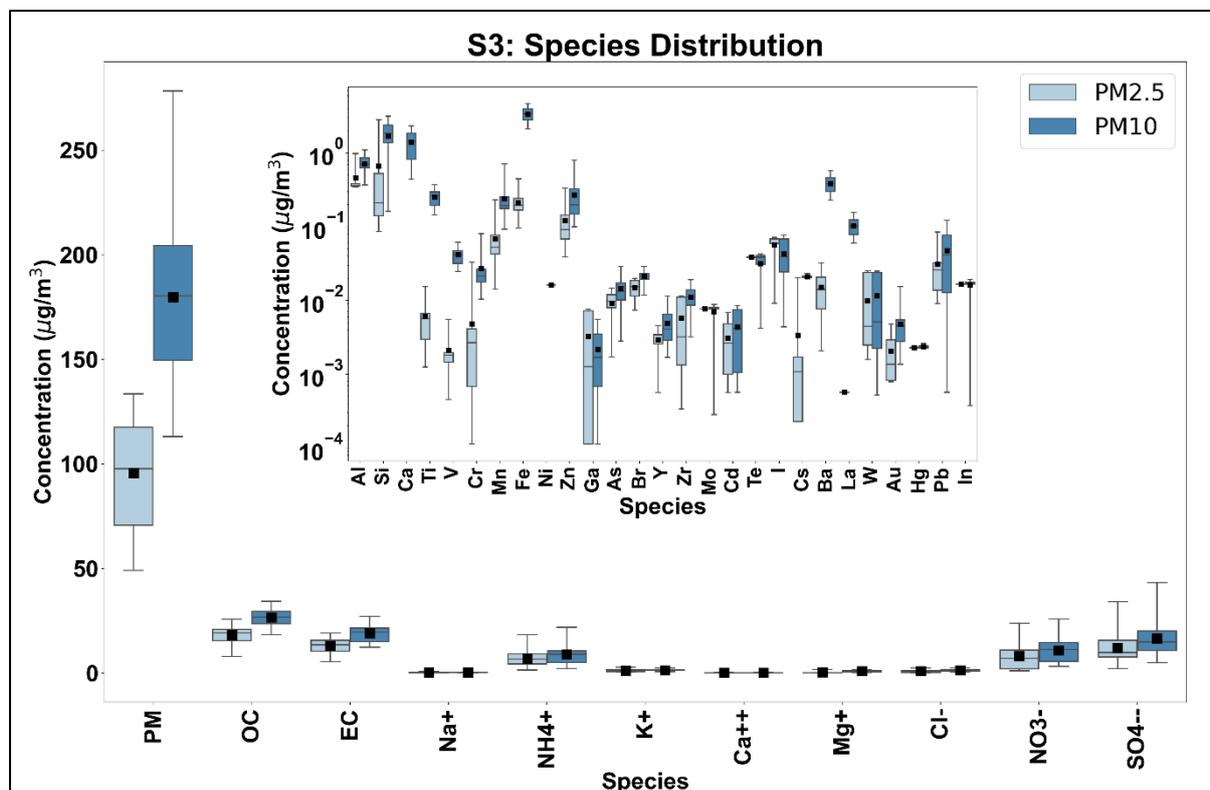


Figure 14 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at District Collector Office site (S3) in Balasore region during the winter season

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

2.6.1.5.4. Site 4: Municipality Office (S4)

Fig. 15 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , NO_3^- , and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $\text{PM}_{2.5}$ and PM_{10} observed at S4 i.e. Municipality Office site in Balasore region during winter season (January 1-18, 2023). OC, EC, SO_4^{--} , NO_3^- and NH_4^+ are the most abundant species having seasonal mean concentrations greater than $5.0 \mu\text{g}/\text{m}^3$ in both $\text{PM}_{2.5}$ and PM_{10} . Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

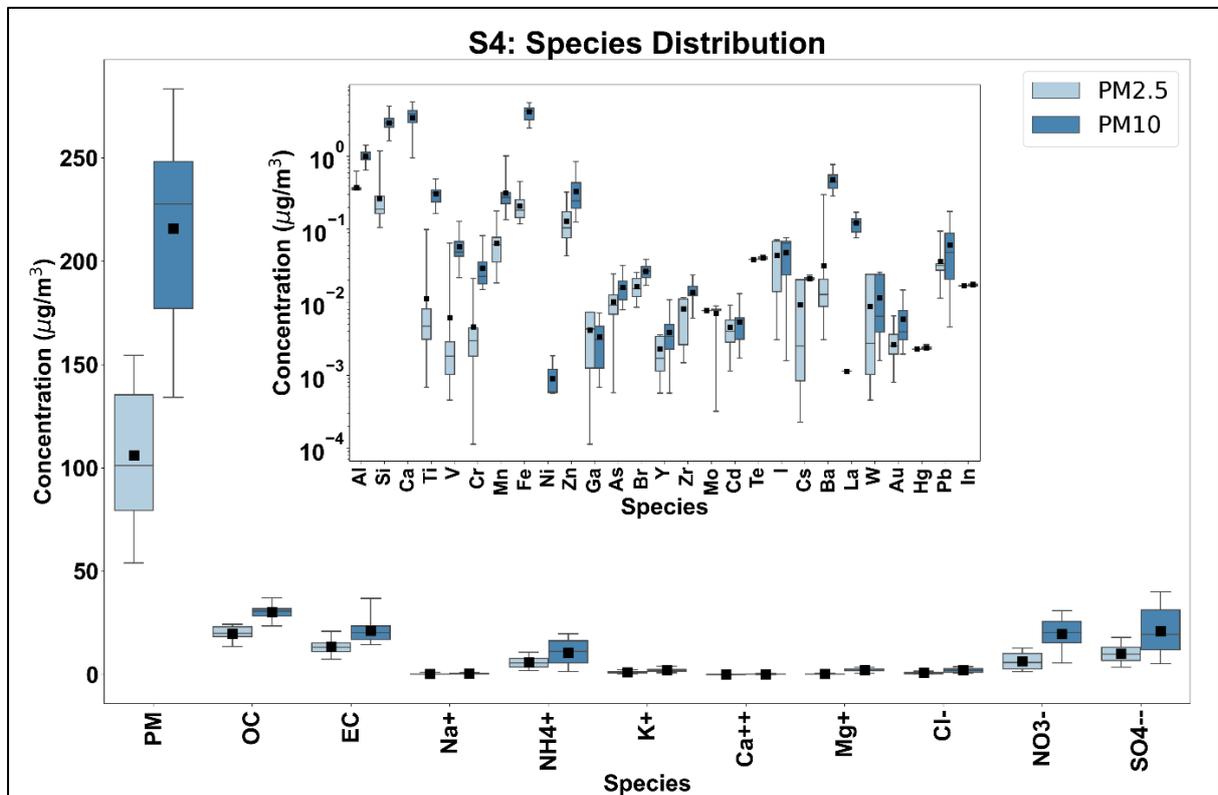


Figure 15 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at Municipality Office site (S4) in Balasore region during the winter season

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

2.6.1.6. 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 Balasore region, during the winter season sampling period i.e. January 1-18, 2023. Levoglucosan, which is considered as a tracer for biomass burning emissions (CPCB, 2010), is detected in significant amounts, in PM samples collected over Balasore region during winter season. Apart from levoglucosan, alkane group is also found to dominate the molecular markers mass, during the winter season over Balasore region.

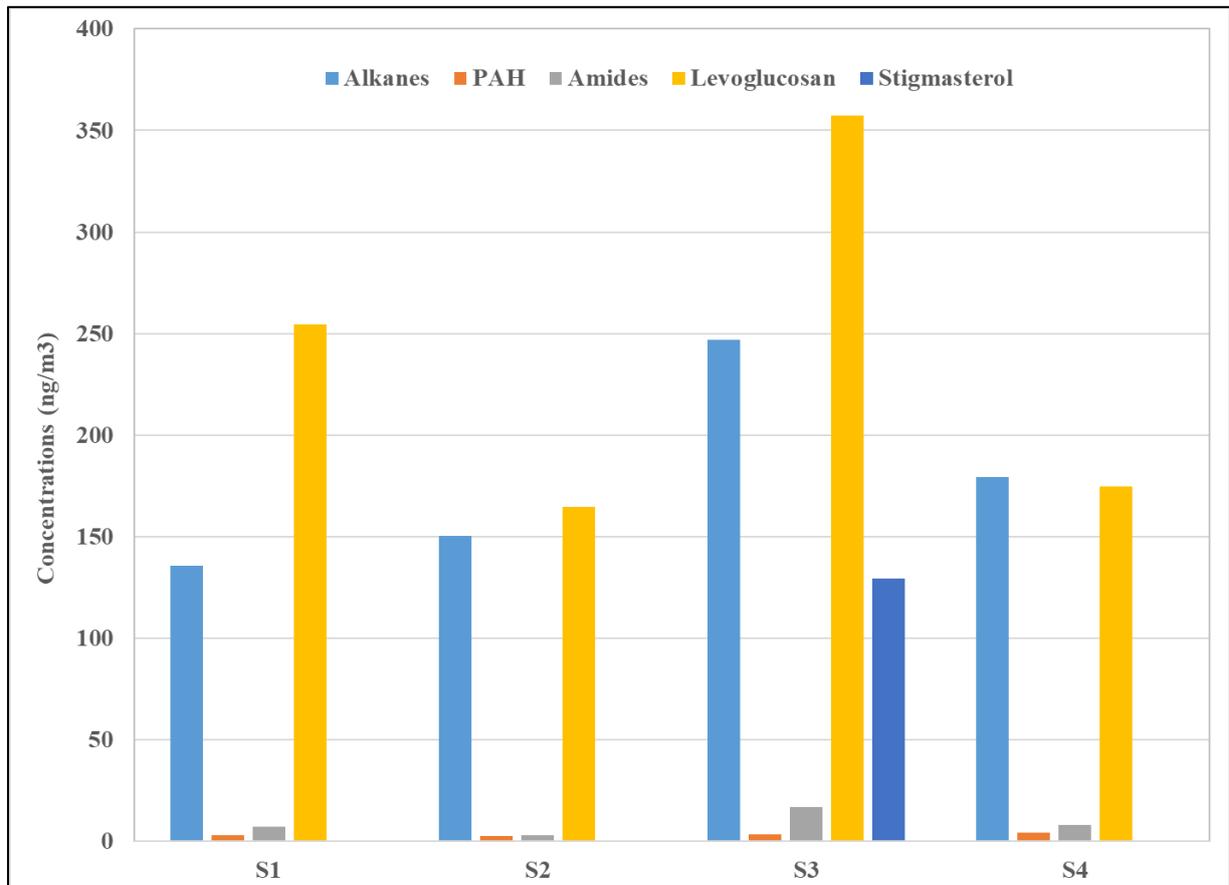


Figure 16: The seasonal mean concentrations of molecular marker species in PM_{2.5} (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Balasore region during the winter season sampling period (January 1-18, 2023).

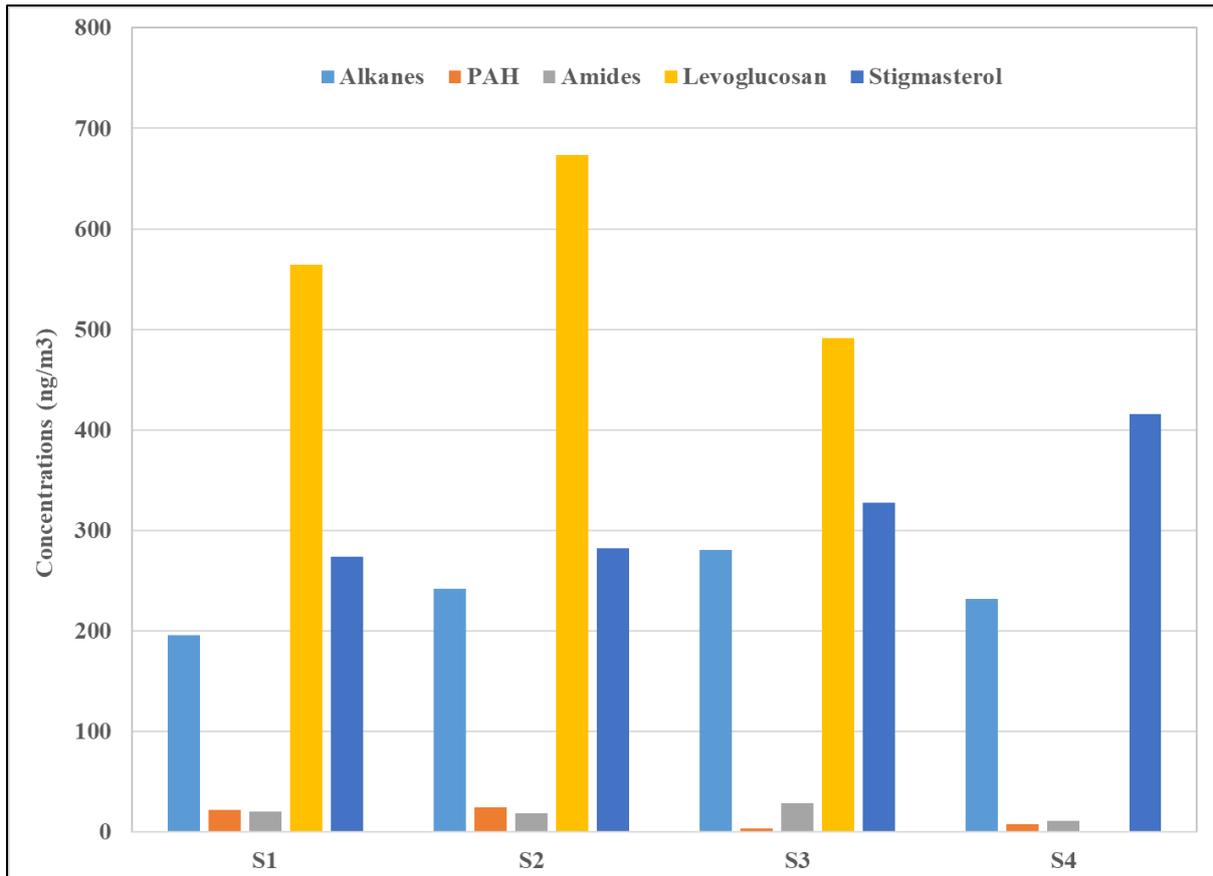


Figure 17: The seasonal mean concentrations of molecular marker species in PM₁₀ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Balasore region during the winter season sampling period (January 1-18, 2023).

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 Balasore region, during the winter season sampling period i.e. January 1-18, 2023.

The winter season SO₂ concentrations were less than 5 µg/m³ at all sites and hence are reported as Below Detection Limit (BDL). The winter season mean concentrations of NO₂ are observed to be 23.6 µg/m³ at Jyoti Hospital (S1), 37.5 µg/m³ at RO Office (S2), 18.7 µg/m³ at Collector Office (S3) and 39.6 µg/m³ at Municipality Office (S4).

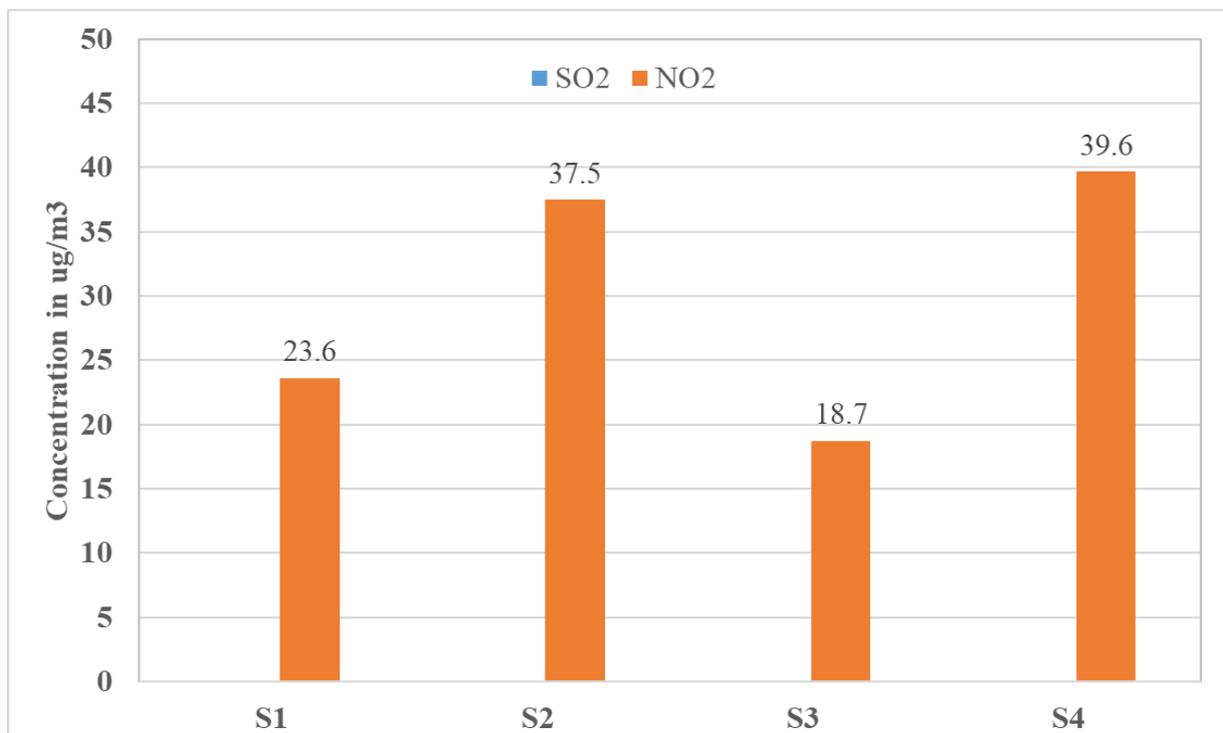


Figure 18: The seasonal mean concentrations of SO₂ and NO₂ observed at three sampling sites in Cutack region during the winter season sampling period (December 11 to 26, 2022)

Fig. 19, represents the seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX), observed at four sampling locations in Balasore region, during the winter season sampling period i.e. January 1-18, 2023. The winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among four sampling sites range from 20.0 to 31.8 ng/m³, 41.1 to 198.1 ng/m³, 78.3 to 1796.9 ng/m³ and 136.0 to 1797.4 ng/m³, respectively. In general, the lowest concentrations were observed at Jyoti Hospital site (S1) while the highest concentrations were observed at RO Office, Balasore (S2). 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.

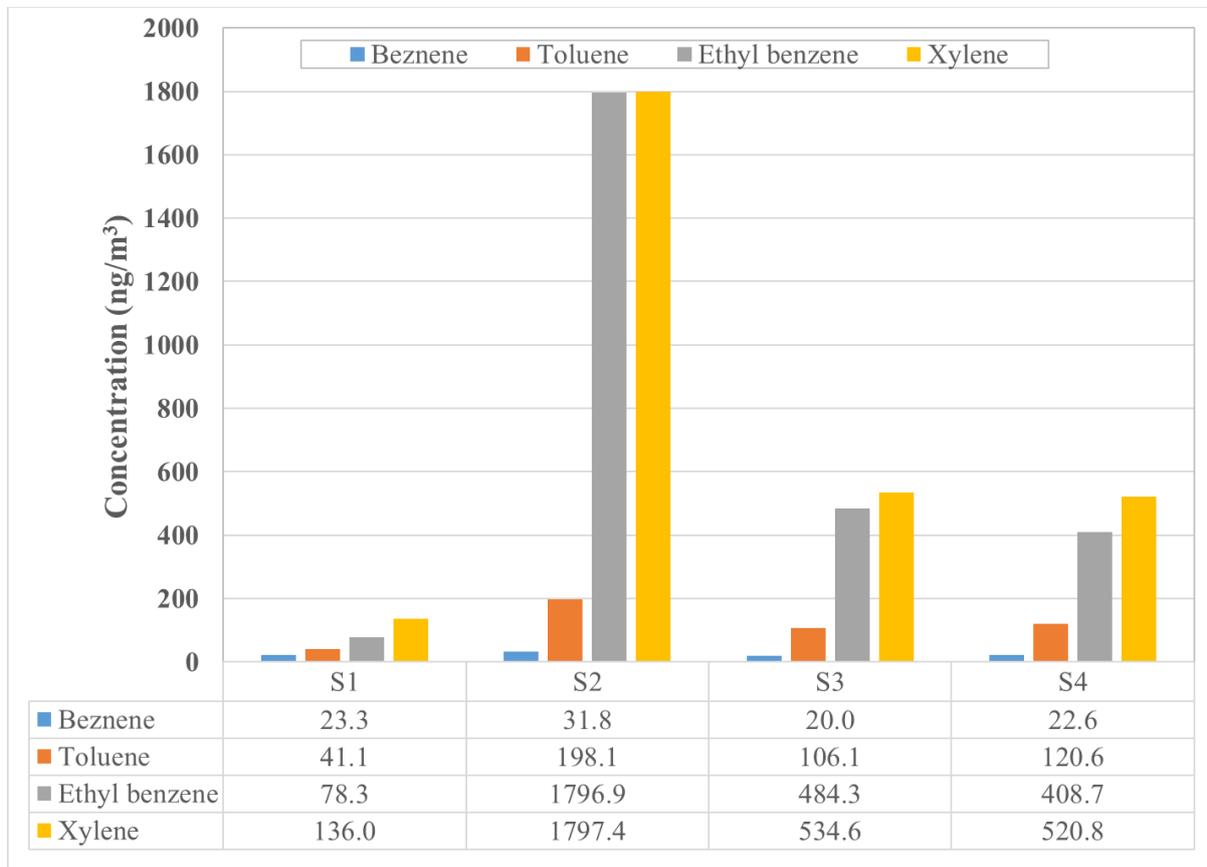


Figure 19: The seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) observed at four sampling sites in Balasore region during the winter season sampling period (January 1-18, 2023)

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 Balasore region during the summer season i.e. Mar 21 – Apr 7, 2023. The mean PM_{2.5} and PM₁₀ mass concentrations during the entire sampling period over all sites were 23.9 and 52.6 µg/m³, respectively. The mean PM_{2.5} concentrations exhibited a 4-fold range and ranged from a minimum of 9.6 µg/m³ (S1 i.e. Jyoti Hospital) to a maximum of 42.1 µg/m³ (at S4 i.e. Municipality Office). Similarly, the mean PM₁₀ concentrations exhibited a 7-fold range and ranged from 17.5 µg/m³ (S1 i.e. Jyoti Hospital) to 130.7 µg/m³ (S2 i.e. RO Office). 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. The daily averaged PM₁₀ concentrations exceeded the NAAQS limit at only two sites; S2 i.e. RO Office and S3 i.e. District Collector Office (6.3-25%) with minimum exceedance at S3 i.e. District Collector Office (6.3%) and maximum exceedance at S2 i.e. RO Office (25%).

2.6.2.2. Spatial variability

The highest seasonal mean PM_{2.5} concentrations were observed at S2 i.e. RO Office (27.3 µg/m³) while the lowest was recorded at S1 i.e. Jyoti Hospital (19.3 µg/m³). These two locations also reported the significant variability in PM_{2.5} concentrations, respectively. For example, daily PM_{2.5} concentrations ranged from 18.2 to 41.7 µg/m³ at S2 i.e. RO Office while it ranged from 9.6 to 35.2 µg/m³ at S1 i.e. Jyoti Hospital. This could be attributed to activities around the S2 i.e. RO Office including, industrial stack emission, fugitive emissions, heavy duty traffic, and road dust re-suspension. S1 i.e. Jyoti Hospital on the other hand, is a background site and is relatively unaffected by the industrial emissions.

The highest seasonal mean PM₁₀ concentrations were observed at S2 i.e. RO Office (77.5 µg/m³) while the lowest were recorded at S1 i.e. Jyoti Hospital (36.1 µg/m³). The PM₁₀ concentrations showed highest variability at S2 i.e. RO Office ranging from a minimum of 47.6 to a maximum of 130.7 µg/m³. This could be attributed to stack emissions, fugitive emissions, road dust re-suspension due to movement of heavy vehicles in the region as well as summer time meteorological conditions (low RH and higher wind speed).

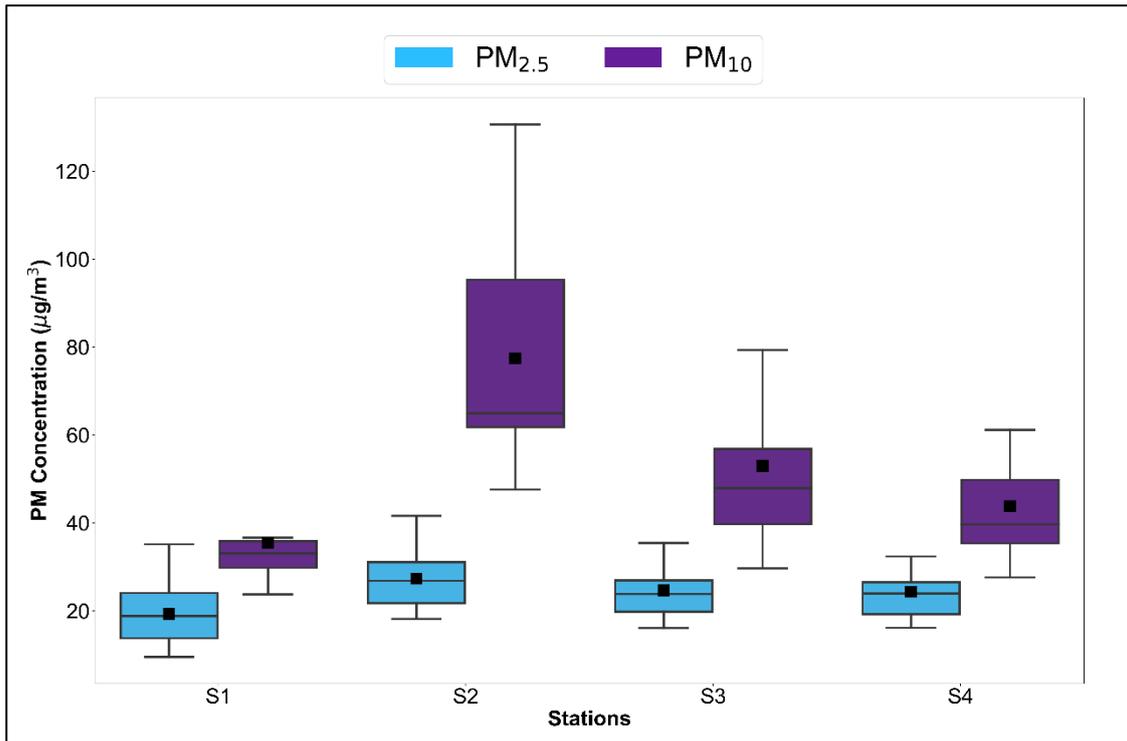


Figure 20 Boxplot showing distribution of daily PM_{2.5} (blue colored boxes) and PM₁₀ (violet colored boxes) concentrations observed at four sampling sites in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023)

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

2.6.2.3. Temporal variability

Fig. 21 shows the daily time-series of PM_{2.5} and PM₁₀ observed at four selected sampling locations in Balasore region during the summer season sampling period. Only valid samples between Mar 21 - Apr 7, 2023 are considered for this analysis. Overall, the PM concentrations exhibit slightly increasing trend during summer season sampling campaign.

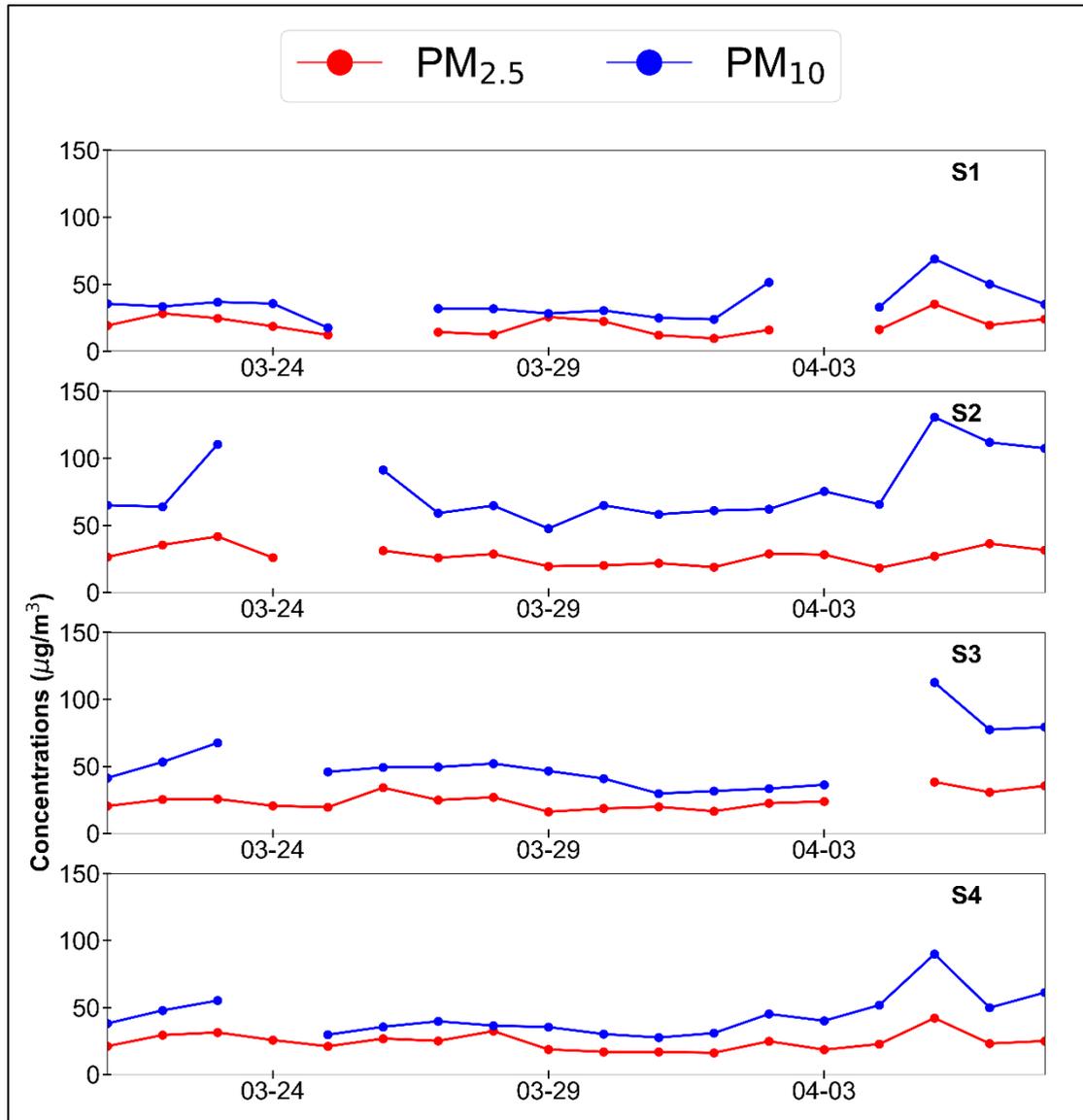


Figure 21 Daily time-series of $PM_{2.5}$ (red) and PM_{10} (blue) concentrations observed at four sites in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023)

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

Fig. 22 shows distribution of daily $PM_{2.5}$ to PM_{10} ratios observed at four selected sites during the summer season sampling period (Mar 21 - Apr 7, 2023). The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.50, varying from 0.21 to 0.91. The highest summer season mean $PM_{2.5}$ to PM_{10} ratio was observed at S4 i.e. Municipality Office site (0.57) while the lowest was observed at S2 i.e. RO Office site (0.37). This variability in fine and coarse mode particles may be attributed to variability in PM chemical composition, which is in turn affected by various sources and meteorological conditions.

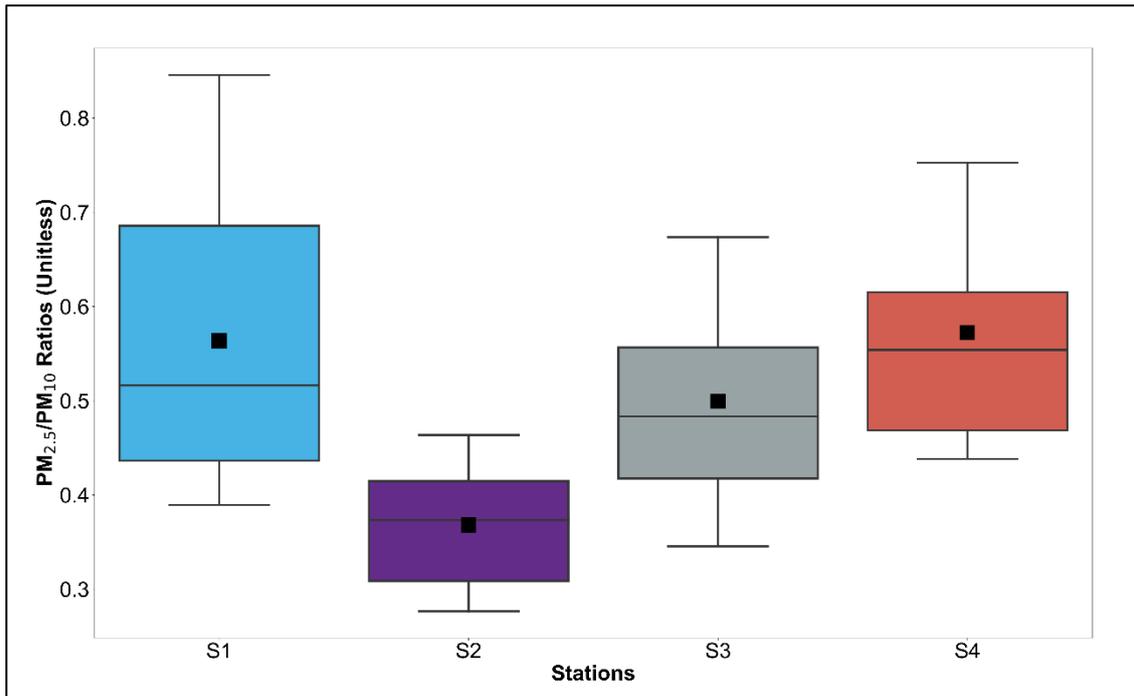


Figure 22 Boxplot showing distribution of $PM_{2.5}$ to PM_{10} ratios at four selected sites in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023)

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

2.6.2.5. Chemical composition of PM_{2.5} and PM₁₀

2.6.2.5.1. Site 1: Jyoti Hospital

Fig. 23 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na⁺, NH₄⁺, K⁺, Ca⁺⁺, Mg⁺⁺, Cl⁻, NO₃⁻, and SO₄⁻) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in PM_{2.5} and PM₁₀ observed at S1 i.e. Jyoti Hospital site in Balasore region during the summer season (Mar 21 - Apr , 2023). OC is the most abundant species having seasonal mean concentrations greater than 5.0 µg/m³ in both PM_{2.5} and PM₁₀. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

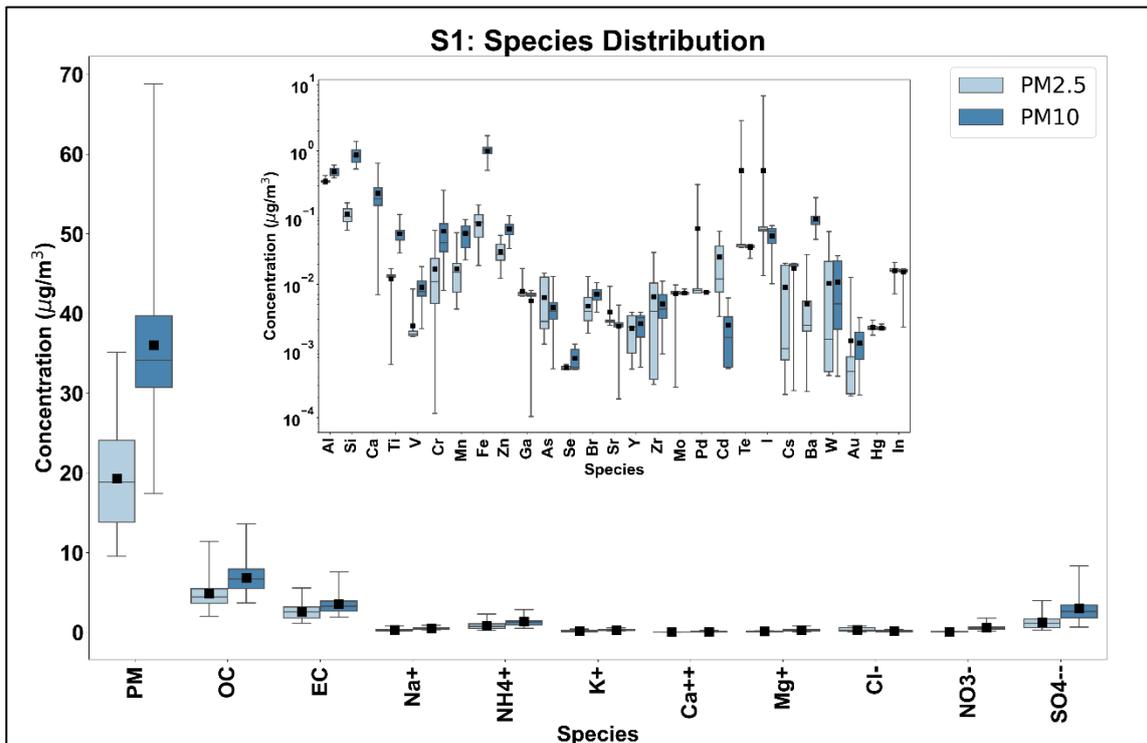


Figure 23 Box plots showing distribution of different species observed in PM_{2.5} and PM₁₀ at S1 i.e. Jyoti Hospital in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023).

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

2.6.2.5.2. Site 2: RO Office

Fig. 24 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , NO_3^- , and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $\text{PM}_{2.5}$ and PM_{10} observed at S2 i.e. RO Office site in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023). OC in $\text{PM}_{2.5}$ and OC and EC 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.

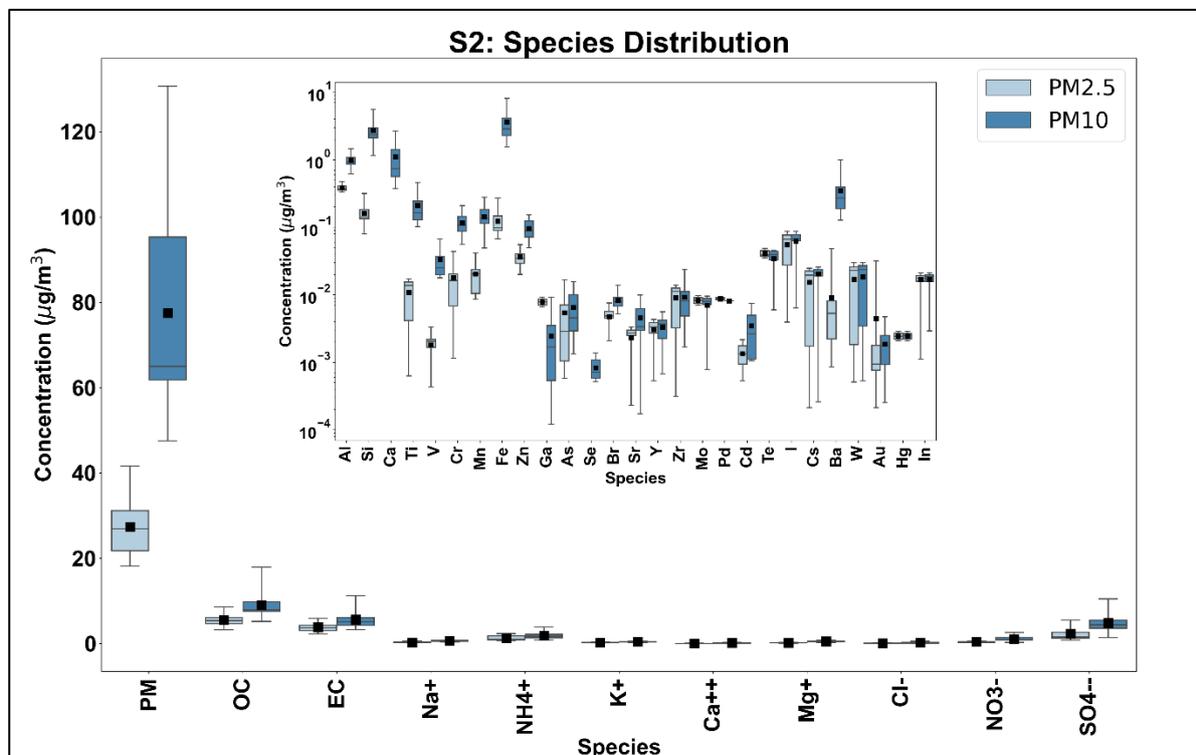


Figure 24 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at S2 i.e. RO Office in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023)

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

2.6.2.5.3. Site 3: District Collector Office

Fig. 25 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , NO_3^- , and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $\text{PM}_{2.5}$ and PM_{10} observed at S3 i.e. District Collector Office in Balasore region during the summer season (Mar 21 - Apr 7, 2023). OC, PO_4^- 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.

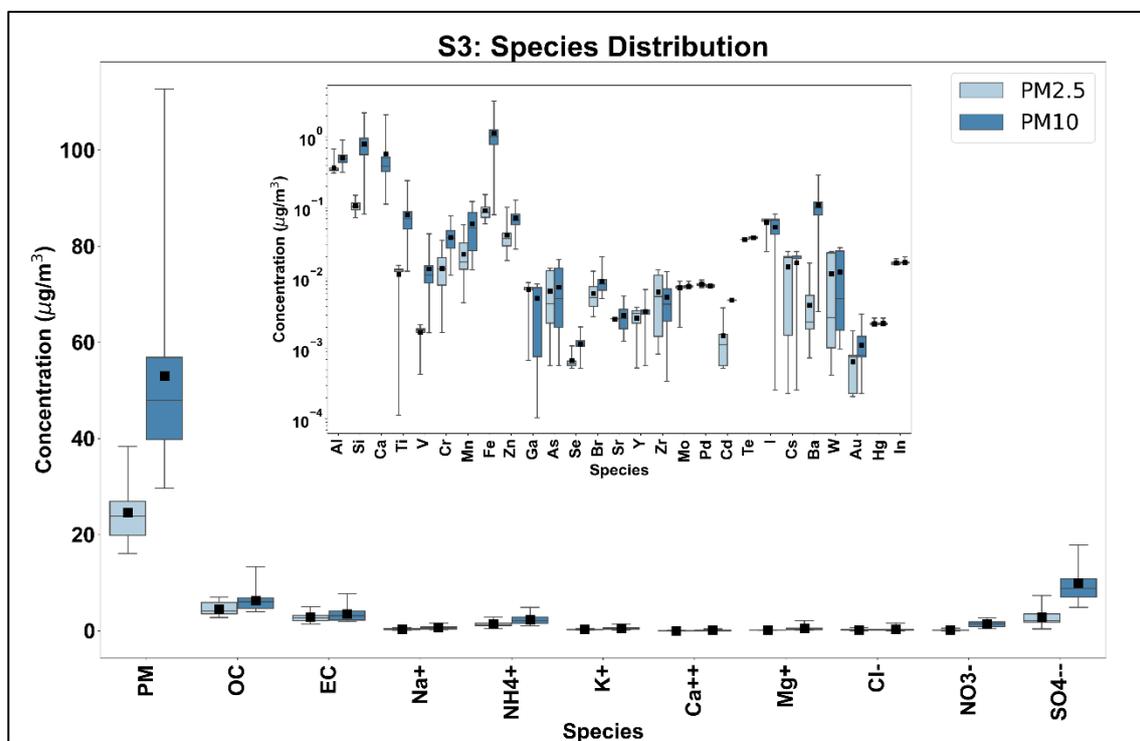


Figure 25 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at S3 i.e. District Collector Office in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023)

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

2.6.2.5.4. Site 4: Municipality Office

Fig. 26 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+ , NH_4^+ , K^+ , Ca^{++} , Mg^{++} , Cl^- , NO_3^- , and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $\text{PM}_{2.5}$ and PM_{10} observed at S4 i.e. Municipality Office in Balasore region during the summer season (Mar 21 - Apr 7, 2023). OC are the most abundant species having seasonal mean concentrations greater than $5.0 \mu\text{g}/\text{m}^3$ in both $\text{PM}_{2.5}$ and PM_{10} . Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

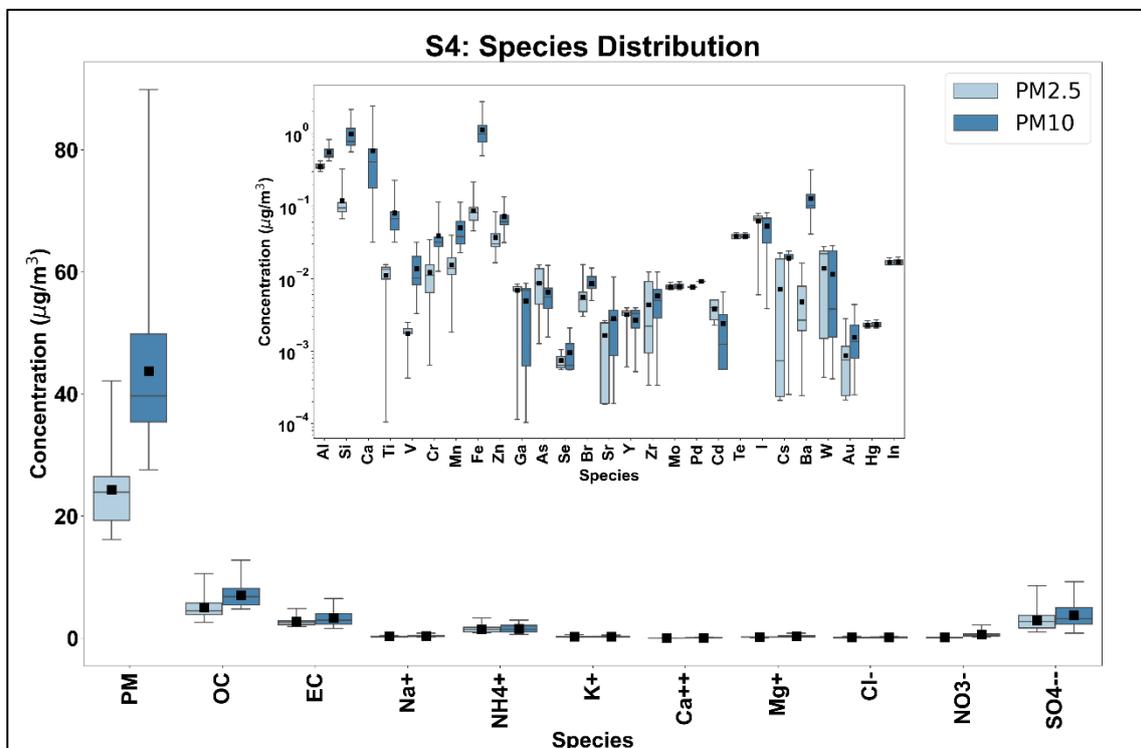


Figure 26 Box plots showing distribution of different species observed in $\text{PM}_{2.5}$ and PM_{10} at S4 i.e. Municipality Office in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023)

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

2.6.2.6. Molecular Markers in PM_{2.5} and PM₁₀

Fig. 27 and 28, represents the seasonal mean concentrations of molecular markers observed at three sampling locations in Balasore region, during the summer season sampling period i.e. Mar 21 - Apr 7, 2023. Levoglucosan, which is considered as a tracer for biomass burning emissions (CPCB, 2010), is detected in significant amounts, in PM samples collected over Balasore region during summer season, as well. Apart from levoglucosan, alkane group is also found to dominate the molecular markers mass, during the winter season over Balasore region.

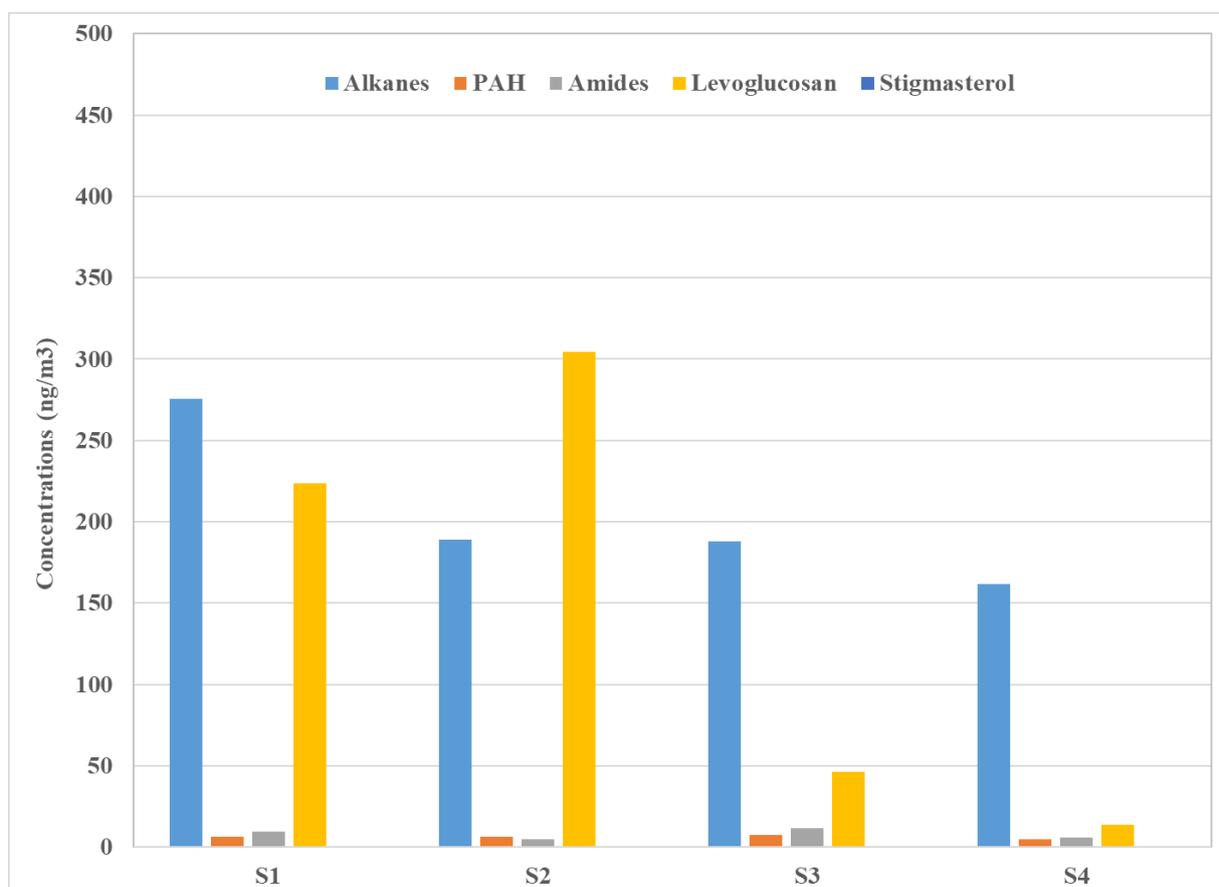


Figure 27: The seasonal mean concentrations of molecular marker species in PM_{2.5} (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Balasore region during the winter season sampling period (December 11-26, 2022).

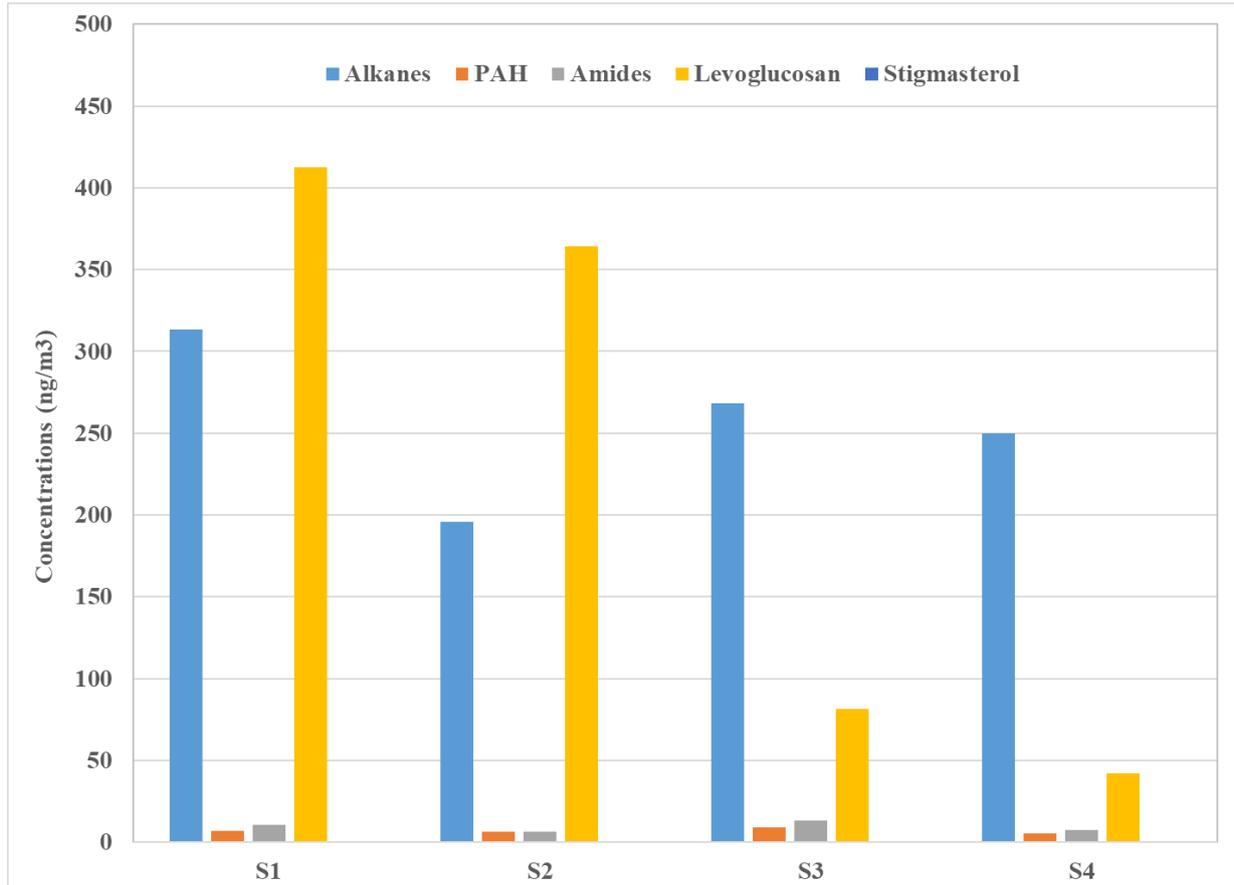


Figure 28: The seasonal mean concentrations of molecular marker species in PM₁₀ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Balasore region during the winter season sampling period (December 11-26, 2022).

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 0.60 (winter) and 0.78 (summer) for PM_{2.5} whereas it is found to be 0.78 (winter) and 0.93 (summer) for PM₁₀, respectively. These correlation coefficients are consistent with other published literature, with average values varying from 0.73 to 0.96 (Chow et al. 2015; Huang et al. 2014; 2017). In general, the PM_{Chem} concentrations are less than those of PM_{Grav} and the difference is defined as unknown. The unknown mass could be attributed to: i) the water retained in the sampling membrane and particulate matter, ii) volatilization of organic matter and the decomposition of ammonium nitrate that may occur during the period between weighing and chemical measurements (Huang et al. 2017) and iii) uncertainties associated with conversion factors used in the estimation of metal oxides and OC to OM conversion (Cheung et al. 2011).

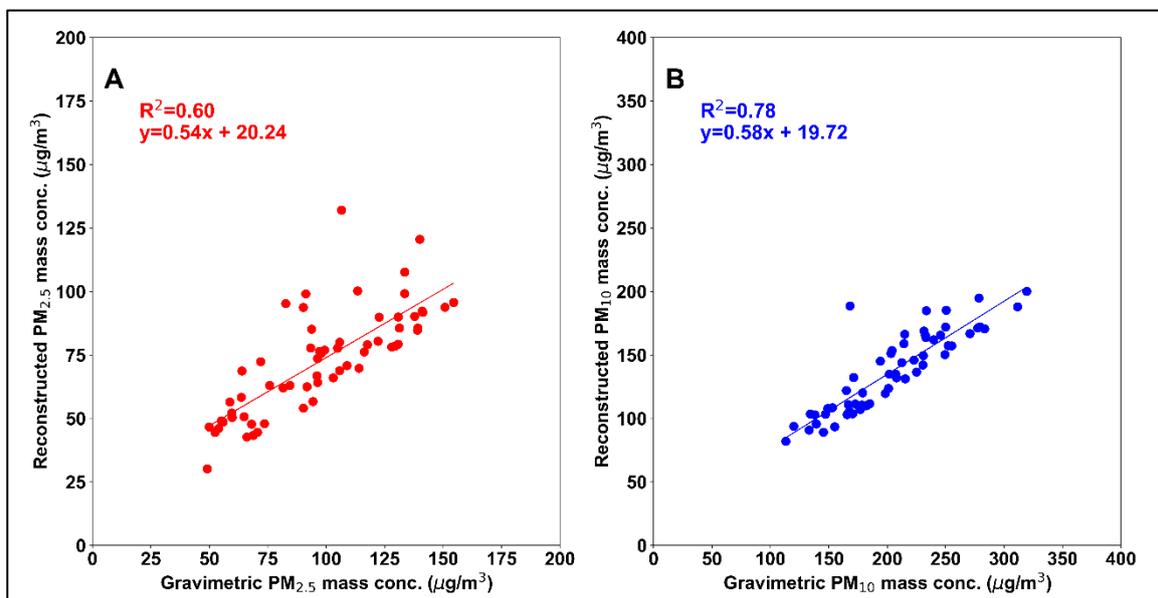


Figure 29 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) PM_{2.5} and (B) PM₁₀ in Balasore region during the winter season sampling period (Jan 01 - 18, 2023)

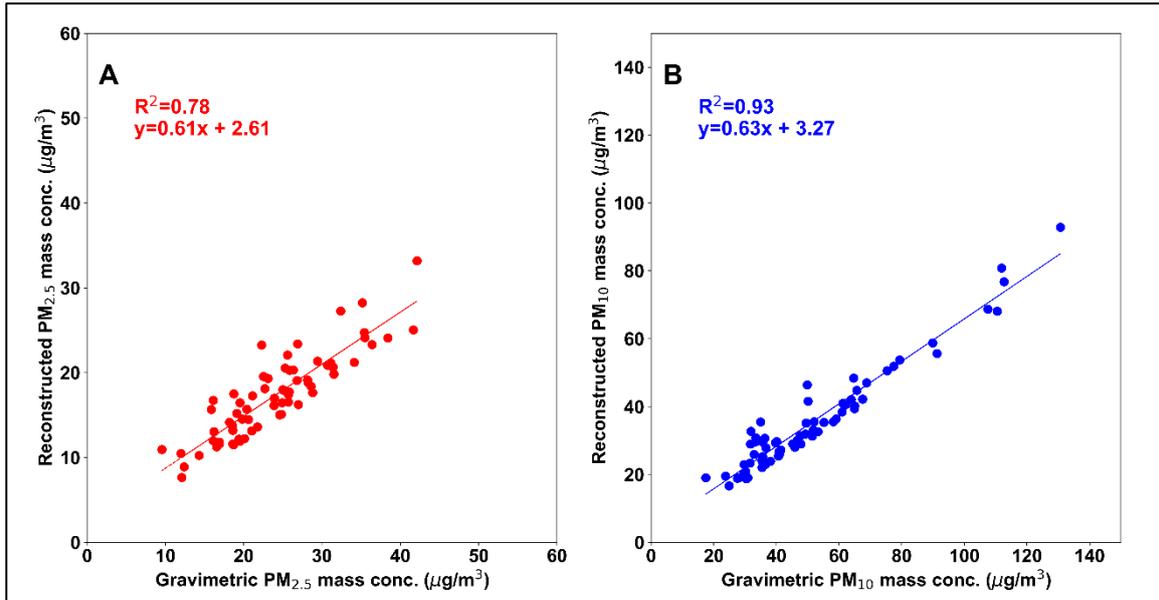


Figure 30 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) PM_{2.5} and (B) PM₁₀ in Balasore region during the summer season sampling period (Mar 21 - Apr 7, 2023)

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 Balasore region, respectively. Overall, the fractions of major chemical composition 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 of 30.4 to 33.2% in PM_{2.5} and 22.6 to 24.6% in PM₁₀. The seasonal mean OM concentrations among the four sites in the winter season ranged from 28.7 to 33.4 µg/m³ in PM_{2.5} while it ranged from 42.8 to 52.8 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 Balasore region. The seasonal mean contributions from SNA varied from 18.0 to 28.4% in PM_{2.5} while it varied from 18.0 to 20.3% in PM₁₀. The seasonal mean SNA concentrations among the four sites ranged from 18.1 to 26.5 µg/m³ in PM_{2.5} whereas it ranged from 36.4 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 between SO₂ and sulfate 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 1.9 to 3.8% in PM_{2.5} while it varied from 9.3 to 12.6% in PM₁₀. The seasonal mean CM concentrations in PM₁₀ varied from a minimum of 16.7 to 27.8 µg/m³ in PM₁₀. In contrast, the CM concentrations in fine fraction i.e. PM_{2.5} were relatively lower and ranged from 1.7 to 3.8 µg/m³.

The seasonal mean contributions from EC ranged between 12.9 and 16.0% in PM_{2.5} while it ranged between 9.8 and 11.2% in PM₁₀. The seasonal mean elemental carbon (EC) concentrations during winter season varied from 12.8 to 16.1 µg/m³ in PM_{2.5} whereas it ranged from 19.1 to 24.6 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 1.8 to 2.0%. The seasonal

mean TE concentrations ranged from 1.6 to 1.9 $\mu\text{g}/\text{m}^3$ and 3.3 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 Balasore, with contributions ranging from 0.8 to 1.3%. The seasonal mean SS ranged from 0.8 to 1.3 $\mu\text{g}/\text{m}^3$ in $\text{PM}_{2.5}$ while it ranged from 1.6 to 2.5 $\mu\text{g}/\text{m}^3$ in PM_{10} .

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

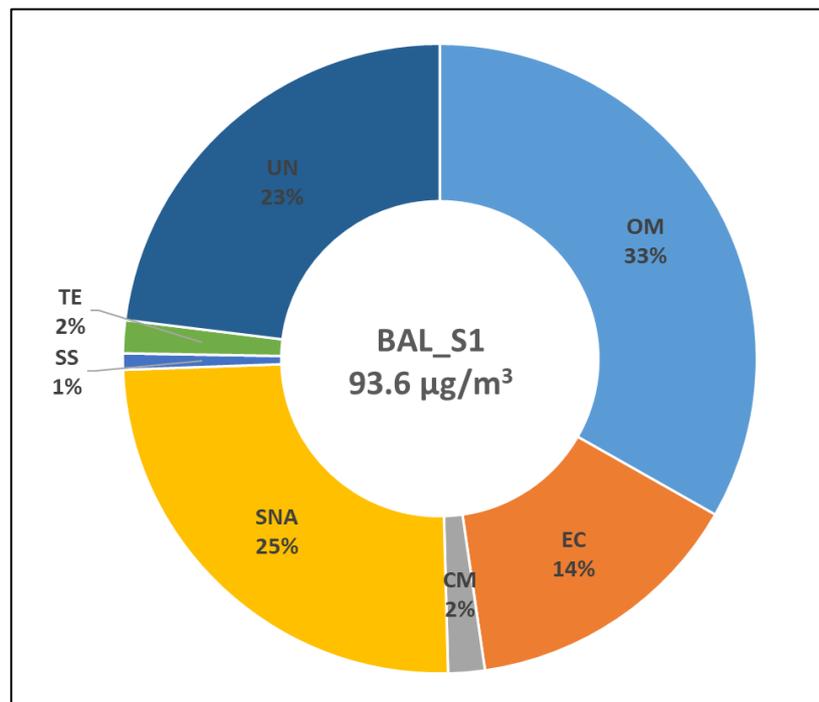


Figure 31: The reconstructed mass of $\text{PM}_{2.5}$ at S1 i.e. Jyoti Hospital in Balasore region during the winter season

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

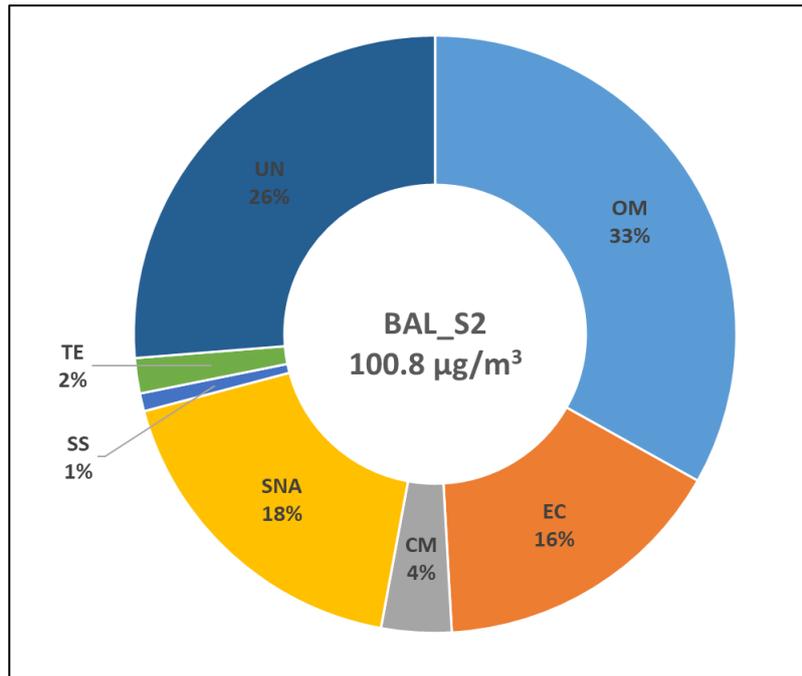


Figure 32: The reconstructed mass of PM_{2.5} at S2 i.e. RO Office in Balasore region during the winter season

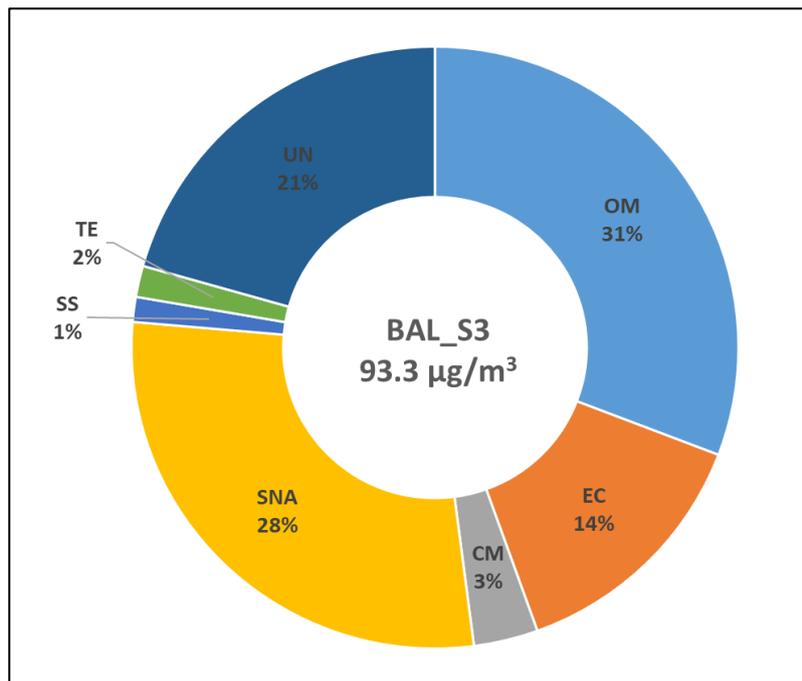


Figure 33: The reconstructed mass of PM_{2.5} at S3 i.e. District Collector Office in Balasore region during the winter season

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

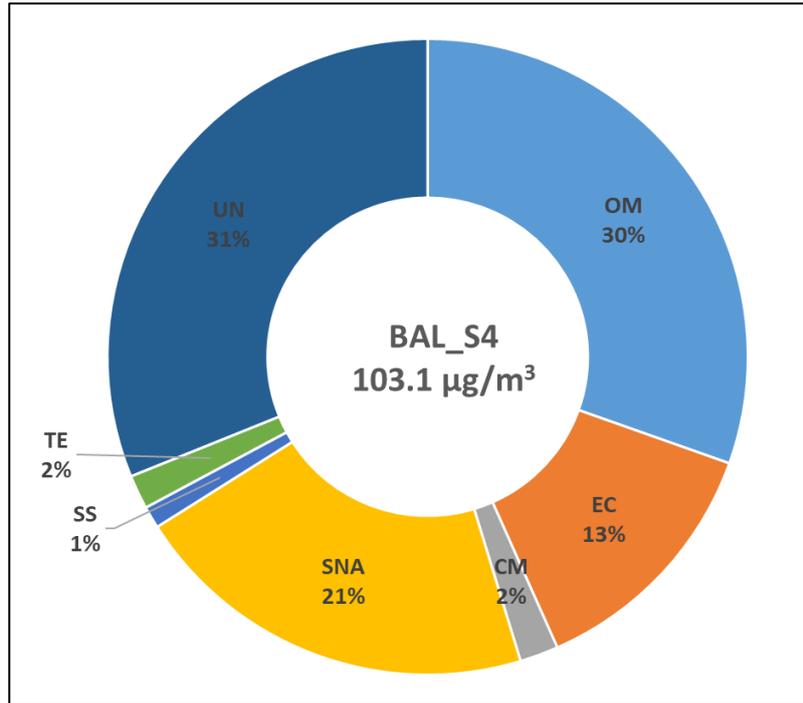


Figure 34: The reconstructed mass of $PM_{2.5}$ at S4 i.e. Municipality Office in Balasore region during the winter season

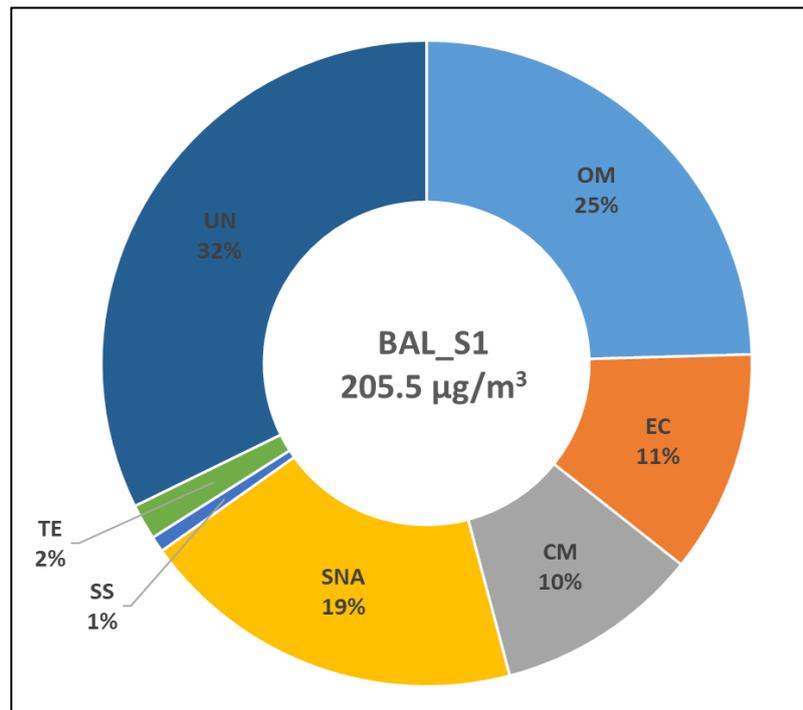


Figure 35: The reconstructed mass of PM_{10} at S1 i.e. Jyoti Hospital in Balasore region during the winter season.

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.

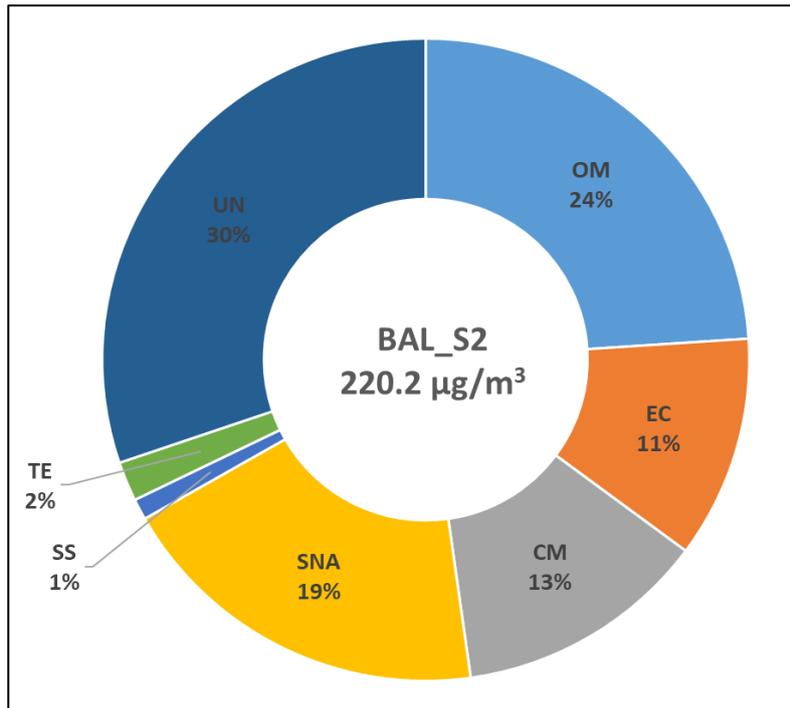


Figure 36: The reconstructed mass of PM₁₀ at S2 i.e. RO Office in Balasore region during the winter season

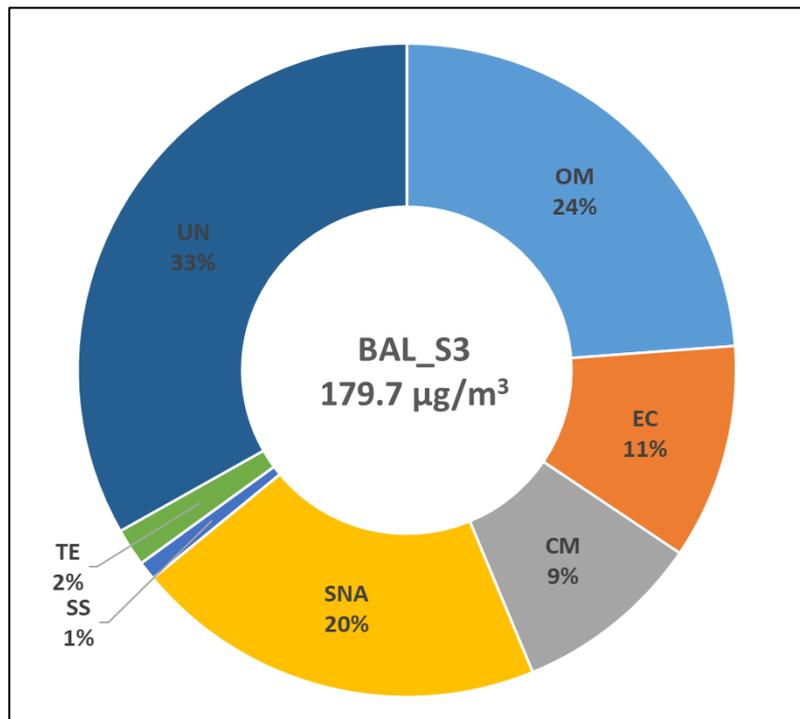


Figure 37: The reconstructed mass of PM₁₀ at S3 i.e. District Collector Office in Balasore region during the winter season

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

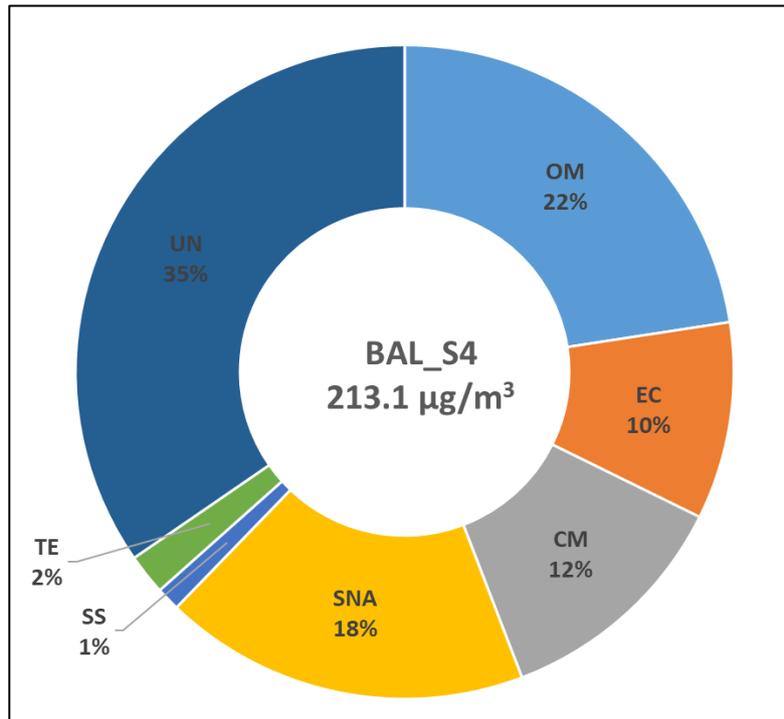


Figure 38: The reconstructed mass of PM₁₀ at S4 i.e. Municipality Office in Balasore region during the winter season.

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 Balasore region, respectively. Overall, the fractions of major chemical compositions followed the order of OM > EC > SNA > CM > TE > SS in PM_{2.5} whereas this order changed to OM > CM > EC > SNA > TE > SS in 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 29.2 to 40.5% in PM_{2.5} and 18.7 to 30.6% in PM₁₀. The seasonal mean OM concentrations in the summer season ranged from 7.2 to 8.8 µg/m³ in PM_{2.5} while it ranged from 10.0 to 14.5 µg/m³ in PM₁₀.

Crustal Mass (CM) is the most important contributor to coarse fraction i.e. PM₁₀ during summer season. The seasonal mean contributions from CM varied from 5.3 to 6.6% in PM_{2.5} while it varied from 12.9 to 25.7% in PM₁₀. The seasonal mean CM concentrations in PM₁₀ varied from a minimum of 6.2 to 19.9 µg/m³ in PM₁₀. In contrast, the CM concentrations in fine fraction i.e. PM_{2.5} were relatively lower and ranged from 1.3 to 1.6 µg/m³.

Secondary inorganic aerosols, represented as SNA, is the third and fourth major component observed in PM_{2.5} and PM₁₀ fractions during the summer season in Balasore region, respectively. The seasonal mean contributions from SNA varied from 13.3 to 18.8% in PM_{2.5} while it varied from 10.0 to 26.0% in PM₁₀. The seasonal mean SNA concentrations ranged from 2.2 to 4.6 µg/m³ in PM_{2.5} whereas it ranged from 5.0 to 13.8 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 11.4 and 14.1% in PM_{2.5} while it ranged between 6.6 and 9.9% in PM₁₀. The daily averaged elemental carbon (EC) concentrations during summer season varied from 2.6 to 3.9 µg/m³ in PM_{2.5} whereas it ranged from 3.3 to 5.6 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 2.2 to 2.9%. The seasonal mean TE concentrations ranged from 0.6 to 1.2 µg/m³ and 1.1 to 2.2 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 Balasore region, with contributions ranging from 1.1 to 2.7%. The seasonal mean SS ranged from 0.3 to 0.5 µg/m³ in PM_{2.5} while it ranged from 0.6 to 1.0 µg/m³ in PM₁₀.

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

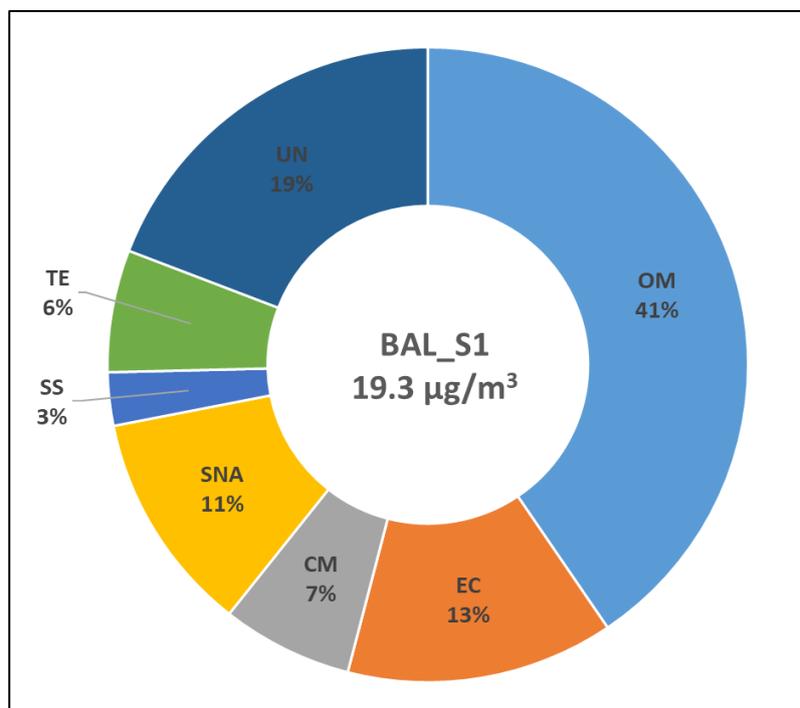


Figure 39: The reconstructed mass of PM_{2.5} at S1 i.e. Jyoti Hospital in Balasore region during the summer season

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

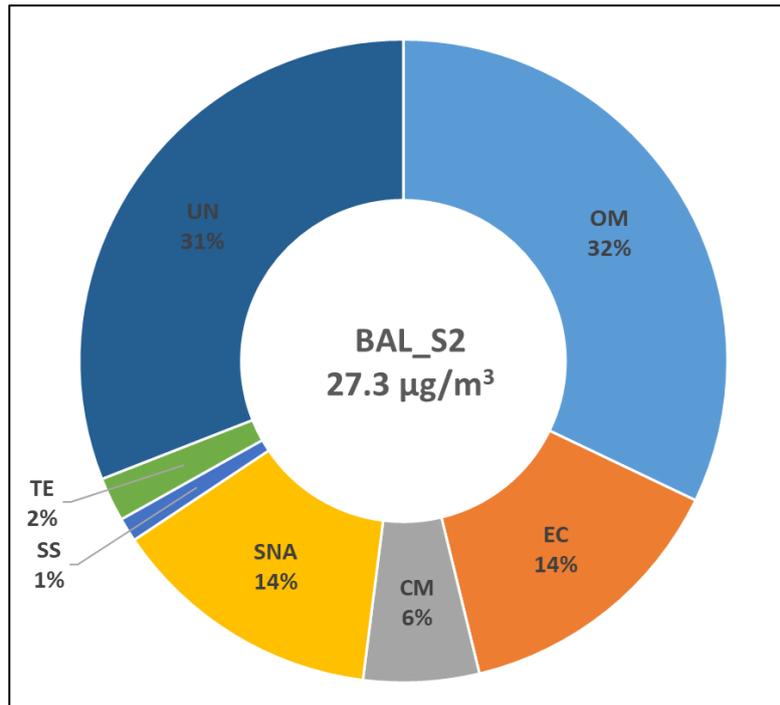


Figure 40: The reconstructed mass of PM_{2.5} at S2 i.e. RO Office in Balasore region during the summer season

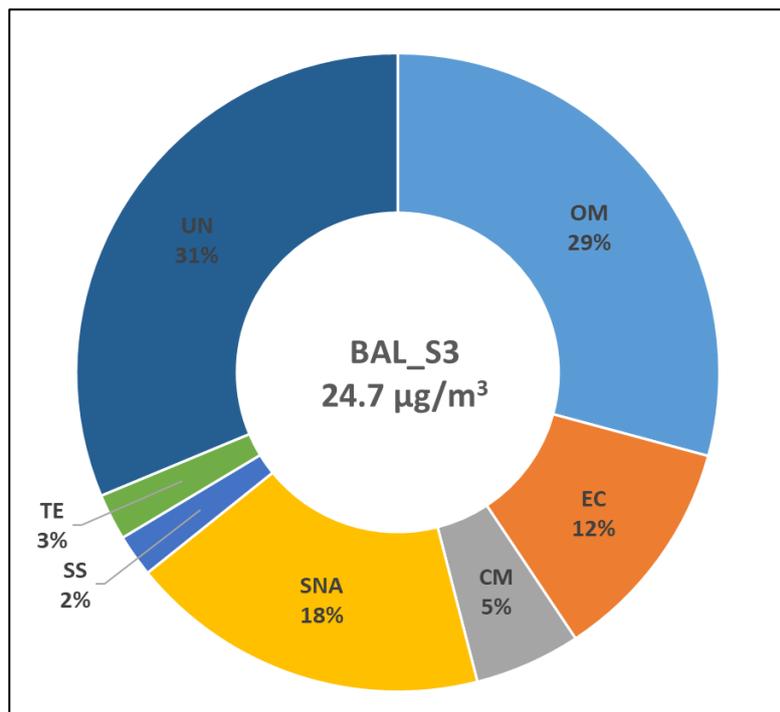


Figure 41: The reconstructed mass of PM_{2.5} at S3 i.e. District Collector Office in Balasore region during the summer season

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

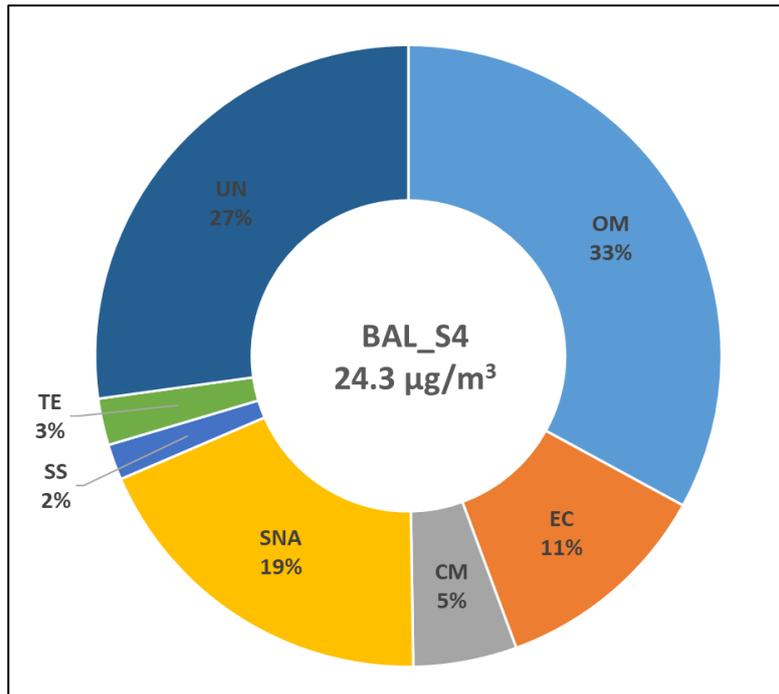


Figure 42: The reconstructed mass of $PM_{2.5}$ at S4 i.e. Municipality Office in Balasore region during the summer season

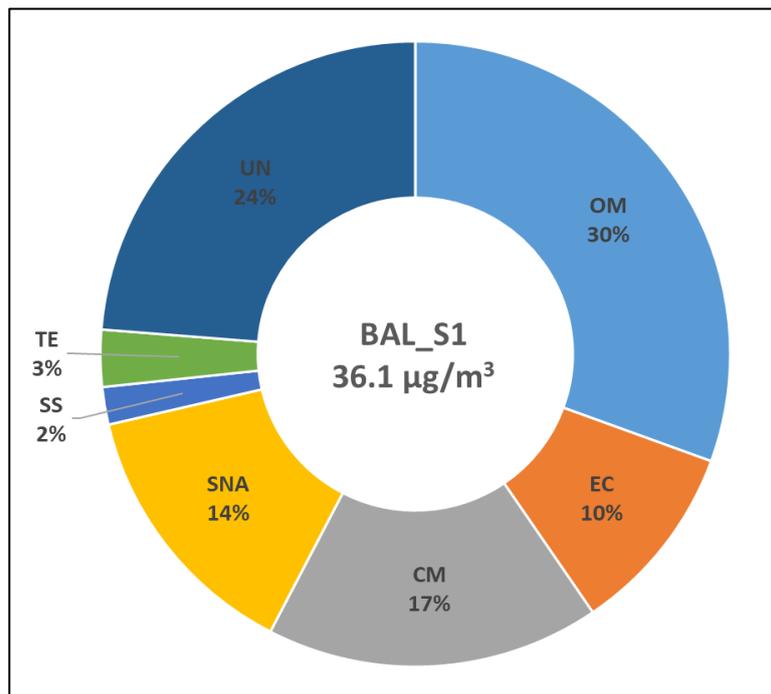


Figure 43: The reconstructed mass of PM_{10} at S1 i.e. Jyoti Hospital in Balasore region during the summer season.

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.

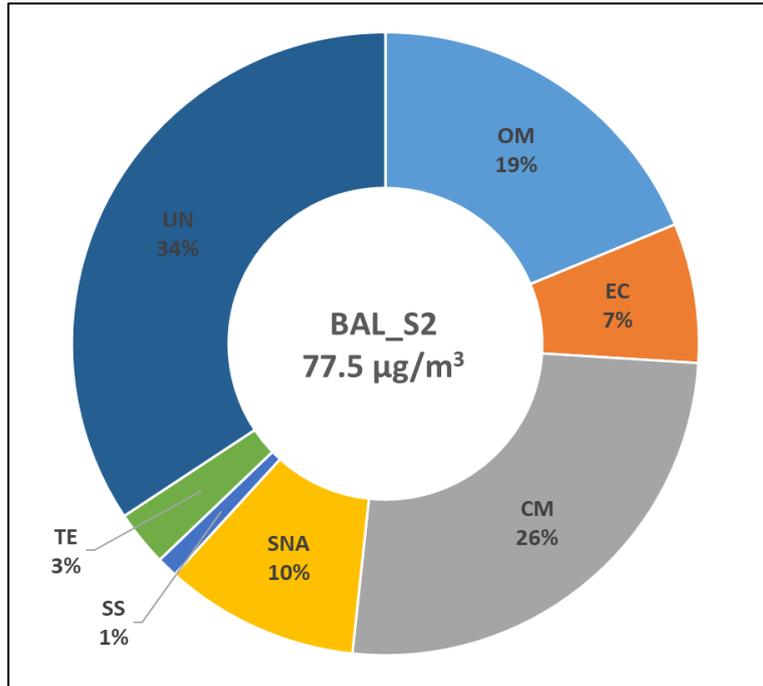


Figure 44: The reconstructed mass of PM₁₀ at S2 i.e. RO Office in Balasore region during the summer season

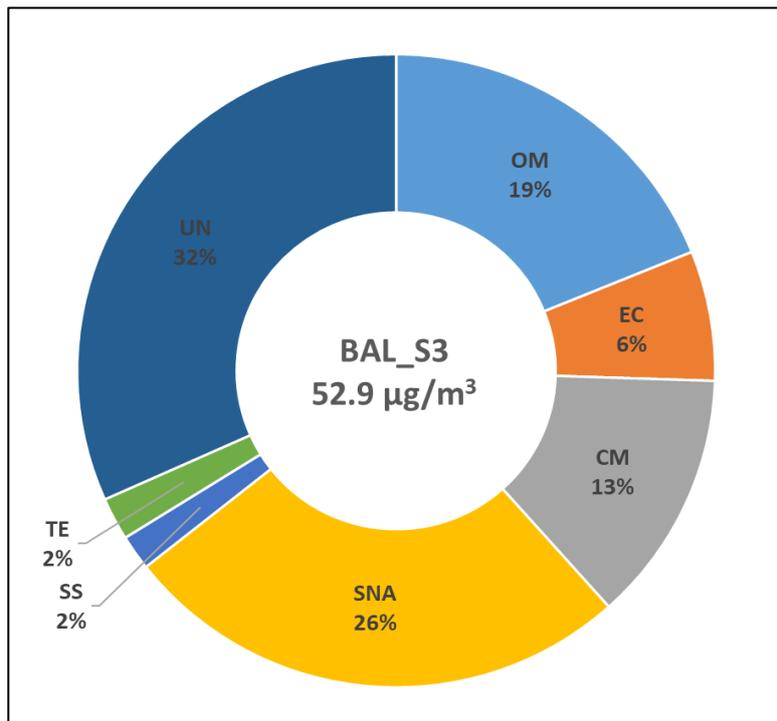


Figure 45: The reconstructed mass of PM₁₀ at S3 i.e. District Collector Office in Balasore region during the summer season

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.

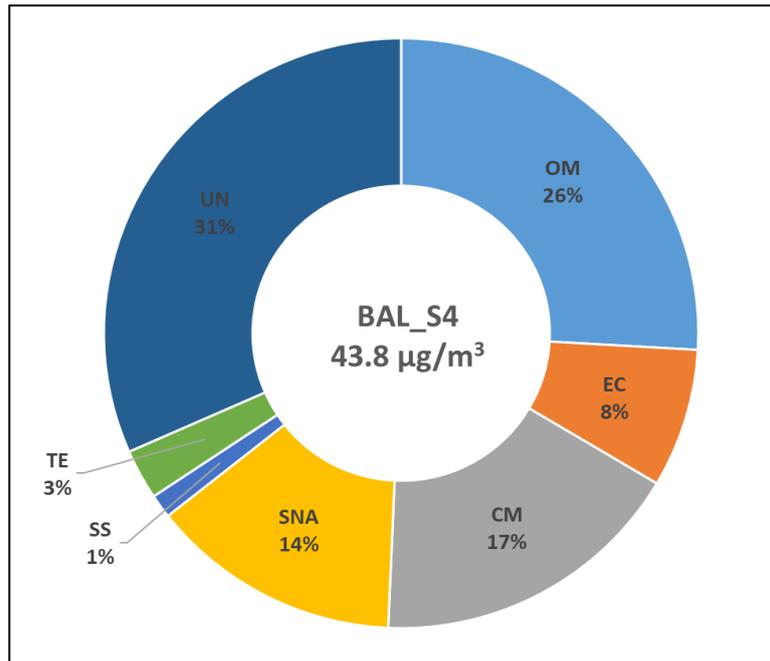


Figure 46: The reconstructed mass of PM₁₀ at S4 i.e. Municipality Office in Balasore region during the summer season.

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 Balasore region during the winter and summer seasons, respectively. Table 3 provides summary of average chemical ratios.

The OC/EC ratio indicate the origins of carbonaceous fraction (Salameh et al. 2014) and is commonly used to assess the impacts of fossil fuel emissions and aging, and the formation of secondary organic aerosols (Niu et al. 2016). The average OC/EC ratio in the present study is less than 2, indicates that carbonaceous fraction is originated from primary sources during the both winter and summer seasons. A good correlation ($R > 0.8$) is observed between OC and EC in both PM_{2.5} and PM₁₀ at sampling sites implies their primary source signature (Srinivas and Sarin, 2014). A relatively lower OC/EC ratio at S2 i.e. RO Office, 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 0.05 to 0.07 in PM_{2.5} and PM₁₀. Similarly, K⁺/EC ratios ranged from 0.07 to 0.10 in PM_{2.5} and PM₁₀. The summer season K⁺/OC ratios ranged from 0.04 to 0.08 PM_{2.5} and PM₁₀. Similarly, K⁺/EC ratios ranged from 0.06 to 0.16 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 0.51 to 0.66 in PM_{2.5} whereas it varied from 0.33 to 0.73 in PM₁₀. Similarly, summer-time NO₃⁻/SO₄⁻ ratios varied from 0.01 to 0.07 in PM_{2.5} whereas it varied from 0.14 to 0.25 in PM₁₀. Ratios less than unity indicates the dominance of stationary sources over mobile sources in Balasore region. Very low NO₃⁻/SO₄⁻ ratios (< 0.07 in PM_{2.5} and < 0.25 in

PM₁₀.) during the summer season, also suggest the possibility of long-range sulfate aerosol transport.

The average Cl⁻/Na⁺ ratio of seawater is 1.8 and in general a ratio greater than 10, indicates anthropogenic origin of Cl⁻ ions. In the present study, the winter season mean Cl⁻/Na⁺ ratio ranged from 2.46 to 3.05 in PM_{2.5} whereas it ranged from 3.40 to 4.19 in PM₁₀. The summer season mean Cl⁻/Na⁺ ratio ranged from 0.08 to 0.46 in PM_{2.5} whereas it ranged from 0.27 to 0.39 in PM₁₀. The ratios less than 10 at all sites, indicate the natural origin of Cl⁻ ions such as marine aerosols.

Additionally, to understand the neutralization reactions in detail, Degree of Neutralization (DON) suggested by Adams et al. (1999) is calculated (refer Eq. 4) for daily PM_{2.5} and PM₁₀ samples. In Eq. 5, [NH₄⁺], [SO₄⁻] and [NO₃⁻] represents the molar concentrations of ammonium, sulfate and nitrate ions, respectively observed over 24-h sampling. A DON < 1 indicates an ammonium deficiency; DON = 1 indicates complete neutralization whereas DON > 1 indicates the presence of surplus ammonium in the atmosphere. It is important to note that, DON is a daily averaged value calculated from integrated 24-h filter-based samples, there are likely to be diurnal variations in the actual acidity of sulfate and nitrate particles.

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

In winter season, the average DON values ranged from 0.98 to 1.13 in PM_{2.5} and 0.80 to 1.05 in PM₁₀ at four sampling locations in Balasore region. The winter-time ratios near unity indicate complete neutralization of aerosol particles.

In summer season, the average DON values ranged from 1.49 to 2.02 in PM_{2.5} and 0.58 to 1.15 in PM₁₀ at four sampling locations in Balasore region. It shows the presence of excess ammonium during the summer season, which in turn implies the basic nature of sulfate and nitrate particles.

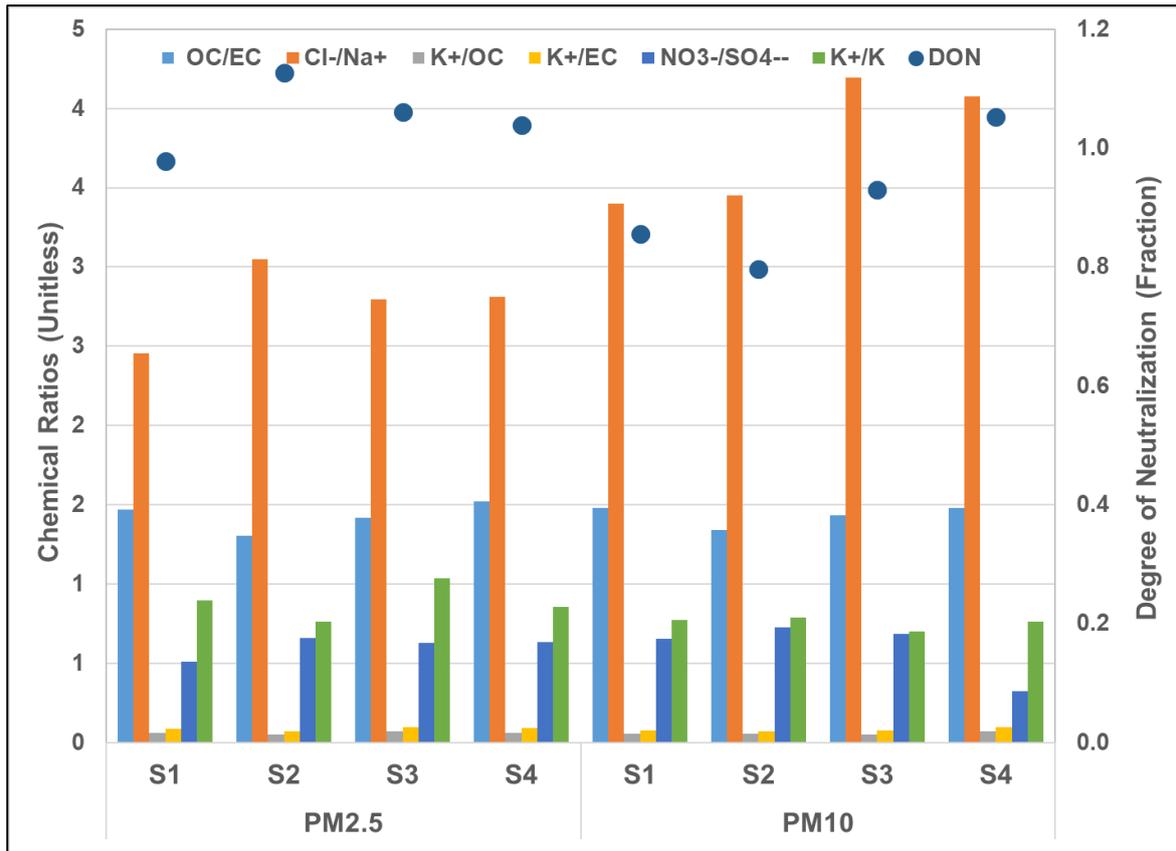


Figure 47: Chemical ratios i.e. OC to EC ratio, Cl⁻ to Na⁺ ratio, K⁺ to OC ratio, K⁺ to EC, NO₃⁻ to SO₄⁻⁻ ratio, and degree of neutralization (DON) observed at four sampling locations during the winter season in Balasore region.

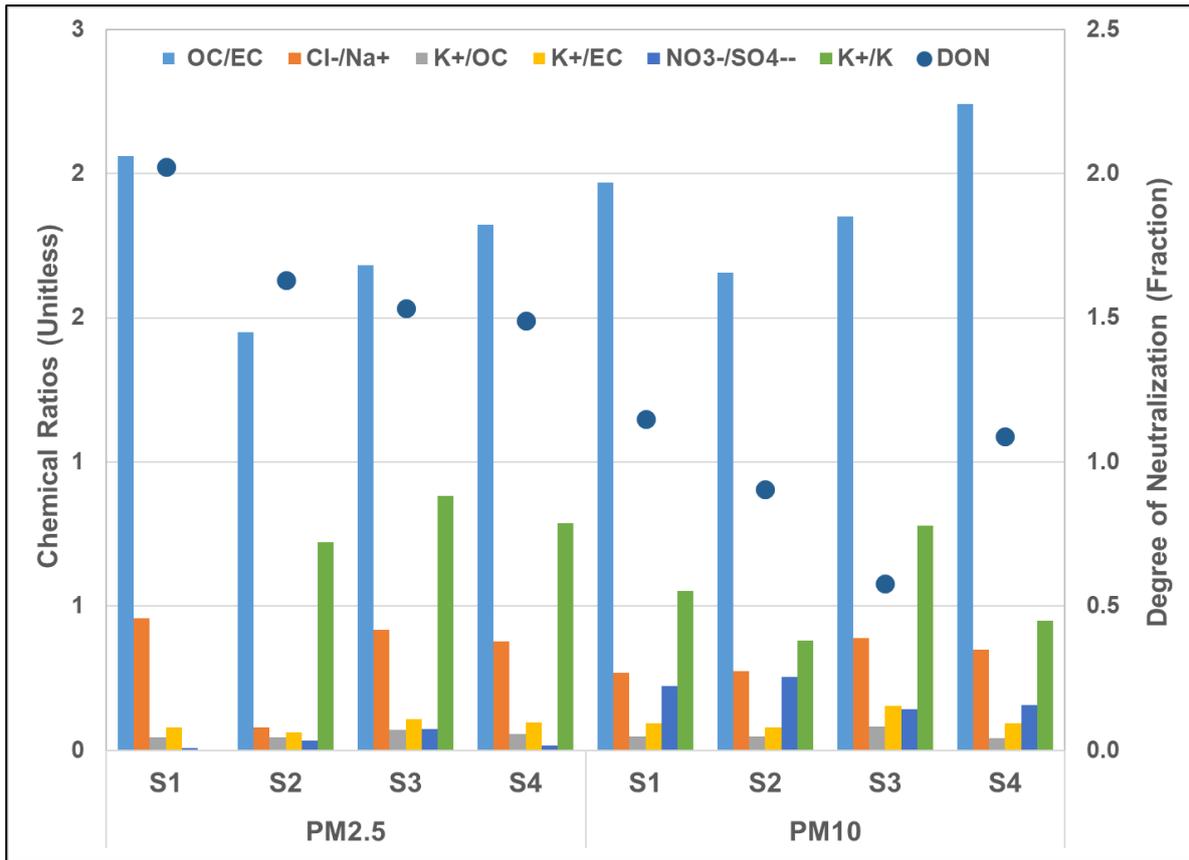


Figure 48: Chemical ratios i.e. OC to EC ratio, Cl⁻ to Na⁺ ratio, K⁺ to OC ratio, K⁺ to EC, NO₃⁻ to SO₄⁻⁻ ratio, and degree of neutralization (DON) observed at four sampling locations during the summer season in Balasore region.

Table 3 Summary of different chemical ratios observed at four sampling locations during the winter and summer seasons in Balasore region

Fraction	Site	OC/EC	Cl ⁻ /Na ⁺	K ⁺ /OC	K ⁺ /EC	NO ₃ ⁻ / SO ₄ ⁻	DON
Winter PM _{2.5}	S1	1.47	2.46	0.06	0.09	0.51	0.98
	S2	1.31	3.05	0.05	0.07	0.66	1.13
	S3	1.42	2.80	0.07	0.10	0.63	1.06
	S4	1.52	2.81	0.06	0.09	0.63	1.04
Winter PM ₁₀	S1	1.48	3.40	0.06	0.08	0.66	0.86
	S2	1.34	3.45	0.06	0.07	0.73	0.80
	S3	1.43	4.19	0.05	0.08	0.69	0.93
	S4	1.48	4.08	0.07	0.10	0.33	1.05
Summer PM _{2.5}	S1	2.06	0.46	0.05	0.08	0.01	2.02
	S2	1.45	0.08	0.04	0.06	0.03	1.63
	S3	1.68	0.42	0.07	0.11	0.07	1.53
	S4	1.82	0.38	0.06	0.10	0.02	1.49
Summer PM ₁₀	S1	1.97	0.27	0.05	0.10	0.22	1.15
	S2	1.66	0.28	0.05	0.08	0.25	0.91
	S3	1.85	0.39	0.08	0.16	0.14	0.58
	S4	2.24	0.35	0.04	0.09	0.16	1.09

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 Balasore region. Five pollution sources were apportioned using the average concentration data including i) transport (TRAN), ii) road and construction dust (DUST), iii) biomass burning (BCOM), iv) industry and thermal powerplants and fugitive dust (INDU) and v) secondary aerosols (SECY). The residual/un-apportioned mass is considered to be originating from the unidentified sources (UNID).

2.9.1. WINTER SEASON

2.9.1.1. Site 1: Jyoti Hospital

Fig. 49 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S1 i.e. Jyoti Hospital during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 93.6 µg/m³ and 205.5 µg/m³, respectively. The winter time PM_{2.5} mass was found to be dominated by secondary aerosols with highest contribution of 39.0%. The other sources of PM_{2.5} at this site were identified as dust (27.6%), biomass and solid waste combustion (12.3%), transport (8.2%), and industry (1.8%). The winter-time PM₁₀ concentrations at this site were also dominated by dust (37.3%), followed by, secondary aerosols (33.6%), biomass and solid waste combustion (6.7%), transport (4.4%), and industry (1.6%). About 11.2% and 16.3% 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.

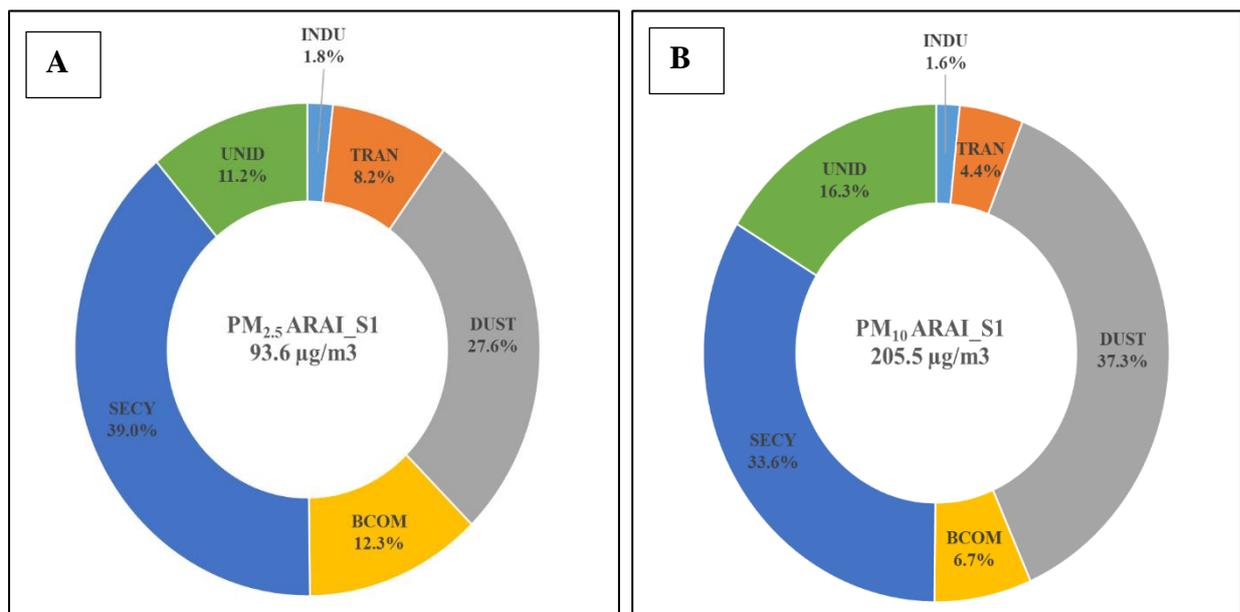


Figure 49 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S1 i.e. Jyoti Hospital during the winter season in Balasore region

2.9.1.2. Site 2: RO Office

Fig. 50 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S2 i.e. RO Office during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 110.8 µg/m³ and 220.2 µg/m³, respectively. The winter time PM_{2.5} mass was found to be dominated by secondary aerosols with highest contribution of 42.1%. The other sources of PM_{2.5} at this site were identified as dust (28.8%), biomass and solid waste combustion (13.0%),

transport (7.6%), and industry (1.4%). The winter-time PM₁₀ concentrations at this site were dominated by dust (41.7%), followed by secondary aerosols (29.7%), biomass and solid waste combustion (6.9%), transport (4.1%) and industry (1.3%). About 7.2% and 16.2% 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.

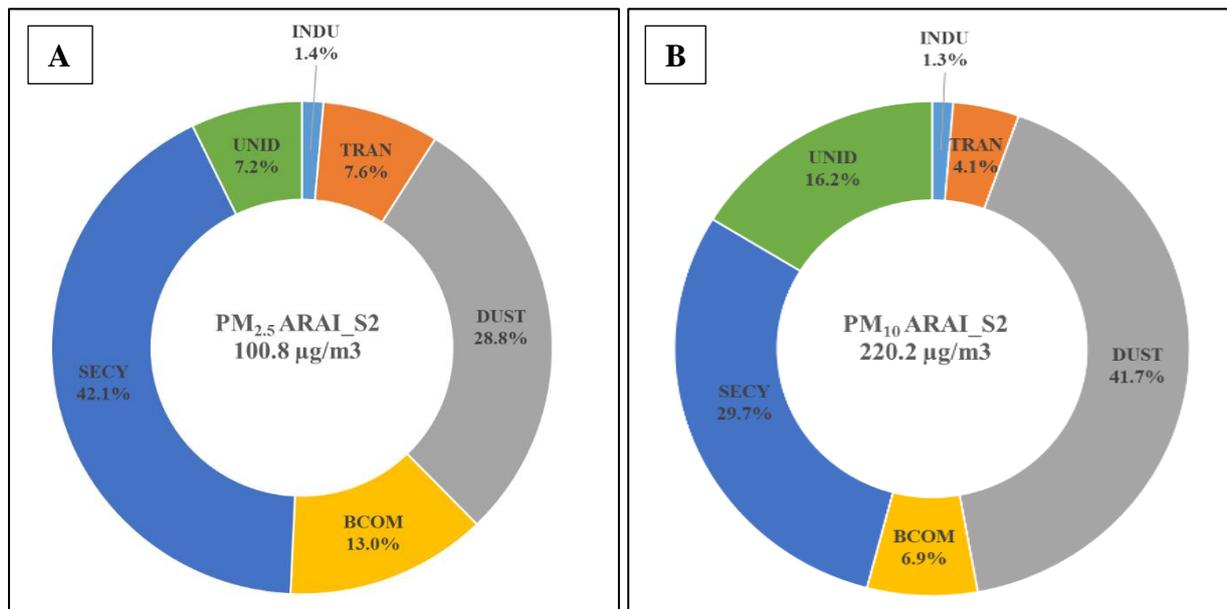


Figure 50 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S2 i.e. RO Office during winter season

2.9.1.3. Site 3: District Collector Office

Fig. 51 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S3 i.e. District Collector Office during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 93.3 µg/m³ and 179.7 µg/m³, respectively. The winter time PM_{2.5} mass was found to be dominated by secondary aerosols with highest contribution of 36.7%. The other sources of PM_{2.5} at this site were identified as biomass and solid waste combustion (26.5%), dust (21.0%), transport (7.0%), and industry (6.0%). The winter-time PM₁₀ concentrations at this site were dominated by dust (35.1%), followed by secondary aerosols (27.8%), biomass and solid waste combustion (18.6%), industry (5.1%), and transport (4.4%). About 2.7% and 9.1% 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.

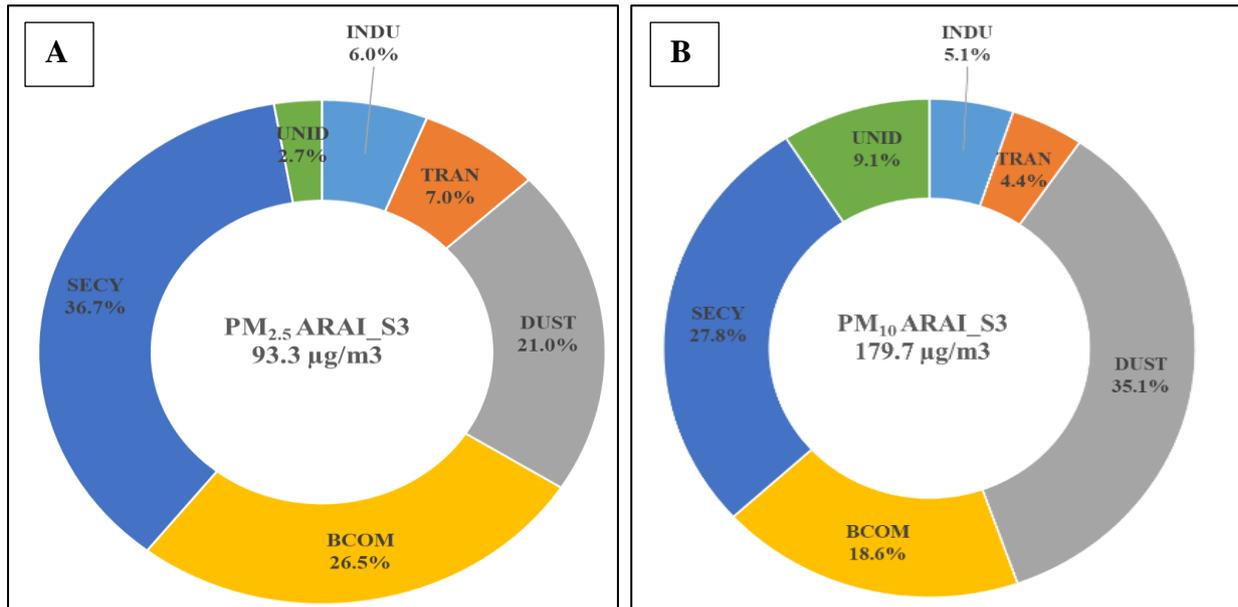


Figure 51 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S3 i.e. District Collector Office during winter season

2.9.1.4. Site 4: Municipality Office

Fig. 52 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S4 i.e. Municipality Office site during winter season. The winter season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 103.1 µg/m³ and 213.1 µg/m³, respectively. The winter time PM_{2.5} mass was found to be dominated by secondary aerosols with highest contribution of 42.3%. The other sources of PM_{2.5} at this site were identified as biomass and solid waste combustion (23.7%), dust (19.2%), transport (7.6%), and industry (5.1%). The winter-time PM₁₀ concentrations at this site were dominated by dust (32.0%), followed by secondary aerosols (31.8%), biomass and solid waste combustion (17.2%), transport (4.9%) and industry (4.2%). About 2.1% and 9.9% 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.

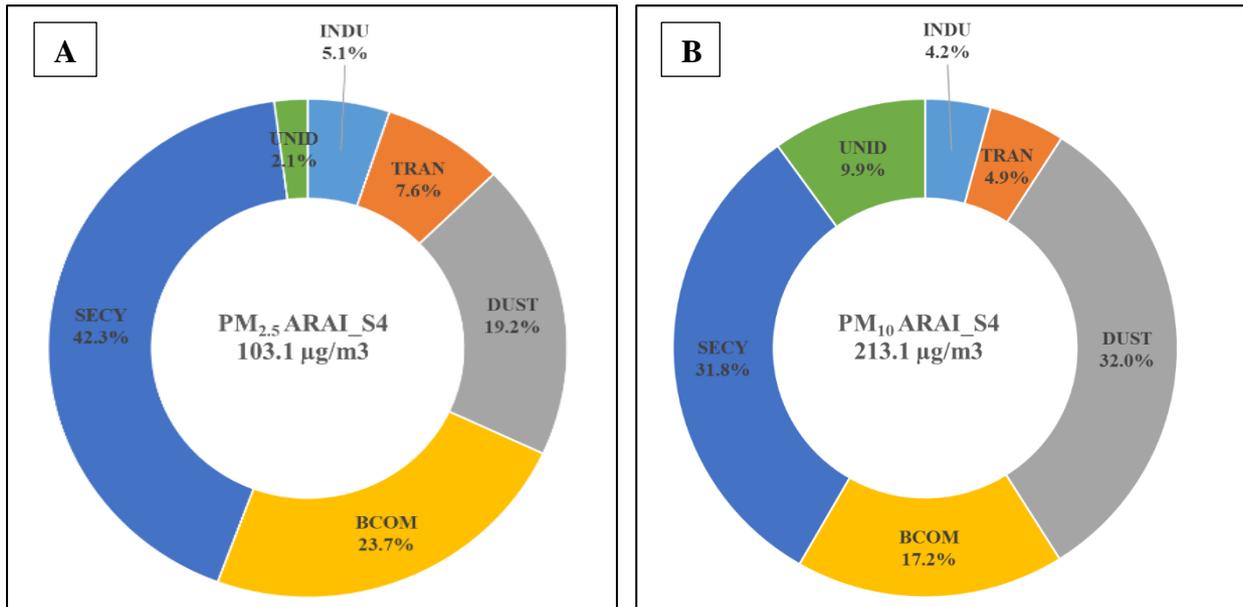


Figure 52 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S4 i.e. Municipality Office during winter season

2.9.2. SUMMMER SEASON

2.9.2.1. Site 1: Jyoti Hospital

Fig. 53 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S1 i.e. Jyoti Hospital during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 19.3 µg/m³ and 36.1 µg/m³, respectively. The summer time PM_{2.5} mass was found to be dominated by secondary aerosols with highest contribution of 27.2%. The other sources of PM_{2.5} at this site were identified as dust (19.8%), biomass and solid waste combustion (17.5%), transport (7.6%), and industry (0.8%). The summer-time PM₁₀ concentrations at this site were dominated by dust (44.2%), followed by, secondary aerosols (22.8%), biomass and solid waste combustion (12.1%), transport (4.3%), and. industry (0.7%). About 27.0% and 15.9% 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.

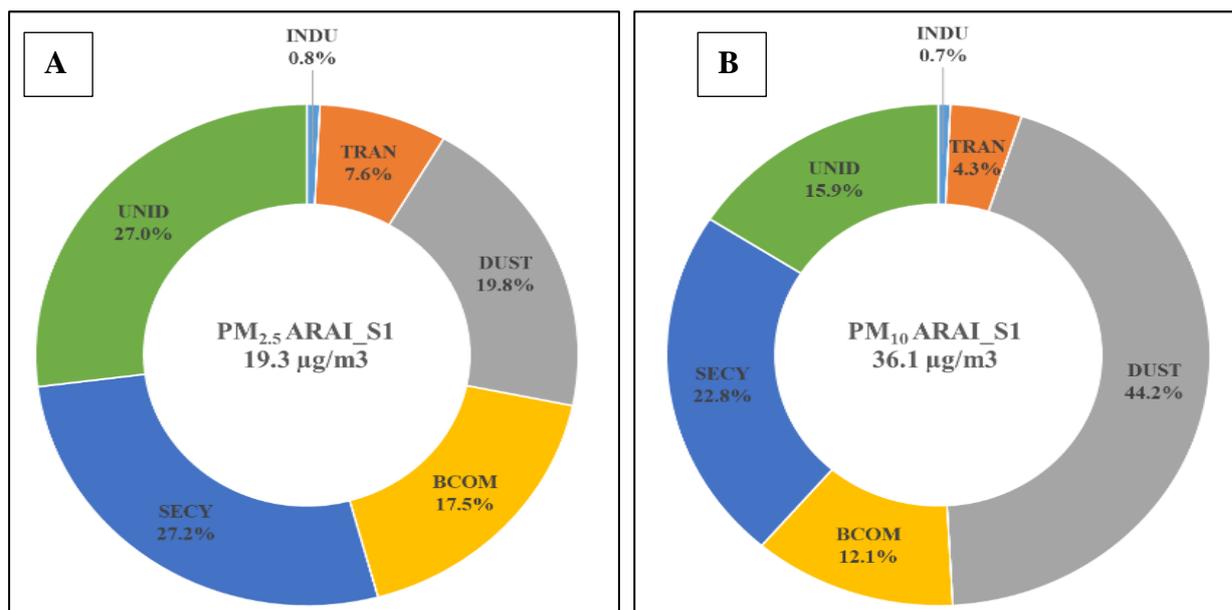


Figure 53 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S1 i.e. Jyoti Hospital during the summer season in Balasore region

2.9.2.2. Site 2: RO Office

Fig. 54 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S2 i.e. RO Office during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 27.3 µg/m³ and 77.5 µg/m³, respectively. The summer time PM_{2.5} mass was found to be dominated by dusty sources with highest contribution of 24.5%. The other sources of PM_{2.5} at this site were identified as secondary aerosols (21.2%), biomass and solid waste combustion (19.8%), transport (9.0%), and industry (1.2%). The summer-time PM₁₀ concentrations at this site were also dominated by dust (45.7%), followed by secondary aerosols (14.5%), biomass and solid waste combustion (11.3%), transport (4.5%), and industry (1.5%). About 24.3% and 21.9% 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.

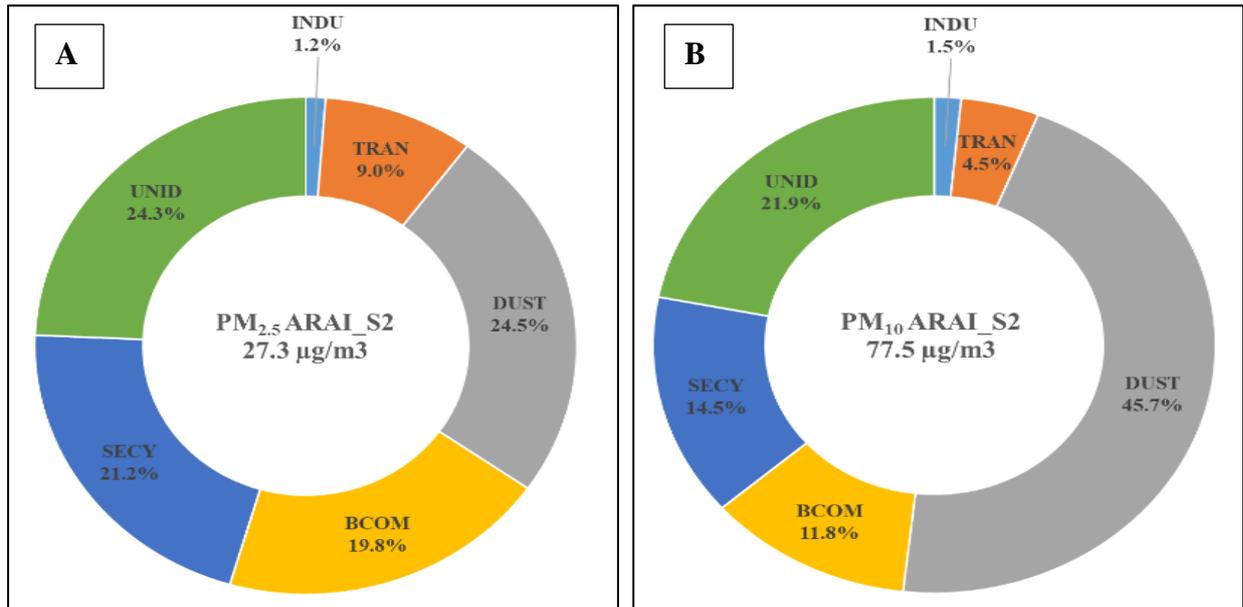


Figure 54 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S2 i.e. RO Office during summer season

2.9.2.3. Site 3: District Collector Office

Fig. 55 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S3 i.e. District Collector Office during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 24.7 µg/m³ and 52.9 µg/m³, respectively. The summer time PM_{2.5} mass was found to be dominated by biomass and solid waste combustion with highest contribution of 25.2%. The other sources of PM_{2.5} at this site were identified as secondary aerosols (20.9%), dusty (19.6%), transport (17.4%) and industry (5.0%). The summer-time PM₁₀ concentrations at this site were dominated by dust (34.6%), followed by biomass and solid waste combustion (22.8%), secondary aerosols (20.4%), transport (5.1%) and industry (4.4%). About 11.8% and 7.0% 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.

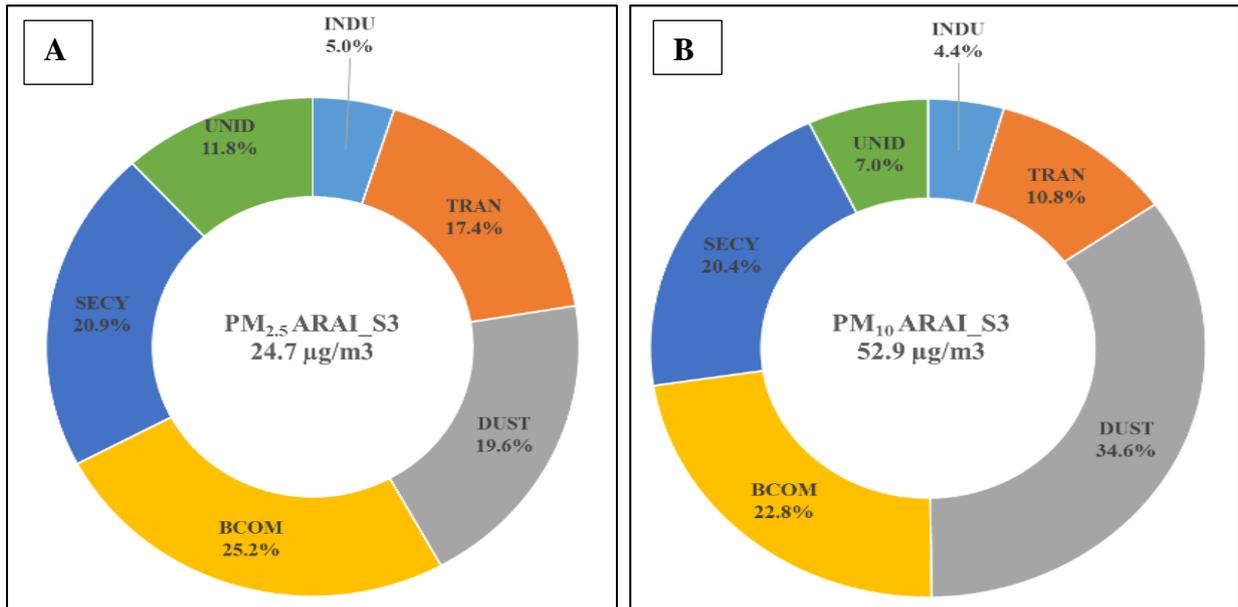


Figure 55 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S3 i.e. District Collector Office during summer season

2.9.2.4. Site 4: Municipality Office

Fig. 56 shows the sectoral source contributions to PM_{2.5} and PM₁₀ at S4 i.e. Municipality Office site during summer season. The summer season mean modelled PM_{2.5} and PM₁₀ concentrations at this site were 24.3 µg/m³ and 43.8 µg/m³, respectively. The summer time PM_{2.5} mass was found to be dominated by secondary aerosols with highest contribution of 26.5%. The other sources of PM_{2.5} at this site were identified as biomass and solid waste combustion (16.6%), transport (16.9%), dust (11.3%) and industry (2.5%). The summer-time PM₁₀ concentrations at this site were dominated by dust, followed by secondary aerosols (25.5%), biomass and solid waste combustion (14.3%), transport (11.9%) and industries (2.4%). About 26.2% and 11.4% 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.

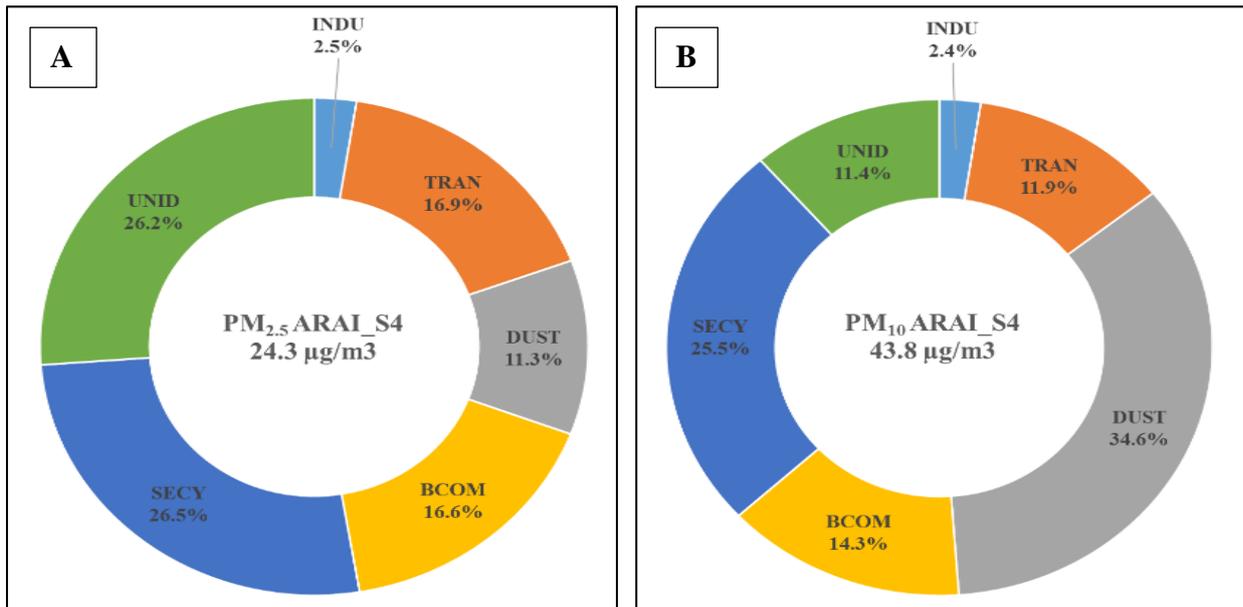


Figure 56 Sectoral source contributions to PM_{2.5} (A) and PM₁₀ (B) at S4 i.e. Municipality Office during summer season

2.9.3. City-level source contribution analysis

The city-level average source contributions were determined, using the site-wise source contribution estimates obtained in the previous section. Fig. 57 and 58 presents the average source contributions to ambient PM_{2.5} and PM₁₀ at Balasore during winter and summer seasons, respectively.

Overall, the winter-time PM_{2.5} mass at Balasore (Fig. 57) are found to be dominated by secondary aerosols sector with highest contribution of 40.0%. The other sources of PM_{2.5} at Balasore are identified as dust (24.1%), solid waste and biomass combustion (18.9%), transport (7.6%), and industry (3.6%). Similarly, the winter-time PM₁₀ mass at Balasore is found to be dominated by dust (36.5%), followed by secondary aerosols (30.7%), solid waste and biomass combustion (12.4%), transport (4.5%), and industries (3.1%). Additionally, about 5.8% and 12.9% 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.

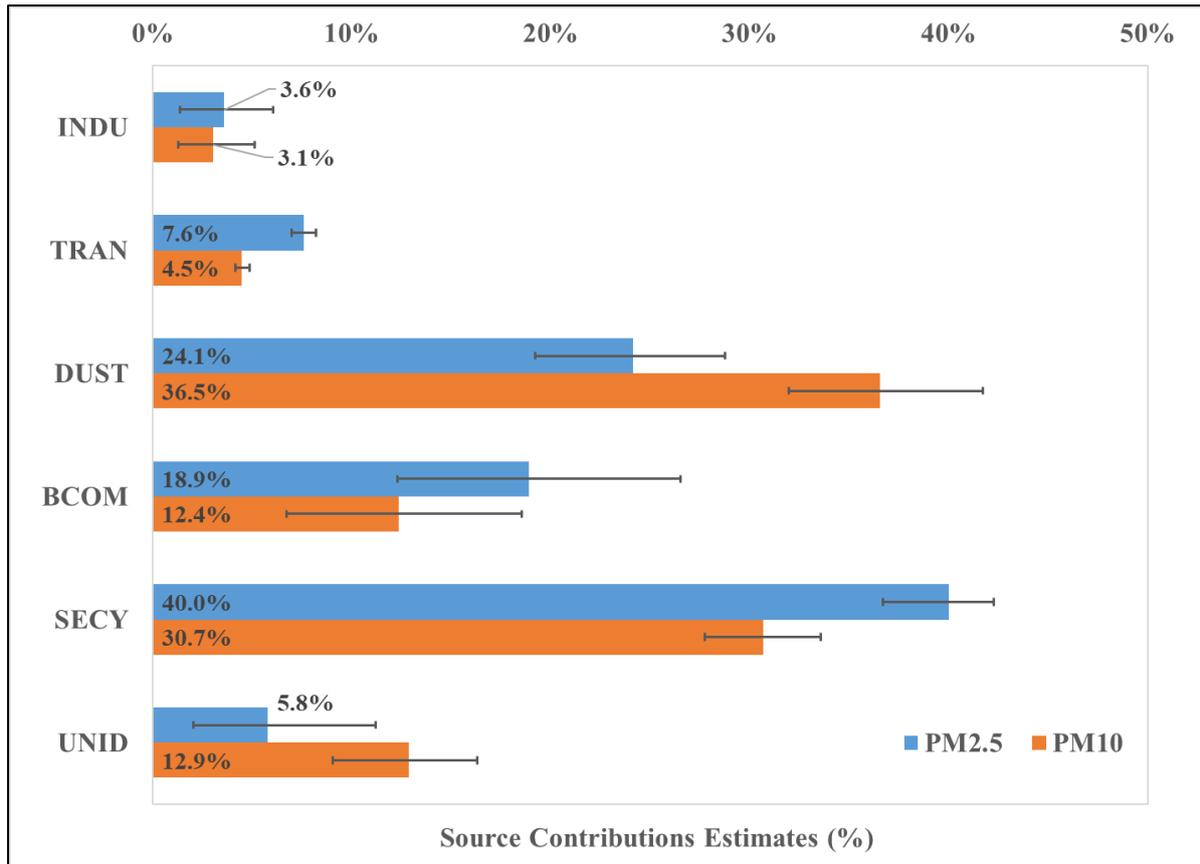


Figure 57 City-level source contribution estimates (SCE) for Balasore region using CMB receptor model during winter season

(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 four sampling sites.)

The summer-time PM_{2.5} mass at Balasore (Fig. 58) is found to be dominated by secondary aerosols with highest contribution of 23.9%. The other summer-time sources of PM_{2.5} at Balasore region are identified as solid waste and biomass combustion (19.8%), dust (18.8%), transport (12.7%), and industry (2.3%). Similarly, the summer-time PM₁₀ mass at Balasore is found to be dominated by dust (39.8%), followed by secondary aerosols (20.8%), solid waste and biomass combustion (15.3%), transport (5.0%), and industry (2.3%). Additionally, about 10.7% and 8.0% 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.

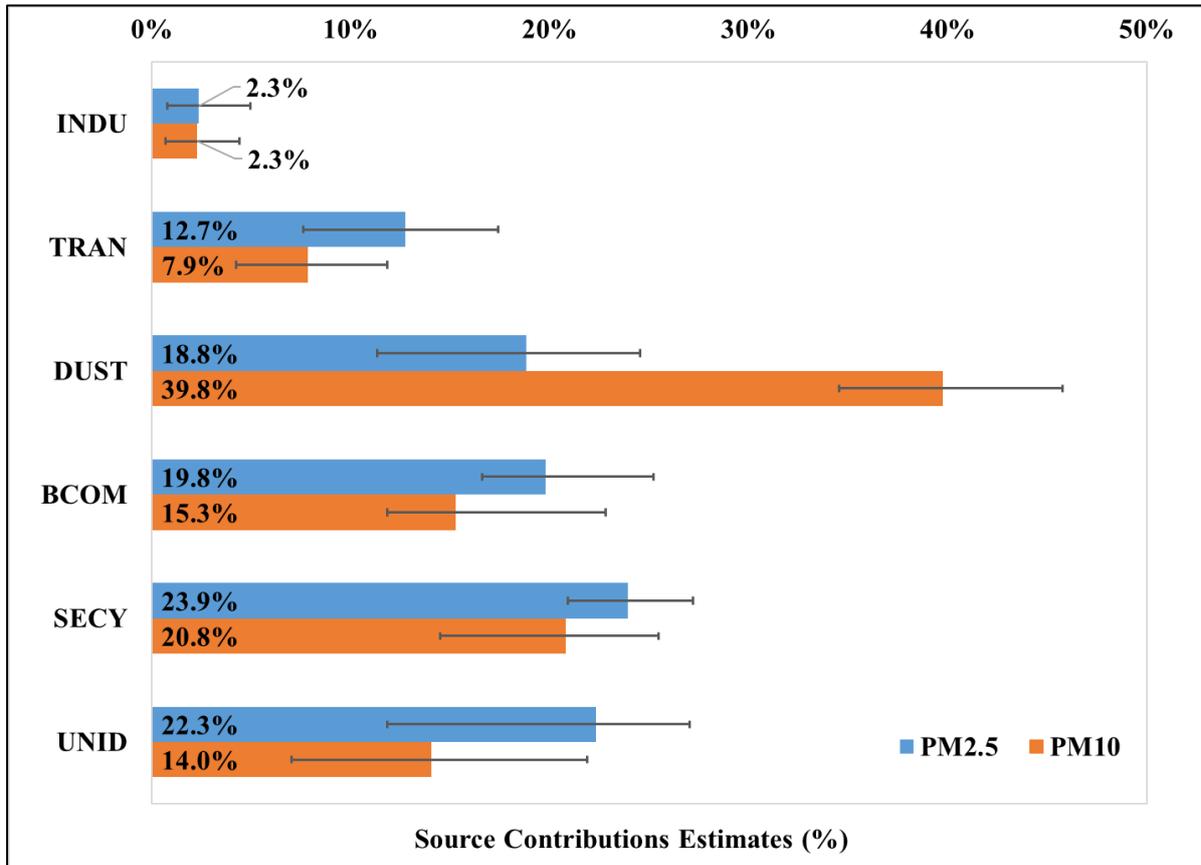


Figure 58 City-level source contribution estimates (SCE) for Balasore region using CMB receptor model during summer season (March 21 – April 7, 2023)

(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 four sampling sites.)

It is important to note that, despite being a small town with population less than 2 lakh and less air polluting activities such as traffic, major industries, etc., Balasore exhibited significantly higher ambient PM levels.

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: 2022) of air pollutant loads originating from eleven sectors in Balasore region. The scope of this study includes:

- Quantification of emission loads originating from sectors including: Transport, Re-suspended road dust, Residential, Open waste burning, Hotels, Restaurants and Bakeries, Construction, Diesel generators, Industries, Brick kilns, Crematoria and Fugitive emission in Balasore 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 Balasore region. The first phase of the emission inventory development involves research on previous emission inventories in the region, reconnaissance surveys, collection of secondary datasets. Based on this data analysis, air pollution sources in the study domain were identified. Once the air polluting sources in the study domain are identified, the primary data collection surveys were taken up for different sectors.

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

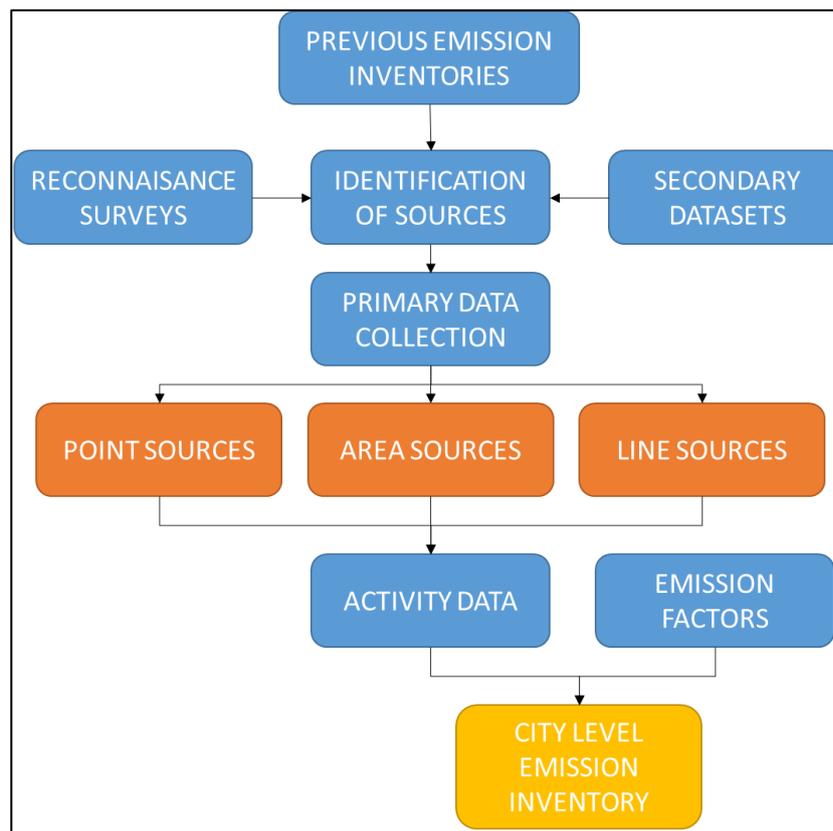


Figure 59: Approach adopted for emission inventory development at regional level

The study area was divided into high resolution grid cells at 2 X 2 km² grids using GIS tools. A total 54 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.

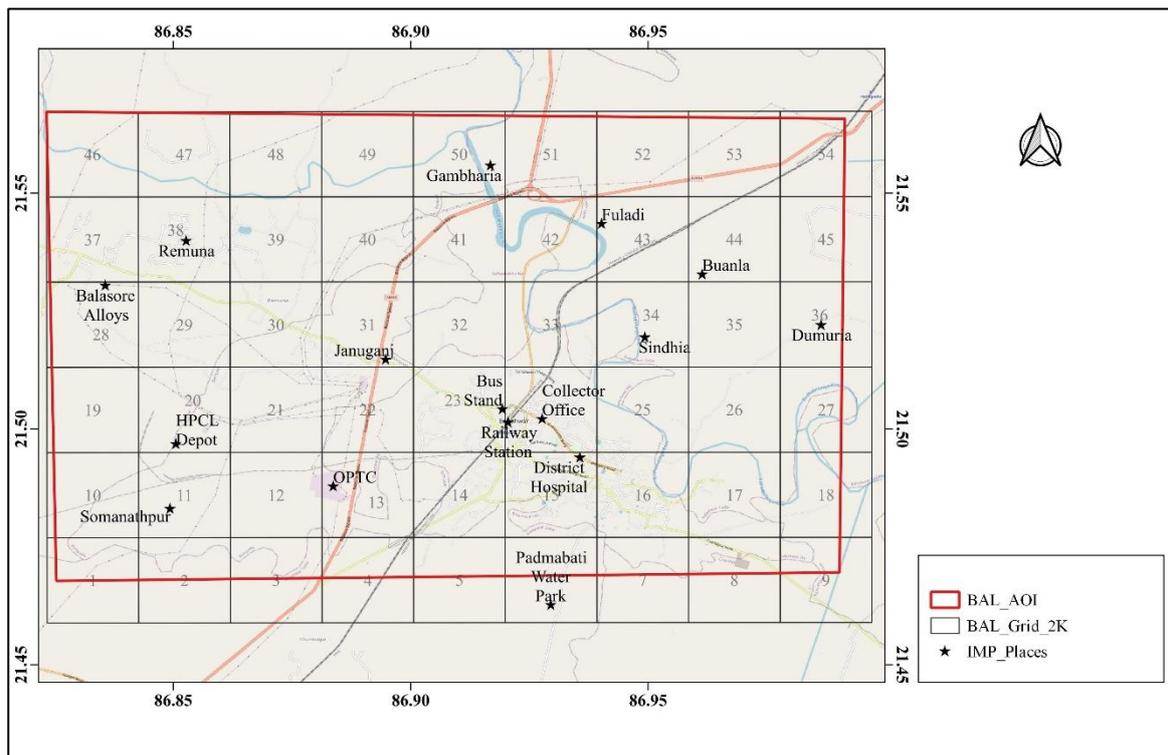


Figure 60: Map showing study area overlaid with emission inventory grids with horizontal spacing of 2 x 2 km²

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 4 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 4: Different air pollution sources inventorised in this study for Balasore region

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

Details of primary and secondary data collection surveys are provided in sectoral manner in subsequent sections. Air pollution sources were categorized into three main types i.e. point, area and line sources and details of sectors included in each type are provided in Table 4. 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 5 and 6 summarizes the primary and secondary data collection used in this study.

Table 5: 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 countsParking 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 6 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. 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):

$$\text{Transport Emissions} = \text{VKT} \times \text{EF}_{EX} \dots \dots \dots (7)$$

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

3.4.2.1. Road network digitization

Road network in the study area was digitized using Google Earth application (Fig. 60). Roads in Balasore region are classified into five categories viz. i) highways, ii) major roads, iii) intermediate roads, iv) minor roads and v) residential roads. After complete digitization, road lengths were calculated for each link in the network using GIS software. Category-wise gridded road lengths were also computed using GIS software.

3.4.2.2. Reconnaissance survey

A Reconnaissance survey was conducted in the Balasore 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 13 survey locations were identified in the Balasore region to perform the classified vehicle count surveys and 4 areas/localities around the sampling sites were selected for Parking lot surveys.

3.4.2.3. Traffic counts and vehicle fleet characteristics

Estimation of reasonably accurate vehicular emissions requires a good characterisation of the in-service vehicle fleet. Important characteristics of vehicle fleet include information on vehicle type, size, fuel type, age and emission control technologies. The historic vehicle registration data provides preliminary information vehicle type, size and fuel-type. The vehicle fleet in Balasore 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. 62 depicts the vehicle categories used in this study.

Traffic count surveys were carried out to obtain the information of on-road vehicles plying in the city, such as total number of vehicles, variation of vehicles on different road categories (major, minor and arterial), transit vehicles, temporal variations, etc. Traffic count surveys were conducted by manual counting by teams of surveyors. At each of the selected location, category-wise traffic count data is collected in single direction. The vehicles are counted during the peak hours i.e. 08:00 to 13:00 hours and 15:00 to 18:00 hours on selected weekdays and weekend during March, 2023 to April, 2023. Parking lot surveys were also carried out to understand the distribution of existing vehicular fleet as per model, vintage, technology, fuel mix, average daily distance travelled, occupancy, and mileage. Parking lot

surveys are carried out in 4 areas/localities around the selected sampling sites (S1-S4) in Balasore region during March, 2023 to April, 2023. Table 7 and 8 shows the details of locations of vehicle count surveys and parking lot surveys respectively.

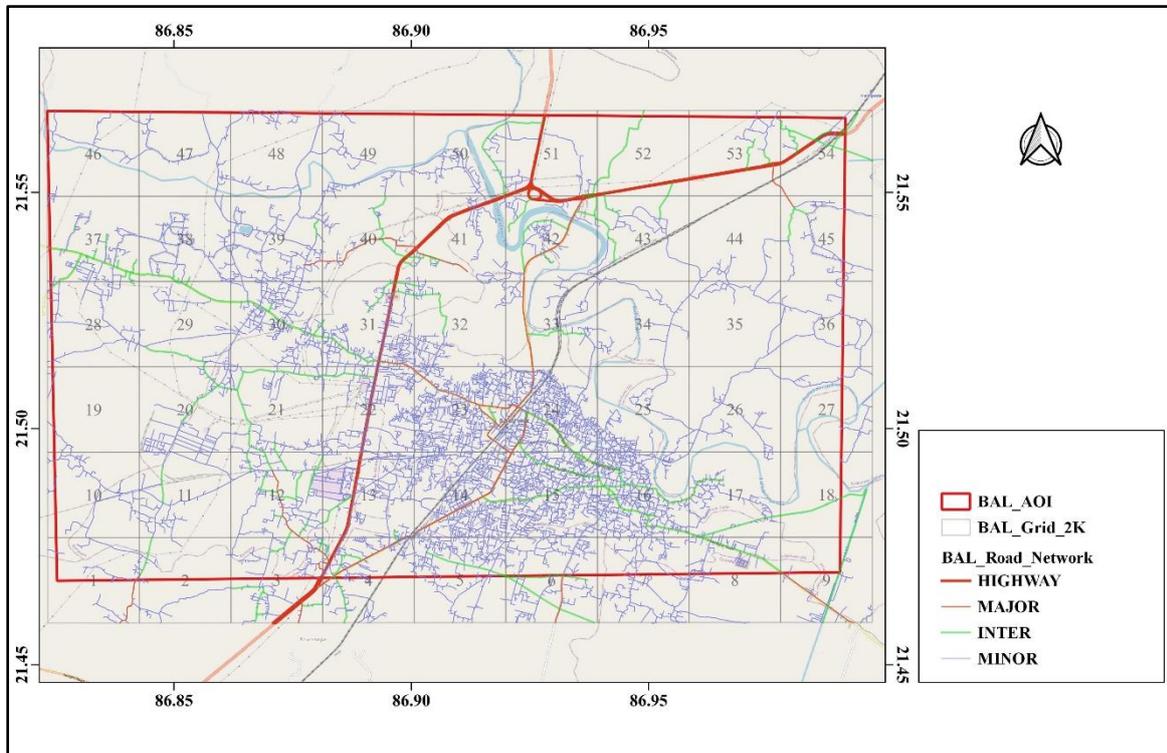


Figure 61: Map showing road network in Balasore region and surrounding areas digitized using OpenStreetMap and Google Earth Applications

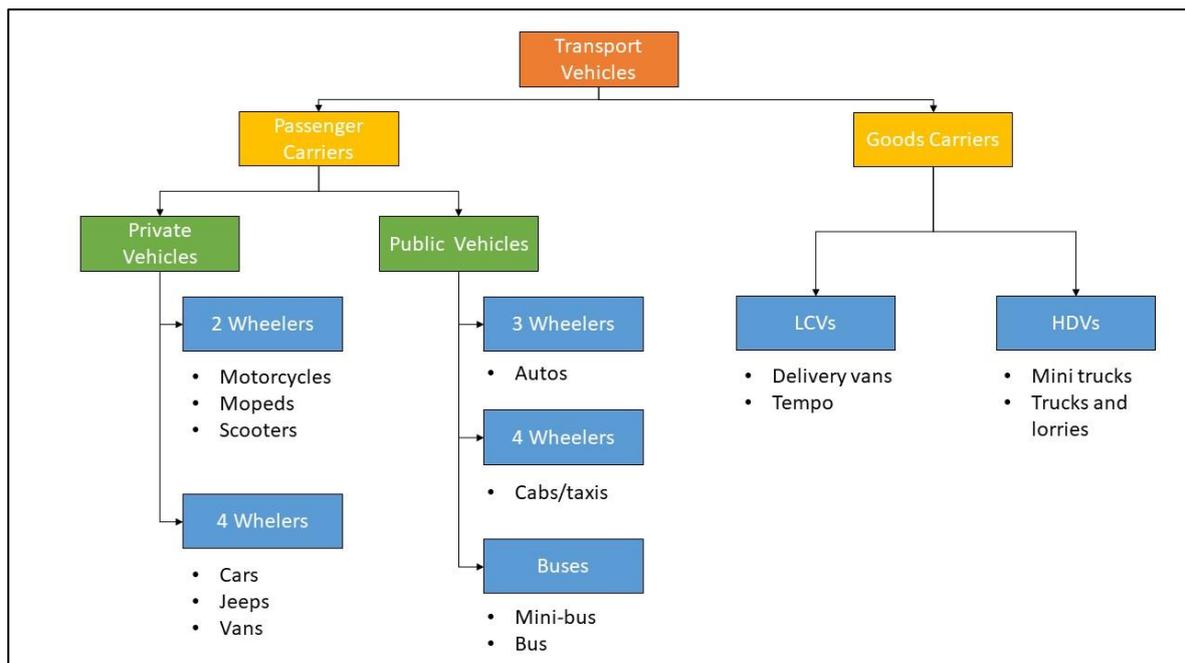


Figure 62: Vehicle categories used in this study

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 Balasore region. The data generated through road network mapping, vehicle count surveys, parking lot surveys, and vehicle registration analysis was used to calculate the vehicle kilometres 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 7: Locations of vehicle count surveys in Balasore region

Code	Road Type	Road Name	Latitude	Longitude
VC1	Minor	Bateswar Road	21.4889	86.9432
VC2	Major	Chandipur Road	21.4872	86.9413
VC3	Minor	Killa Pokhri Road	21.4902	86.9464
VC4	Highway	Cuttack Highway	21.4749	86.8845
VC5	Major	Basudevpur-Balasore Road	21.4728	86.8909
VC6	Intermediate	Arad Bazar Road	21.5083	86.9253
VC7	Major	Chatu Pacorda,OT Rd	21.4966	86.9222

Code	Road Type	Road Name	Latitude	Longitude
VC8	Major	Railway Colony	21.5048	86.9162
VC9	Minor	Kalidaspur	21.5116	86.9035
VC10	Major	Sidheswar Colony	21.5137	86.8984
VC11	Highway	Kolkata Highway	21.5118	86.8924
VC12	Minor	Purastampur	21.4671	86.8846
VC13	Intermediate	Phandi Chowk	21.5042	86.9249

Table 8 Locations of Parking Lot Surveys in Balasore region

Location No.	Area Name
P1	Jyoti Hospital, Karkora area
P2	Kalidaspur area
P3	Manikhamb area
P4	Municipality, old Balasore area

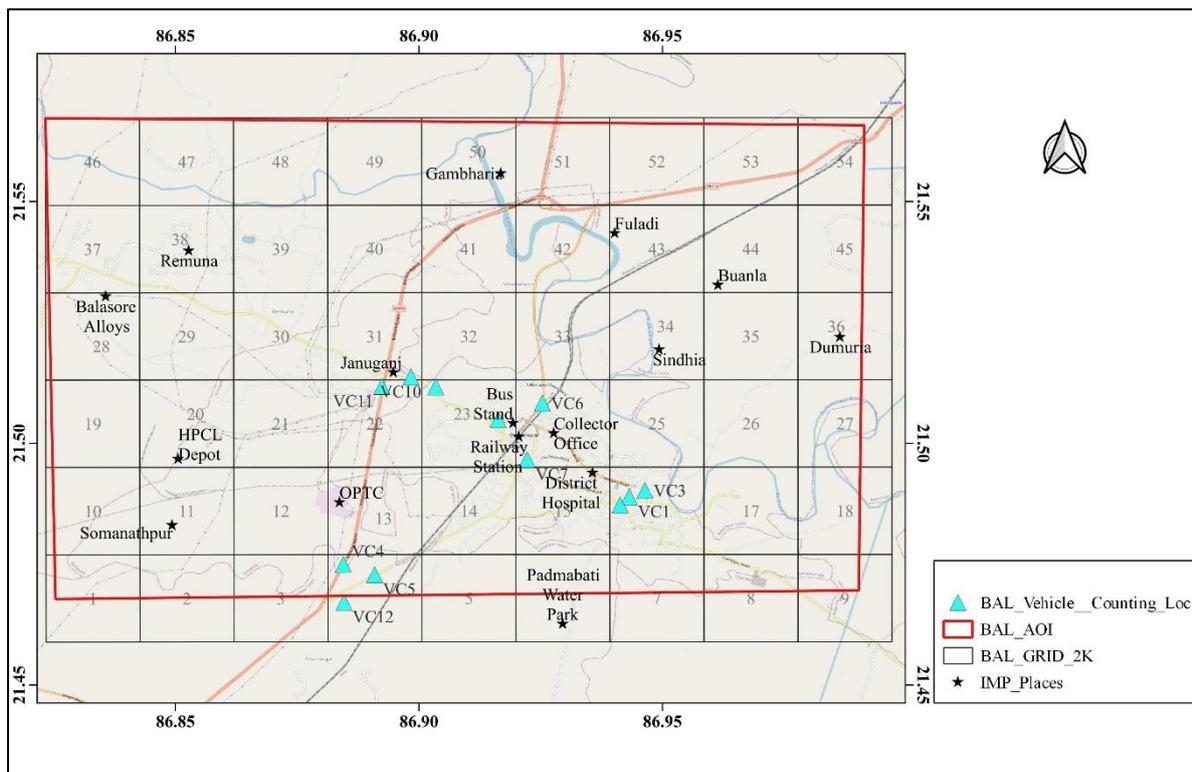


Figure 63: Map showing selected locations in Balasore region for vehicle counting surveys.

Fig. 64 presents the classified vehicle count observed at different types of roads in region. Major roads such as VC7, VC8, and VC10 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 more or less similar, on both weekdays and weekend.

Fig. 65 depicts the observed percentage distribution of vehicles according to Bharat standards in Balasore region. A total of 575 vehicles were surveyed in the region during the primary surveys. The BS-III category vehicles are observed to be maximum (53.1%) followed by BS-IV (21.7%), BS-VI (11.0%), BS-II (9.5%), and BS-I (4.2%).

Fig. 66 shows the estimated daily vehicle kilometres travelled by each category of vehicles in the Balasore region. The daily VKT is estimated to be 102.8 lakh km and is dominated by two wheelers (86.69%) followed by passenger cars (4.47%), LCV (3.21%). All other vehicle categories together constitute about 5.63% of the daily VKT in Balasore region.

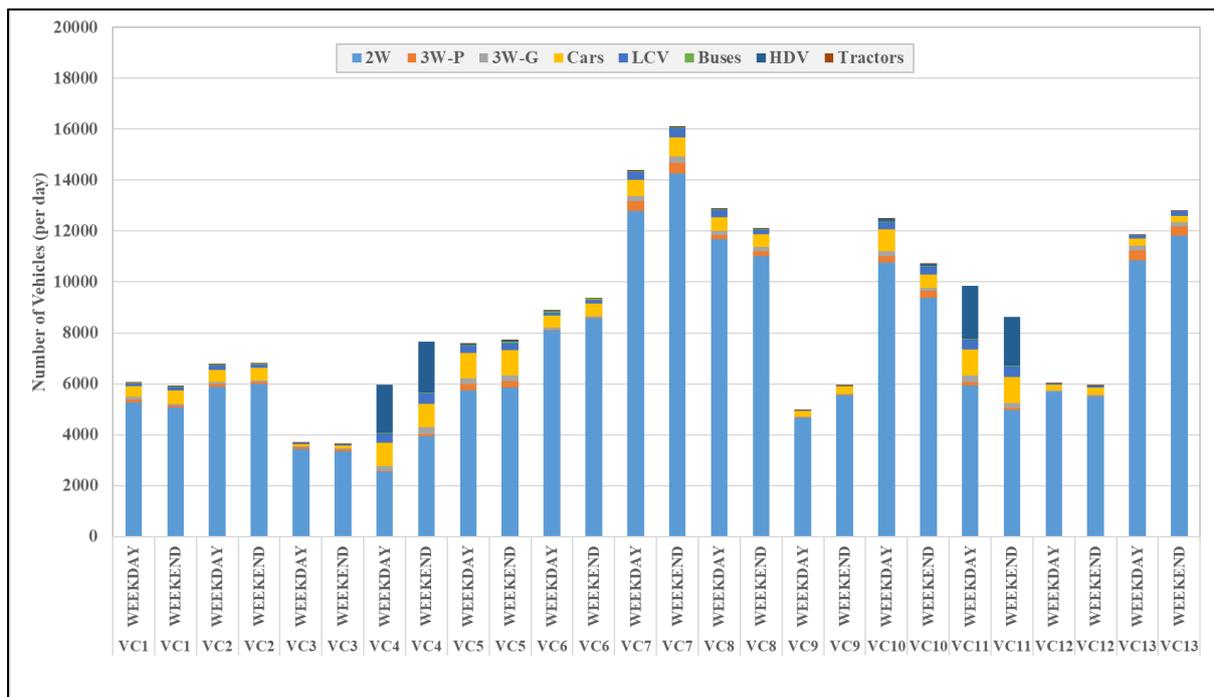


Figure 64: Classified vehicle counts observed at selected locations in Balasore region during the primary surveys.

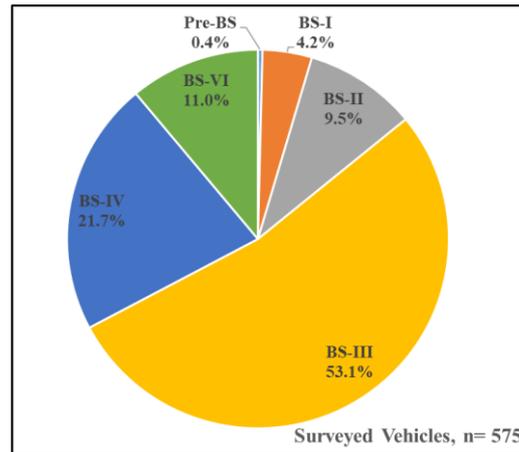


Figure 65: Distribution of vehicles as per different Bharat standards (BS) in Balasore region obtained through parking lot surveys.

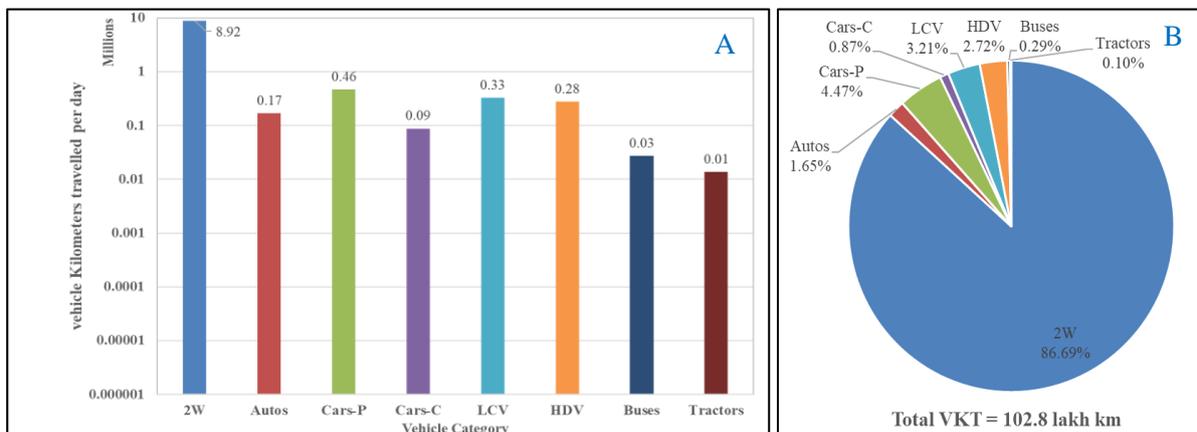


Figure 66: Daily vehicle kilometers travelled (A) and percent distribution (B) by different category of vehicles in Balasore region.

In 66 (A), the numbers of top of each bar represent daily VKT in millions and y-axis scale is expressed as a logarithmic scale.

3.4.3. Road Dust Resuspension

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:

$$\text{Emissions load} = \text{VKT} \times \text{EF}_{RD} \dots \dots \dots (8)$$

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

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

Where,

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

k = constant (function of particle size) in g/VKT, value of k for 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 Balasore region. The gross vehicle weights for different classes are obtained from vehicle specifications sheets through online surveys. Number of rainy and wet days in year 2022, were obtained from ERA5 reanalysis data used for dispersion modelling. The paved road emission factors for PM_{2.5} and PM₁₀ are listed in Table 9. These emission factors are then multiplied by gridded VKT values obtained earlier for calculation of vehicular emissions to obtain total road dust emissions.

Table 9: Road dust re-suspension emission factors (in g/km) used in this study

Fraction	AREA TYPE	HIGHWAY	MAJOR	INTERMEDIATE	MINOR	RESIDENTIAL
PM _{2.5}	URBAN	4.45	0.21	0.26	0.32	0.55
PM _{2.5}	INDUSTRIAL	8.57	0.36	0.26	0.26	0.45
PM _{2.5}	RURAL	6.51	0.45	0.29	0.29	0.49
PM ₁₀	URBAN	18.39	0.89	1.09	1.32	2.26
PM ₁₀	INDUSTRIAL	35.44	1.48	1.09	1.08	1.85
PM ₁₀	RURAL	26.91	1.86	1.20	1.19	2.04

3.4.4. Residential

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

$$E_p = \sum_{f=1}^6 \text{Pop}_f \times C_f \times \text{EF}_{f,p} \dots \dots \dots (10)$$

where, E_p is the emissions of a particular pollutant (p) from the residential sector, Pop_f is the population of the study region using a particular fuel (f), C_f is the per capita consumption of a particular fuel (f), and $\text{EF}_{f,p}$ 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 Balasore region is available for year 2011 but the region has undergone huge transformation in the last decade and old data cannot be used. Hence, the gridded population of the study area (Refer Fig. 67) 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 Balasore region as a part of this study. The emission factors for residential sector used in this study are summarized in Table 10.

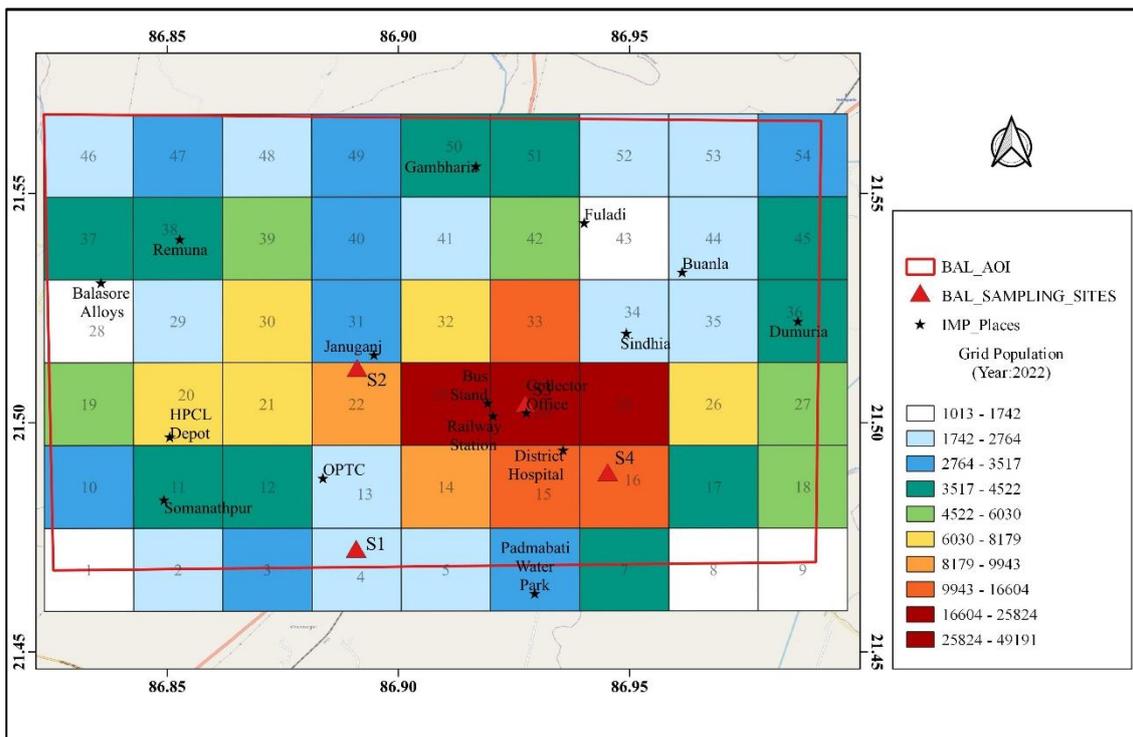


Figure 67 Map showing the estimated gridded population of the study area in year 2022

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

Fuel type	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO	NMVOC
Fuel wood	6.8	4.6	0.8	1.7	66.5	15.9
Crop residue	8.6	5.7	0.7	1.8	64	8.5
Dung cake	10.5	4.4	0.6	1	78.6	24.1
Coal	8.3	4	15.3	2.16	59.5	10.5
Kerosene	3.6	3	0.4	1.3	43	17
LPG	0.4	0.4	0.4	2.9	2	19

#EFs adopted from Datta and Sharma (2014)

3.4.5. Open Waste Burning

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

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

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 ~400 gm (City Sanitation Plan, Balasore). MSW burnt refers to the non-inert fraction of the uncollected MSW left behind after collection (MSW_C), recycling (MSW_R), and secondary use as fodder, fertilizer, and fuel (MSW_F). f_i in eq. 12 stands for the inert fraction of the waste (ash and dust), which is estimated to be about 15% 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

3.4.6. Hotels, Restaurants, Bakeries and Eateries

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 and wood are also used in tandoors and/or barbeques. The common fuels used by restaurants/hotels in Balasore region are LPG, coal and wood. The equation (13) used for calculating emissions by this sector:

$$E_p = C_f \times EF_{f,p} \dots \dots \dots (13)$$

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

Primary surveys were conducted in different localities of Balasore region to understand the fuel usage pattern in hotels, restaurants, bakeries ad open eateries. The locations of hotels, restaurants, bakeries are obtained from online food delivery portals and google maps. The data collected fuel consumption in restaurants and open eateries is used to quantify the emissions for year 2022. The emissions factors are used from the CPCB (2011, refer Table 12). It is also assumed that no control devices are installed in the restaurants to control the emissions.

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

Fuel	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO	NMVOCs
Coal	14	8.4	13.3	3.99	24.92	9
LPG	2.1	2.1	0.4	1.8	0.252	10.5
Wood	17.3	12.1	0.2	1.3	126.3	0.01

3.4.7. 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. January, 2022 vs November/December, 2022) are visually/manually compared. The newly constructed buildings were marked using polygon tool in Google earth application. Fig. 68 shows the map of construction locations identified using the satellite imagery. The emissions are obtained by using equation 14.

$$E = A_s \times EF \dots \dots \dots \text{Eq. (14)}$$

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.

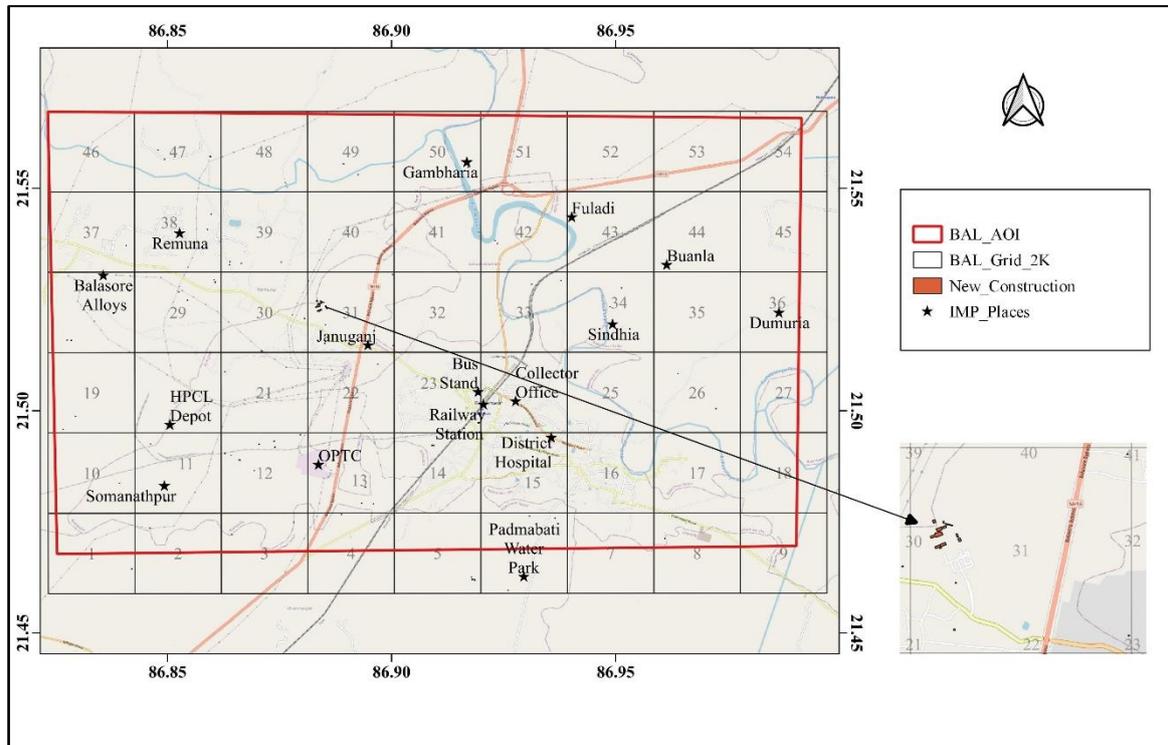


Figure 68 Map showing construction areas identified using the satellite imagery in Balasore region. The inset view shows zoomed in view of new construction activities in grid no. 31 of the study domains.

3.4.8. Diesel Generators

The diesel generators are commonly used in the case of power failures and are considered as an important source of air pollution. The primary sample data such as installed capacity, fuel consumption, frequency and time of usage, and locations is obtained through primary surveys in localities around 4 sampling sites. 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	NM VOC
Diesel generator	0.00133	0.001197	0.00124	0.0188	0.00406	0.026857

3.4.9. Industries

There are no major air polluting industries within the study domain. As per the data collected from Balasore regional office of State Pollution Control Board (OSPCB), there are a few industrial units which mainly include rubber industries, paper industry, and ferrochrome industry units. The collected data included data on manufacturing process, stack dimensions, fuel usage, installed control equipment and stack emissions of pollutants. Industrial stacks emissions are not routinely monitored in the small-scale units; hence emissions are estimated based on the fuel usage.

3.4.10. Fugitive dust

In addition to stack emissions from industrial units described previously, fugitive dust can 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 14 provides the emission factors for material handling used in this study.

Table 14: 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

3.4.11. Brick Kilns

Brick kilns are an important source of air pollution, especially in the peripheral areas of the urban centres. This study used latest available satellite imagery to locate and identify the operational brick kilns over the study domain. The study domain has 49 number of brick kilns and all of them are Fixed Chimney Bull’s Trench Kiln (FCBTK) type. Fig. 69 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 15. The total emissions from brick kilns calculated using Eq. 15

$$E_p = W_b \times EF \dots \dots \dots (15)$$

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

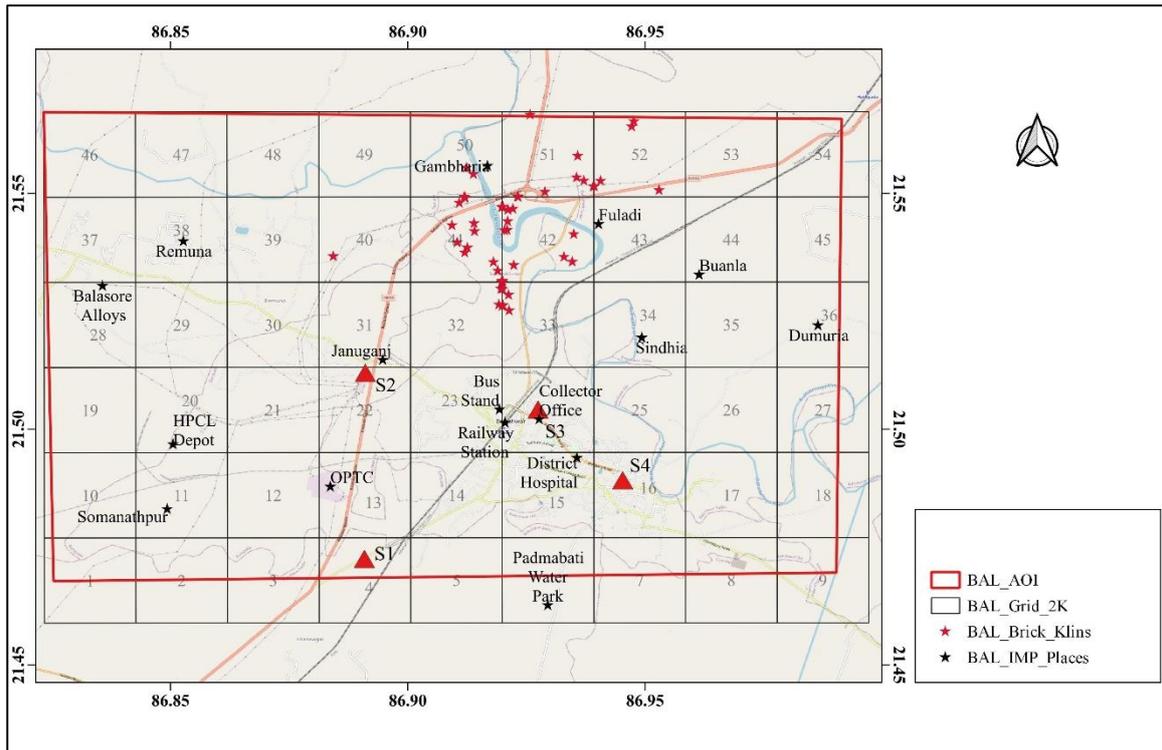


Figure 69 Map showing locations of brick kilns in the Balasore study domain identified using satellite imagery

Table 15 Emission Factors (g/kg) for different technology brick kilns

Technology	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO	NM VOC
FCBTK	0.875	0.18	0.59	0.00005	2.94	0.1
Clamp	1.3	1	0.3	0.00015	10	0.15
Zig-zag	0.26	0.13	0.32	0.00004	1.47	0.1

3.4.12. Crematoria

Cremating the bodies of dead people is an ancient ritual and practice in India. The total emissions from cremation calculated using Eq. 16.

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

Where, E_p is the emission of a particular pollutant p , F_b is the amount of fuel used per body in the crematoria, $EF_{f,p}$ is Emission factor for pollutant p . The average number of dead bodies cremated each month is calculated based on crude death rate of Balasore 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 16. The emissions are quantified using equation 16.

Table 16: Emission Factors for crematoria (g/body)

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

3.5. 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, PM_{2.5}, SO₂, NO_x, 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 Winiwarer, 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 Bhubaneswar-Cuttack region. Although, the sectors discussed above represent regional emissions in Bhubaneswar-Cuttack region adequately; there are certain sectors which are not considered in this study. This section presents a brief discussion on excluded sectors/sources of air pollution in the present emission inventory.

3.6.1. Agricultural burning and forest fires

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

3.6.2. Rail transport

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

3.7. Sectorial Emission Inventory

3.7.1. Transport

Figure 70 shows the emissions of pollutants originating from transport sector in Balasore region. It can be seen that CO is the maximum contributing pollutant from transport sector in Balasore with emissions of 7,533 tonnes per year, followed by NMVOCs (6,350 tonnes per year), and NO_x (3,135 tonnes per year). Transport sector contribution to regional PM₁₀ and PM_{2.5} emissions was found to be 245 and 221 tonnes per year, respectively. It is important to note that, the vehicular exhaust PM emissions predominantly consist of fine particles i.e. particles having aerodynamic diameter less than or equal to 2.5 µm (Ketzel et al., 2007). Following the approach suggested by Sharma and Dikshit (2016), PM vehicular exhaust emission factors are used directly for quantifying PM₁₀ while PM_{2.5} fraction is assumed to be 90% of PM₁₀ emissions.

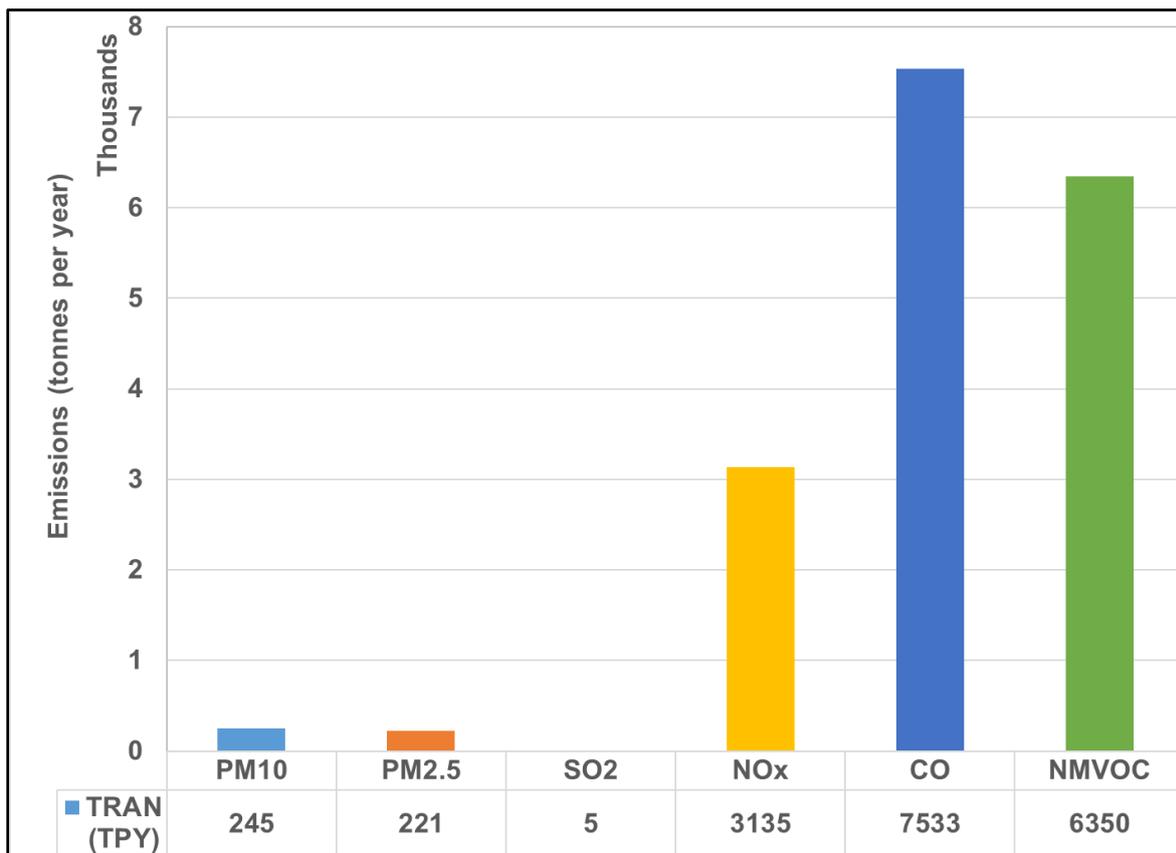


Figure 70: Emission loads (tonnes per year) of pollutants originating from the transport in Balasore region

3.7.2. Road dust resuspension

The PM emissions generated due to road dust re-suspension in Balasore region are depicted in Fig. 71. 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 3,572 tonnes per year. The fine fraction i.e. PM_{2.5} emissions are estimated to be 864 tonnes per year in 2022. PM_{2.5} emissions from road dust re-suspension are about four times lower than PM₁₀ emissions.

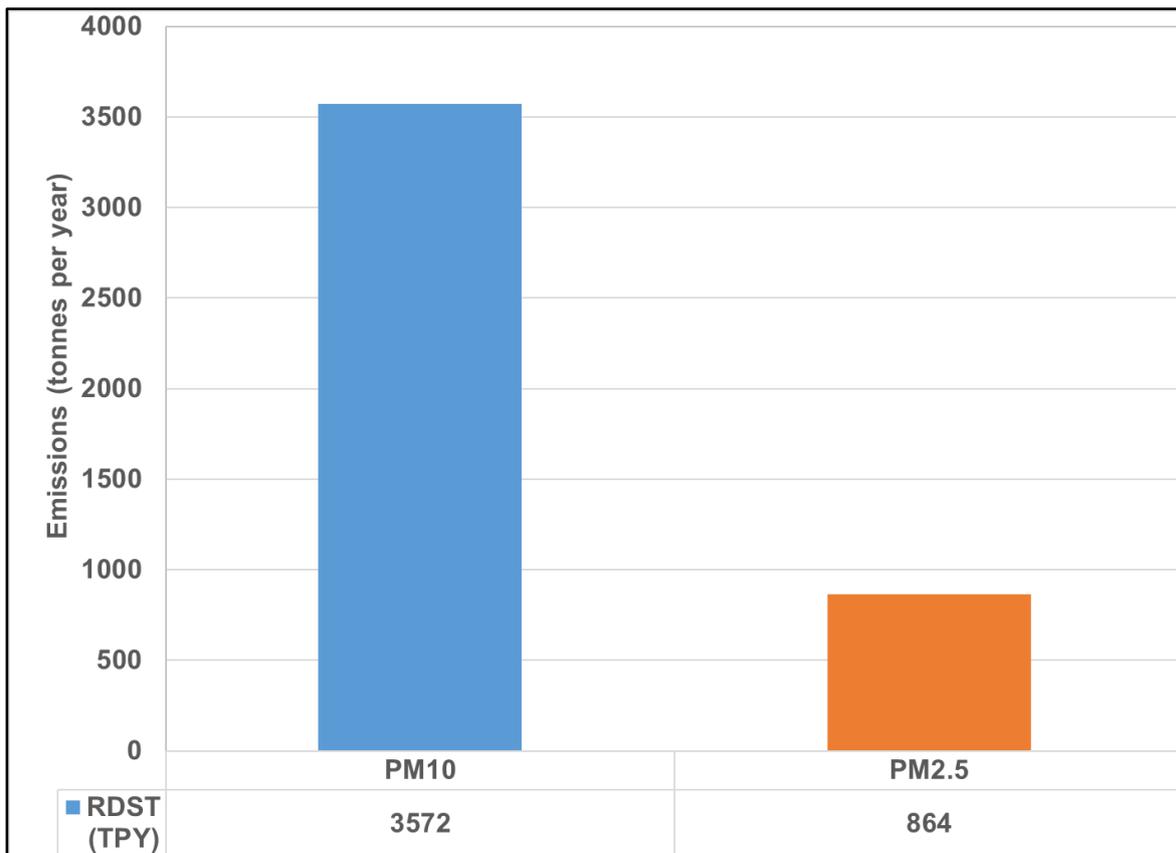


Figure 71: Emission load (tonnes per year) of pollutants originating from the road dust resuspension sector in Balasore region

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

3.7.3. Residential

Figure 72 depicts the emission loads originating from residential sector in Balasore 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 3641 tonnes per year, followed by NMVOCs (979 tonnes per year), PM₁₀ (373 tonnes per year), PM_{2.5} (253 tonnes per year), NO_x (110 tonnes per year) and SO₂ (46 tonnes per year).

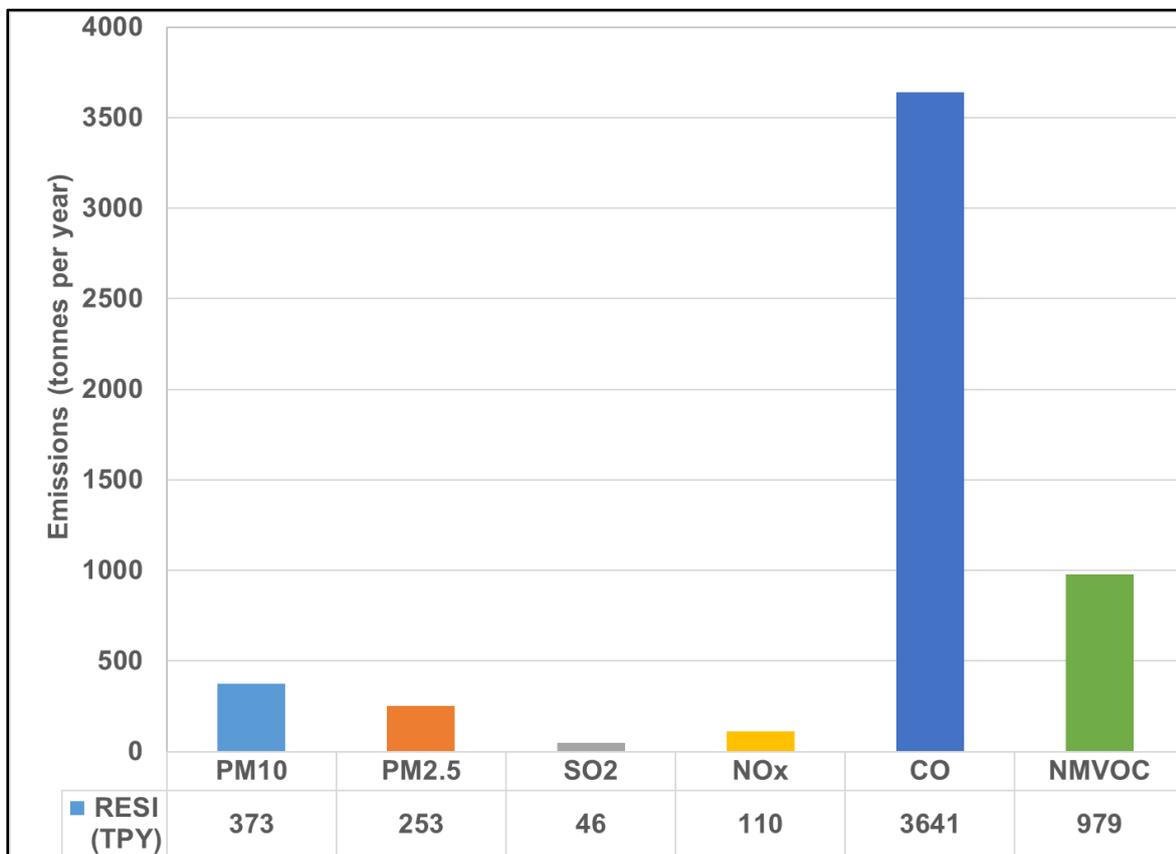


Figure 72: Emissions load (tonnes/year) of pollutants originating from residential sector in Balasore region

3.7.4. Open waste burning

Figure 73 presents the emissions of air pollutants originating from open waste burning in Balasore region. It is observed that, due to incomplete combustion of the waste a large amount of CO would be introduced into the atmosphere (2144 tonnes per year) followed by NMVOCs (464 tonnes per year), PM₁₀ (448 tonnes per year), PM_{2.5} (416 tonnes per year), NO_x (64 tonnes per year) and SO₂ (29 tonnes per year).

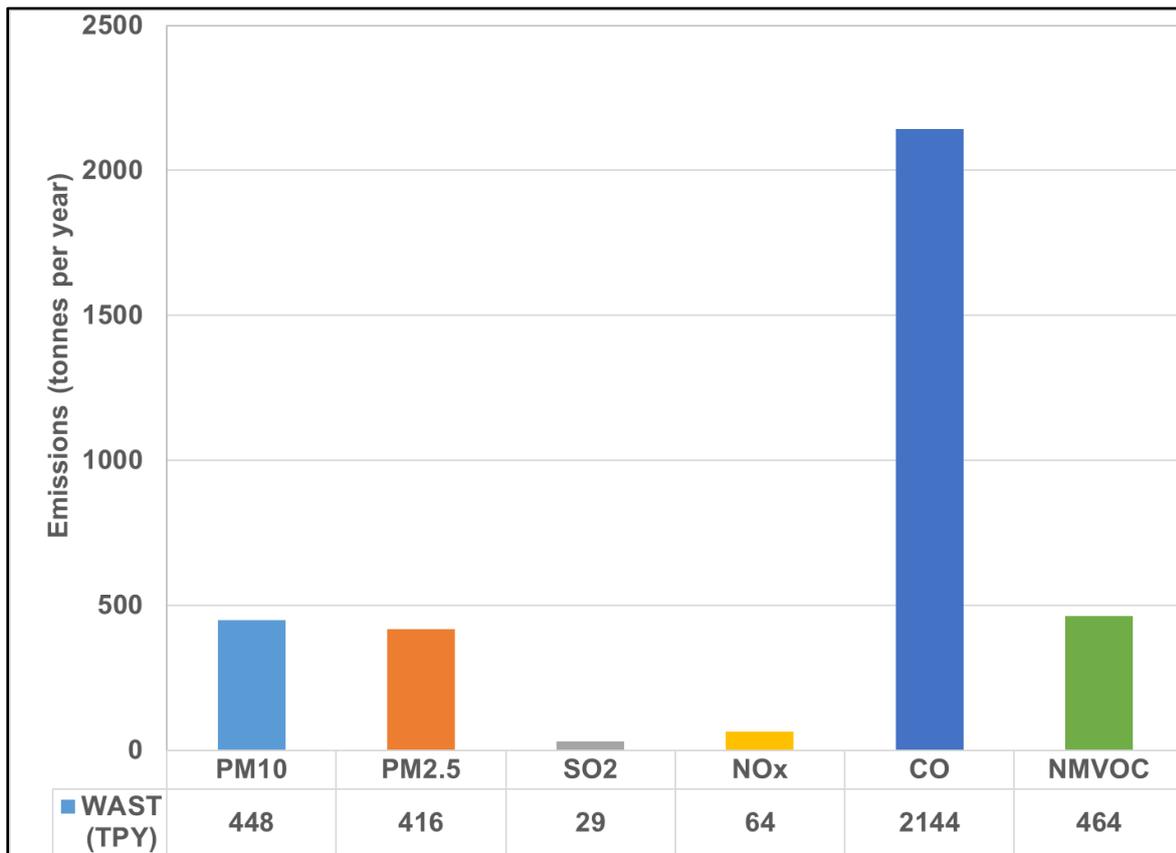


Figure 73 Emission load (tonnes per year) of pollutants originating from the open waste burning sector in Balasore region

3.7.5. Hotels, restaurants and bakeries

Figure 74 presents the emissions load contributed by hotels, restaurants, bakeries and open eateries in Balasore region. CO has been found to be the major contributor 1107 tonnes per year, followed by, PM₁₀ (201 tonnes per year), PM_{2.5} (135 tonnes per year), NMVOC (52 tonnes per year), SO₂ (61 tonnes per year) and NO_x (30 tonnes per year).

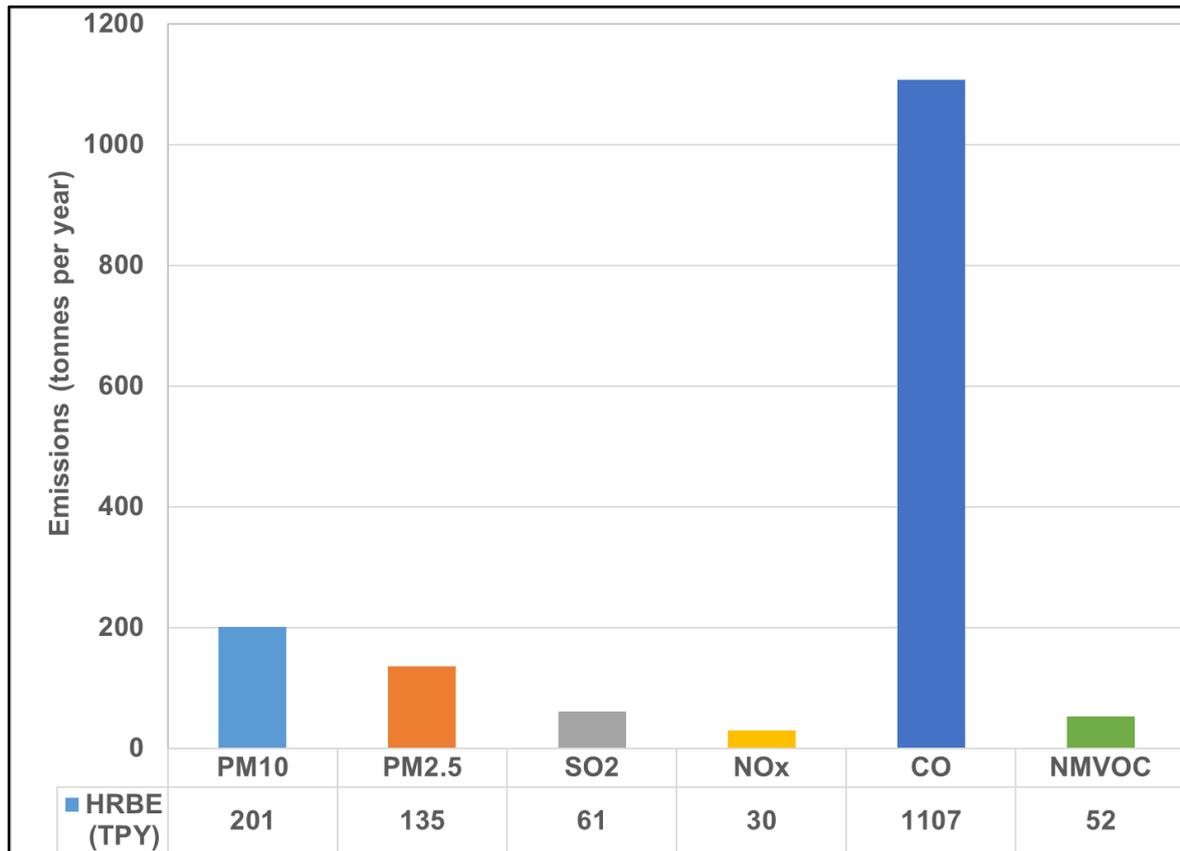


Figure 74: Emissions load (tonnes per year) of pollutants originating from hotels, restaurants and bakeries in Balasore region

3.7.6. Construction

Figure 75 shows the PM₁₀ and PM_{2.5} emissions originating from construction activities in Balasore region. Construction sector is estimated to contribute about 12 tonnes per year of PM₁₀ and 3 tonnes per year of PM_{2.5}.

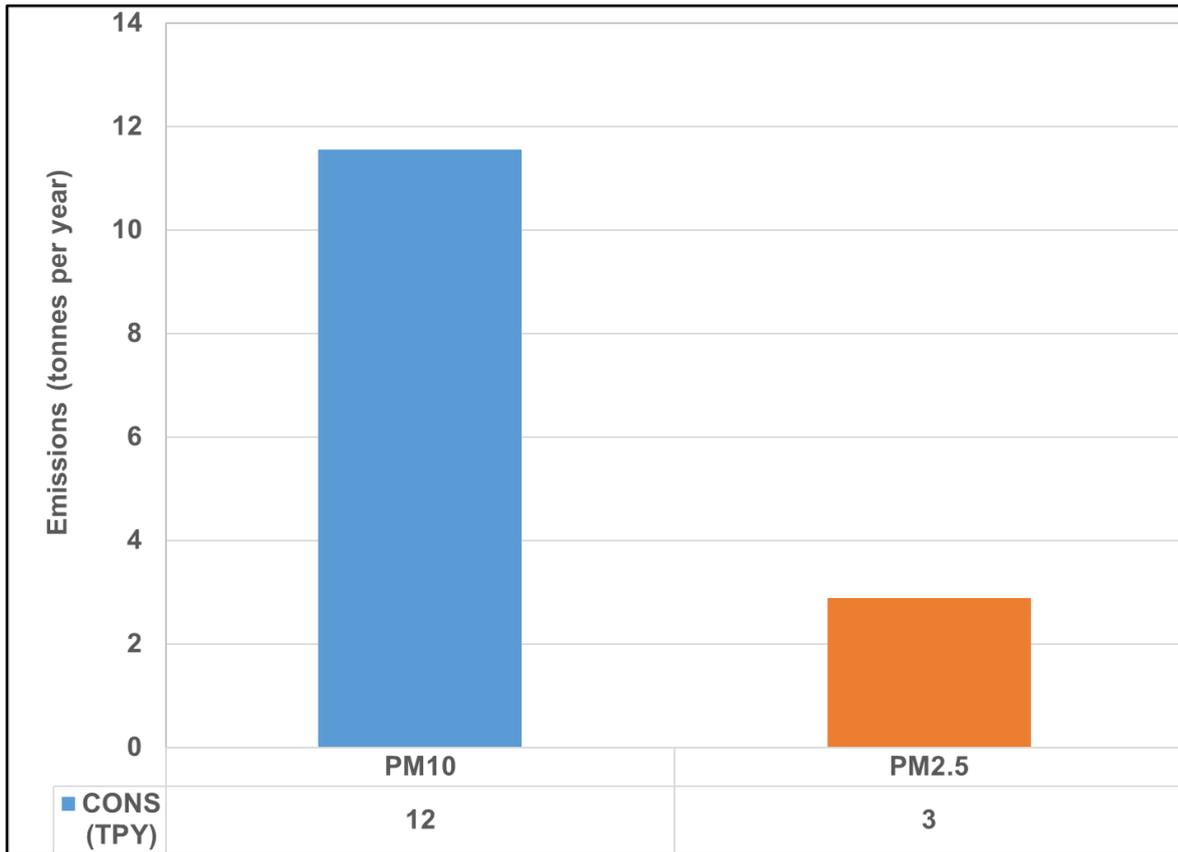


Figure 75: Emissions load (tons/year) of pollutants originating from construction activities in Balasore region

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

3.7.7. Diesel generators

As discussed earlier, diesel generators are only used during the power failure emergency but can significantly contribute to ambient air pollutants. Figure 76 shows emissions of pollutants originating from diesel generators usage in Balasore region. NMVOC is the major contributor (1506 tonnes per year) from diesel generators, followed by NO_x (1128 tonnes per year), CO (244 tonnes per year), PM₁₀ (111 tonnes per year), PM_{2.5} (96 tonnes per year), SO₂ (74 tonnes per year).

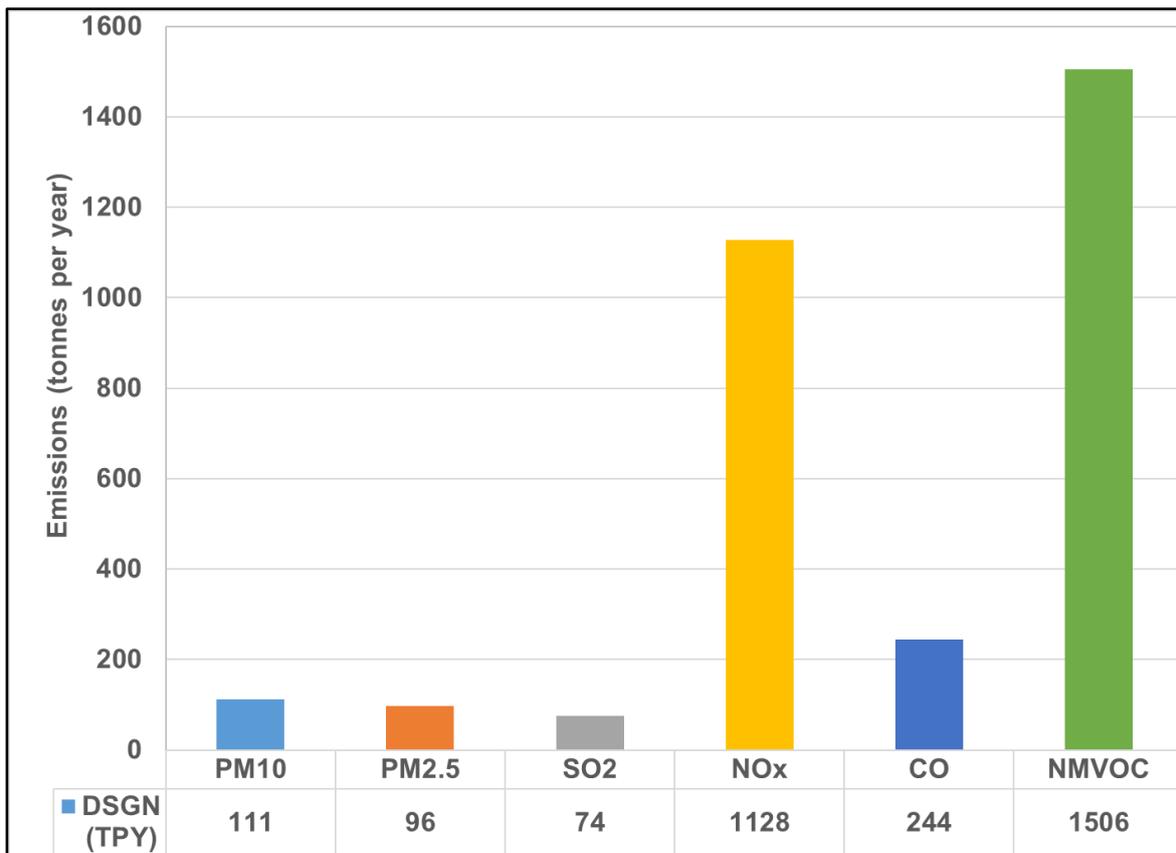


Figure 76 Emissions load (tonnes per year) of pollutants originating from diesel generators usage in Balasore region

3.7.8. Industries

As discussed earlier, Balasore is not an industrial city but there are few industrial units mainly include pulp and paper industries. Figure 77, shows the stack emissions originating from these industries. SO₂ emissions are found to be highest among the industrial pollutants i.e. 1285 tonnes per year, followed by NO_x (894 tonnes per year) and PM₁₀ (366 tonnes per year), CO (358 tonnes per year), PM_{2.5} (244 tonnes per year) and NMVOC (8 tonnes per year).

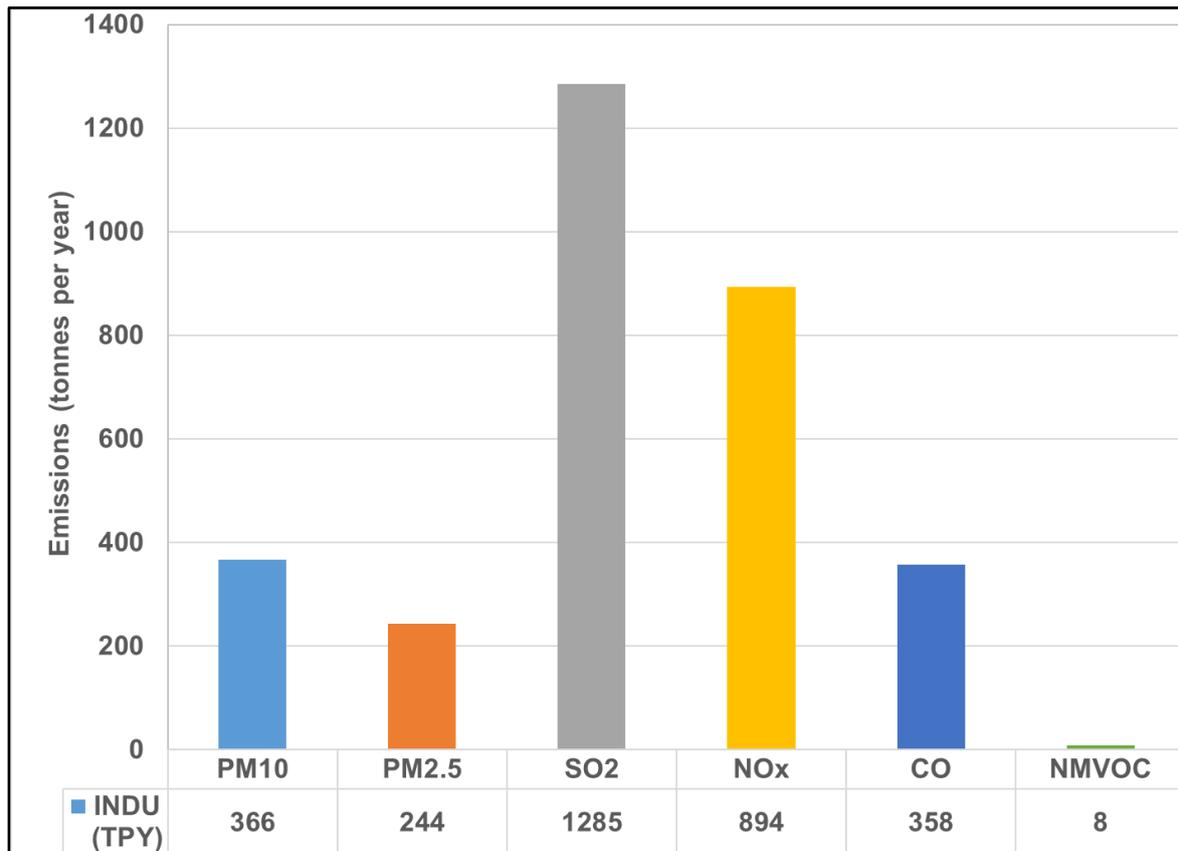


Figure 77: Emissions load (tonnes per year) of pollutants originating from industrial sector in Balasore region

3.7.9. 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 78 shows the fugitive emissions load originating from industrial units in Balasore region. PM₁₀ was estimated to be 72 tonnes per year, followed by PM_{2.5} (7 tonnes per year).

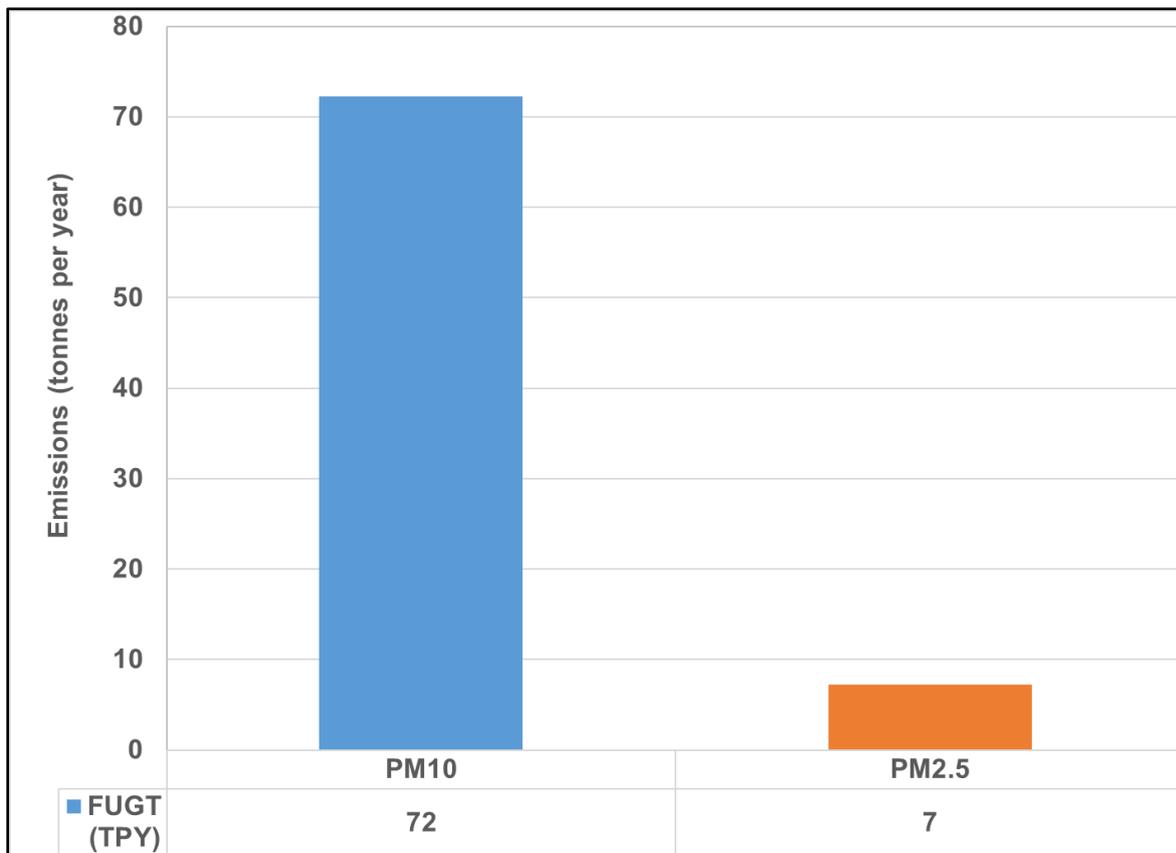


Figure 78: Emissions load (tonnes per year) of pollutants originating from fugitive operations in Balasore region

3.7.10. Brick Kilns

Figure 79 shows the emissions of pollutants originating from brick kilns in Balasore region. CO is the maximum contributor with emissions of 113 tonnes per year, followed by PM₁₀ (33.6 tonnes per year), SO₂ (23 tonnes per year), PM_{2.5} (7 tonnes per year) and NMVOC (4 tonnes per year). NO_x was found to be lowest contributor with emission of less than 0.1 tonnes per year.

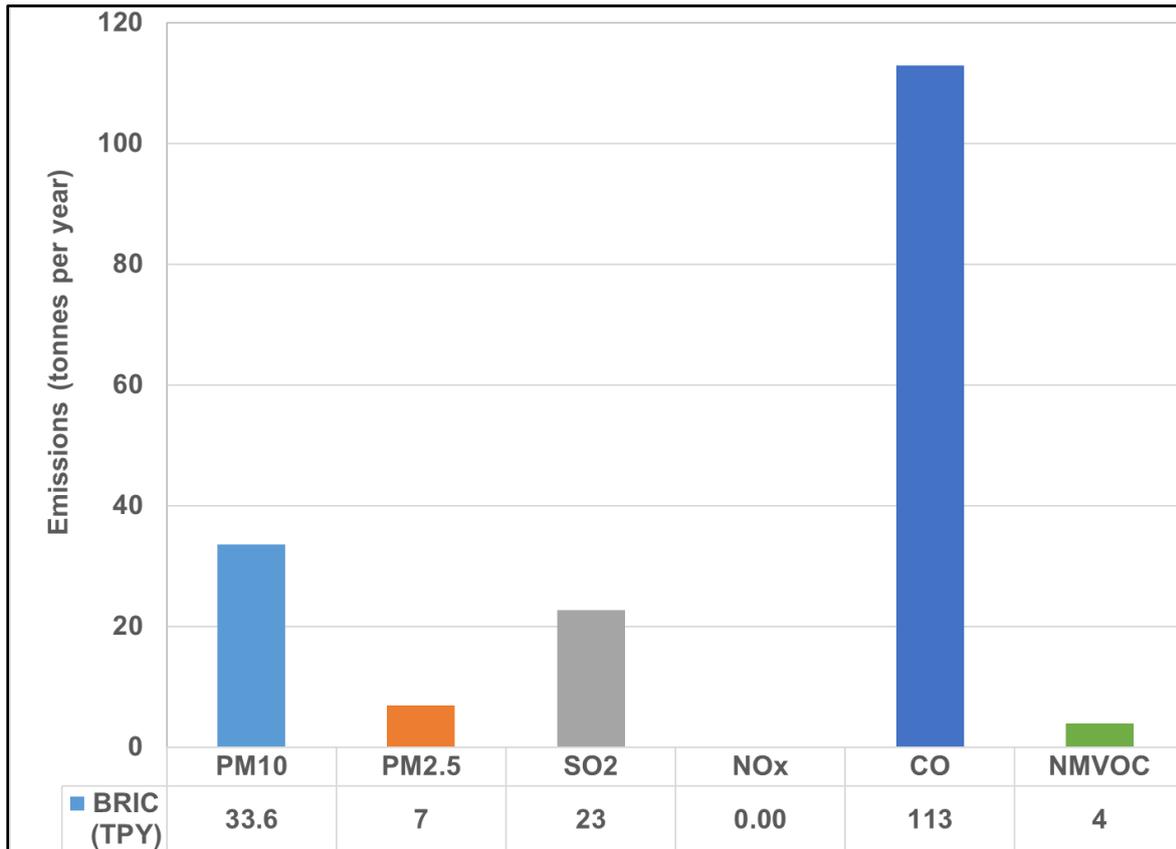


Figure 79 Emissions loads (tonnes per year) of pollutants originating from brick kilns in Balasore region

3.7.11. Crematoria

Figure 80 shows the emissions of pollutants originating from cremation activities in Balasore region. Due to incomplete combustion of wood in wood pyres, CO is the maximum contributor with emissions of 43 tonnes per year, followed by NMVOCs (24 tonnes per year), PM₁₀ (9 tonnes per year) and PM_{2.5} (4 tonnes per year). NO_x was found to contribute 1 tonne 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.

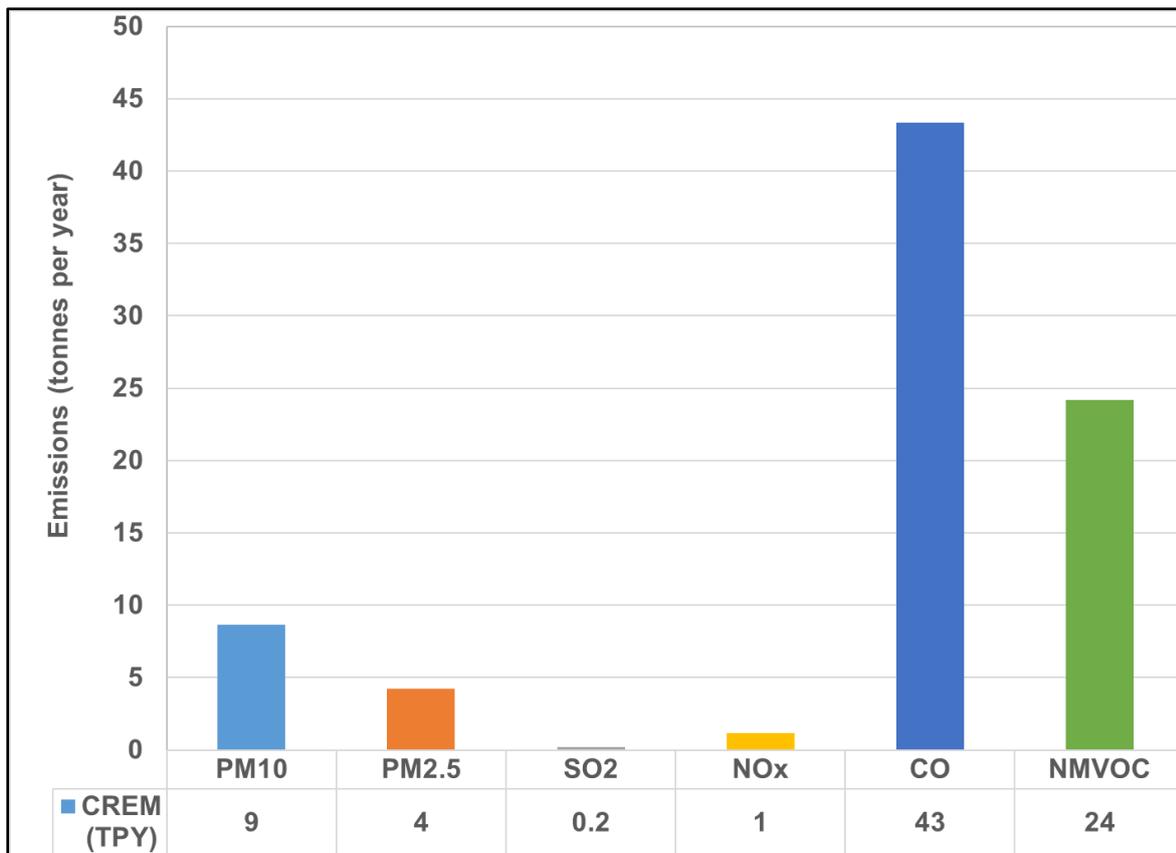


Figure 80 Emissions loads (tonnes per year) of pollutants originating from crematoria in Balasore region

3.6. Regional Emission Inventory

The overall baseline emission inventory (Year 2022) for the Balasore region is presented in Table 17. The sectoral contribution to pollutants is provided in Fig. 81 to 86.

The total PM₁₀ emission load in the Balasore region is estimated to be 5,443 tonnes per year. The top four contributors to PM₁₀ emissions are resuspended road dust (65.6%), followed by open waste burning (8.2%), residential (6.9%), and industries (6.7%). 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 Balasore region is estimated to be 2,251 tonnes per year. The top four contributors to PM_{2.5} emissions are resuspended road dust (38.4%), followed by open waste burning (18.5%), residential (11.3%), and industries (10.8%). Other PM_{2.5} contributors include transport (9.8%), hotel, restaurants and bakeries (6.0%) and diesel generators (4.3%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

SO₂ emission load in the Balasore region is estimated to be 1,104 tonnes per year. The top four contributors to SO₂ emissions are industrial emissions (84.4%), diesel generators (4.9%), hotel, restaurants and bakeries (4.0%), and residential (3.0%). All Other sectors contributes SO₂ emissions less than 2%.

The annual NO_x emission load in the Balasore region is estimated to be 5,361 tonnes per year. Transport sector (58.5%), diesel generators (21.0%) and industries (16.7) are the largest contributors to NO_x emissions. Remaining sectors such as residential, hotel, restaurants and bakeries and open waste burning together contributes about 3.4%.

The total annual CO emissions in the Balasore region are estimated to be 1,5183 tonnes per year. The top four contributors to CO emissions are transport (49.6%), residential (24.0%), open waste burning (14.1%), and hotel, restaurants and bakeries (7.3%). All remaining sectors together contribute about 4.1% of total CO emissions in the region.

Fig. 87-91 shows the spatial distribution of pollutants over Balasore region for baseline year 2022.

Table 17: Baseline (Year 2022) Emission Inventory for the Balasore region (tonnes per year) of Odisha

Sector	PM10	PM2.5	SO ₂	NO _x	CO	NM VOC
Transport (TRAN)	245 ± 49	221 ± 44	5 ± 0	3135 ± 1248	7533 ± 2450	6350 ± 3353
Road dust re-suspension (RDST)	3572 ± 935	864 ± 226	NA	NA	NA	NA
Residential (RESI)	373 ± 107	253 ± 72	46 ± 5	110 ± 30	3641 ± 1044	979 ± 499
Waste burning (WAST)	448 ± 150	416 ± 140	29 ± 9	64 ± 21	2144 ± 722	464 ± 250
Hotels, Restaurants, Bakeries and Open eateries (HRBE)	201 ± 13	135 ± 9	61 ± 2	30 ± 2	1107 ± 76	52 ± 28
Construction (CONS)	12 ± 0	3 ± 0	NA	NA	NA	NA
Diesel Generators (DSGN)	111 ± 12	96 ± 10	74 ± 3	1128 ± 98	244 ± 21	1506 ± 768
Industries (INDU)	366 ± 75	244 ± 50	1285 ± 143	894 ± 184	358 ± 73	8 ± 2
Fugitive (FUGT)	72 ± 1365	7 ± 558	NA	NA	NA	NA
Brick Kilns (BRIC)	34 ± 18	7 ± 3	23 ± 12	< 0.1	113 ± 61	4 ± 2
Crematoria (CREM)	9 ± 2	4 ± 1	0.2 ± 0	1 ± 0	43 ± 12	24 ± 12
Total	5443 ± 2731	2251 ± 1116	1523 ± 354	5361 ± 3171	15183 ± 8923	9386 ± 4914

Note - “NA” indicates the emissions quantification is not applicable for a particular sector

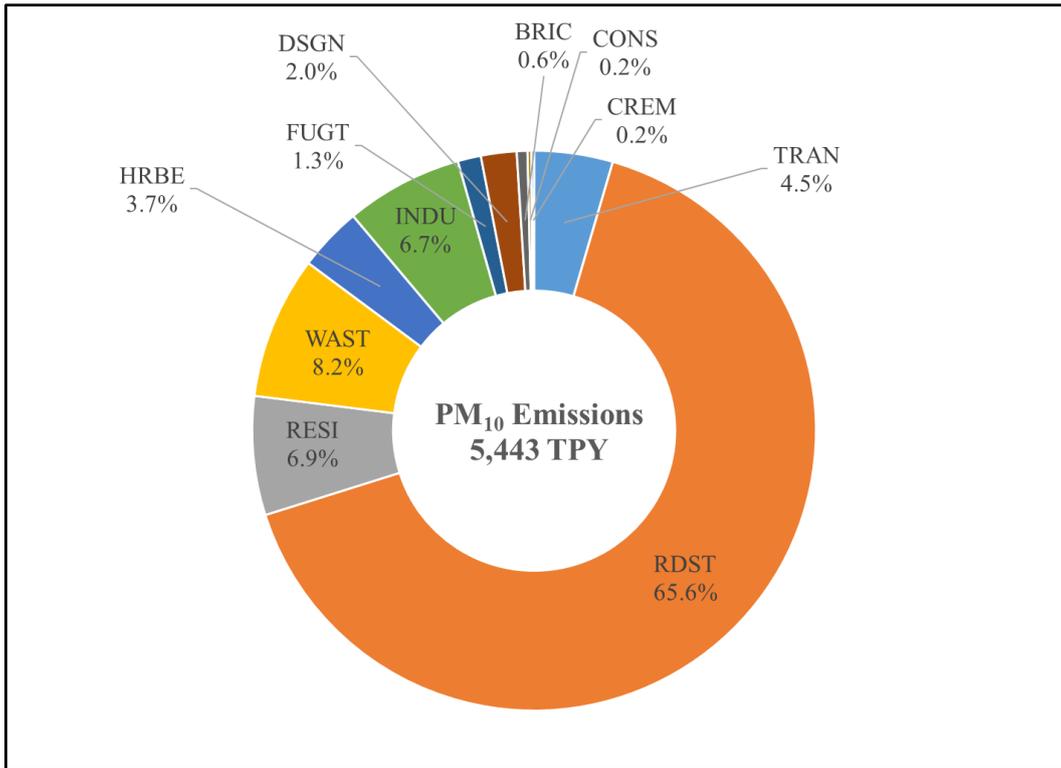


Figure 81 Sectoral contribution to annual PM₁₀ emissions in Balasore Region

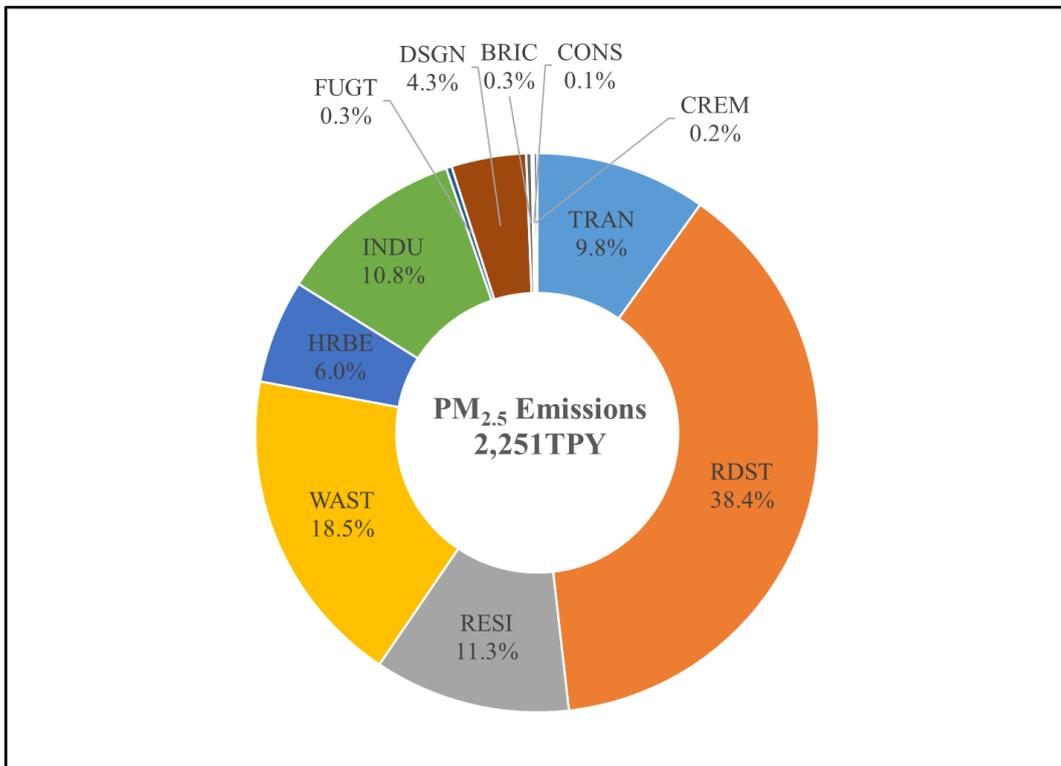


Figure 82 Sectoral contribution to annual PM_{2.5} emissions in Balasore region

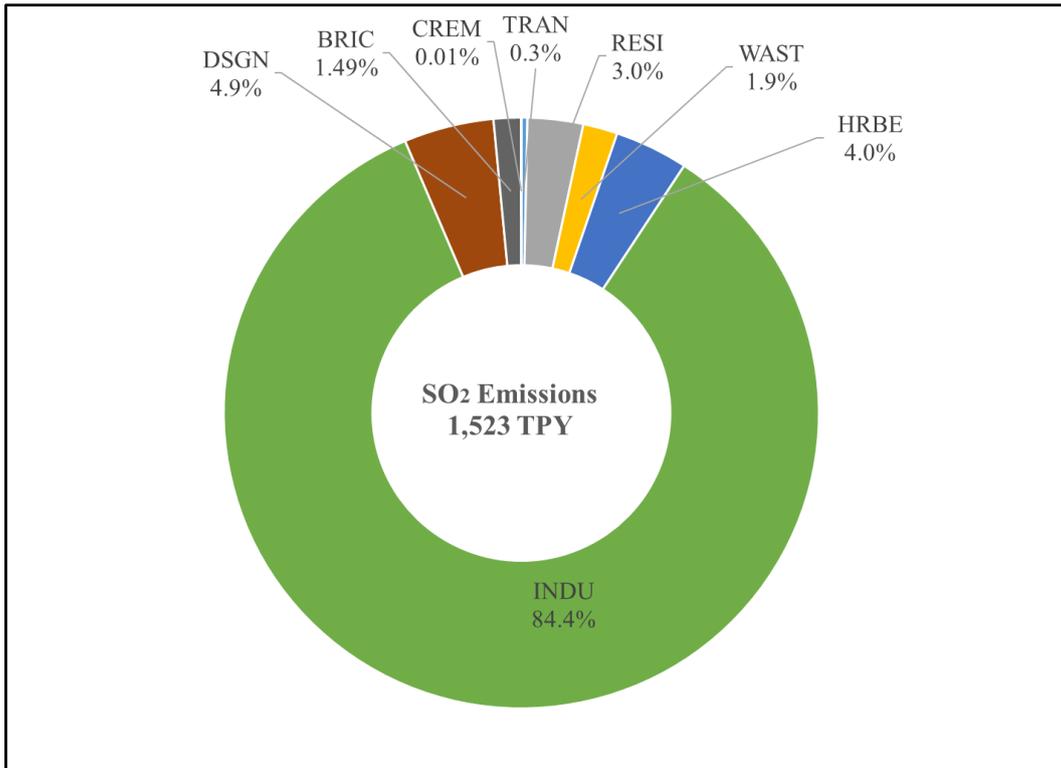


Figure 83 Sectoral contribution to annual SO₂ emissions in Balasore region

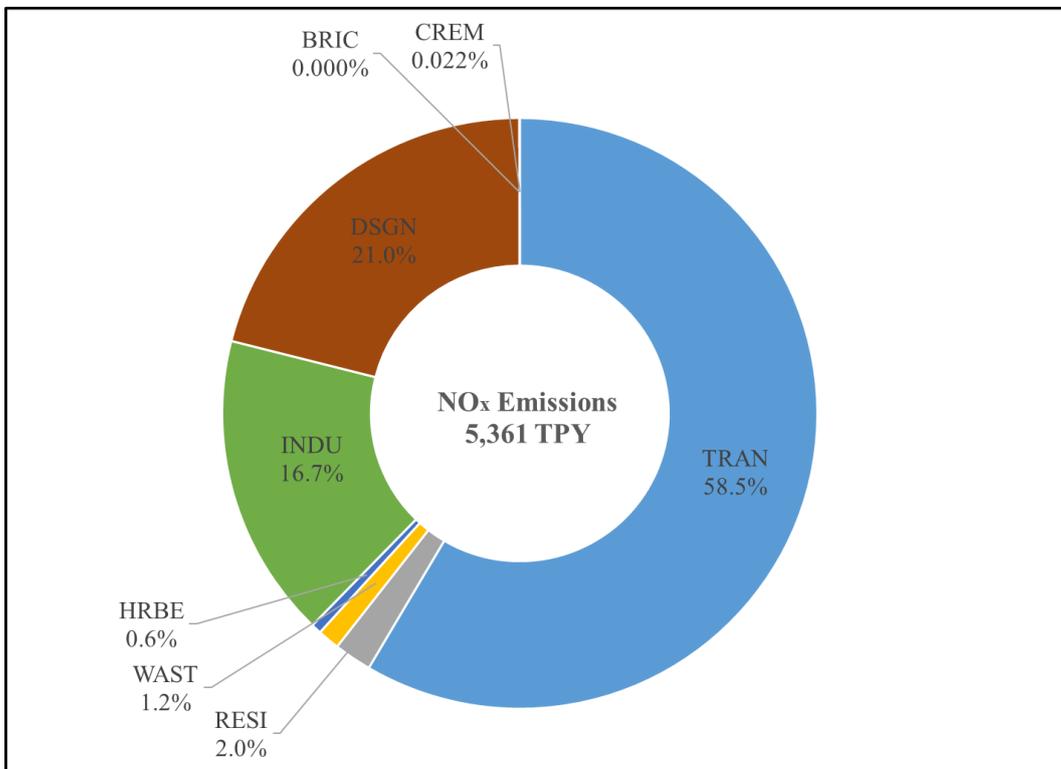


Figure 84 Sectoral contribution to annual NO_x emissions in Balasore region

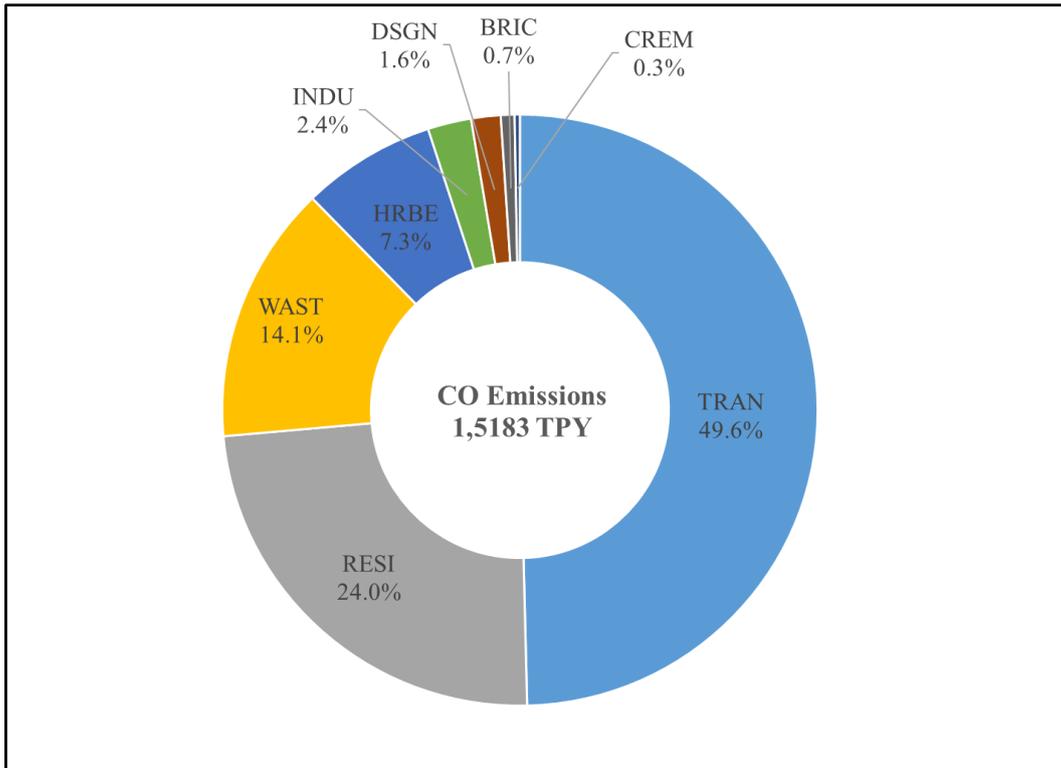


Figure 85 Sectoral contribution to annual CO emissions in Balasore region

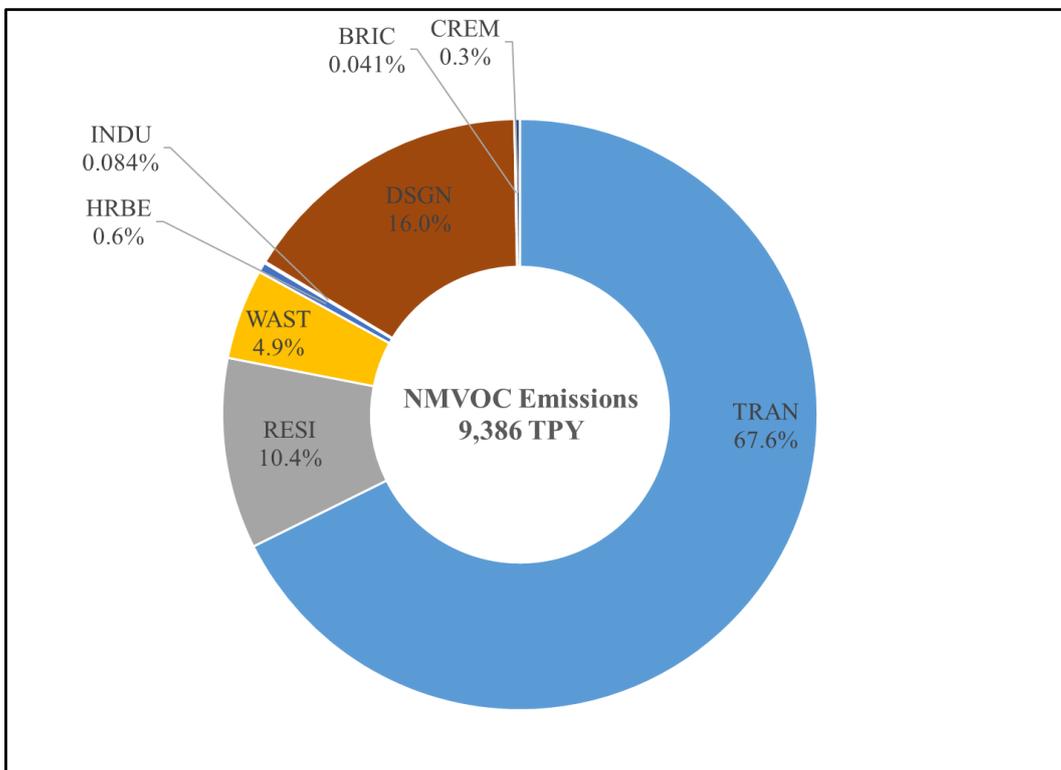


Figure 86 Sectoral contribution to annual NMVOC emissions in Balasore region

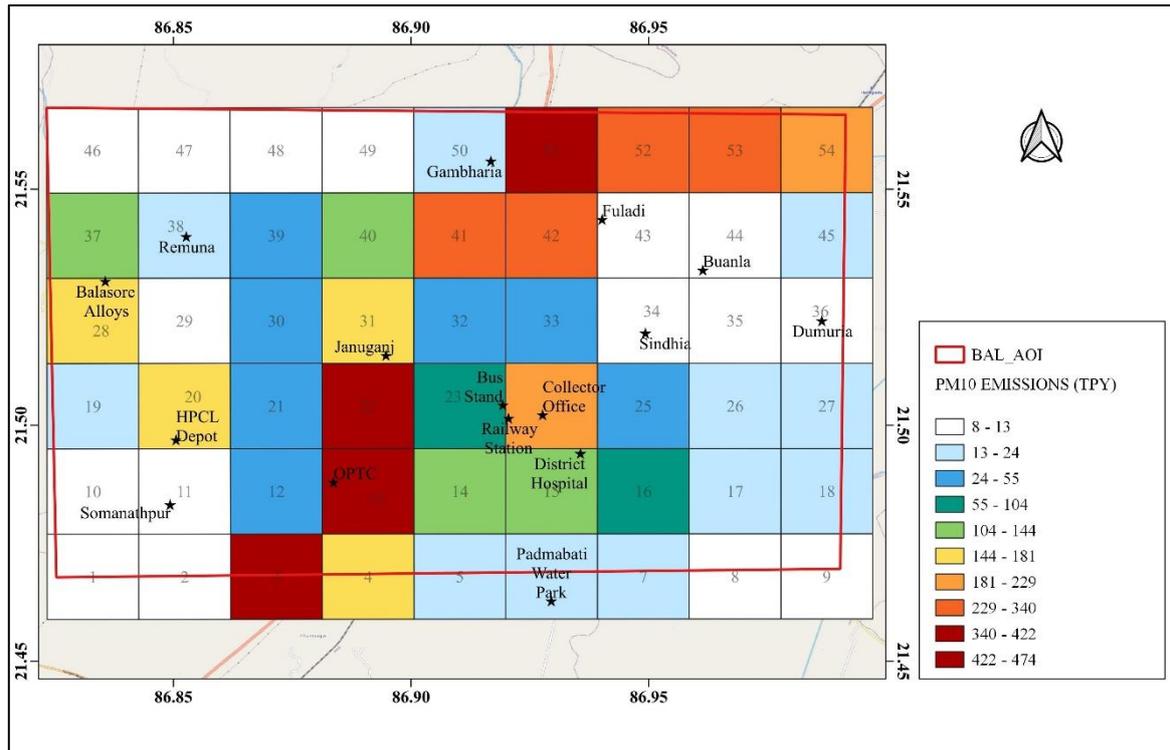


Figure 87: Spatial distribution of PM₁₀ emissions (tonnes per year) in Balasore region for year 2022

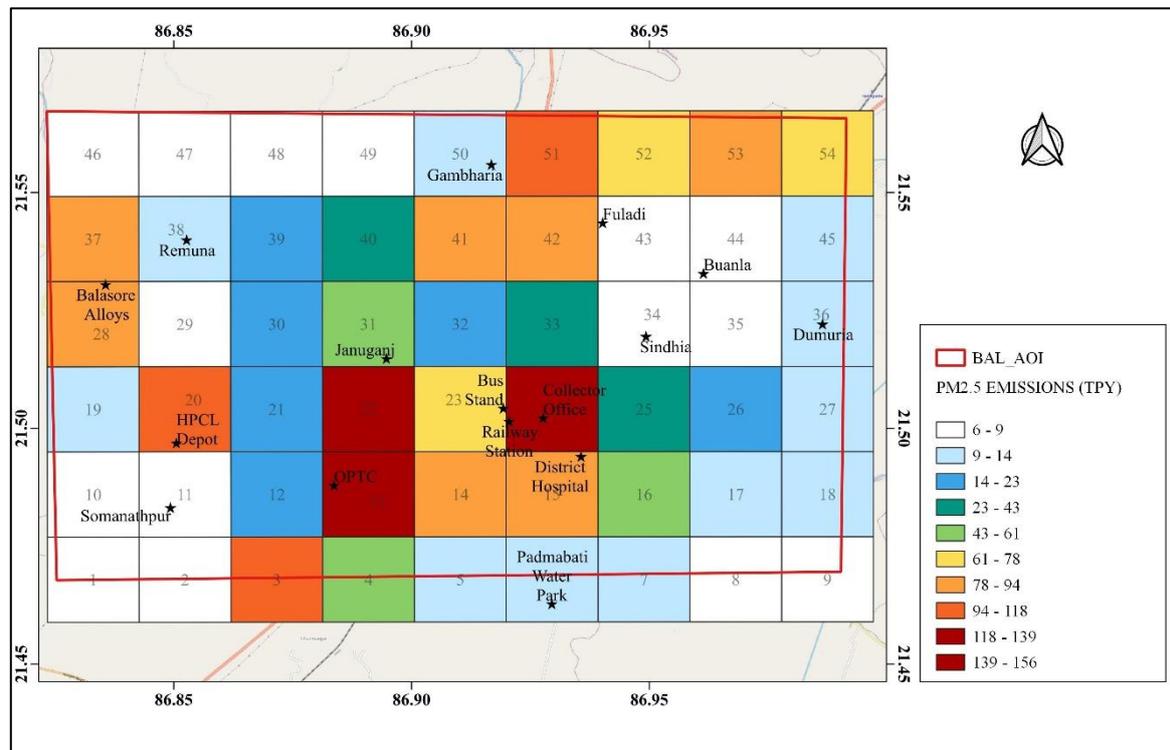


Figure 88: Spatial distribution of PM_{2.5} emissions (tonnes per year) in Balasore region for year 2022

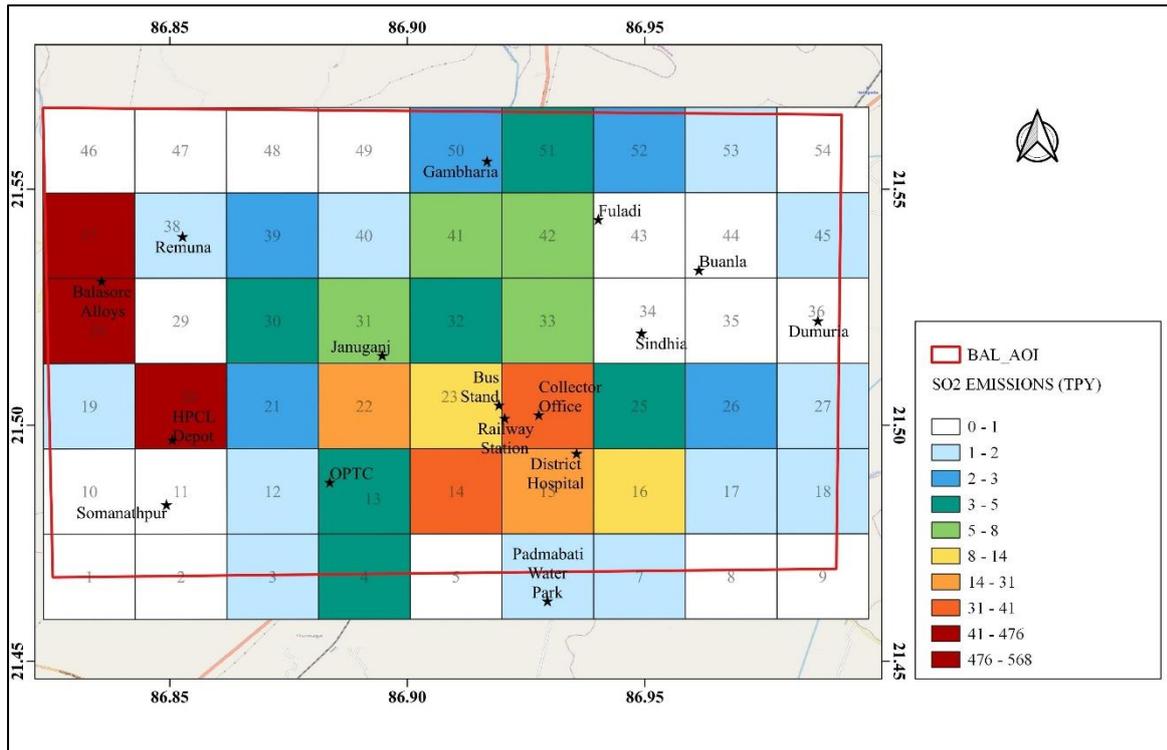


Figure 89 Spatial distribution of SO₂ emissions (tonnes per year) in Balasore region for year 2022

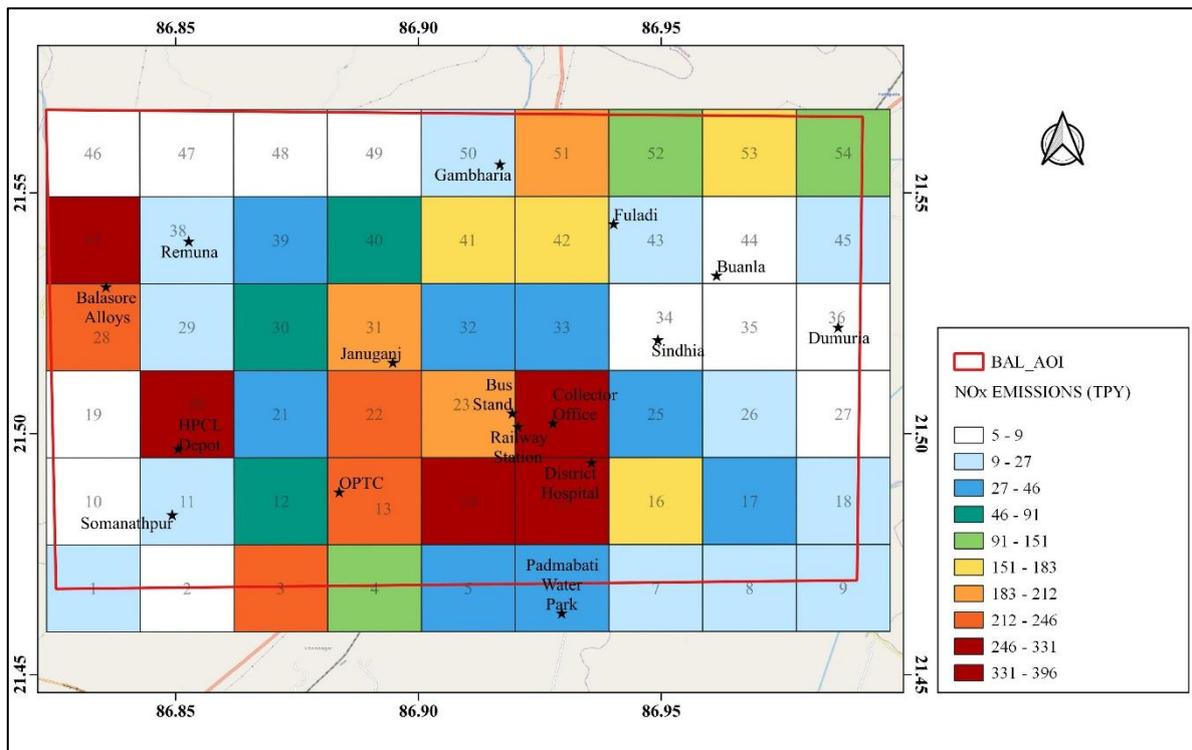


Figure 90 Spatial distribution of NO_x emissions (tonnes per year) in Balasore region for year 2022

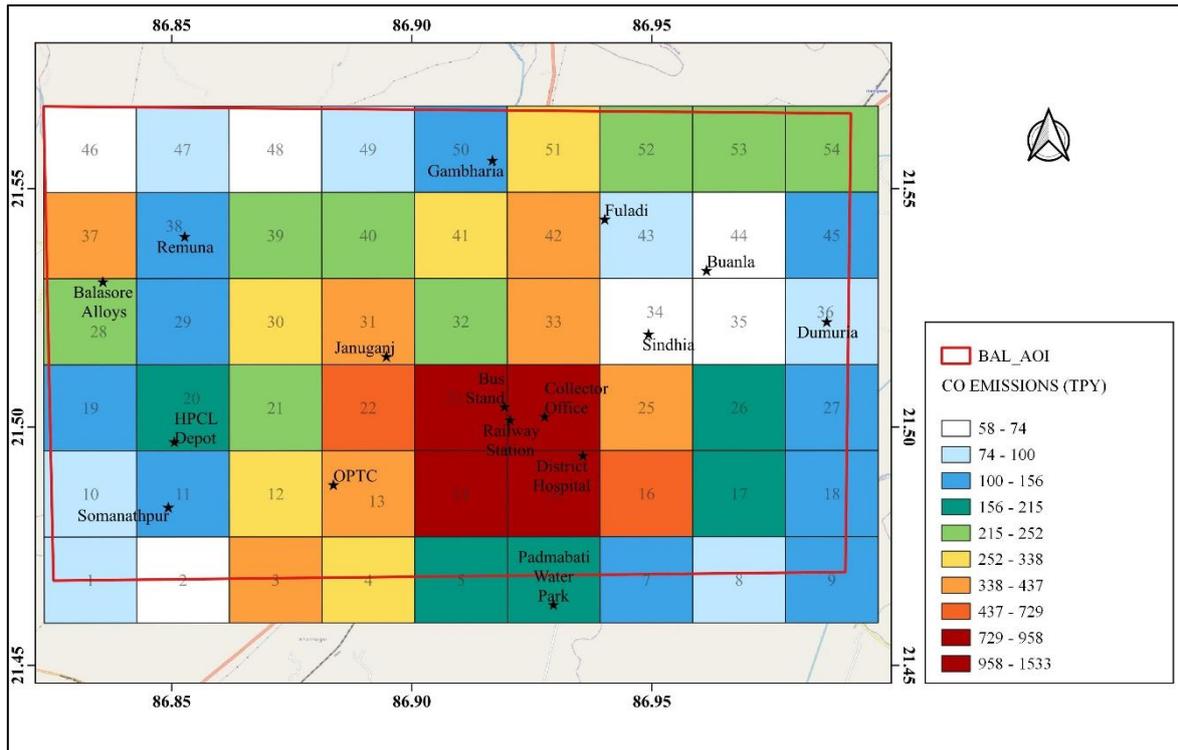


Figure 91 Spatial distribution of CO emissions (tonnes per year) in Balasore region for year 2022

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).

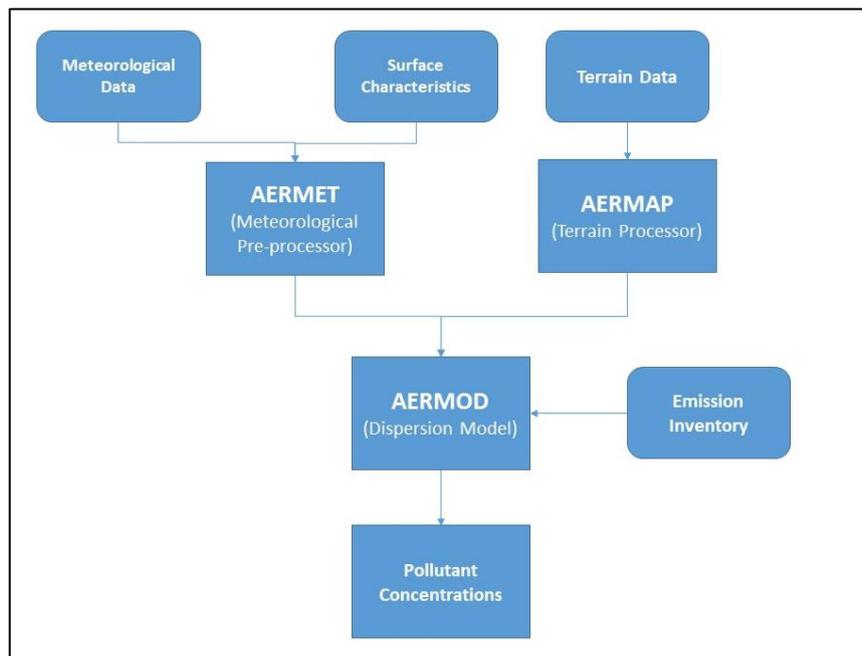


Figure 92 Flow diagram of AERMOD Modelling System used in this study to simulate the air pollutant concentrations

Fig. 92 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.

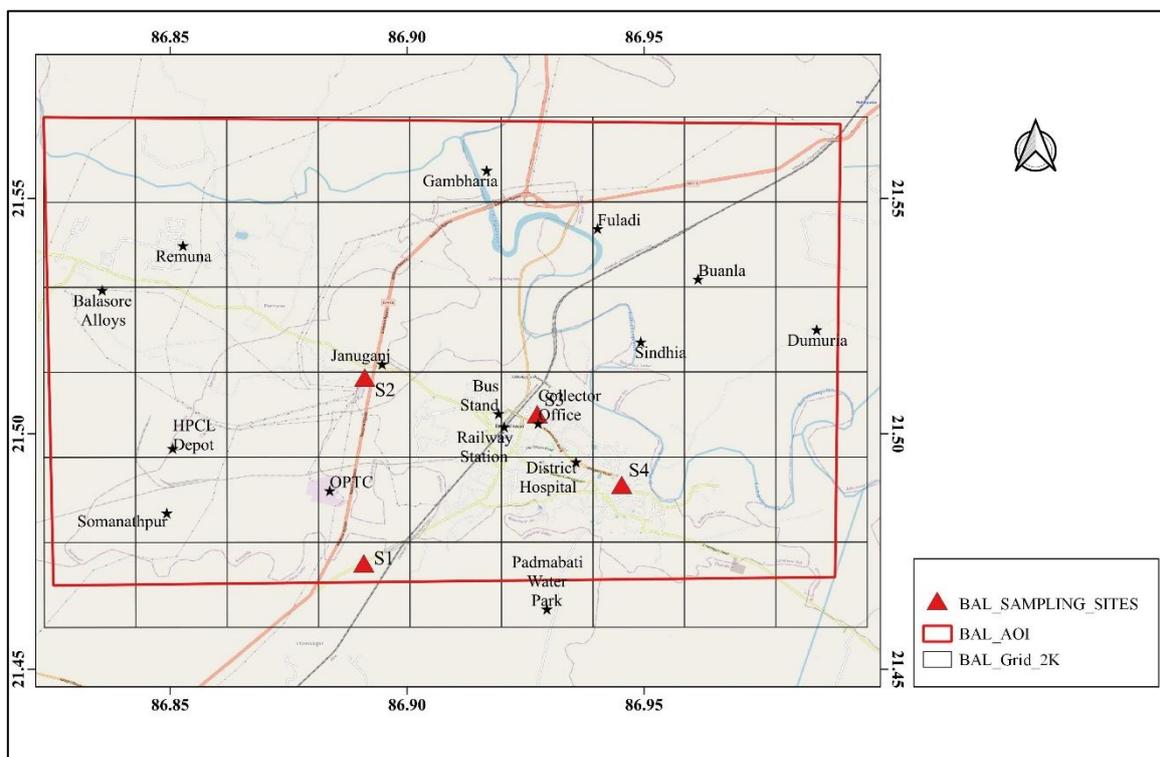


Figure 93 Map showing dispersion modelling domain i.e. Balasore region and surrounding areas

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 93).

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.

This study primarily uses ERA5 reanalysis meteorological data. ERA5 is the fifth generation ECMWF reanalysis for the global climate and weather for the past 4 to 7 decades. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics. Data has been re-gridded to a regular lat-lon grid of 0.25 degrees for the reanalysis and 0.5 degrees for the uncertainty estimate. Table 18 provides summary of ERA5 reanalysis dataset.

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

Table 18 Details of ERA5 meteorological dataset used in this study

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

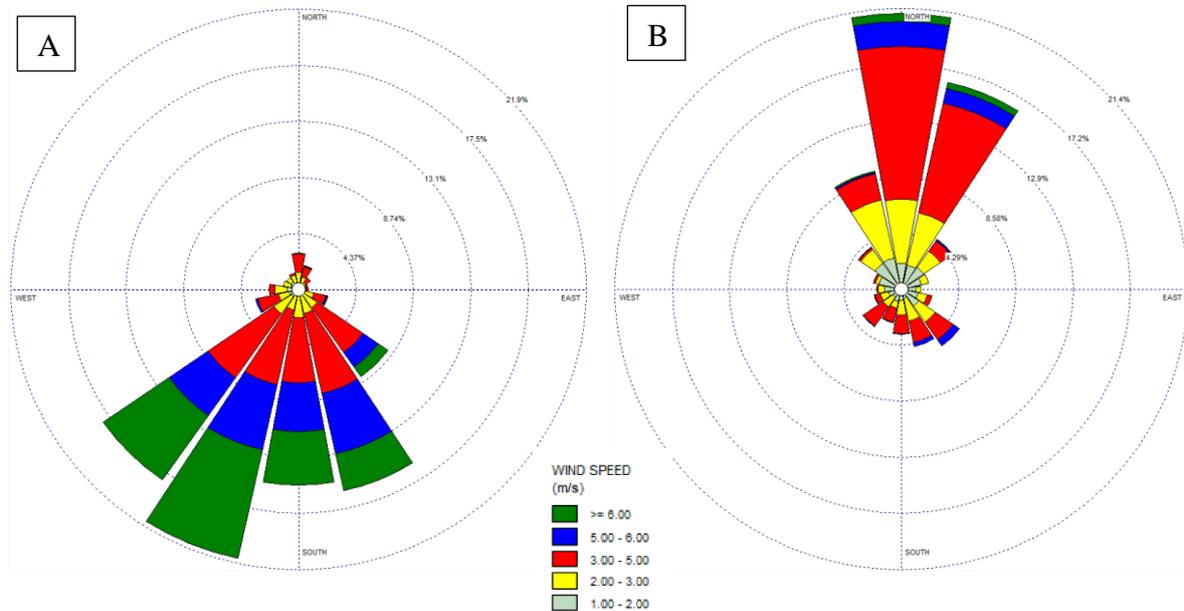


Figure 94 Windrose diagrams showing the wind speed and direction frequency distribution over Balasore region during summer (A) and winter (B) seasons of year 2022

Fig. 94 shows the wind speed and direction frequency distribution over Balasore region during summer (A) and winter (B) seasons of year 2022. The predominant wind directions during the summer season over Balasore region are observed to be from south of south west (SSW, ~22%); followed by south west (SW, ~17.5%), south of south east (SSE, ~16%), south (S, 14%). The calm winds i.e. < 1 m/s, are observed for 2.1% of time, during summer season.

In the winter season, the winds are observed to blow from north, with maximum from north (N, > 21.4%), followed by north of north east (NNE, >16%), north of north west (NNW, >8.5%) directions. Calm winds i.e. < 1 m/s, constituted a significant portion i.e. 12.7%, during the winter season.

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 Balasore region was downloaded and processed using AERMAP processor.

Fig. 95 shows the contour map showing terrain elevations over Balasore region 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 ~1.1 m (above MSL) towards eastern part to a maximum of ~31.9 m (above MSL) towards western part of the modelling domain.

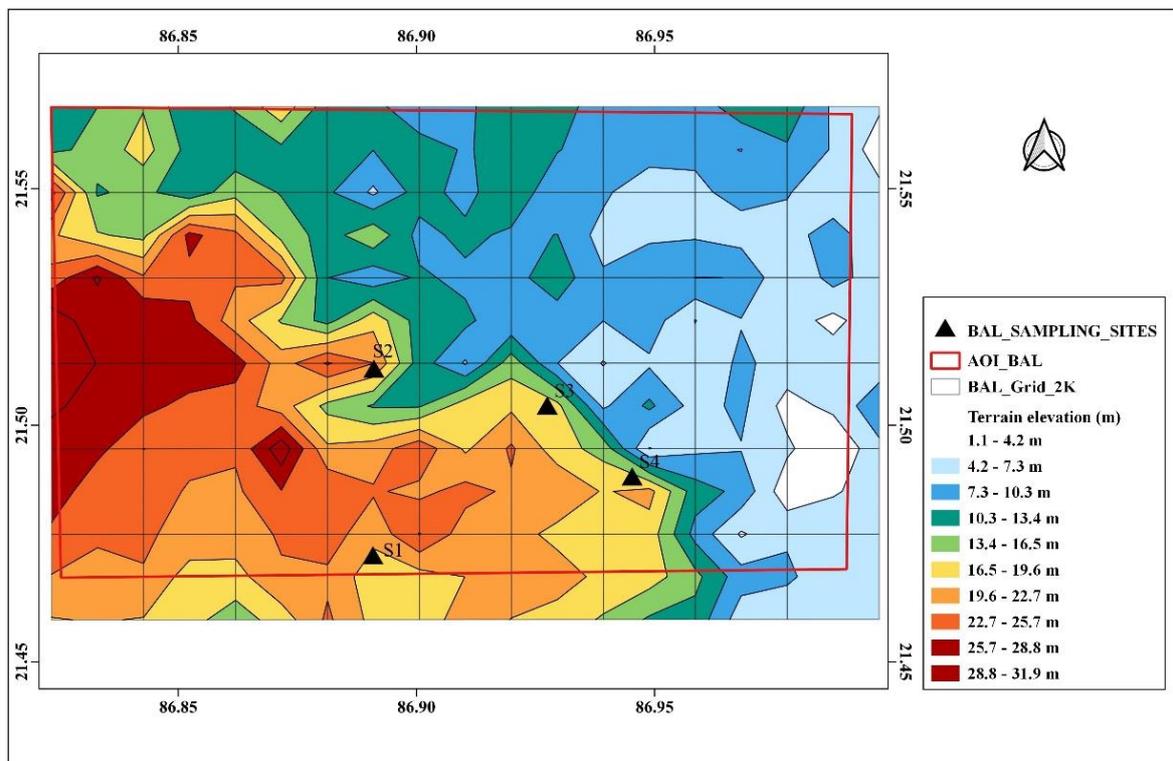


Figure 95 Contour map showing terrain elevations extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m)

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, fugitive dust and brick kilns. The stack emissions from industries, crematoria, and FCBTK brick kilns are modelled as point sources. Fugitive dust sources are modelled as area polygon 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 247 gridded receptors. Additionally, four discrete receptors are also configured, to represent the locations for ARAI sampling sites. The height of each receptor is set to 1.5 m above ground level i.e. mean breathing level for humans. Figure 96 shows map of the modelling domain overlaid by gridded and discrete receptors configured in this study.

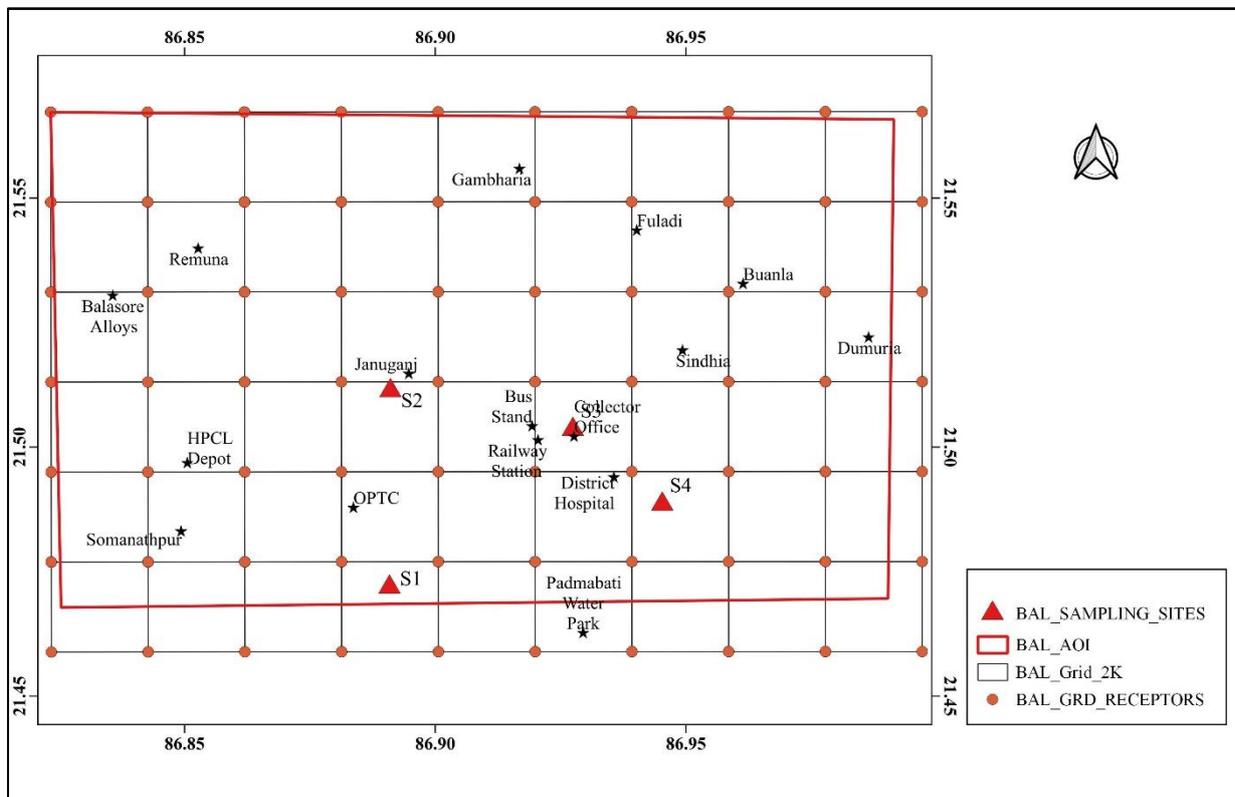


Figure 96 Map showing modelling domain overlaid by gridded and discrete receptors configured in this study.

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

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

S. No.	Description	Symbol	Details
1.	Length of modelling domain in X-direction	X	34 km
2.	Length of modelling domain in Y-direction	Y	32 km
3.	X-direction receptor grid resolution	ΔX	1000 m
4.	Y-direction receptor grid resolution	ΔY	1000 m
5.	Receptor height	H_R	1.5 m
6.	Total number of gridded receptors	N_{GRD}	247
7.	Total number of discrete receptors	N_{DISC}	4
8.	Source configuration in AERMOD	--	<ul style="list-style-type: none"> • Industries, FCBTK, Crematoria: Point source • Clamp Brick kilns: Volume source • Industrial fugitive dust: Area polygon sources • All other sectors: Area sources having L=2000 m and W= 2000 m
9.	Meteorology: Surface data	--	ERA5 fifth generation ECMWF reanalysis: <ul style="list-style-type: none"> • Dry bulb temperature • Wet bulb temperature • Cloud cover • Wind speed at 10 m • Wind direction at 10 m
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. Continuous air quality monitoring stations were not operational during baseline year 2022, hence NAMP observations were used to derive the background concentrations. NAMP monitoring stations are operated manually and the background concentrations are derived using annual average concentrations reported at NAMP stations with suitable assumptions.

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

4.7. Dispersion Model Validation

Due to lack of CAAQM measurements in Balasore region, the AERMOD simulated concentrations of pollutants including PM_{2.5}, PM₁₀, and NO₂, are compared against monthly mean of reported observations at NAMP stations in Balasore. The Pearson correlation coefficient (R) is found to be greater than 0.65 for PM₁₀ and 0.51 for PM_{2.5}. Overall, the AERMOD model is found to simulate the monthly average concentrations of the pollutants with a good accuracy compared to NAMP observations.

4.8. Spatial Distribution of Modelled Pollutants

Fig. 97 - 101 shows the spatial distribution of modelled pollutant annual mean concentrations of PM₁₀, PM_{2.5}, SO₂, NO₂ and CO for year 2022, 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 central part and north-eastern parts of the study domain. These highest concentrations can be attributed to the air polluting sources such exhaust emissions, road dust emissions due to vehicular movement, brick kilns, fuel combustion in households and commercial facilities. The lowest estimated pollutant concentrations on the peripheral part of the study domain i.e. north-western (NW)

and south-eastern (SE), could be attributed to no and or less air polluting activities, emissions and effective diffusion, dispersion and removal of pollutants to some extent (Han et al., 2020).

The spatial distribution of gaseous pollutants such as SO₂ (Refer Fig. 92) is mainly governed by the use of solid fuels in brick kilns. The NO₂ and CO concentrations are found to be distributed across the domain. The vehicular exhaust emissions are main sources of NO_x. In addition to industries and traffic, incomplete combustion of solid fuels such as coal and wood for domestic and commercial purposes in the region, explains the persistent CO concentrations.

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

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

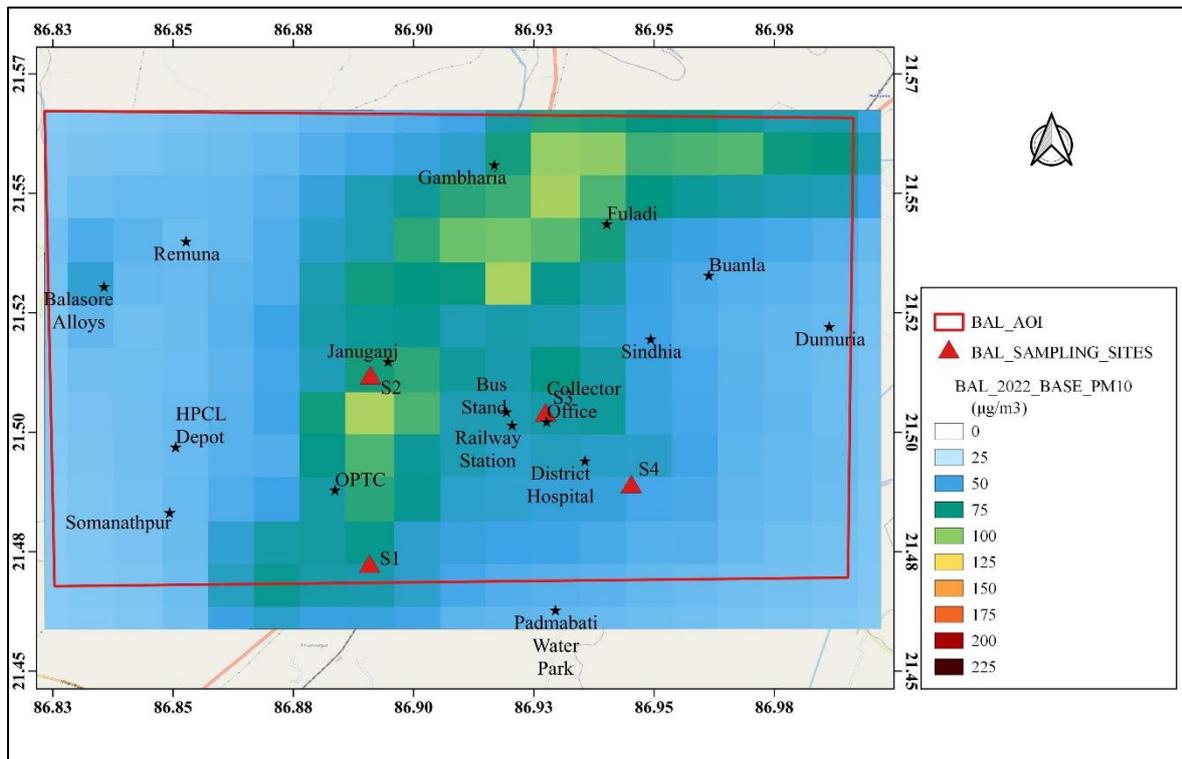


Figure 97 Map showing spatial distribution of annual mean PM₁₀ concentrations (µg/m³) over Balasore for year 2022

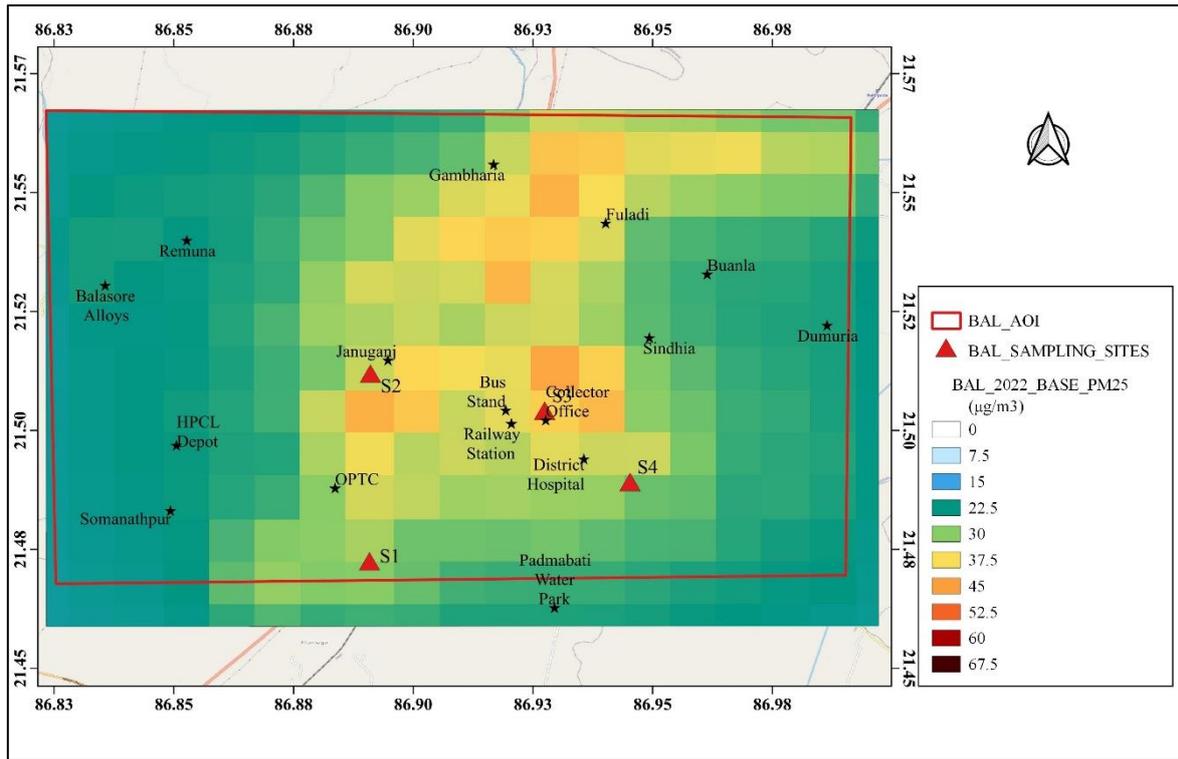


Figure 98 Map showing spatial distribution of annual mean $PM_{2.5}$ concentrations ($\mu\text{g}/\text{m}^3$) over Balasore for year 2022

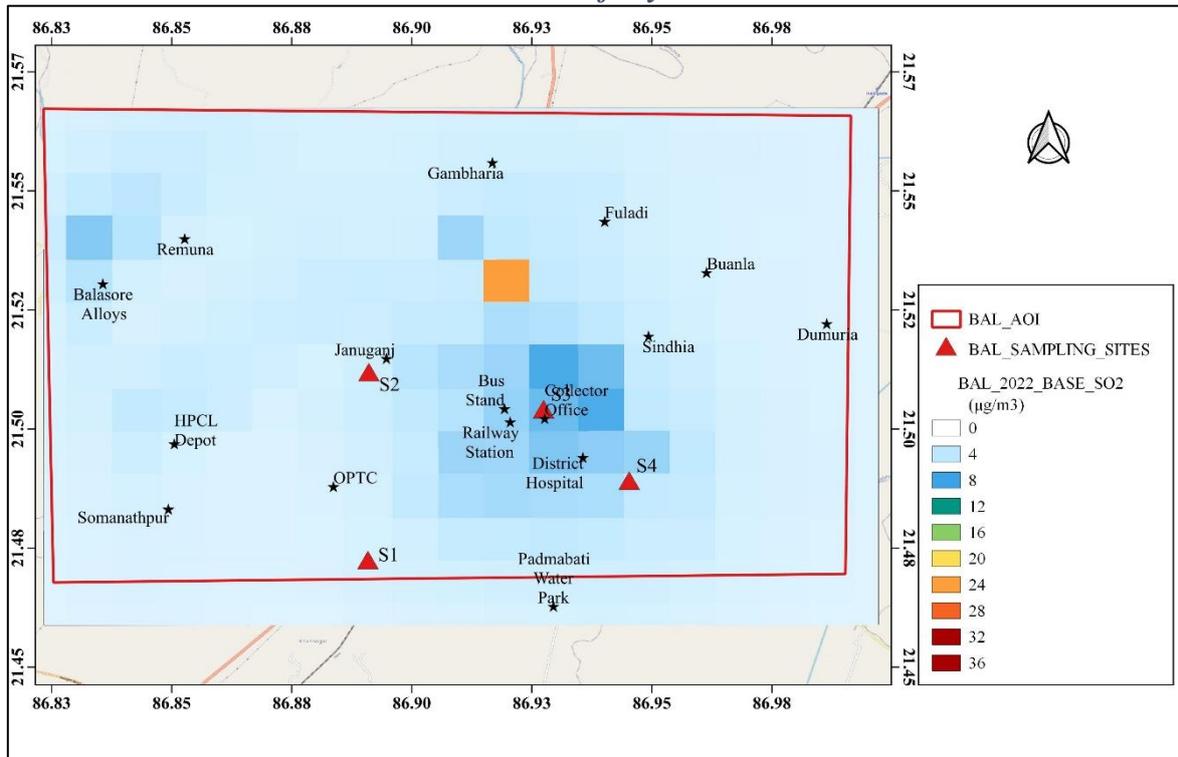


Figure 99 Map showing spatial distribution of annual mean SO_2 concentrations ($\mu\text{g}/\text{m}^3$) over Balasore for year 2022

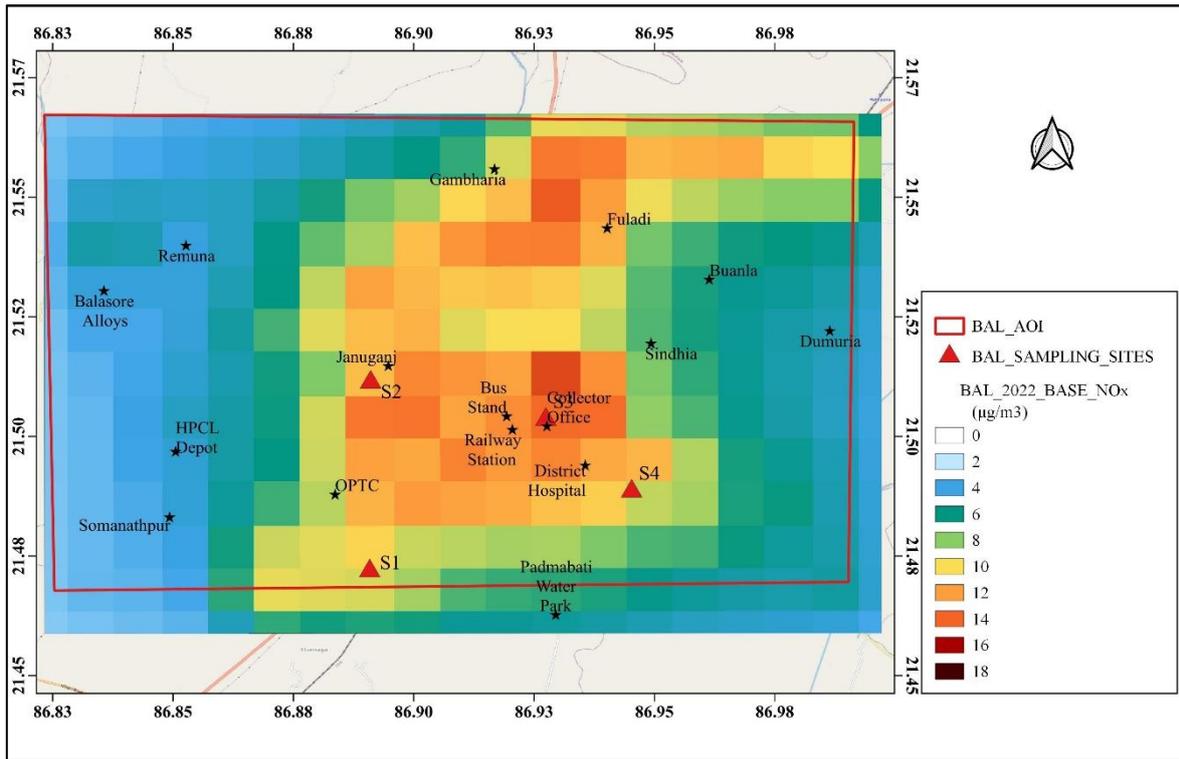


Figure 100 Map showing spatial distribution of annual mean NO₂ concentrations (µg/m³) over Balasore for year 2022

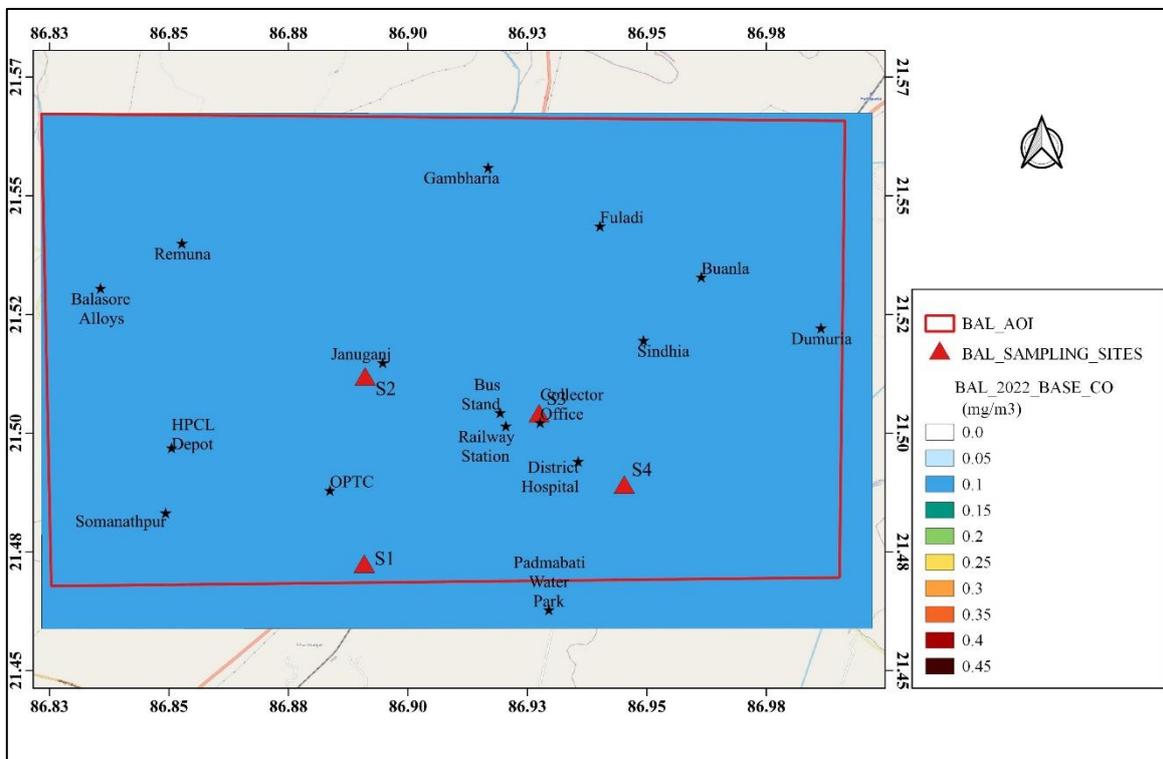


Figure 101 Map showing spatial distribution of annual mean CO concentrations (mg/m³) over Balasore for year 2022

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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 2022. 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 Balasore 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 2027 and 2032 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 2027 and 2032 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), improvement in NMT & public transport, reduction in silt loading on road surfaces, 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 (2027) and long term (2032). 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 2027 and 2032. 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 Balasore 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 percent ethanol blending in gasoline i.e. E20 fuelled vehicles in Balasore region, is included in the analysis in years 2027 and 2032. 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 2027 to 2032 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 Balasore region as well, which will in turn lead to significant reduction in vehicular exhaust emissions. The effect of increased EV penetration in Balasore 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 Balasore 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 2027 and 2032, respectively, due to promotion of NMT in Balasore region.

Table 20 Percentage VKT reduction of selected vehicle categories during future scenarios

Year	BAU	SC-I	SC-II
2027	0.25%	0.5%	1.0%
2032	0.5%	1.0%	2.0%

5.2.5. Public Transport Improvement (PTI)

Public transportation systems play a vital role in reducing traffic and environmental pollution. Many researchers world-wide have demonstrated the potential emission reductions from a shift towards public transport and zero emission buses (Al-Kheder, 2021; Carroll et al., 2019; Bakker and Konings, 2018). The VKT shift approach used by Sharma et al. (2010 and 2014) is adopted to calculate the VKT shifted to buses and emission reductions achieved. The details of assumptions are provided in Annexure-H.

5.3. Re-suspended Road Dust

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

There are no major air polluting industries in Balasore region however there are few coal-based industries located in Industrial estate in western part of the study area. For industries, it has been suggested to first maintain the air pollution control equipment properly and parallelly adopt Best Available Technologies (BAT) in their sector to achieve emission reductions in future years.

5.5. Residential, HRBE and Open Waste Burning Sectors

The quantification of emissions for future years, from residential sector mainly considers the increase in population and changes in fuel usage pattern in Balasore 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.

5.6. Brick Kilns Sector

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

5.7. Construction Sector

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

5.8. Crematoria Sector

Although, the emissions originating from crematoria contribute less than 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 electric crematoria till 2032 under different scenarios.

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

5.9. No Further Control (NFC) Scenario

The NFC scenario considers the activities in each sector would increase following the sectoral growth rates and no additional controls would be implemented till years 2027 and 2032. 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 2027 and 2032.

Table 21 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 NFC scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> • The vehicles in Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • 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 Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • No change in the silt loading on different road types in 2027 and 2032. 	Assumptions
3.	INDU	<ul style="list-style-type: none"> • Industrial emissions are assumed to grow at an annual rate of 8.5% • No additional emission reduction measures in-place i.e. same as baseline year 2022 	Odisha Economic Survey 2022-23, Assumptions
4.	RESI	<ul style="list-style-type: none"> • The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area remains same as the baseline year 2022 	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5..	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 2027 and 2032 would remain same as baseline year. 	
6.	HRBE	<ul style="list-style-type: none"> The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. The fuel usage characteristics and technology would remain same as the baseline year. 	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	<ul style="list-style-type: none"> The brick kilns are estimated to follow an annual growth rate of 6.4% till 2032. No change in the technology compared to baseline year 	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	<ul style="list-style-type: none"> The construction activities are assumed to increase at an annual growth rate of 6.4% till 2032 No reduction in PM. 	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> The deaths in 2027 and 2032 are estimated using the crude death rate (CDR). No electric crematoria. 	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	FUGT	<ul style="list-style-type: none"> Thermal powerplants are assumed to operate at same capacity as base year (2022) No additional controls in future years 	Assumptions
11.	DSGN	<ul style="list-style-type: none"> Residential and Commercial facilities are assumed to grow as per their sector-specific growth rates described above No additional control measures 	Odisha Economic Survey 2022-23, Assumptions

5.10. Business-As-Usual (BAU) Scenario

The BAU scenario considers the activity changes due to already planned policies/interventions by the government in years 2027 and 2032. 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 2027 and 2032 BAU scenario.

Table 22 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 BAU scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> • The vehicles in Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • 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 BMRCL, 2023 Assumptions
2.	RDST	<ul style="list-style-type: none"> • The vehicles in Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • The silt loading on different road types calculated by assuming following: <ul style="list-style-type: none"> ○ Year 2027: 15% silt load reduction @ Highways and Major roads and 10% silt load reduction @ Inter, Minor and residential roads 	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> ○ Year 2032: 30% silt load reduction @ Highways and Major roads and 20% silt load reduction @ Inter, Minor and residential roads 	
3.	INDU	<ul style="list-style-type: none"> • Industrial emissions are assumed to grow at an annual rate of 8.5% • Assumed an emission reduction for Industries: <ul style="list-style-type: none"> ○ 2027: 5% reduction in all pollutants w.r.t. corresponding NFC ○ 2032: 10% reduction in all pollutants w.r.t. corresponding NFC 	Odisha Economic Survey 2022-23, Assumptions
4.	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 2027: <ol style="list-style-type: none"> 1. Urban HH: 60% 2. Rural HH: 35% 3. Slum HH: 35% ○ Year 2032: <ol style="list-style-type: none"> 1. Urban HH: 60% 2. Rural HH: 40% 3. Slum HH: 40% 	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5..	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 2027: <ol style="list-style-type: none"> 1. Urban Area: 65% 2. Rural Area: 40% 3. Slum Area: 55% ○ Year 2032: <ol style="list-style-type: none"> 1. Urban HH: 70% 	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> 2. Rural HH: 50% 3. Slum HH: 60% 	
6.	HRBE	<ul style="list-style-type: none"> • The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • 10% and 20% facilities would be converted from wood/coal to LPG in years 2027 and 2032, respectively. 	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	<ul style="list-style-type: none"> • The brick kilns are estimated to follow an annual growth rate of 6.4% till 2032. • No change in the technology compared to baseline year. 	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	<ul style="list-style-type: none"> • The construction activities are assumed to increase at growth rate of 6.4% till 2032 • 2.5% and 5% reduction in PM in years 2027 and 2032, respectively, due to adoption of Good construction practices and stricter enforcement. 	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> • The deaths in 2027 and 2032 are estimated using the crude death rate. • The 30% of the cremations would be converted to electricity-based cremations. 	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	FUGT	<ul style="list-style-type: none"> • Industrial emissions are assumed to grow at an annual rate of 8.5% • 5% and 10% PM emission reduction compared to corresponding NFC scenarios in years 2027 and 2032, respectively. 	Assumptions
11.	DSGN	<ul style="list-style-type: none"> • Residential, commercial and industrial facilities are assumed to grow as per their sector-specific growth rates described above • Daily usage hours are assumed to vary between 2 – 3.5 hours depending on locality 	Odisha Economic Survey 2022-23, Assumptions

5.11. Scenario – I (SC-I)

The SC-I scenario considers the activity changes due to already planned policies/interventions by the government in years 2027 and 2032. 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 2027 and 2032 SC-I.

Table 23 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 SC-I scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> • The vehicles in Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • 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 BMRCL, 2023 Assumptions
2.	RDST	<ul style="list-style-type: none"> • The vehicles in Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • The silt loading on different road types calculated by assuming following: <ul style="list-style-type: none"> ○ Year 2027: 30% silt load reduction @ Highways and Major roads and 20% silt load reduction @ Inter, Minor and residential roads ○ Year 2032: 60% silt load reduction @ Highways and Major roads and 40% silt load reduction @ Inter, Minor and residential roads 	Assumptions
3.	INDU	<ul style="list-style-type: none"> • Industrial emissions are assumed to grow at an annual rate of 8.5% • Assumed an emission reduction for Industries: 	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> ○ 2027: 10% reduction in all pollutants w.r.t. corresponding NFC ○ 2032: 25% reduction in all pollutants w.r.t. corresponding NFC 	
4.	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 2027: <ol style="list-style-type: none"> 1. Urban HH: 70% 2. Rural HH: 50% 3. Slum HH: 50% ○ Year 2032: <ol style="list-style-type: none"> 1. Urban HH: 75% 2. Rural HH: 60% 3. Slum HH: 60% 	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	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 2027: <ol style="list-style-type: none"> 1. Urban Area: 70% 2. Rural Area: 50% 3. Slum Area: 60% ○ Year 2032: <ol style="list-style-type: none"> 1. Urban HH: 80% 2. Rural HH: 60% 3. Slum HH: 70% 	Assumptions
6.	HRBE	<ul style="list-style-type: none"> ● The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. ● 20 and 40% facilities would be converted from wood/coal to LPG in years 2027 and 2032, respectively. 	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	<ul style="list-style-type: none"> ● The brick kilns are estimated to follow a growth rate of 6.4% till 2032. ● All FCBTK brick kilns within urban areas would be converted to Zig-Zag kilns by 2027. 	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> All brick kilns within Urban + Industrial areas are converted to Zig-Zag technology by 2032. 	
8.	CONS	<ul style="list-style-type: none"> The construction activities are assumed to increase at growth rate of 6.4% till 2032 10 and 15% reduction in PM for years 2027 and 2032, respectively, due to adoption of Good construction practices and stricter enforcement. 	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> The deaths in 2027 and 2032 are estimated using the crude death rate. The 30% and 60% of the cremations would be converted to electricity-based cremations, by 2027 and 2032, respectively. 	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	FUGT	<ul style="list-style-type: none"> Industrial emissions are assumed to grow at an annual rate of 8.5% 20% and 25% PM emission reduction compared to corresponding NFC scenarios in years 2027 and 2032 	Assumptions
11.	DSGN	<ul style="list-style-type: none"> Residential, commercial and industrial facilities are assumed to grow as per their sector-specific growth rates described above Daily usage hours are assumed to vary between 1.5-3.0 hours depending on locality 	Odisha Economic Survey 2022-23, Assumptions

5.12. Scenario – II (SC-II)

The SC-II scenario considers the activity changes due to already planned policies/interventions by the government in years 2027 and 2032. 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 2027 and 2032 SC-II scenario.

Table 24 Sector-wise growth rate, assumptions, considerations and controls used to estimate the emissions for 2027 and 2032 SC-II scenario

Sr. No.	Sector	Assumptions, considerations and controls	References
1.	TRAN	<ul style="list-style-type: none"> • The vehicles in Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • 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 BMRCL, 2023 Assumptions
2.	RDST	<ul style="list-style-type: none"> • The vehicles in Balasore region are estimated to grow at a CAGR of 8.1% till 2032. • The silt loading on different road types calculated by assuming following: <ul style="list-style-type: none"> ○ Year 2027: 50% silt load reduction @ Highways and Major roads and 30% silt load reduction @ Inter, Minor and residential roads ○ Year 2032: 90% silt load reduction @ Highways and Major roads and 60% silt load reduction @ Inter, Minor and residential roads 	Assumptions
3.	INDU	<ul style="list-style-type: none"> • Industrial emissions are assumed to grow at an annual rate of 8.5% • Assumed an emission reduction for Industries: 	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		<ul style="list-style-type: none"> ○ 2027: 25% reduction in all pollutants w.r.t. corresponding NFC ○ 2032: 50% reduction in all pollutants w.r.t. corresponding NFC 	
4.	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 2027: <ol style="list-style-type: none"> 1. Urban HH: 80% 2. Rural HH: 60% 3. Slum HH: 60% ○ Year 2032: <ol style="list-style-type: none"> 1. Urban HH: 90% 2. Rural HH: 80% 3. Slum HH: 80% 	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	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 2027: <ol style="list-style-type: none"> 1. Urban Area: 80% 2. Rural Area: 60% 3. Slum Area: 70% ○ Year 2032: <ol style="list-style-type: none"> 1. Urban HH: 90% 2. Rural HH: 70% 3. Slum HH: 80% 	Assumptions
6.	HRBE	<ul style="list-style-type: none"> • The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • 30 and 50% facilities would be converted from wood/coal to LPG by years 2027 and 2032, respectively. 	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	<ul style="list-style-type: none"> • The brick kilns are estimated to follow a growth rate of 6.4% till 2032. • All brick kilns within study area would be converted to VSBK/Zig-Zag technology by 2032. 	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
8.	CONS	<ul style="list-style-type: none"> The construction activities are assumed to increase at growth rate of 6.4% till 2032 20 and 30% reduction in PM for years 2027 and 2032, respectively, due to adoption of Good construction practices and stricter enforcement. 	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	<ul style="list-style-type: none"> The deaths in 2027 and 2032 are estimated using the crude death rate. The 60% and 100% of the cremations would be converted to electricity, by 2027 and 2032, respectively. 	Based on past trends of crude death rate of Odisha (Vital statistics of India based civil registration systems 2020) Assumptions
10.	FUGT	<ul style="list-style-type: none"> Industrial emissions are assumed to grow at an annual rate of 8.5% 25% and 50% PM emission reduction compared to corresponding NFC scenarios in years 2027 and 2032. 	Assumptions
11.	DSGN	<ul style="list-style-type: none"> Residential, commercial and industrial facilities are assumed to grow as per their sector-specific growth rates described above Daily usage hours are assumed to vary between 1 to 1.5 hours depending on locality 	Odisha Economic Survey 2022-23, Assumptions

5.13. Projected Emissions for 2027 and 2032

This section discusses the projected emissions of pollutants under consideration with implementation of considered scenarios in 2027 and 2032 in Balasore region. As discussed earlier, these scenarios consider implementation of various control measures explained in Section 5.12 in Balasore region with varying factors for 2027 and 2032. Table 25 and Figures 102 to 106 presents the summary of estimated emissions (tonnes per year) of selected pollutants for four scenarios in Balasore region for years 2027 and 2032.

The No further control (NFC) scenario emissions are compared against the baseline year emissions of 2022. The NFC scenario projections in Balasore region indicate a potential increase in PM₁₀ emissions to 8938 tonnes per year in 2027 i.e. an increase of 64.2% w.r.t. baseline year 2022 and to 13792 tonnes per year in 2032 i.e. an increase of 153.4% w.r.t. baseline year 2022. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to reach to 3280 (45.7%) and to 4632 tonnes per year (i.e. 105.8%) in 2027 and 2032, respectively. The projected emissions of SO₂ indicate a potential increase to 2150 tonnes per year in 2027 i.e. an increase of 41.2% w.r.t. baseline year 2022 and to 2779 tonnes per year in 2032 i.e. an increase of 82.5% w.r.t. baseline year 2022. The projected emissions of NO_x indicate a potential increase to 6384 tonnes per year in 2027 i.e. an increase of 19.1% w.r.t. baseline year 2022 and to 7080 tonnes per year in 2032 i.e. an increase of 32.1% w.r.t. baseline year 2022. The CO emissions are expected to increase to 13948 tonnes per year in 2027 i.e. a decrease of 8.1% and 17322 tonnes per year in 2032 i.e. an increase of 14.1% w.r.t. baseline year 2022.

The BAU projections in Balasore region indicate a potential decrease of PM₁₀ emissions to 7879 tonnes per year in 2027 i.e. a decrease of 11.9 % w.r.t. NFC 2027 and to 10346 tonnes per year in 2032 i.e. a decrease of 25.0% w.r.t. NFC 2032. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 2957 (-9.8%) and to 3578 tonnes per year (i.e. -22.8%) in 2027 and 2032, respectively. Sulphur dioxide (SO₂) emissions are projected to decrease by 5.8% (i.e. 2026 tonnes per year) and decrease by 11.6% (i.e. 2457 tonnes per year) in 2027 and 2032, respectively relative to their respective NFC scenarios. The projected emissions of NO_x indicate a potential reduction to 6039 tonnes per year in 2027 i.e. a decrease of 5.4% w.r.t. NFC_2027 and to 6126 tonnes per year in 2032 i.e. a decrease of 13.5% w.r.t. NFC 2032. The CO emissions are expected to decrease to 13114 tonnes per year in 2027 i.e. a

decrease of 6.0% w.r.t. NFC 2027 and 15323 tonnes per year in 2032 i.e. a decrease of 11.5% w.r.t. NFC 2032.

The SC-I projections in Balasore region indicate a potential decrease of PM₁₀ emissions to 6703 tonnes per year in 2027 i.e. a decrease of 25.0% w.r.t. NFC 2027 and to 6705 tonnes per year in 2032 i.e. a decrease of 47.0% w.r.t. NFC 2032. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 2533 (-22.8%) and to 2454 tonnes per year (i.e. -47.0%) in 2027 and 2032, respectively. Sulphur dioxide emissions are projected to decline by 11.9% (i.e. 1894 tonnes per year) and 27.2% (i.e. 2024 tonnes per year) in 2027 and 2032, respectively, relative to their respective NFC scenarios. Similarly, projected emissions of NO_x indicate a potential reduction to 5611 tonnes per year in 2027 i.e. a decrease of 12.1% w.r.t. NFC 2027 and to 5350 tonnes per year in 2032 i.e. a decrease of -24.4% w.r.t. NFC 2032. The CO emissions are expected to decrease to 11566 tonnes per year in 2027 i.e. a decrease of 17.1% w.r.t. NFC 2027 and 12704 tonnes per year in 2032 i.e. a decrease of 26.7% w.r.t. NFC 2032.

The SC-II projections in Balasore region indicate a potential decrease of PM₁₀ emissions to 5101 tonnes per year in 2027 i.e. a decrease of 42.9% w.r.t. NFC 2027 and to 2782 tonnes per year in 2032 i.e. a decrease of 79.8% w.r.t. NFC 2032. The finer PM fraction i.e. PM_{2.5} emissions are also estimated to decrease to 1977 (i.e. -39.7%) and to 1240 tonnes per year (i.e. -73.2%) in 2027 and 2032, respectively. Sulphur dioxide (SO₂) emissions are projected to decline by 26.7% (i.e. 1577 tonnes per year) and 50.8% (i.e. 1366 tonnes per year) in 2027 and 2032, respectively, relative to their respective NFC scenarios. Similarly, the projected emissions of NO_x indicate a potential reduction to 5019 tonnes per year in 2027 i.e. a decrease of 21.4 w.r.t. NFC 2027 and to 4356 tonnes per year in 2032 i.e. a decrease of 38.5% w.r.t. NFC 2032. The CO emissions are expected to decrease to 9955 tonnes per year in 2027 i.e. a decrease of 28.6% w.r.t. NFC 2027 and 10013 tonnes per year in 2032 i.e. a decrease of 42.2% w.r.t. NFC 2032.

Table 25 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Balasore region for years 2022, 2027 and 2032

Year	Scenario	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO
2022	BASE	5,443	2,251	1,523	5,361	15,183
2027	NFC	8,938	3,280	2,150	6,384	13,948
	BAU	7,879	2,957	2,026	6,039	13,114
	SC_I	6,703	2,533	1,894	5,611	11,566
	SC_II	5,101	1,977	1,577	5,019	9,955
2032	NFC	13,792	4,632	2,779	7,080	17,322
	BAU	10,346	3,578	2,457	6,126	15,323
	SC_I	6,705	2,454	2,024	5,350	12,704
	SC_II	2,782	1,240	1,366	4,356	10,013

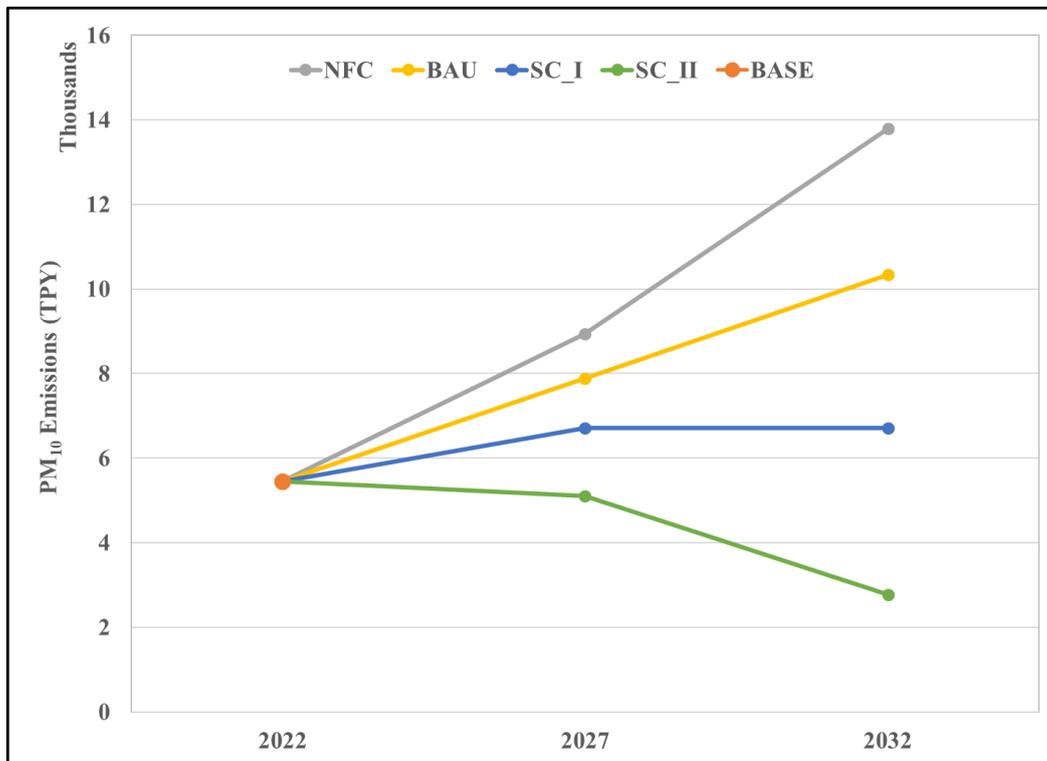


Figure 102 PM₁₀ Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

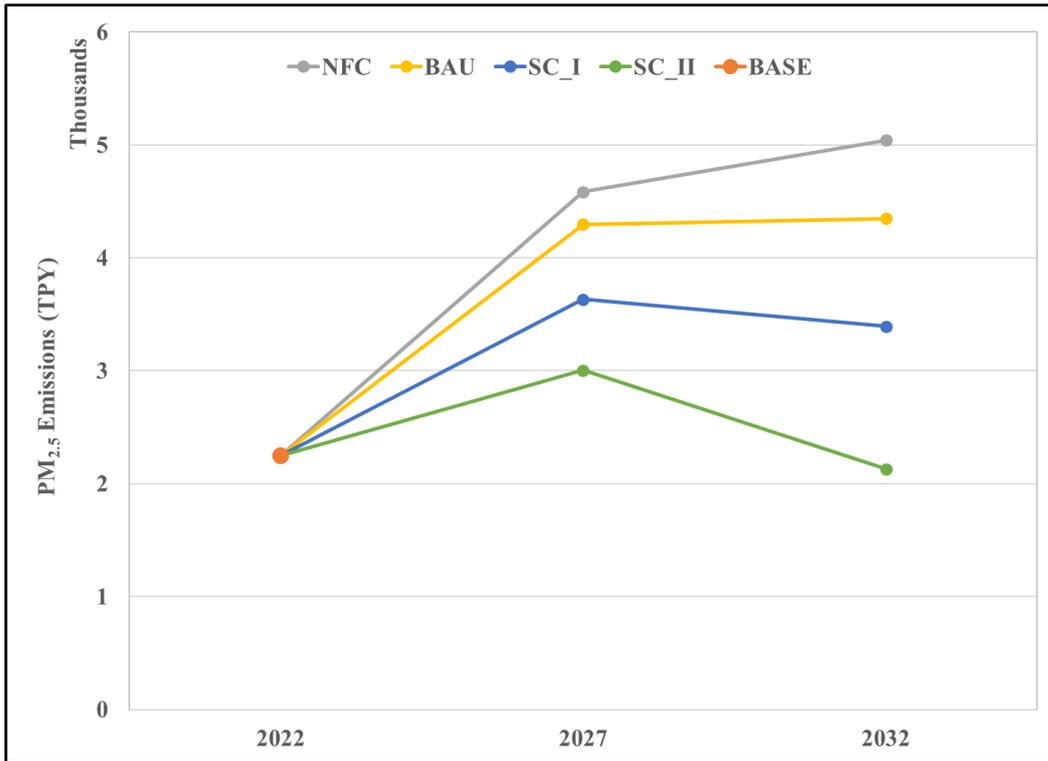


Figure 103 PM_{2.5} Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

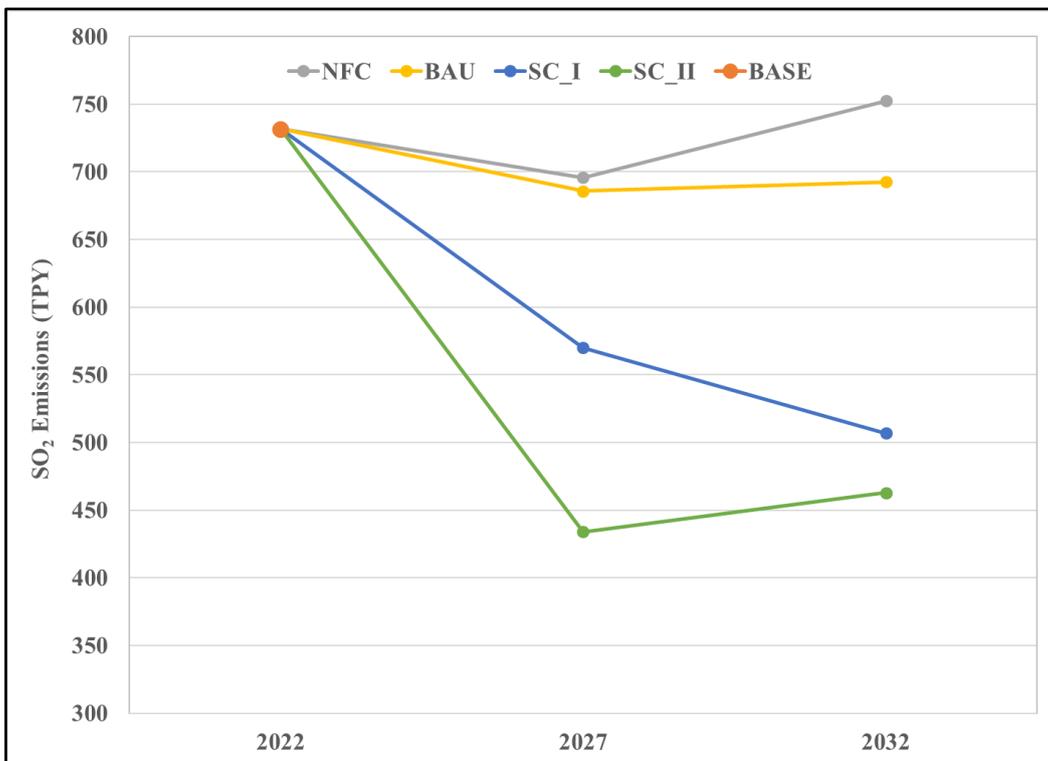


Figure 104 SO₂ Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

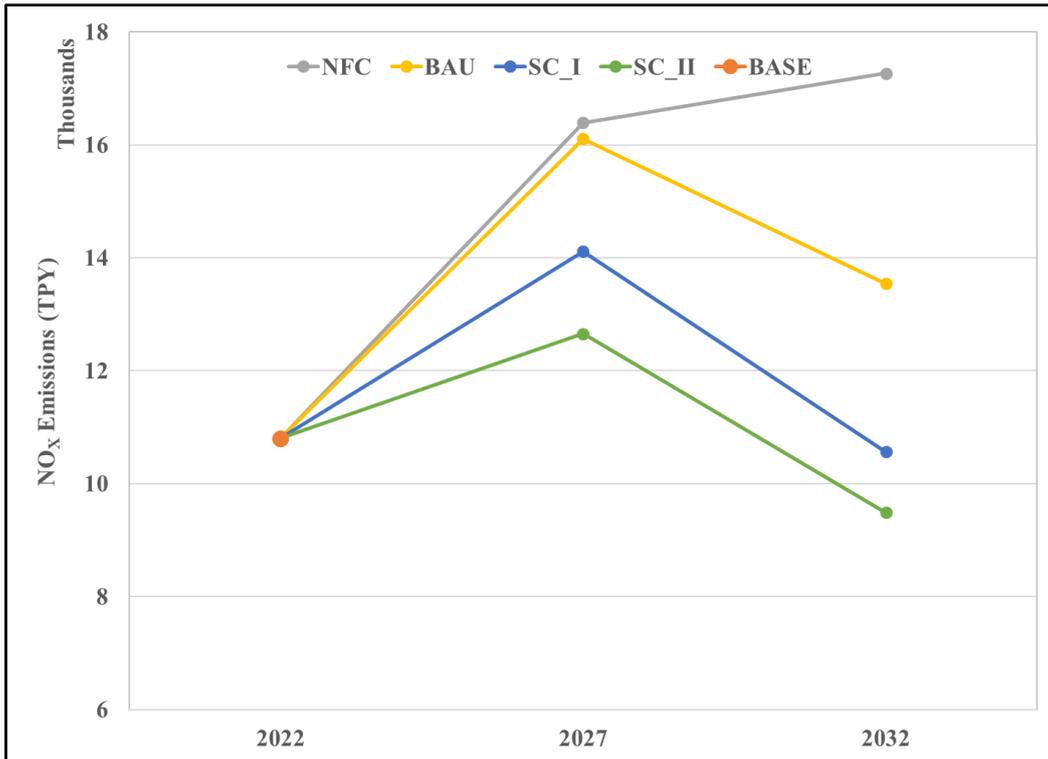


Figure 105 NO_x Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

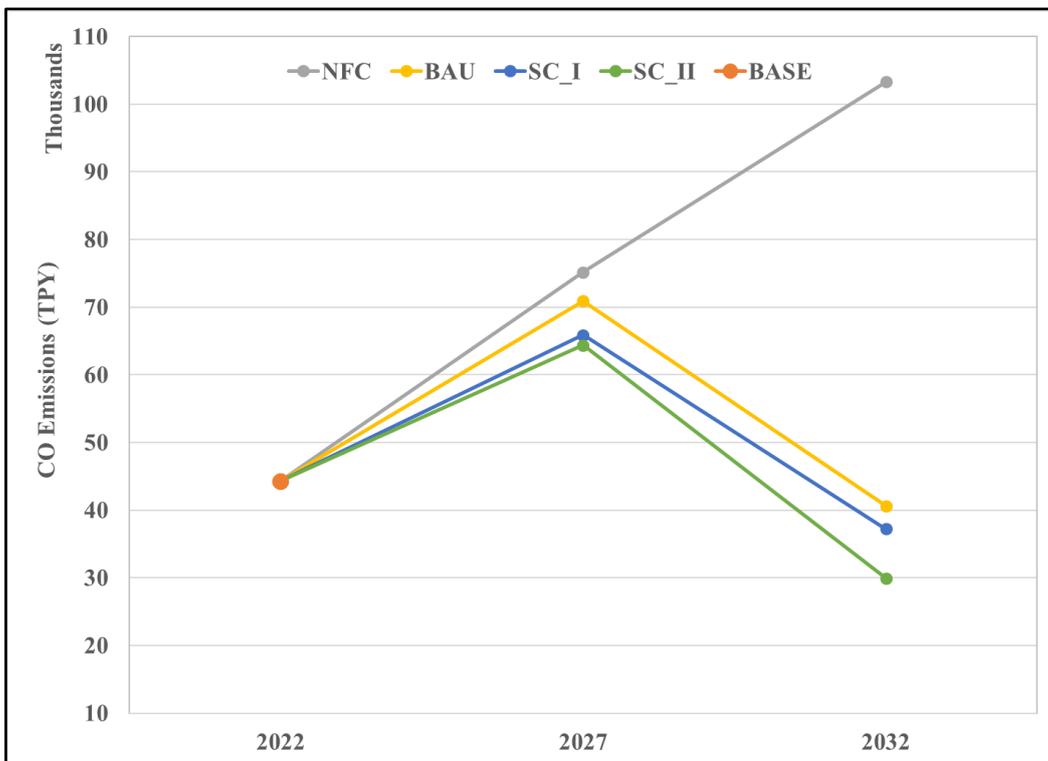


Figure 106 CO Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

5.13.1. Sector-wise emission reduction potentials

Table 26 and Fig. 107-111 shows sector-wise and total estimated emission reduction potential (%) of pollutants w.r.t. respective NFC scenarios in Balasore region for years 2027 and 2032. The total emissions of particulate matter in 2027 can be reduced upto maximum 42.9% and 39.7% in PM₁₀ and PM_{2.5}, respectively w.r.t. NFC 2027 scenario. Similarly, total emissions of particulate matter in 2032 can be reduced upto maximum 79.8% and 73.2% in PM₁₀ and PM_{2.5}, respectively w.r.t. NFC 2032 scenario. In year 2032 the sectoral emission reduction potential for PM₁₀ in decreasing order of reduction are road dust (upto 68.53%), industries (upto 2.46%), open waste burning (upto 2.44%) and residential (upto 2.35%). Remaining PM₁₀ emission sources together contribute 4.03% reduction in PM₁₀. Similarly, for PM_{2.5} significant emission reductions can be obtained in re-suspended road dust (upto 49.37%), open waste burning (upto 6.76%), industries (upto 4.88%), and residential (upto 4.72%)

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

Year	Sector	PM ₁₀			PM _{2.5}		
		BAU	SC-I	SC-II	BAU	SC-I	SC-II
2027	INDU	-0.29%	-0.59%	-1.46%	-0.5%	-1.1%	-2.65%
	TRAN	-0.01%	-0.13%	-0.30%	0.0%	-0.3%	-0.73%
	RDST	-10.05%	-20.21%	-33.94%	-6.6%	-13.3%	-22.37%
	WAST	-0.34%	-1.16%	-2.32%	-0.9%	-2.9%	-5.87%
	CONS	0.00%	-0.02%	-0.03%	0.0%	0.0%	-0.02%
	DSGN	-0.28%	-0.55%	-0.83%	-0.7%	-1.3%	-1.97%
	RESI	-0.47%	-1.45%	-2.18%	-0.9%	-2.7%	-4.00%
	BRIC	-0.03%	-0.03%	-0.43%	0.0%	0.0%	-0.14%
	HRBE	-0.32%	-0.65%	-0.97%	-0.6%	-1.2%	-1.75%
	CREM	0.00%	-0.11%	-0.17%	0.0%	-0.3%	-0.48%
	FUGT	-0.06%	-0.12%	-0.29%	0.0%	0.0%	-0.08%
	Total	-11.9%	-25.0%	-42.9%	-9.8%	-22.8%	-39.7%
2032	INDU	-0.49%	-1.23%	-2.46%	-0.98%	-2.44%	-4.88%
	TRAN	-0.08%	-0.19%	-0.37%	-0.21%	-0.51%	-1.00%
	RDST	-21.87%	-44.55%	-68.53%	-15.75%	-32.09%	-49.37%
	WAST	-0.81%	-1.63%	-2.44%	-2.25%	-4.50%	-6.76%
	CONS	-0.01%	-0.02%	-0.04%	-0.01%	-0.02%	-0.03%
	DSGN	-0.46%	-0.71%	-0.94%	-1.18%	-1.84%	-2.43%
	RESI	-0.51%	-1.46%	-2.35%	-1.02%	-2.92%	-4.72%
	BRIC	-0.03%	-0.10%	-0.35%	-0.01%	-0.05%	-0.12%
	HRBE	-0.56%	-1.12%	-1.68%	-1.10%	-2.21%	-3.31%
	CREM	-0.07%	-0.12%	-0.16%	-0.22%	-0.37%	-0.47%
	FUGT	-0.10%	-0.25%	-0.49%	-0.03%	-0.07%	-0.15%
	Total	-25.0%	-51.4%	-79.8%	-22.8%	-47.0%	-73.2%

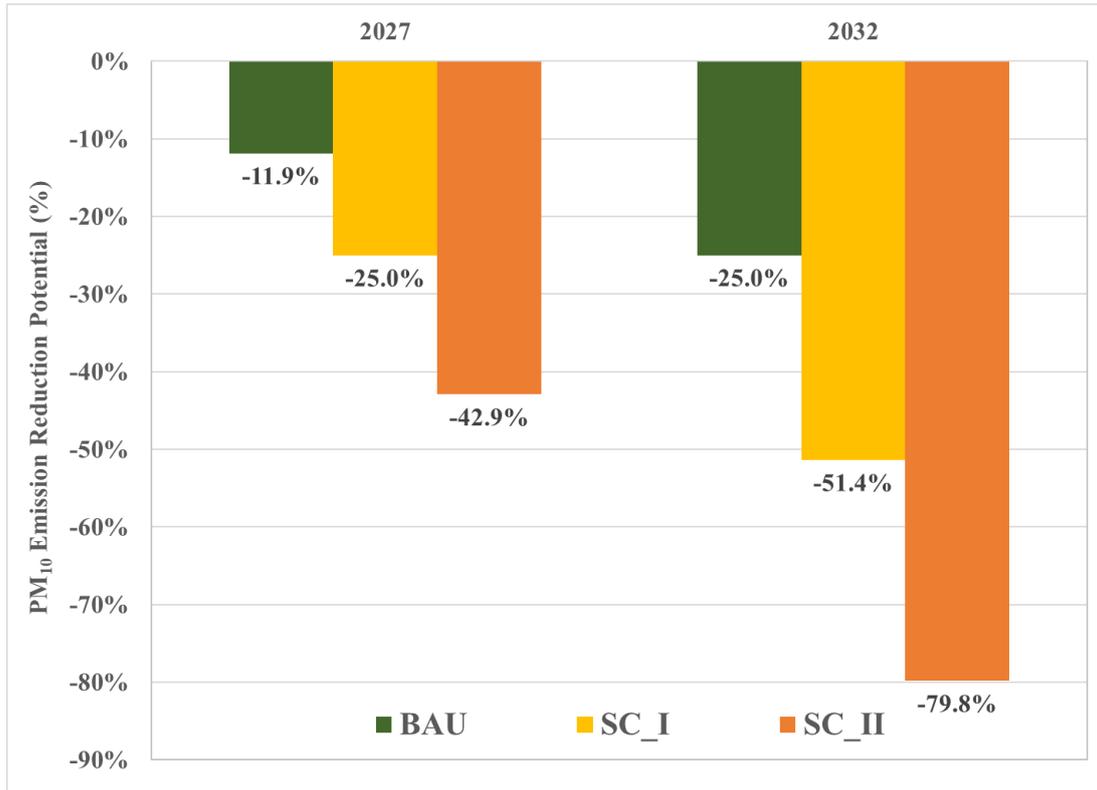


Figure 107 PM10 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

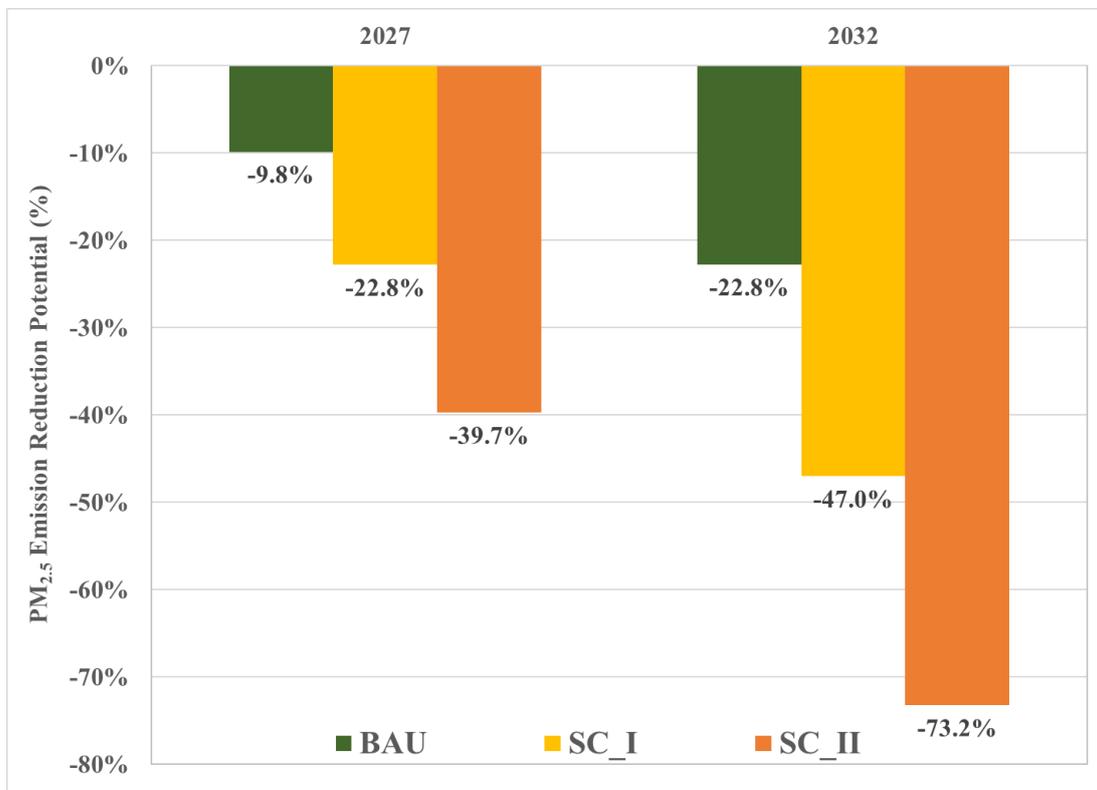


Figure 108 PM2.5 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

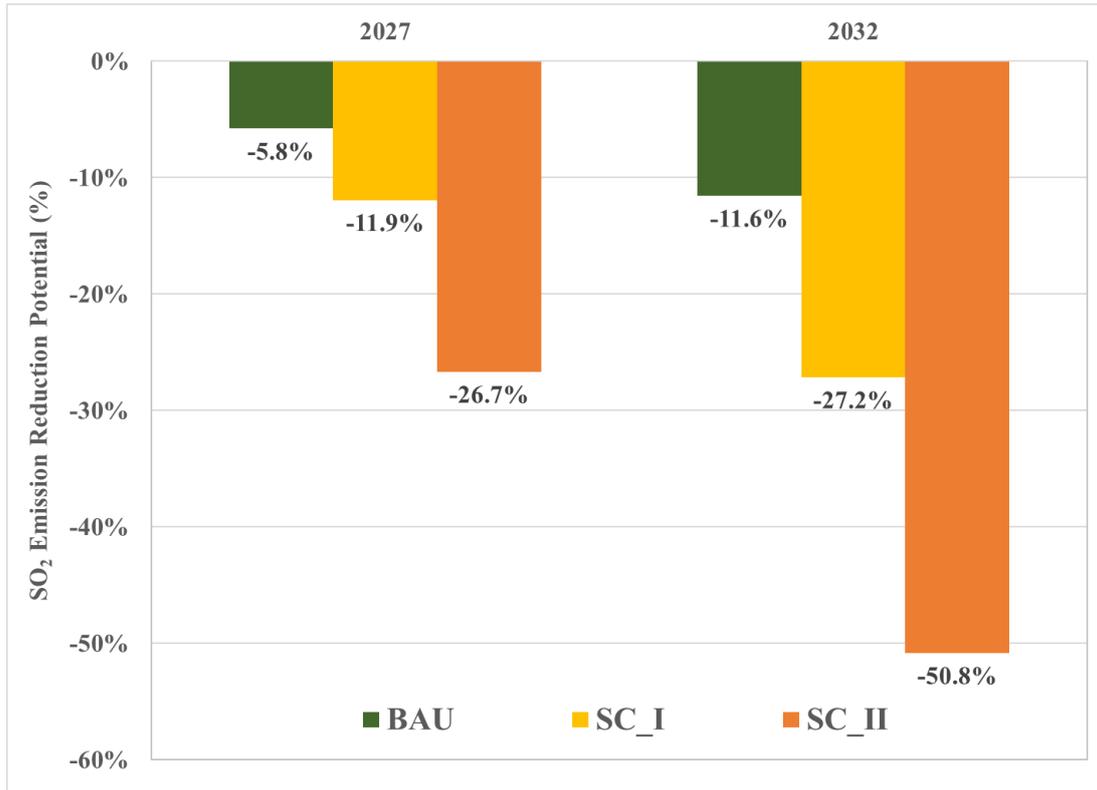


Figure 109 SO₂ Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

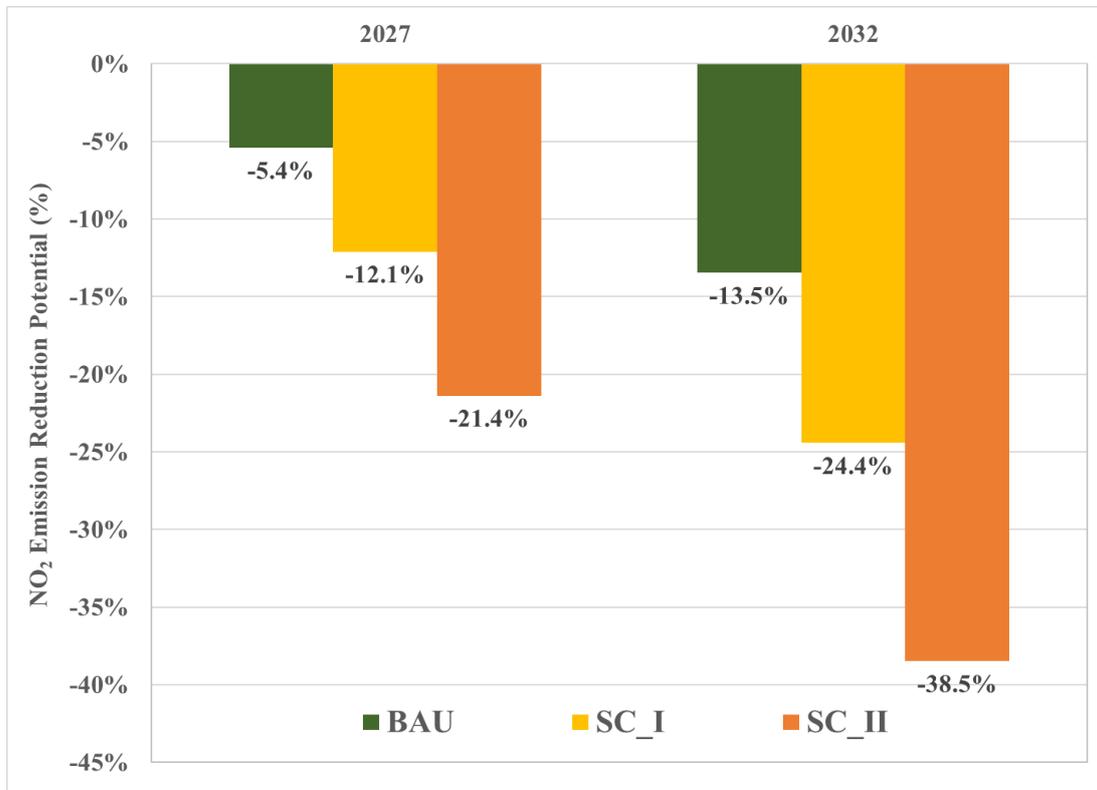


Figure 110 NO_x Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

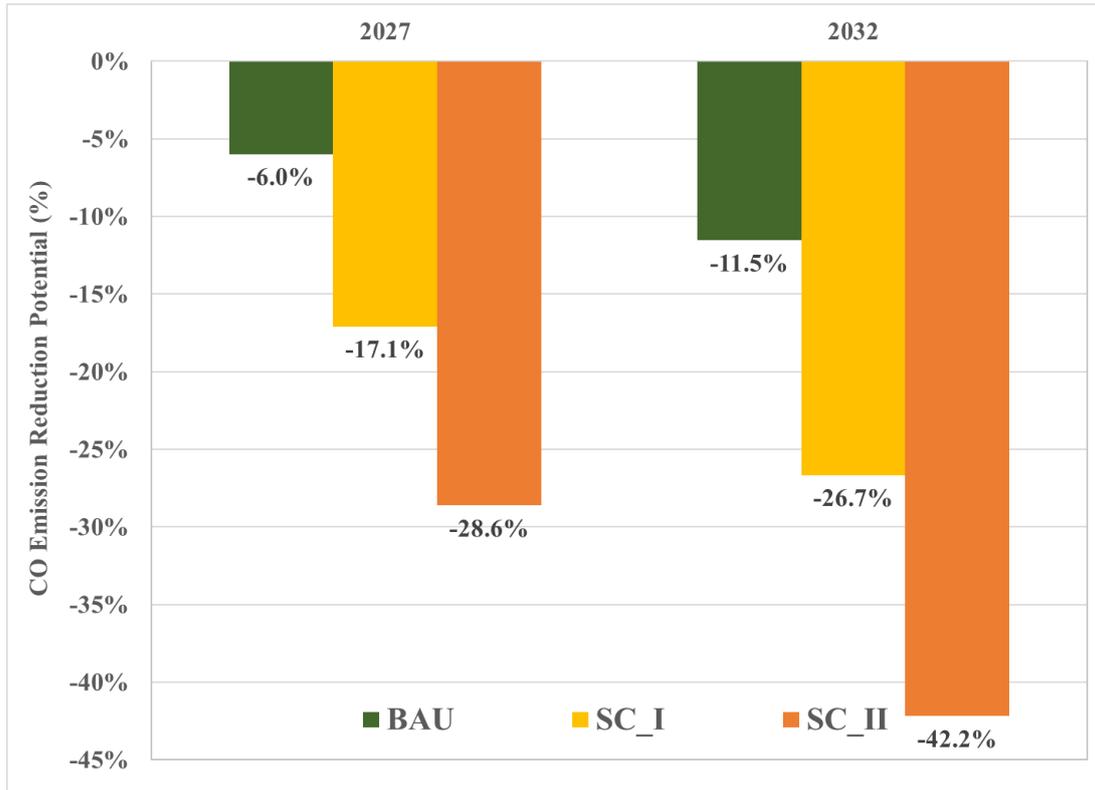


Figure 111 CO Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

5.14. Air Quality Benefits

Air quality benefits of four designed scenarios were assessed for years 2027 and 2032 using AERMOD modelled annual mean pollutant concentrations in Balasore. The spatial distribution of pollutant (PM₁₀, PM_{2.5}, SO₂, NO₂, CO) concentration levels over Balasore region are plotted in gridded format using QGIS. The annual mean concentrations are plotted for year 2027 and 2032 for different scenarios.

In general, the highest estimated concentrations of particulate matter i.e. PM₁₀ and PM_{2.5} are observed towards central parts of Balasore as well as southern parts of the study domain. These highest concentrations can be attributed to the air polluting sources such exhaust emissions, road dust emissions due to vehicular movement, fuel combustion in households and commercial facilities. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2027 and 2032 due to proposed changes in technology and fuels of vehicles such as EV adoption, increased penetration of BS-VI vehicles, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, NMT & improvement in public transport, introduction of mass rapid transit system (MRTS), increasing use 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 112-113, the PM₁₀ concentrations for NFC scenario in 2027 and 2032, are mainly concentrated in the central parts of the Balasores. The domain-averaged annual PM₁₀ concentrations (i.e. mean of annual concentrations of 247 receptors in the study domain) estimated by AERMOD during four scenarios are 68.1, 63.6, 58.7 and 52.1 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual PM₁₀ concentrations during year 2032 are estimated to be 88.7, 74.1, 58.8 and 42.3 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 5.6%, 11.8% and 20.1% in 2027 and 14.0%, 28.7% and 44.4% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 114-115, the PM_{2.5} concentrations, are also concentrated in central parts of the Balasore. The domain-averaged annual PM_{2.5} concentrations (i.e. mean of annual concentrations of 247 receptors in the study domain) estimated by AERMOD during four scenarios are 31.5, 30.2, 28.5 and 26.5 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual PM_{2.5} concentrations during year 2032 are estimated to be 36.9, 32.7, 28.2 and 23.5 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 3.7%, 8.5%, and 14.4% in 2027 and 10.0%, 20.6%, and 31.7% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 116-117, the SO₂ concentrations, are concentrated in the central parts of the Balasore. The domain-averaged annual SO₂ concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 3.5, 3.4, 3.2 and 2.9 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual SO₂ concentrations (i.e. mean of annual concentrations of 247 receptors in the study domain) are estimated to be 4.1, 3.7, 3.3 and 2.8 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2032, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 4.2%, 9.3%, and 16.0% in 2027 and 9.4%, 18.6%, 29.6% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 118-119, the NO₂ concentrations, are also concentrated in central parts of the Balasore. Ambient NO₂ concentrations are mainly driven by ground-level line sources and are found to be highest in the vicinity of highways and major roads where heavy vehicle movement is high. The domain-averaged annual NO₂ concentrations (i.e. mean of annual concentrations of 247 receptors in the study domain) estimated by AERMOD during four scenarios are 7.4, 7.3, 7.1 and 6.8 µg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual NO₂ concentrations during year 2032 are estimated to be 7.6, 7.1, 6.7 and 6.3 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 1.8%, 4.5%, and 8.0% in 2027. With implementation of control measures considered in different scenarios, an estimated reduction of 5.2%, 9.5%, and 15.0% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 120-121, the CO concentrations, are also concentrated in the central, parts of the Balasore. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 247 receptors in the study domain) estimated by AERMOD during four scenarios are 0.161, 0.158, 0.152 and 0.146 mg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 247 receptors in the study domain) estimated to be 0.178, 0.170, 0.160 and 0.149 mg/m³ for NFC, BAU, SC-I and SC-II scenarios in year 2032, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 1.8%, 5.3%, and 8.8% in 2027 and 4.0%, 9.2%, 14.7% in 2032, 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.

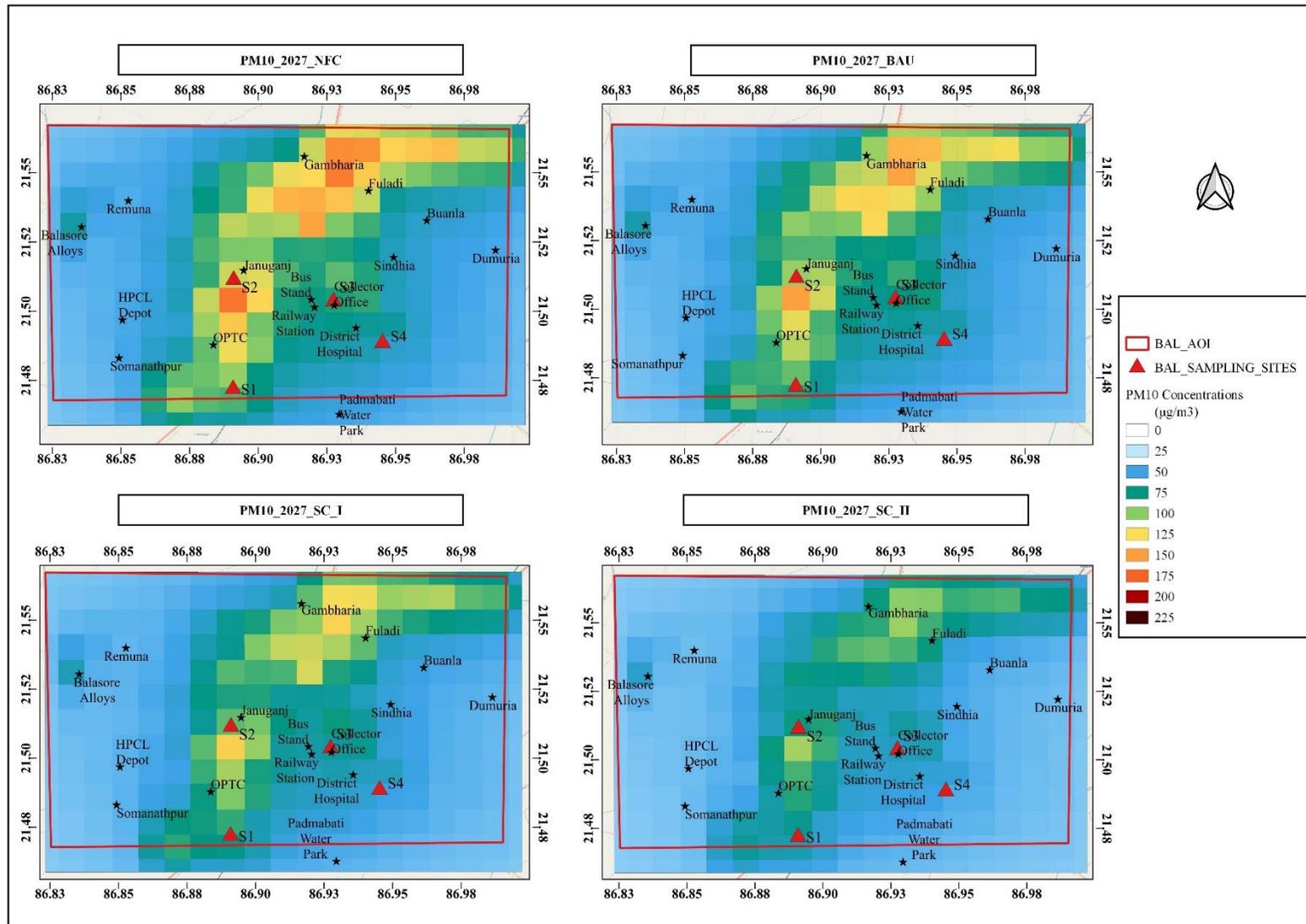


Figure 112 Spatial distribution of annual mean PM₁₀ concentrations ($\mu\text{g}/\text{m}^3$) for four scenarios in year 2027 over Balasore region

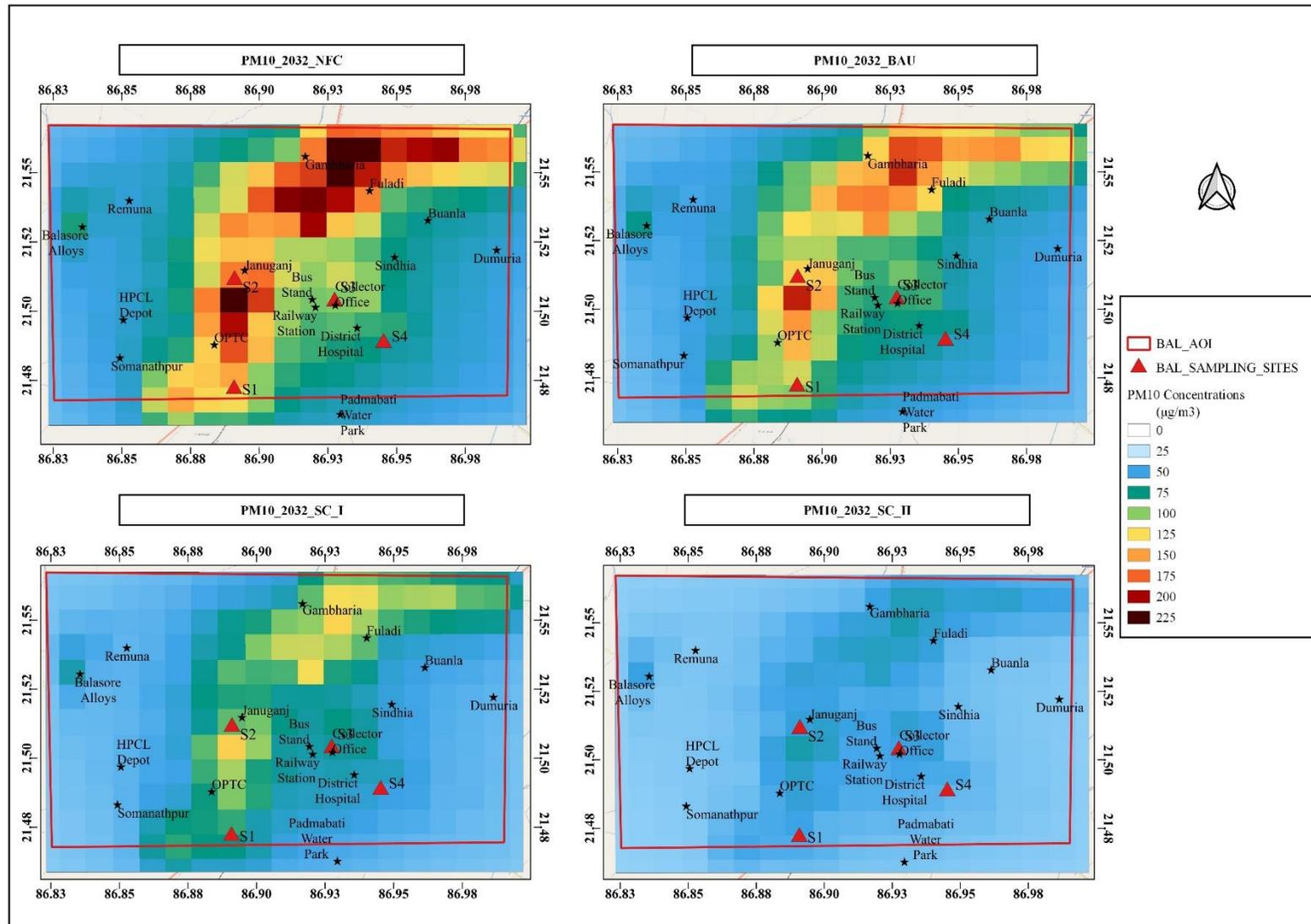


Figure 113 Spatial distribution of annual mean PM₁₀ concentrations ($\mu\text{g}/\text{m}^3$) for four scenarios in year 2032 over Balasore region

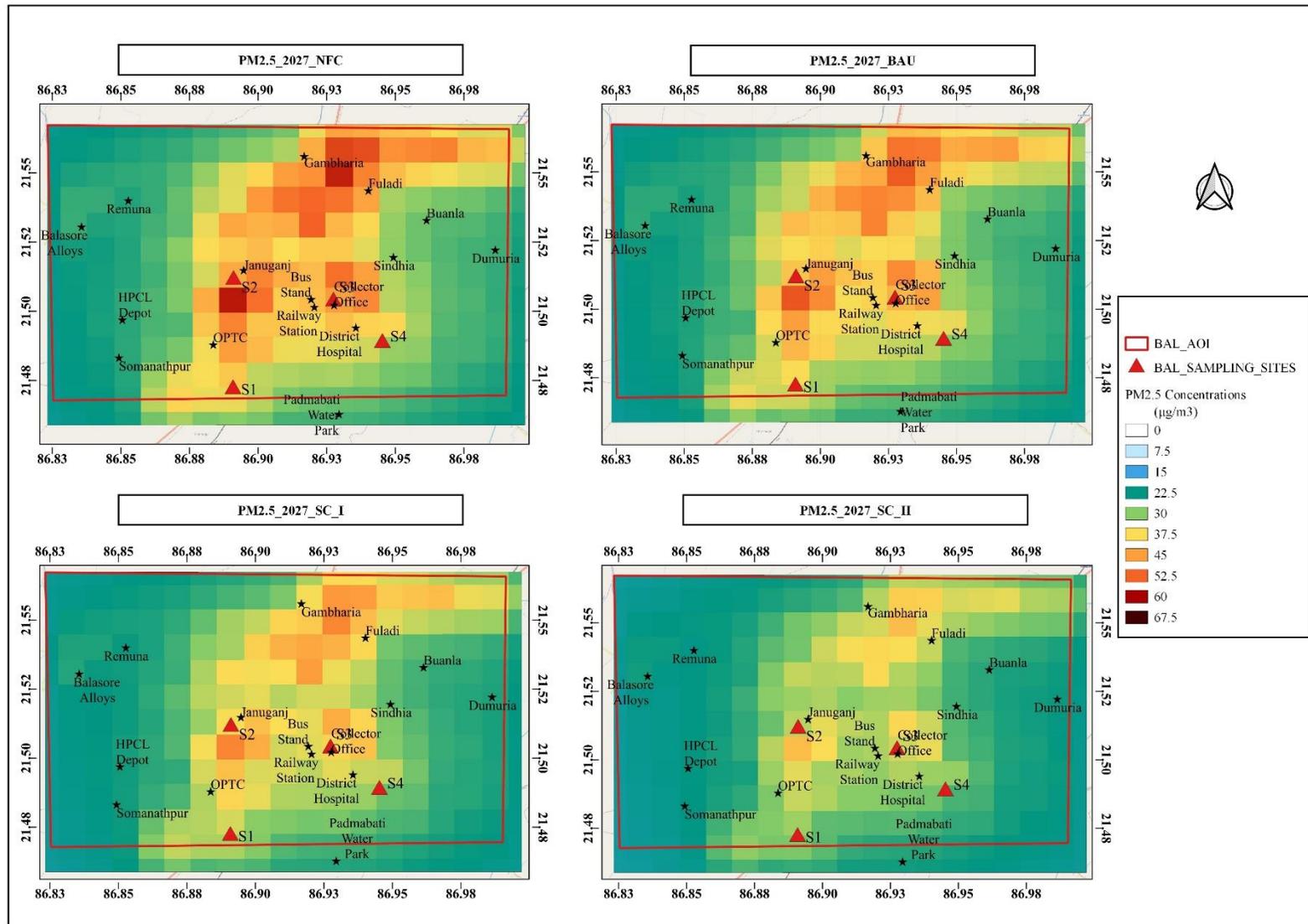


Figure 114 Spatial distribution of annual mean PM_{2.5} concentrations (µg/m³) for four scenarios in year 2027 over Balasore region

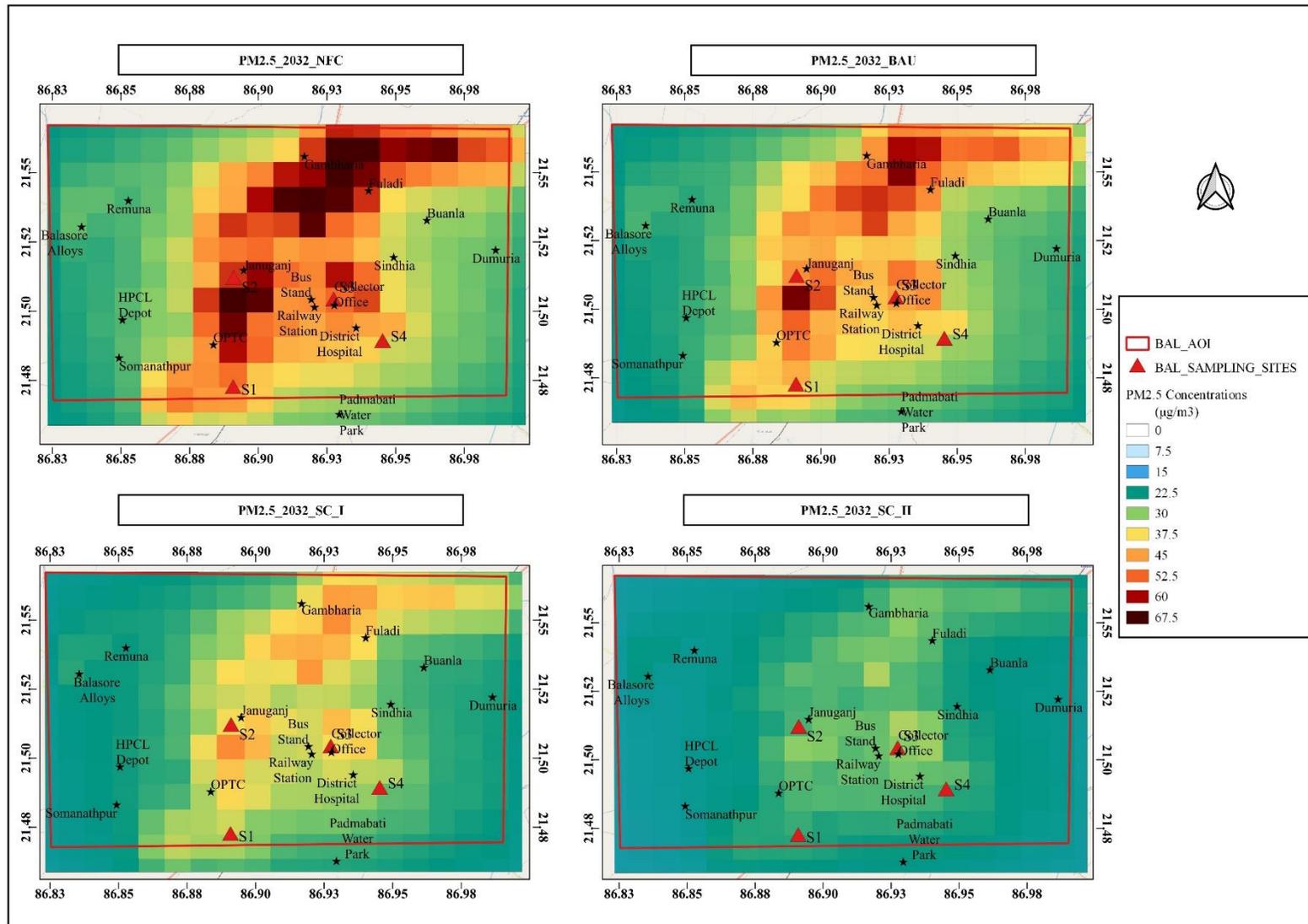


Figure 115 Spatial distribution of annual mean PM_{2.5} concentrations (µg/m³) for four scenarios in year 2032 over Balasore region

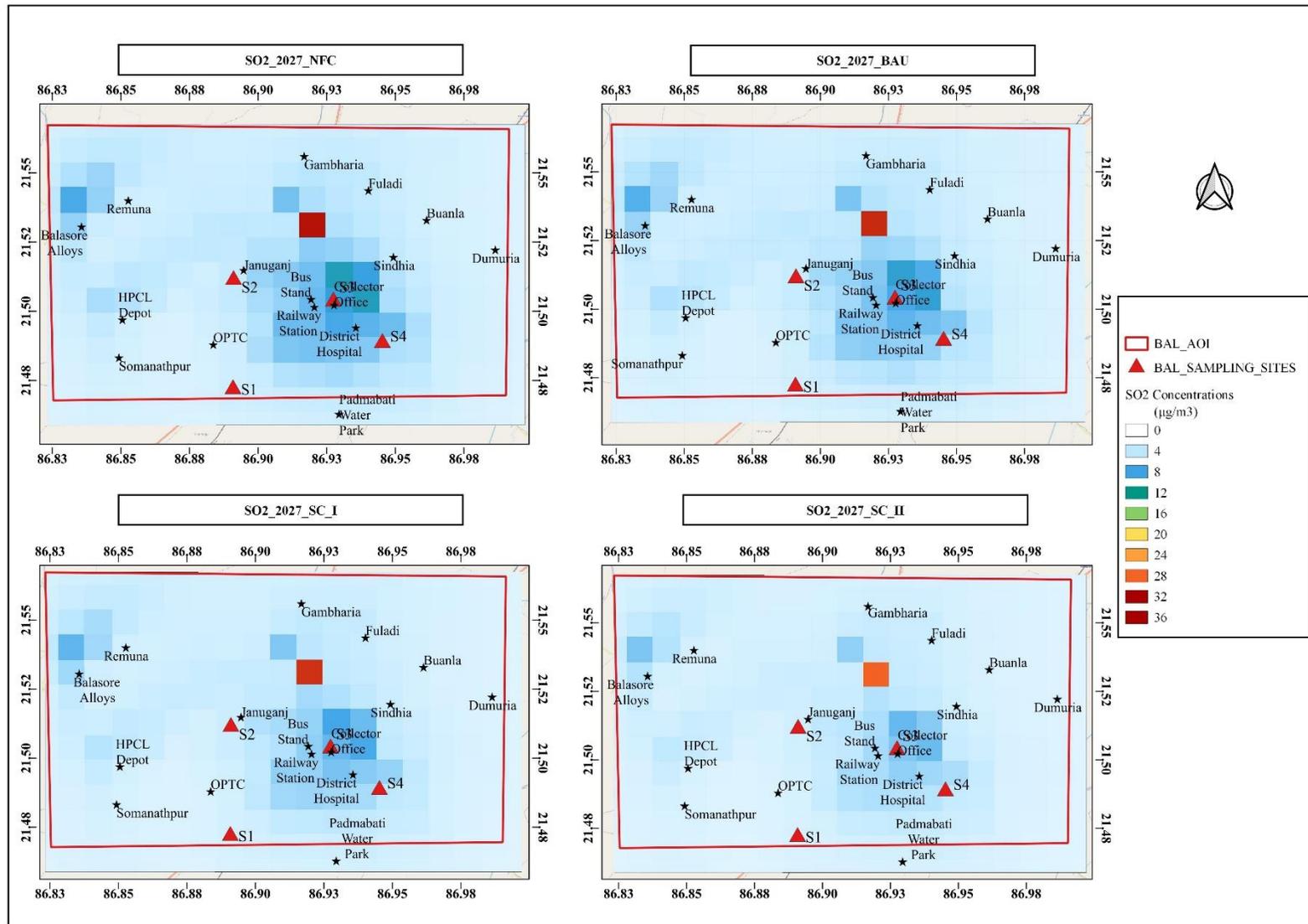


Figure 116 Spatial distribution of annual mean SO₂ concentrations (µg/m³) for four scenarios in year 2027 over Balasore region

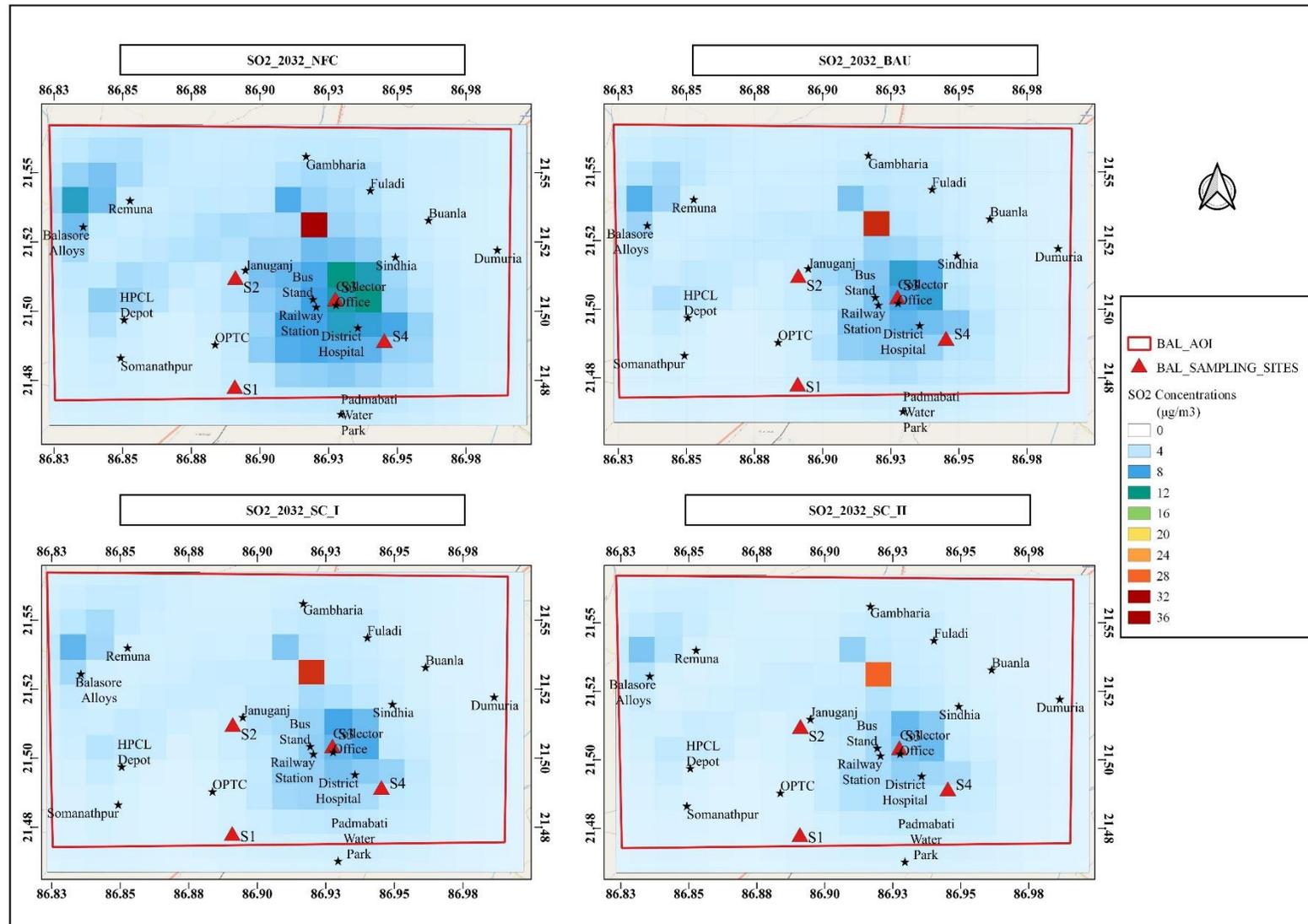


Figure 117 Spatial distribution of annual mean SO₂ concentrations (µg/m³) for four scenarios in year 2032 over Balasore region

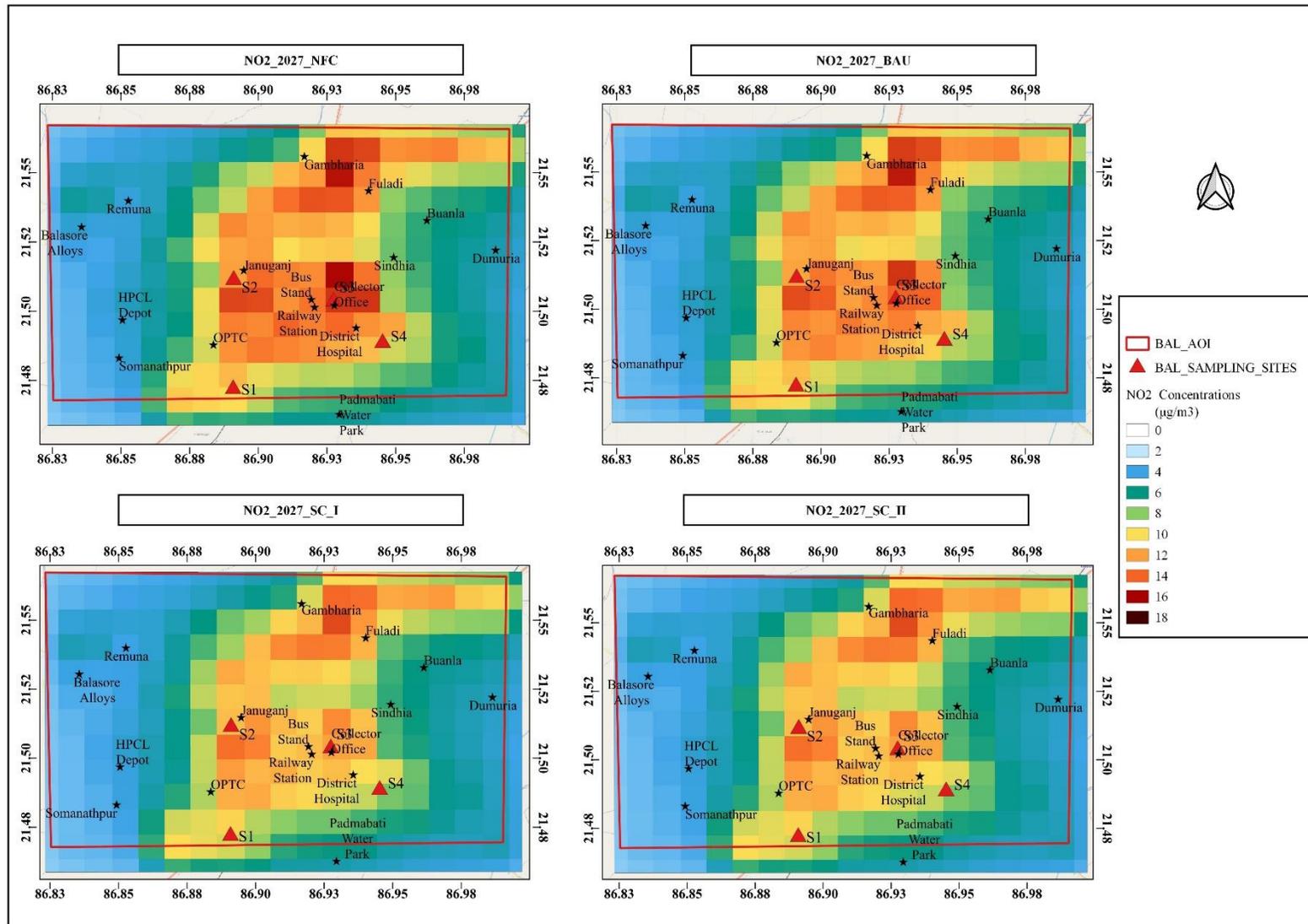


Figure 118 Spatial distribution of annual mean NO₂ concentrations (µg/m³) for four scenarios in year 2027 over Balasore region

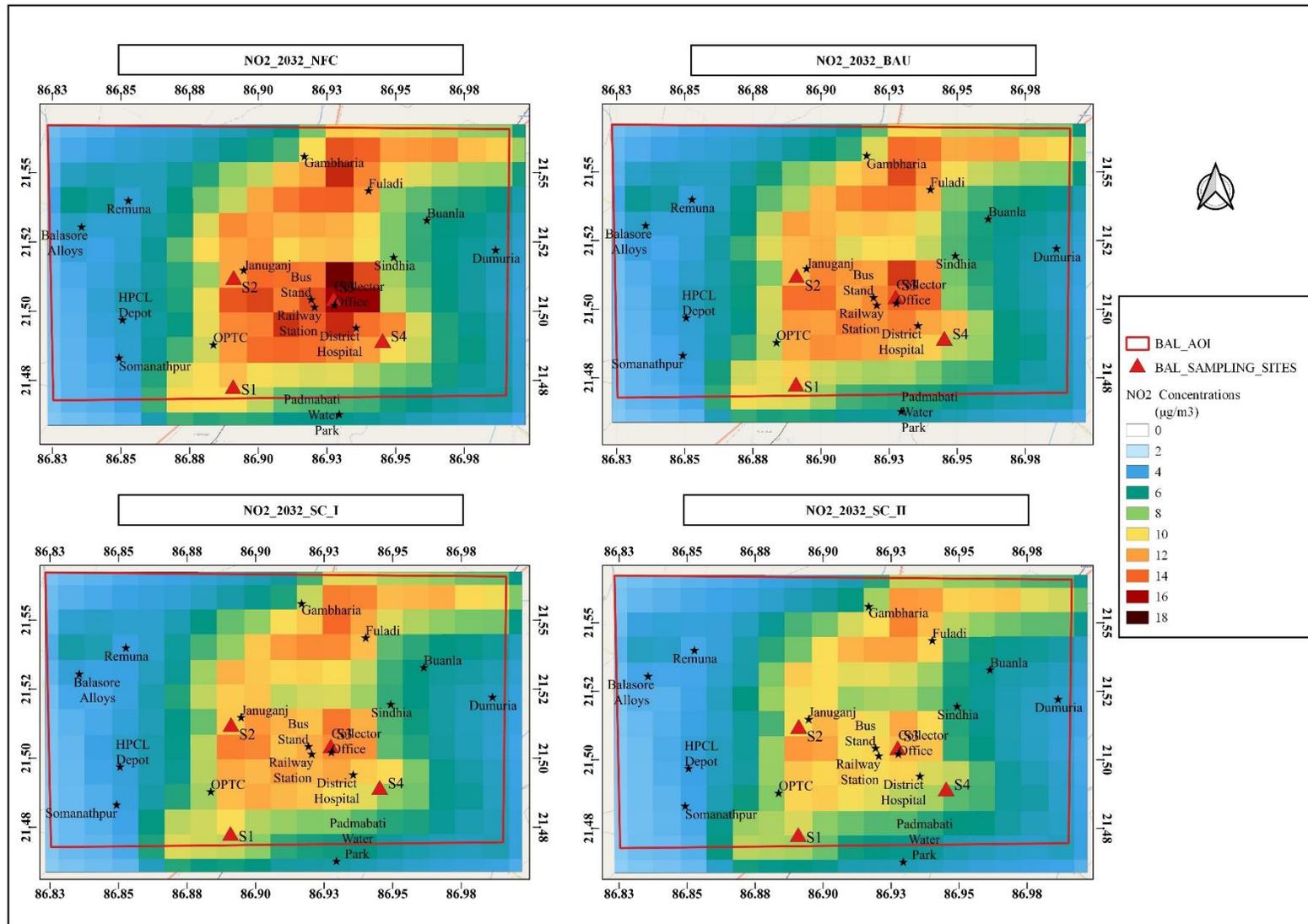


Figure 119 Spatial distribution of annual mean NO₂ concentrations (µg/m³) for four scenarios in year 2032 over Balasore region

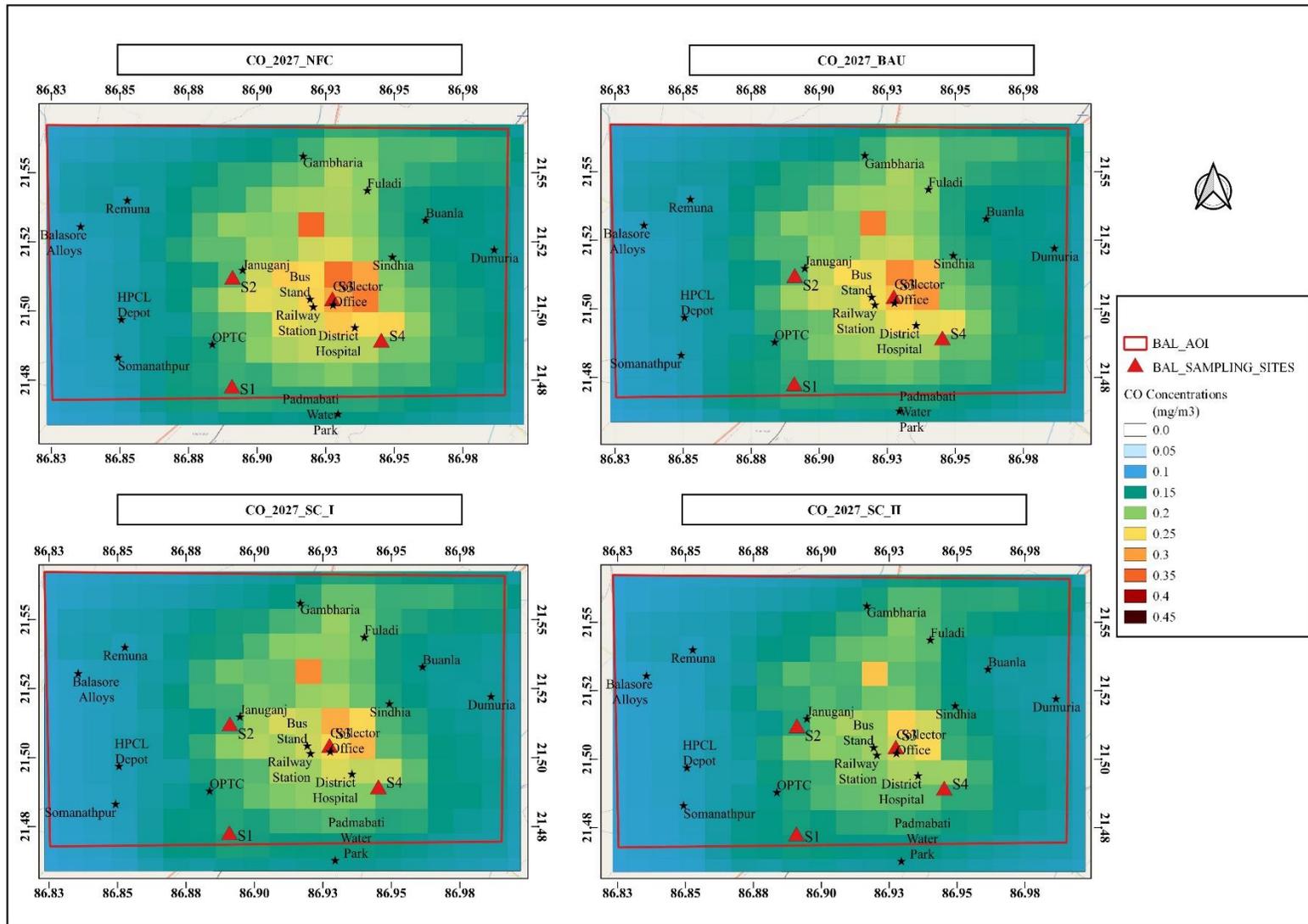


Figure 120 Spatial distribution of annual mean CO concentrations (mg/m³) for four scenarios in year 2027 over Balasore region

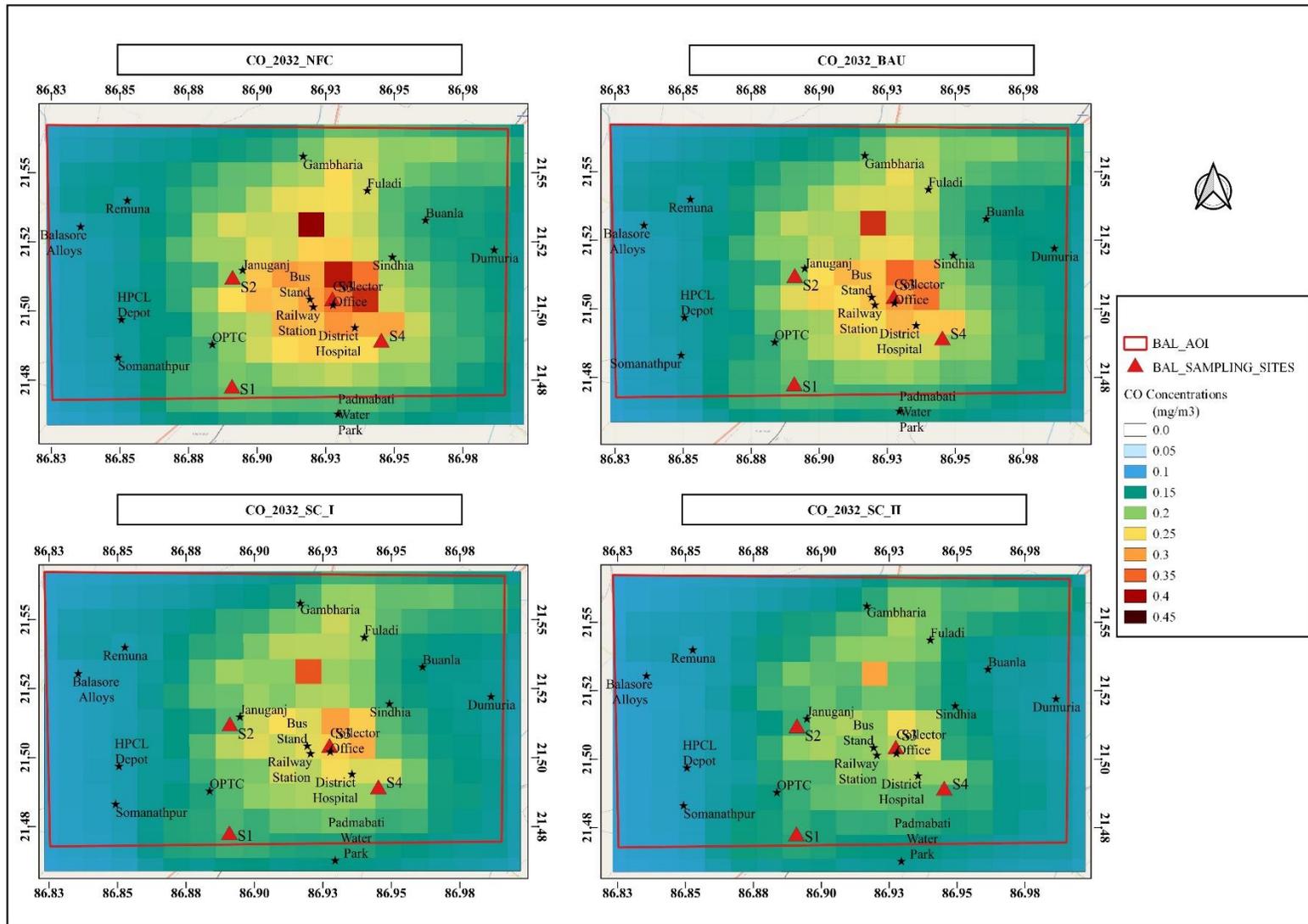


Figure 121 Spatial distribution of annual mean CO concentrations (mg/m^3) for four scenarios in year 2032 over Balasore region

This study also assessed location -specific air quality benefits due to implementation of different scenarios in 2027 and 2032. Three representative locations, i.e. ARAI sampling locations (S1-S4), were selected to understand the impact of control measures on air quality. Tables 27 to 30 presents the percentage change in air pollutants annual mean concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at three selected locations in Balasore region.

Table 27 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S1 i.e. Jyoti Hospital , Balasore sampling location

Year/Scenario	2027			2032		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-8.0%	-16.5%	-27.8%	-19.3%	-39.5%	-61.0%
PM _{2.5}	-5.1%	-11.1%	-18.8%	-13.9%	-28.5%	-44.0%
SO ₂	-4.0%	-8.7%	-14.0%	-9.2%	-18.3%	-27.4%
NO ₂	-1.3%	-3.8%	-7.1%	-4.6%	-9.4%	-14.9%
CO	-3.9%	-11.0%	-18.7%	-7.7%	-17.6%	-27.9%

Table 28 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S2 i.e. RO Office, Balasore sampling location

Year/Scenario	2027			2032		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-9.7%	-19.8%	-33.5%	-22.1%	-45.0%	-69.7%
PM _{2.5}	-7.0%	-14.7%	-25.0%	-17.4%	-35.6%	-55.1%
SO ₂	-5.0%	-10.6%	-18.2%	-10.7%	-21.4%	-33.9%
NO ₂	-1.2%	-3.7%	-7.3%	-4.6%	-8.8%	-14.9%
CO	-4.9%	-12.9%	-21.7%	-8.7%	-19.9%	-31.8%

Table 29 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S3 i.e. District Collector Office, Balasore sampling location

Year/Scenario	2027			2032		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-7.0%	-14.8%	-24.6%	-15.9%	-32.1%	-48.8%
PM _{2.5}	-6.2%	-13.5%	-22.2%	-13.8%	-27.4%	-41.2%
SO ₂	-9.4%	-19.4%	-30.0%	-19.1%	-34.3%	-49.9%
NO ₂	-5.8%	-12.4%	-19.8%	-13.0%	-21.5%	-31.2%
CO	-8.6%	-19.8%	-31.9%	-14.5%	-31.3%	-48.5%

Table 30 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S4 i.e. Municipality Office, Balasore sampling location

Year/Scenario	2027			2032		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM ₁₀	-5.4%	-11.4%	-18.9%	-12.9%	-26.2%	-39.5%
PM _{2.5}	-4.4%	-9.8%	-16.0%	-10.4%	-20.9%	-31.4%
SO ₂	-8.0%	-16.7%	-25.8%	-16.7%	-30.0%	-43.7%
NO ₂	-4.9%	-10.5%	-16.6%	-11.6%	-18.8%	-26.9%
CO	-7.7%	-18.1%	-29.0%	-12.8%	-27.8%	-43.4%

5.14.1. Air quality benefits in terms of Air Quality Indices

Air quality index (AQI) is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (*Ott, 1978*). In this study, a two-step methodology recommended by CPCB is used to calculate daily AQI values (*CPCB, 2015*). A sub-index (*CPCB, 2015*; refer Eq. (18)) 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. (17)). 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.

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

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

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

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

This section discusses the air quality indices (AQI) calculated at representative site i.e. Collector Office, Balasore (S3) for different scenarios in 2027 and 2032 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. 122 shows the distribution of six AQI categories at Collector Office, Balasore (S3) in Balasore region for modelled concentrations in year 2022, while Fig. 123 and Fig. 124 shows the distribution of AQI categories for different scenarios in 2027 and 2032, respectively.

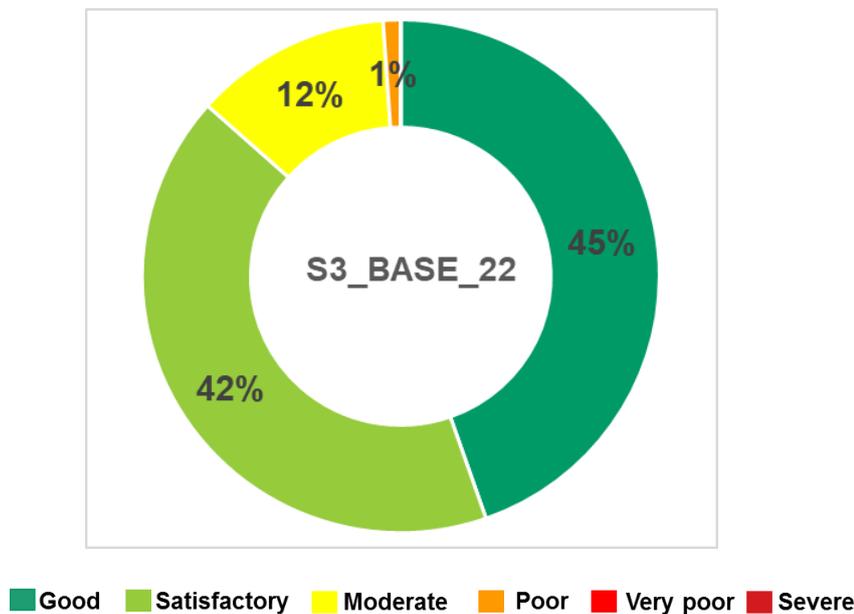


Figure 122 Distribution of six AQI categories at District Collector Office, Balasore (S3) in Balasore region for modelled pollutant concentrations for baseline year 2022

The AQI at the selected location during baseline scenario in 2022 is mainly driven by PM₁₀ and on few occasions by PM_{2.5}. An examination of modelled AQI for the baseline scenario revealed that air quality index, is mainly distributed in Good (45%), Satisfactory (42%), and moderate (12%) classes.

The AQI distribution in NFC scenarios during year 2027 shows degraded air quality compared to baseline year with 34% Good, 44% satisfactory, 17% moderate, 4% poor, and 1% very poor days. In year 2032, the air quality situation would further degrade if no further actions are taken. For example, The AQI distribution in NFC scenarios during year 2032 shows degraded air quality compared to baseline year with 23% Good, 48% satisfactory, 18% moderate, 7% poor, 4% very poor.

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 78% and 71% in 2027 and 2032, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 82% and 82% in 2027 and 2032, respectively under BAU scenario, to 84% and 88% in 2027 and 2032, respectively under SC-I, to 90% and 99% in 2027 and 2032, respectively under SC-II scenario. Fig 123 and 124 represents the distribution of AQI categories in four scenarios at Collector Office, Balasore (S3) for years 2027 and 2032, respectively.

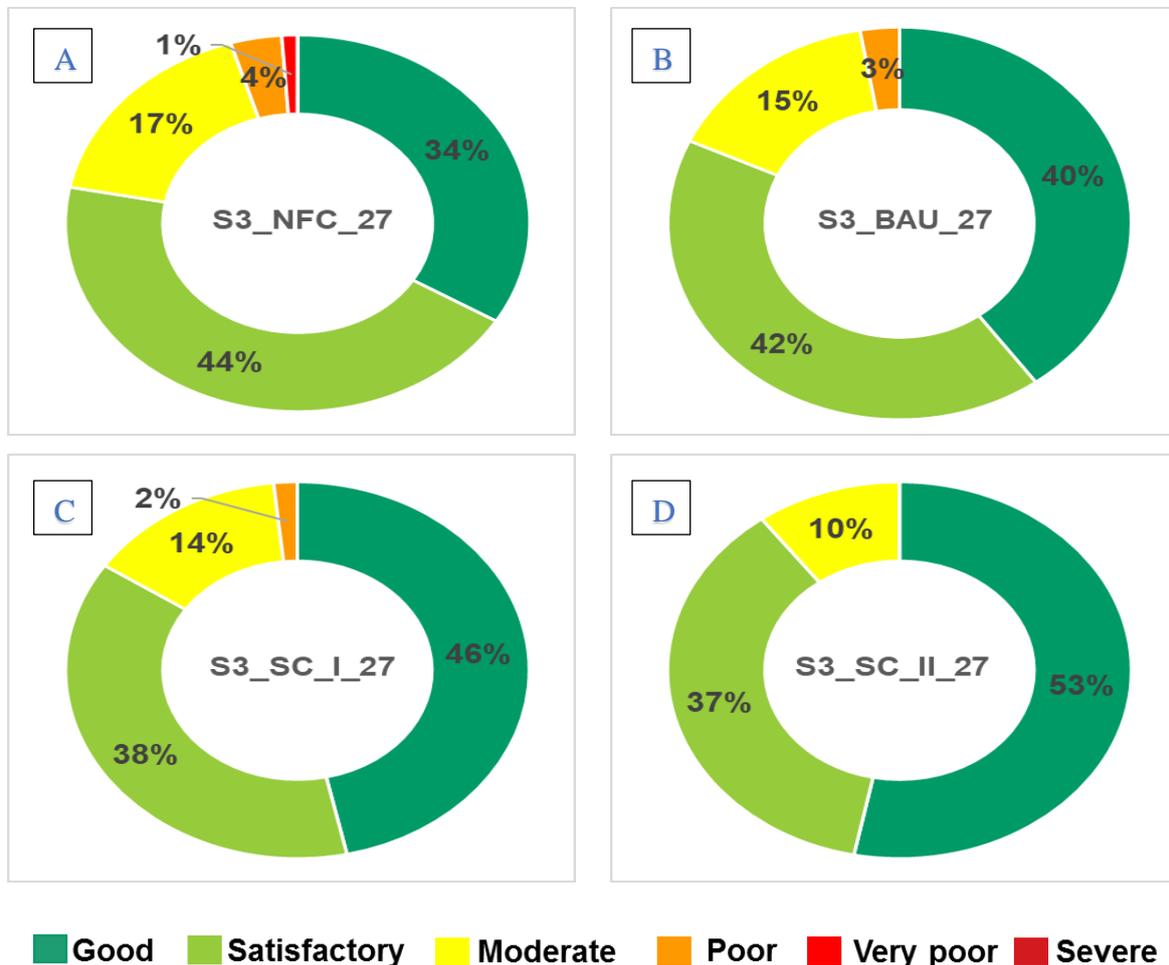


Figure 123 Distribution of six AQI categories at District Collector Office, Balasore (S3) in Balasore region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2027

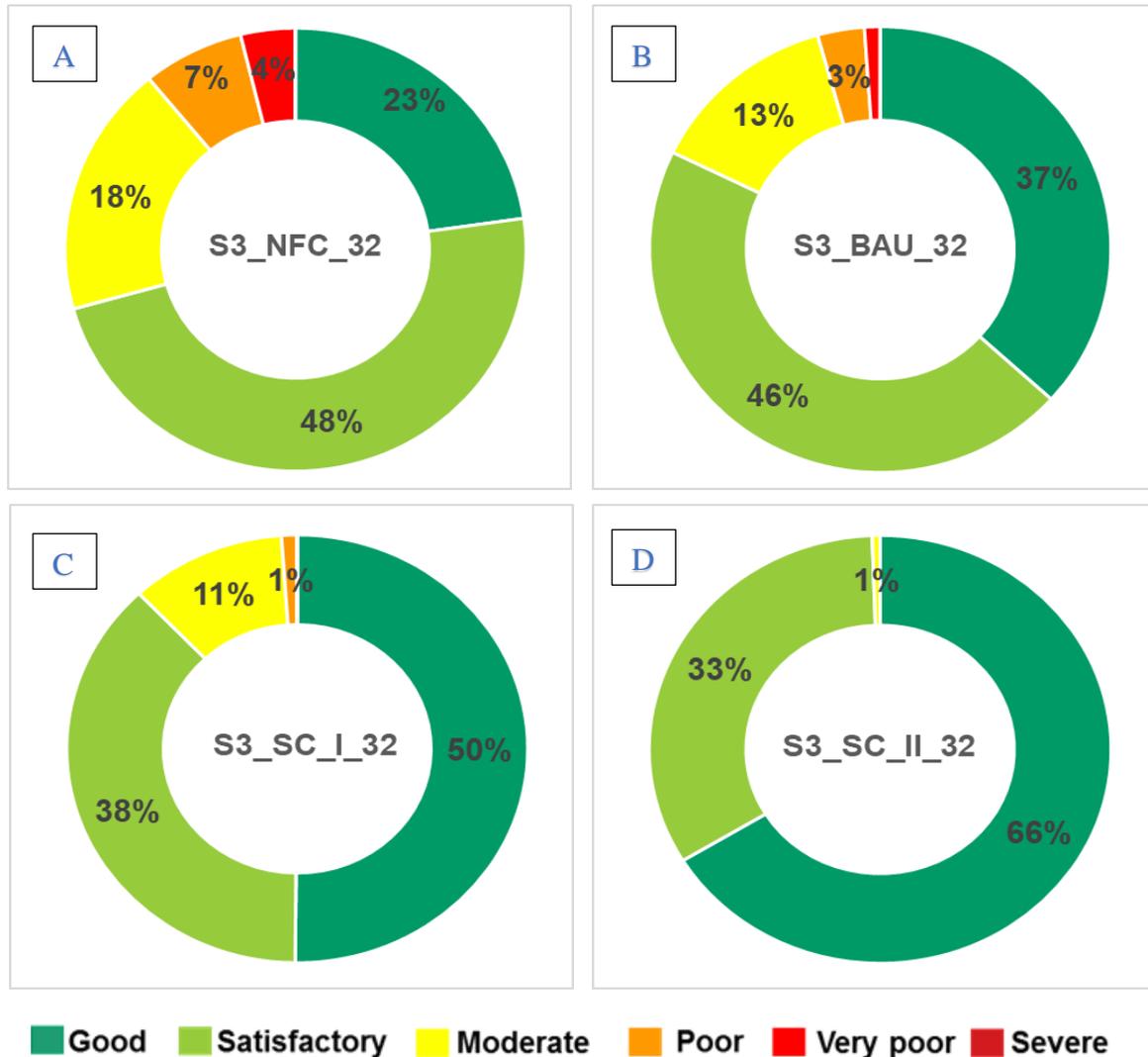


Figure 124 Distribution of six AQI categories at District Collector Office, Balasore (S3) in Balasore region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2032

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Balasore region as well. These findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level PM concentrations by 40% by the year 2027, as compared to 2017 i.e. base year.

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Chapter 6: Clean Air Action Plan

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

Table ES-31 Proposed Air quality action plan for Balasore Region

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

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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Identify road stretches with high dust generation and use Foggers to 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
Industry	<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.	OSPCB	6 months
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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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
	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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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
	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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	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
	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	Municipality/ Local Govt. Body, OSPCB, NGOs	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	announcements through waste collection vehicle, organizing awareness seminars at the community level		
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	Municipality/ Local Govt. Body	1 year
CAAQMS	Increase the number of air quality monitoring stations, as per applicable Govt. guidelines.	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 μ m, 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 1100⁰C

6.0 PPEs TO BE USED:

Cotton hand gloves, safety shoes

7.0 Procedure:

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

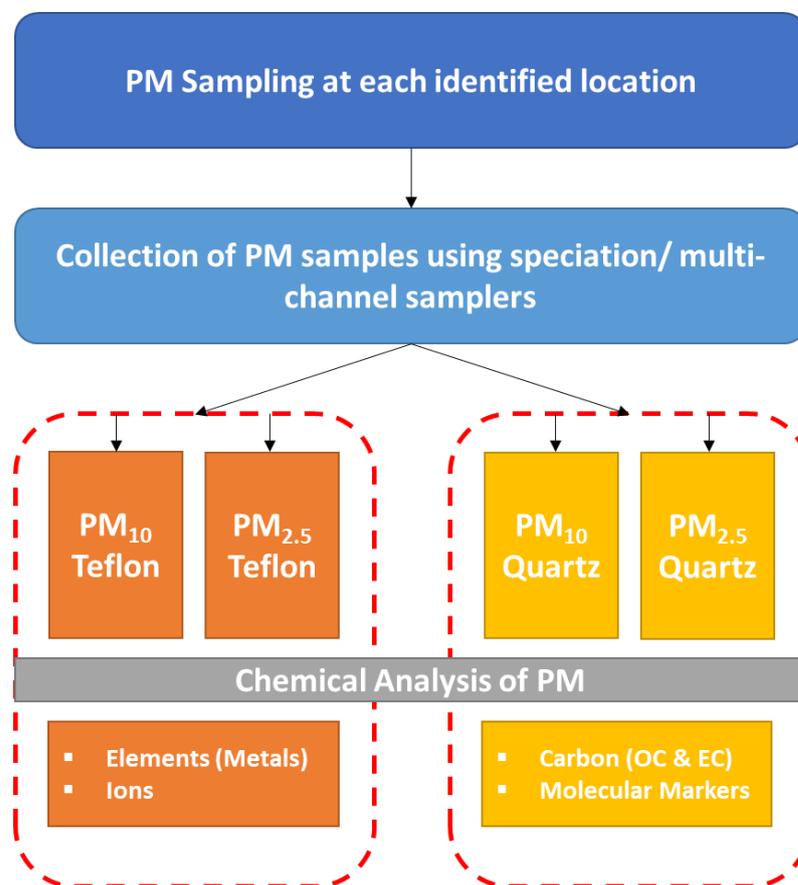
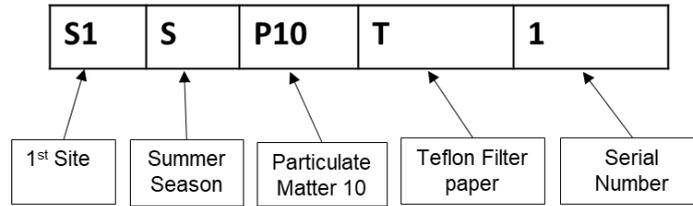


Fig. A-1: Arrangement of filter papers for multi-channel speciation samplers

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



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

- 7.4 Select filter paper as per above nomenclature. Visually inspect filter paper for any damages, pinholes or any other collection. If any anomalies are found, then discard filter paper.
- 7.5 Load filter paper in cartridge as per below table:

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

- 7.6 Start Speciation sampler as per standard procedure.

8.0 Sampling Site photographs



Jyoti Hospital



RO Office



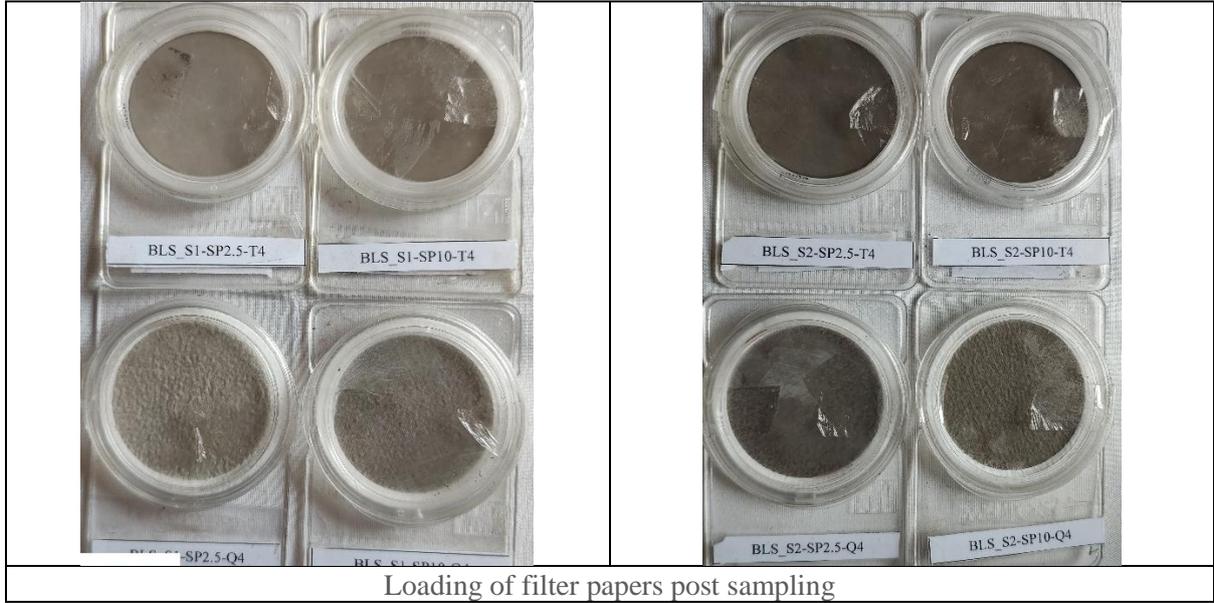
District Collector Office



Municipality Office



Gaseous Sampling Collection (SO_2 & NO_x)



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 Column
- Suppressor
- Conductivity detector
- Automated Sampler

4.2 IC Operating Conditions:

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

Sample loop volume:	25 µl for anions and cations
Acquisition Software	Chromeleon Software Version 7.2.9
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:

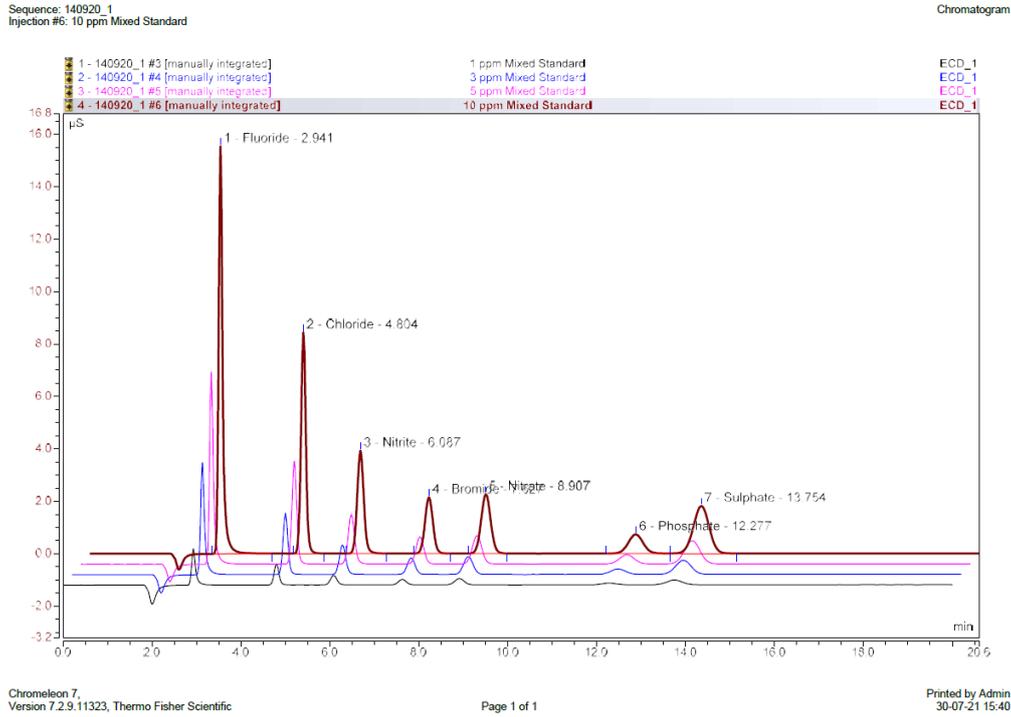


Fig. C-1: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Anion

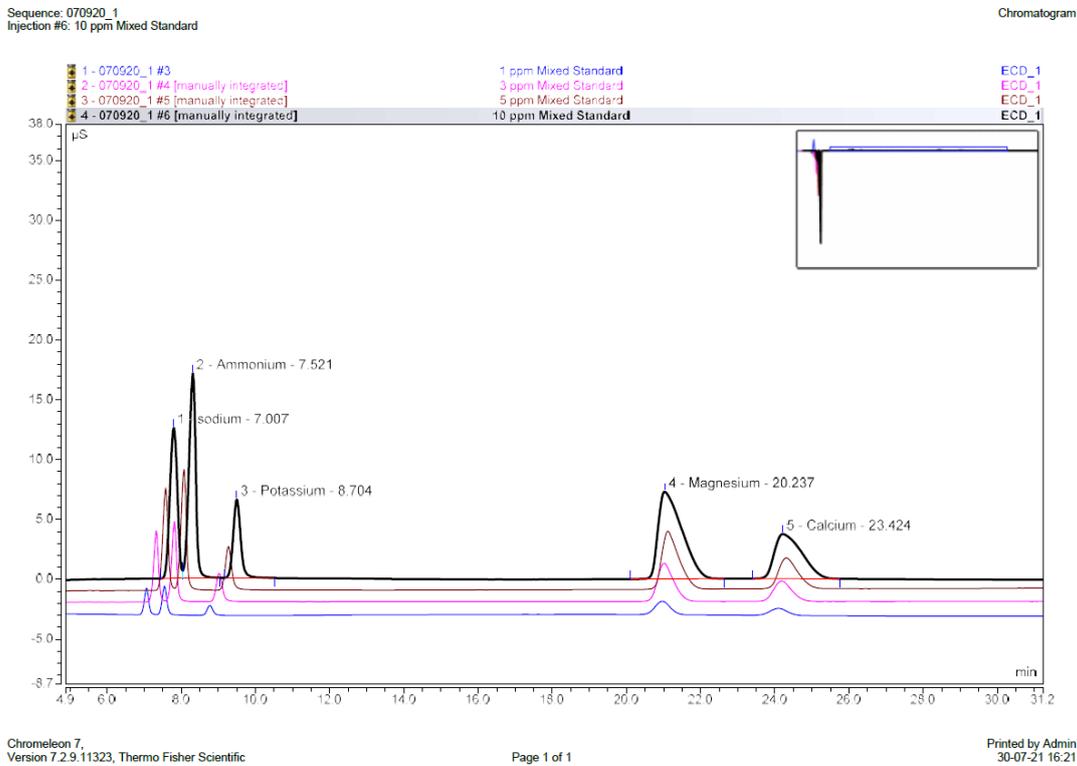


Fig. C-2: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Cation

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 µg/cm².

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

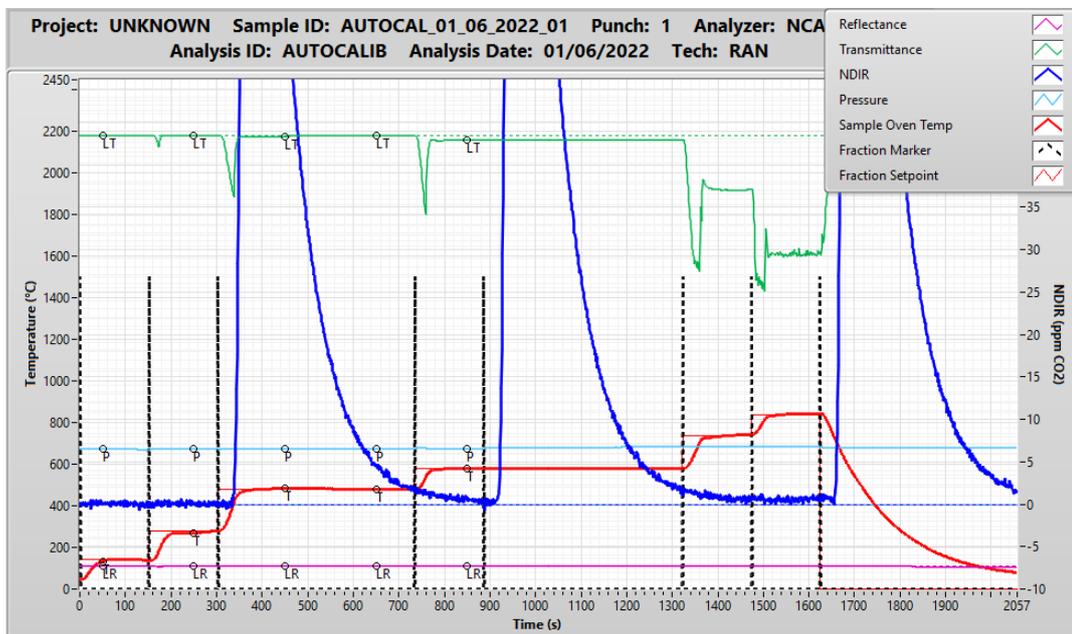


Fig. E-1: Typical example of Auto-calibration run taken on every day before actual testing starts

Annexure-F: QA/QC

Outlines of Field and Laboratory Performance Audits

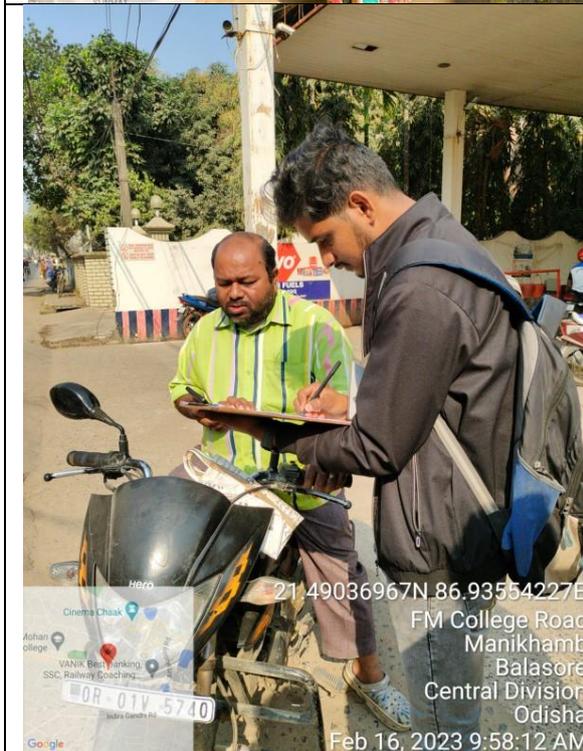
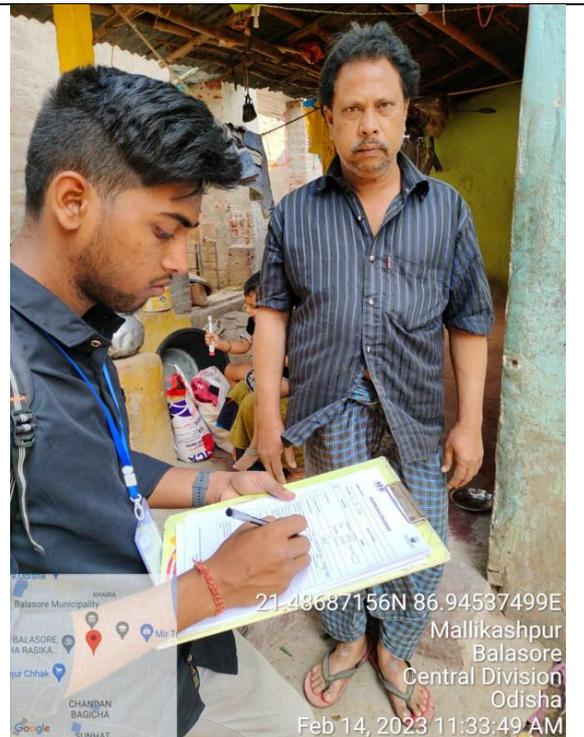
Sr. No.	Parameter	Standard Ref. Method	Test procedure/ SOP	Analytical technique/ method	Calibration standard details	Performance test method	Perform. test frequency	Calibration periodicity	Primary standard
1	Sample flow	ERT/DRI modified	TP-AQM-Samp-AML	Instrumex samplers	Calibrated rotameter	Calibrated 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

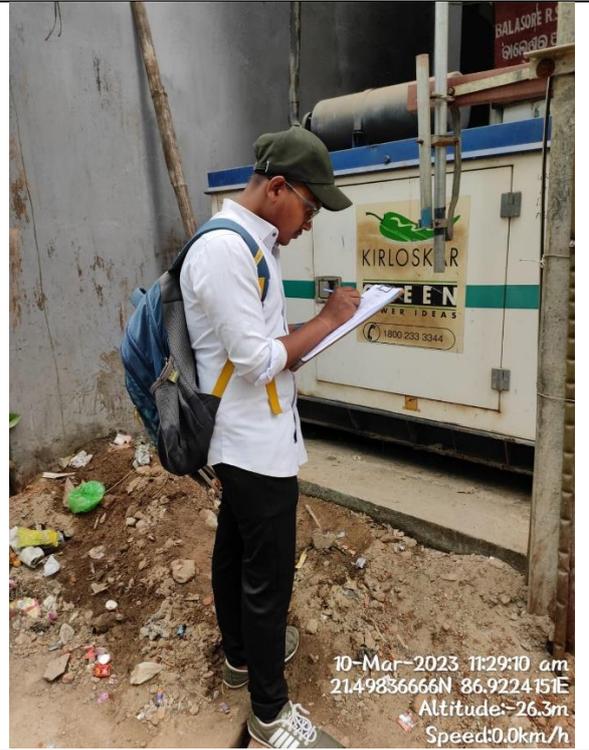
Annexure-G: Emission Inventory Activities



Figure G.125 Construction activity in Balasore in January 2022 and December 2022

Photographs taken during primary data collection surveys in Balasore region





Photographs taken during road dust sampling at Balasore



Photographs showing activities in Balasore region



Open Waste



Industrial Stacks

Annexure-H: Assumptions for Transport Sector

Table H.1: Considerations/Assumptions for quantification of vehicular emissions for four scenarios in 2027

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
1	Emission Standards	All Four Scenarios	Implementation of BS-VI standards starting April, 2020						
2	Roll-out of E20 fuel	NFC 2027	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	E20 roll-out from Y2025	NA	NA	NA
		BAU 2027	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_2027	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_2027	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 2027	EV penetration in newly registered vehicles a) 4% between 2021-25 b) 4% between 2026-32	EV penetration in newly registered vehicles a) 3% between 2021-25 b) 3% between 2026-32	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 1% between 2026-32	NA	NA	NA	EV penetration in newly registered vehicles a) 0% between 2021-25 b) 6% between 2026-32
		BAU 2027	EV penetration in newly registered vehicles	EV penetration in newly registered	EV penetration in newly registered	EV penetration in newly registered	NA	NA	EV penetration in newly registered

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
			a) 8% between 2021-25 b) 12% between 2026-32	vehicles a) 11% between 2021-25 b) 15% between 2026-32	vehicles a) 1% between 2021-25 b) 4% between 2026-32	vehicles a) 3% between 2021-25 b) 8% between 2026-32			vehicles a) 1% between 2021-25 b) 5% between 2026-32
		SC_I_2027	EV penetration in newly registered vehicles a) 11% between 2021-25 b) 21% between 2026-32	EV penetration in newly registered vehicles a) 15% between 2021-25 b) 24% between 2026-32	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 7% between 2026-32	EV penetration in newly registered vehicles a) 6% between 2021-25 b) 16% between 2026-32	NA	NA	EV penetration in newly registered vehicles a) 3% between 2021-25 b) 9% between 2026-32
		SC_II_2027	EV penetration in newly registered vehicles a) 17% between 2021-25 b) 39% between 2026-32	EV penetration in newly registered vehicles a) 21% between 2021-25 b) 41% between 2026-32	EV penetration in newly registered vehicles a) 2% between 2021-25 b) 14% between 2026-32	EV penetration in newly registered vehicles a) 11% between 2021-25 b) 31% between 2026-32	NA	NA	EV penetration in newly registered vehicles a) 7% between 2021-25 b) 18% between 2026-32
3	Increased CNG Penetration	NFC 2027	NA	CNG penetration in newly	CNG penetration in newly	CNG penetration in newly	NA	NA	NA

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				registered vehicles a) 12% between 2021-25 b) 12% between 2026-32	registered vehicles a) 3% between 2021-25 b) 3% between 2026-32	registered vehicles a) 5% between 2021-25 b) 5% between 2026-32			
		BAU 2027	NA	CNG penetration in newly registered vehicles a) 15% between 2021-25 b) 20% between 2026-32	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 3% between 2026-32	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 5% between 2026-32	NA	NA	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 5% between 2026-32
		SC_I_2027	NA	CNG penetration in newly registered vehicles a) 35% between 2021-25 b) 30% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 10% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 10% between 2026-32	NA	NA	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 10% between 2026-32

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
		SC_II_2027	NA	CNG penetration in newly registered vehicles a) 40% between 2021-25 b) 40% between 2026-32	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 20% between 2026-32	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 15% between 2026-32	NA	NA	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 20% between 2026-32
6	NMT Share	NFC 2027	No VKT reduction by 2027	No VKT reduction by 2027	No VKT reduction by 2027	No VKT reduction by 2027	NA	NA	No VKT reduction by 2027
		BAU 2027	0.25% VKT reduction by 2027	0.25% VKT reduction by 2027	0.25% VKT reduction by 2027	0.25% VKT reduction by 2027	NA	NA	0.25% VKT reduction by 2027
		SC_I_2027	0.5% VKT reduction by 2027	0.5% VKT reduction by 2027	0.5% VKT reduction by 2027	0.5% VKT reduction by 2027	NA	NA	0.5% VKT reduction by 2027
		SC_II_2027	1% VKT reduction by 2027	1% VKT reduction by 2027	1% VKT reduction by 2027	1% VKT reduction by 2027	NA	NA	1% VKT reduction by 2027
4	Mass Rapid Transit System (MRTS)/ Metro	NFC 2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		BAU 2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		SC_I_2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS
		SC_II_2027	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS	No MRTS

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
5	Improved Public Transport/ VKT Reduction (%)	NFC 2027	No improvement in public transport						
		BAU 2027	0.24% VKT reduction by year 2027	3.28% VKT reduction by year 2027	1.30% VKT reduction by year 2027	1.71% VKT reduction by year 2027	NA	NA	15 buses per lakh population and all new buses procured would be Electric vehicles
		SC_I_2027	0.32% VKT reduction by year 2027	4.33 VKT reduction by year 2027	1.72% VKT reduction by year 2027	2.25% VKT reduction by year 2027	NA	NA	20 buses per lakh population and all new buses procured would be Electric vehicles
		SC_II_2027	0.40% VKT reduction by year 2027	5.52% VKT reduction by year 2027	2.19% VKT reduction by year 2027	2.87% VKT reduction by year 2027	NA	NA	25 buses per lakh population and all new buses procured would be Electric vehicles

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
6	Improve and strengthen PUC programme	NFC 2027	No Change in super-emitters percentage						
		BAU 2027	No Change in super-emitters percentage						
		SC_I_2027	10% Reduction in super-emitters percentage compared to NFC 2027						
		SC_II_2027	25% Reduction in super-emitters percentage compared to NFC 2027						

Table H.2: Considerations/Assumptions for quantification of vehicular emissions for four scenarios in 2032

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 2032	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_2032	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_2032	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	EV penetration in newly registered vehicles a) 4% between 2021-25 b) 4% between 2026-32	EV penetration in newly registered vehicles a) 3% between 2021-25 b) 3% between 2026-32	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 1% between 2026-32	NA	NA	NA	EV penetration in newly registered vehicles a) 0% between 2021-25 b) 6% between 2026-32
		BAU 2032	EV penetration in newly registered vehicles a) 8% between 2021-25 b) 16%	EV penetration in newly registered vehicles a) 11% between 2021-25 b) 17%	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 6%	EV penetration in newly registered vehicles a) 3% between 2021-25 b) 13%	NA	NA	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 7% between 2026-32

			between 2026-32	between 2026-32	between 2026-32	between 2026-32			
		SC_I_2032	EV penetration in newly registered vehicles a) 11% between 2021-25 b) 30% between 2026-32	EV penetration in newly registered vehicles a) 15% between 2021-25 b) 32% between 2026-32	EV penetration in newly registered vehicles a) 1% between 2021-25 b) 11% between 2026-32	EV penetration in newly registered vehicles a) 6% between 2021-25 b) 11% between 2026-32	NA	NA	EV penetration in newly registered vehicles a) 3% between 2021-25 b) 14% between 2026- 32
		SC_II_2032	EV penetration in newly registered vehicles a) 17% between 2021-25 b) 59% between 2026-32	EV penetration in newly registered vehicles a) 21% between 2021-25 b) 60% between 2026-32	EV penetration in newly registered vehicles a) 2% between 2021-25 b) 22% between 2026-32	EV penetration in newly registered vehicles a) 11% between 2021-25 b) 50% between 2026-32	NA	NA	EV penetration in newly registered vehicles a) 7% between 2021-25 b) 28% between 2026- 32
3	Increased CNG Penetration	NFC	NA	CNG penetration in newly registered vehicles a) 12% between 2021-25	CNG penetration in newly registered vehicles a) 3% between 2021-25	CNG penetration in newly registered vehicles a) 5% between 2021-25	NA	NA	NA

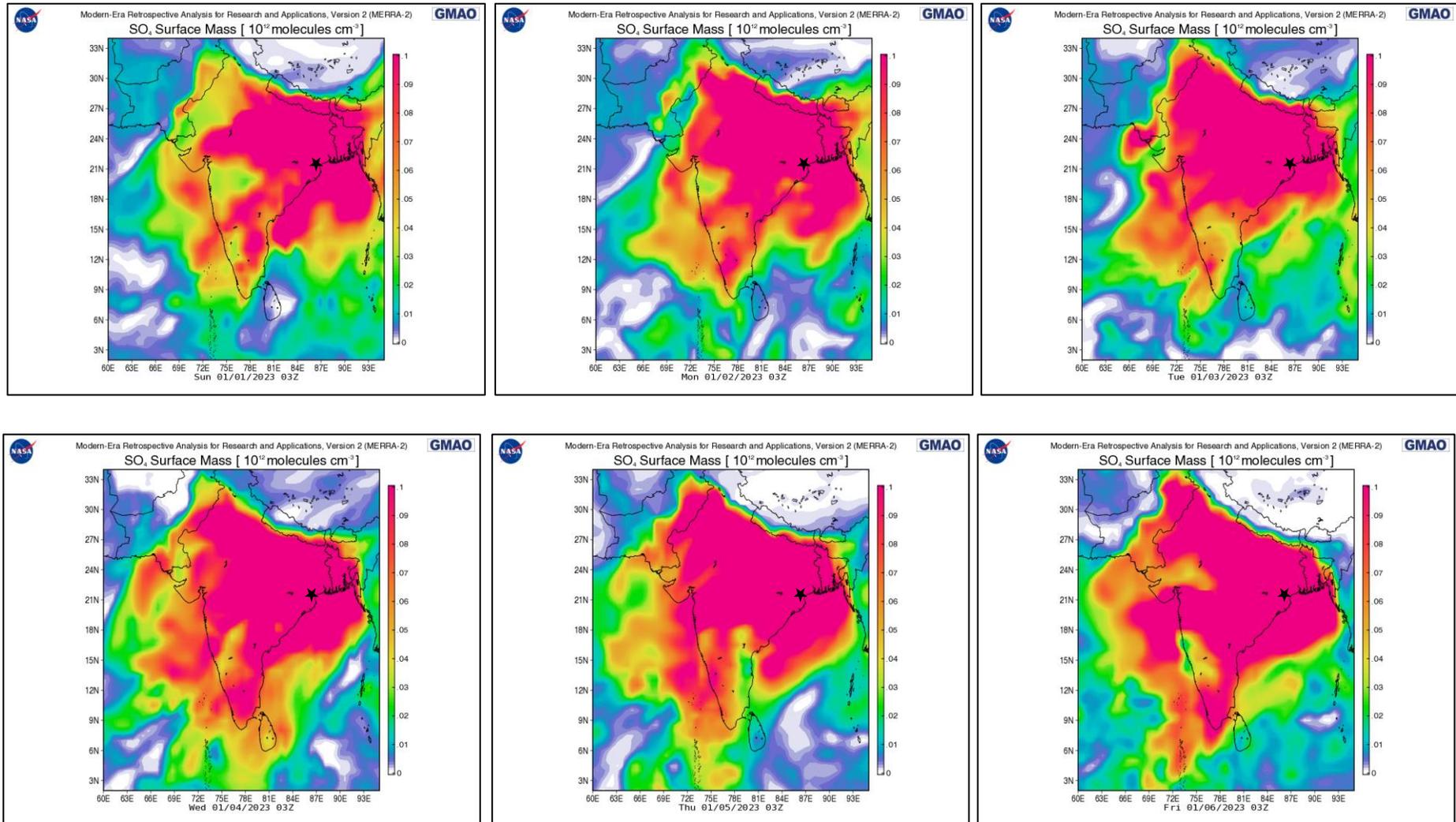
				b) 12% between 2026-32	b) 3% between 2026-32	b) 5% between 2026-32			
		BAU 2032	NA	CNG penetration in newly registered vehicles a) 15% between 2021-25 b) 25% between 2026-32	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 5% between 2026-32	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 10% between 2026-32	NA	NA	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 10% between 2026- 32
		SC_I_2032	NA	CNG penetration in newly registered vehicles a) 35% between 2021-25 b) 38% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 15% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 15% between 2026-32	NA	NA	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 15% between 2026- 32
		SC_II_2032	NA	CNG penetration in newly registered vehicles a) 40% between 2021-25 b) 30%	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 30%	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 25%	NA	NA	CNG penetration in newly registered vehicles a) 10% between 2021- 25 b) 30%

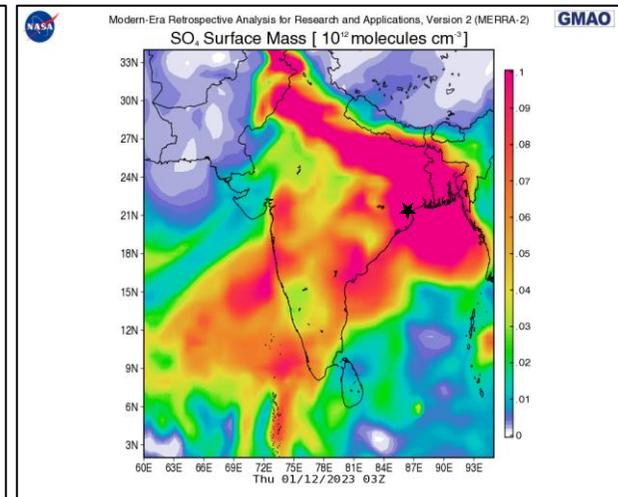
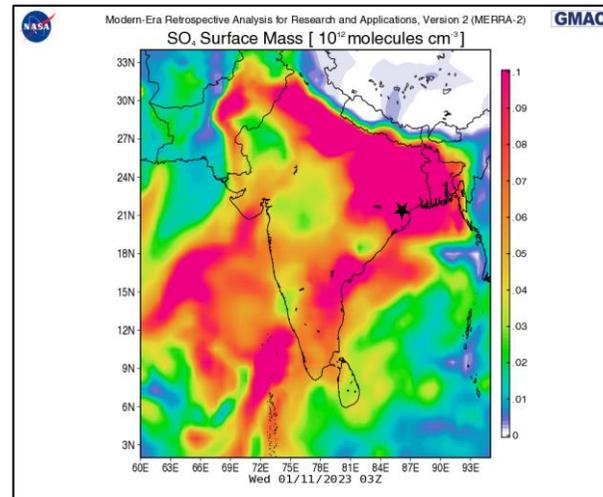
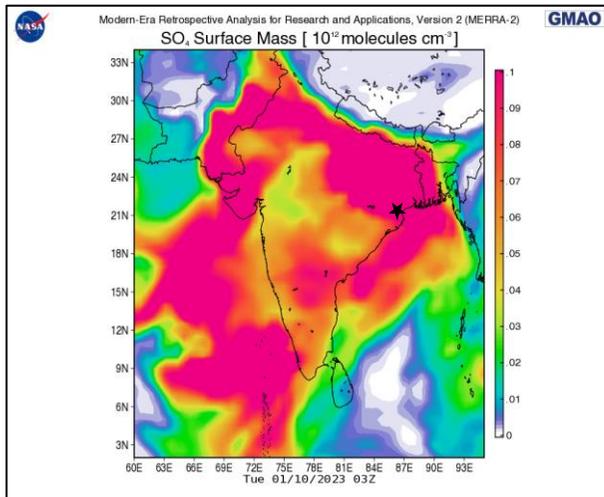
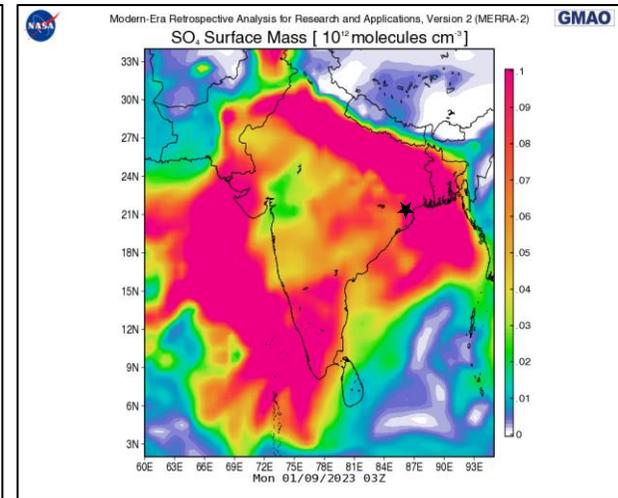
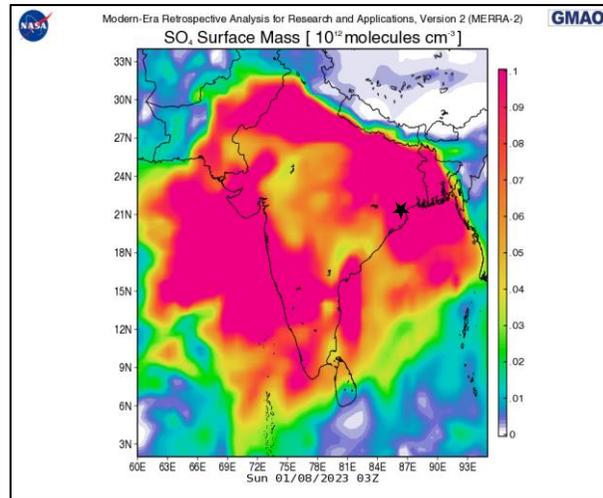
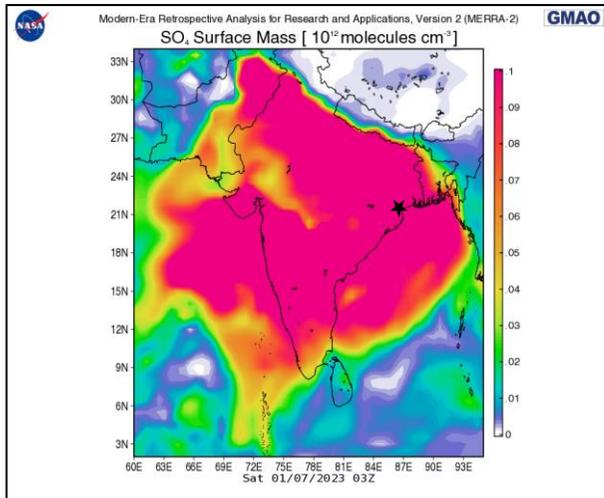
				between 2026-32	between 2026-32	between 2026-32			between 2026-32
6	NMT Share	NFC	No VKT reduction by 2032	No VKT reduction by 2032	No VKT reduction by 2032	No VKT reduction by 2032	NA	NA	No VKT reduction by 2032
		BAU 2032	0.5% VKT reduction by 2032	0.5% VKT reduction by 2032	0.5% VKT reduction by 2032	0.5% VKT reduction by 2032	NA	NA	0.5% VKT reduction by 2032
		SC_I_2032	1% VKT reduction by 2032	1% VKT reduction by 2032	1% VKT reduction by 2032	1% VKT reduction by 2032	NA	NA	1% VKT reduction by 2032
		SC_II_2032	2% VKT reduction by 2032	2% VKT reduction by 2032	2% VKT reduction by 2032	2% VKT reduction by 2032	NA	NA	2% VKT reduction by 2032
4	Mass Rapid Transit System (MRTS)/ Metro	NFC	No MRTS						
		BAU 2032	No MRTS	NA	NA	No MRTS	No MRTS	NA	NA
No MRTS		SC_I_2032	No MRTS	NA	NA	No MRTS	No MRTS	NA	NA
		SC_II_2032	No MRTS	NA	NA	No MRTS	No MRTS	NA	NA
5	Improved Public Transport/ VKT Reduction (%)	NFC	No improvement in public transport						
		BAU 2032	0.20% VKT reduction by year 2032	2.78% VKT reduction by year 2032	1.10% VKT reduction by year 2032	1.45% VKT reduction by year 2032	NA	NA	20 buses per lakh population and all new buses procured would be

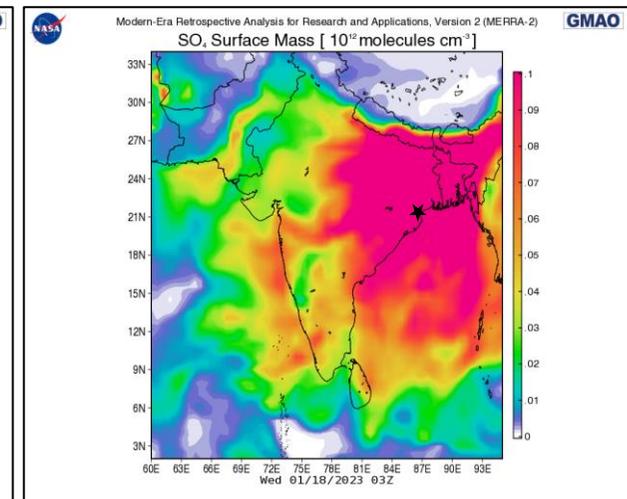
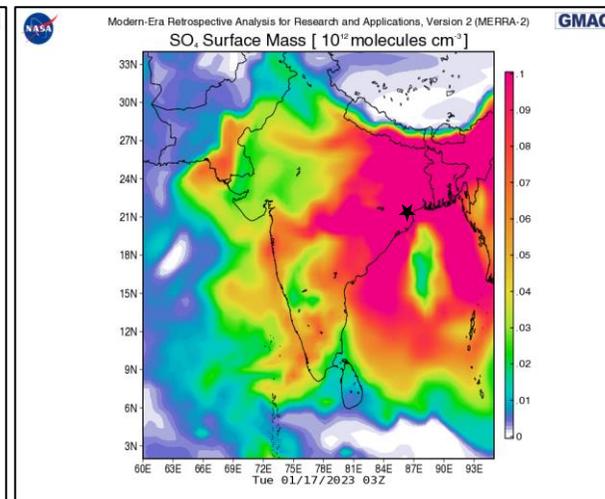
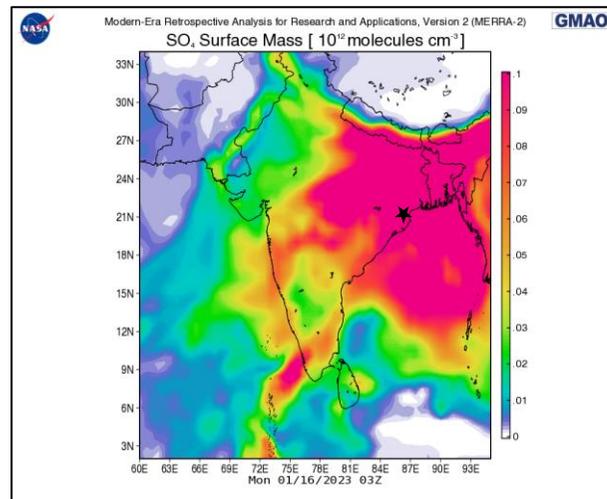
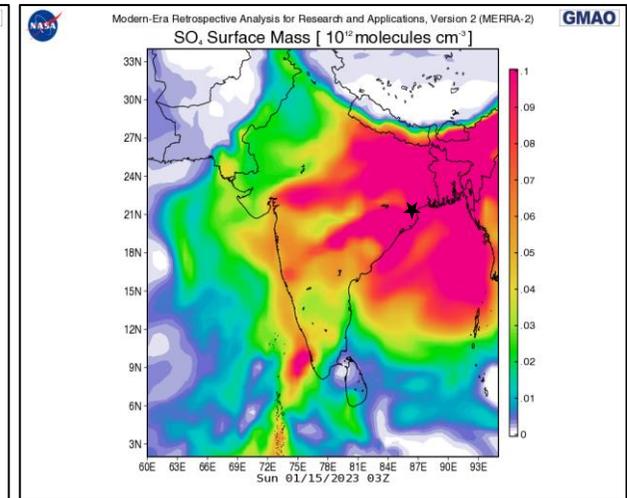
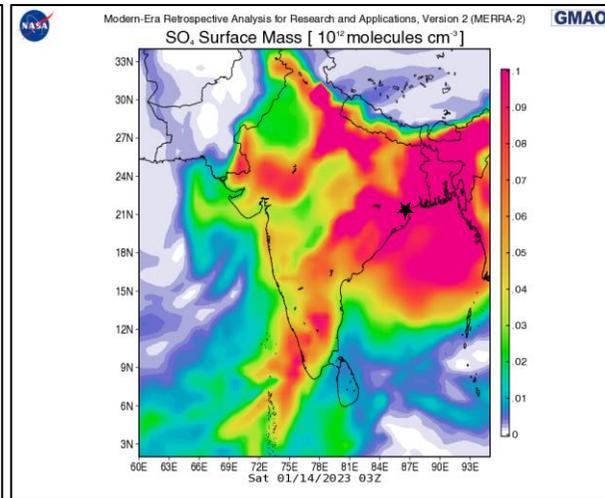
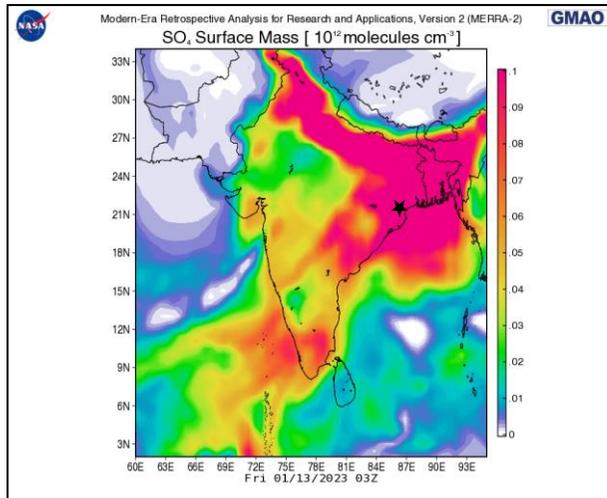
									Electric vehicles
		SC_I_2032	0.32% VKT reduction by year 2032	4.33% VKT reduction by year 2032	1.72% VKT reduction by year 2032	2.25 % VKT reduction by year 2032	NA	NA	25 buses per lakh population and all new buses procured would be Electric vehicles
		SC_II_2032	0.42% VKT reduction by year 2032	6.20% VKT reduction by year 2032	2.1% VKT reduction by year 2032	2.85% VKT reduction by year 2032	NA	NA	30 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 2032	10% Reduction in super-emitters percentage compared to NFC 2032						
		SC_I_2032	25% Reduction in super-emitters percentage compared to NFC 2032						
		SC_II_2032	50% Reduction in super-emitters percentage compared to NFC 2032						

Annexure-I: MERRA-2 Re-analysis Data

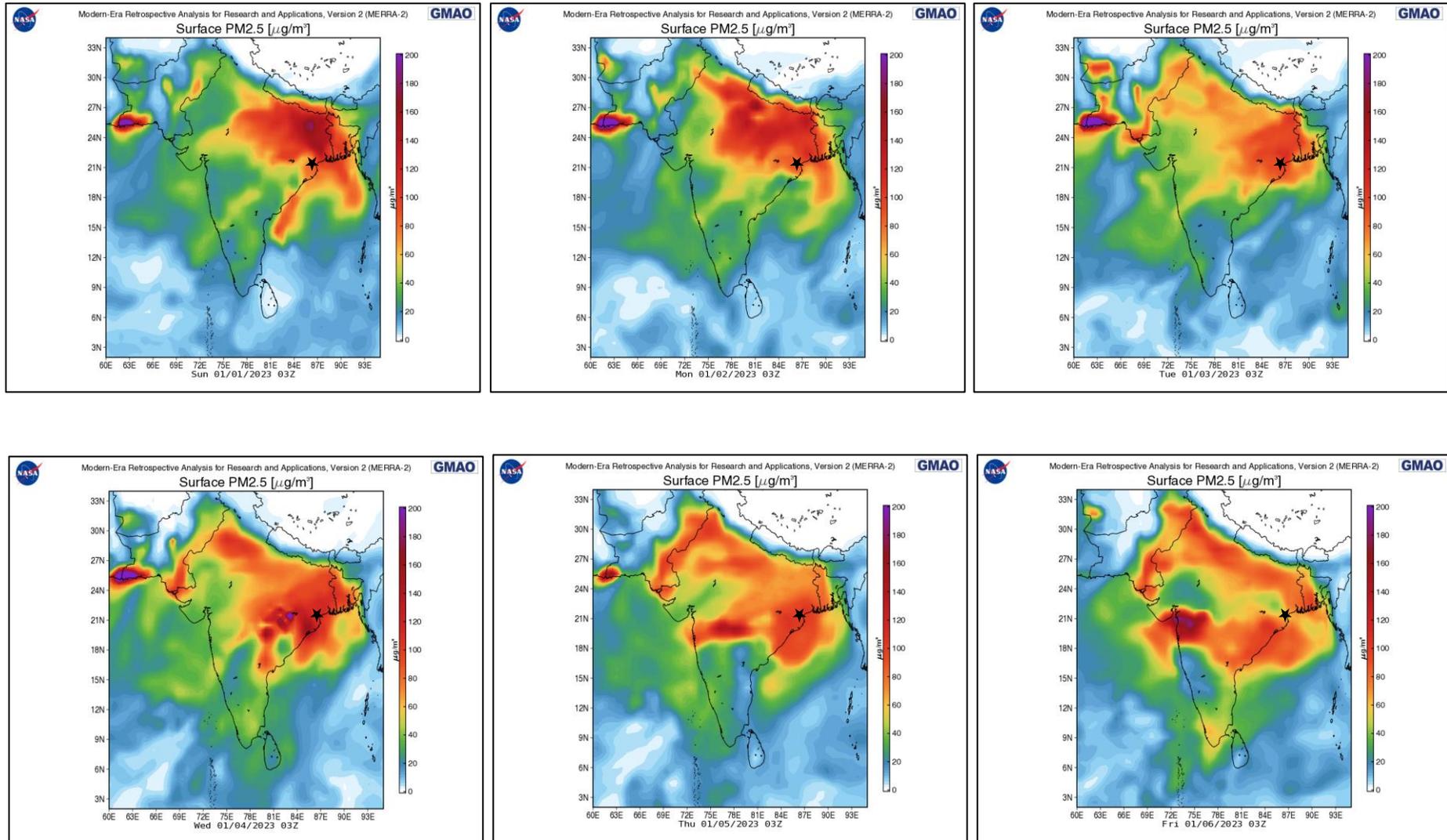
MERRA-2 Re-analysis data of Sulfate for Winter season:

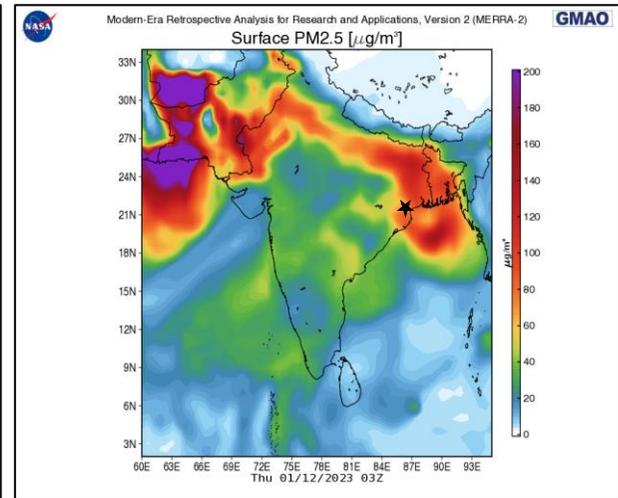
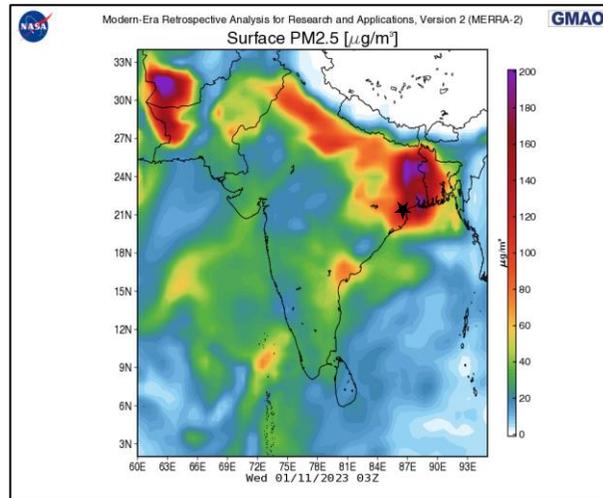
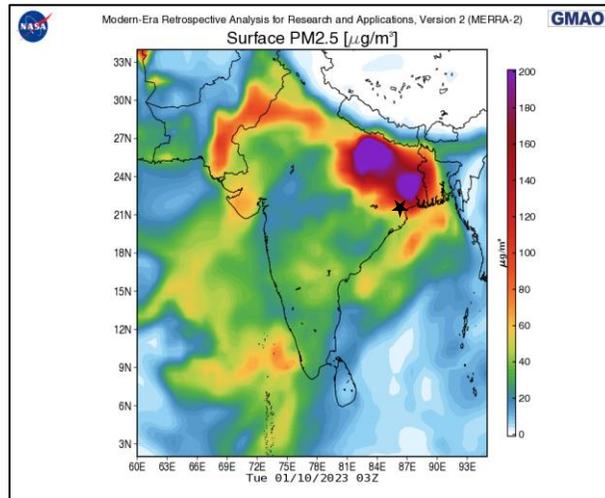
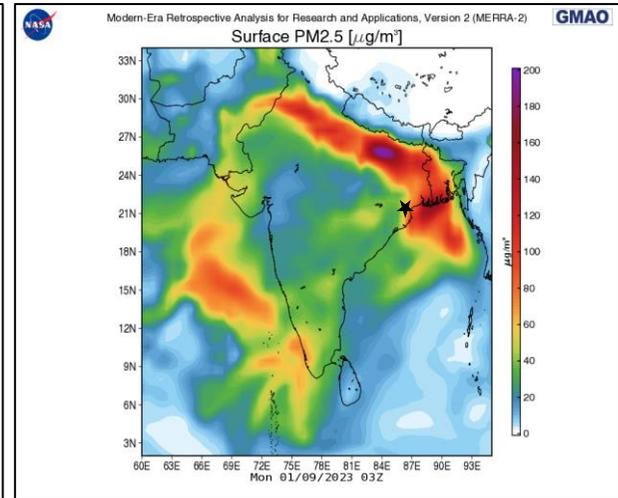
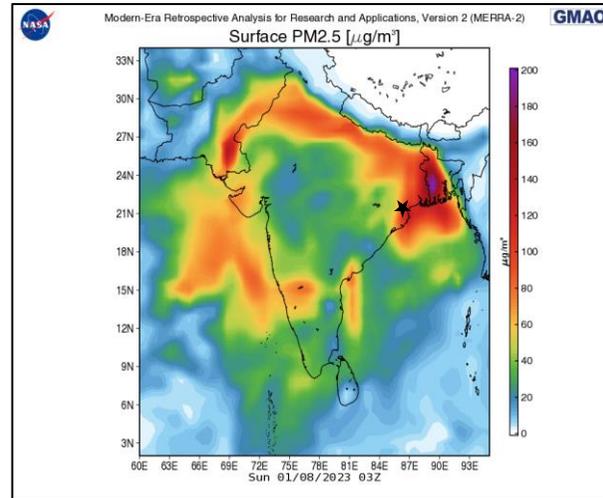
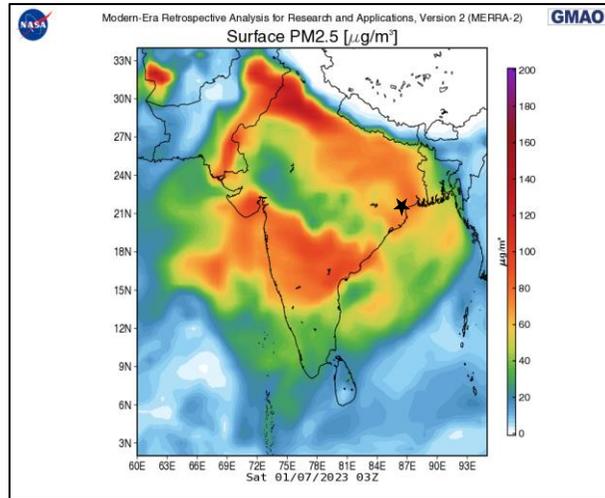


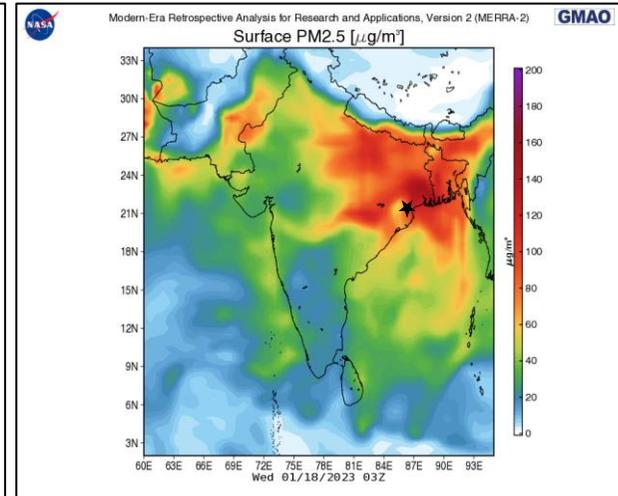
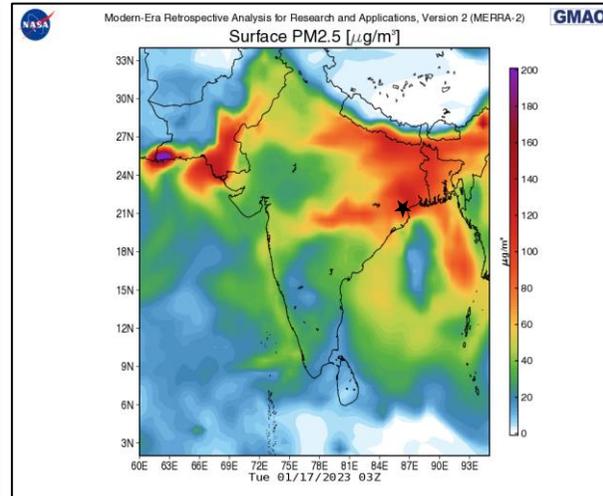
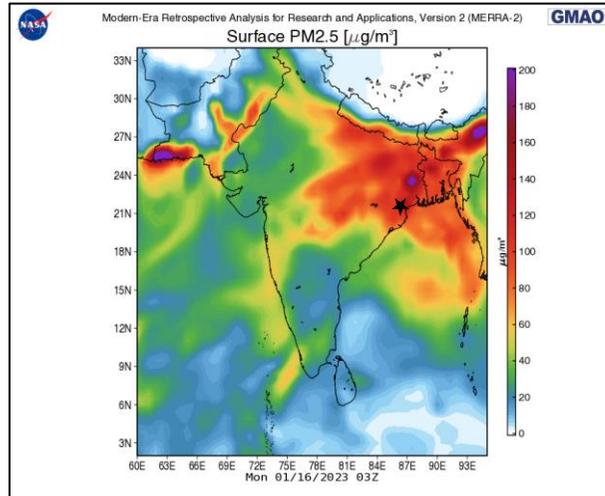
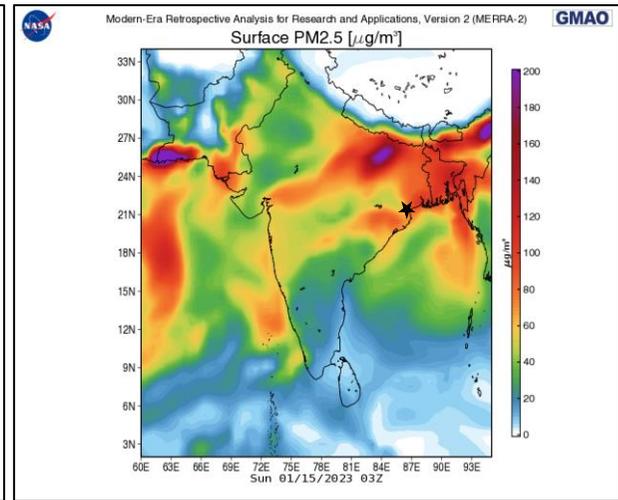
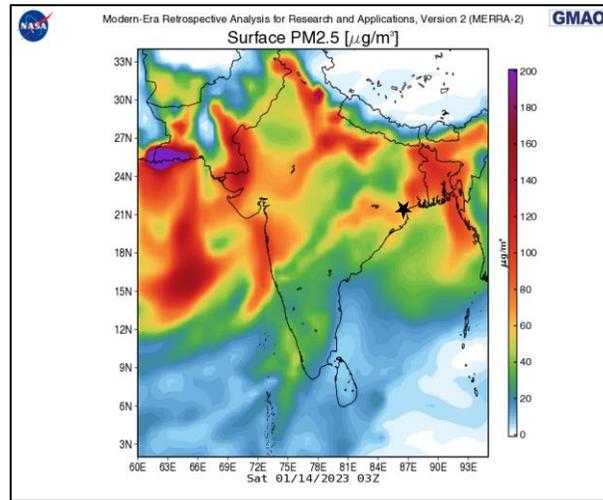
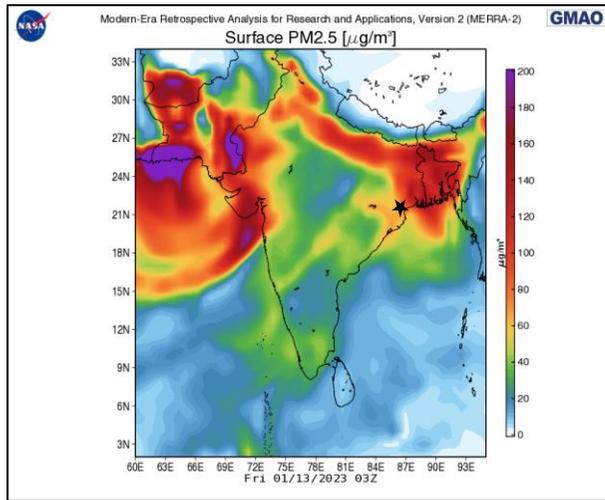




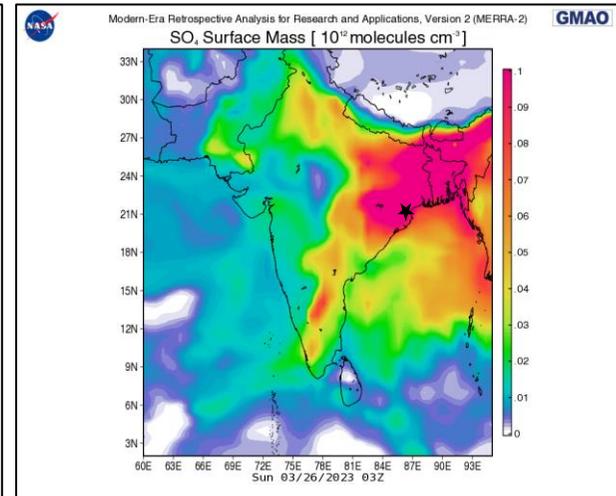
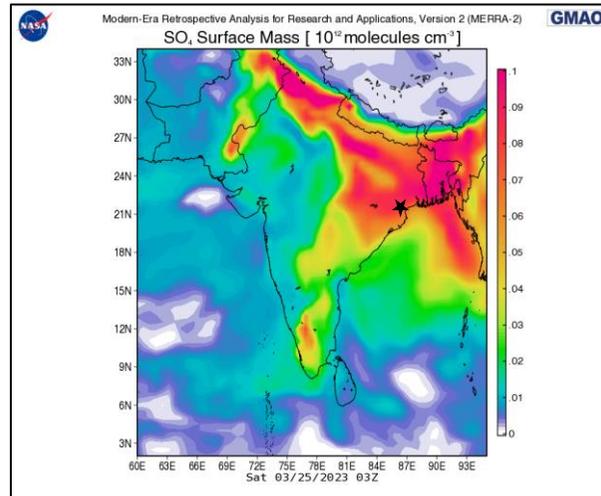
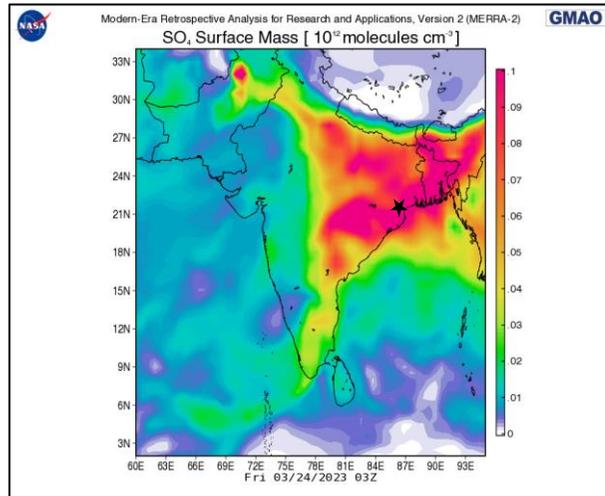
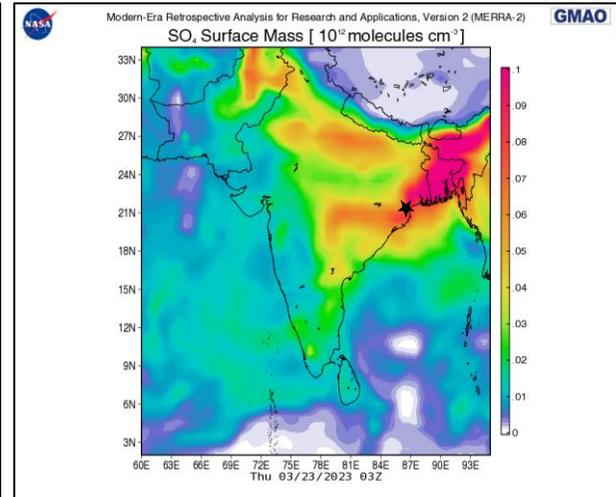
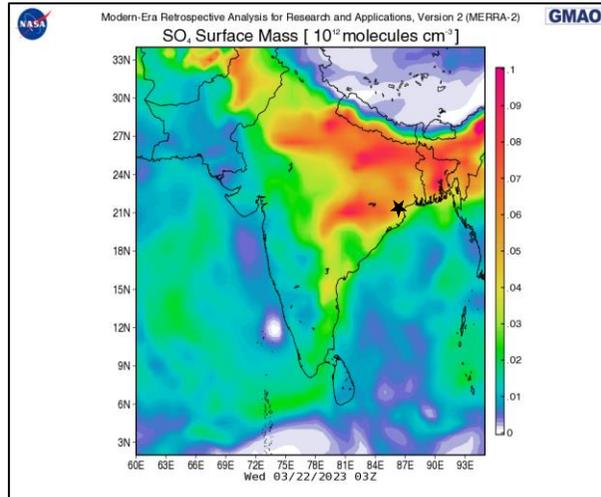
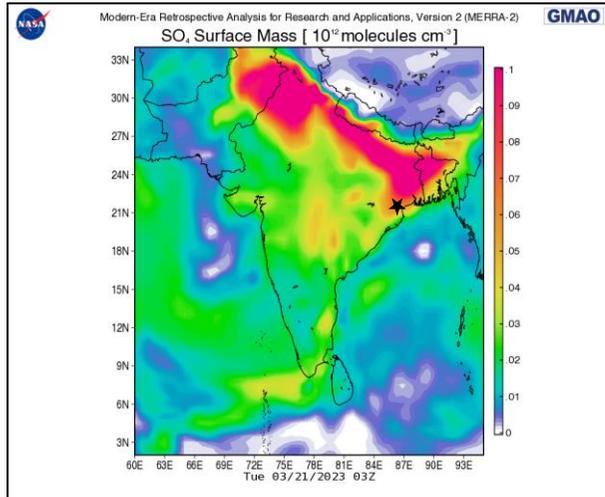
Merra-2 Re-analysis data of Surface PM2.5 for Winter season:

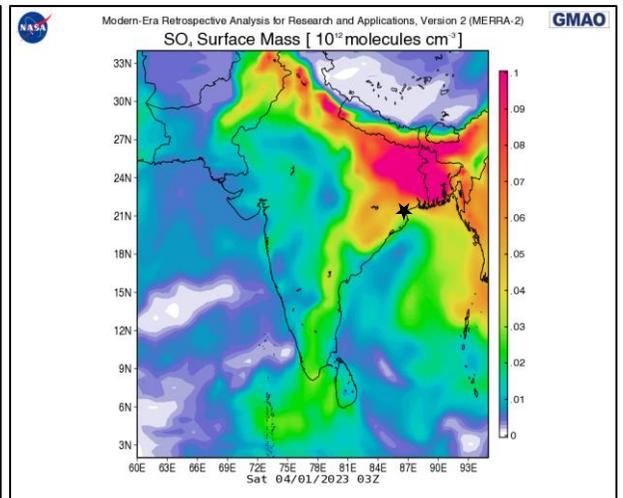
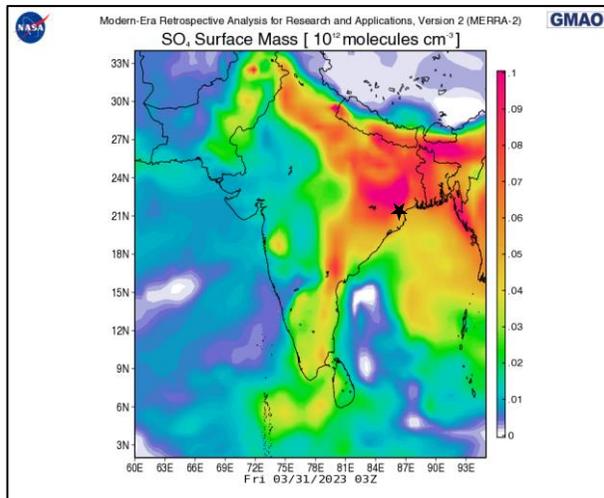
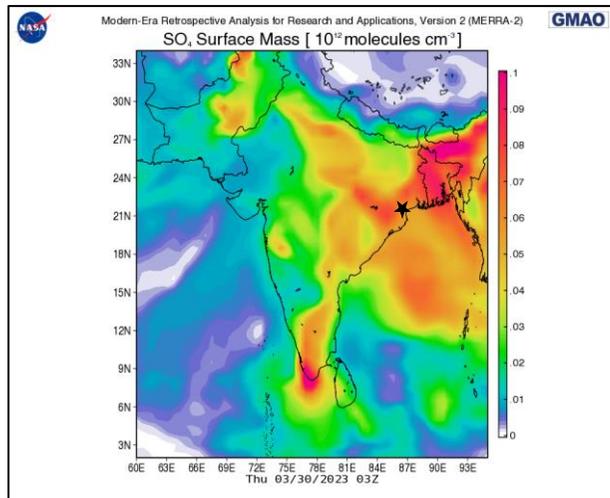
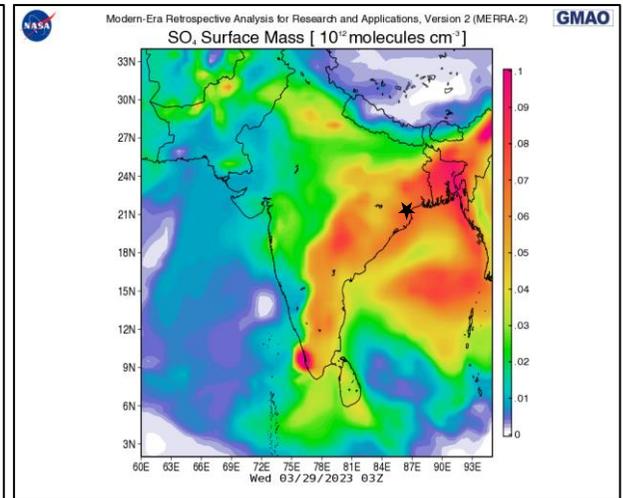
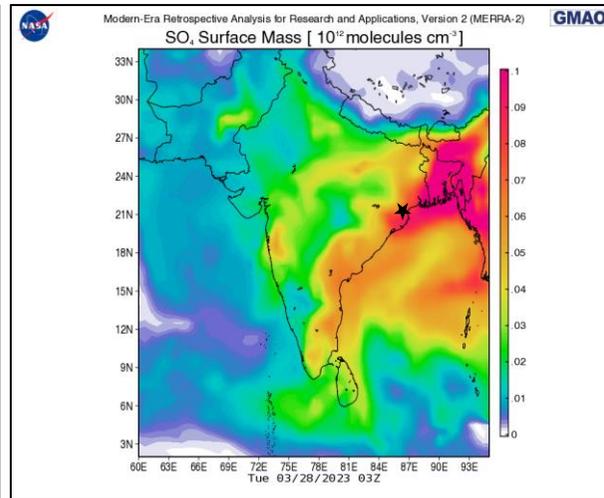
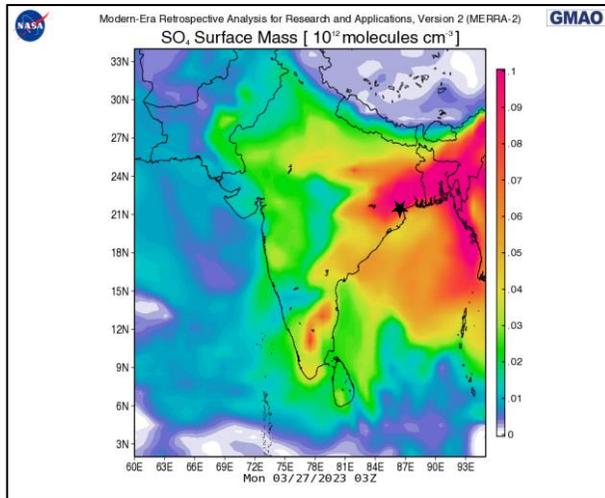


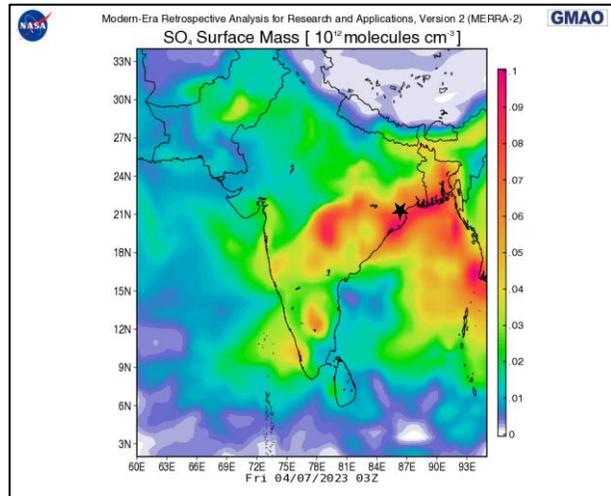
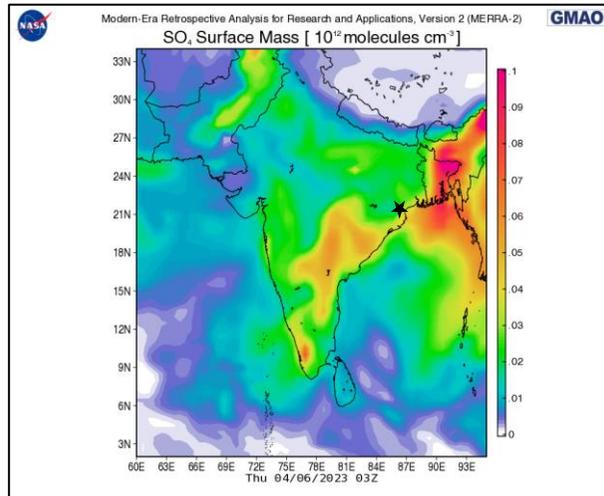
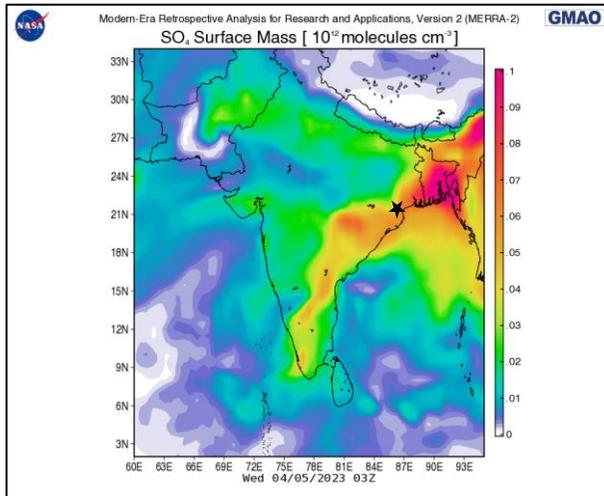
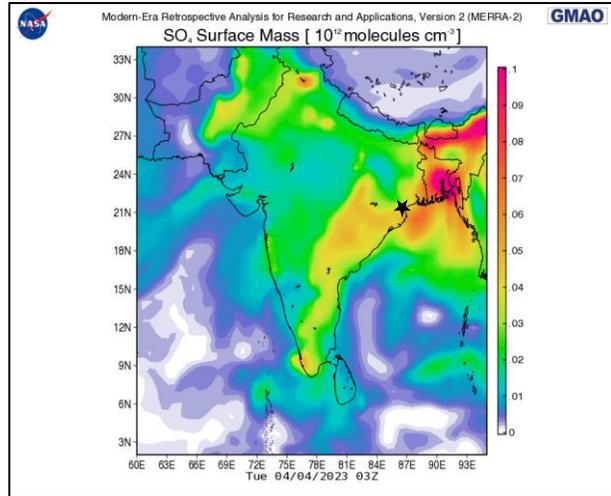
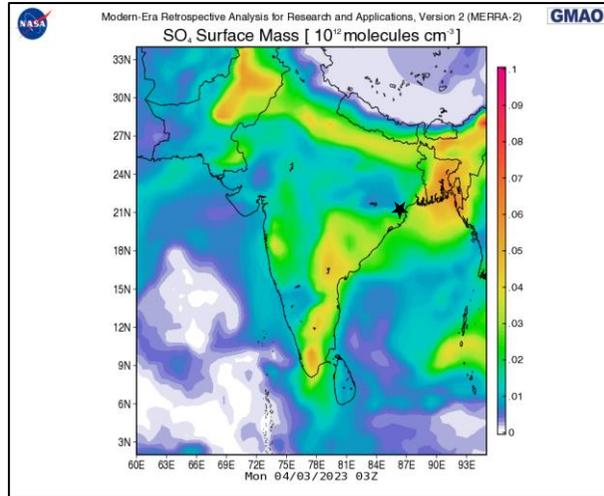
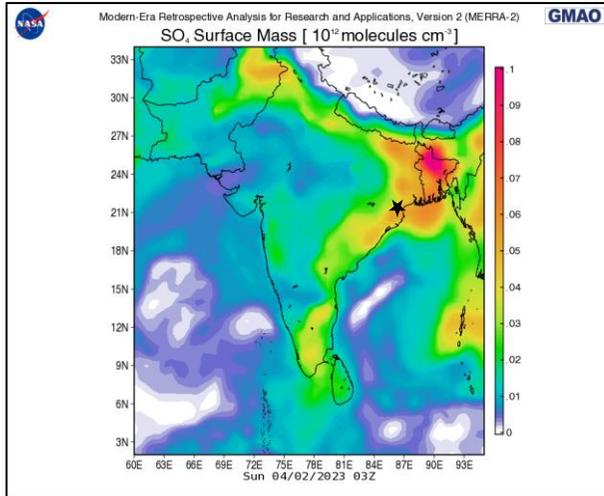




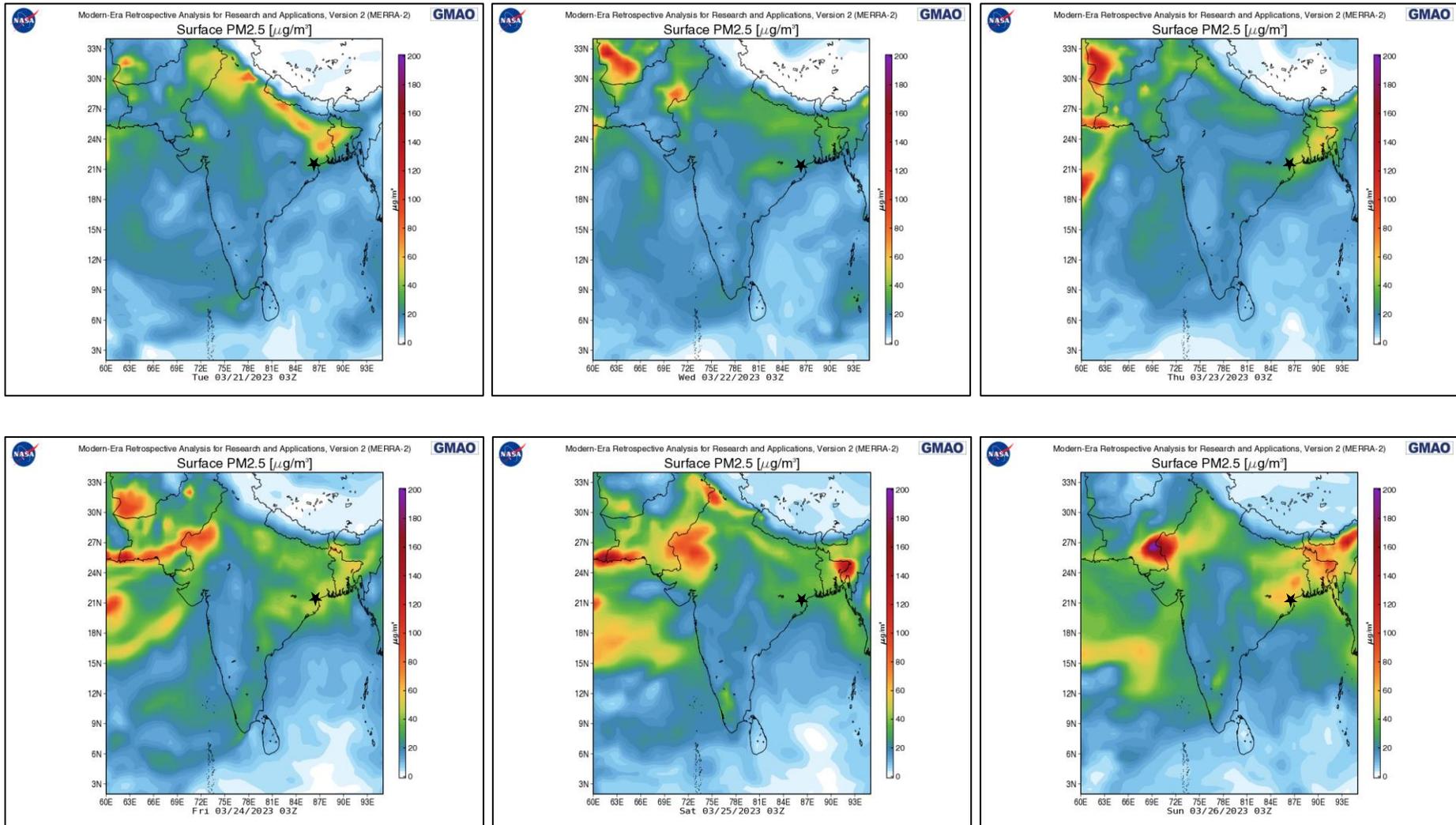
MERRA-2 Re-analysis data of Sulfate for Summer season:

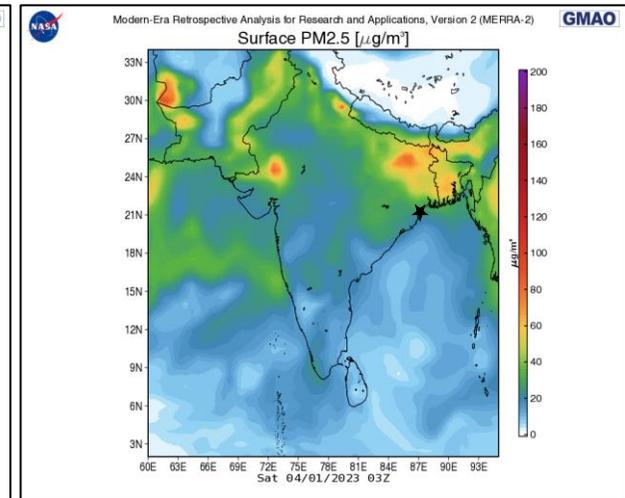
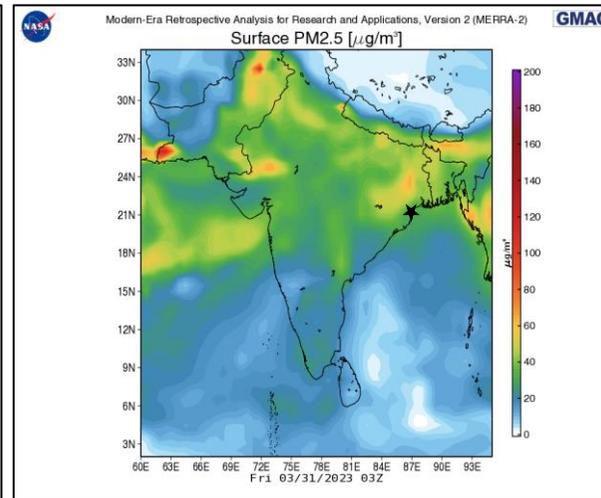
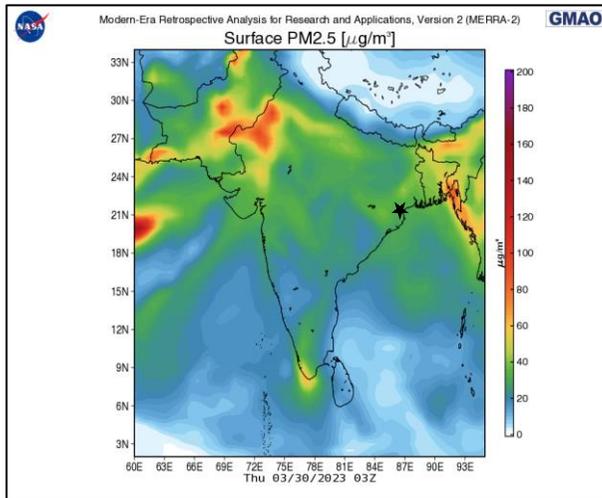
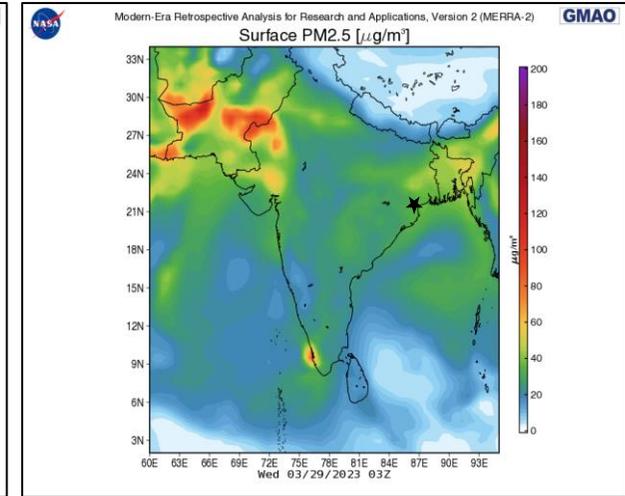
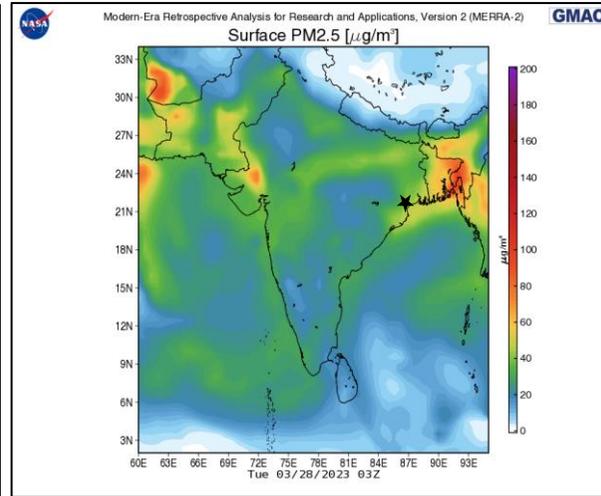
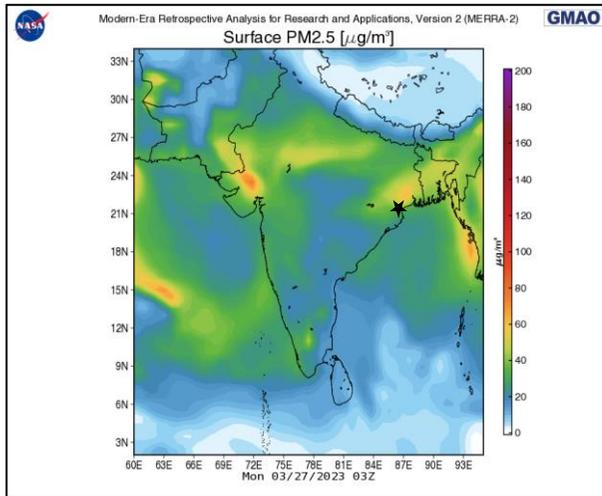


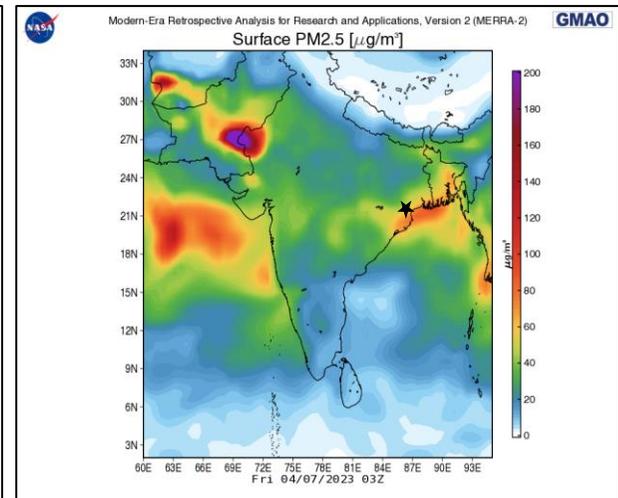
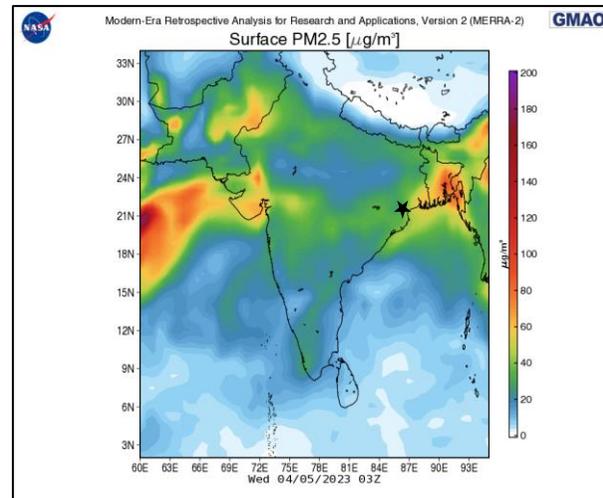
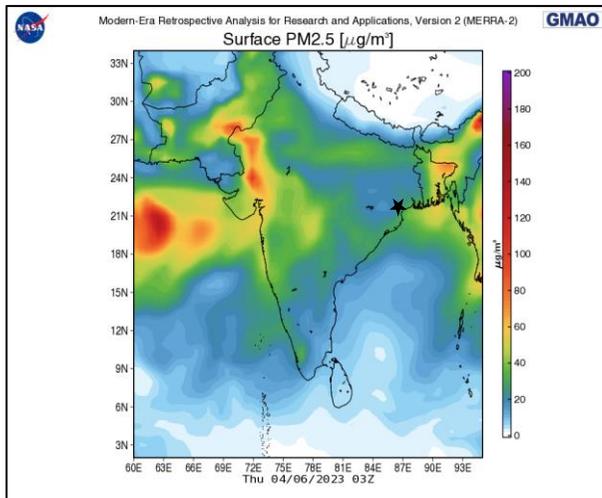
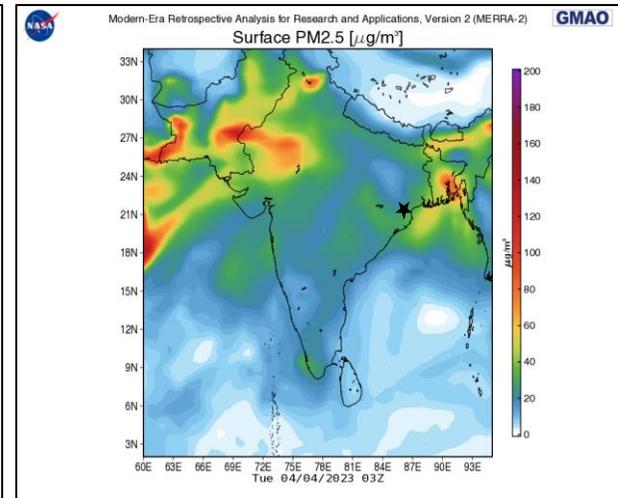
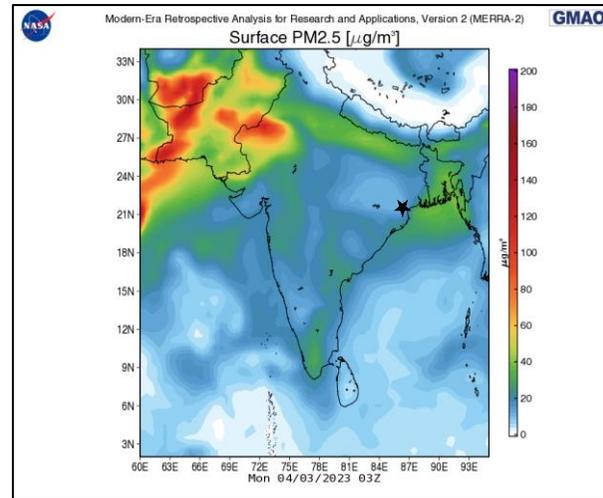
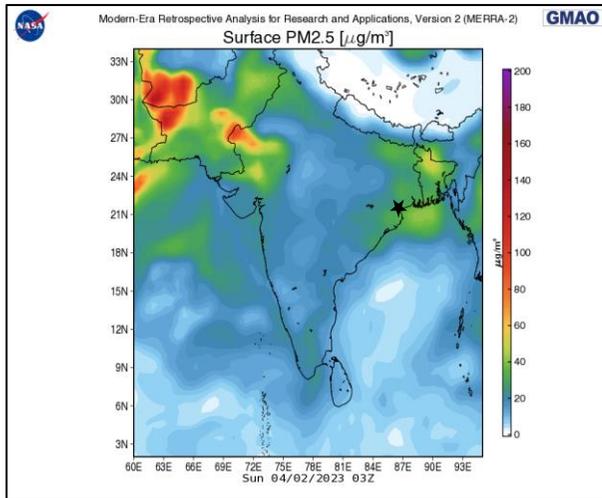




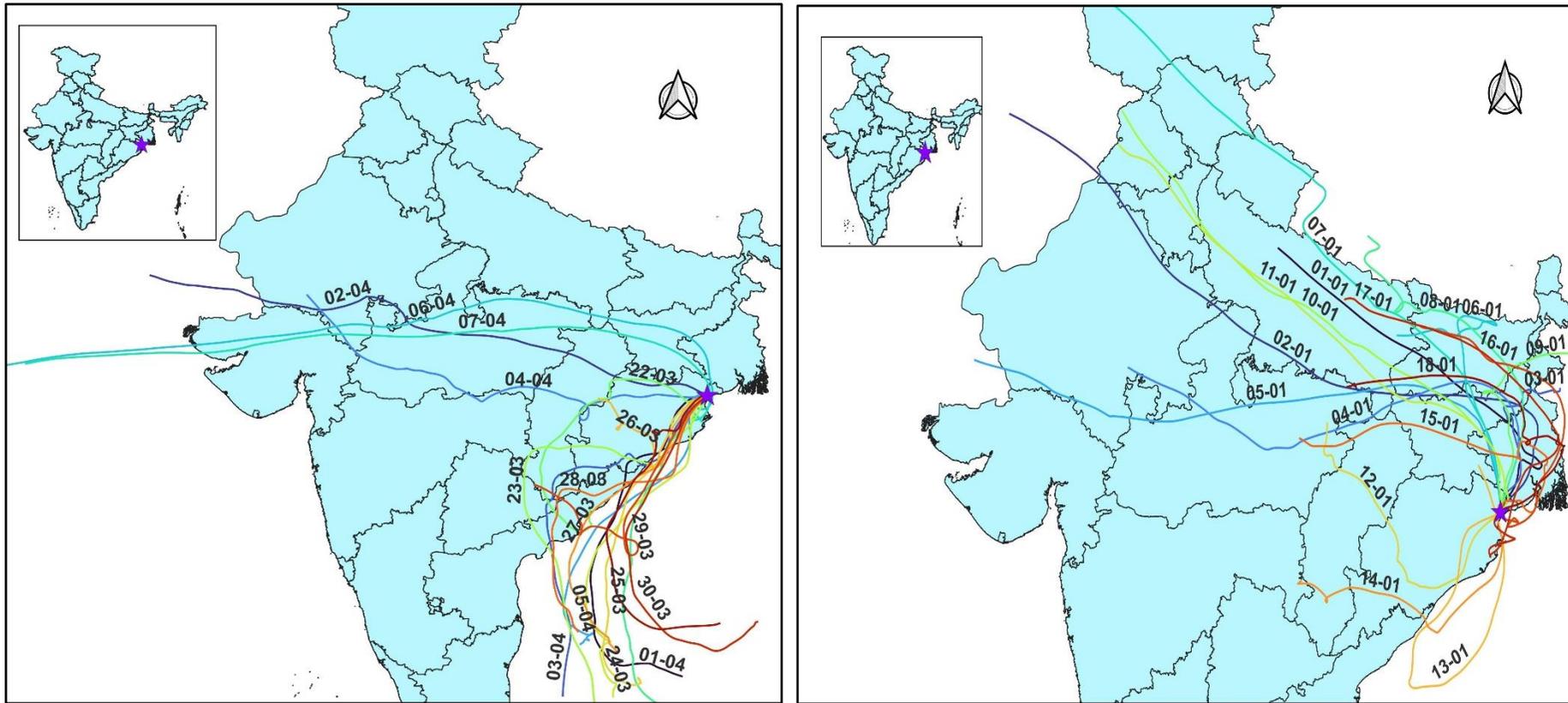
MERRA-2 Re-analysis data of Surface PM2.5 for Summer season:







HYSPLIT Back-trajectories over Balasore



HYSPLIT Back-Trajectories for Balasore during the sampling period in Summer and Winter seasons

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+

---- END OF THE REPORT---