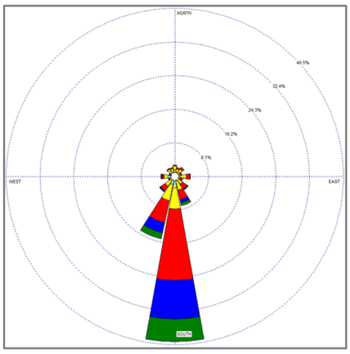
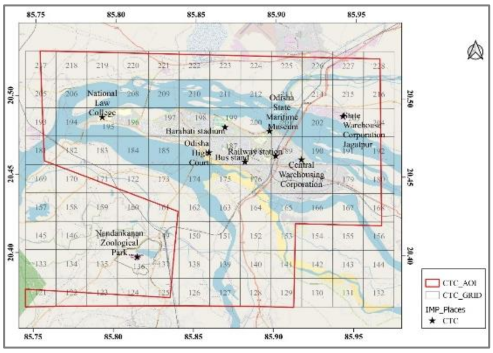
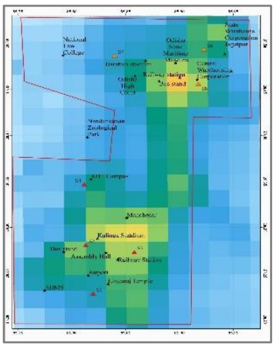
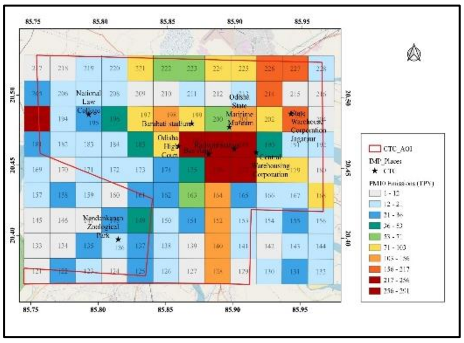
Report No.: ARAI/ERL/OSPCB_PKG_II/CTC/2024-25/Final_Report

FINAL REPORT

Emission Inventory and Source Apportionment Study of Cuttack Region in Odisha

Submitted to

State Pollution Control Board, Odisha (OSPCB)

Submitted by

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

December 2024

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Suggested format for citation:

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

Disclaimer

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

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Acknowledgements

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

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

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

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

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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 PM_{10} concentrations.

To address the air pollution issues of the Cuttack 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 Cuttack Region in Odisha". The main aim of this study is to identify and characterize various emission sources in Cuttack region of Odisha and help the regulatory agencies in prioritizing the actions for improving the air quality. The major objectives of the study are:

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

Cuttack city is located in Cuttack district and is the former capital city of Odisha in eastern India. Located at the confluence of the Mahanadi and Kathajodi rivers, Cuttack has always been a strategic crossroads, influencing trade, politics, and cultural exchange in eastern India. In recent years, Cuttack has undergone rapid urban development.

Air quality sampling and chemical analysis

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

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

Code	Location	Latitude	Longitude	Category
S5	BDO Office - Block Chhaka, Naya Bazaar, Cuttack, Odisha 753004	20° 27' 19.82" N	85° 55' 3.59" E	Mixed
S6	Varun Beverages Ltd (Pepsi) - Jagatpur Industrial Estate, Jagatpur, Odisha 754021	20° 29' 33.38" N	85° 55' 21.84" E	Industrial
S7	Baimundi Nursing Home - Baimundi Ln, Bidanasi, Cuttack, Odisha 753014	20° 29' 9.06" N	85° 50' 23.62" E	Residential (LIG and MIG)

The ambient $PM_{2.5}$ and PM_{10} samples were collected in the study area, during two critical seasons i.e. winter (December 11 to 26, 2022) and summer (April 10 to 27, 2023). The ambient $PM_{2.5}$ and PM_{10} samples were collected using multi-channel speciation samplers for 24 hours at a flow rate of 16.7 LPM. Teflon filters were used for measurement of gravimetric mass, elemental concentrations, and water-soluble ions while the quartz-fiber filters were analysed for carbonaceous materials. The Teflon filters were subjected to analysis of elements using Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRF) method while the water-soluble inorganic ionic components were determined using ion chromatography method. Similarly, the quartz filter samples were used for the analysis of organic carbon (OC) and elemental carbon (EC) using a Thermal/Optical Carbon Analyzer (DRI Model 2001A; Desert Research Institute, USA) following IMPROVE_A protocol (Chow et al. 2007). After the carbon fraction analysis, remaining part of the quartz filter papers were subjected to molecular markers (alkanes, hopanes, amides, levoglucosan and stigmasterol) analysis using Gas chromatography – mass spectrometry (GC-MS) method.

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

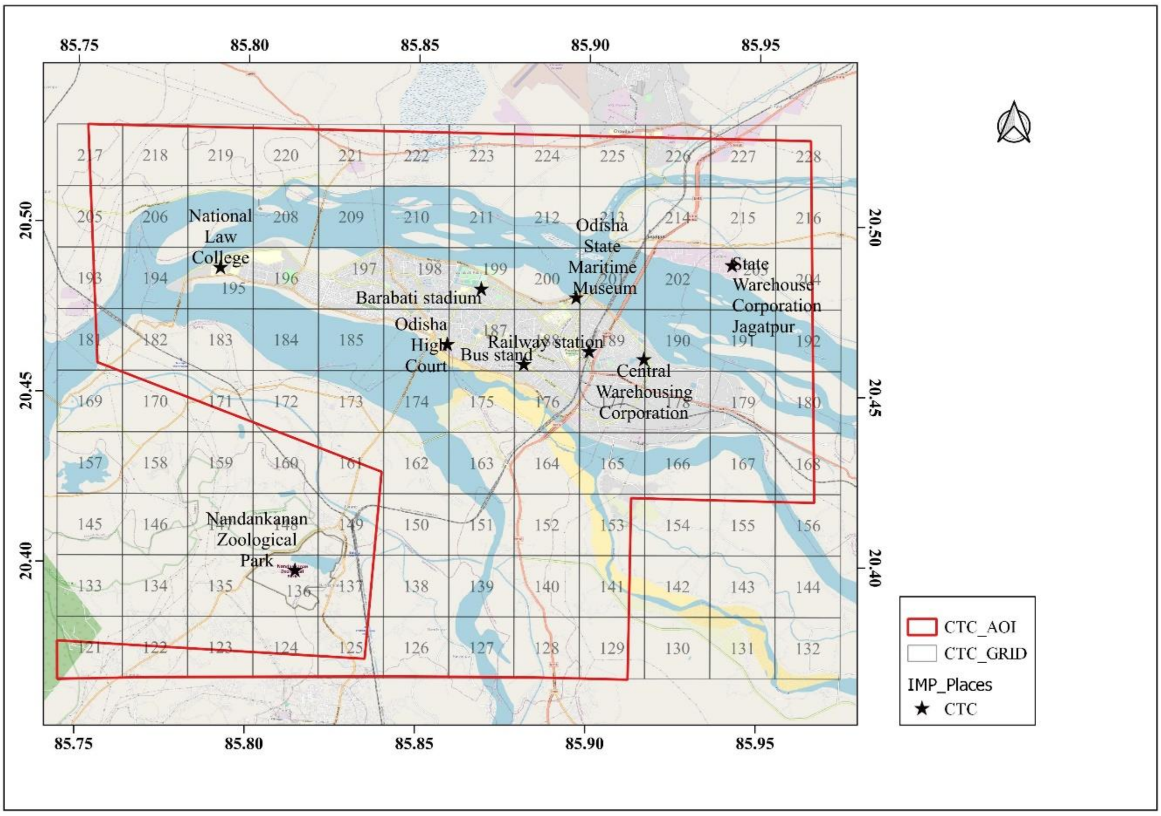


Figure ES-1 Cuttack region map showing locations of three sampling sites (violet coloured triangles) selected for source apportionment study

The winter-season mean $PM_{2.5}$ and PM_{10} mass concentrations over all sites were 86.8 and 227.9 µg/m3, respectively. The highest seasonal mean $PM_{2.5}$ concentrations were observed at S5 i.e. BDO office (91.9 µg/m^3) while the lowest were recorded at S7, i.e. Baimundi Nursing Home (78.7 µg/m^3). The highest seasonal mean PM_{10} concentrations were observed at S5 i.e. BDO office (240.9 µg/m^3) while the lowest were recorded at S7 i.e. Baimundi Nursing Home (212.7 µg/m^3). The mean value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.39, varying from 0.27 to 0.63., which in turn indicates a mix of dusty and combustion sources.

The summer-season mean $PM_{2.5}$ and PM_{10} mass concentrations over all sites were 52.5 and 134.1 µg/m^3, respectively. The highest seasonal mean $PM_{2.5}$ concentrations were observed at S6 i.e. Varun Beverages Ltd. (Pepsi) (55.9 µg/m^3) while the lowest was recorded at S5 i.e. BDO Office (47.3 µg/m^3). Similarly, the highest seasonal mean PM_{10} concentrations were observed at S7 i.e. Baimundi Nursing Home (139.1 µg/m^3) while the lowest were recorded at S5 i.e. BDO Office (130.7 µg/m^3). The mean value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.41, varying from 0.20 to 0.61, 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 0.72 (winter) and 0.94 (summer) for $PM_{2.5}$ whereas it is found to be 0.93 (winter) and 0.98 (summer) for PM_{10}, respectively. During the winter season, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM> CM > SNA > EC > TE > SS in PM_{10}. Similarly, during the summer season, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM > CM > SNA > EC > TE > SS in PM_{10}. Additionally, chemical ratios such as OC/EC, Cl-/Na+, K+/OC, K+/EC, NO3-/$SO4^{--}$ and degree of neutralization (DON) were also used as indicators to qualitatively assess the contributions from air polluting sources.

As discussed earlier, the gaseous pollutants i.e. SO_2 and NO_2 and VOCs (i.e. Benzene, Toluene, Ethyl Benzene and Xylene) were also monitored at three sampling locations in Cuttack region, during the winter season sampling period i.e. December 11 to 26, 2022. The winter season SO_2 concentrations were less than 5 µg/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 32.06 µg/m^3 at BDO Office, Nayabazar (S5), 26.88 µg/m^3 at Varun Beverages Ltd., Jagatpur (S6), and 56.25 µg/m^3 at Baimundi Nursing Home, Bidanasi (S7). In case of VOCs, winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among three sampling sites range from 18.0 to 41.9 ng/m^3, 104.2 to 332.4 ng/m^3, 395.4 to 3318.3 ng/m^3 and 698.3 to 3066.6 ng/m^3, respectively.

Receptor modelling

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

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

Overall, the winter-time $PM_{2.5}$ mass at Cuttack region (Fig. ES-2 [A]) are found to be dominated by solid waste and biomass combustion sector with highest contribution of 29.8%. The other sources of $PM_{2.5}$ at Cuttack are identified as transport (24.5%), dust (21.2%), secondary aerosols (14.5%), and industry (1.8%). Similarly, the winter-time PM_{10} mass at Cuttack is found to be dominated by dust (34.9%), followed by solid waste and biomass combustion (20.6%), secondary aerosols (18.9%), transport (12.5%), and industry (2.4%). Additionally, about 8.3% and 10.6% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

The summer-time $PM_{2.5}$ mass at Cuttack (Fig. ES-2 [B]) is found to be dominated by dust with highest contribution of 30.1%. The other summer-time sources of $PM_{2.5}$ at Cuttack region are identified as transport (25.9%), solid waste and biomass combustion (19.3%), secondary aerosols (17.3%), and industry (1.2%). Similarly, the summer-time PM_{10} mass at Cuttack region is also found to be dominated by dust (43.5%), followed by secondary aerosols (20.4%), transport (12.1%), solid waste and biomass combustion (11.8%), and industry (1.5%). Additionally, about 6.2% and 10.7% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

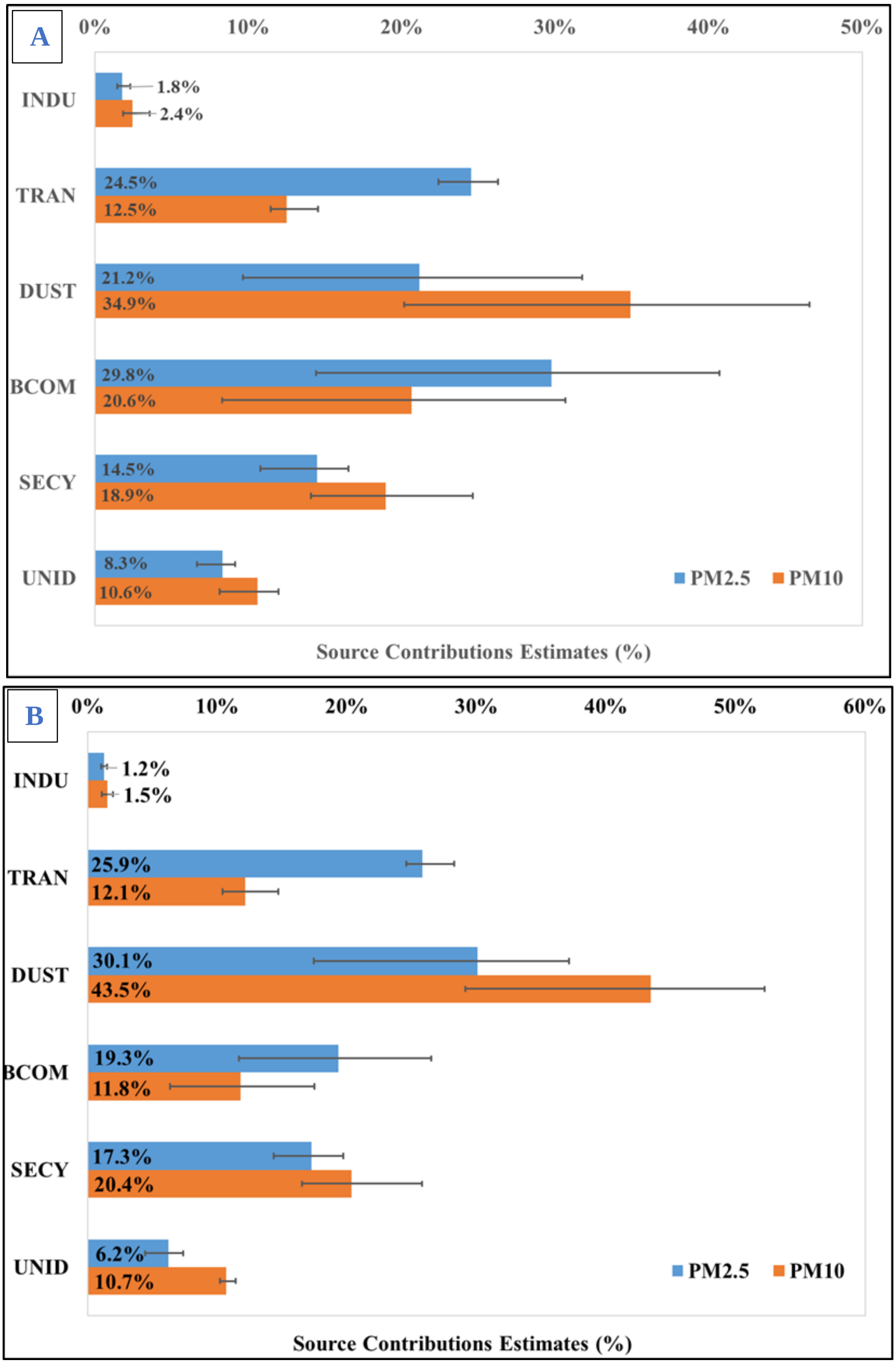


Figure ES-2 City-level source contribution estimates (SCE) for Cuttack region using CMB receptor model during winter (A) and summer (B) seasons

Emission Inventory

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

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

The overall baseline emission inventory (Year 2022) for the Cuttack region is presented in Table ES-2, while the pollutant wise contribution is shown in Fig. ES-3. The spatial distribution of the pollutants in Cuttack region is provided in Fig. ES-4, ES-5 and ES-6. The total PM_{10} emission load in the Cuttack region is estimated to be 16,895 tonnes per year. The total PM_{10} emission load in the Cuttack region is estimated to be 6,404 tonnes per year. The top four contributors to PM_{10} emissions are resuspended road dust (35.6%), followed by industries and thermal powerplants (13.5%), residential emissions (11.6%), and transport (11.2%). Similarly, $PM_{2.5}$ emission load in the Cuttack region is estimated to be 3,163 tonnes per year. The top four contributors to $PM_{2.5}$ emissions are re-suspended transport (20.4%), road dust (19.2%), residential (15.3%), and open waste burning (14.8%). 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 Cuttack Region in year 2022

Sector	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	NMVOC
Industries and powerplants	866 ± 93	305 ± 32	994 ± 38	4596 ± 331	317 ± 24	146 ± 0
Fugitive dust	202 ± 108	20 ± 10	NA#	NA#	NA#	NA#
Transport	716 ± 197	644 ± 177	11 ± 2	7504 ± 4014	17310 ± 9257	11956 ± 77
Road dust	2282 ± 577	607 ± 153	NA#	NA#	NA#	NA#
Residential	745 ± 387	485 ± 252	293 ± 49	259 ± 134	6942 ± 3612	2084 ± 265
Open waste burning	503 ± 281	467 ± 261	32 ± 17	72 ± 40	2408 ± 1346	521 ± 6438
Hotels, Restaurants, Bakeries and Open eateries	493 ± 272	317 ± 175	287 ± 72	106 ± 58	1894 ± 1047	231 ± 124
Construction	77 ± 16	19 ± 4	NA#	NA#	NA#	NA#
Brick Kilns	32 ± 17	13 ± 7	16 ± 8	0 ± 0	159 ± 87	4 ± 1664
Diesel Generators	250 ± 130	214 ± 111	155 ± 38	2355 ± 1226	508 ± 264	3091 ± 1062
Wind-blown Riverbed Erosion dust (WBDT)	194 ± 54	49 ± 13	NA#	NA#	NA#	NA#
Crematoria	44 ± 22	22 ± 11	1 ± 0.5	6 ± 3	220 ± 113	123 ± 62
Total	**6404 ± 2160**	**3163 ± 1211**	**1791 ± 228**	**14898 ± 5809**	**29758 ± 15754**	**18155 ± 9671**

NA# indicates the emissions quantification is not applicable for a particular sector. The value after ± indicates, uncertainty range (tonnes) in emissions estimate.

The gaseous pollutants, included in the study were SO_2, NO_X, CO and NMVOC. The SO_2, NO_X, CO and NMVOC emission loads for year 2022 in the study domain are estimated to be 1791, 14898, 29758 and 18155 tonnes per year, respectively.

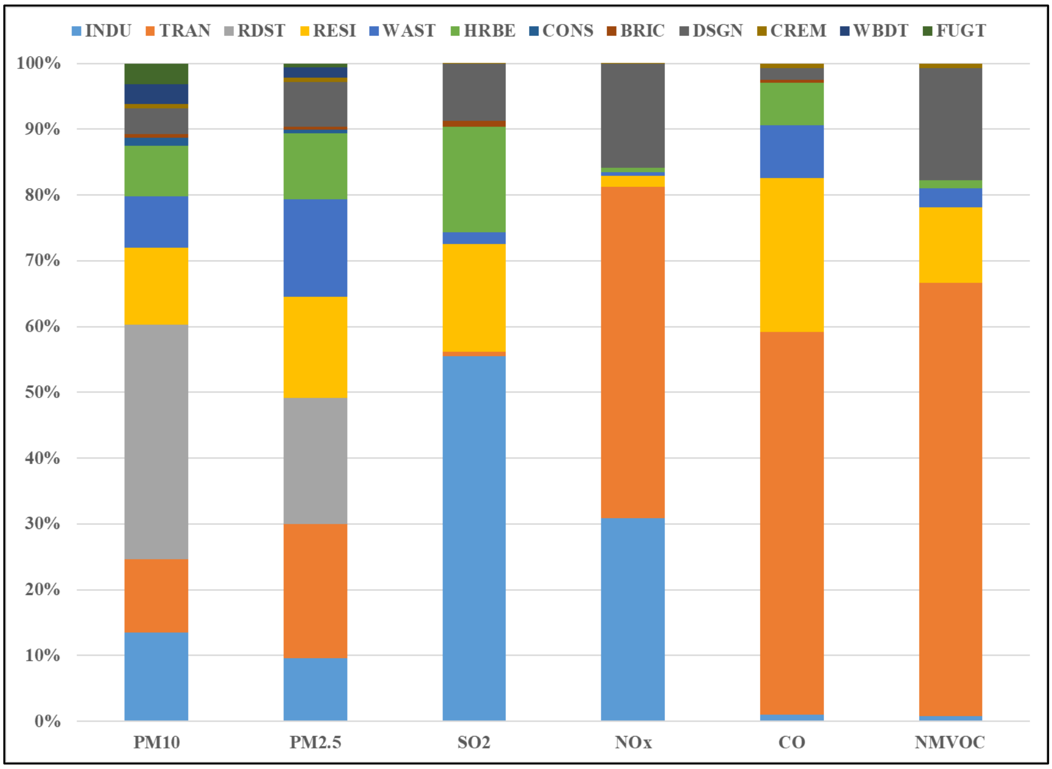


Figure ES-3 Sector-wise contribution to air pollutant emissions of A) PM_{10}, B) $PM_{2.5}$, C) SO_2, D) NOX, E) CO and F) NMVOC in Cuttack region in 2022

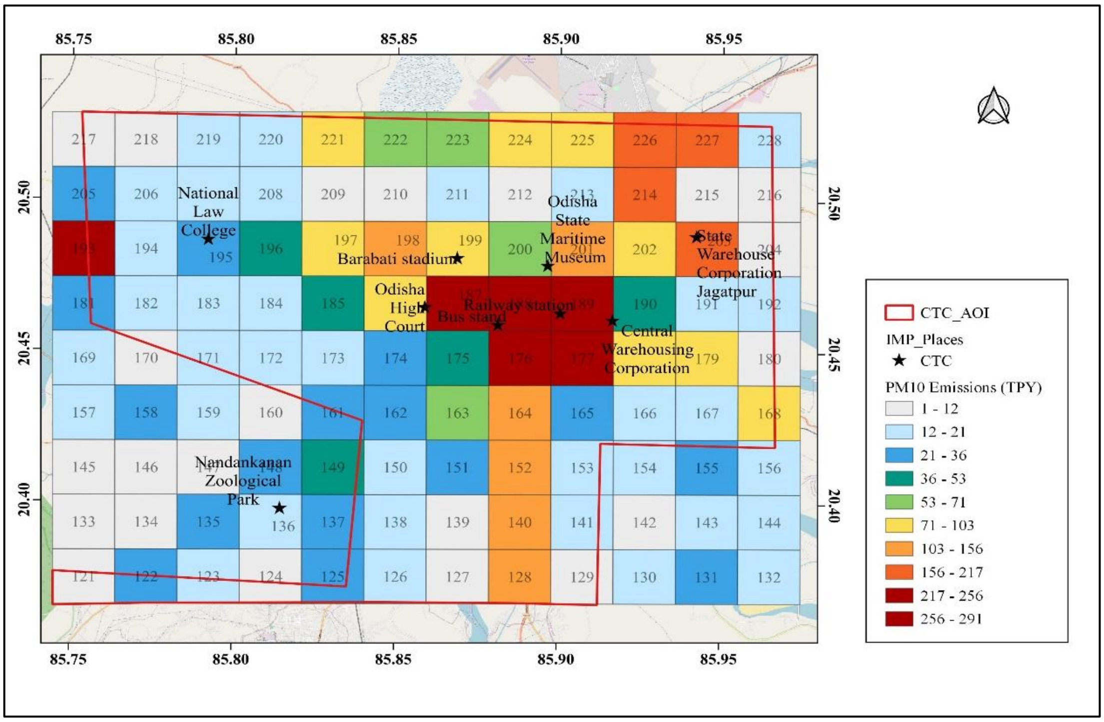
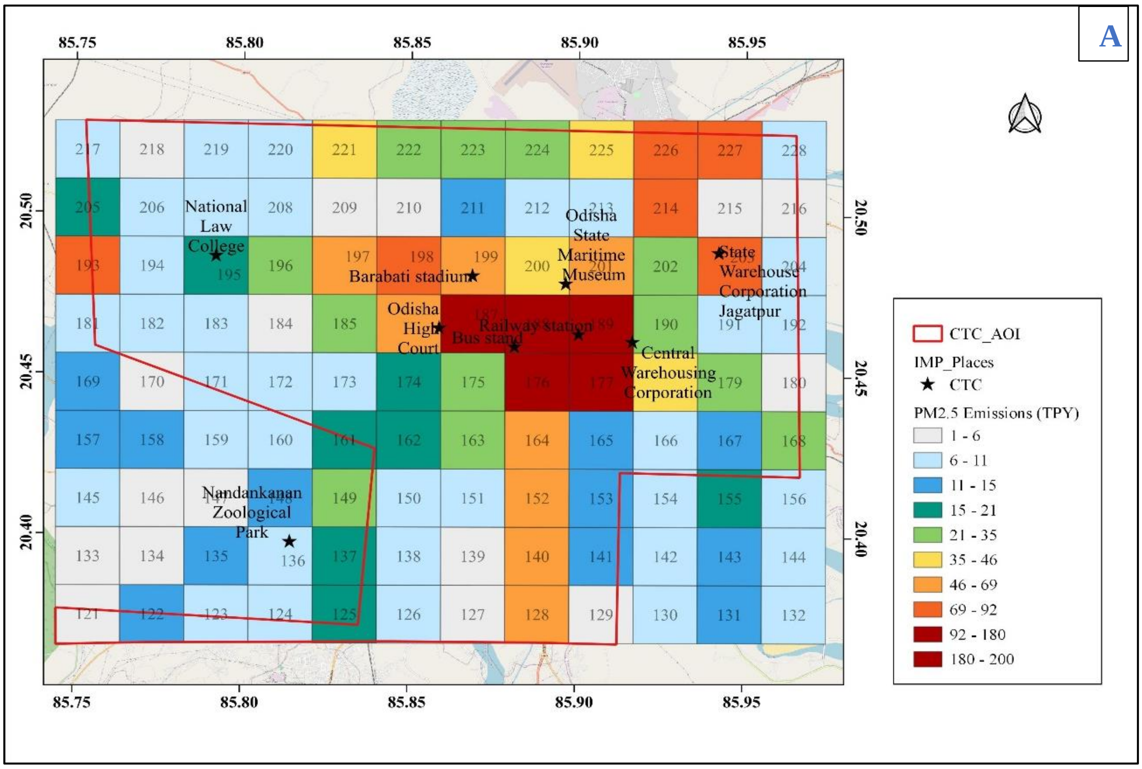


Figure ES-4 Spatial distribution of air pollutant emissions of PM_{10} (tonnes per year) in Cuttack region in 2022.



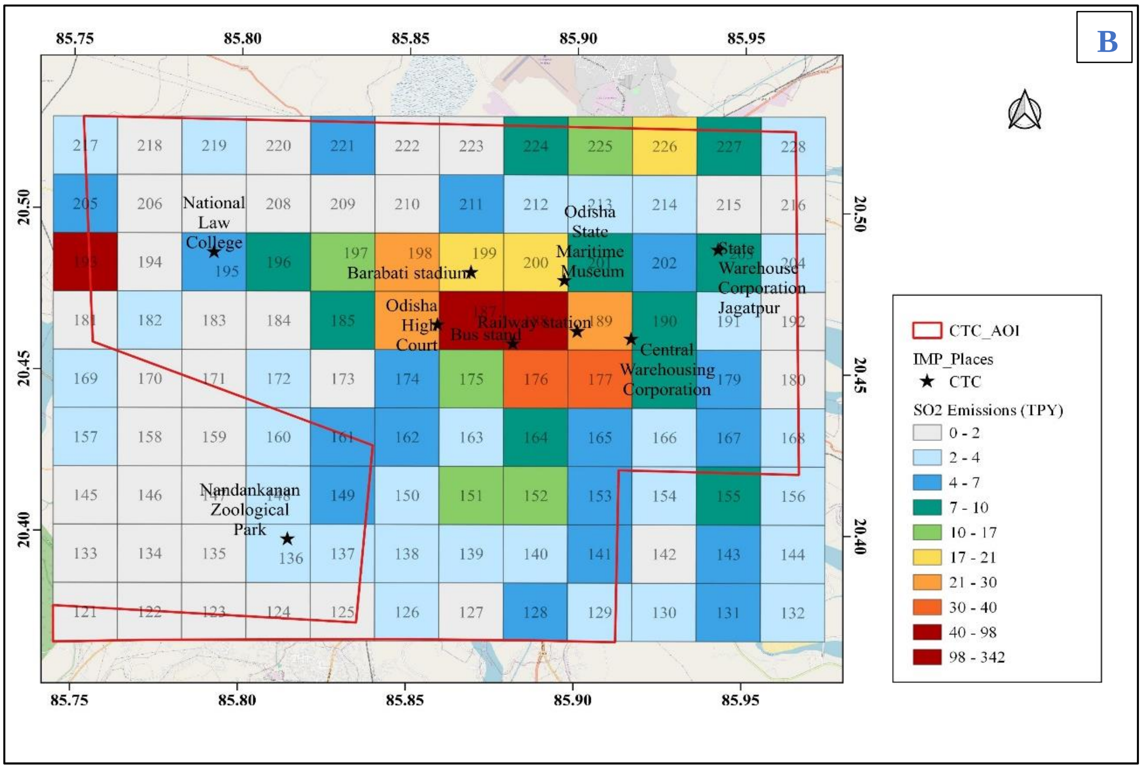
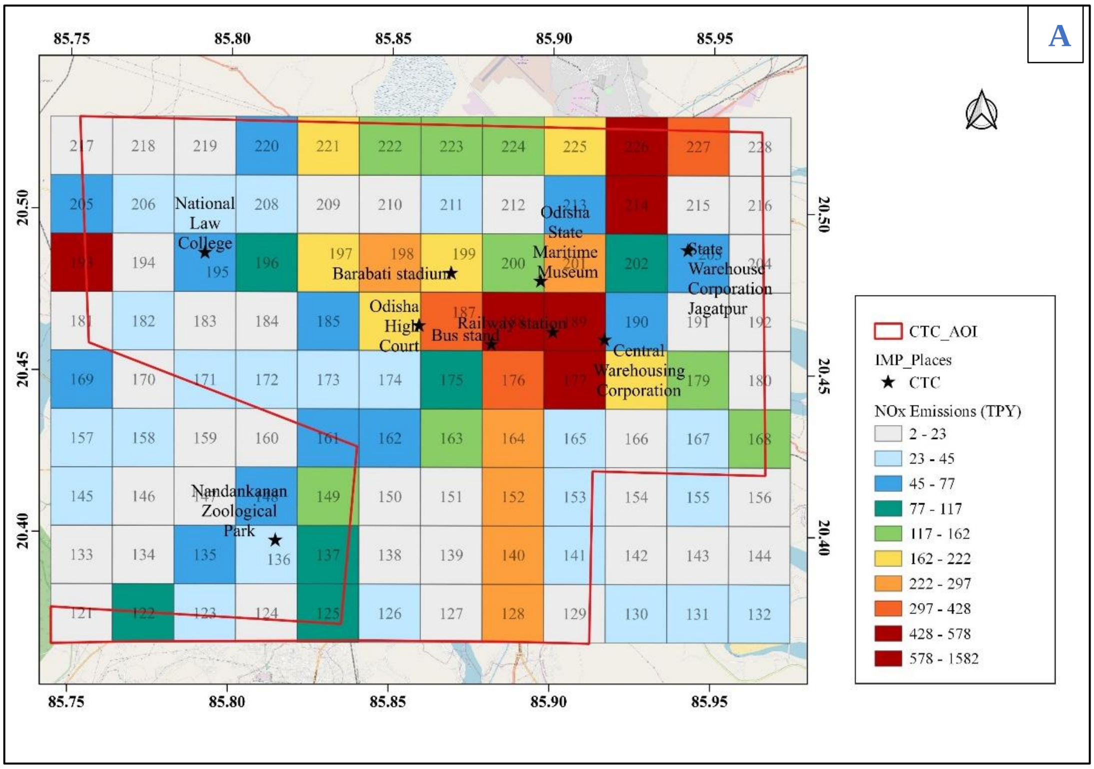


Figure ES-5 Spatial distribution of air pollutant emissions A)PM2.5 and SO_2 *(tonnes per year) in Cuttack region in 2022.*



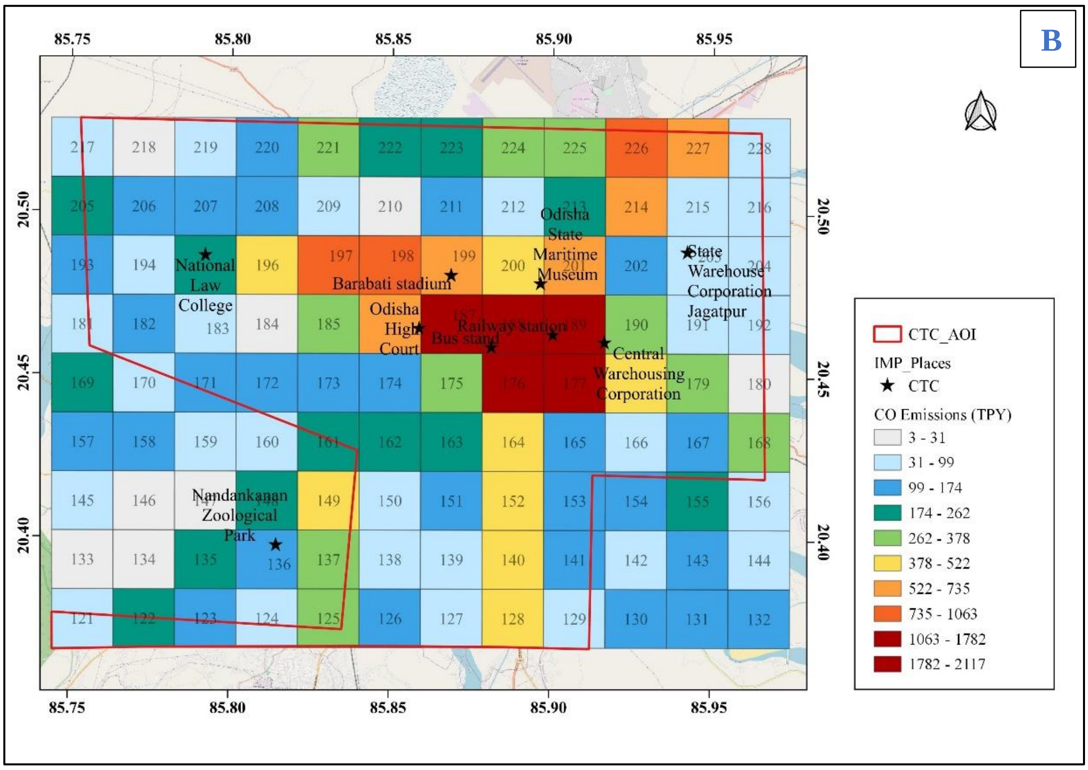


Figure ES-6 Spatial distribution of air pollutant emissions A) NOx and B) CO (tonnes per year) in Cuttack region in 2022.

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 Bhubaneswar and Cuttack 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 km^2, except the industries and thermal powerplants, crematoria, industrial fugitive dust and brick kilns. The stack emissions from industries, thermal powerplants, 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 260 gridded receptors (refer Fig. ES-7). Additionally, seven 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 $PM_{2.5}$, PM_{10}, SO_2, and NO_2 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 Bhubaneswar-Cuttack region, with a reasonable accuracy. Fig. ES-8 and Fig. ES-9 shows the spatial distribution of AERMOD simulated PM_{10} and $PM_{2.5}$ concentrations during baseline year, respectively.

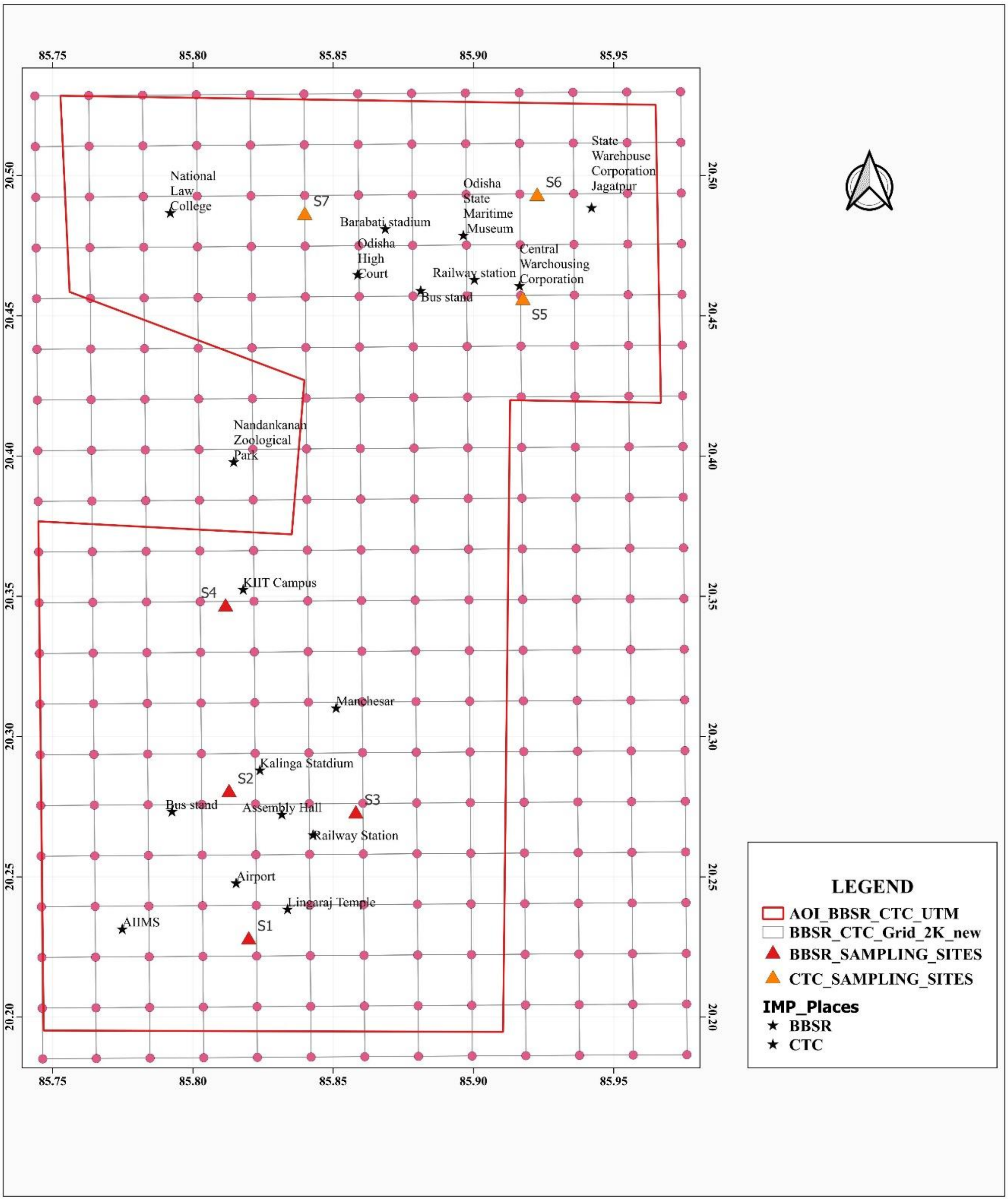


Figure ES-7 Map showing AERMOD modelling domain overlaid by gridded and discrete receptors configured in this study.

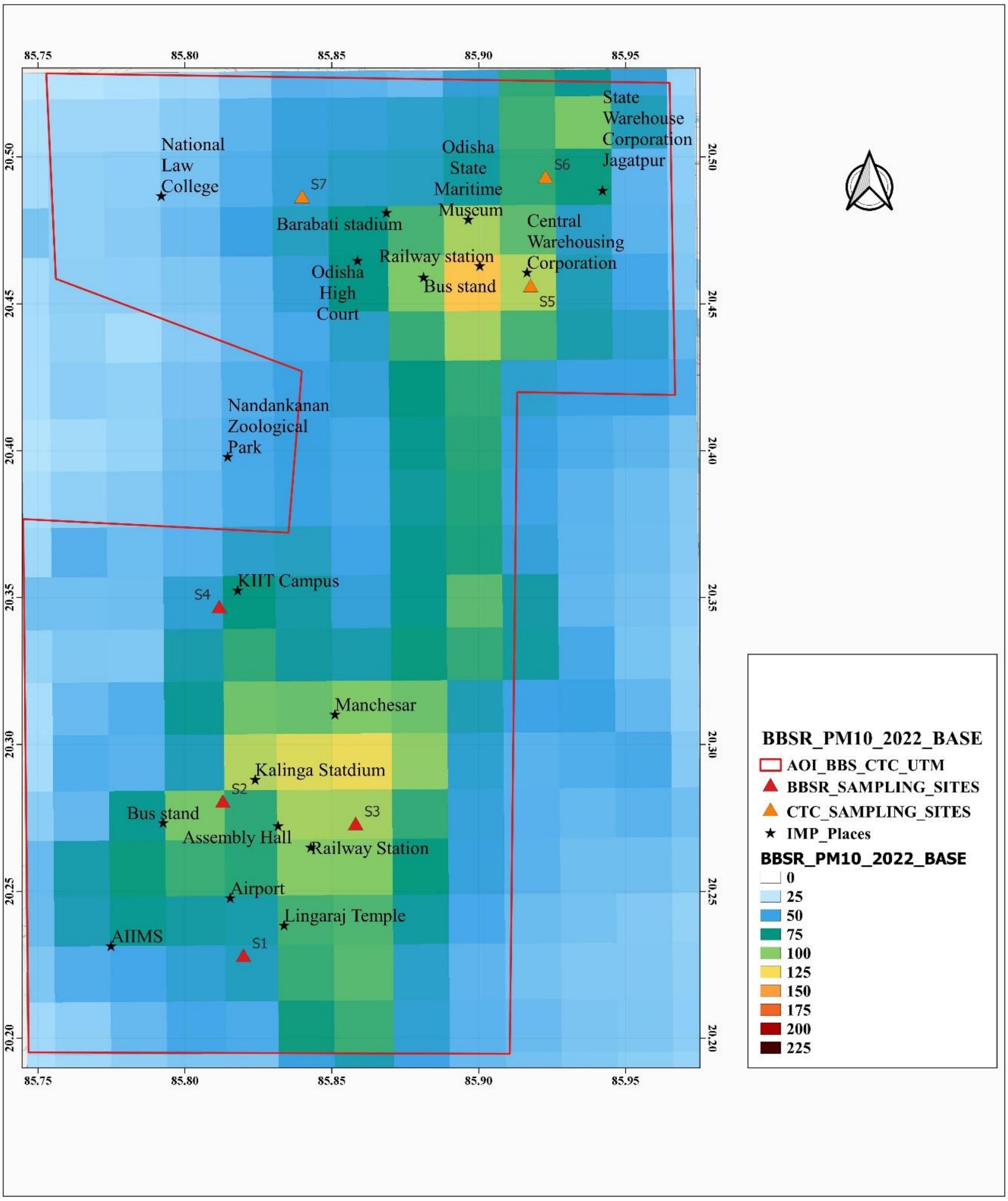


Figure ES-8 Map showing spatial distribution of** PM_{10} **annual mean concentrations** ($\mu g/m^3$) **over Bhubaneswar-Cuttack region for year 2022

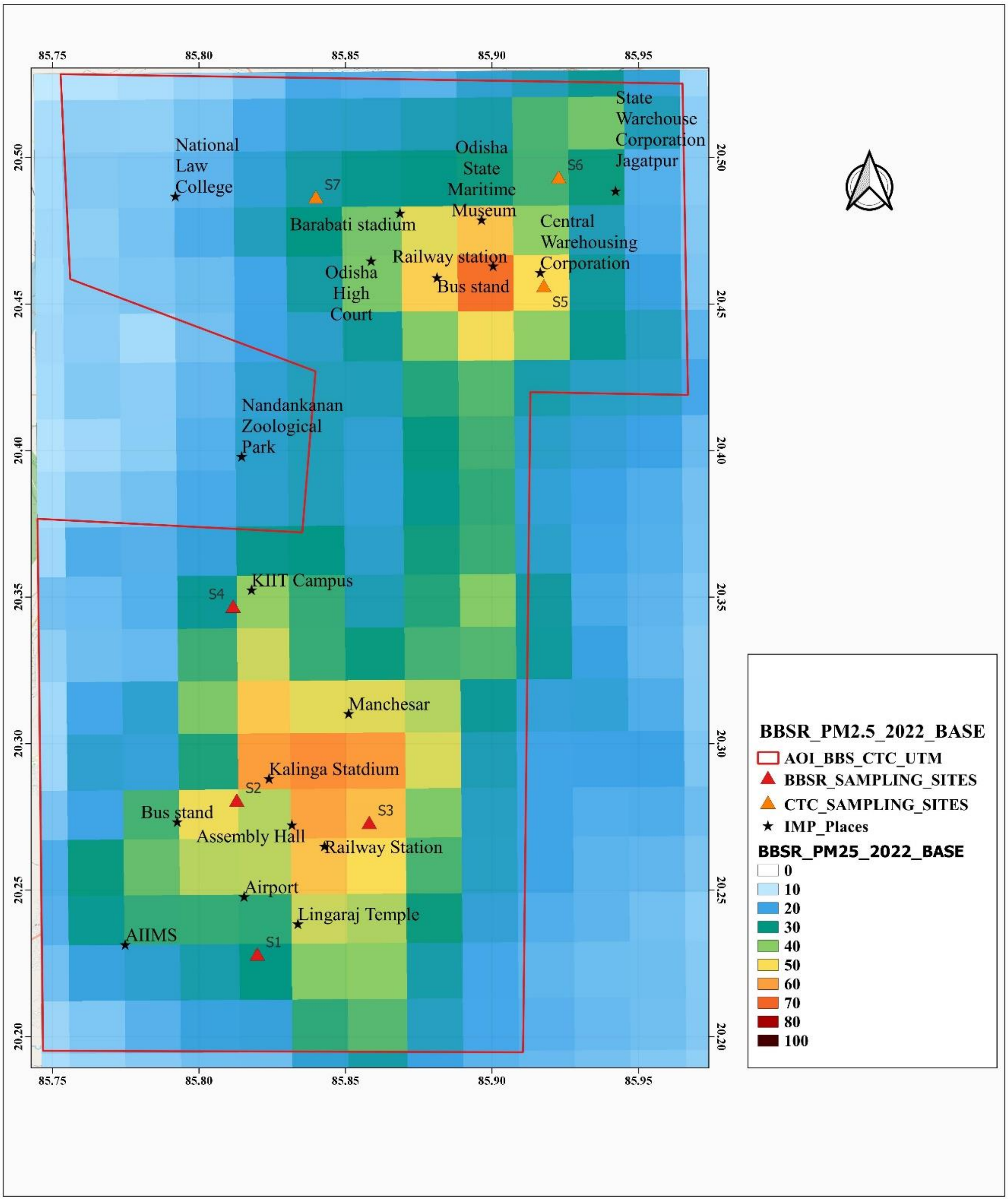


Figure ES-9 Map showing spatial distribution of** $PM_{2.5}$ **annual mean concentrations** ($\mu g/m^3$) **over Bhubaneswar-Cuttack region for year 2022

Future projections and air quality benefits

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 2021. Four hypothetical emission scenarios viz. i) No further control (NFC), ii) Business-as-usual (BAU), iii) Scenario – I (SC-I) and iv) Scenario – II (SC-II); are developed for Cuttack 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 assumptions and considerations in each scenario are described in this section. Table ES-3 summarizes the estimated emissions (tonnes per year) of selected pollutants under four scenarios in Cuttack region for years 2022, 2027 and 2032.

Table ES-3 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Cuttack region for years 2022, 2027 and 2032

Year	Scenario	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
2022	BASE	6,404	3,163	1,791	14,898	29,758
2027	NFC	7,709	3,794	2,028	16,815	37,588
	BAU	6,837	3,368	1,109	16,222	35,072
	SC_I	5,868	2,847	986	14,937	31,610
	SC_II	4,744	2,349	793	13,338	28,377
2032	NFC	9,798	4,552	2,290	17,718	45,108
	BAU	7,545	3,505	1,268	15,141	39,139
	SC_I	5,392	2,609	923	13,478	34,425
	SC_II	2,999	1,608	665	11,171	28,890

The NFC scenario projections in Cuttack region indicate a potential increase in PM_{10} emissions to 7709 tonnes per year in 2027 i.e. an increase of 20.4% w.r.t. baseline year 2022 and to 9798 tonnes per year in 2032 i.e. an increase of 53.0% w.r.t. baseline year 2022. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to reach to 3794 (20.0%) and to 4552 tonnes per year (i.e. 43.9%) in 2027 and 2032, respectively. The BAU projections in Cuttack region indicate a potential decrease of PM_{10} emissions to 6837 tonnes per year in 2027 i.e. a decrease of 11.3 % w.r.t. NFC 2027 and to 7545 tonnes per year in 2032 i.e. a decrease of 23.0% w.r.t. NFC 2032. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 3368 (-11.2%) and to 3505 tonnes per year (i.e. -23.0%) in 2027 and 2032, respectively.

The SC-I projections in Cuttack region indicate a potential decrease of PM_{10} emissions to 5868 tonnes per year in 2027 i.e. a decrease of 23.9% w.r.t. NFC 2027 and to 5392 tonnes per year in 2032 i.e. a decrease of 45.0% % w.r.t. NFC 2032. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 2847 (-25.0%) and to 2609 tonnes per year (i.e. -42.7%) in 2027 and 2032, respectively. The SC-II projections in Cuttack region indicate a potential decrease of PM_{10} emissions to 4744 tonnes per year in 2027 i.e. a decrease of 38.5% w.r.t. NFC 2027 and to 2999 tonnes per year in 2032 i.e. a decrease of 69.4% w.r.t. NFC 2032. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 2349 (i.e. -38.1%) and to 1608 tonnes per year (i.e. -64.7%) in 2027 and 2032, respectively.

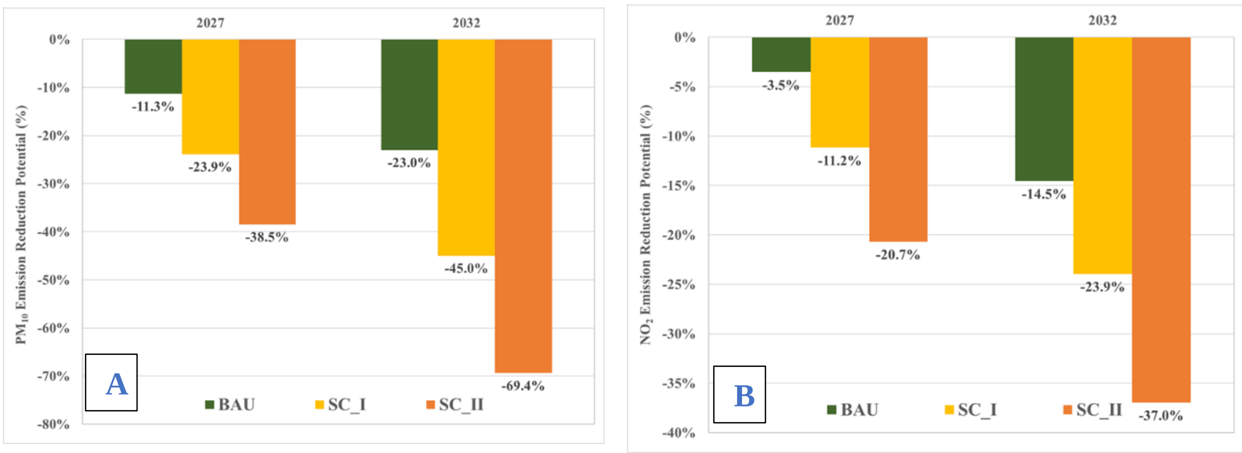


Figure ES-10 Estimated** PM_{10} **(A) and** $PM_{2.5}$ **(B) emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2027 and 2032)

Air quality benefits of four designed scenarios were assessed for years 2027 and 2032 using AERMOD modelled annual mean pollutant concentrations in Bhubaneswar-Cuttack 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 6.7%, 14.3%, and 22.8% in 2027 and 16.3%, 30.2%, and 46.3% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively. In case of $PM_{2.5}$, with implementation of control measures considered in different scenarios, an estimated reduction of 6.3%, 14.4%, and 22.4% in 2027 and 15.0%, 28.7%, and 43.4% 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. Three representative locations, i.e. ARAI sampling locations (S5-S), were selected to understand the impact of control measures on air quality. Table ES-4 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 Cuttack region.

Table ES-4 Percentage change in predicted ambient air quality concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S5 i.e. BDO Office, Naya Bazar sampling location

Year/Scenario	2027			2032		
Pollutant	BAU	SC-I	SC-II	BAU	SC-I	SC-II
PM_{10}	-10.0%	-20.5%	-33.0%	-21.6%	-42.4%	-64.7%
$PM_{2.5}$	-9.3%	-19.8%	-31.0%	-20.5%	-39.1%	-58.8%
SO_2	-5.6%	-11.8%	-26.8%	-5.5%	-28.7%	-46.8%
NO_2	-0.8%	-2.7%	-5.1%	-3.2%	-6.3%	-10.8%
CO	-4.4%	-9.8%	-15.6%	-9.3%	-16.5%	-24.4%

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, For example, the combined proportion of Good and Satisfactory AQI classes in NFC is 59% and 48% in 2027 and 2032, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 68% and 60% in 2027 and 2032, respectively under BAU scenario, to 76% and 82% in 2027 and 2032, respectively under SC-I, to 85% 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 Cuttack 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.

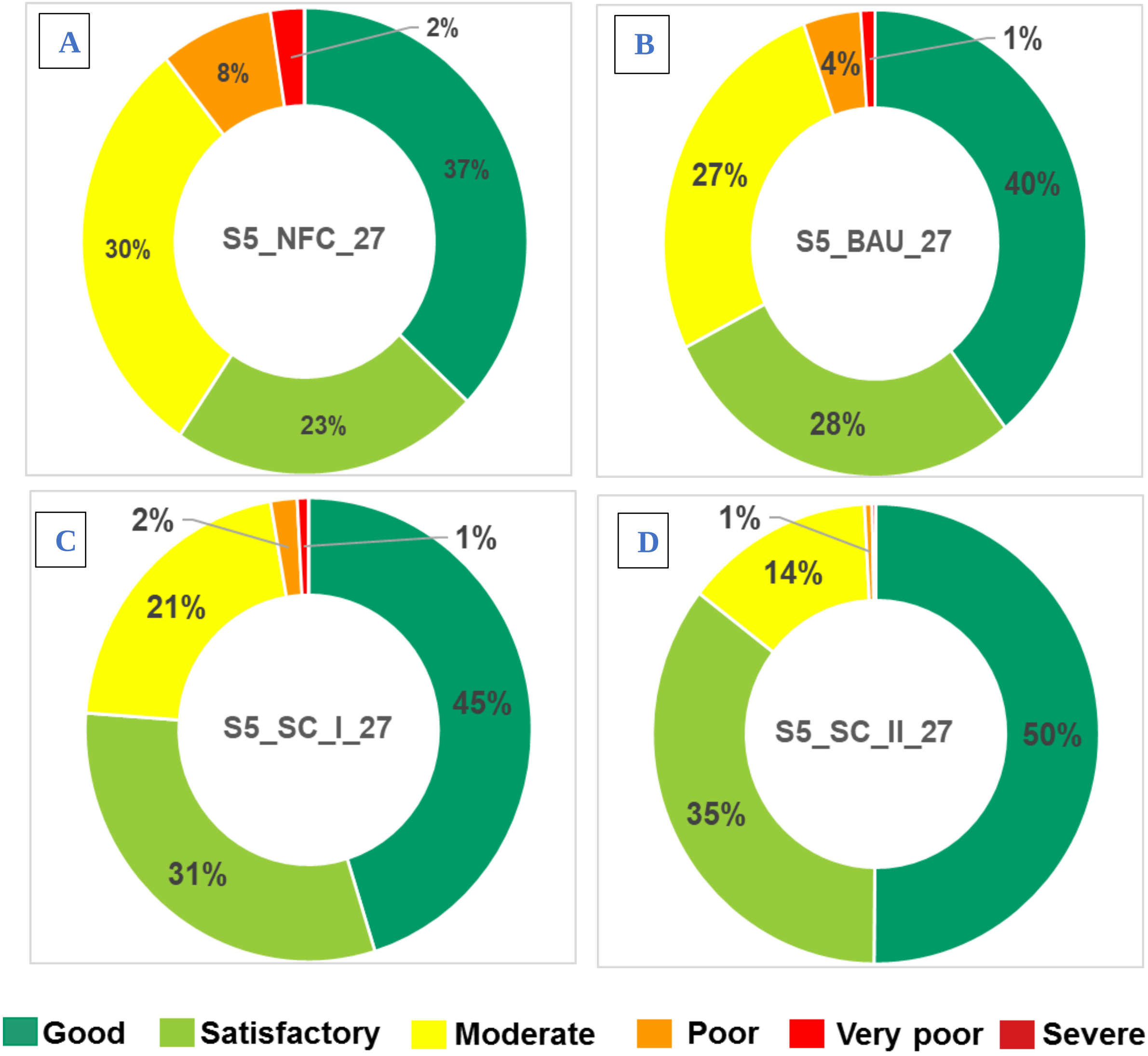


Figure ES-11 Distribution of six AQI categories* at BDO Office, Nayabazar (S5) *in Cuttack region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2027

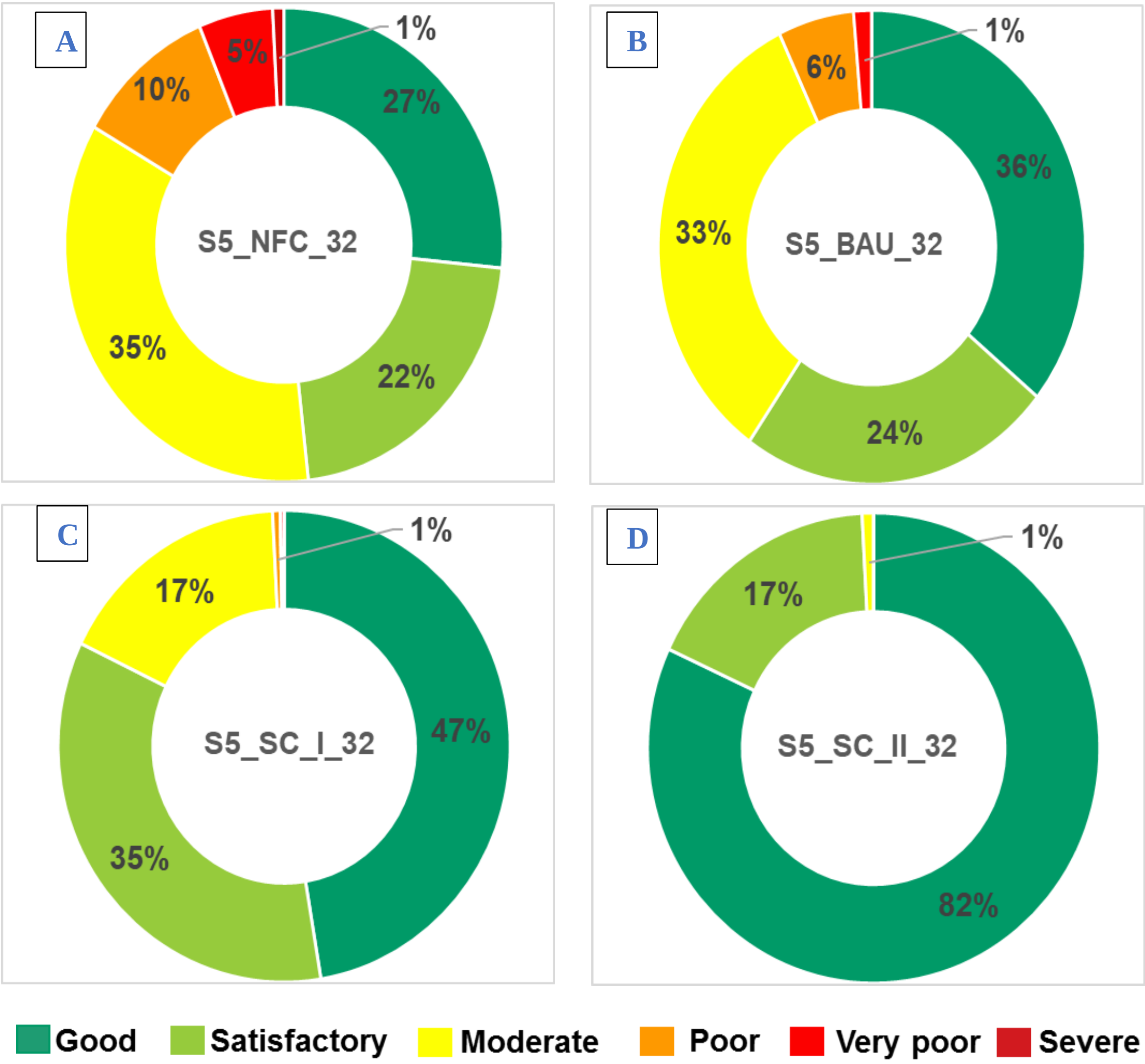


Figure ES-12 Distribution of six AQI categories at BDO Office, Nayabazar (S5) in *Cuttack region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2032*

Clean Air Action Plan

Table ES-5 presents the proposed air quality action plan for Cuttack 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 Cuttack 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.	Municipal Corporation / 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.	Municipal Corporation	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	Municipal Corporation	1 -2 years
	Declare NO-vehicle zones in hot-spots, university / school premises.	Municipal Corporation / University / School	6 months
	Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Examine existing framework for removing broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.	Municipal Corporation/ Local Govt. Body	6 months
	B) Technology		
	Improve and strengthen PUC program. (SMS based system to alerts, Linking of PUC centres with remote server and elimination of manual intervention in PUC testing, Fitness and calibration audits of PUC centres adopted with defined team for verification, Integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, Linking of PUC certificates with annual vehicle insurance, etc.)	RTO	1 year
	Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Oil Companies/ GAIL / State Government	3 years
	The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	Municipal Corporation/ 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 / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	Municipal Corporation/ Local Govt. Body	6 months
	All the canals/nallah's side roads should be concrete / brick lined.	Municipal Corporation/ Local Govt. Body	1 year

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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Adoption of Cleaner Fuels: • Cleaner fuel implementation to be encouraged and incentivized. • Discourage the fuels with high sulphur content. • A favourable taxation and pricing policy for mass adoption.	OSPCB	1 year
	Ensuring installation/Up-gradation and operation of air pollution control devices in industries	OSPCB	6 months
	Disposal of all non-hazardous wastes into the designated dumping sites	OSPCB	Continuous
	Industry shall prepare plant wise inventory of vents and ensure that it is routed to vapour recovery system followed by flare system, wherever applicable.	OSPCB	6 months
	Regeneration frequency of Adsorption / absorption system / Activated carbon bed should be clearly defined as per the trend data of previous cycles and should be documented.	OSPCB	6 months
	Industry should include a special training module regarding "fugitive emissions and its health impacts on individual and surrounding communities" for its staff, operating personnel & Drivers to spread awareness about risk/hazard associated with spills and leaks of various chemicals.	OSPCB	Continuous
	Bank guarantee should be taken for the compliance of conditions imposed in CTO/CTE for control of Environmental Pollution from industries.	OSPCB	6 months
	Industrial units to install water spraying system of internal roads and washing of tyres of vehicles	OSPCB	6 months
	Development of mobile facility/van for continuous ambient air quality monitoring for different localities.	OSPCB	6 months
Thermal Power Plants	• Implementation of new thermal power plant standards in all power plants by an early date. The power plants need to comply with the new emission standards. • Check status of compliance and prepare a transition plan for each plant to meet the new standards. This should apply to all state owned, private and captive power plants:	OSPCB	2 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	• Plants found not meeting set emission reduction targets to be penalized. • Prepare plan for full utilization of flyash, and also carry out monitoring, sprinkling of water (recycled water) especially during summer months to curtail wind-blown ash. • Progressively close the older and more polluting thermal power plants and to move to cleaner natural gas • Installation of Flue Gas Desulfurization (FGD) units to reduce the SO_2 emissions. (Efficiency 50 to 99.8% based on age of plant, sulfur content in coal etc) • Prepare a roadmap for cleaner plants and Incentivize their operation by giving them the priority over other polluting plants.		
Open Waste Burning	Improving door to door waste collection efficiency to 100%.	Municipal Corporation/ Local Govt. Body	1 year
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	Municipal Corporation/ 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, Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Encouraging the reduce, recycle and reuse policy for waste in city	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body	1 year
	Effective management of landfill sites through increasing the recycling rate, installing waste to energy conversion plants, restricting illegal waste	Municipal Corporation/ Local Govt. Body	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	dumping, proper disposal of hazardous waste, as per Hazardous waste management rule 2016, to prevent greenhouse gas emissions from site		
	Reduce the VKT of waste collection vehicles with route optimisation technique.	Municipal Corporation/ 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	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	Municipal Corporation/ Local Govt. Body	Immediate
	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	3 months
	Develop and implement dust control measures such as site covering, fugitive emission control, installing air pollution controlling devices for all types of construction activities i.e. buildings and infrastructure.	Municipal Corporation/ 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.	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body / OSPCB	1 Year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
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	Municipal Corporation/ Local Govt. Body / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	Municipal Corporation/ 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	Municipal Corporation/ Local Govt. Body / State Government	5 years
	Leverage rooftop solar programme to reduce dependence on DG sets.	Municipal Corporation/ Local Govt. Body	1 year
	Installation of Retrofitted Emission Control Devices (RECD) to diesel generators as per CPCB guidelines	OSPCB	1 year
Residential	Ensure easy availability of affordable cleaner cooking fuels (LPG/ PNG/biogas) for all to achieve 100% LPG adoption.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP/BP, etc.)	1-3 years
	Expanding coverage of LPG under Pradhan Mantri Ujjwala Yojana (PMUY).	State / Central Government	1-2 years
	Introduce schemes for providing subsidized LPG connections as well as providing means of finance to small tea vendors/hawkers who are using kerosene stoves in order to reduce emissions from burning of kerosene	State / Central Government	1-2 years
	Introduction of improved *Chullahs* (low emission *Chullahs*) in rural areas	Municipal Corporation/ 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	Municipal Corporation/ Local Govt. Body	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
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.	Municipal Corporation/ 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	Municipal Corporation/ 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.	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
	Encourage the use of public transport for daily commute.	Municipal Corporation/ 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	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	Municipal Corporation/ 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, PM_{10} i.e. particles with aerodynamic diameter less than or equal to 10 µm, has also been shown to affect health in the short-term while long-term effects are yet to be confirmed (Katzman et al., 2010). The particulate matter is considered dangerous, primarily due to its fine size; but its chemical composition makes it even more hazardous for humans (Pope III et al., 2002, 2006). Particulate matter often consists of carbon, sulfate and nitrate compounds, but also may include other substances such as heavy Elements (WB and IHME, 2016), mineral dust and sea salt. The chemical composition of PM offers valuable information to identify the contributions of specific sources and to understand aerosol properties and processes that could affect health, climate, and atmospheric conditions.

The Central Pollution Control Board (CPCB), New Delhi has identified 131 cities in India where the prescribed annual National Ambient Air Quality Standards (NAAQS) are violated. Considering the health impacts associated with PM, the Indian planning and regulatory agencies have also aligned their roadmap towards effectively addressing the $PM_{2.5}$ pollution. India's National Clean Air Program (NCAP) launched by Ministry of Environment, Forest and Climate Change (MoEFCC) in 2019 aims to reduce the national level $PM_{2.5}$ and PM_{10} concentrations by 20-30% by year 2024, taking 2017 as the base year for the comparison of concentration. The earlier/original targets were recently revised to achieve reductions up to 40% of PM_{10} concentrations by 2025-26 (MoEFCC, 2023). The overall objective of the India's NCAP is comprehensive mitigation actions for prevention, control and abatement of air pollution besides augmenting the air quality monitoring network across the country and strengthening the awareness and capacity building activities (MoEFCC, 2020).

NCAP has identified 16 key components in order to achieve national level $PM_{2.5}$ and PM_{10} targets. It is proposed to extend emission inventory and source apportionment of particulate matter to non-attainment cities in India and plan actions for controlling and reducing air pollution based on such scientific studies. A cost-effective approach for improving air quality in such cities involve (i) identification of emission sources; (ii) assessment of extent of contribution of these sources on ambient environment; (iii) prioritizing the sources that need to be tackled; (iv) evaluating various options for controlling the sources with regard to feasibility and economic viability; and (v) formulation and implementation of most appropriate action plans (MoEFCC, 2020).

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

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

1.2. Brief Description of the study area

Cuttack, one of India's oldest cities dating back to the 10th century AD under the Keshari dynasty, has been shaped by centuries of governance by dynasties like the Mughals and British, creating a rich historical legacy. Today, Cuttack thrives as a cultural hub celebrated for its Odissi dance, Tarakasi silver filigree, and fine handloom textiles. Economically vital, it serves as a major commercial center in Odisha, renowned for its textile and handicraft industries and bustling wholesale markets. Tourists are drawn to its historical landmarks such as Barabati Fort, Cuttack Chandi Temple, Odisha Maritime Museum, and Qadam Rasool Mosque. The city hosts vibrant festivals like Durga Puja and Bali Yatra, showcasing its cultural diversity. Home to institutions like Ravenshaw University, Cuttack also benefits from excellent connectivity, situated adjacent to Bhubaneswar in the Cuttack-Bhubaneswar metropolitan area, facilitating seamless travel and trade across eastern India.

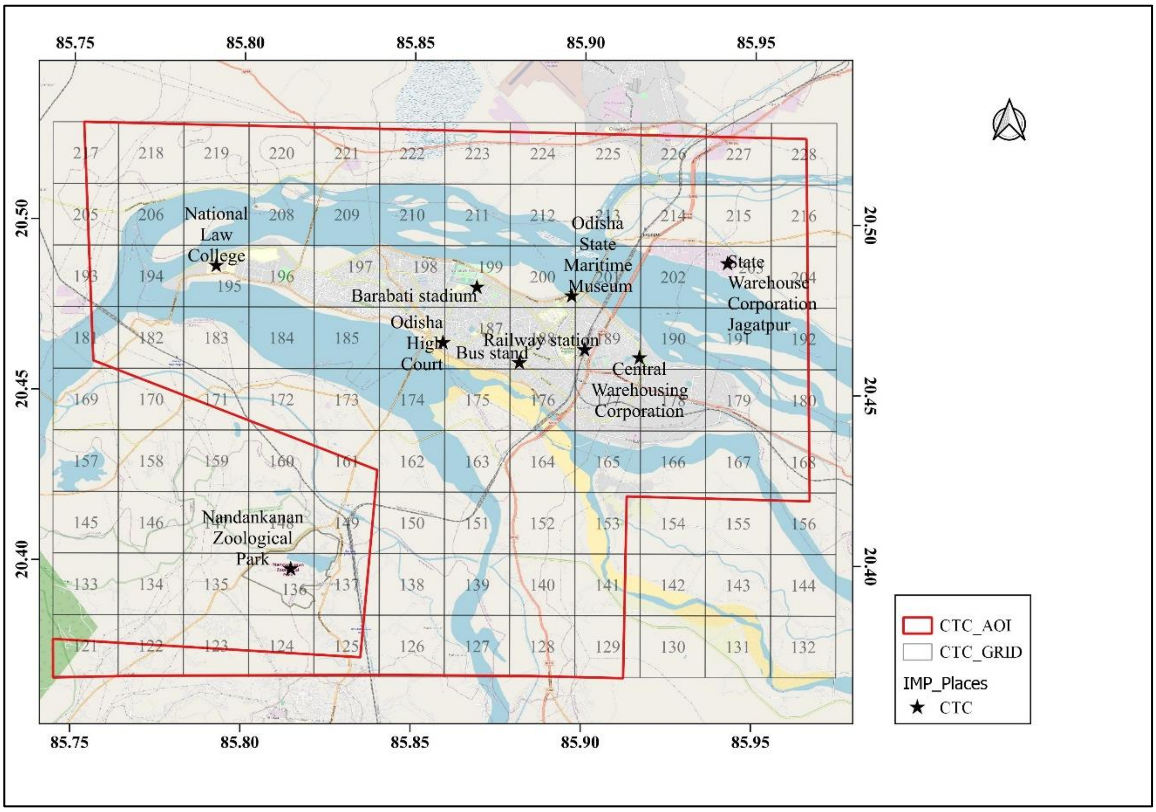


Figure 2 Map showing study area i.e. Cuttack region

1.2.1. Geography

Cuttack, also known as business capital of Odisha. Cuttack city is flanked by Mahanadi river on the north and Kathajodi river on the south (Fig. 2). The study area of Cuttack city lies in between geographic coordinates from 85.74457, 20.41999 to 85.97386, 20.52991 in the

Cuttack district of Odisha at an average elevation of about 36 m above mean sea level. It is important to note that, the study area for this study extends beyond the municipal limits of Cuttack and covers an area of 288 km^2. Fig. 2, shows the study area divided into grids of size 2 x 2 km^2 for the emission inventory purpose.

1.2.2. Weather and Climate

Cuttack experiences a tropical wet and dry climate and receives abundant rainfall during Southwest monsoon (June – September). The highest and lowest temperatures are generally observed in the months of May and January, respectively. Cuttack receives an annual average rainfall of about ~1,597 mm, with highest rainfall in the month of August.

1.2.3. Demography

According to Census of India 2011, the total population of Cuttack municipal council was 6,10,189. The estimated population for year 2022 is 6,46,867. As discussed previously, the study area extends beyond municipal limits and geo-located population details are not available for this region. Hence, first we derived the gridded population of the study area for year 2011, using population dataset prepared by Balk et al. (2020). The gridded population for year 2022 is 7,39,934 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.

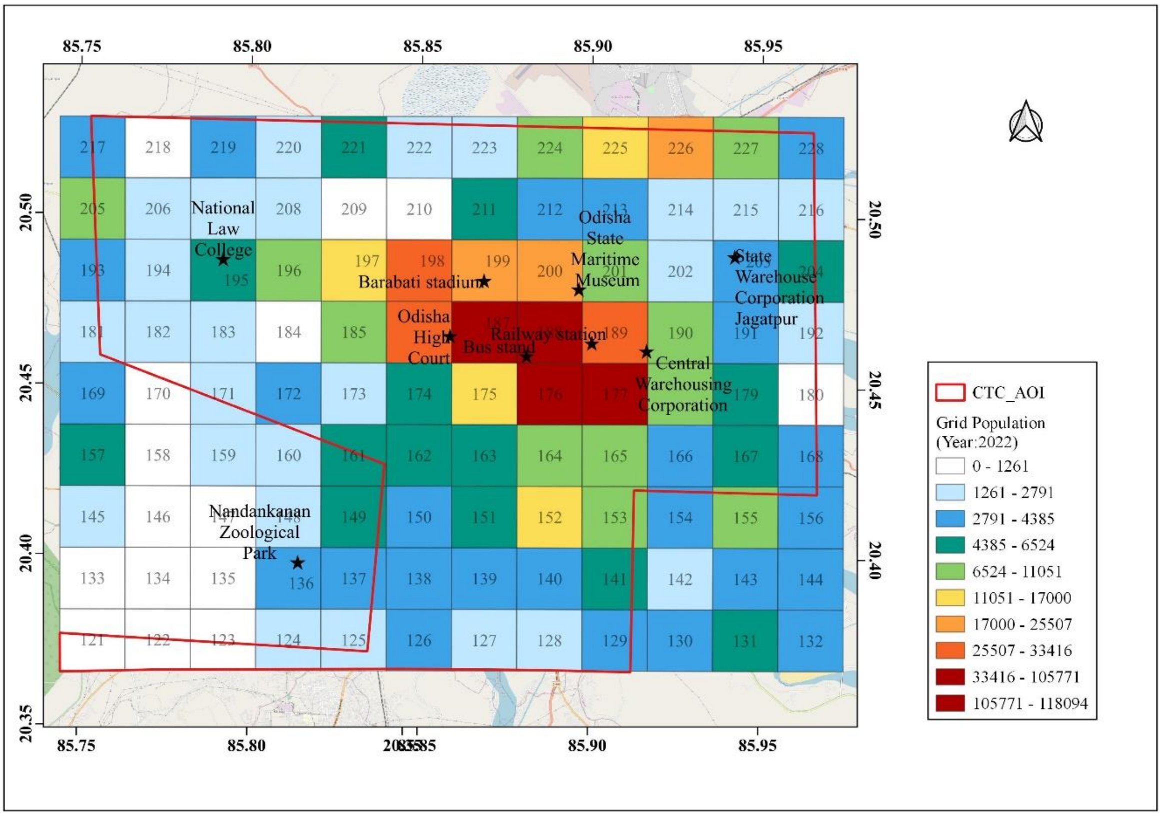


Figure 3: The estimated gridded population of the study area for year 2022.

1.3. Objectives of the Project

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

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

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

1.4. Scope of Work

1.1. Sampling of Particulate Matter (PM_{10} & $PM_{2.5}$) using speciation samplers at identified sites (3 locations in Cuttack region). Sampling (24 hrs) for minimum 15 days at each location in 2 critical seasons i.e. winter and summer. Additionally, sampling and analysis for SO_2, NO_2, Benzene, Toulene, Ethyl Benzene and Xylene identified locations during winter season only.

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

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

1.4. To conduct data collection surveys and calculate baseline emission loads of air pollutants including: PM_{10}, $PM_{2.5}$, SO_2, NOx, CO and NMVOCs originating from various sources for Cuttack region for year 2022.

1.5. To project the baseline emission loads using growth rate method for future years (2027 and 2032) and plan control actions in consultation with stakeholders.

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

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

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

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

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

1.5. Integrated framework for source apportionment study

This section discusses the overall framework designed to carry out the present study. In general, two fundamental scientific approaches are used to identify and quantify the sources of particulate matter: (A) bottom-up or dispersion model-based approach (Fig. 4) and (B) top-down or receptor model-based approach (Fig. 5).

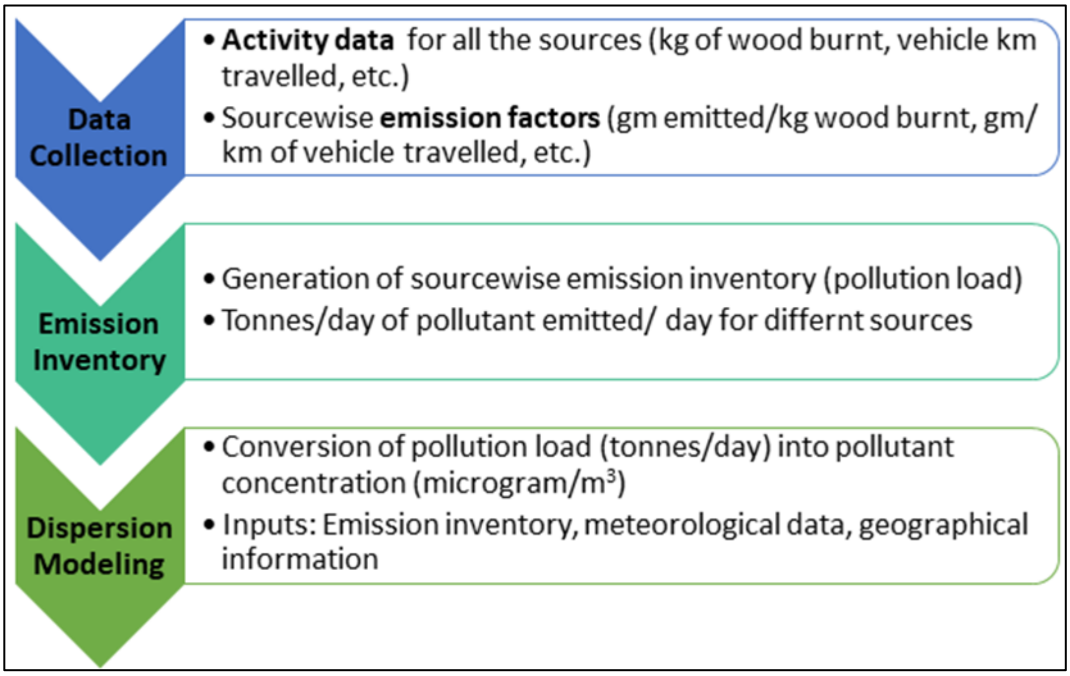


Figure 4 Bottom-up approach for Particulate Matter Source Apportionment

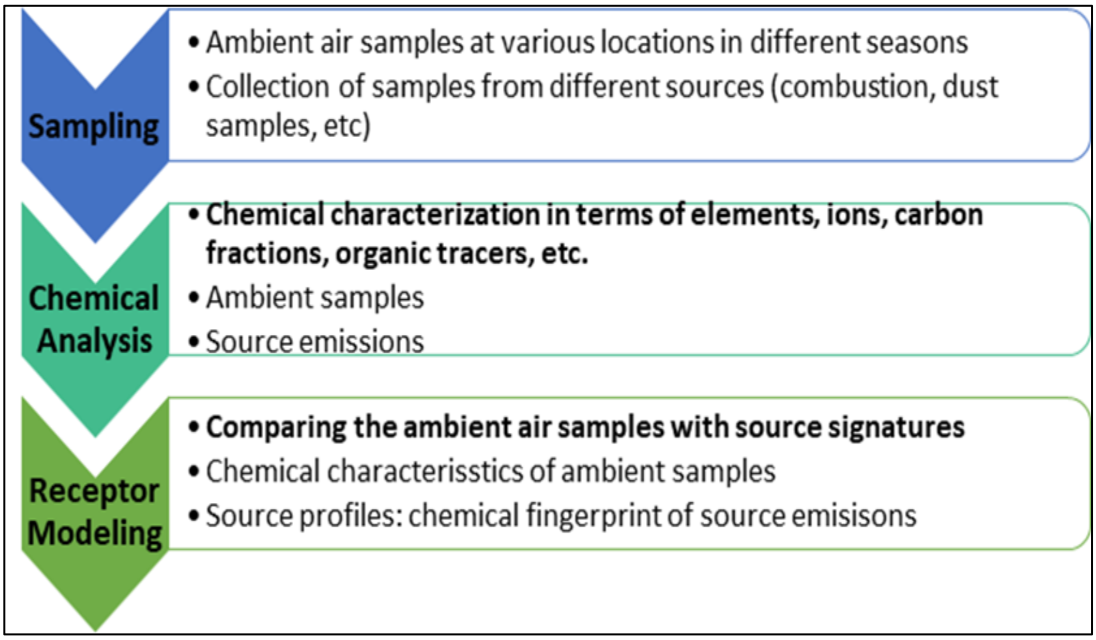


Figure 5 Top-down approach for Particulate Matter Source Apportionment

The bottom-up approach includes identification of air pollution sources and their emission strengths using activity data and available emission factors (Fig. 4). These emissions are then used as input to dispersion models such as AERMOD, WRF-Chem etc. along with meteorological parameters and land use characteristics to predict pollutant concentrations over space and time. The top-down approach on the other hand include sampling air at identified receptor locations and deducing the potential air pollution sources by correlating common physical and chemical characteristics between the sources and collected samples (Fig. 5). These two approaches and their inter-relations are described in a step-wise manner in the following sections.

Fig. 6 illustrates the details of the integrated approach, combining the two approaches described above, adopted for Emission Inventory and Source Apportionment study of Cuttack region in Odisha.

1.6. Organization of the Report

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

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

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

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

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

Chapter 5 describes the various emission control scenarios designed for Cuttack region in future years i.e. 2027 and 2032 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.

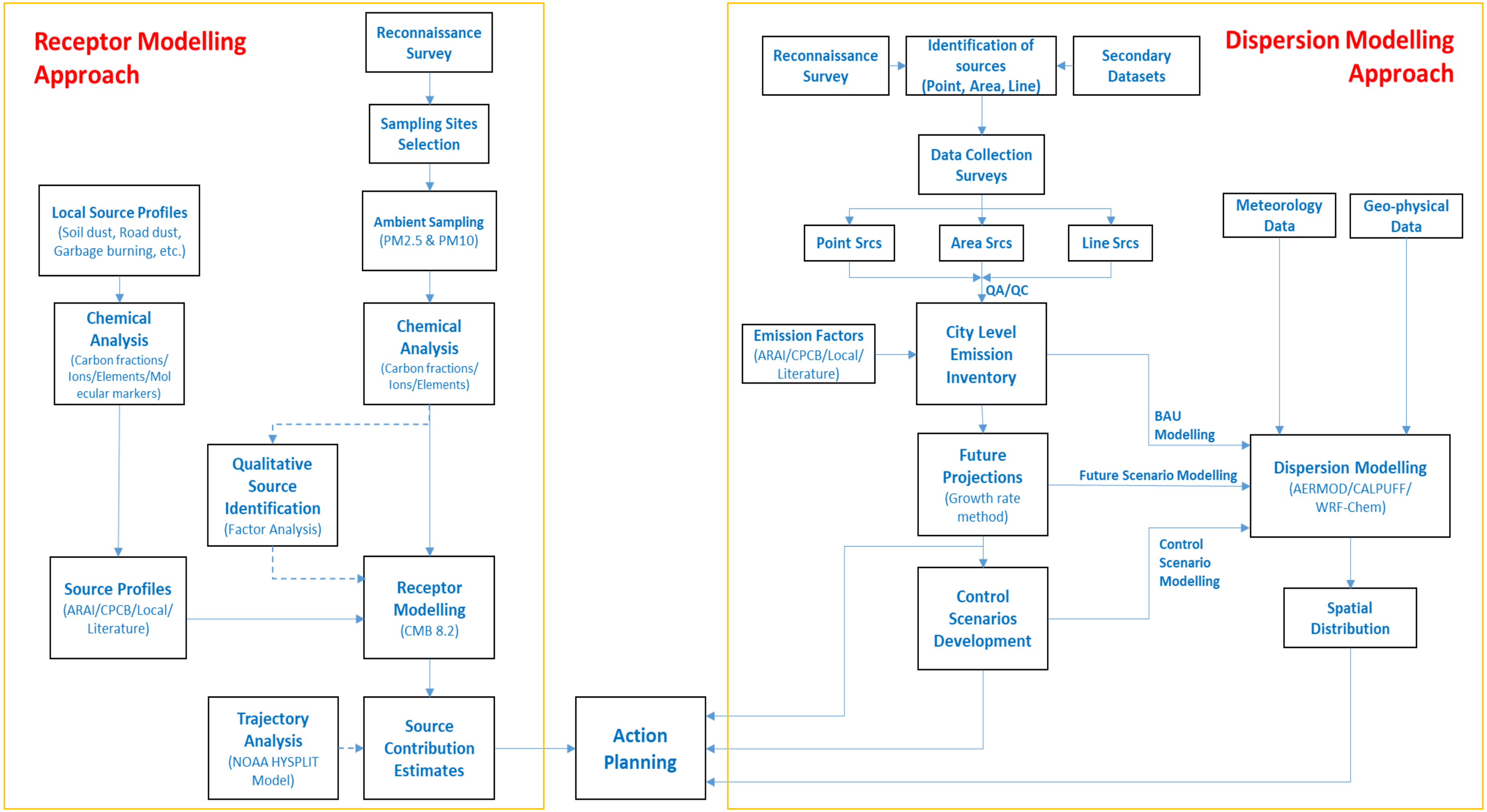


Figure 6 Framework for integrated emission inventory and source apportionment study of Cuttack region in Odisha

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

2.1. Introduction

The main objective of ambient air quality monitoring was to generate the baseline data of ambient concentrations of PM_{10} and $PM_{2.5}$ and to identify the major sources contributing to it. Monitoring was conducted in two critical seasons i.e. winter and summer, to capture the seasonal variations. A comprehensive exercise to monitor air quality was carried out during winter season i.e. December 11 to 26, 2022 and summer season i.e. April 10 to 27, 2023 at 3 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) three sampling locations are identified for this study in Cuttack region. Figure 7 and Table 1 respectively show the geographic distribution and details of the sampling sites, which include 1 residential site, 1 mixed land use site and 1 industrial site. These sites are located in different parts of study domain and can provide an integrated insight into the characteristic of PM2.5 and PM10 over Cuttack region. For example, the residential site, such as at Baimundi Nursing Home, Bidanasi (S7), is surrounded by typical residential areas with low-to-middle income group households while other two sites i.e. BDO Office, Nayabazar (S5) and Varun Beverages Ltd. (Pepsi), Jagatpur (S6) typically represent mixed land use and industrial sites, respectively.

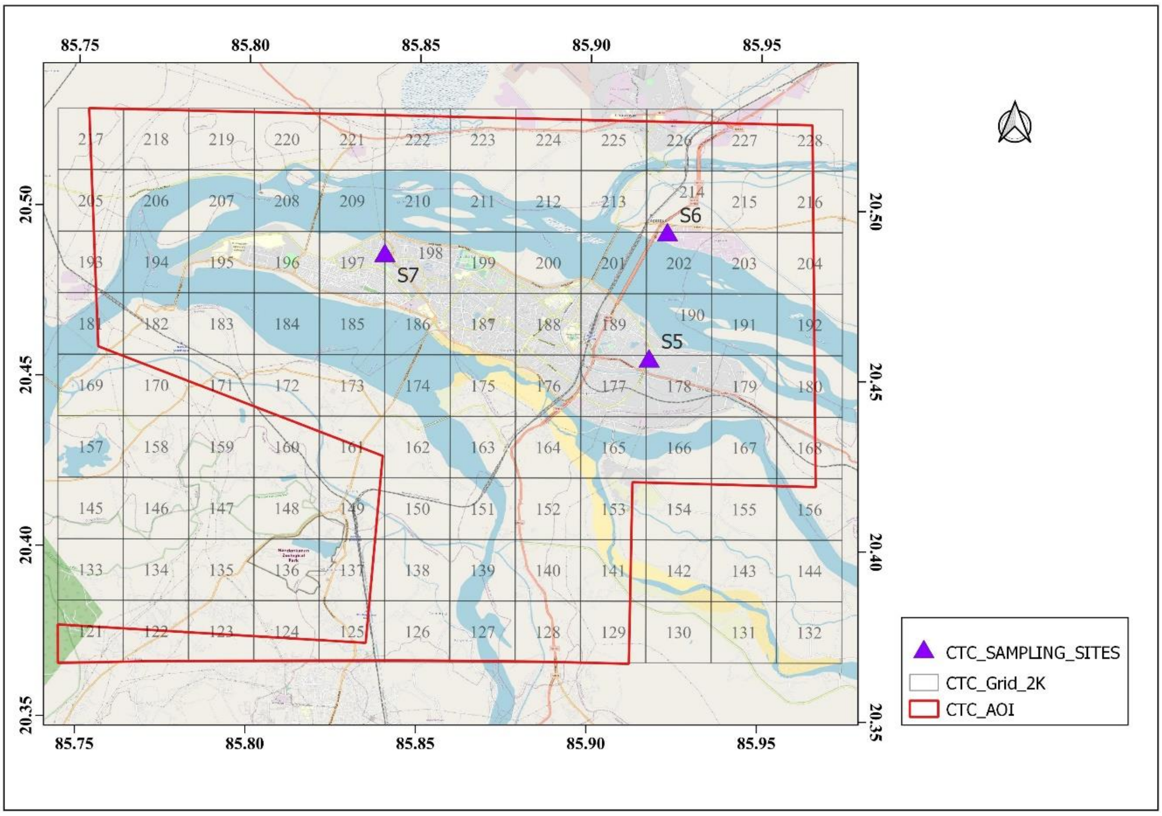


Figure 7 Cuttack region map showing locations of three sampling sites (violet coloured triangles) selected for source apportionment study

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

Code	Location	Latitude	Longitude	Category
S5	BDO Office - Block Chhaka, Naya Bazaar, Cuttack, Odisha 753004	20° 27' 19.82" N	85° 55' 3.59" E	Mixed
S6	Varun Beverages Ltd (Pepsi) - Jagatpur Industrial Estate, Jagatpur, Odisha 754021	20° 29' 33.38" N	85° 55' 21.84" E	Industrial
S7	Baimundi Nursing Home - Baimundi Ln, Bidanasi, Cuttack, Odisha 753014	20° 29' 9.06" N	85° 50' 23.62" E	Residential (LIG and MIG)

2.2.2. Sampling schedule

The ambient $PM_{2.5}$ and PM_{10} samples were collected in the study area, during two critical seasons i.e. winter and summer. As shown in Fig. 8, the winter season sampling was conducted at identified locations from December 11 to 26, 2022 while summer season sampling was conducted from April 10 to 27, 2023.

WINTER	SITE	Dec-22																	
		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	BDO OFFICE																		
	VARUN BEVERAGES LTD. (PEPSI) OFFICE																		
	BAIMUNDI NURSING HOME																		

SUMMER	SITE	Apr-23																	
		10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	BDO OFFICE																		
	VARUN BEVERAGES LTD. (PEPSI) OFFICE																		
	BAIMUNDI NURSING HOME																		

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

2.2.3. Sampling and gravimetric analysis

$PM_{2.5}$ and PM_{10} samples were collected using multi-channel speciation samplers for 24 hours at a flow rate of 16.7 LPM during both the winter and summer seasons. Samples were simultaneously collected on 47 mm diameter polytetrafluoroethylene (PTFE) membrane filters (Whatman make; GE Healthcare Life Sciences, India) and quartz fiber filters (Tissuequartz™ 2500QAT-UP; Pall Corporation, USA) for both $PM_{2.5}$ and PM_{10}. Teflon filters were used for measurement of gravimetric mass, elemental concentrations, and water-soluble ions while the quartz-fiber filters were analyzed for carbonaceous materials. Each filter paper was visually inspected for damage, if any, before and after sampling. The filter papers were conditioned before and after sampling in desiccators to attain equilibration under the controlled temperature (20 – 30 ^{0}C) and relative humidity (20 – 35%) for 24 hours. Additionally, the quartz-fiber filter papers were pre-baked at 900 ^{0}C for 3 hours in an oven to remove any deposited organic compounds. The conditioned filters were transferred to individual cassettes to avoid the contamination of filters on the way and cassettes were then stored at ~4 ^{0}C to minimize the evaporation of volatile compounds. Filters were handled only using tweezers coated with

Teflon tape to reduce the possibility of contamination. As discussed earlier, Teflon filter papers were weighed before and after sampling for the determination of collected particulate mass using a Mettler Toledo electronic microbalance (Model: XP2U).

2.2.4. Chemical analysis of PM

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

2.2.4.1. Elemental/Organic Carbon

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

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

2.2.4.2. Elements

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

2.2.4.3. Ions

Ionic species are those that are soluble in water. Anions and cations were analyzed using an ion chromatograph with conductivity detector. In $PM_{2.5}$ and PM_{10} samples, ions that are analysed on an ion chromatograph are grouped under anions such as fluoride, chloride, bromide, nitrite, nitrate, sulphate and under cations such as sodium, ammonium, potassium, calcium, and magnesium. Sample preparation was done by using the ultrasonication method. Milli-Q grade water, freshly produced from the Gradient A10 Millipore system and having resistivity of 18

M-Ohm, was used for sample preparation and analysis. Laboratory blank, field blank, and samples were always filtered through 0.2-micron nylon membrane filters to avoid background matrix interference.

2.2.4.4. Molecular Markers

After the carbon analysis, remaining PM samples on quartz filters were used for molecular marker analysis. For analysis of molecular markers, the daily PM samples were extracted together, to form composite samples and have sufficient mass to represent the whole monitoring period. Prior to analysis, composite samples were extracted by Soxhlet extraction with 1:1 dichloromethane: acetone solvent mixture for a period of 16 hrs. The extracts were evaporated to 4 ml by using a Kuderna-Danish apparatus. Gas chromatography – mass spectrometry (GC-MS) system (GC-MS Make; Thermofisher Scientific) with TB5 column was used for quantitative determination of 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 PM2.5 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-Docasane, n-Tricosane, n-Tetracosane, n-Pentacosane, n-Hexacosane, n-Heptacosane, n-Octacosane, Nonacosane, n-Tricontane, n-Hentriacontane, n-Dotriacontane, n-Tritriacontane, n-Tetracontane, n-Pentatriacontane, n-Hexatriacontane, Heptatriacontane, Octatriacontane, Nonatriacontane, n-Tetracontane
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

2.2.5. Gases and Volatile Organic Compounds (VOCs)

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

The gaseous samples for ambient SO_2 and NO_2 determination, were collected at three sampling sites, on daily basis during the winter season sampling period i.e. December 11 to 26, 2022. The samples were collected by sampling for 24-hours, at a flowrate of 0.2 LPM, in two separate impingers containing appropriate absorbing solutions for SO_2 and NO_2. The ambient SO_2 and NO_2 concentrations were determined in the laboratory following the procedure prescribed in Indian standard IS:5182, 2001, RA 2017, part 2 and 6, respectively.

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

2.3. Quality Assurance/Quality Control

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

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

2.4. Chemical Mass Reconstruction

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

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

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

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

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

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

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

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

The chemical reconstruction method explained above was applied to all 3 sites over Cuttack region and reconstructed PM mass (PM_{Chem}) was compared against the corresponding observed gravimetric mass (PM_{Grav}).

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

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

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

In this equation, Ci is the ambient concentrations of the species i measured at the receptor site, P is the number of contributing sources, Fij is the fraction of the emissions of the species i starting from the source j, and Sj indicates the ambient contribution of the source j (Srivastava and Jain, 2007).

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

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

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

2.6. Results and discussions

2.6.1. Winter season

2.6.1.1. PM mass concentrations

Fig. 9, presents the distribution of daily PM2.5 and PM10 concentrations observed at three sampling locations in Cuttack region during the winter season i.e. Dec 11 – 26, 2022. The mean PM2.5 and PM10 mass concentrations during the entire sampling period over all sites were 86.8 and 227.9 µg/m3, respectively. The mean PM2.5 concentrations exhibited a 2-fold range and ranged from a minimum of 58.5 µg/m3 (at Baimundi Nursing home i.e. S7) to a maximum of 134.3 µg/m^3 (at BDO Office i.e. S5). Similarly, the mean PM10 concentrations exhibited a 3-fold range and ranged from 125.0 µg/m3 (at Baimundi Nursing home i.e. S7) to 356.1 µg/m3 (at Varun Beaverages, Pepsi office i.e. S6).

The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 µg/m^3 for $PM_{2.5}$ and PM_{10}, respectively. The winter-time $PM_{2.5}$ concentrations were observed to exceed the daily NAAQS limit at all sites (90.9 to 100%) with minimum exceedance at S7, i.e. Baimundi Nursing Home (90.9%). The daily averaged PM_{10} 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 S5 i.e. BDO office (91.9 µg/m^3) while the lowest were recorded at S7, i.e. Baimundi Nursing Home (78.7 µg/m^3). These two BDO Office i.e. S5 and Baimundi Nursing Home i.e. S7 locations were reported the highest and lowest variability in $PM_{2.5}$ concentrations. For example, $PM_{2.5}$ concentrations ranged from 63.0 to 134.3 at S5 i.e. BDO Office while it ranged from 58.5 to 106.3 at S7, i.e. Baimundi Nursing Home.

The highest seasonal mean PM_{10} concentrations were observed at S5 i.e. BDO office (240.9 µg/m^3) while the lowest were recorded at S7 i.e. Baimundi Nursing Home (212.7 µg/m^3). The PM_{10} concentrations showed highest variability at S5 i.e. BDO Office ranging from a minimum of 136.5 to a maximum of 351.5 µg/m^3 while it ranged between 125.0 and 287.0 µg/m^3 at S7 i.e. Baimundi Nursing Home.

These concentration levels can be attributed to air polluting activities around each site. For example, sampling site at Varun Beverages Ltd., Jagatpur (S6) is located in the Jagatpur Industrial estate, and is likely to be impacted by industrial emissions. In addition to Industrial stack emissions and fugitive emissions, road dust re-suspension due to movement of heavy vehicles in the region can be one of the major reasons for highest particulate levels.

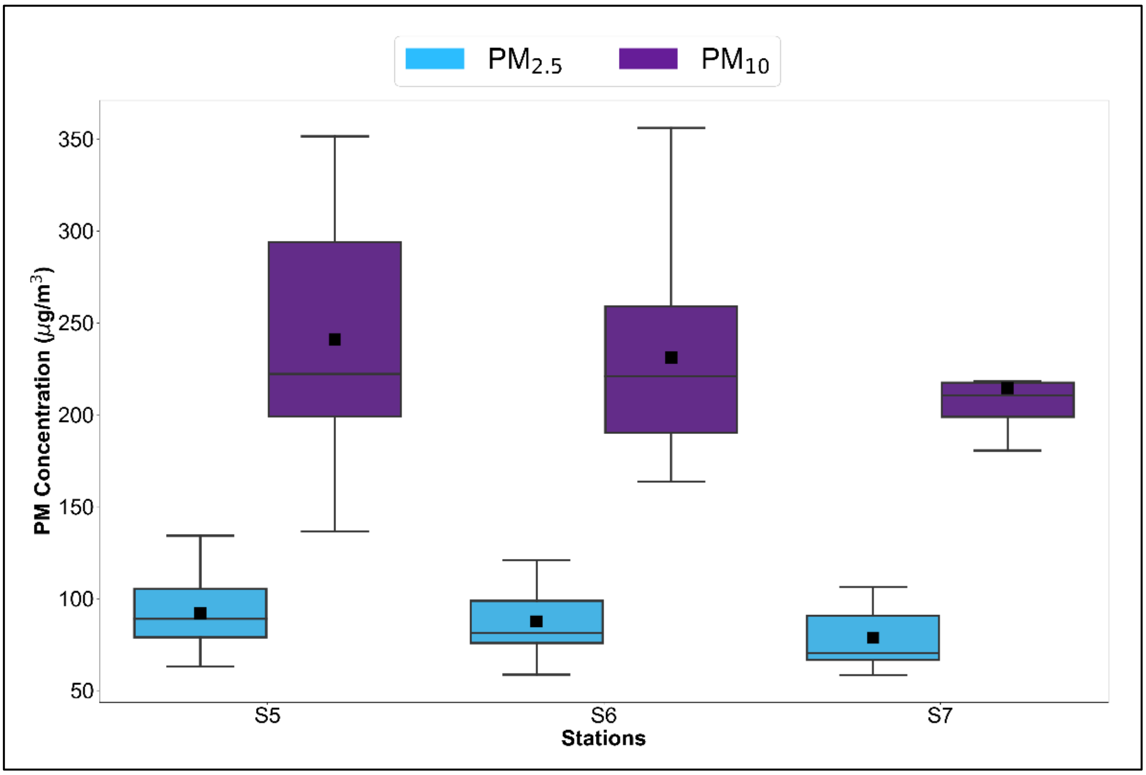


Figure 9 Boxplot showing distribution of daily $PM_{2.5}$ (blue colored boxes) and PM_{10} (violet colored boxes) concentrations observed at three sampling sites in Cuttack region during the winter season sampling period (Dec 11 – 26, 2022).

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

2.6.1.3. Temporal variability

Fig. 10 shows daily time-series of PM2.5 and PM10 observed at three selected sampling locations in Cuttack region during the winter season sampling period. Only valid samples between Dec 11 - 26, 2022 are considered for this analysis. Overall, the PM concentrations showed an increasing trend from December 11 to 20 at all sites, followed by a decreasing trend towards end of the winter season sampling period. This could be attributed to the meteorological phenomena over Cuttack region during the winter season.

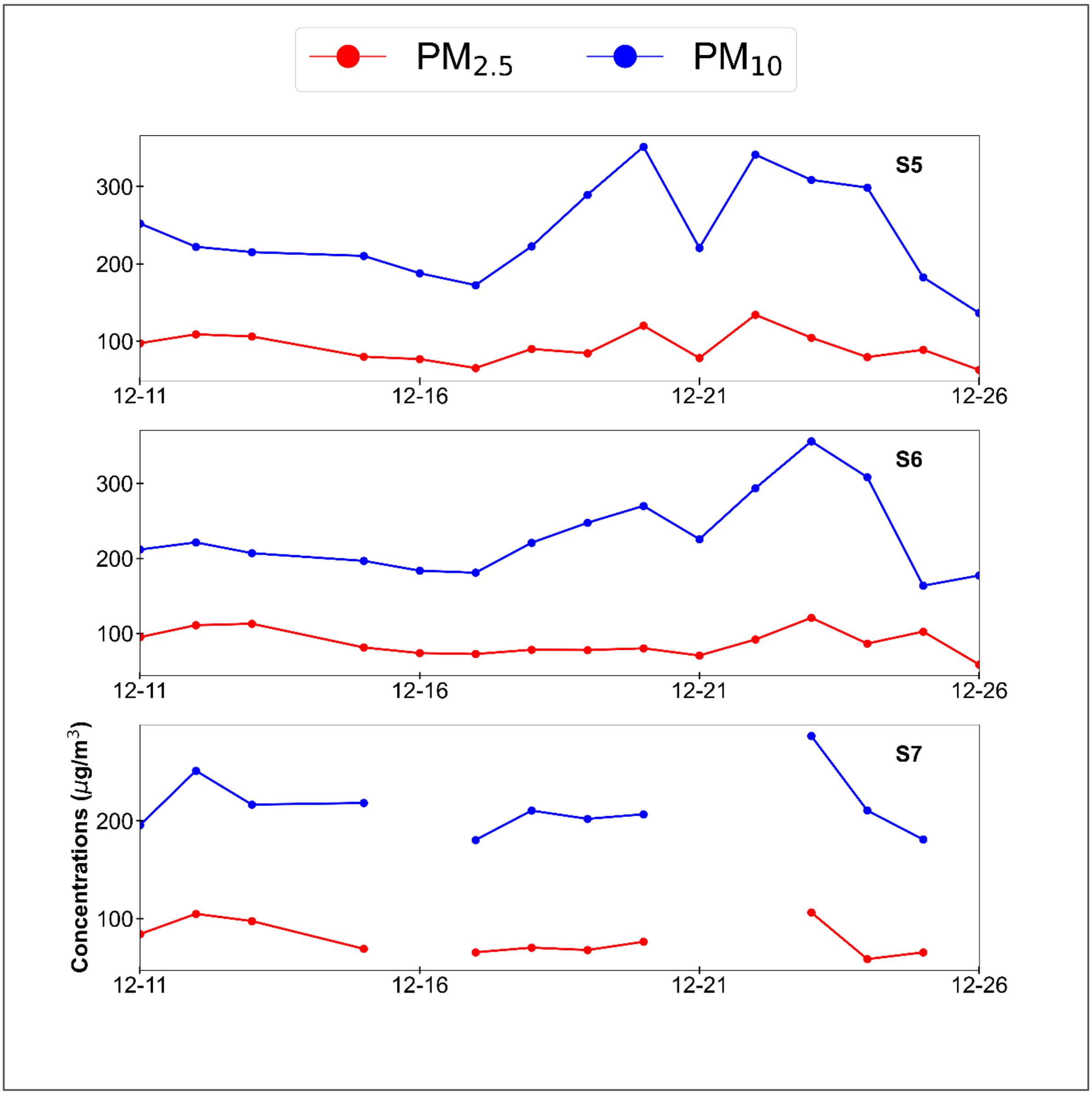


Figure 10 Daily time-series of $PM_{2.5}$ (red) and PM_{10} (blue) concentrations observed at three sites in Cuttack region during the winter season sampling (Dec 11-26, 2022)

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

Fig. 11 shows distribution of daily $PM_{2.5}$ to PM_{10} ratios observed at three selected sites during the winter season sampling. The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.39, varying from 0.27 to 0.63. The highest winter season mean $PM_{2.5}$ to PM_{10} ratio was observed at S6 i.e. Varun Beverages Ltd. (Pepsi) Office (0.63) while the lowest was observed at S5 i.e. BDO Office (0.27). This variability in fine and coarse mode particles may be attributed to variability in PM chemical composition, which is in turn affected by various sources and meteorological conditions.

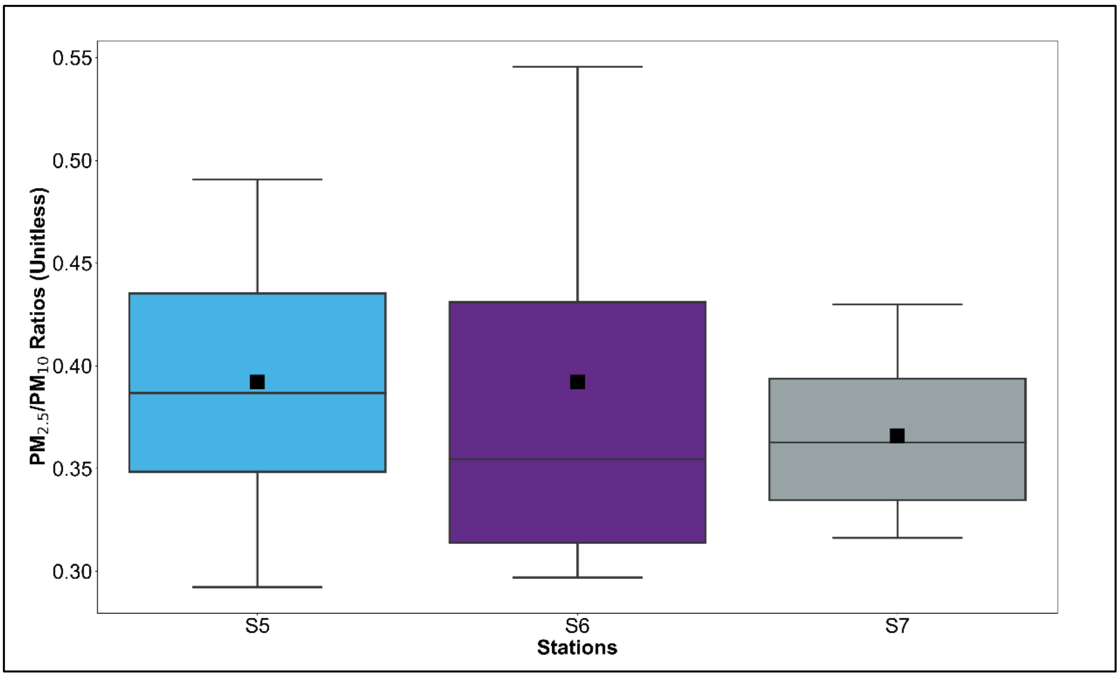


Figure 11 Boxplot showing distribution of $PM_{2.5}$ to PM_{10} ratios at three selected sites in Cuttack region during the winter season (Dec 11-26, 2022)

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

2.6.1.5. Chemical composition of PM2.5 and PM10

2.6.1.5.1. Site 5: BDO Office (S5)

Fig. 12 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at BDO Office site (S5) in Cuttack region during the winter season. OC, EC and SO4-- in PM2.5 and OC, EC, SO4-- and NO3- in PM10 are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

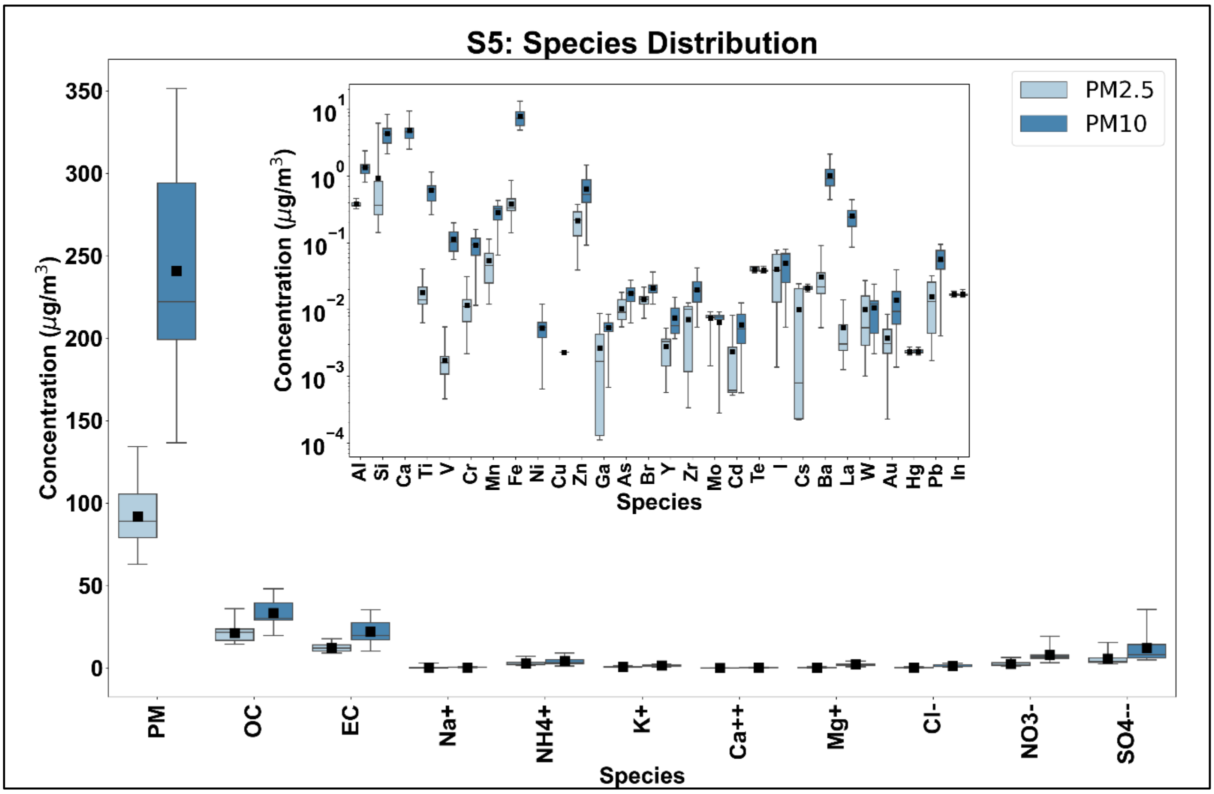


Figure 12 Box plots showing distribution of different species observed in $PM_{2.5}$ and PM_{10} at BDO Office site (S5) in Cuttack region during the winter season

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 6: Varun Beverages Ltd (Pepsi Office) (S6)

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 $PM_{2.5}$ and PM_{10} observed at Varun Beverages Ltd site (Pepsi Office) (S6) in Cuttack region during winter season (December 11-26, 2022). OC, EC and SO4-- in PM2.5 and OC, EC, SO4--, NO3- and Fe in PM10 are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

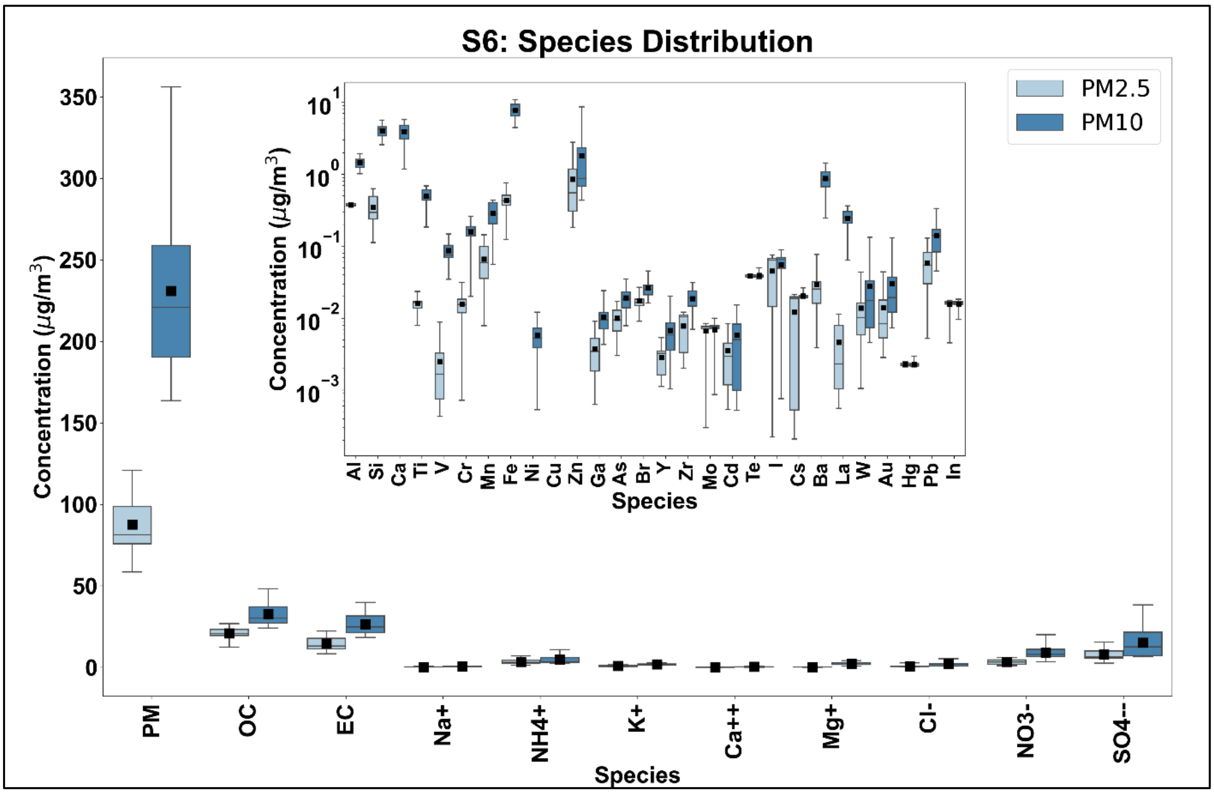


Figure 13 Box plots showing distribution of different species observed in $PM_{2.5}$ and PM_{10} at Varun Beverages Ltd site (Pepsi Office) (S6) in Cuttack region during the winter season

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 7: Baimundi Nursing Home (S7)

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 $PM_{2.5}$ and PM_{10} observedat Baimundi Nursing Home site (S7) in Cuttack region during the winter season. OC, EC and SO_4^{--} in $PM_{2.5}$ and OC, EC, SO4--, NO3- and Fe in PM10 are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace elements concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

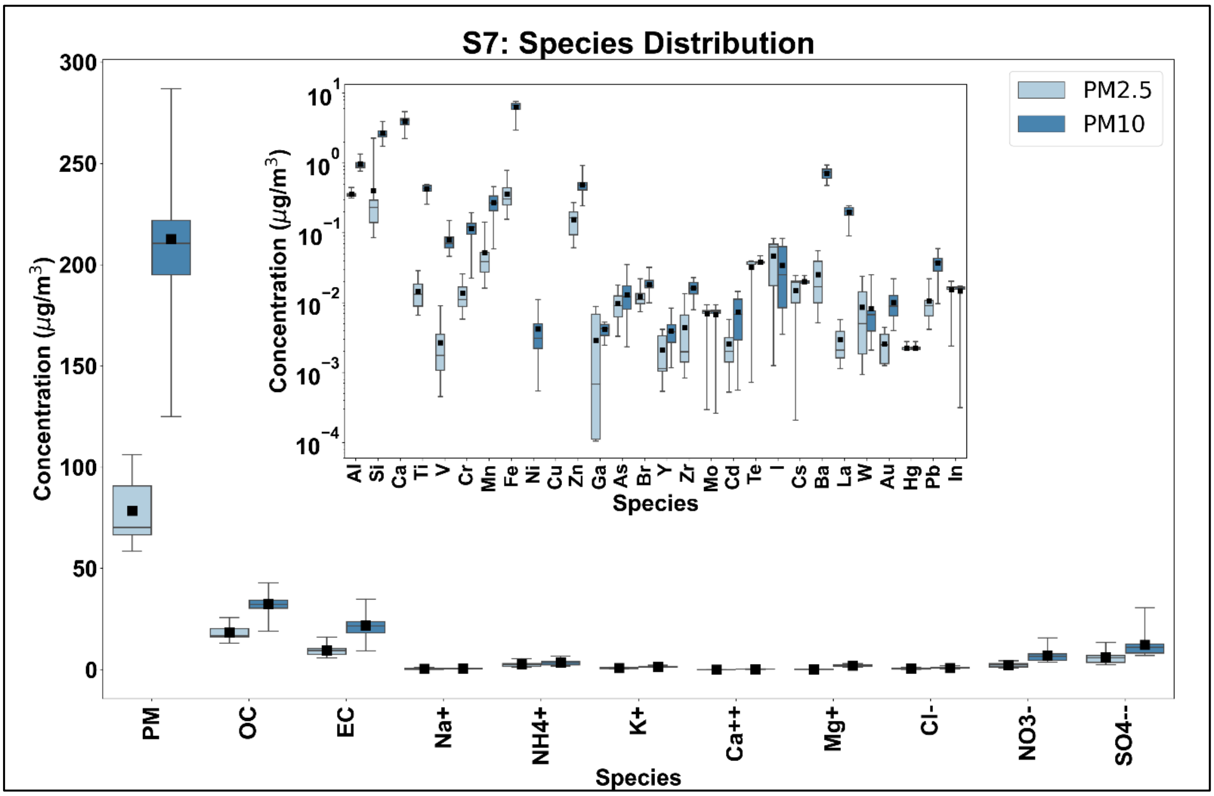


Figure 14 Box plots showing distribution of different species observed in $PM_{2.5}$ and PM_{10} at Baimundi Nursing Home site (S7) in Cuttack region during the winter season

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 PM_{10}

Fig. 15 and 16, represents the seasonal mean concentrations of molecular markers observed at three sampling locations in Cuttack region, during the winter season sampling period i.e. December 11 to 26, 2022. Alkane group is found to dominate the molecular markers mass, during the winter season over Cuttack region. Besides Alkanes, Levoglucosan, which is considered as a tracer for biomass burning emissions (CPCB, 2010), is also detected in significant amounts, in PM samples collected over Cuttack region during winter season.

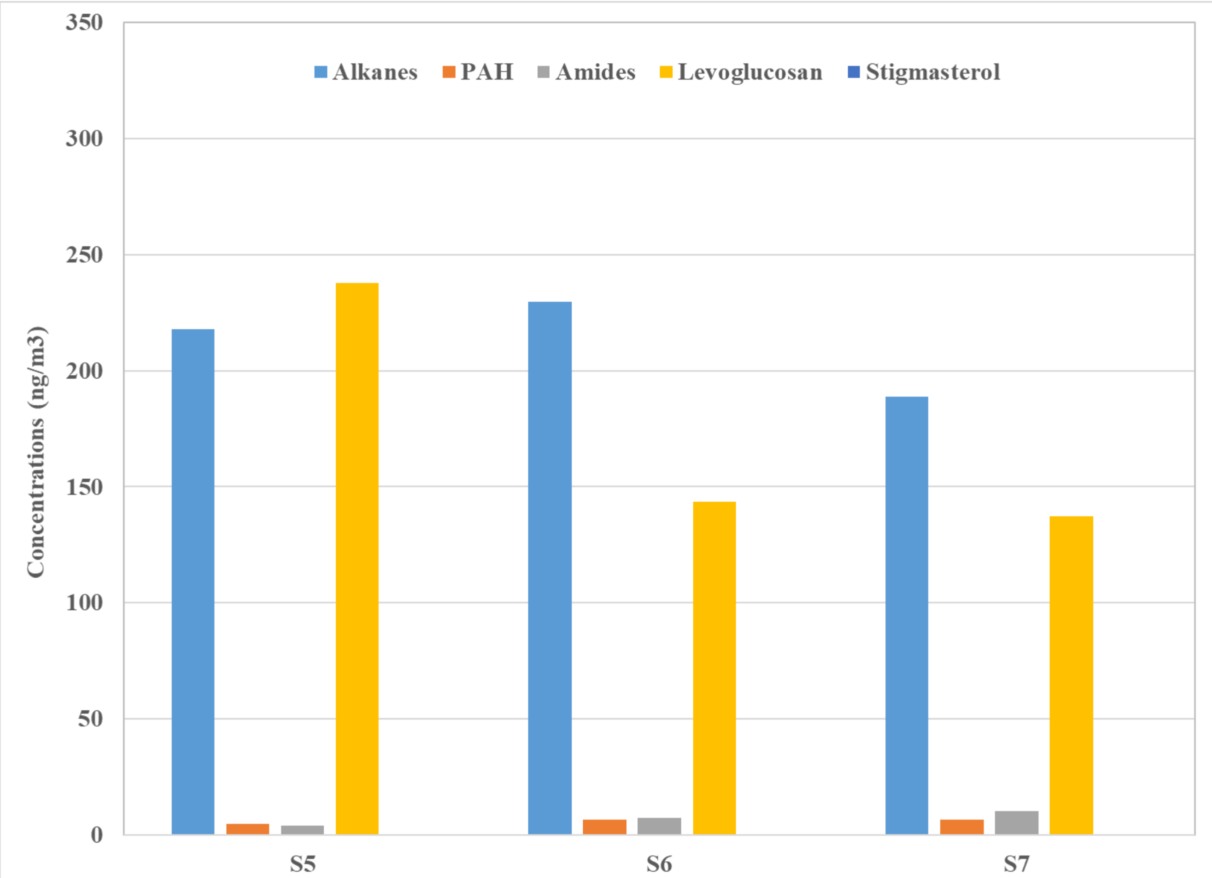


Figure 15: The seasonal mean concentrations of molecular marker species in $PM_{2.5}$ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Cuttack region during the winter season sampling period (December 11-26, 2022).

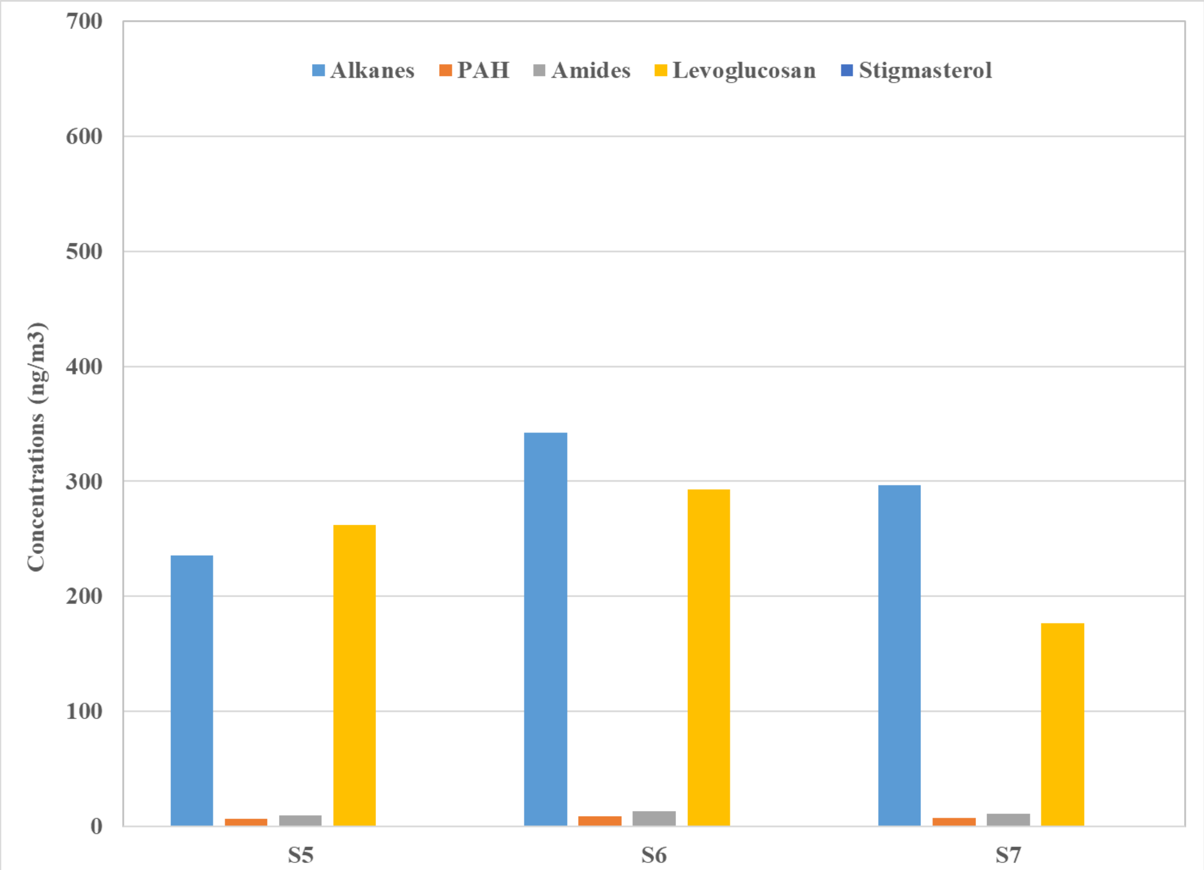


Figure 16: The seasonal mean concentrations of molecular marker species in PM_{10} (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Cuttack region during the winter season sampling period (December 11-26, 2022).

2.6.1.7. Gaseous pollutants and VOCs

Fig. 17, represents the seasonal mean concentrations of gaseous pollutants i.e. SO_2 and NO_2 observed at three sampling locations in Cuttack region, during the winter season sampling period i.e. December 11 to 26, 2022.

The winter season SO_2 concentrations were less than 5 µg/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 32.06 µg/m^3 at BDO Office, Nayabazar (S5), 26.88 µg/m^3 at Varun Beverages Ltd., Jagatpur (S6), and 56.25 µg/m^3 at Baimundi Nursing Home, Bidanasi (S7).

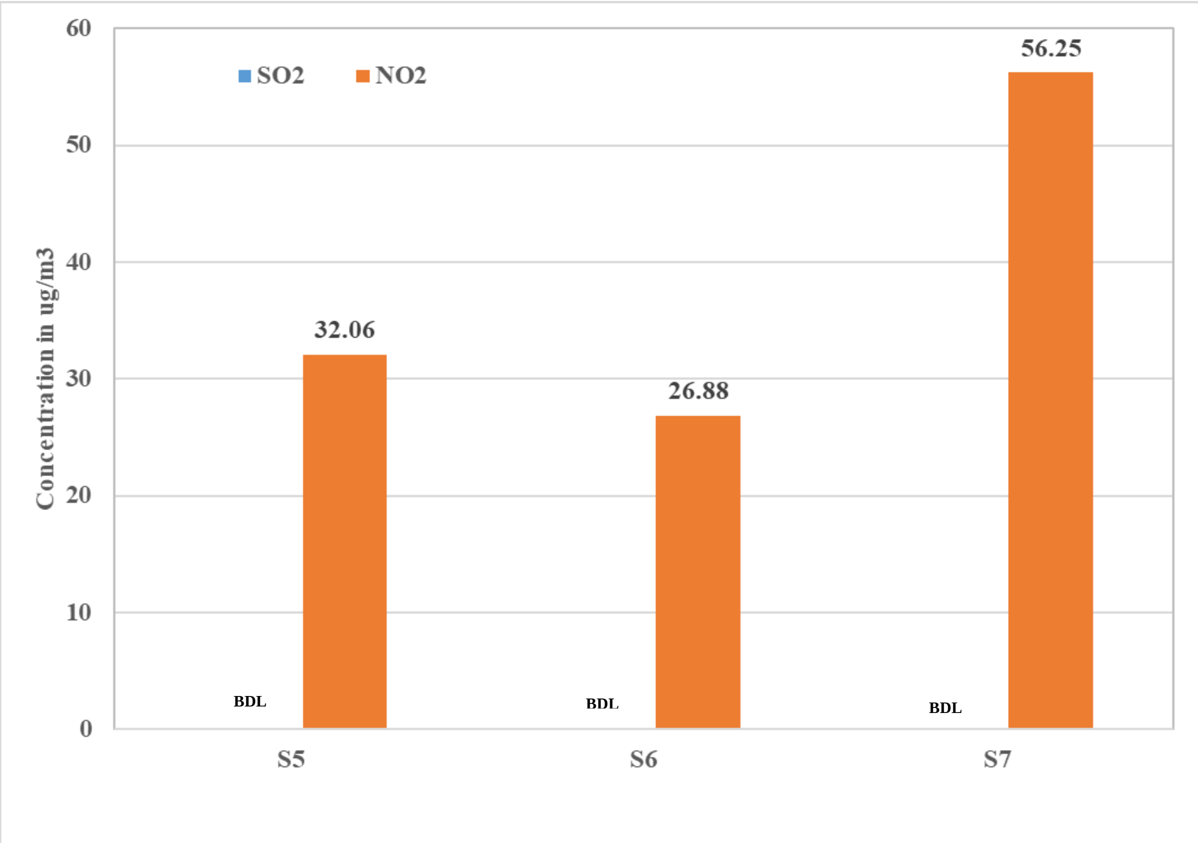
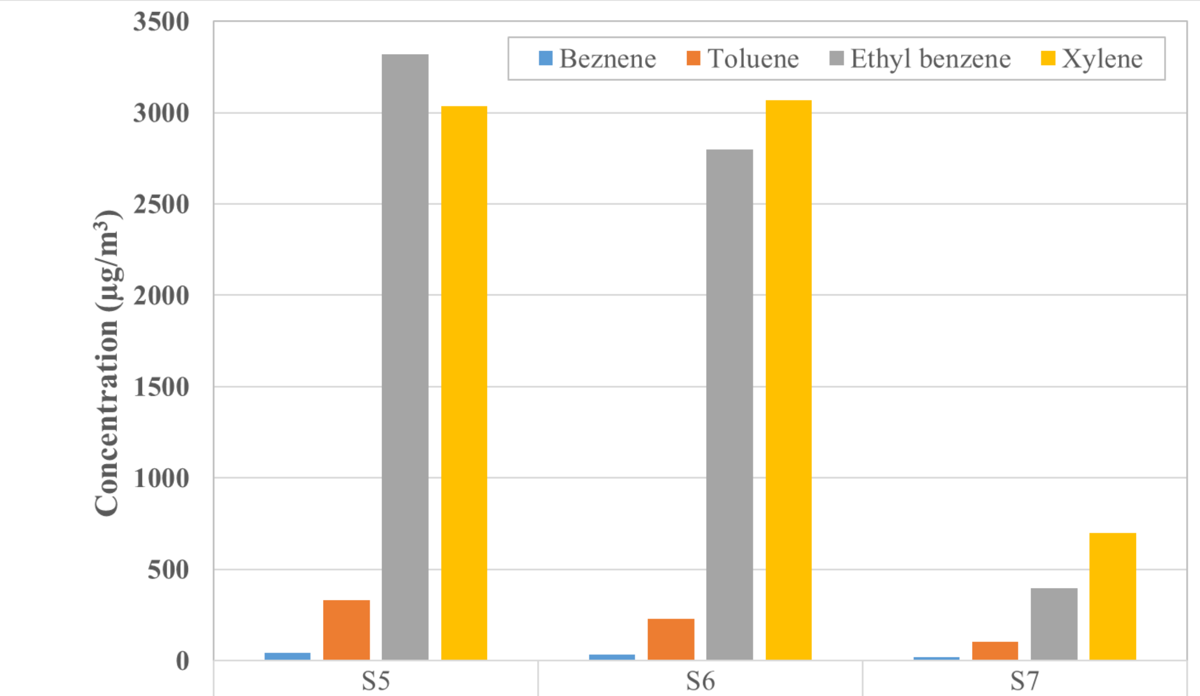


Figure 17: The seasonal mean concentrations of SO_2 *and* NO_2 *observed at three sampling sites in Cutack region during the winter season sampling period (December 11 to 26, 2022)*

Fig. 18, represents the seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX), observed at three sampling locations in Cuttack region, during the winter season sampling period i.e. December 11 to 26, 2022. The winter season mean concentrations of Benzene, Toluene, Ethyl Benzene and Xylene among three sampling sites range from 18.0 to 41.9 ng/m^3, 104.2 to 332.4 ng/m^3, 395.4 to 3318.3 ng/m^3 and 698.3 to 3066.6 ng/m^3, respectively. In general, the lowest concentrations were observed at Baimundi Nursing Home, Bidanasi (S7) while the highest concentrations were observed at BDO Office, Nayabazar (S5). 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.



	S5	S6	S7
Beznene	41.9	34.8	18.0
Toluene	332.4	231.0	104.2
Ethyl benzene	3318.3	2797.6	395.4
Xylene	3036.8	3066.6	698.3

Figure 18: The seasonal mean concentrations of VOCs i.e. Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) observed at three sampling sites in Cuttack region during the winter season sampling period (December 11 to 26, 2022)

2.6.2. Summer season

2.6.2.1. PM mass concentrations

Fig. 19, presents the distribution of daily $PM_{2.5}$ and PM_{10} concentrations observed at three sampling locations in Cuttack region during the summer season i.e. April 10 – 27, 2023. The mean $PM_{2.5}$ and PM_{10} mass concentrations during the entire sampling period over all sites were 52.5 and 134.1 µg/m^3, respectively. The mean $PM_{2.5}$ concentrations exhibited a 4-fold range and ranged from a minimum of 21.3 µg/m^3 (S5 i.e. BDO Office) to a maximum of 85.3 µg/m^3 (at S7 i.e. Baimundi Nursing Home). Similarly, the mean PM_{10} concentrations exhibited a 5-fold range and ranged from 50.3 µg/m^3 (S5 i.e. BDO Office) to 238.1 µg/m^3 (S7 i.e. Baimundi Nursing Home).

The National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB) prescribes a 24-h limit of 60 and 100 µg/m^3 for $PM_{2.5}$ and PM_{10}, respectively. The summer-time $PM_{2.5}$ concentrations were observed to exceed the daily NAAQS limit at all sites (28 to 47%) with minimum exceedance at S5 i.e. BDO Office (28%) and maximum at S6 i.e. Varun Beverages Ltd. (Pepsi) (47%). The daily averaged PM_{10} concentrations exceeded the NAAQS limit at all sites (61-67%) with minimum exceedance at S7 i.e. Baimundi Nursing Home (61%) and maximum at S5 i.e. BDO Office and S6 i.e. Varun Beverages Ltd. (Pepsi) (67%).

2.6.2.2. Spatial variability

The highest seasonal mean $PM_{2.5}$ concentrations were observed at S6 i.e. Varun Beverages Ltd. (Pepsi) (55.9 µg/m^3) while the lowest was recorded at S5 i.e. BDO Office (47.3 µg/m^3). The S7 i.e. Baimundi Nursing Home and S6 i.e. Varun Beverages Ltd. (Pepsi) are reported the significant variability in $PM_{2.5}$ concentrations, respectively. For example, daily $PM_{2.5}$ concentrations ranged from 21.8 to 85.3 µg/m^3 at S7 i.e. Baimundi Nursing Home while it ranged from 24.8 to 82.1 µg/m^3 at S6 i.e. Varun Beverages Ltd. (Pepsi). This could be attributed to activities around the S6 i.e. Varun Beverages Ltd. (Pepsi) including, industrial stack emissions, fugitive emissions, heavy duty traffic, and road dust re-suspension. S2 i.e. BDO Office on the other hand, is a city location and is relatively unaffected by the industrial emissions.

The highest seasonal mean PM_{10} concentrations were observed at S7 i.e. Baimundi Nursing Home (139.1 µg/m^3) while the lowest were recorded at S5 i.e. BDO Office (130.7

µg/m^3). The PM_{10} concentrations showed highest variability at S7 i.e. Baimundi Nursing Home ranging from a minimum of 50.9 to a maximum of 238.1 µg/m^3. This variability at S7 could be attributed to dusty sources including road dust, construction dust and dry riverbed erosion dust re-suspension due to summer time meteorological conditions (low RH and higher wind speed).

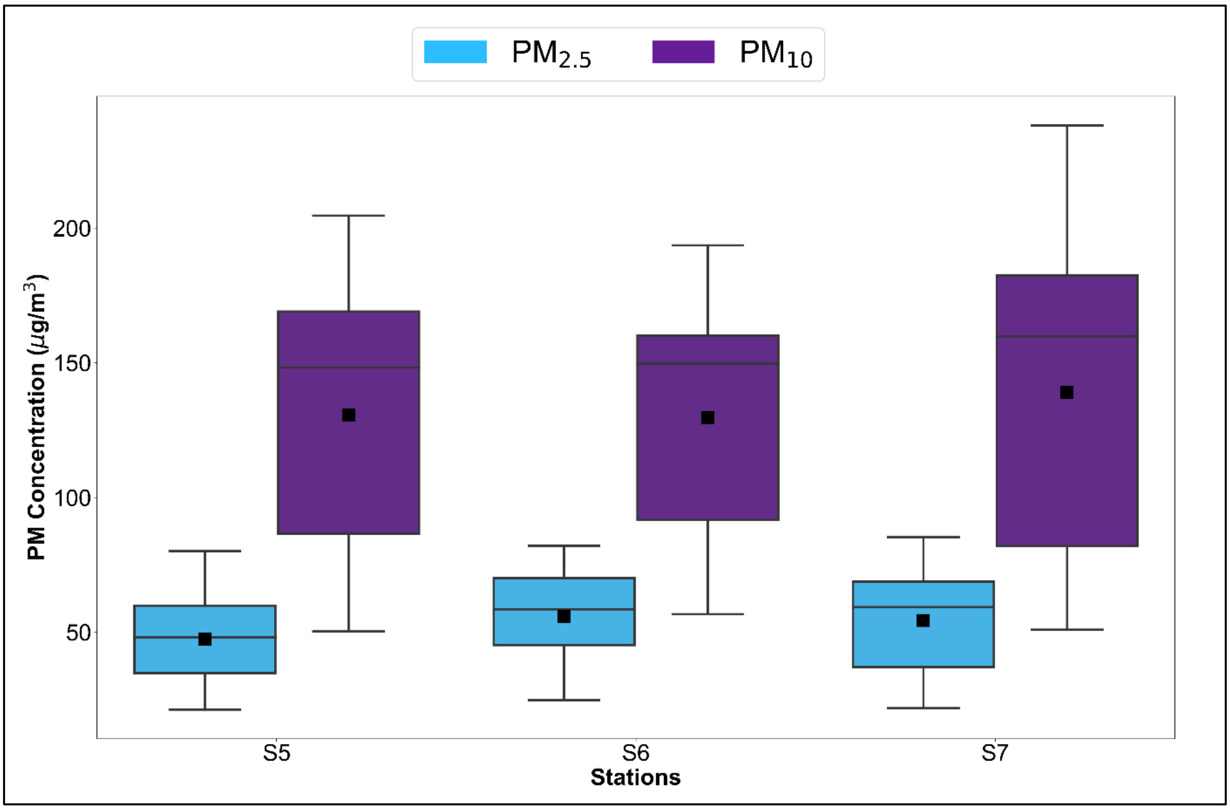


Figure 19 Boxplot showing distribution of daily $PM_{2.5}$ (blue colored boxes) and PM_{10} (violet colored boxes) concentrations observed at three sampling sites in Cuttack region during the summer season sampling period (April 10 - 27, 2023)

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. 20 shows the daily time-series of $PM_{2.5}$ and PM_{10} observed at three selected sampling locations in Cuttack region during the summer season sampling period. Only valid samples between April 10 - 27, 2023 are considered for this analysis. Overall, the PM concentrations shows decreasing trend during summer season sampling campaign.

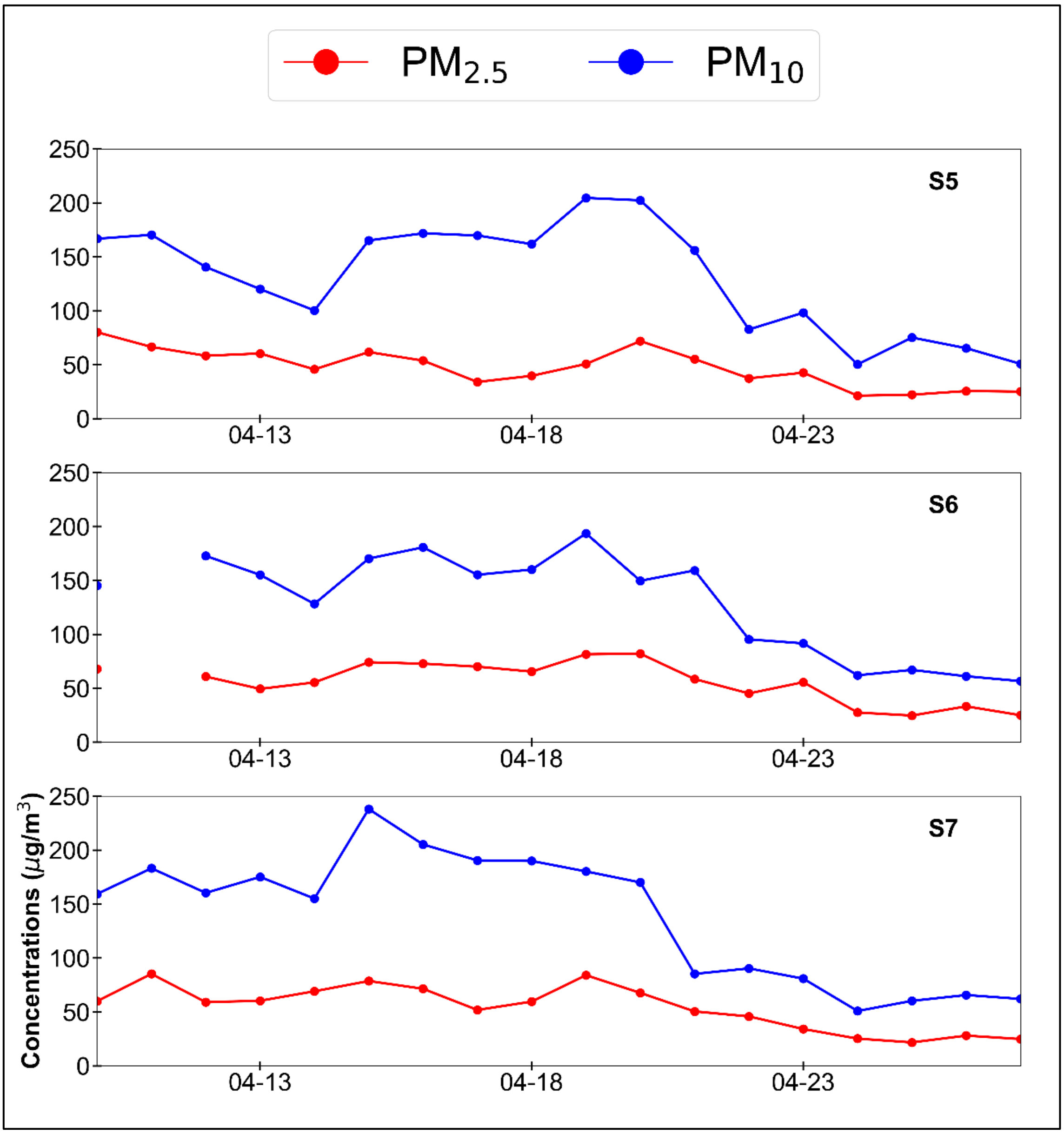


Figure 20 Daily time-series of $PM_{2.5}$ (red) and PM_{10} (blue) concentrations observed at three sites in Cuttack region during the summer season sampling period (April 10 - 27, 2023)

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

Fig. 21 shows distribution of daily $PM_{2.5}$ to PM_{10} ratios observed at three selected sites during the summer season sampling period (April 10 - 27, 2023). The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.41, varying from 0.20 to 0.61. The highest summer season mean $PM_{2.5}$ to PM_{10} ratio was observed at S6 i.e. Varun Beverages Ltd. (Pepsi) (0.61) while the lowest was observed at S5 i.e. BDO Office (0.20). This variability in fine and coarse mode particles may be attributed to variability in PM chemical composition, which is in turn affected by various sources and meteorological conditions.

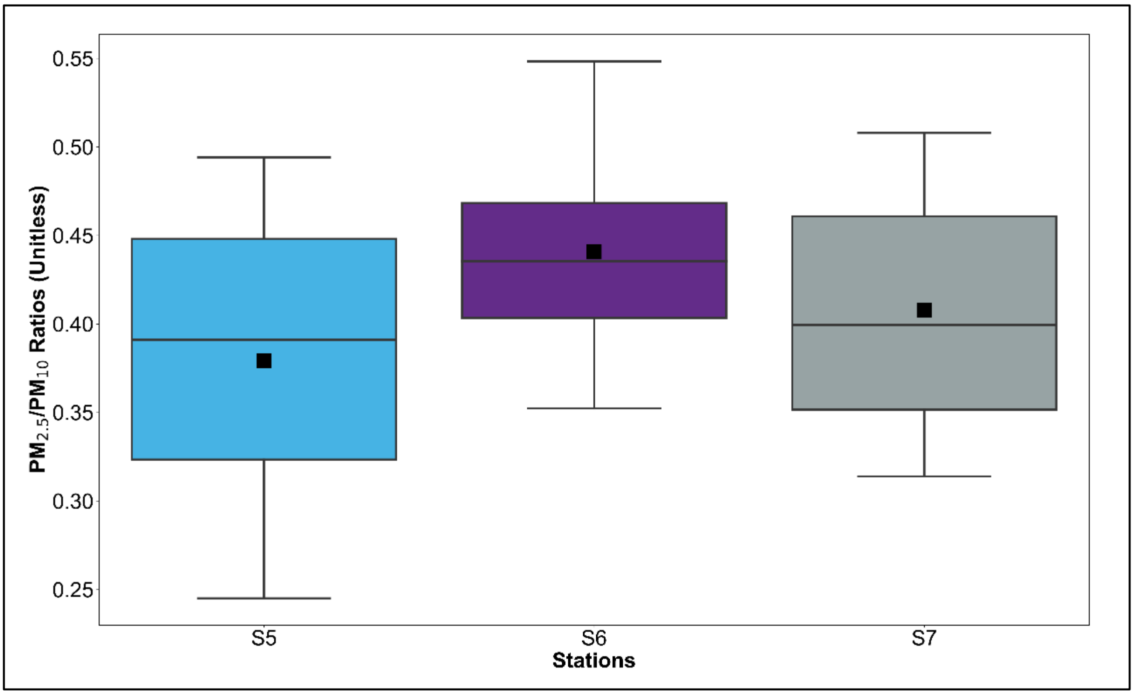


Figure 21 Boxplot showing distribution of** $PM_{2.5}$ **to** PM_{10} **ratios at three selected sites in Cuttack region during the summer season sampling period (April 10 - 27, 2023)

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 PM_{10}

2.6.2.5.1. Site 5: BDO Office (S5)

Fig. 22 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^{+}, NH_4^{+}, K^{+}, Ca^{++}, Mg^{++}, Cl^{-}, NO_3^{-}, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S5 i.e. BDO Office site in Cuttack region during the summer season (April 10 - 27, 2023). OC and SO_4^{--} in $PM_{2.5}$ and OC, EC and SO_4^{--} PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m³. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

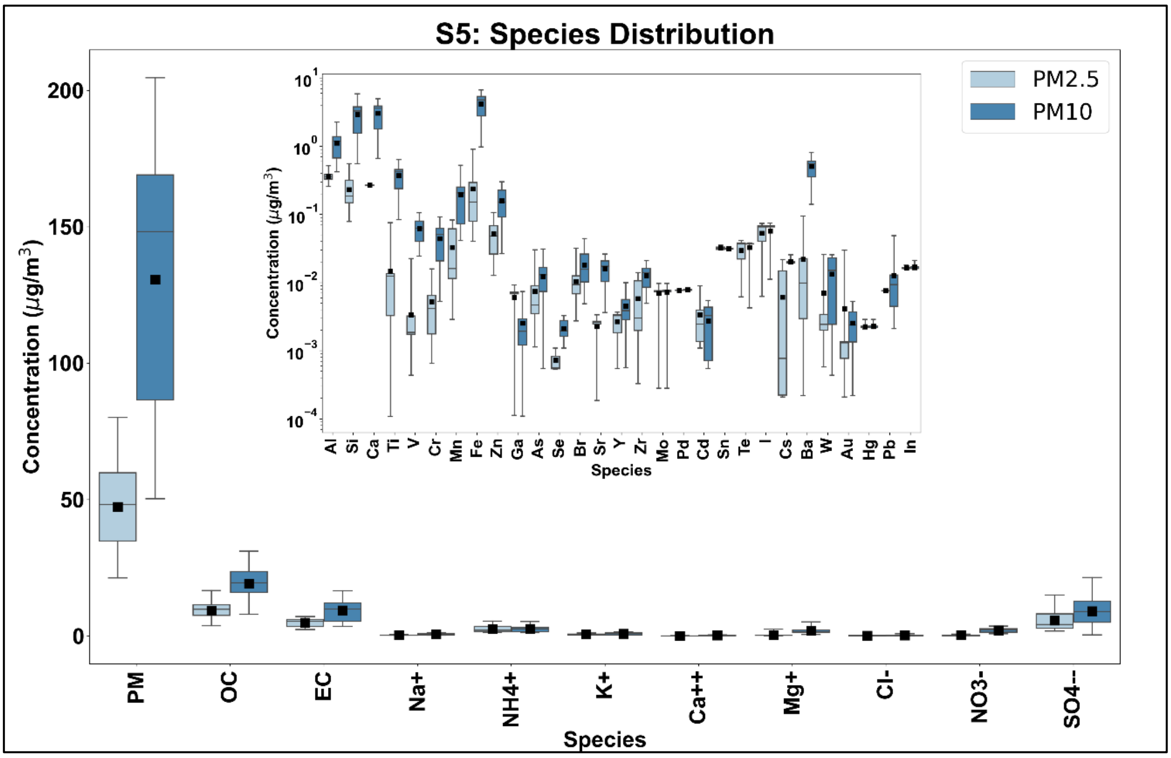


Figure 22 Box plots showing distribution of different species observed in $PM_{2.5}$ and PM_{10} at S5 i.e. BDO Office (S5) in Cuttack region during the summer season sampling period (April 10 - 27, 2023).

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 6: Varun Beverages Ltd (Pepsi) (S6)

Fig. 23 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S6 i.e. Varun Beverages Ltd (Pepsi) site in Cuttack region during the summer season sampling period (April 10 - 27, 2023). OC, EC, and SO_4^{--} in both $PM_{2.5}$ and PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

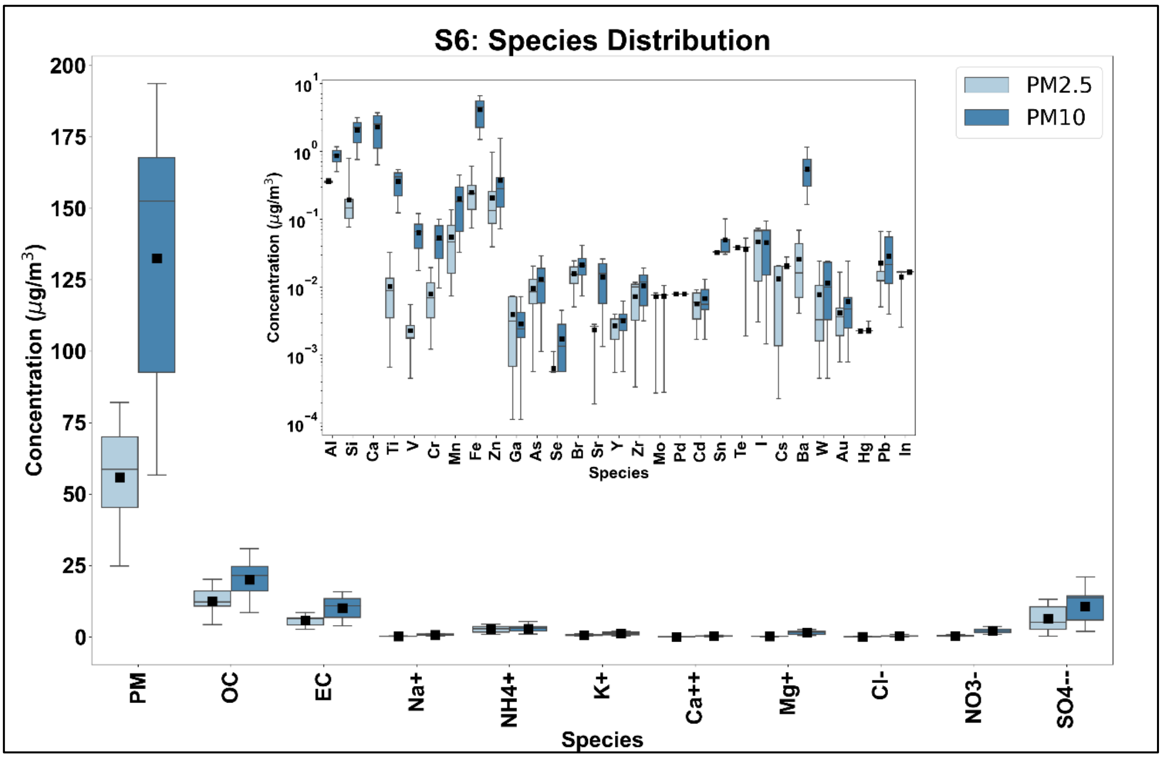


Figure 23 Box plots showing distribution of different species observed in $PM_{2.5}$ and PM_{10} at S6 i.e. Varun Beverages Ltd (Pepsi) site in Cuttack region during the summer season sampling period (April 10 - 27, 2023)

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 7: Baimundi Nursing Home (S7)

Fig. 24 shows the frequency distribution of chemical constituents including carbon fractions (OC, EC), ions (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}, Cl^-, NO_3^-, and SO_4^{--}) and selected elements (Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Zn, Ga, As, Br, Sr, Y, Zr, Mo, Pd, Ag, Cd, Sn, Te, I, Cs, Ba, La, W, Au, Hg, Pb, In) in $PM_{2.5}$ and PM_{10} observed at S7 i.e. Baimundi Nursing Home in Cuttack region during the summer season (April 10 - 27, 2023). OC, EC, and SO_4^{--} in both $PM_{2.5}$ and PM_{10} are the most abundant species having seasonal mean concentrations greater than 5.0 µg/m^3. Trace element concentrations were several orders of magnitude lower compared to other species and showed significant variance over the sampling period.

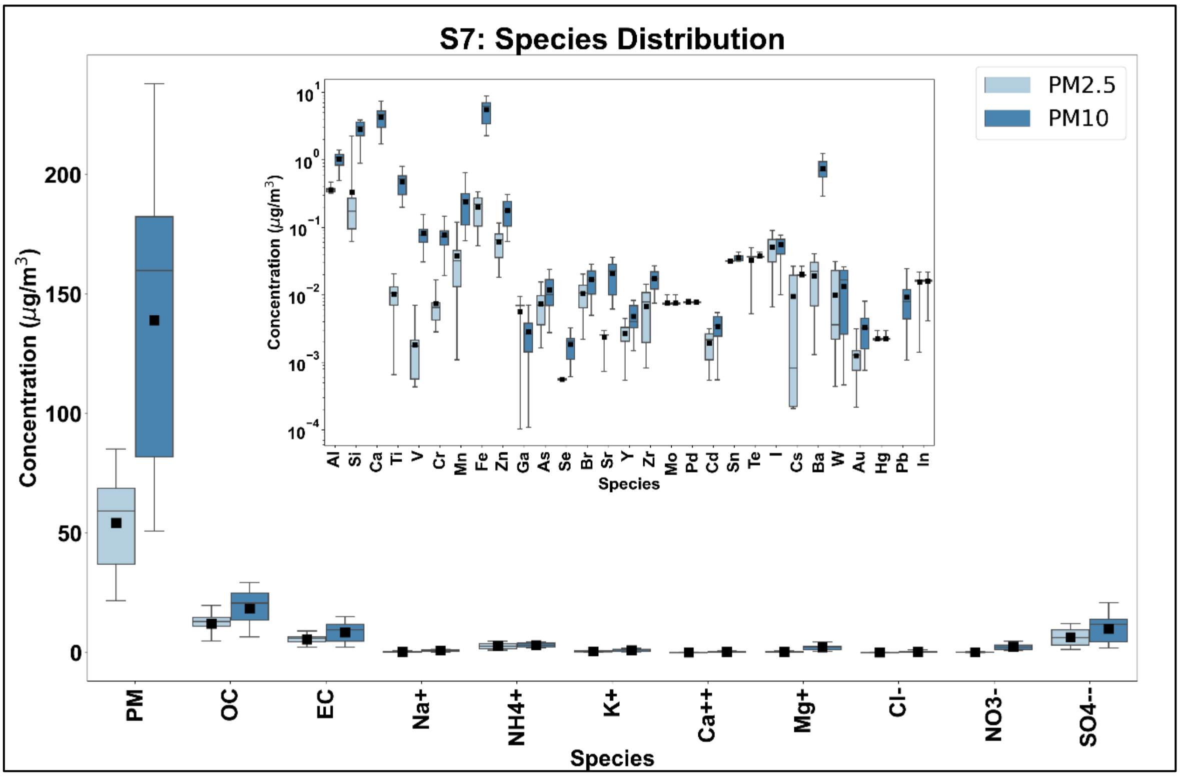


Figure 24 Box plots showing distribution of different species observed in $PM_{2.5}$ and PM_{10} at S7 i.e. Baimundi Nursing Home in Cuttack region during the summer season sampling period (April 10 - 27, 2023)

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 PM_{10}

Fig. 25 and 26, represents the seasonal mean concentrations of molecular markers observed at three sampling locations in Cuttack region, during the summer season sampling period i.e. April 10 to 27, 2023. Levoglucosan is found to dominate the molecular markers mass, during the summer season. Levoglucosan is considered as a tracer for biomass burning emissions.

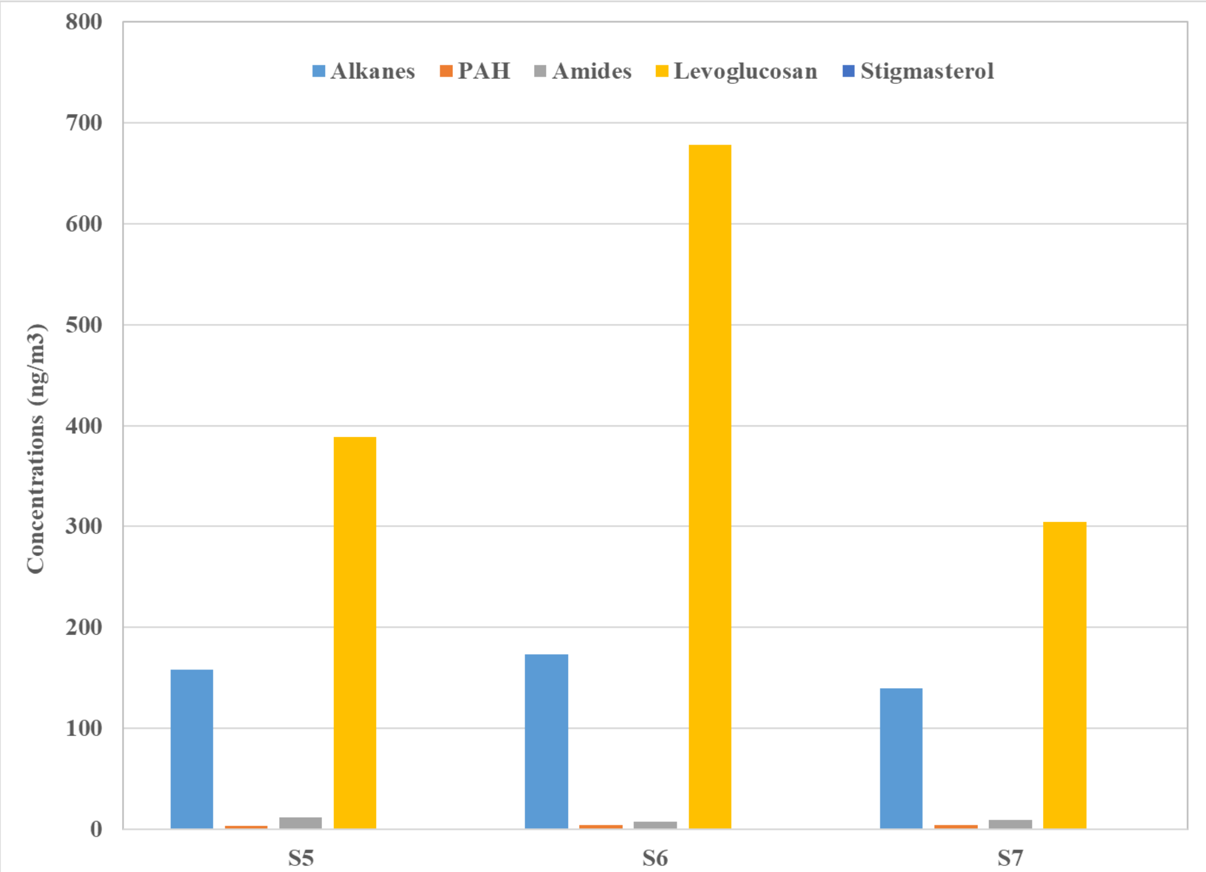


Figure 25 The seasonal mean concentrations of molecular marker species in $PM_{2.5}$ (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Cuttack region during the summer season sampling period (April 10 to 27, 2023).

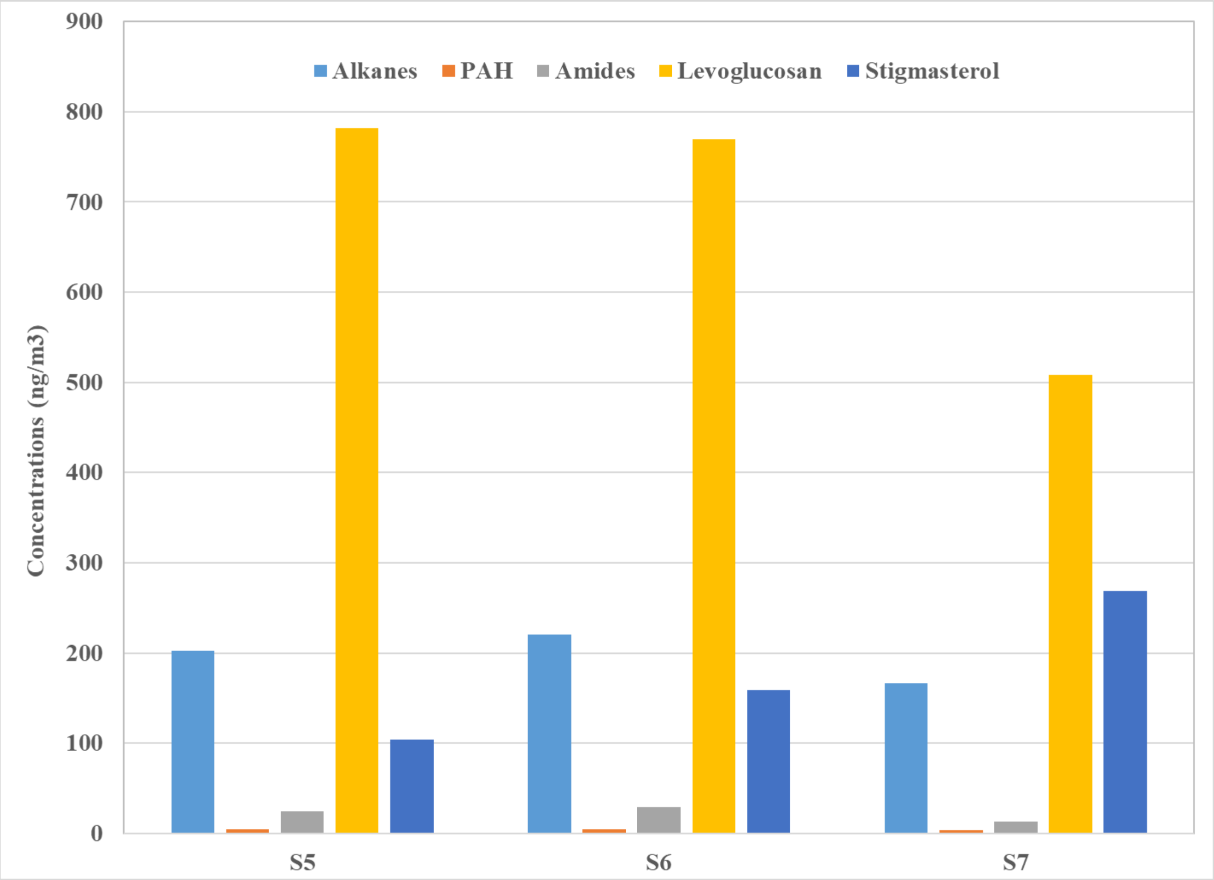


Figure 26 The seasonal mean concentrations of molecular marker species in PM_{10} (grouped into Alkanes, PAHs, Amides, Levoglucosan, and Stigmasterol) observed at three sampling sites in Cuttack region during the summer season sampling period (April 10 to 27, 2023).

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

2.7.1. Validation of mass reconstruction methodology

As discussed in section 2.6.1.1, $PM_{2.5}$ and PM_{10} mass concentrations were reconstructed. Fig. 27 and 28 shows the scatter plots of the 24-hour averaged reconstructed and gravimetric mass concentrations for the winter and summer season sampling duration, respectively. The reconstructed mass was significantly related to gravimetric mass in both winter and summer seasons. The squared correlation coefficient, R^2 is found to be 0.72 (winter) and 0.94 (summer) for $PM_{2.5}$ whereas it is found to be 0.93 (winter) and 0.98 (summer) for PM_{10}, respectively. These correlation coefficients are consistent with other published literature, with average values varying from 0.73 to 0.96 (Chow et al. 2015; Huang et al. 2014; 2017). In general, the PM_{Chem} concentrations are less than those of PM_{Grav} and the difference is defined as unknown. The unknown mass could be attributed to: i) the water retained in the sampling membrane and particulate matter, ii) volatilization of organic matter and the decomposition of ammonium nitrate that may occur during the period between weighing and chemical measurements (Huang et al. 2017) and iii) uncertainties associated with conversion factors used in the estimation of metal oxides and OC to OM conversion (Cheung et al. 2011).

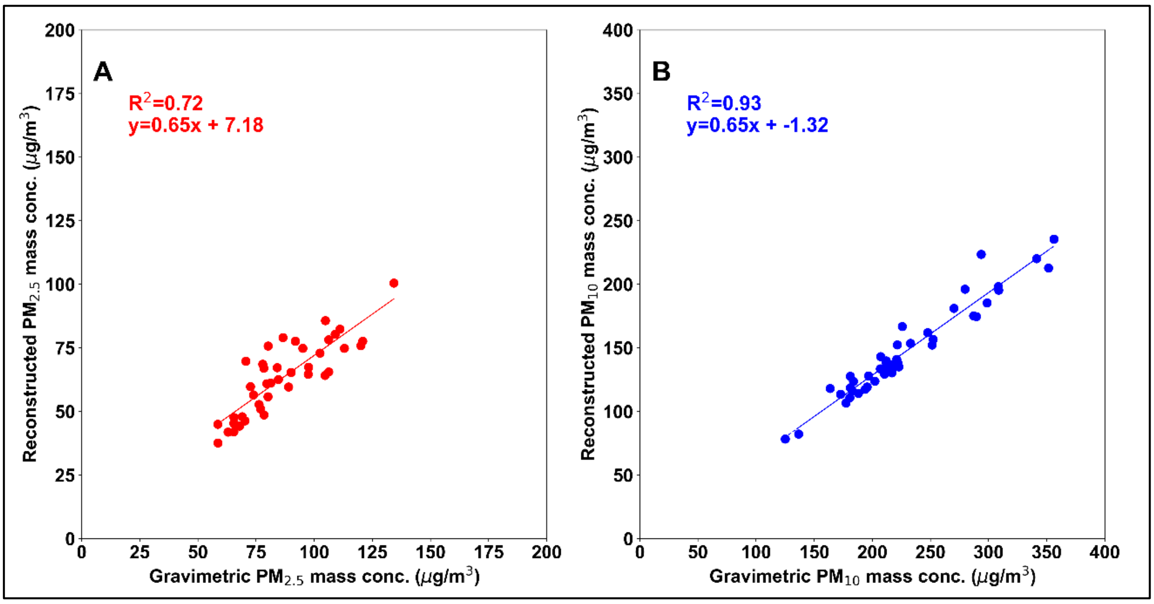


Figure 27 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) $PM_{2.5}$ and (B) PM_{10} in Cuttack region during the winter season sampling period (December 11 - 26, 2022)

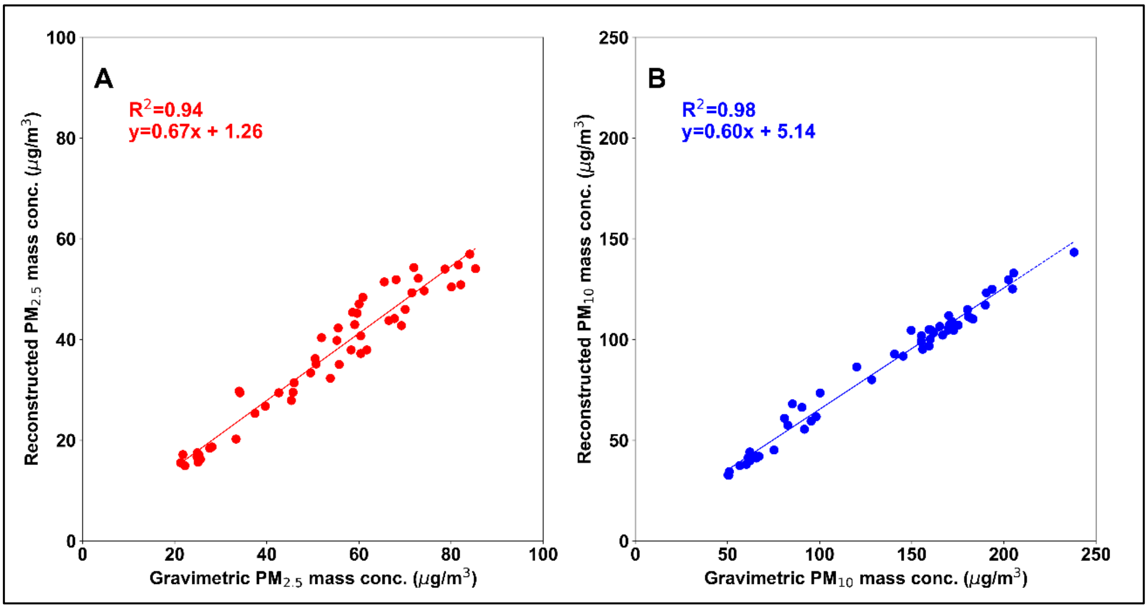


Figure 28 Scatter plots showing the correlation between observed and reconstructed mass concentrations of (A) $PM_{2.5}$ and (B) PM_{10} in Cuttack region during the summer season sampling period (April 10 – 27, 2023)

2.7.2. Winter Season: Reconstructed chemical mass

Fig. 29 to 31 and 32 to 34 presents the reconstructed chemical compositions of $PM_{2.5}$ and PM_{10} during the winter season at Three sampling locations in Cuttack region, respectively. Overall, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in PM2.5 whereas this order changed to OM> CM > SNA > EC > TE > SS in PM10.

The Organic mass (OM) was the most abundant component in PM2.5 during the winter season, with seasonal mean contribution of 37.0 to 38.2% in PM2.5 and 22.2 to 24.4% in PM10. The seasonal mean OM concentrations among the three sites in the winter season ranged from 29.4 to 34.0 µg/m3 in PM2.5 while it ranged from 52.0 to 53.4 µg/m3 in PM10.

Secondary inorganic aerosols, represented as SNA, are the second major component observed in $PM_{2.5}$ and PM_{10} fractions during the winter season in Cuttack region. The seasonal mean contributions from SNA varied from 12.0 to 16.8% in $PM_{2.5}$ while it varied from 10.0 to 12.5% in PM_{10}. The seasonal mean SNA concentrations among the three sites ranged from 11.0 to 14.7 µg/m^3 in $PM_{2.5}$ whereas it ranged from 23.0 to 29.0 µg/m^3 in PM_{10}. The relative contributions indicate significant share of SNA in $PM_{2.5}$ during the winter season and can be mainly attributed to gas to particle conversion between SO_2 and sulfate particles.

The seasonal mean contributions from EC ranged between 12.2 and 16.6% in $PM_{2.5}$ while it ranged between 9.2 and 11.5% in PM_{10}. The seasonal mean elemental carbon (EC) concentrations during winter season varied from 9.6 to 14.6 $\mu g/m^3$ in $PM_{2.5}$ whereas it ranged from 21.9 to 26.5 $\mu g/m^3$ in PM_{10}.

Crustal Mass (CM) is also an important contributor to coarse fraction i.e. PM_{10} during winter season. The seasonal mean contributions from CM varied from 3.2 to 4.5% in $PM_{2.5}$ while it varied from 14.8 to 17.4% in PM_{10}. The seasonal mean CM concentrations in PM_{10} varied from a minimum of 31.4 to 42.0 $\mu g/m^3$ in PM_{10}. In contrast, the CM concentrations in fine fraction i.e. $PM_{2.5}$ were relatively lower and ranged from 2.7 to 4.1 $\mu g/m^3$.

Trace elements (TE) also form an important part of the reconstructed mass in coarse fraction i.e. PM_{10} during the winter season, with contributions ranging from 2.2 to 2.9%. The seasonal mean TE concentrations ranged from 1.7 to 2.5 $\mu g/m^3$ and 4.8 to 6.8 $\mu g/m^3$ in $PM_{2.5}$ and PM_{10}, respectively.

The Sea salt (SS) represented by a sum of Na+ and Cl- ions, are the minor contributors to $PM_{2.5}$ and PM_{10} masses during the winter season over Cuttack region, with contributions ranging from 0.7 to 1.3%. The seasonal mean SS ranged from 0.7 to 1.0 $\mu g/m^3$ in $PM_{2.5}$ while it ranged from 1.5 to 2.6 $\mu g/m^3$ in PM_{10}.

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

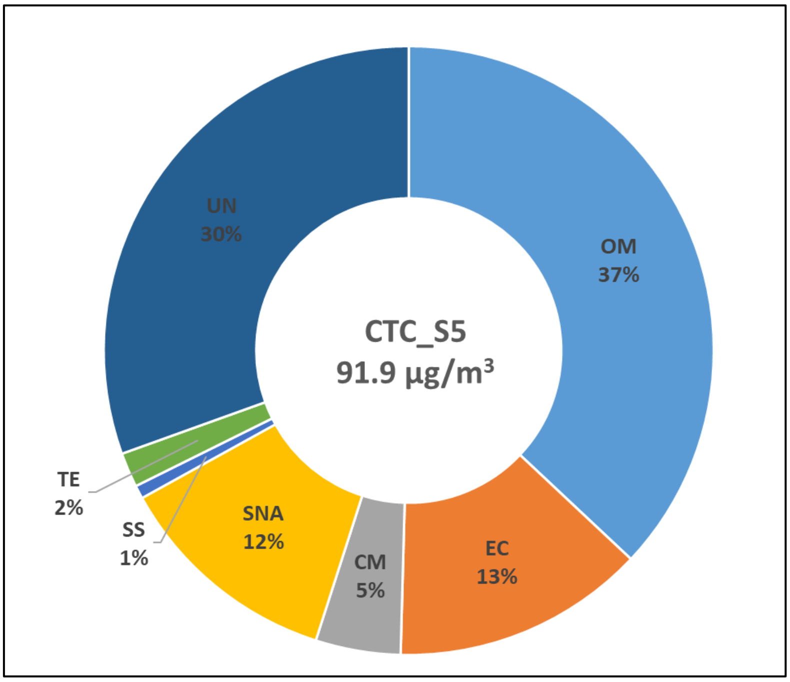


Figure 29: The reconstructed mass of $PM_{2.5}$ at S5 i.e. BDO Office in Cuttack region during the winter season

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.

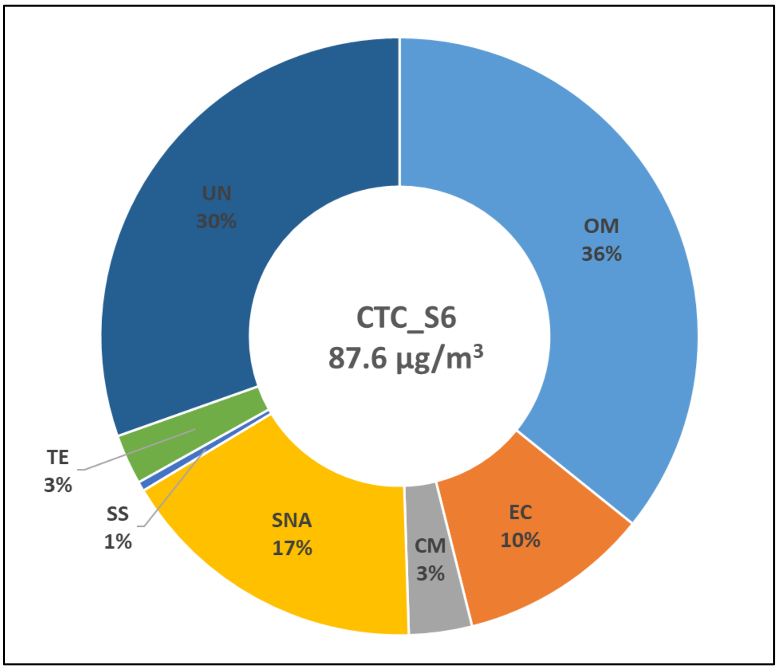


Figure 30: The reconstructed mass of PM2.5 at S6 i.e. Varun Beverages Ltd (Pepsi) in Cuttack region during the winter season

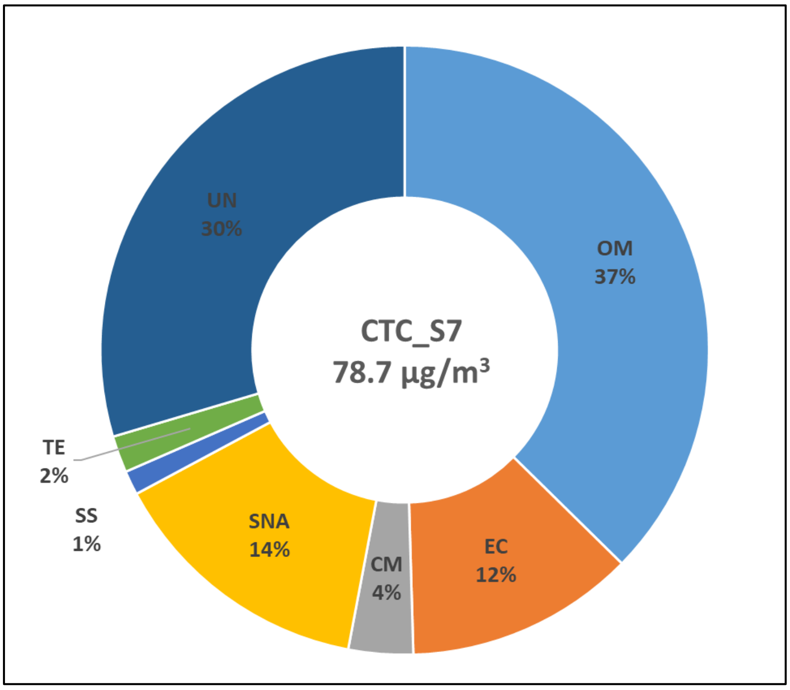


Figure 31: The reconstructed mass of PM2.5 at S7 i.e. Baimundi Nursing Home in Cuttack region during the winter season

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.

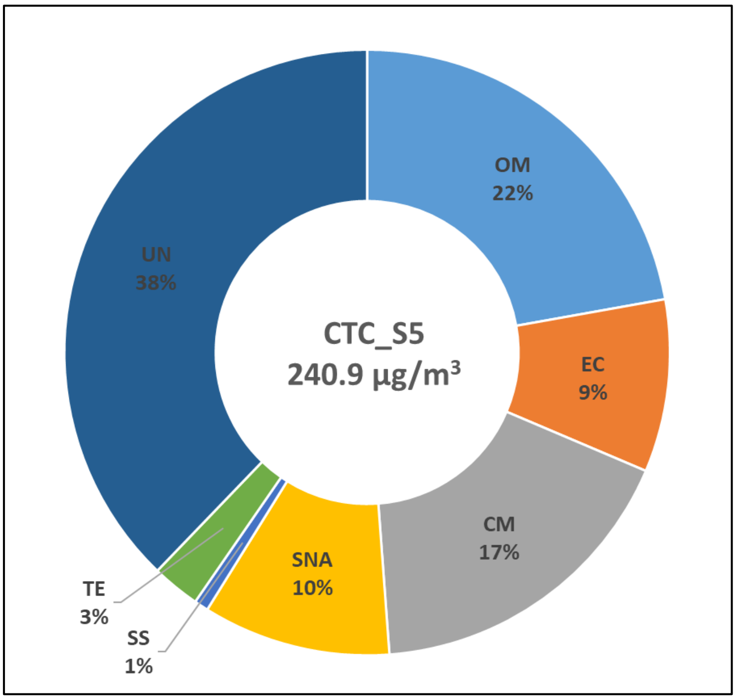


Figure 32: The reconstructed mass of PM_{10} at S5 i.e. BDO Office in Cuttack region during the winter season.

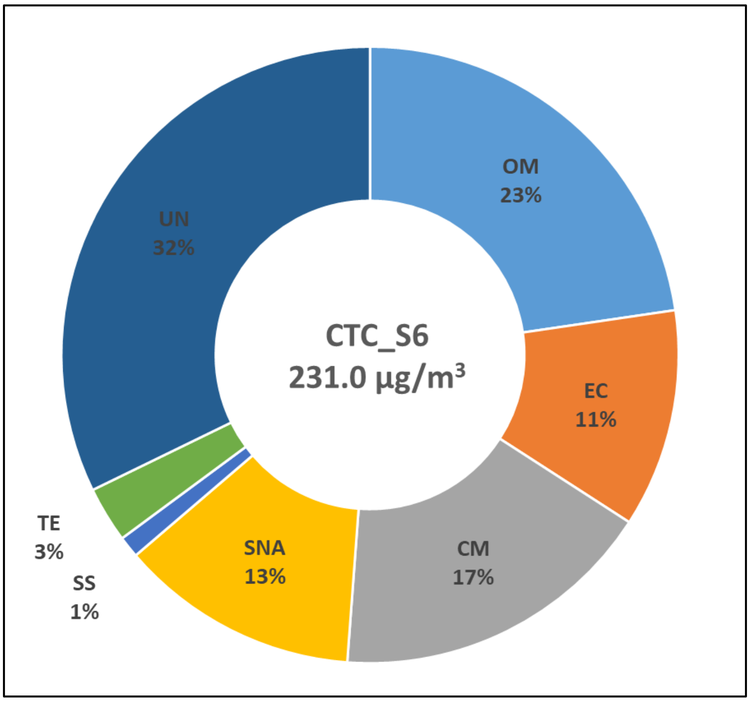


Figure 33: The reconstructed mass of PM_{10} at S6 i.e. Varun Beverages Ltd (Pepsi) in Cuttack region during the winter season

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.

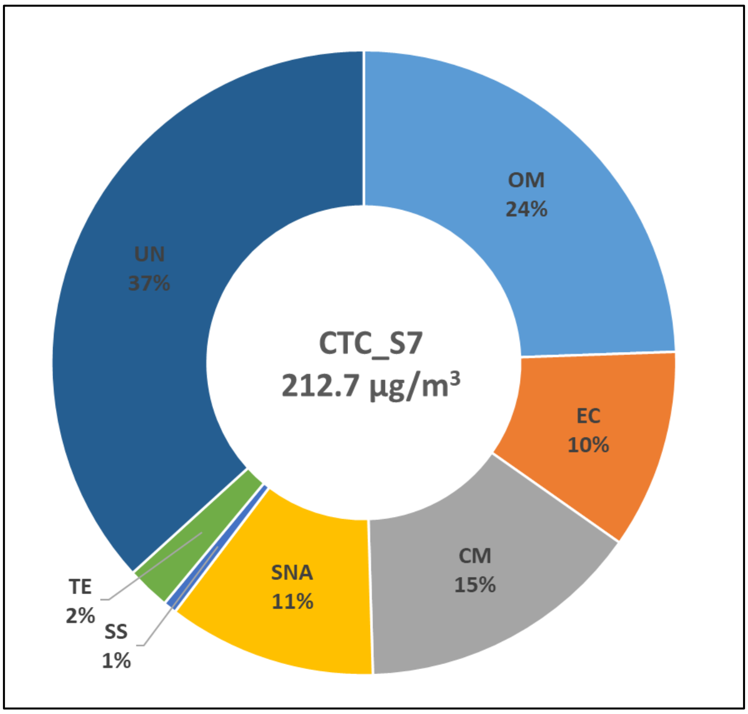


Figure 34: The reconstructed mass of PM_{10} at S7 i.e. Baimundi Nursing Home in Cuttack region during the winter season

Summer Season: Reconstructed chemical mass

Fig. 35 to 37 and 38 to 40 presents the reconstructed chemical compositions of $PM_{2.5}$ and PM_{10} during the summer season at three sampling locations in Cuttack region, respectively. Overall, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > TE > SS in $PM_{2.5}$ whereas this order changed to OM > CM > SNA > EC > TE > SS in PM_{10}.

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 31.5 to 35.8% in $PM_{2.5}$ and 21.3 to 24.2%. The seasonal mean OM concentrations in the summer season ranged from 14.9 to 20.0 µg/m^3 in $PM_{2.5}$ while it ranged from 29.7 to 32.1 µg/m^3 in PM_{10}.

Crustal Mass (CM) is the most important contributor to coarse fraction i.e. PM_{10} during summer season. The seasonal mean contributions from CM varied from 3.4 to 4.2% in $PM_{2.5}$ while it varied from 16.2 to 22.0% in PM_{10}. The seasonal mean CM concentrations in PM_{10} varied from a minimum of 21.4 to 30.6 µg/m^3 in PM_{10}. In contrast, the CM concentrations in fine fraction i.e. $PM_{2.5}$ were relatively lower and ranged from 1.9 to 2.1 µg/m^3.

Secondary inorganic aerosols, represented as SNA, is the third and fourth major component observed in $PM_{2.5}$ and PM_{10} fractions during the summer season in Cuttack region, respectively. The seasonal mean contributions from SNA varied from 16.9 to 18.2% in $PM_{2.5}$ while it varied from 10.5 to 11.9% in PM_{10}. The seasonal mean SNA concentrations ranged from 8.6 to 9.6 µg/m^3 in $PM_{2.5}$ whereas it ranged from 13.8 to 15.8 µg/m^3 in PM_{10}. The relative contributions indicate significant share of SNA in $PM_{2.5}$ during the summer season.

The seasonal mean contributions from EC ranged between 10.2 and 10.4% in $PM_{2.5}$ while it ranged between 6.1 and 7.7% in PM_{10}. The daily averaged elemental carbon (EC) concentrations during summer season varied from 4.9 to 5.8 µg/m^3 in $PM_{2.5}$ whereas it ranged from 8.5 to 10.2 µg/m^3 in PM_{10}.

Trace elements (TE) form an important part of the reconstructed mass in coarse fraction i.e. PM_{10} during the summer season, with contributions ranging from 3.3 to 4.0%. The seasonal mean TE concentrations ranged from 0.9 to 1.5 µg/m^3 and 3.3 to 4.0 µg/m^3 in $PM_{2.5}$ and PM_{10}, respectively.

The Sea salt (SS) represented by a sum of Na+ and Cl- ions, are the minor contributors to $PM_{2.5}$ and PM_{10} masses during the summer season over Cuttack region, with contributions ranging from 0.5 to 0.9%. The seasonal mean SS ranged from 0.3 to 0.4 µg/m^3 in $PM_{2.5}$ while it ranged from 0.9 to 1.2 µg/m^3 in PM_{10}.

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

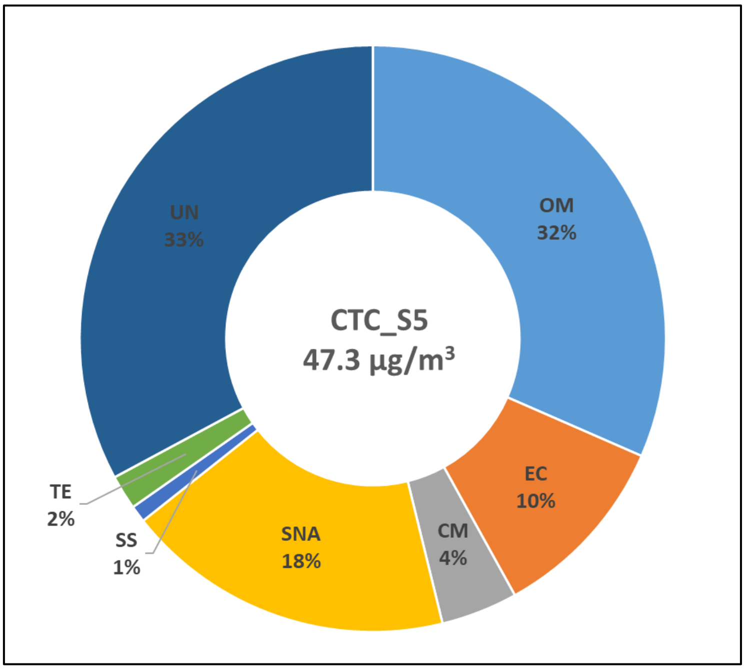


Figure 35: The reconstructed mass of $PM_{2.5}$ at S5 i.e. BDO Office in Cuttack region during the summer season

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.

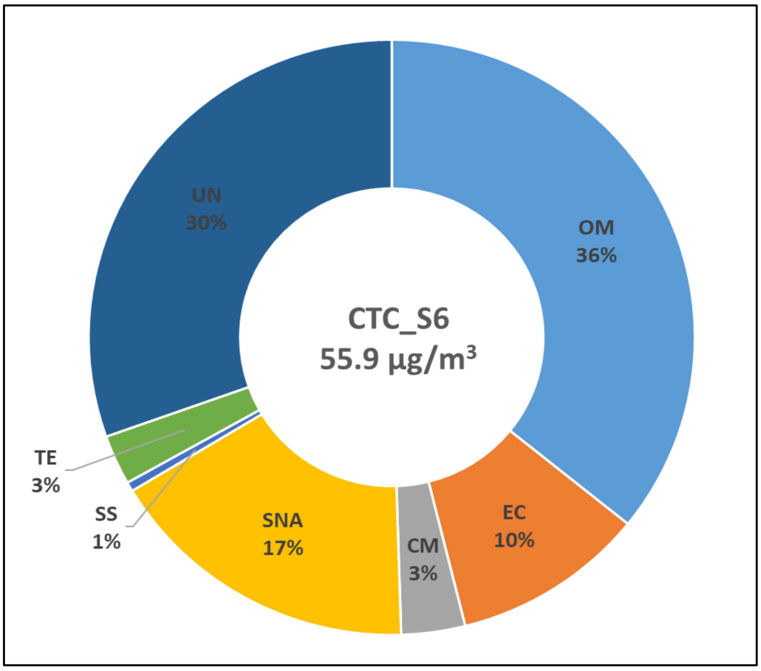


Figure 36: The reconstructed mass of PM2.5 at S6 i.e. Varun Beverages Ltd (Pepsi) in Cuttack region during the summer season

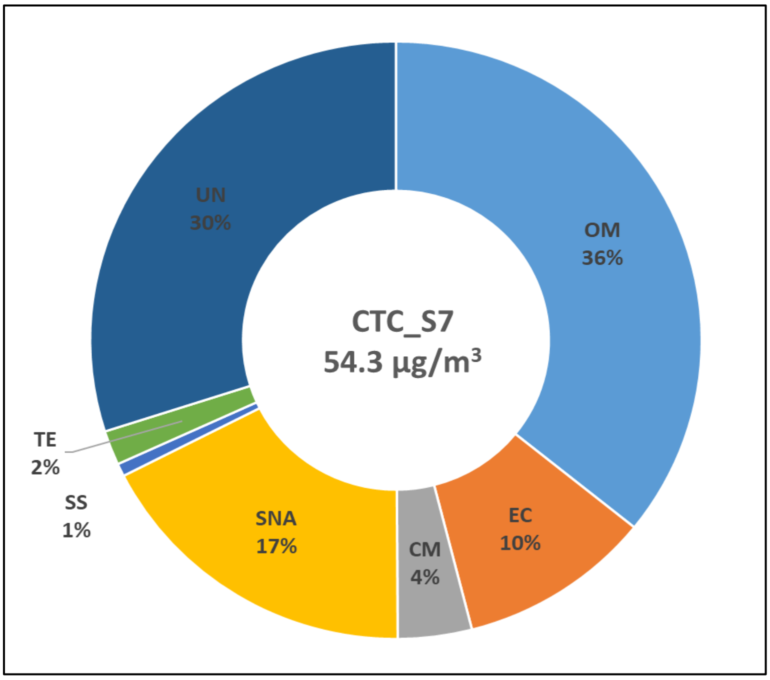


Figure 37: The reconstructed mass of PM2.5 at S7 i.e. Baimundi Nursing Home in Cuttack region during the summer season

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.

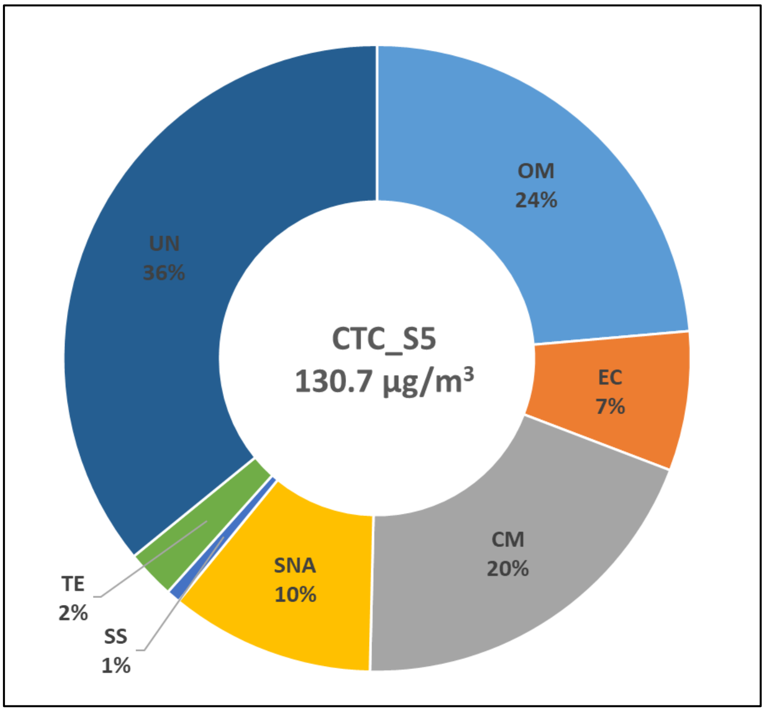


Figure 38: The reconstructed mass of PM_{10} at S5 i.e. BDO Office in Cuttack region during the summer season.

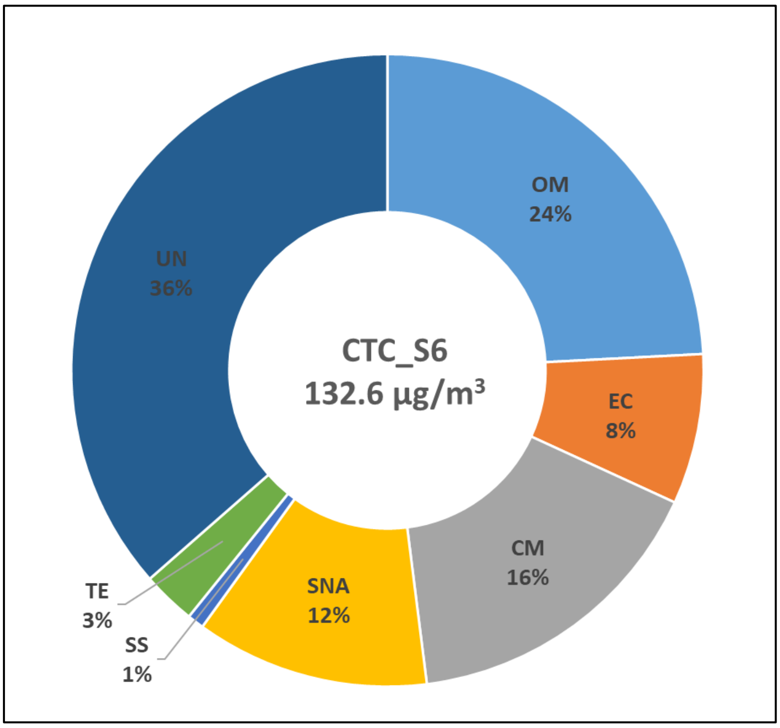


Figure 39: The reconstructed mass of PM_{10} at S6 i.e. Varun Beverages Ltd (Pepsi) in Cuttack region during the summer season

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.

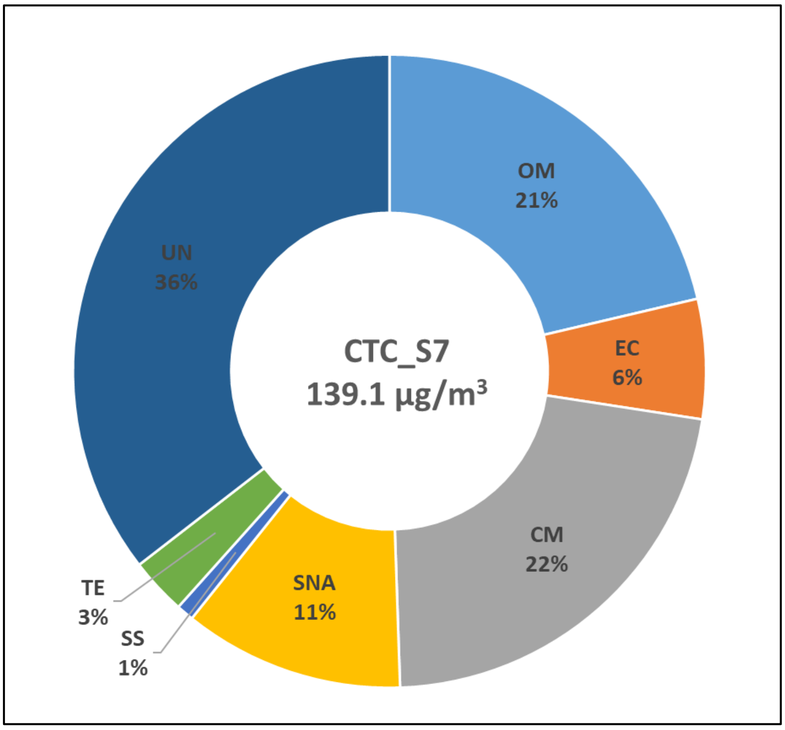


Figure 40: The reconstructed mass of PM_{10} at S7 i.e. Baimundi Nursing Home in Cuttack region during the summer season

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

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

The chemical ratios of OC/EC, Cl^-/Na^+, K^+/OC, K^+/EC, NO_3^-/SO_4^{--} and degree of neutralization (DON) have been used as indicators to qualitatively assess the contributions from air polluting sources in the region and these ratios were calculated for our study sites. Fig. 41 shows the chemical ratios i.e. i) OC to EC ratio, ii) Cl^- to Na^+ ratio, iii) K^+ to OC ratio, iv) K^+ to EC, v) NO_3^- to SO_4^{--} ratio, and vi) degree of neutralization (DON) in $PM_{2.5}$ and PM_{10} observed at three sampling locations in Cuttack region during the winter and summer seasons, respectively. Table 2 provides summary of average chemical ratios.

The OC/EC ratio indicate the origins of carbonaceous fraction (Salameh et al. 2014) and is commonly used to assess the impacts of fossil fuel emissions and aging, and the formation of secondary organic aerosols (Niu et al. 2016). The average OC/EC ratio in the present study is close to 2, indicates that carbonaceous fraction is originated from primary sources during the both winter and summer seasons. A good correlation ($R > 0.8$) is observed between OC and EC in both $PM_{2.5}$ and PM_{10} at sampling sites implies their primary source signature (Srinivas and Sarin, 2014).

Soluble potassium (K^+) concentrations were used to determine the possibility of contribution from biomass burning. Fossil fuel combustion seems to produce very little potassium and exhibit K^+/OC and K^+/EC ratios close to zero while other combustion sources such as biomass combustion and Savannah burning are characterized by K^+/OC ratios ranging from 0.08 to 0.10 (Echalar et al. 1998) and from 0.04 to 0.13 (Andreae and Merlet 2001), respectively. Similarly, K^+/EC ratios for biomass burning are reported to vary from 0.20 to 0.69 (Andreae 1983; Ram and Sarin 2010). The winter season K^+/OC ratios ranged from 0.03 to 0.06 in $PM_{2.5}$ and PM_{10}. Similarly, K^+/EC ratios ranged from 0.06 to 0.09 in $PM_{2.5}$ and PM_{10}. The summer season K^+/OC ratios ranged from 0.04 to 0.07 $PM_{2.5}$ and PM_{10}. Similarly, K^+/EC ratios ranged from 0.09 to 0.13 in $PM_{2.5}$ and PM_{10}. These ratios suggest possibility of biomass burning in the region.

The NO_3^-/SO_4^{--} ratio has been used by researchers to assess the relative contributions from stationary versus mobile sources of PM (Arimoto et al. 1996). The winter-time NO_3^-/SO_4^{--} ratios varied from 0.40 to 0.50 in $PM_{2.5}$ whereas it varied from 0.61 to 0.74 PM_{10}. Similarly, summer-time NO_3^-/SO_4^{--} ratios varied from 0.04 to 0.08 in $PM_{2.5}$ whereas it varied from 0.24 to 0.31 in PM_{10}. Ratios less than unity indicates the dominance of stationary sources over mobile sources in Cuttack region.

The average Cl^-/Na^+ ratio of seawater is 1.8 and in general a ratio greater than 10, indicates anthropogenic origin of Cl^- ions. In the present study, the winter season mean Cl^-/Na^+ ratio ranged from 1.26 to 2.79 in $PM_{2.5}$ whereas it ranged from 1.68 to 3.98 in PM_{10}. The summer season mean Cl^-/Na^+ ratio ranged from 0.11 to 0.36 in $PM_{2.5}$ whereas it ranged from 0.42 to 0.50 in PM_{10}. The ratios less than 10 at all sites, indicate the natural origin of Cl^- ions such as marine aerosols.

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

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

In winter season, the average DON values ranged from 0.90 to 0.99 in $PM_{2.5}$ and 0.55 to 0.63 in PM_{10} at three sampling locations in Cuttack region. It shows the complete neutralization and/or ammonium deficiency at during the winter season, which in turn implies neutral to slightly acidic nature of sulfate and nitrate particles. This could be explained by the persistent weak solar radiations, cold temperatures, and an obvious decoupling of high organic aerosol concentrations with acid particles, which in turn implies that the observed winter-time organics may be primary in nature (Chu et al., 2004).

In summer season, the average DON values ranged from 1.24 to 2.11 in $PM_{2.5}$ and 0.68 to 1.22 in PM_{10} at three sampling locations in Cuttack region. It shows the presence of excess ammonium during the summer season, which in turn implies the basic nature of sulfate and nitrate particles. This could be attributed to increased ammonia emissions and higher temperatures leading to enhanced photochemical reactions during the summer season.

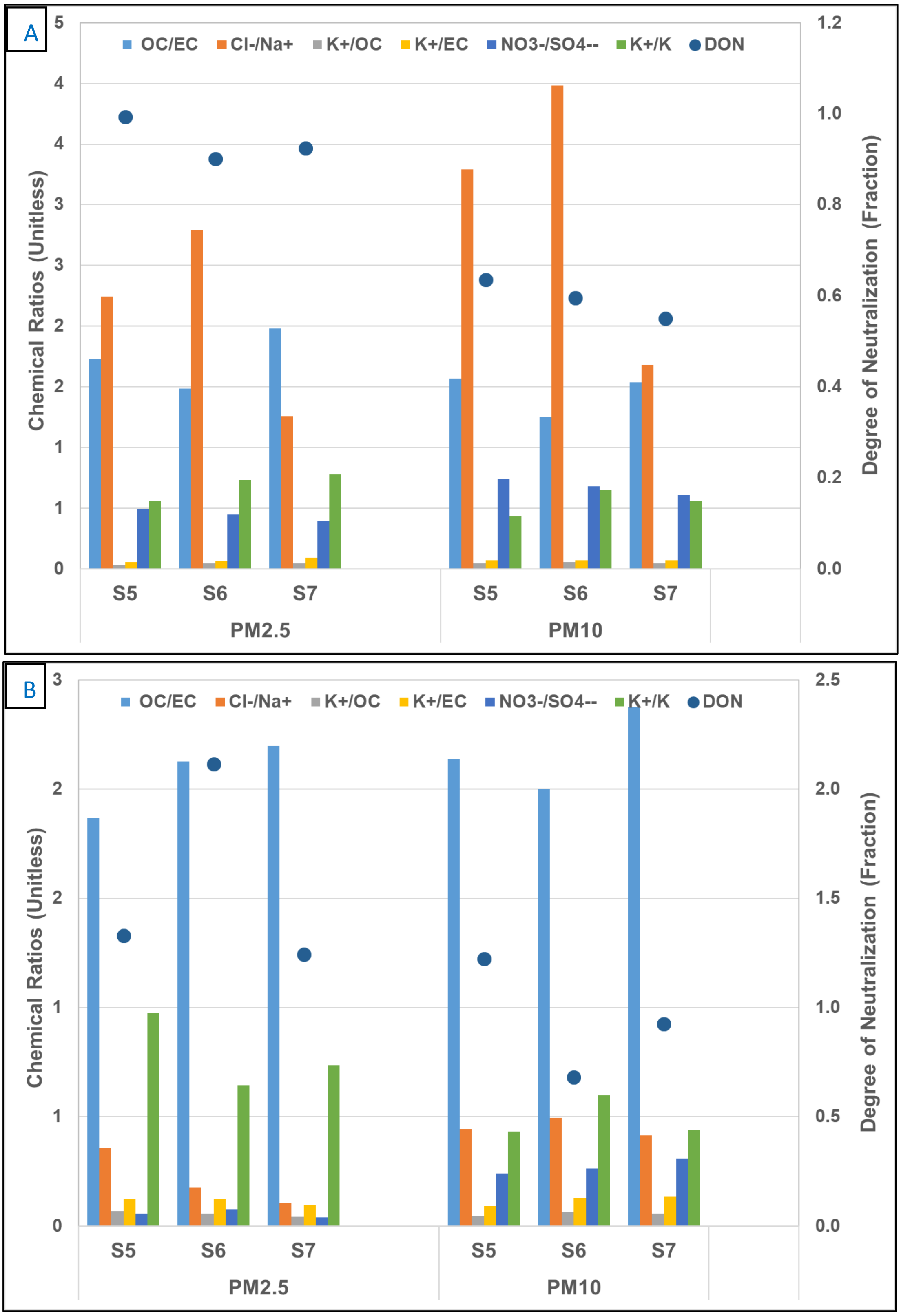


Figure 41: Chemical ratios i.e. OC to EC ratio, Cl^- to Na^+ ratio, K^+ to OC ratio, K^+ to EC, NO_3^- to SO_4^{--} ratio, and degree of neutralization (DON) observed at three sampling locations during the winter (A) and summer (B) seasons in Cuttack region.

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

Fraction	Site	OC/EC	Cl^-/Na^+	K^+/OC	K^+/EC	NO_3^-/SO_4^{--}	DON
Winter $PM_{2.5}$	S5	1.73	2.24	0.03	0.06	0.50	0.99
	S6	1.49	2.79	0.05	0.07	0.45	0.90
	S7	1.98	1.26	0.05	0.09	0.40	0.92
Winter PM_{10}	S5	1.57	3.29	0.04	0.07	0.74	0.63
	S6	1.26	3.98	0.06	0.07	0.68	0.60
	S7	1.54	1.68	0.05	0.07	0.61	0.55
Summer $PM_{2.5}$	S5	1.87	0.36	0.07	0.12	0.06	1.33
	S6	2.13	0.18	0.06	0.12	0.08	2.11
	S7	2.20	0.11	0.04	0.10	0.04	1.24
Summer PM_{10}	S5	2.14	0.44	0.04	0.09	0.24	1.22
	S6	2.00	0.50	0.06	0.13	0.26	0.68
	S7	2.38	0.42	0.06	0.13	0.31	0.93

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

Source contributions to fine and coarse particulate matter i.e. $PM_{2.5}$ and PM_{10} were calculated with the CMB model for the individual daily samples for three sampling sites in Cuttack 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 5: BDO Office

Fig. 42 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S5 i.e. BDO Office during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 91.9 µg/m^3 and 240.9 µg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by biomass and solid waste combustion sources with highest contribution of 34.2%. The other sources of $PM_{2.5}$ at this site were identified as transport (22.4%), dust (22.1%), secondary aerosols (10.8%), and industry (1.5%). The winter-time PM_{10} concentrations at this site were dominated by dusty sources (38.0%), followed by biomass and solid waste combustion (22.9%), secondary aerosols (14.1%), transport (11.5%), and industry (1.8%). About 9.1% and 11.7% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

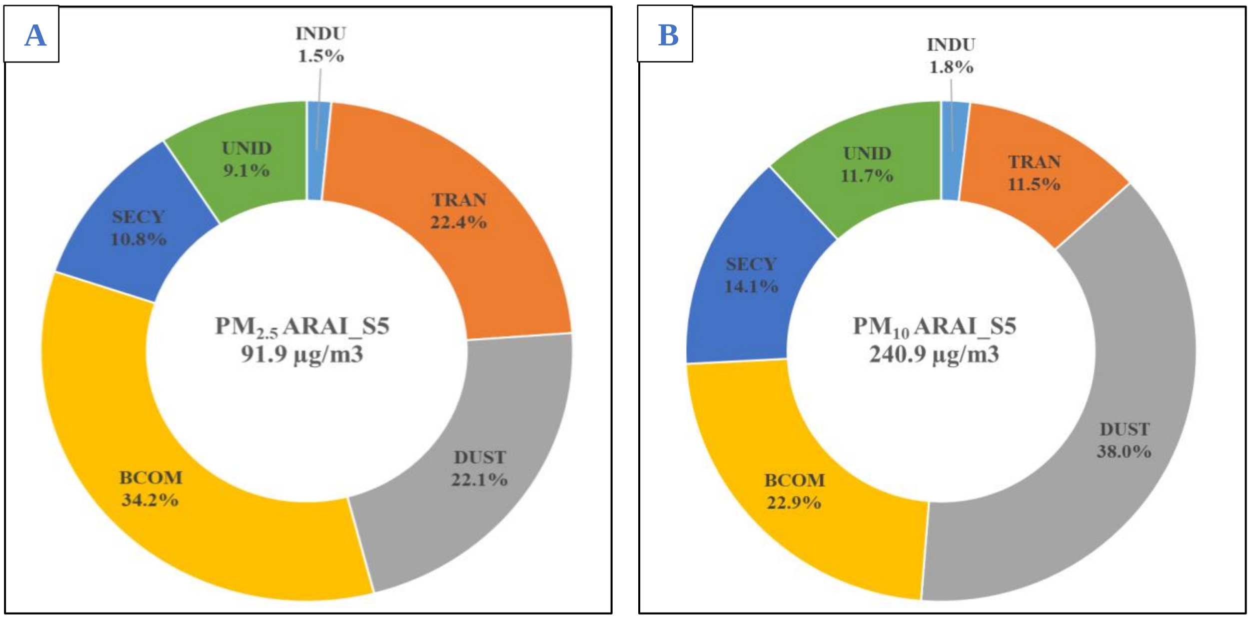


Figure 42 Sectoral source contributions to $PM_{2.5}$ (A) and PM_{10} (B) at S5 i.e. BDO Office during the winter season in Cuttack region

2.9.1.2. Site 6: Varun Beverages Ltd (Pepsi)

Fig. 43 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S6 i.e. Varun Beverages Ltd (Pepsi) during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 87.6 µg/m^3 and 231.0 µg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 31.8%. The other sources of $PM_{2.5}$ at this site were identified as transport (26.3%), secondary aerosols (16.1%), biomass and solid waste combustion (14.4%), and industry (2.3%). The winter-time PM_{10} concentrations at this site were also dominated by dust (46.5%), followed by secondary aerosols (18.4%), transport (11.5%), biomass and solid waste combustion (8.3%), and industry (3.6%). About 9.2% and 12.0% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

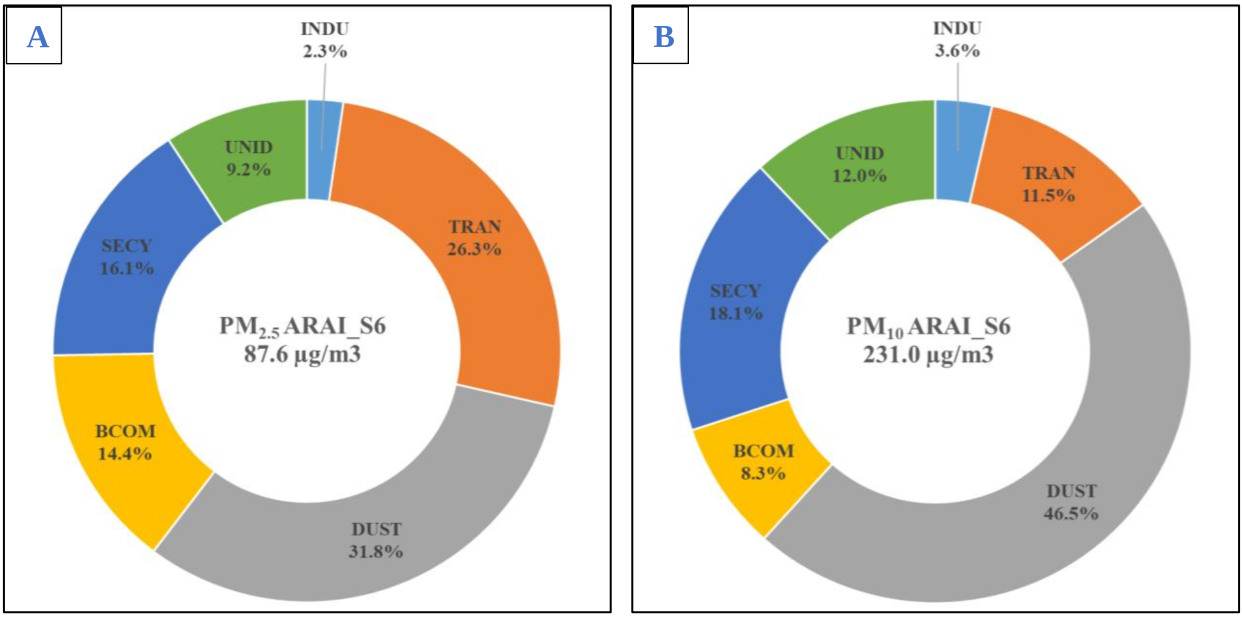


Figure 43 Sectoral source contributions to $PM_{2.5}$ (A) and PM_{10} (B) at S6 i.e. Varun Beverages Ltd (Pepsi) during winter season in Cuttack region

2.9.1.3. Site 7: Baimundi Nursing Home

Fig. 44 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S7 i.e. Baimundi Nursing Home during winter season. The winter season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 78.7 μg/m^3 and 212.7 μg/m^3, respectively. The winter time $PM_{2.5}$ mass was found to be dominated by biomass and solid waste combustion sources with highest contribution of 40.7%. The other sources of $PM_{2.5}$ at this site were identified as transport (24.9%), secondary aerosols (16.5%), dust (9.6%) and industry (1.6%). The winter-time PM_{10} concentrations at this site were also dominated by biomass and solid waste combustion (30.7%), followed by secondary aerosols (24.6%), dust (20.1%), transport (14.5%), and industry (1.9%). About 6.7% and 8.1% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

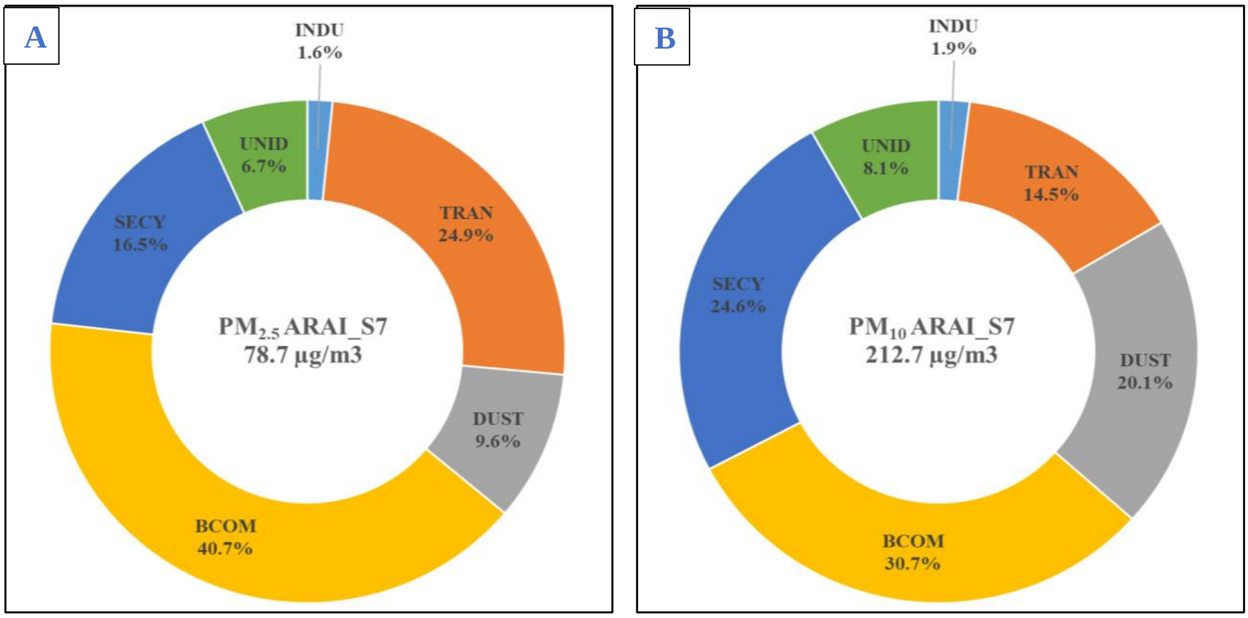


Figure 44 Sectoral source contributions to $PM_{2.5}$ (A) and PM_{10} (B) at S7 i.e. Baimundi Nursing Home during winter season in Cuttack region

2.9.2. SUMMMER SEASON

2.9.2.1. Site 5: BDO Office

Fig. 45 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S5 i.e. BDO Office during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 47.3 μg/m^3 and 130.7 μg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 35.7%. The other sources of $PM_{2.5}$ at this site were identified as transport (24.7%), biomass and solid waste combustion (19.8%), secondary aerosols (14.4%), and industry (1.0%). The summer-time PM_{10} concentrations at this site were also dominated by dust (49.0%), followed by, secondary aerosols (16.5%), biomass and solid waste combustion (11.6%), transport (11.3%), and industry (1.1%). About 4.4% and 10.4% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

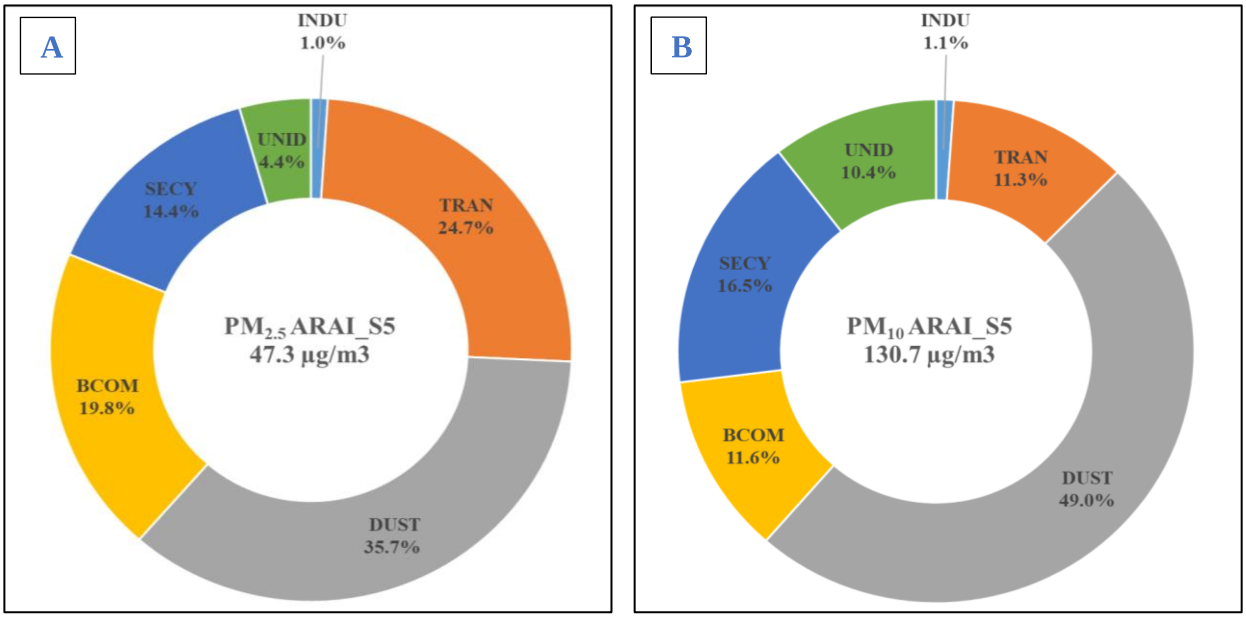


Figure 45 Sectoral source contributions to $PM_{2.5}$ (A) and PM_{10} (B) at S5 i.e. BDO Office during the summer season in Cuttack region

2.9.2.2. Site 6: Varun Beverages Ltd (Pepsi)

Fig. 46 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S6 i.e. Varun Beverages Ltd (Pepsi) during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 55.9 µg/m^3 and 132.6 µg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by dusty sources with highest contribution of 37.1%. The other sources of $PM_{2.5}$ at this site were identified as transport (24.6%), secondary aerosols (17.7%), biomass and solid waste combustion (11.7%), and industry (1.5%). The summer-time PM_{10} concentrations at this site were also dominated by dust (52.2%), followed by secondary aerosols (18.8%), transport (10.4%), biomass and solid waste combustion (6.4%), and industry (2.0%). About 7.4% and 10.2% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

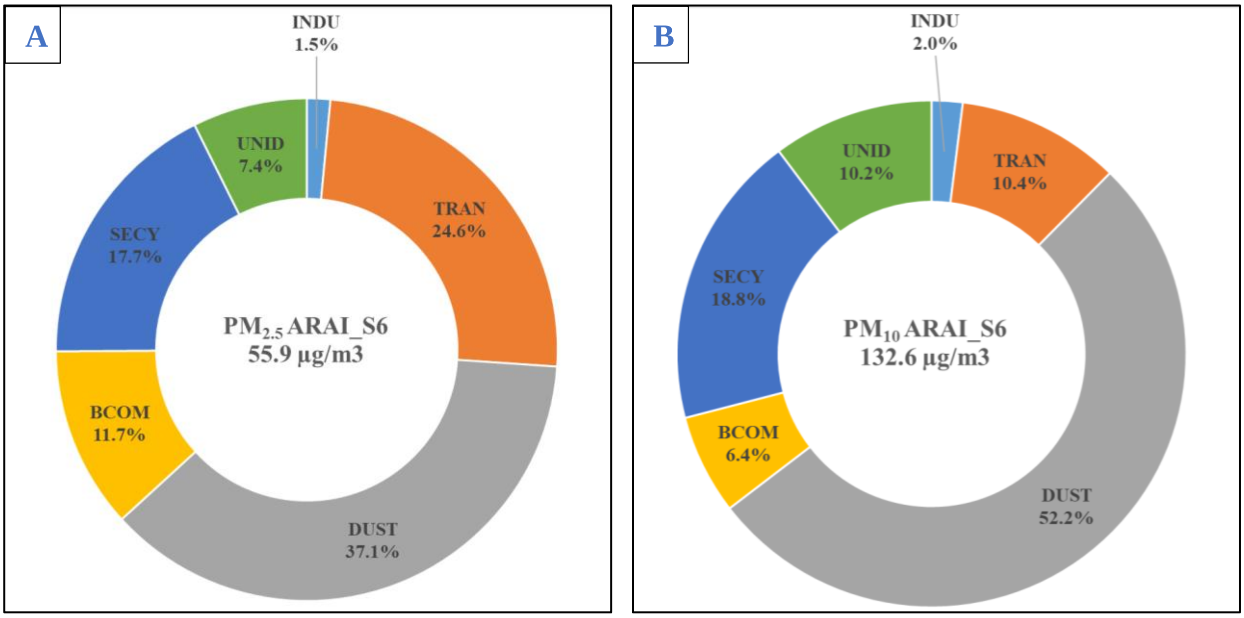


Figure 46 Sectoral source contributions to $PM_{2.5}$ (A) and PM_{10} (B) at S6 i.e. Varun Beverages Ltd (Pepsi) during summer season

2.9.2.3. Site 7: Baimundi Nursing Home

Fig. 47 shows the sectoral source contributions to $PM_{2.5}$ and PM_{10} at S7 i.e. Baimundi Nursing Home during summer season. The summer season mean modelled $PM_{2.5}$ and PM_{10} concentrations at this site were 54.3 µg/m^3 and 139.1 µg/m^3, respectively. The summer time $PM_{2.5}$ mass was found to be dominated by transport with highest contribution of 28.3%. The other sources of $PM_{2.5}$ at this site were identified as biomass and solid waste combustion (26.5%), secondary aerosols (19.7%), dust (17.4%), and industry (1.2%). The summer-time PM_{10} concentrations at this site were dominated by dust (29.2%), followed by secondary aerosols (25.8%), biomass and solid waste combustion (17.5%), transport (14.7%), and industry (1.4%). About 6.8% and 11.4% in $PM_{2.5}$ and PM_{10} mass remained un-apportioned, respectively. This can be attributed to unknown sources as well as process and modelling uncertainties.

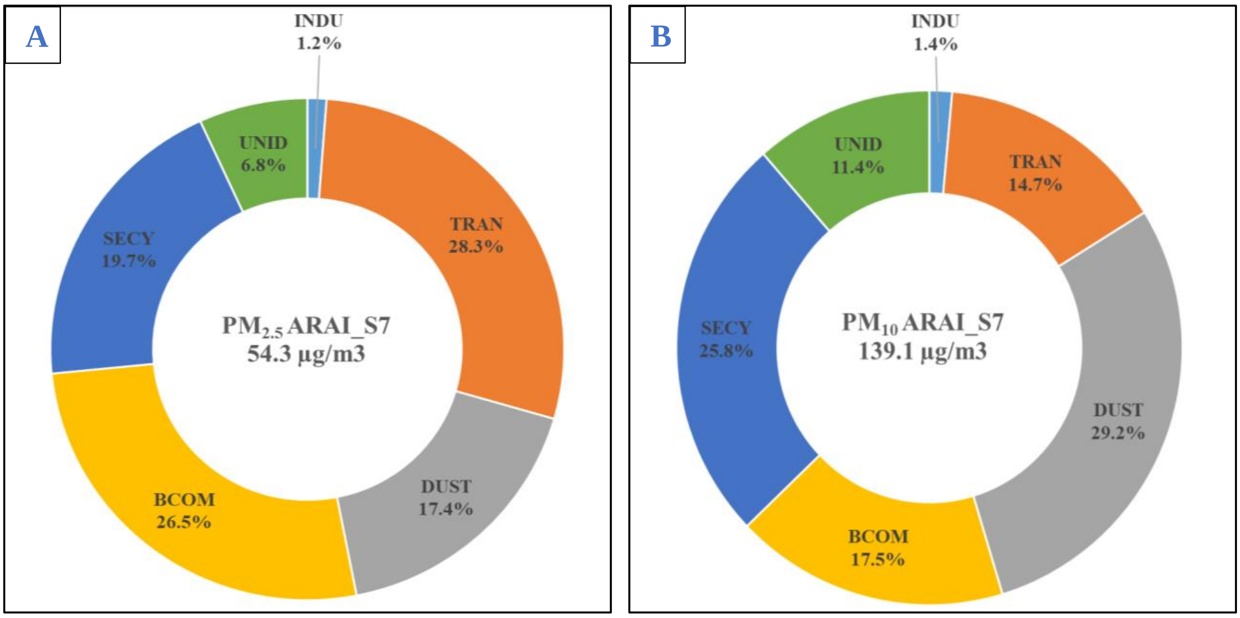


Figure 47 Sectoral source contributions to $PM_{2.5}$ (A) and PM_{10} (B) at S7 i.e. Baimundi Nursing Home during summer season

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. 48 and 49 presents the average source contributions to ambient $PM_{2.5}$ and PM_{10} at Cuttack region during winter and summer seasons, respectively.

Overall, the winter-time $PM_{2.5}$ mass at Cuttack region (Fig. 48) are found to be dominated by solid waste and biomass combustion sector with highest contribution of 29.8%. The other sources of $PM_{2.5}$ at Cuttack region are identified as transport (24.5%), dust (21.2%), secondary aerosols (14.5%), and industry (1.8%). Similarly, the winter-time PM_{10} mass at Cuttack region is found to be dominated by dust (34.9%), followed by solid waste and biomass combustion (20.6%), secondary aerosols (18.9%), transport (12.5%), and industry (2.4%). Additionally, about 8.3% and 10.6% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

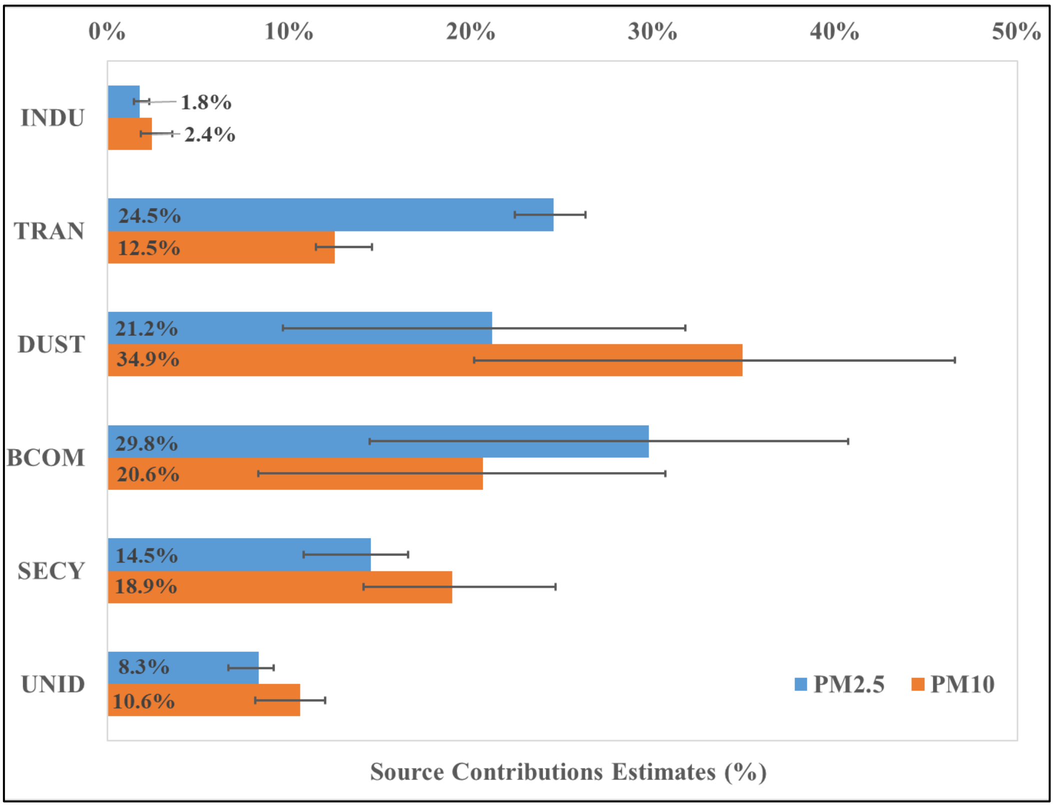


Figure 48 City-level source contribution estimates (SCE) for Cuttack region using CMB receptor model during winter season

The summer-time $PM_{2.5}$ mass at Cuttack region (Fig. 49) is found to be dominated by dust with highest contribution of 30.1%. The other summer-time sources of $PM_{2.5}$ at Cuttack region are identified as transport (25.9%), solid waste and biomass combustion (19.3%), secondary aerosols (17.3%), and industry (1.2%). Similarly, the summer-time PM_{10} mass at Cuttack region is also found to be dominated by dust (43.5%), followed by secondary aerosols (20.4%), transport (12.1%), solid waste and biomass combustion (11.8%), and industry (1.5%). Additionally, about 6.2% and 10.7% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

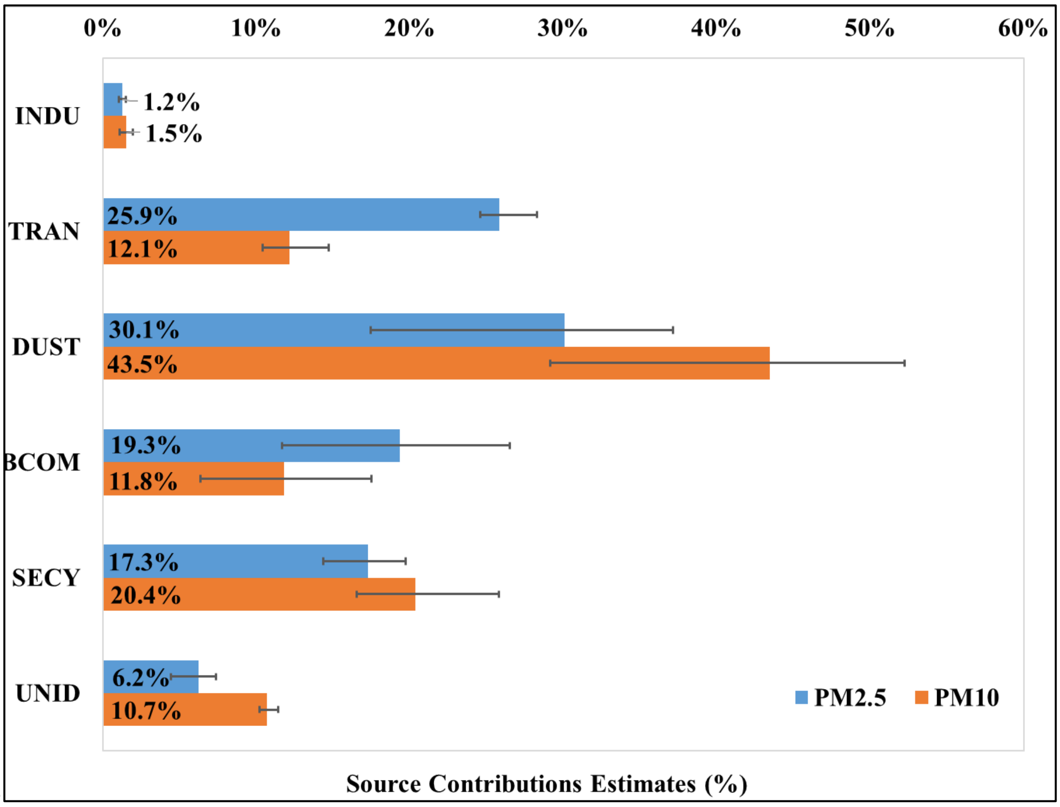


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Figure 49 City-level source contribution estimates (SCE) for Cuttack region using CMB receptor model during summer season (April 10 – 27, 2023)

(Note: The horizontal blue and orange coloured bars in Fig 48 and 49 represent the mean SCE percentage in $PM_{2.5}$ and PM_{10}, respectively while the error bars represent the range of estimated SCE among five sampling sites.)

Chapter 3: Emission Inventory

3.1. Introduction

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

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

3.2. Objectives and Scope of Work

The main objective of this study is development of baseline emission inventory (Year: 2022) of air pollutant loads originating from twelve sectors in Cuttack region. The scope of this study includes:

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

3.3. Approach to the EI development

Figure 50 shows the methodology adopted in development of emission inventory for Cuttack 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.

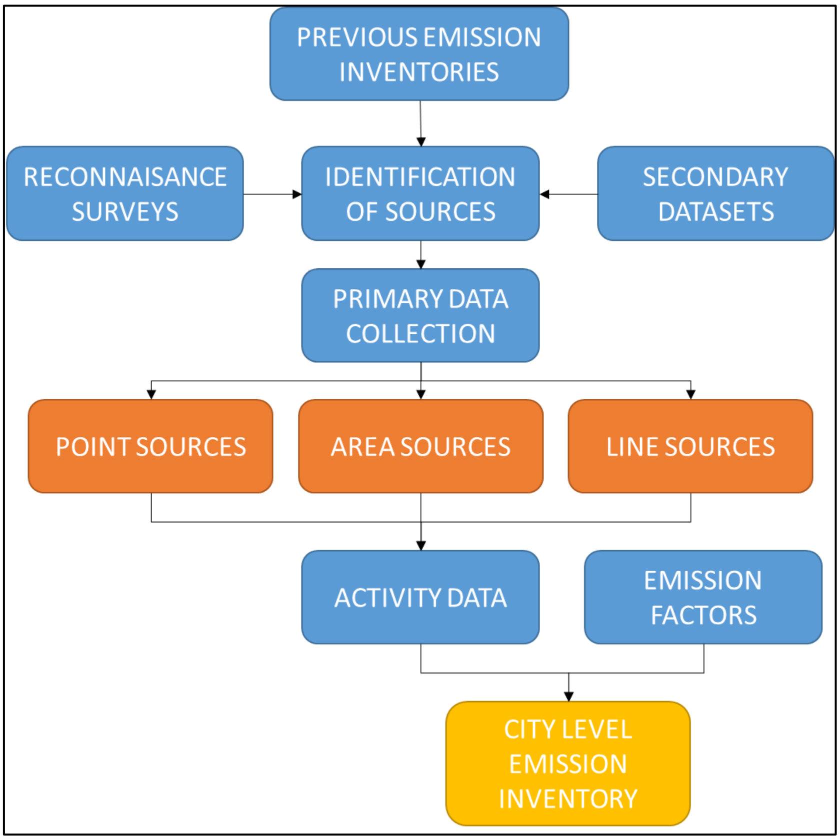

Figure 50: Approach adopted for emission inventory development at regional level

The study area was divided into high resolution grid cells at 2 X 2 km^2 grids using GIS tools. A total 108 grid cells were formed. An emission inventory has been prepared for the study area and thereafter allocated to high resolution grid cells. Fig. 51 presents the gridded study domain (2 x 2 km^2). The methodologies followed for estimation of emissions from different sectors are described in subsequent sections.

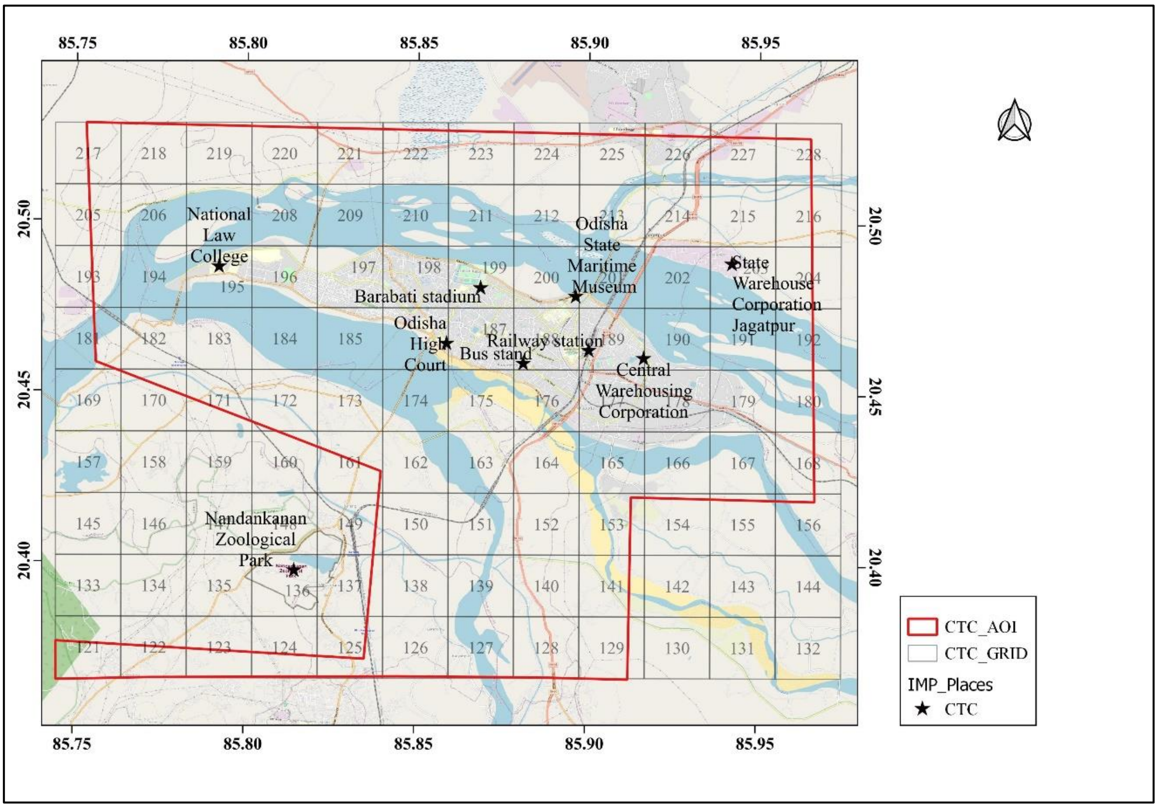

Figure 51: Map showing study area overlaid with emission inventory grids with horizontal spacing of 2 x 2 km^2

3.4. Methodology

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

The widely used emission estimation method based on activity rate and emission factor is used. This method estimates the rate at which a pollutant is released to the atmosphere as a result of certain processes (Shrestha et al., 2013). Table 3 shows the different air pollution sources inventorised for study domain. Emission calculation can be expressed by using the following equation (6):

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

where,

E = Emission load

A = Activity rate

EF = Emission factor

CE = Overall control efficiency (%).

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

Source Type	Sources Included
Point Sources	Industries and thermal powerplants, Crematoria, FCBTK Brick kilns
Area Sources	Fugitive dust, Residential, Open waste burning, Hotels, restaurants and bakeries, Construction, Diesel generators, wind-blown riverbed erosion dust
Line Sources	Transport, Re-suspended road dust

Details of primary and secondary data collection surveys are provided in sectoral manner in subsequent sections. Air pollution sources were categorized into three main types i.e. point, area and line sources and details of sectors included in each type are provided in Table 3. Area sources are sources of pollution that emit a substance from a specific area. These include small pollution sources such as residential, hotels, restaurants and bakeries, construction sites, etc. Although emissions from individual area sources are relatively small per unit, collectively their emissions can be of concern, particularly where large numbers of sources are located in heavily populated areas. Line sources mainly include both on-road vehicles such as two wheelers, cars, trucks and buses (Shrestha et al., 2013).

3.4.1. Primary and secondary data collection

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

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

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

Table 5 Summary of secondary data sources used in this study

Sr. No.	Sector	Secondary Data Sources
1.	Transport	• VAHAN database • MoRTH Annual Reports • Road network from Openstreetmap and Google Inc.
2.	Construction	• Google Earth Inc.
3.	Hotels, Restaurants. Bakeries and Open eateries	• Numbers, types, and locations of facilities through online food delivery portals
4.	Open waste burning	• Solid waste generation, processing and disposal statistics
5.	DG Sets	• Numbers, types, and locations of facilities through open street map, wherever applicable.
6.	Brick Kilns	• Google Earth Inc.
7.	Industry	• OSPCB database
8.	Residential	• National Family Health Survey (NFHS) 2019-2021

3.4.2. Industries and thermal powerplants

There are no major air polluting industries in Cuttack region however there are two coal-based thermal powerplants located at the north-east and north-west periphery of the study area and few industrial units located in Jagatpur area. The details of these thermal powerplants are provided in Table 6.

As per the data collected from Cuttack regional office of State Pollution Control Board (OSPCB), there are a few industrial units which include steel rolling mills, poultries, milk and food processing 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. The emissions from Thermal Powerplants are quantified using coal consumption.

Table 6 Details of Thermal Powerplants in Cuttack region

Sr. No.	Unit Name	Technology	Fuel	Generation capacity (MW)
1	Choudwar Power Station, Cuttack	Sub-critical	Coal	54 MW × 2 30 MW × 1 60 MW × 2
2	Bhubaneswar Power Plant Ltd., Cuttack	Sub-critical	Coal	67.5 MW × 2

3.4.3. Fugitive dust

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

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

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

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

3.4.4. Transport

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

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

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

3.4.4.1. Road network digitization

Road network in the study area was digitized using Google Earth application (Fig. 52). Roads in Cuttack region are classified into five categories viz. i) highways, ii) major roads, iii) intermediate roads, iv) minor roads and v) residential roads. After complete digitization, road lengths were calculated for each link in the network using GIS software. Category-wise gridded road lengths were also computed using GIS software.

3.4.4.2. Reconnaissance survey

A Reconnaissance survey was conducted in the Cuttack 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 6 survey locations were identified in the Cuttack region to perform the classified vehicle count surveys and 3areas/localities were selected for Parking lot surveys.

3.4.4.3. Traffic counts and vehicle fleet characteristics

Estimation of reasonably accurate vehicular emissions requires a good characterisation of the in-service vehicle fleet. Important characteristics of vehicle fleet include information on vehicle type, size, fuel type, age and emission control technologies. The historic vehicle registration data provides preliminary information vehicle type, size and fuel-type. The vehicle fleet in Cuttack 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. 53 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 December, 2022 to February, 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 3 areas/localities around the selected sampling sites (S5-S7) in Cuttack region during December, 2022 to February, 2023. Table 8 and 9 shows the details of locations of vehicle count surveys and parking lot surveys respectively.

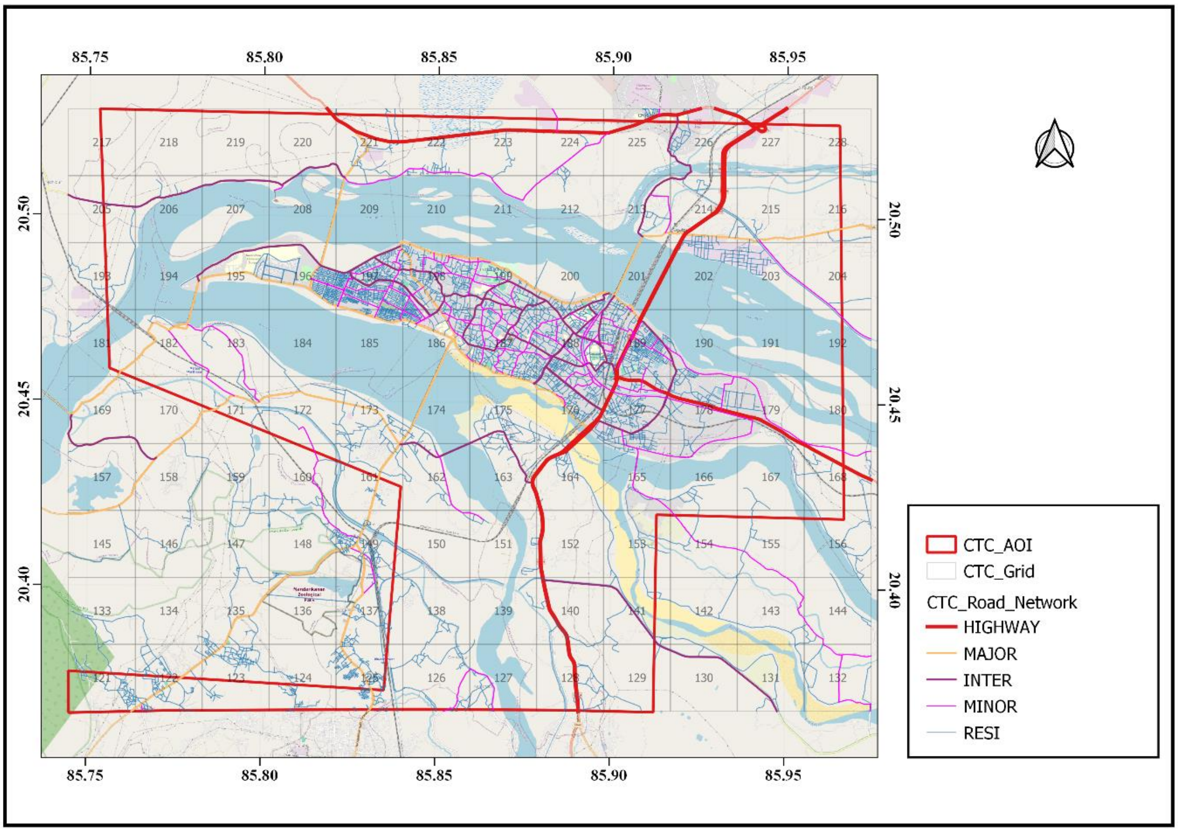

Figure 52: Map showing road network in Cuttack region and surrounding areas digitized using OpenStreetMap and Google Earth Applications

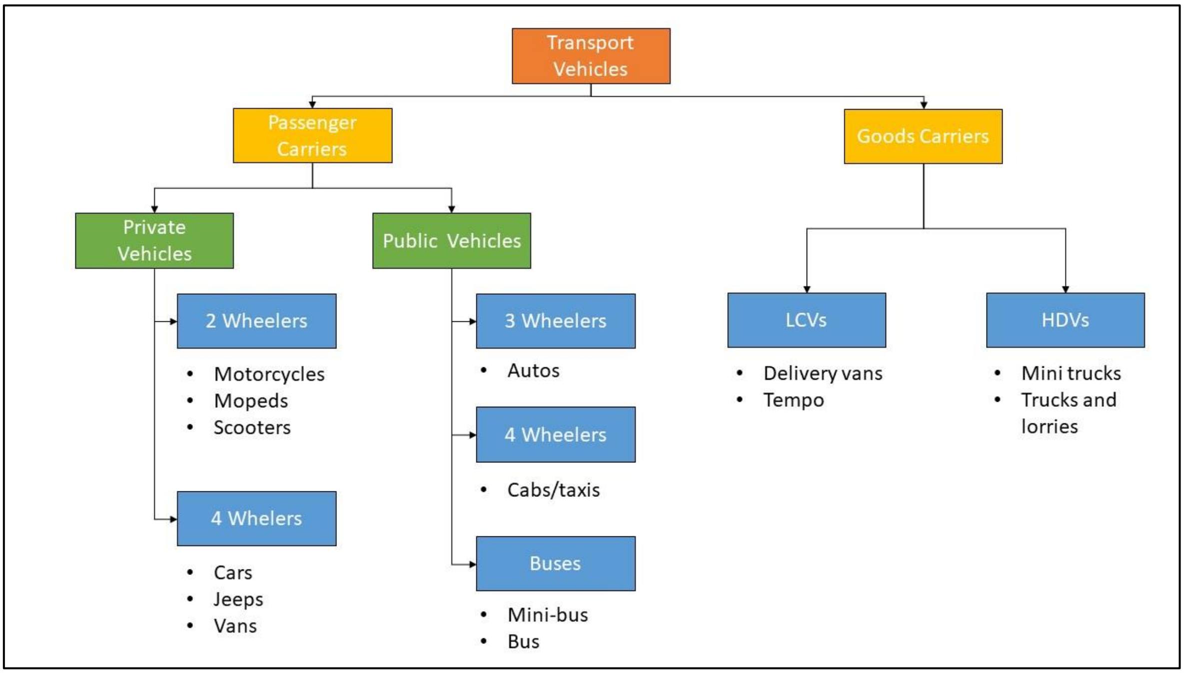

Figure 53: Vehicle categories used in this study

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

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

Table 8: Locations of vehicle count surveys in Cuttack region

Code	Road Name	Road Type	Latitude	Longitude
VC1	Chennai-Kolkata Highway	Highway	20.52297	85.93878
VC2	Katikata - Jaipur Road	Major	20.49473	85.93495
VC3	Cuttack - Paradeep Road	Major	20.45067	85.92248
VC4	Ring Road	Major	20.4828	85.84383
VC5	Bidanasi Main Road	Intermediate	20.48567	85.84046
VC6	Nuasahi Road	Intermediate	20.48612	85.83173

Table 9 Locations of Parking Lot Surveys in Cuttack region

Location No.	Area Name
P1	Nayabazar Area
P2	Jagatpur Area
P3	Bidanasi Area

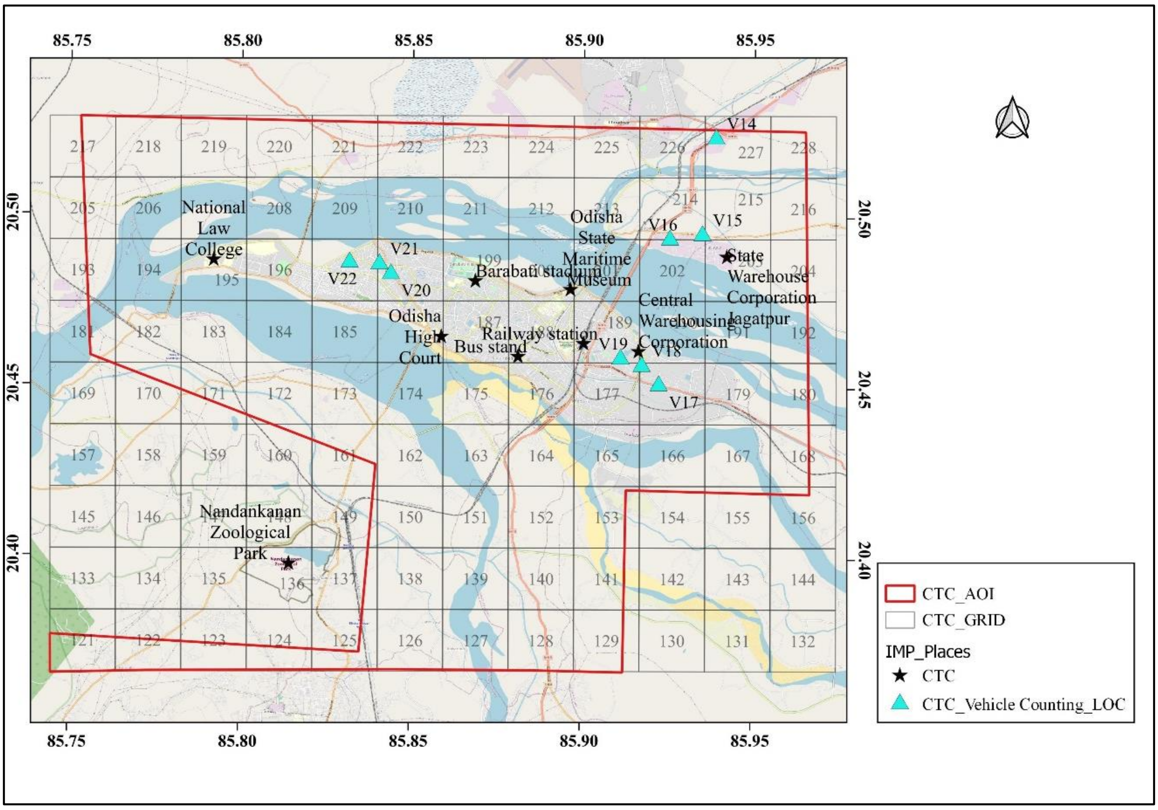

Figure 54: Map showing selected locations in Cuttack region for vehicle counting surveys.

Fig. 55 presents the classified vehicle count observed at different types of roads in Cuttack region. Major roads such as VC15 (Katikata – Jaipur Road), VC16 (Cutack Paradeep Road) and VC14 (Chennai-Kolkata highway) exhibited highest vehicular population in a day, followed by intermediate and minor roads. Further, it is interesting to note that the observed vehicle population remains more or less similar on both weekdays and weekend except VC14, and VC15, which exhibited a significant contrast in vehicular population. This can be attributed to regular traffic during office hours on weekdays.

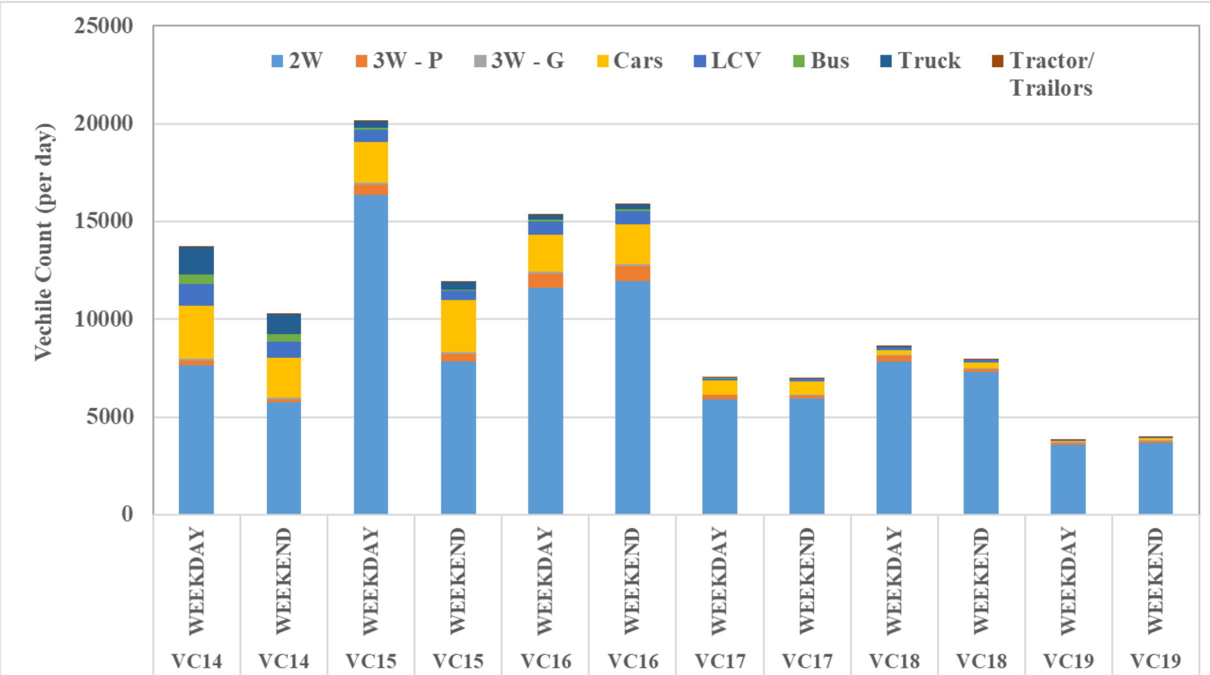

Figure 55: Classified vehicle counts observed at selected locations in Cuttack region during the primary surveys.

Fig. 56 depicts the observed percentage distribution of vehicles according to Bharat standards in Cuttack region. A total of 610 vehicles were surveyed in the region during the primary surveys. The BS-III category vehicles are observed to be maximum (43.1%) followed by BS-IV (31%), BS-VI (18%), BS-II (6.2%), BS-I (1.1%) and pre-BS (0.5%).

Fig. 57 shows the estimated daily vehicle kilometres travelled by each category of vehicles in the Cuttack region. The daily VKT is estimated to be 181.9 lakh km and is dominated by two wheelers (78.4%) followed by passenger cars (8.2%), autos and LCV (4% each), HDVs (2.9%), and buses (1.0%).

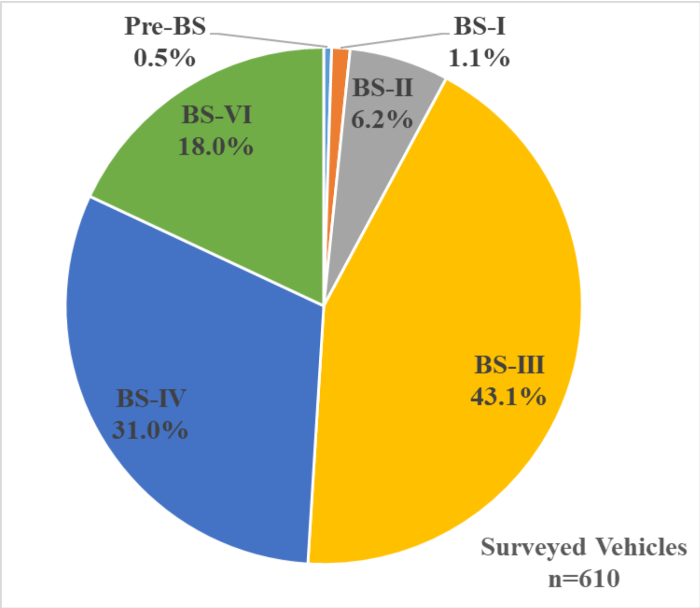

Figure 56: Distribution of vehicles as per different Baharat standards (BS) in Cuttack region obtained through parking lot surveys.

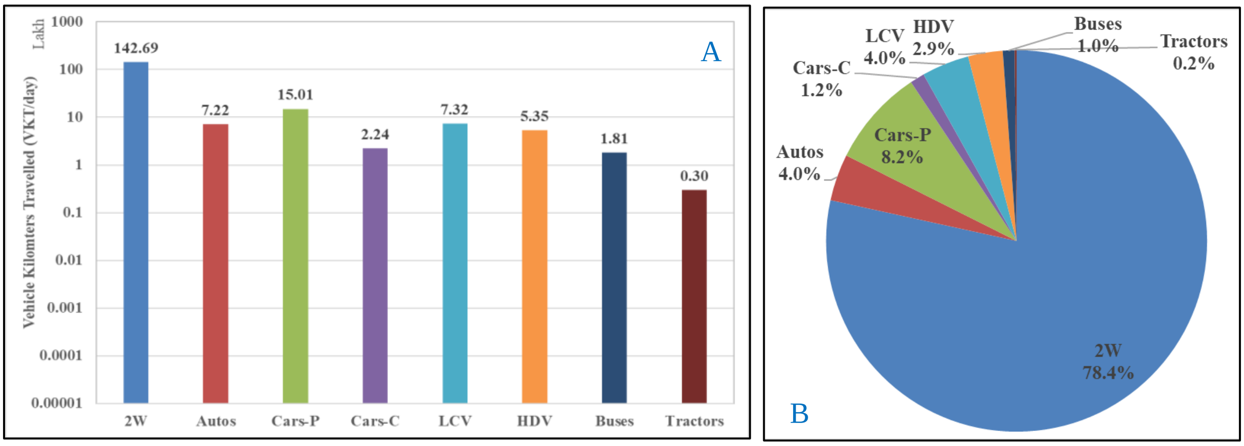

Figure 57: Daily vehicle kilometres travelled (A) and percent distribution (B) by different category of vehicles in Cuttack region.

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

3.4.5. Road Dust 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:

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

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

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

Where,

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

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

sL = road surface silt loading in g/m2

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

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

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

The road dust samples were collected from selected locations to determine the silt loading rates for different category of roads in Cuttack 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 PM_{10} are listed in Table 10. These emission factors are then multiplied by gridded VKT values obtained earlier for calculation of vehicular emissions to obtain total road dust emissions.

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

Fraction	AREA TYPE	HIGHWAY	MAJOR	INTERMEDIATE	MINOR	RESI
$PM_{2.5}$	Urban	0.89	0.16	0.07	0.14	0.29
$PM_{2.5}$	Industrial	0.89	0.18	0.08	0.16	0.33
$PM_{2.5}$	Rural	0.89	0.18	0.08	0.16	0.26
PM_{10}	Urban	3.27	0.66	0.30	0.60	1.18
PM_{10}	Industrial	3.27	0.73	0.32	0.68	1.35
PM_{10}	Rural	3.27	0.73	0.32	0.68	1.08

3.4.6. Residential

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

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

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

The latest census data for Cuttack 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. 58) 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 Cuttack region as a part of this study. The emission factors for residential sector used in this study are summarized in Table 11.

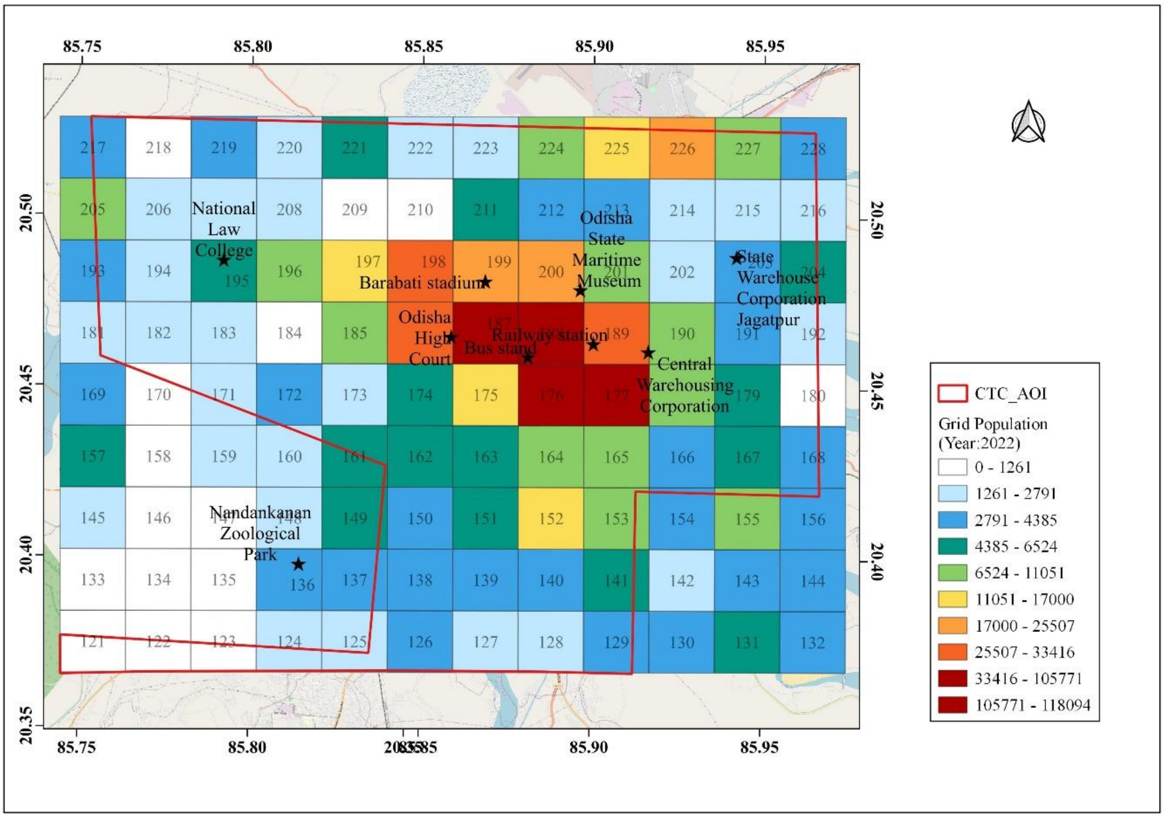

Figure 58 Map showing the estimated gridded population of the Cuttack region in year 2022

Table 11: Emission factors (g/kg) of different pollutants from different fuel types used in the residential sector

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

#EFs adopted from Datta and Sharma (2014)

3.4.7. Open Waste Burning

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

$$\mathbf{E_p = W_b \times EF_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(11)}$$

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

In this study, the MSW burnt for the sake of disposal at the household level or on the street (W_b) is quantified using methodology adopted by Sharma et al. (2019). The MSW generated in the study domain is calculated using per capita MSW generation rate of ~288 gm (CDD & NIUA, 2017). MSW burnt refers to the non-inert fraction of the uncollected MSW left behind after collection (MSW_C), recycling (MSW_R), and secondary use as fodder, fertilizer, and fuel (MSW_F). f_i in eq. 12 stands for the inert fraction of the waste (ash and dust), which is estimated to be about 11.73% for similar regions. Additionally, it is assumed that out of the uncollected waste, 60% of the total waste available to be burned that is actually burned. (IPCC, 2006; Wiedinmyer, 2014).

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

The waste burnt daily is dependent upon the population, per capita waste generation, waste collection efficiency and fraction of uncollected waste burnt. The details on waste generation and waste collection are obtained from statistics available in public domain. The emission factors of various pollutants considered in present study are illustrated in Table 12.

Table 12: Emission factors (g/kg) for open waste burning

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

3.4.8. Hotels, Restaurants and Bakeries

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

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

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

Primary surveys were conducted in different localities of Cuttack 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 13). It is also assumed that no control devices are installed in the restaurants to control the emissions.

Table 13 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

3.4.9. 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. 59 shows the map of construction locations identified using the satellite imagery. The emissions are obtained by using equation 13.

$$\mathbf{E = A_s \times EF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. (14)}$$

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, PM_{10} and $PM_{2.5}$ emissions from construction areas are approximately 25% and 6% of the total PM mass.

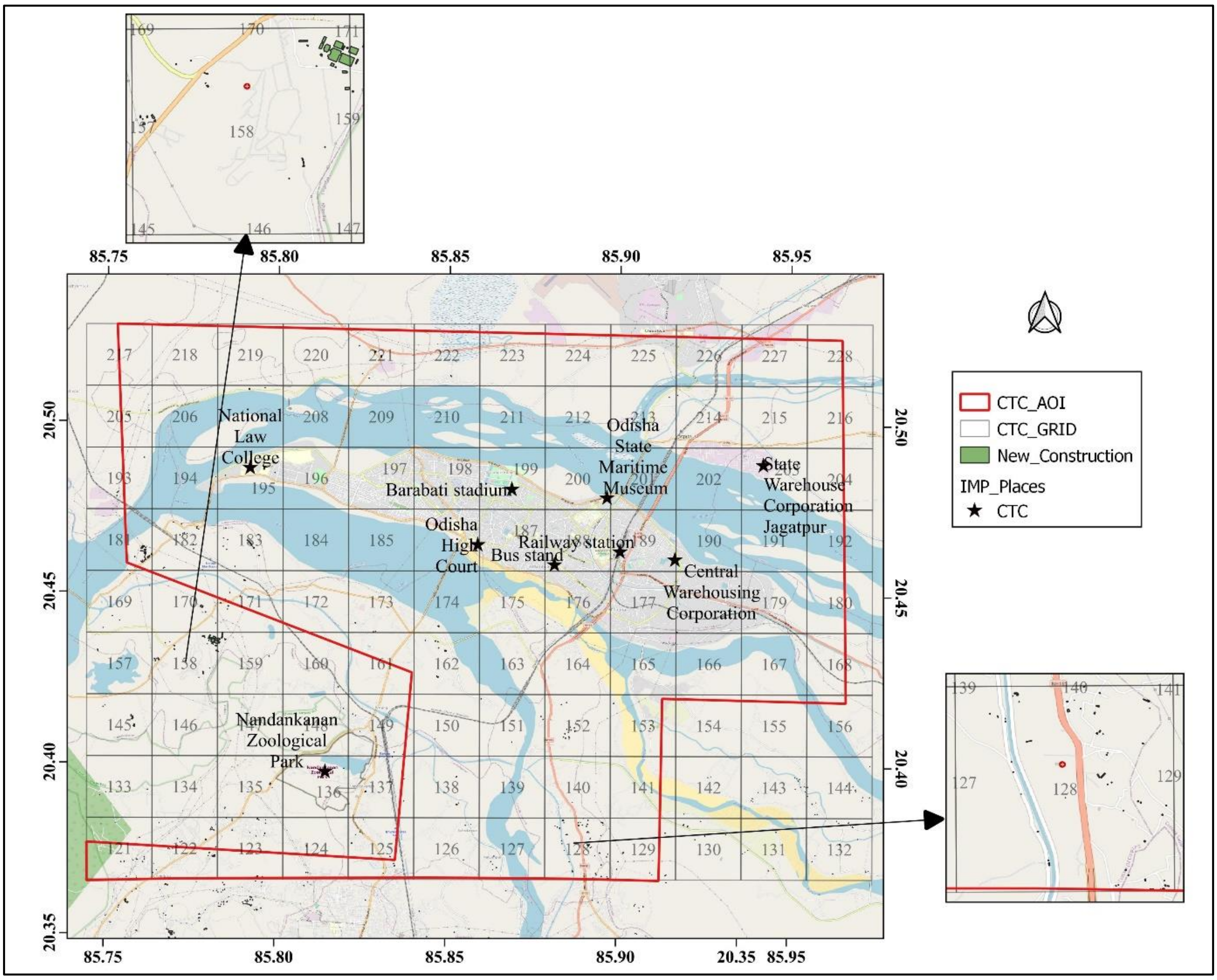

Figure 59 Map showing construction areas identified using the satellite imagery in Cuttack region. The inset view shows zoomed in view of new construction activities in grid no. 128 and 158 of the study domains.

3.4.10. 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 29 number of brick kilns. Most of the brick kilns are of fixed chimney bull's trench kilns (FCBTK). Fig. 60 shows the locations of brick kilns in the study area. The data on production capacity, operation pattern, fuel usage was generated based on personal interactions with the kiln operators.

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

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

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

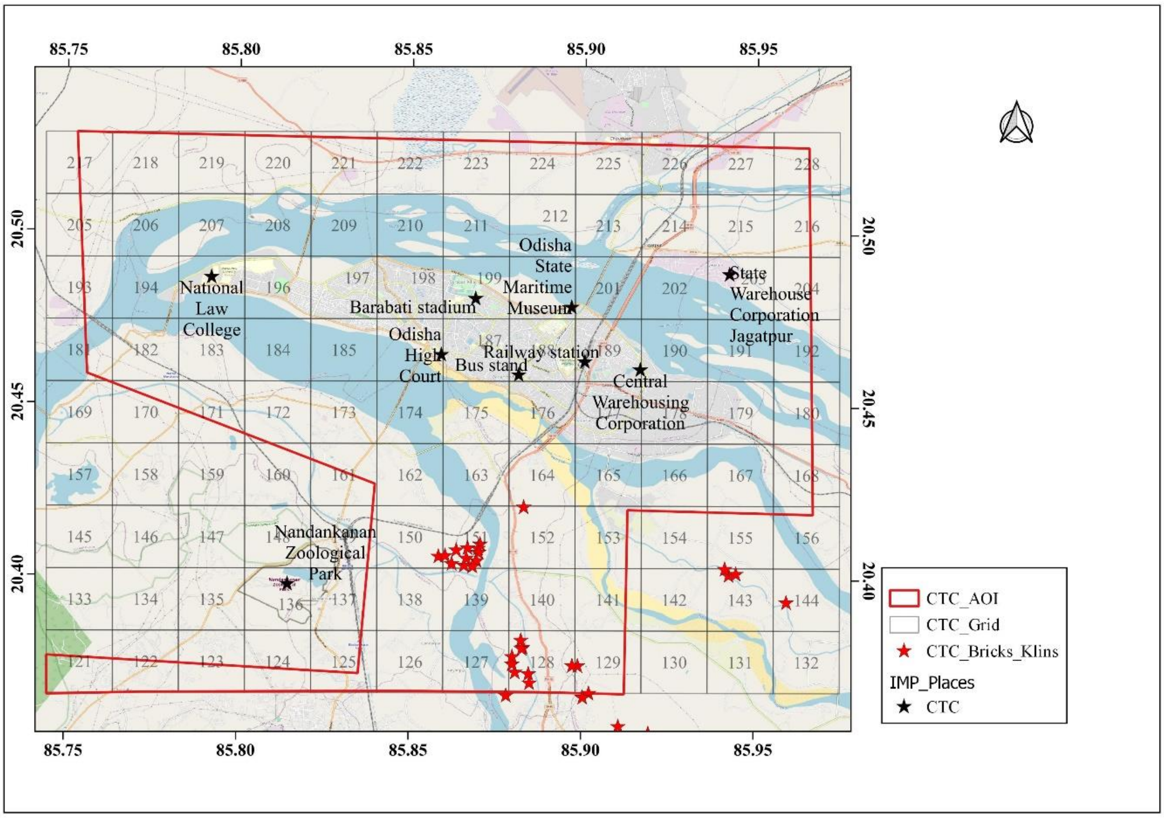

Figure 60 Map showing locations of brick kilns in the Cuttack region study domain identified using satellite imagery

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

Technology	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	NMVOC
FCBTK	0.875	0.18	0.59	0.00005	2.94	0.10
Clamp	1.3	1.0	0.30	0.00015	10.0	0.15
Zig-zag	0.26	0.13	0.32	0.00004	1.47	0.10

3.4.11. 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 3 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 15.

Table 15 Emission factors (kg/kWh) for different pollutants used for diesel generators

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

3.4.12. Wind-blown riverbed erosion dust

Cuttack region stands at the crossroads of two prominent river systems - the Mahanadi and the Kathajodi. The Mahanadi meanders through Cuttack region, nurturing its fertile plains and sustaining the region's agricultural backbone. The Mahanadi branches into Kathajodi river at Cuttack region, creating a confluence that has shaped the city's history, economy, and culture. During the summer season, the riverbeds become dry, leading to the mobilization of sand particles by wind. These airborne particles contribute to particulate matter emissions, with their impact on air pollution dependent on the quantity and dispersal potential of the sand injected into the atmosphere. While large dust particles typically settle close to the source, significant quantities of fine particles are also emitted and can disperse over greater distances.

In the present study, the riverbed erosion dust emissions are calculated using the concept of friction velocity (UESPA, 2006a). When the actual friction velocity (u_*) at a site exceeds the threshold friction velocity (u_t), the erosion is expected to occur. In this study, the meteorology data i.e. hourly average wind speed data (10 m) is used to calculate the frictional velocity. For riverbed sand particles, threshold friction velocity (u_t) is assumed to be 0.2 m/s. Emission flux of erosion dust is estimated as a function of surface frictional velocity and soil texture. The relationships developed by Alfaro and Gomes (2001) for the soil with sandy texture is applied to estimate dust emission fluxes. The PM_{10} emission factor (g/cm2/s) for wind-generated particulate emissions can then be calculated using equation xx. The PM2.5 emissions are calculated using a ratio of 1/4.

$$EF_{PM10} = 1.24 \times 10^{-7} \times u_*^{3.44} \ldots\ldots\ldots\ldots\ldots Eq.(16)$$

The potential dry riverbed area marked in GIS (Refer Fig. 61), is then multiplied by emission factors to get the PM emissions from riverbed erosion.

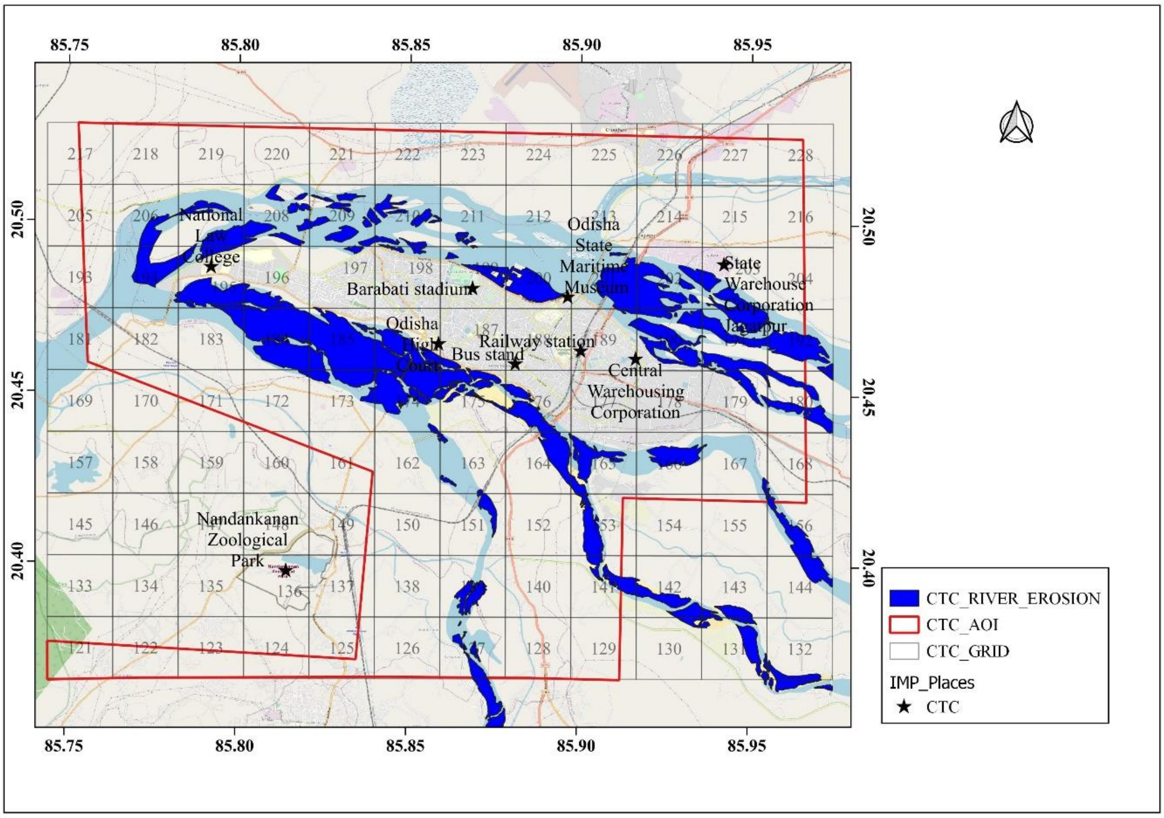

Figure 61: Map showing potential dry riverbed area (marked in blue colored polygons) in Cuttack region and surrounding areas digitized using Google Earth Applications

3.4.13. Crematoria

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

$$E_p = F_b \times EF_{f,p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

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 Khordha 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 14.

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, PM2.5, SO2, NOx, and CO.

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

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

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

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

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. Industries and thermal powerplants

As discussed earlier, there are no major air polluting industries in Cuttack region however there are two coal-based thermal powerplants located at the north-east and north-west periphery of the study area and few industrial units located in Jagatpur area. The thermal powerplants use use coal as the primary fuel. Figure 62, shows the stack emissions originating from the industries and thermal powerplant sectors in Cuttack region. Due to large usage of coal in thermal powerplants, NOx and SO_2 emerged as the major pollutants emitting 4596 and 994 tonnes per year in the base year i.e. 2022. This is followed by PM_{10} (866 tonnes per year), CO (317 tonnes per year) and $PM_{2.5}$ (305 tonnes per year).

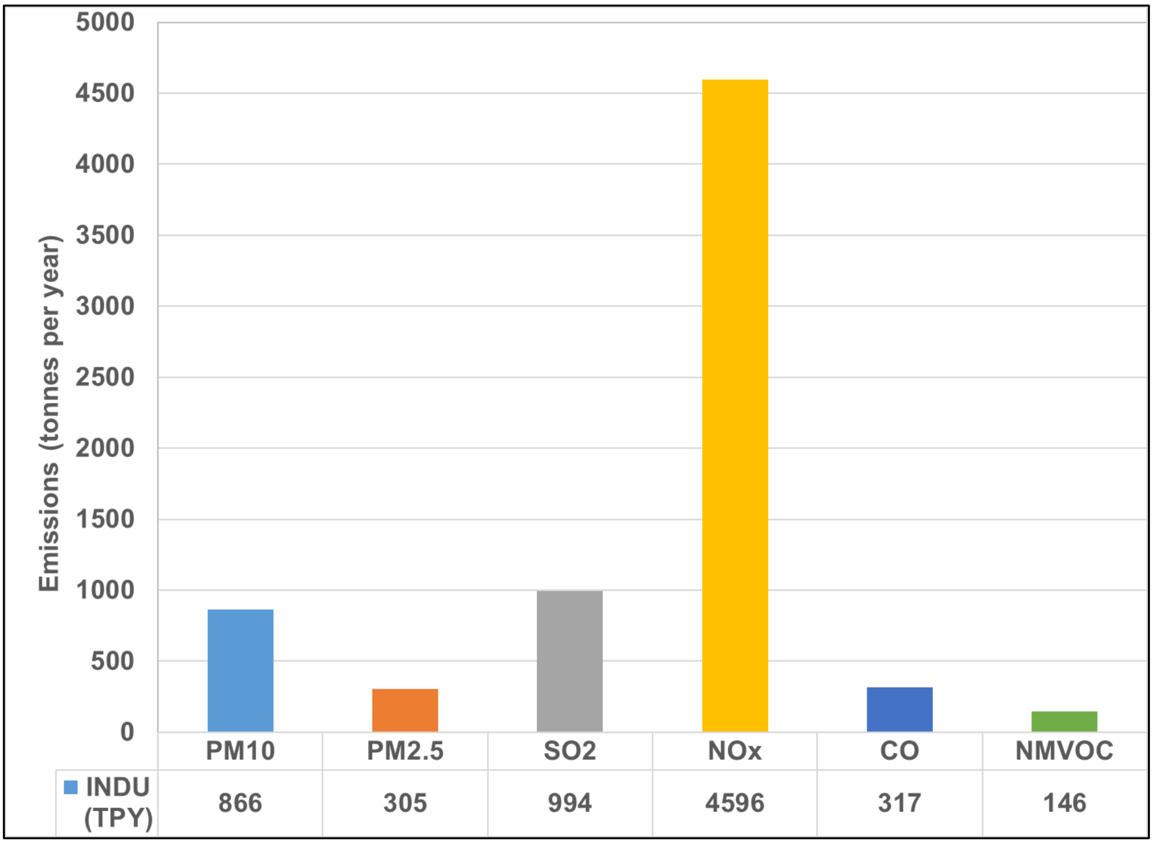

Figure 62: Emissions load (tonnes per year) of pollutants originating from industrial sector in Cuttack region

3.7.2. 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 63 shows the fugitive emissions load originating from two thermal powerplants in Cuttack region. PM_{10} was estimated to be 202 tonnes per year, followed by $PM_{2.5}$ (20 tonnes per year).

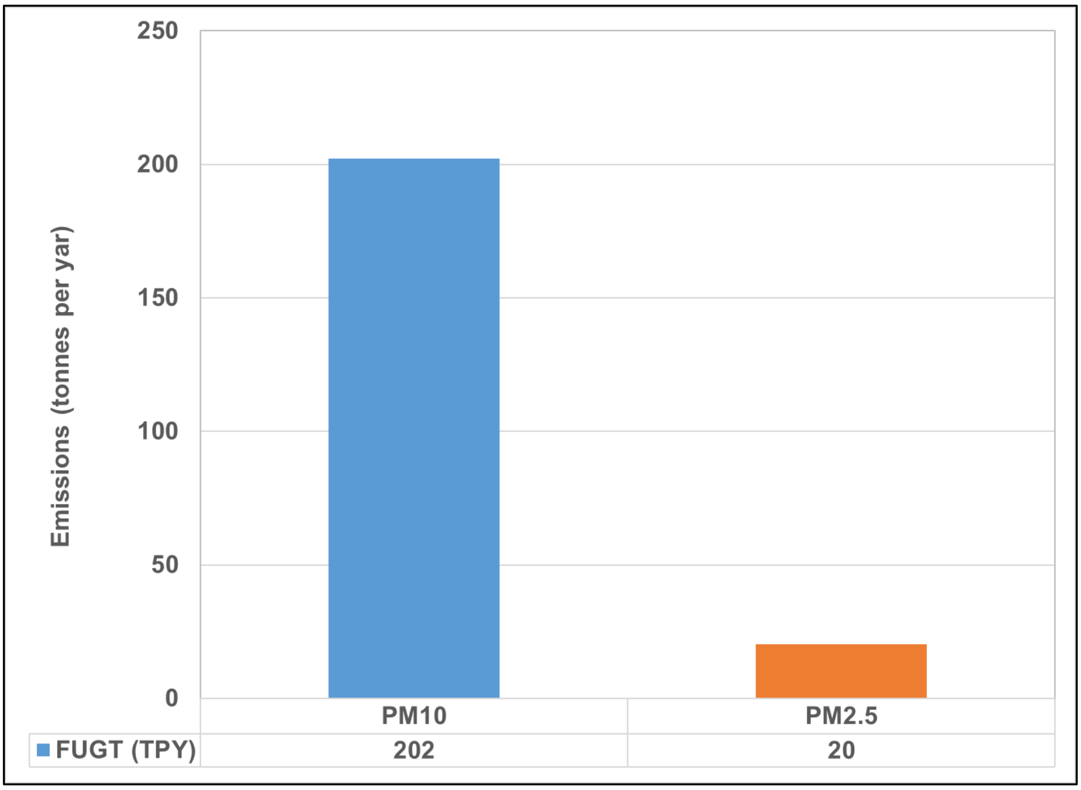

Figure 63: Emissions load (tonnes per year) of pollutants originating from fugitive operations in Cuttack region

3.7.3. Transport

Figure 64 shows the emissions of pollutants originating from transport sector in Cuttack region. It can be seen that CO is the maximum contributing pollutant from transport sector in Cuttack region with emissions of 17310 tonnes per year, followed by NMVOCs (11956 tonnes per year), and NO_X (7504 tonnes per year). Transport sector contribution to regional PM_{10} and $PM_{2.5}$ emissions was found to be 716 and 644 tonnes per year, respectively. It is important to note that, the vehicular exhaust PM emissions predominantly consist of fine particles i.e. particles having aerodynamic diameter less than or equal to 2.5 µm (Ketzel et al., 2007). Following the approach suggested by Sharma and Dikshit (2016), PM vehicular exhaust emission factors are used directly for quantifying PM_{10} while $PM_{2.5}$ fraction is assumed to be 90% of PM_{10} emissions.

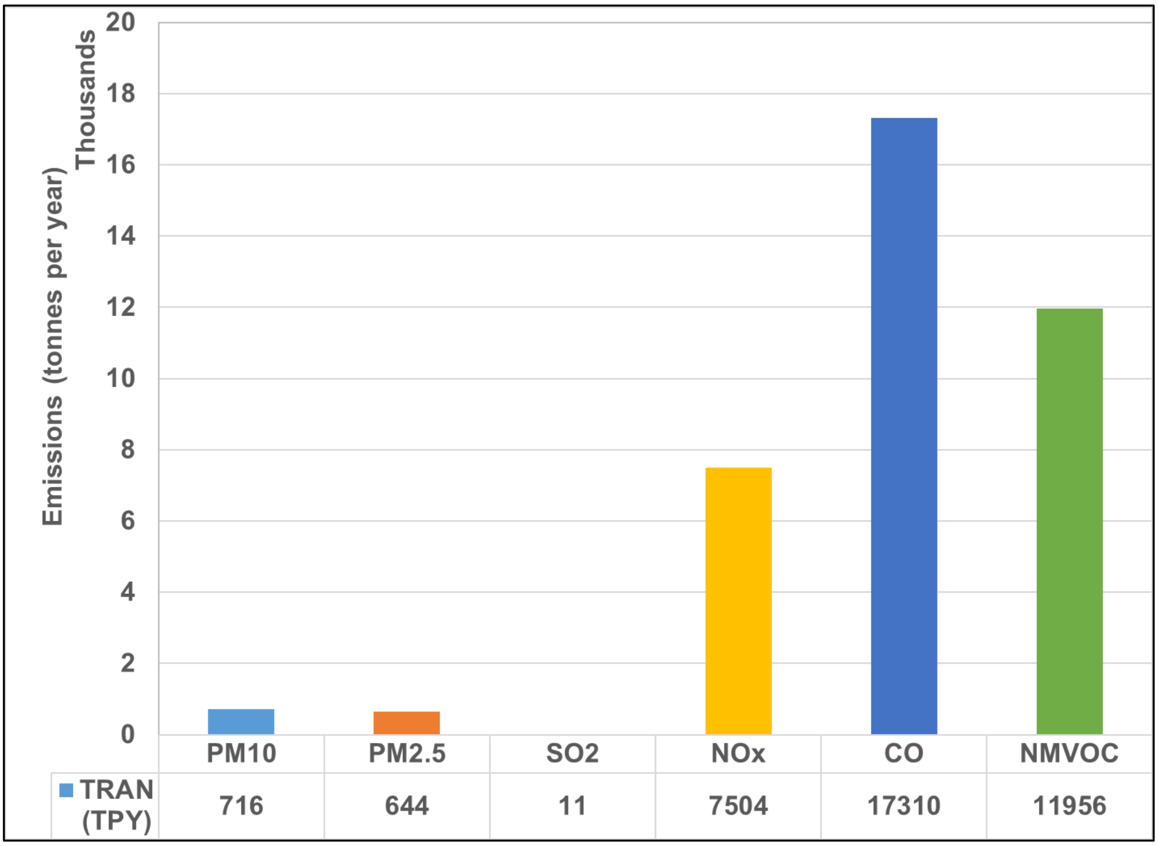

Figure 64: Emission loads (tonnes per year) of pollutants originating from the transport in Cuttack region

3.7.4. Road dust resuspension

The PM emissions generated due to road dust re-suspension in Cuttack region are depicted in Fig. 65. The road dust contributes only to particulate matter and not the gaseous pollutants. The road dust primarily contributes to the coarse fraction of PM i.e. PM_{10} and emissions are estimated to be 2282 tonnes per year. The fine fraction i.e. $PM_{2.5}$ emissions are estimated to be 607 tonnes per year in 2022. $PM_{2.5}$ emissions from road dust re-suspension are about four times lower than PM_{10} emissions.

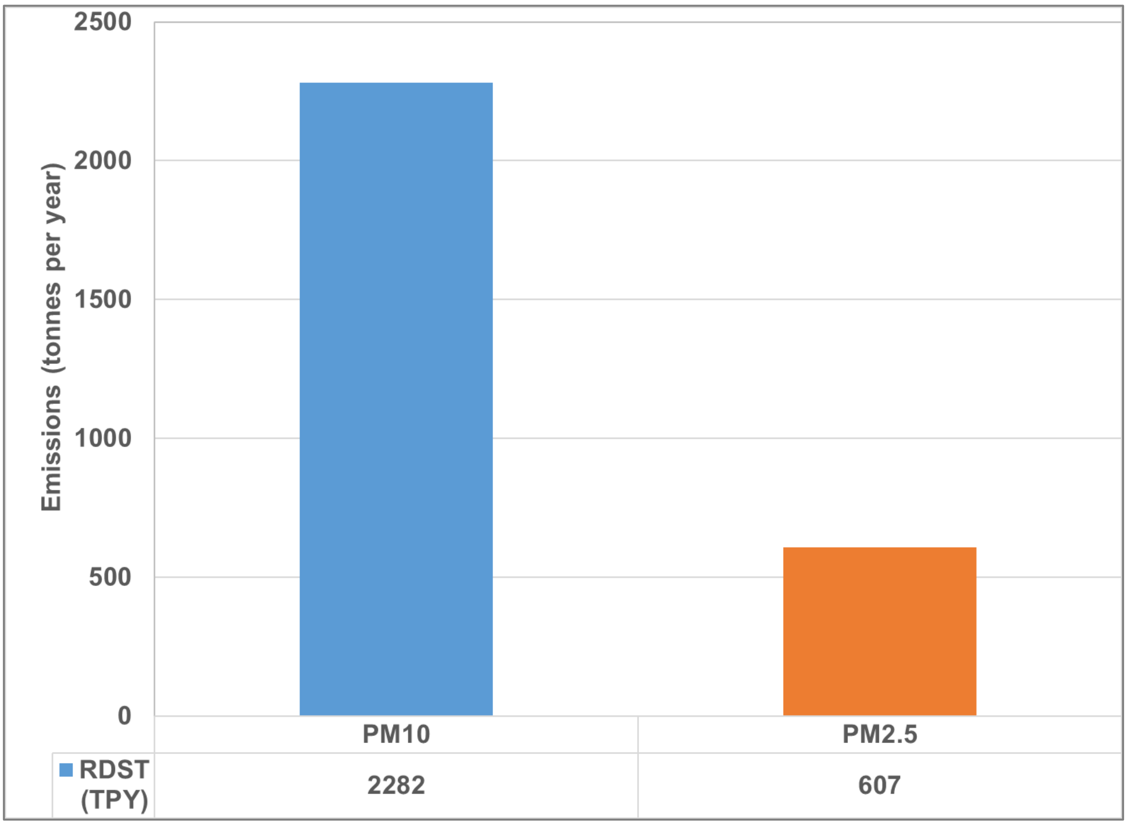

Figure 65: Emission load (tonnes per year) of pollutants originating from the road dust resuspension sector in Cuttack region

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

3.7.5. Residential

Figure 66 depicts the emission loads originating from residential sector in Cuttack 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 6942 tonnes per year, followed by NMVOCs (2084 tonnes per year), PM_{10} (745 tonnes per year), $PM_{2.5}$ (485 tonnes per year), NO_X (259 tonnes per year) and SO_2 (293 tonnes per year).

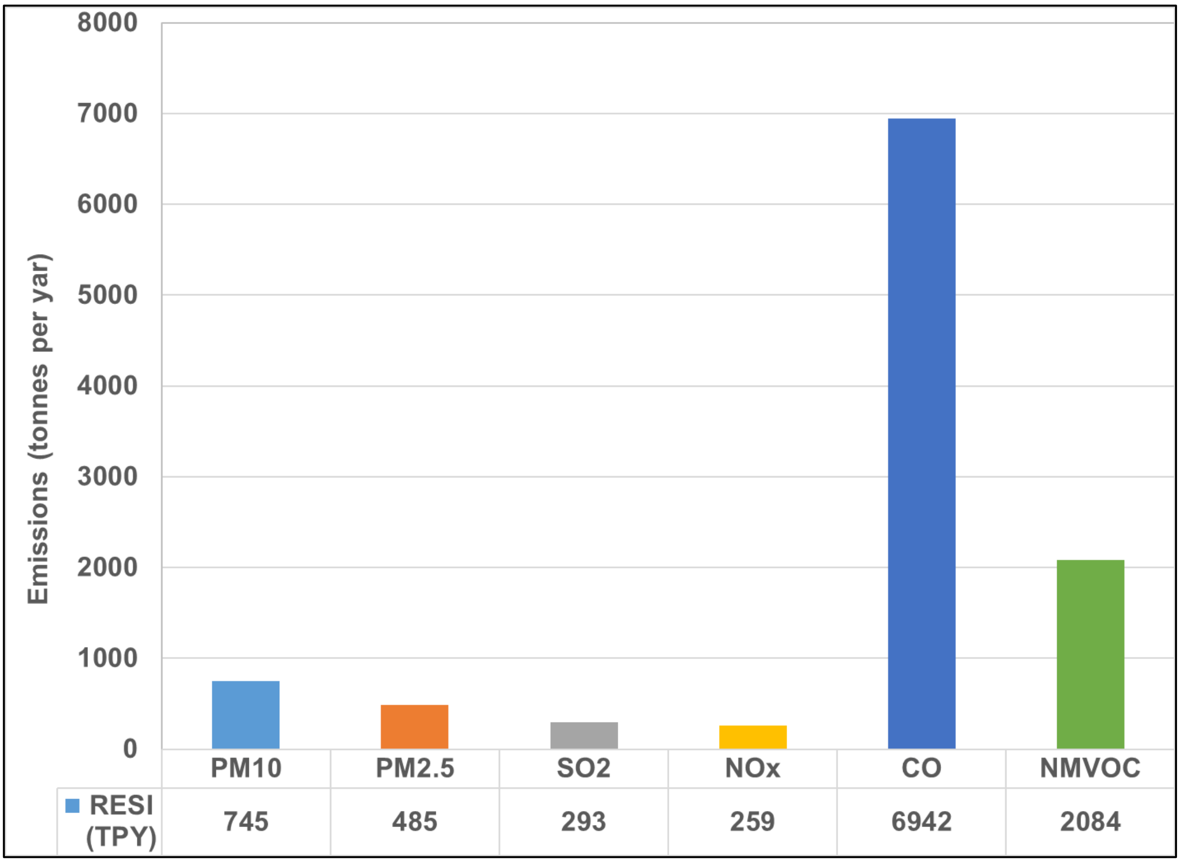

Figure 66: Emissions load (tonnes/year) of pollutants originating from residential sector in Cuttack region

3.7.6. Open waste burning

Figure 67 presents the emissions of air pollutants originating from open waste burning in Cuttack region. It is observed that, due to incomplete combustion of the waste a large amount of CO would be introduced into the atmosphere (2408 tonnes per year) followed by NMVOCs (521 tonnes per year), PM_{10} (503 tonnes per year), $PM_{2.5}$ (467 tonnes per year), NO_X (72 tonnes per year) and SO_2 (32 tonnes per year).

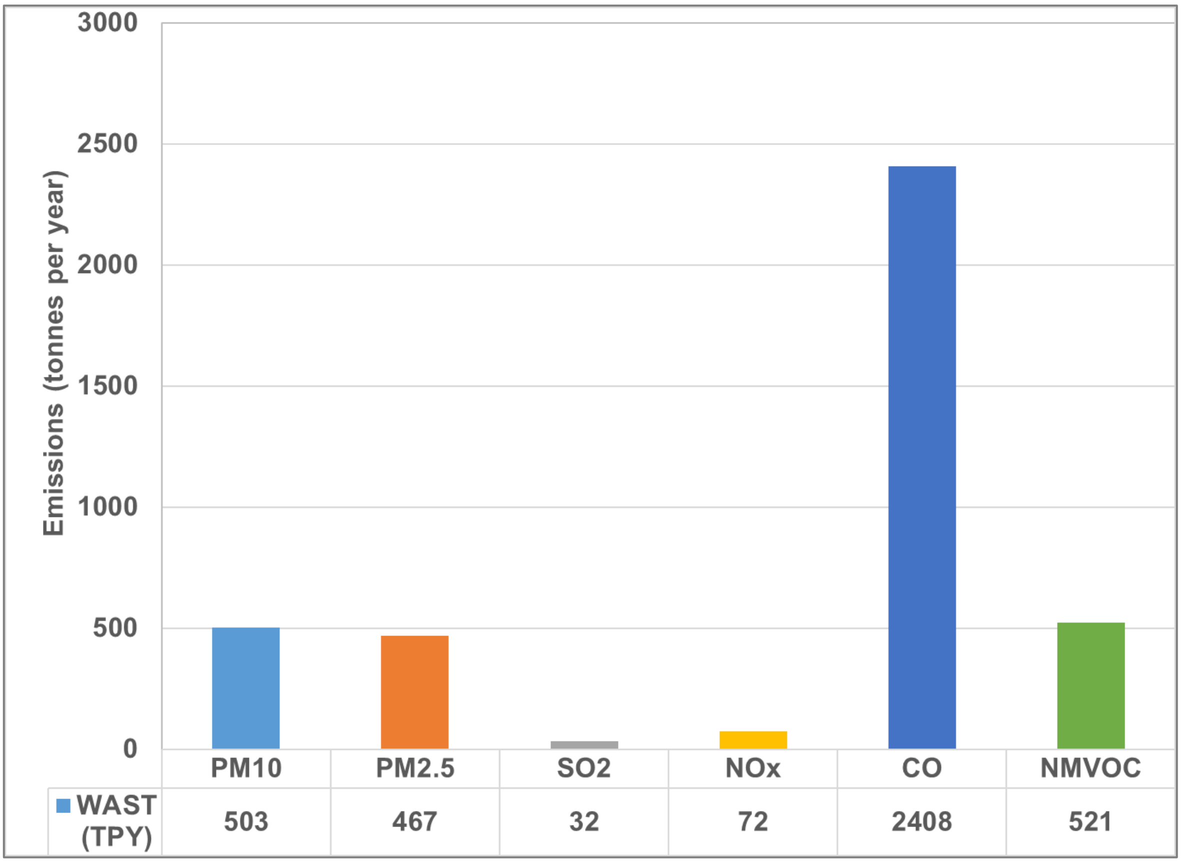

Figure 67 Emission load (tonnes per year) of pollutants originating from the open waste burning sector in Cuttack region

3.7.7. Hotels, restaurants and bakeries

Figure 68 presents the emissions load contributed by hotels, restaurants, bakeries and open eateries in Cuttack region. CO has been found to be the major contributor 1894 tonnes per year, followed by, PM_{10} (493 tonnes per year), $PM_{2.5}$ (317 tonnes per year), SO_2 (287 tonnes per year), NMVOC (231 tonnes per year), and NO_x (106 tonnes per year).

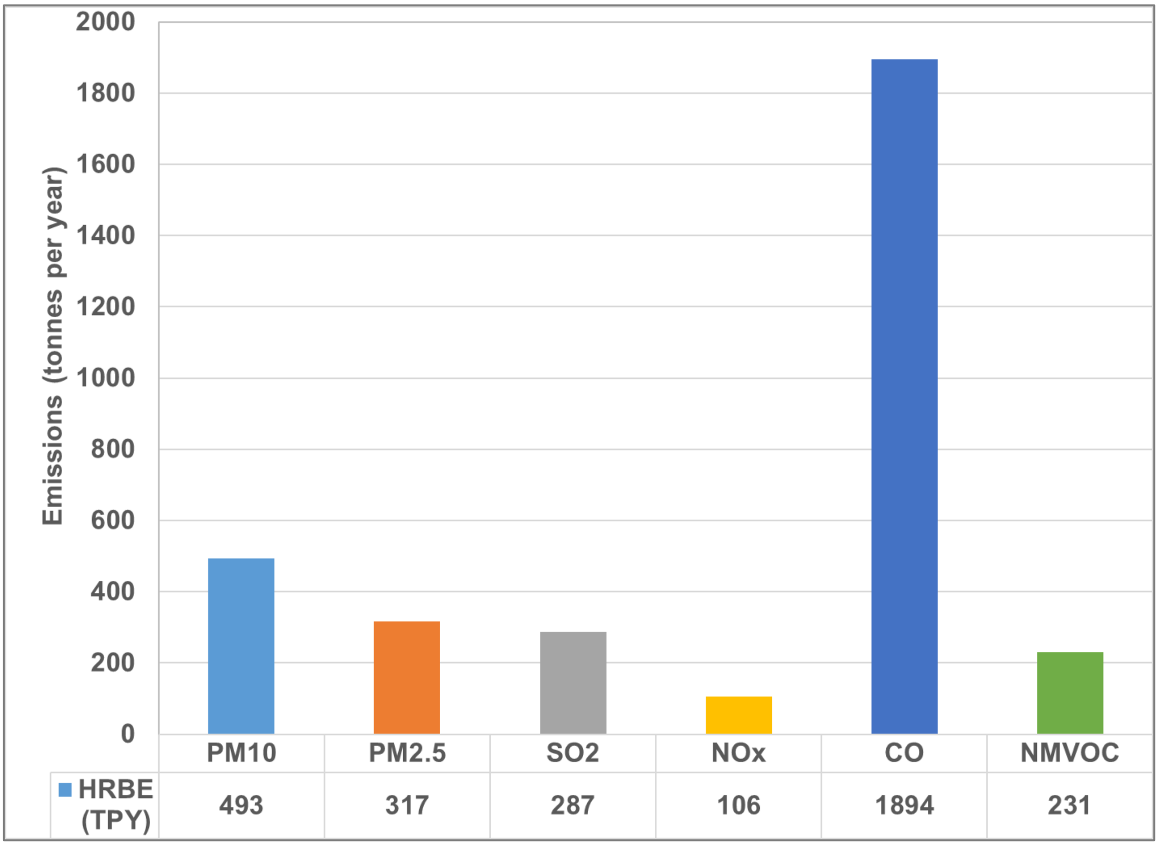

Figure 68: Emissions load (tonnes per year) of pollutants originating from hotels, restaurants and bakeries in Cuttack region

3.7.8. Construction

Figure 69 shows the PM_{10} and $PM_{2.5}$ emissions originating from construction activities in Cuttack region. Construction sector is estimated to contribute about 77 tonnes per year of PM_{10} and 19 tonnes per year of $PM_{2.5}$.

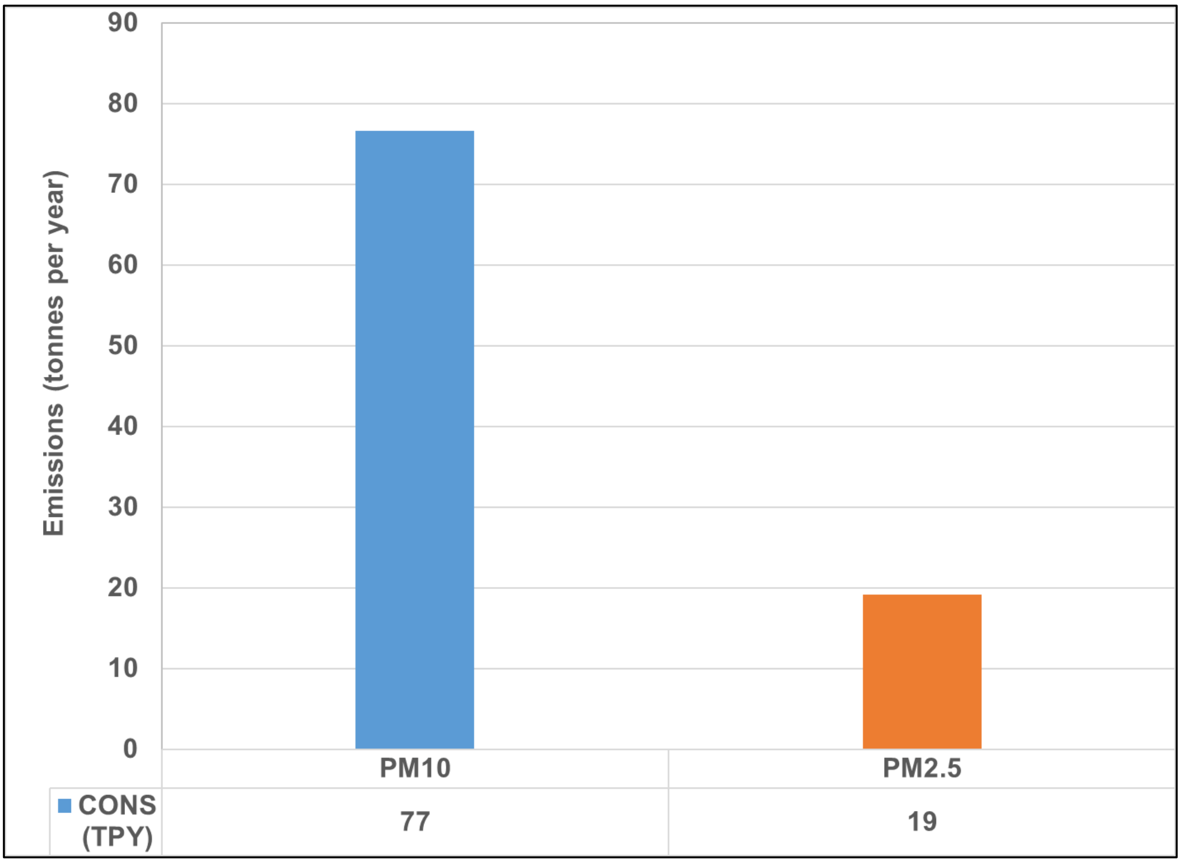

Figure 69: Emissions load (tons/year) of pollutants originating from construction activities in Cuttack region

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

3.7.9. Brick Kilns

Figure 70 shows the emissions of pollutants originating from brick kilns in Cuttack region. CO is the maximum contributor with emissions of 159 tonnes per year, followed by PM_{10} (32 tonnes per year), SO_2 (16 tonnes per year), $PM_{2.5}$ (13 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.

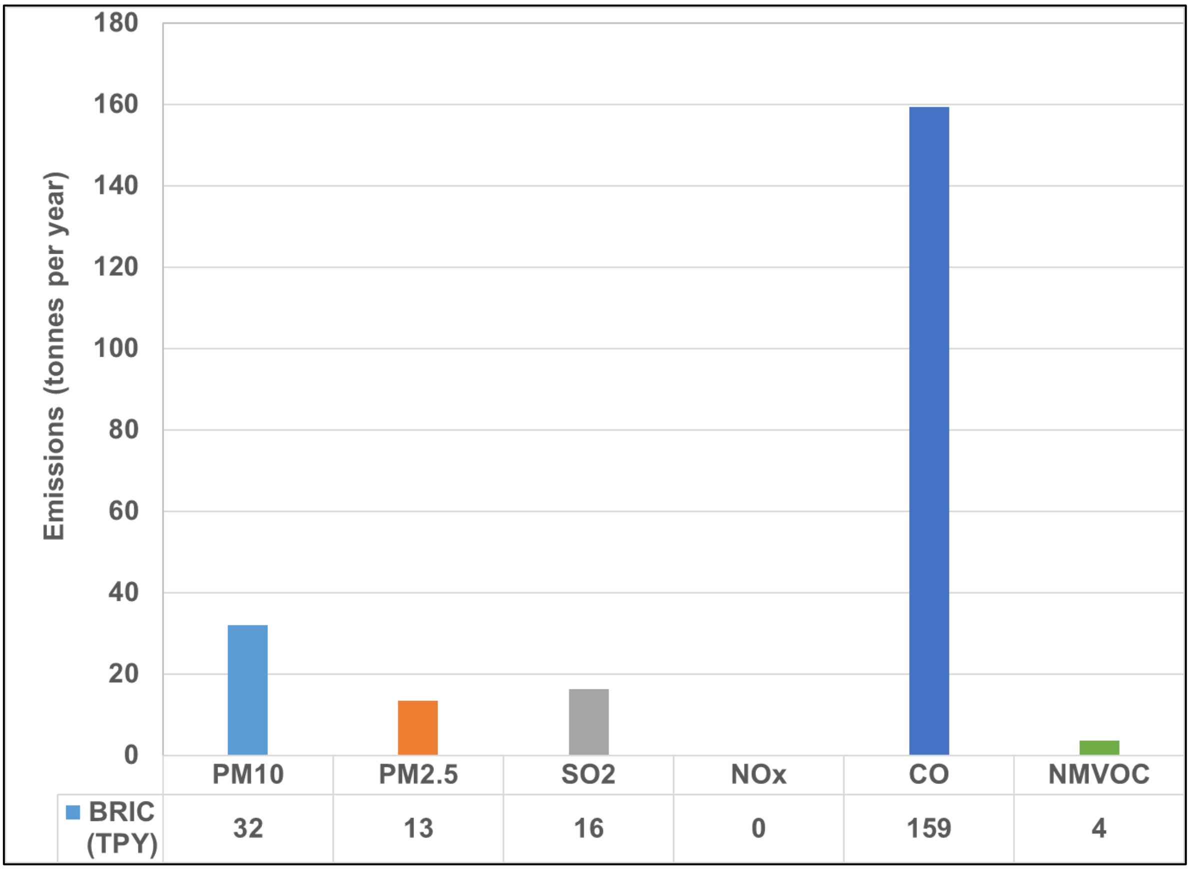

Figure 70 Emissions loads (tonnes per year) of pollutants originating from brick kilns in Cuttack region

3.7.10. Diesel generators

As discussed earlier, diesel generators are only used during the power failure emergency but contribute a significant share in reginal emissions. Figure 71 shows emissions of pollutants originating from diesel generators usage in Cuttack region. NMVOC is the major contributor (3091 tonnes per year) from diesel generators, followed by NO_X (2355 tonnes per year), CO (508 tonnes per year), PM_{10} (250 tonnes per year), $PM_{2.5}$ (214 tonnes per year), SO_2 (155 tonnes per year).

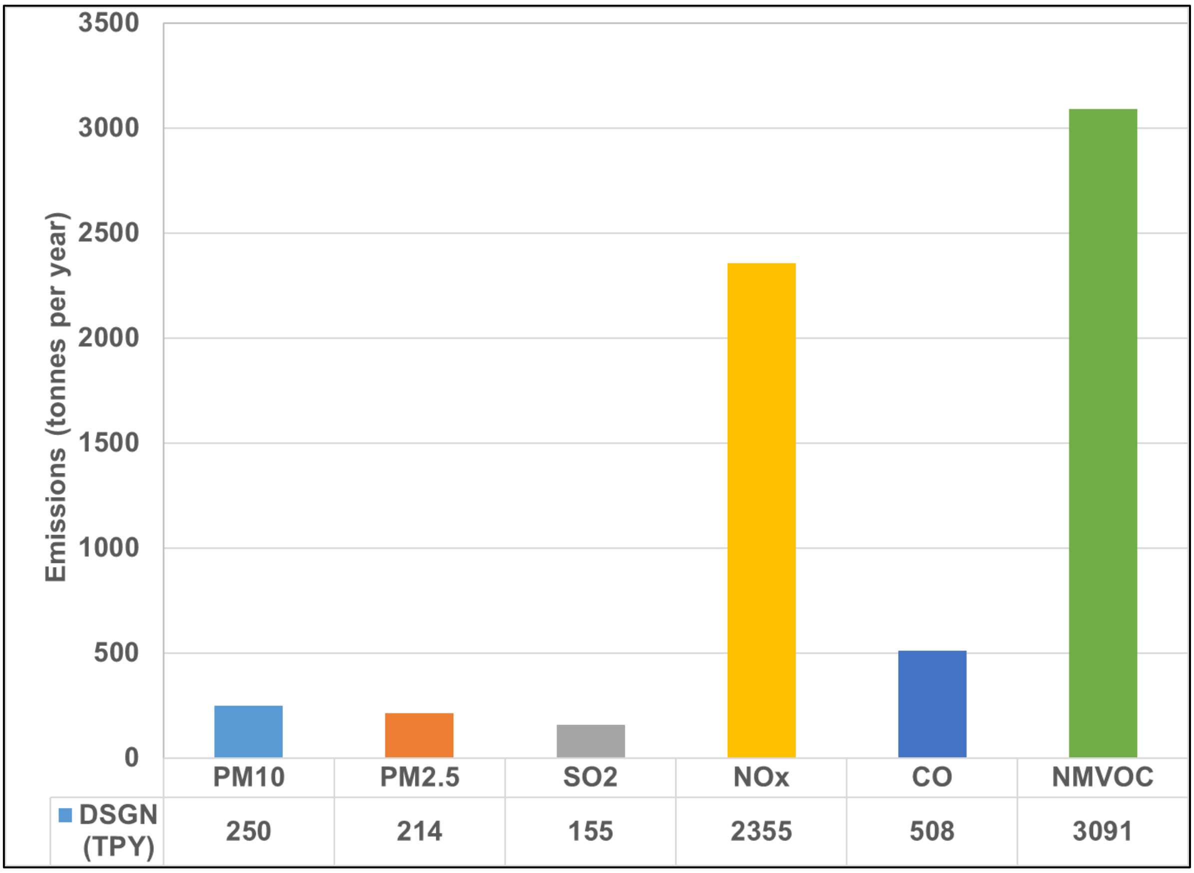

Figure 71 Emissions load (tonnes per year) of pollutants originating from diesel generators usage in Cuttack region

3.7.11. Wind-blown riverbed erosion dust

The wind-blown riverbed erosion dust emissions are estimated using friction velocity method. These emissions are generally released close to surface, thereby increasing their relative contributions to ambient particulate matter. Figure 72 shows the wind-blown riverbed erosion dust emissions load originating from Cuttack region. PM_{10} was estimated to be 194 tonnes per year, followed by $PM_{2.5}$ (49 tonnes per year).

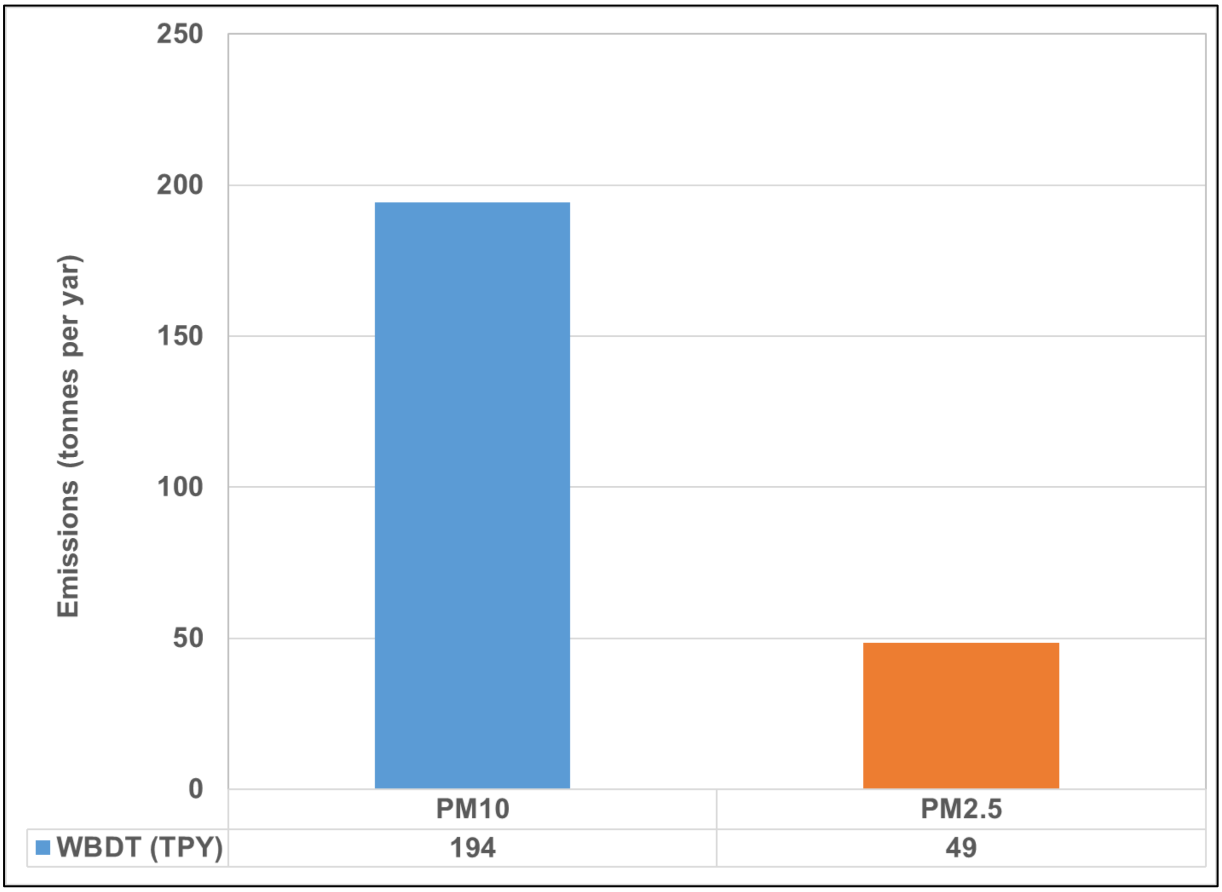

Figure 72: Emissions load (tonnes per year) of pollutants originating from Wind-blown riverbed erosion in Cuttack region

3.7.12. Crematoria

Figure 73 shows the emissions of pollutants originating from cremation activities in Cuttack region. Due to incomplete combustion of wood in wood pyres, CO is the maximum contributor with emissions of 220 tonnes per year, followed by NMVOCs (123 tonnes per year), PM_{10} (44 tonnes per year) and $PM_{2.5}$ (22 tonnes per year). NO_X was found to contribute 6 tonne per year of emissions, while SO_2 was found to contribute 1 tonne per year of emissions.

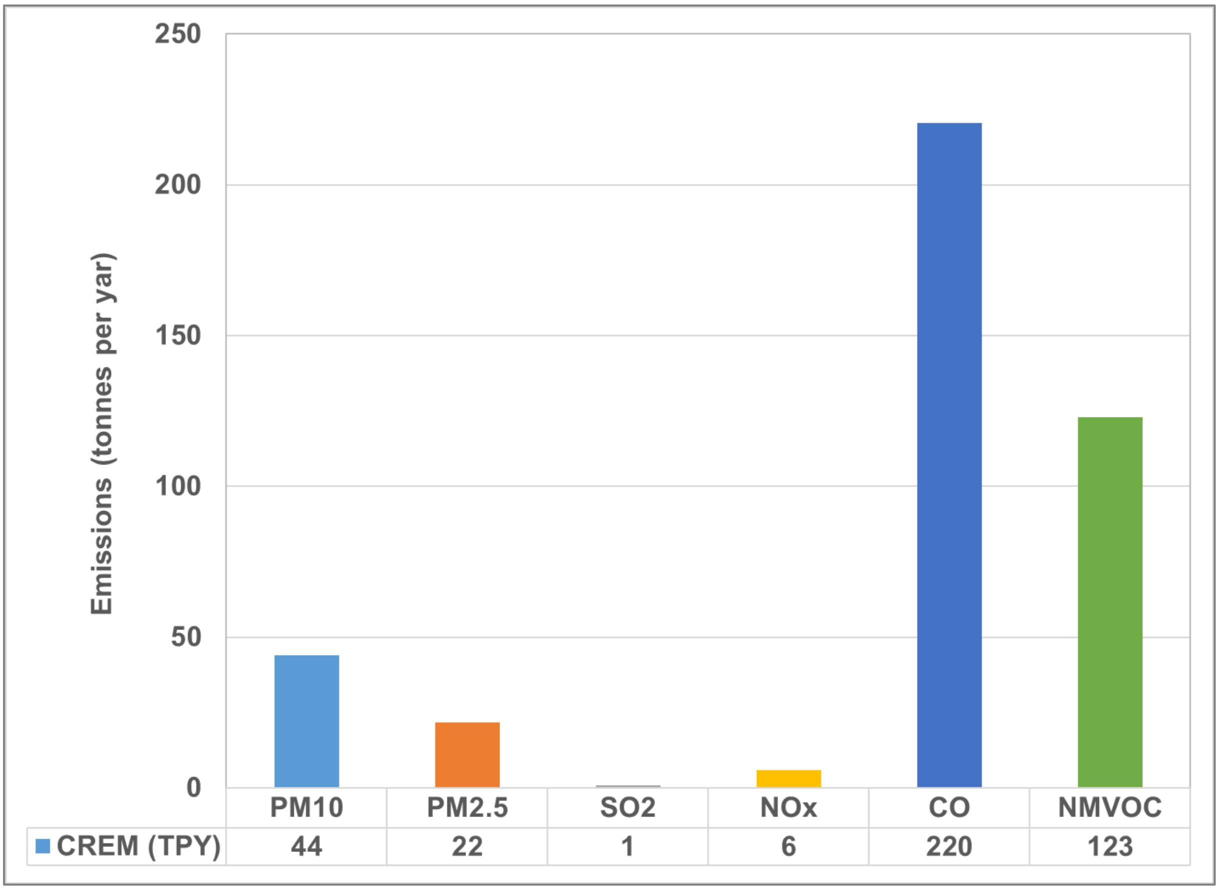

Figure 73 Emissions loads (tonnes per year) of pollutants originating from crematoria in Cuttack region

3.6. Regional Emission Inventory

The overall baseline emission inventory (Year 2022) for the Cuttack region is presented in Table 17. The sectoral contribution to pollutants is provided in Fig. 74 to 79.

The total PM_{10} emission load in the Cuttack region is estimated to be 6,404 tonnes per year. The top four contributors to PM_{10} emissions are resuspended road dust (35.6%), followed by industries and thermal powerplants (13.5%), residential emissions (11.6%), and transport (11.2%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable Daily and seasonal emissions could be highly variable.

$PM_{2.5}$ emission load in the Cuttack region is estimated to be 3,163 tonnes per year. The top four contributors to $PM_{2.5}$ emissions are re-suspended transport (20.4%), road dust (19.2%), residential (15.3%), and open waste burning (14.8%). Other $PM_{2.5}$ contributors include hotel, restaurants and bakeries (10.0%) and industries and powerplants (9.6%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable.

SO_2 emission load in the Cuttack region is estimated to be 1,791 tonnes per year. The top four contributors to SO_2 emissions are industries and thermal powerplants (55.5%), residential (16.4%), Hotels, Restaurants, Bakeries and Open eateries (16.0%), industrial DG (8.7%) and open waste burning (1.8%). All other sectors together contribute less than 1% of the SO_2 emissions.

The annual NO_X emission load in the Cuttack region is estimated to be 14,898 tonnes per year. Transport sector (50.4%), Industries and thermal powerplants (30.9%) and industrial DG (15.8%) are the largest contributors to NO_X emissions. Remaining sectors such as open waste burning, Hotels, Restaurants, Bakeries and Open eateries together contributes less than 1%.

The total annual CO emissions in the Cuttack region are estimated to be 29,758 tonnes per year. Transport sector are the major contributor to CO emissions i.e. 58.2%, followed by residential (23.3%), open waste burning (8.1%) and Hotels, Restaurants, Bakeries and Open eateries (6.4%). All remaining sectors together contribute about 4% of total CO emissions in the region.

Fig. 80-84 shows the spatial distribution of pollutants over Cuttack region for baseline year 2022.

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

Sector	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	NMVOC
Industries and powerplants	866 ± 93	305 ± 32	994 ± 38	4596 ± 331	317 ± 24	146 ± 0
Fugitive dust	202 ± 108	20 ± 10	NA#	NA#	NA#	NA#
Transport	716 ± 197	644 ± 177	11 ± 2	7504 ± 4014	17310 ± 9257	11956 ± 77
Road dust	2282 ± 577	607 ± 153	NA#	NA#	NA#	NA#
Residential	745 ± 387	485 ± 252	293 ± 49	259 ± 134	6942 ± 3612	2084 ± 265
Open waste burning	503 ± 281	467 ± 261	32 ± 17	72 ± 40	2408 ± 1346	521 ± 6438
Hotels, Restaurants, Bakeries and Open eateries	493 ± 272	317 ± 175	287 ± 72	106 ± 58	1894 ± 1047	231 ± 124
Construction	77 ± 16	19 ± 4	NA#	NA#	NA#	NA#
Brick Kilns	32 ± 17	13 ± 7	16 ± 8	0 ± 0	159 ± 87	4 ± 1664
Diesel Generators	250 ± 130	214 ± 111	155 ± 38	2355 ± 1226	508 ± 264	3091 ± 1062
Wind-blown Riverbed Erosion dust (WBDT)	194 ± 54	49 ± 13	NA#	NA#	NA#	NA#
Crematoria	44 ± 22	22 ± 11	1 ± 0.5	6 ± 3	220 ± 113	123 ± 62
Total	**6404 ± 2160**	**3163 ± 1211**	**1791 ± 228**	**14898 ± 5809**	**29758 ± 15754**	**18155 ± 9671**

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

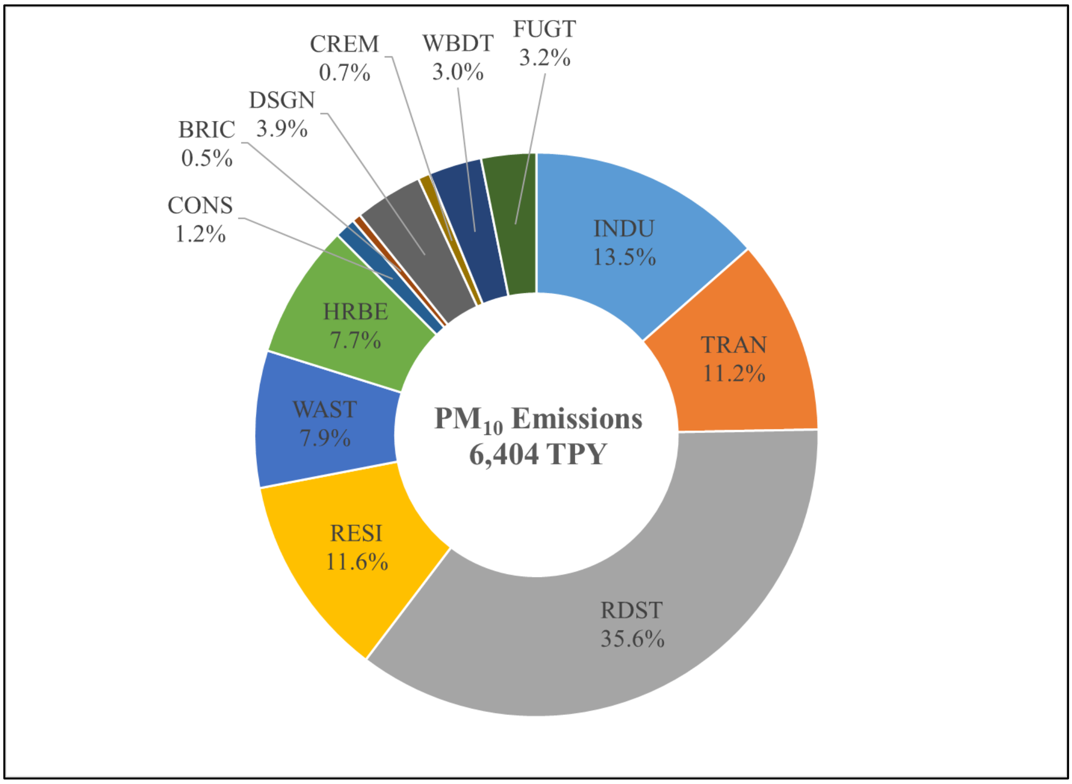

Figure 74 Sectoral contribution to annual PM_{10} *emissions in Cuttack region*

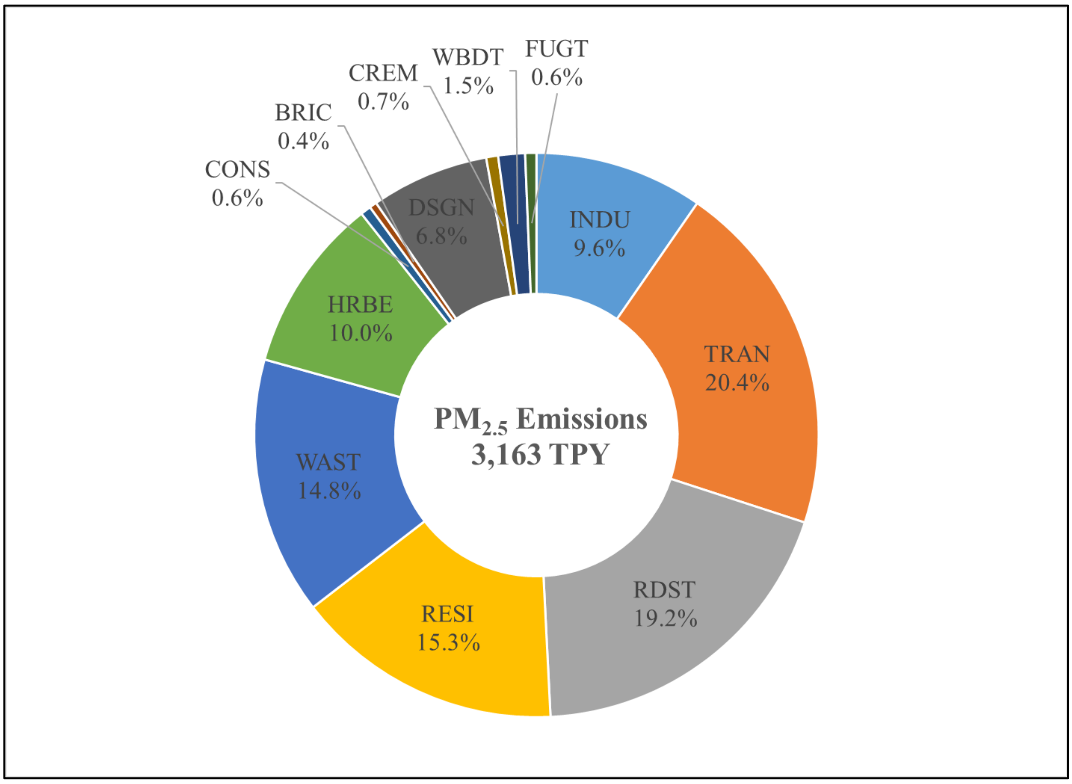

Figure 75 Sectoral contribution to annual $PM_{2.5}$ *emissions in Cuttack region*

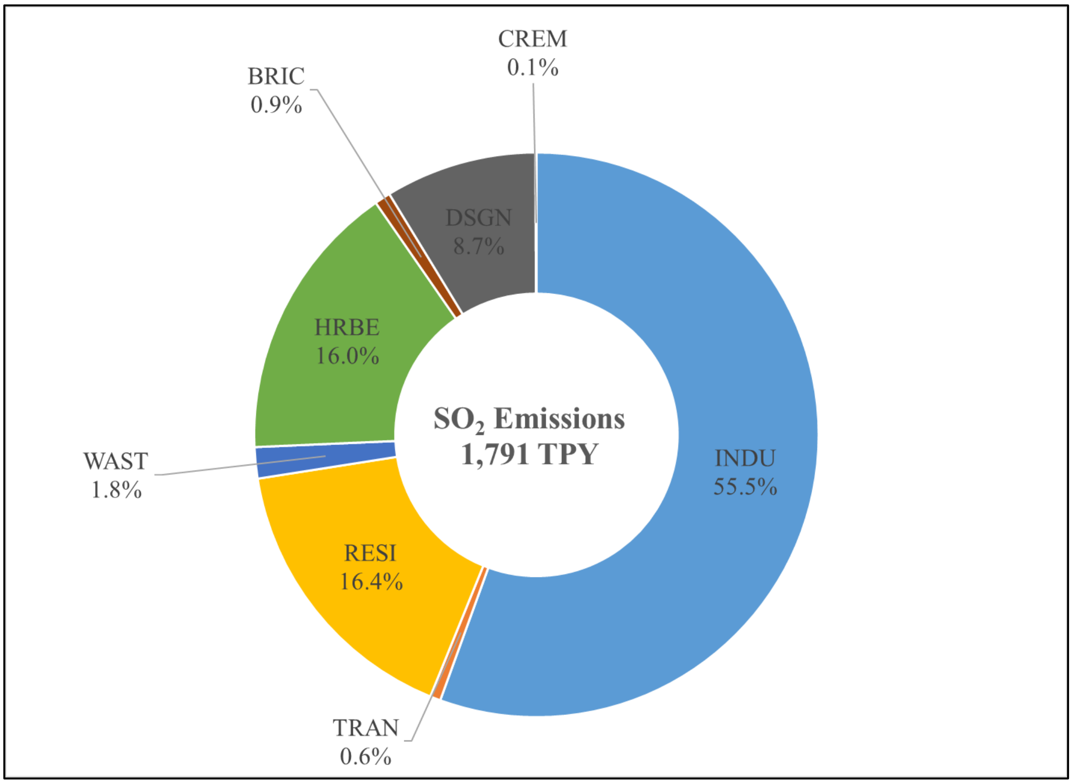

Figure 76 Sectoral contribution to annual SO_2 *emissions in Cuttack region*

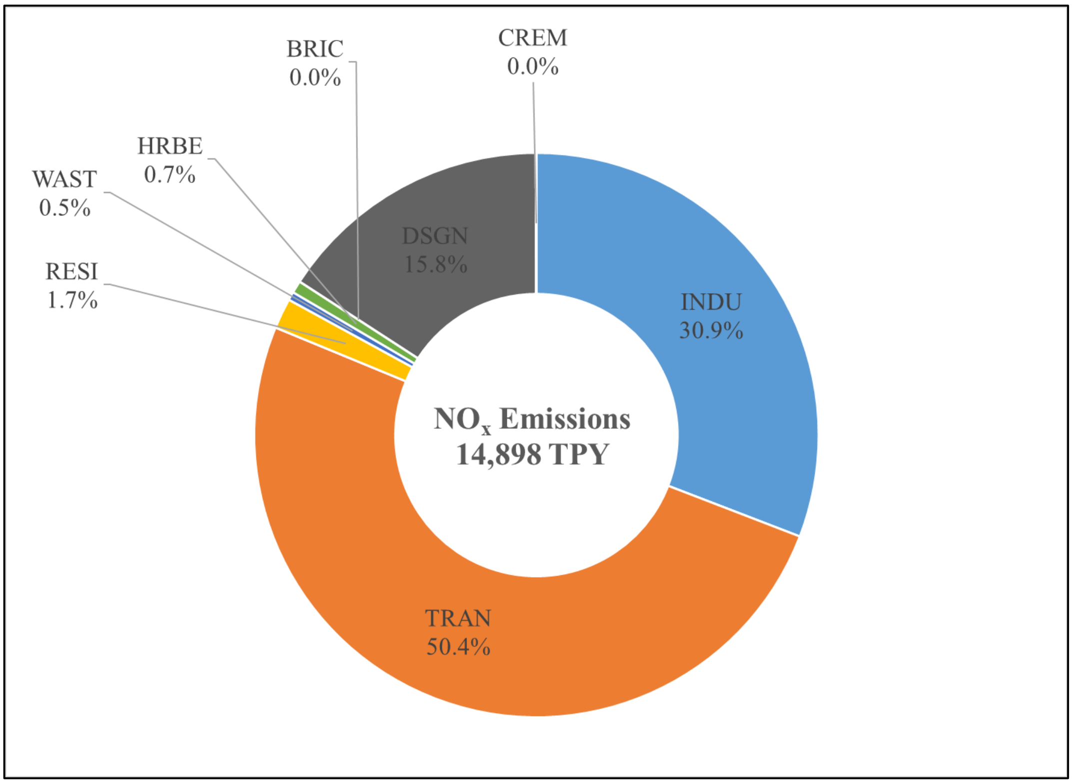

Figure 77 Sectoral contribution to annual NO_X *emissions in Cuttack region*

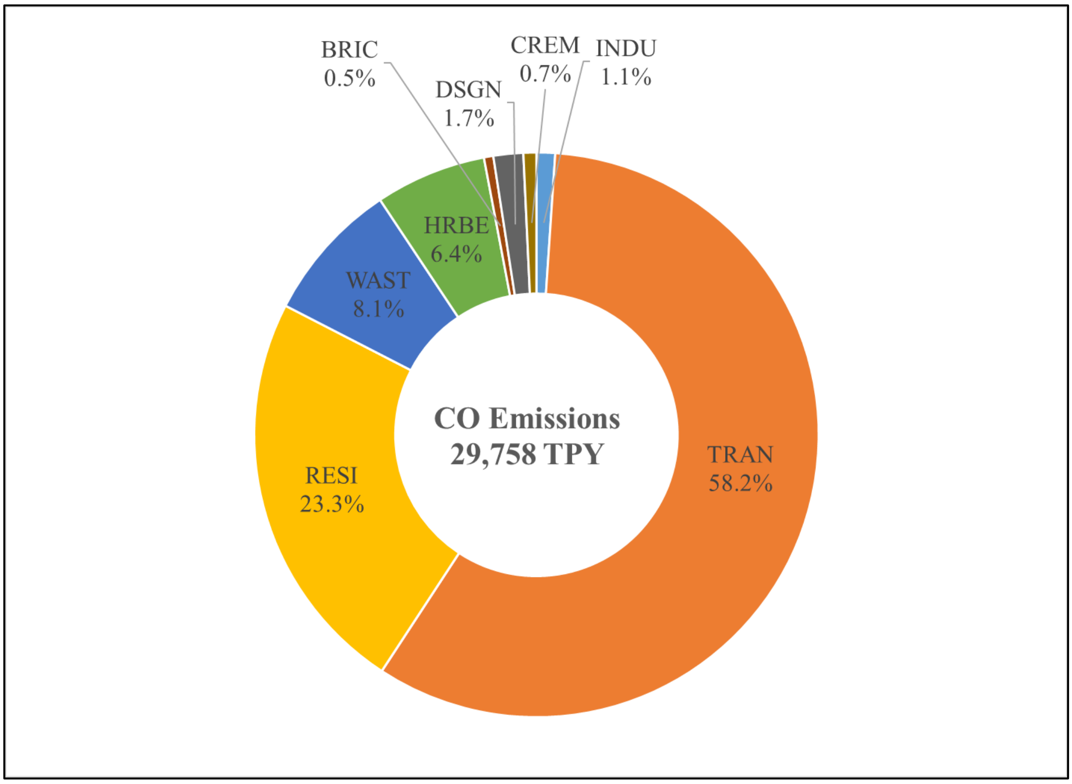

Figure 78 Sectoral contribution to annual CO emissions in Cuttack region

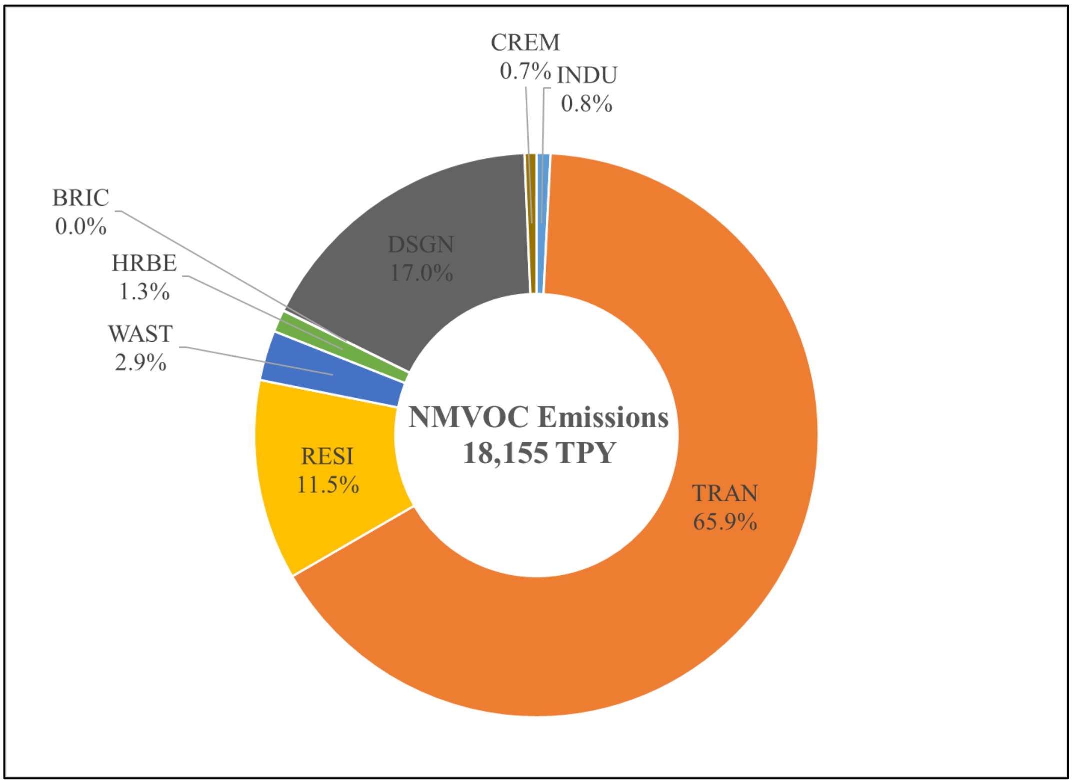

Figure 79 Sectoral contribution to annual NMVOC emissions in Cuttack region

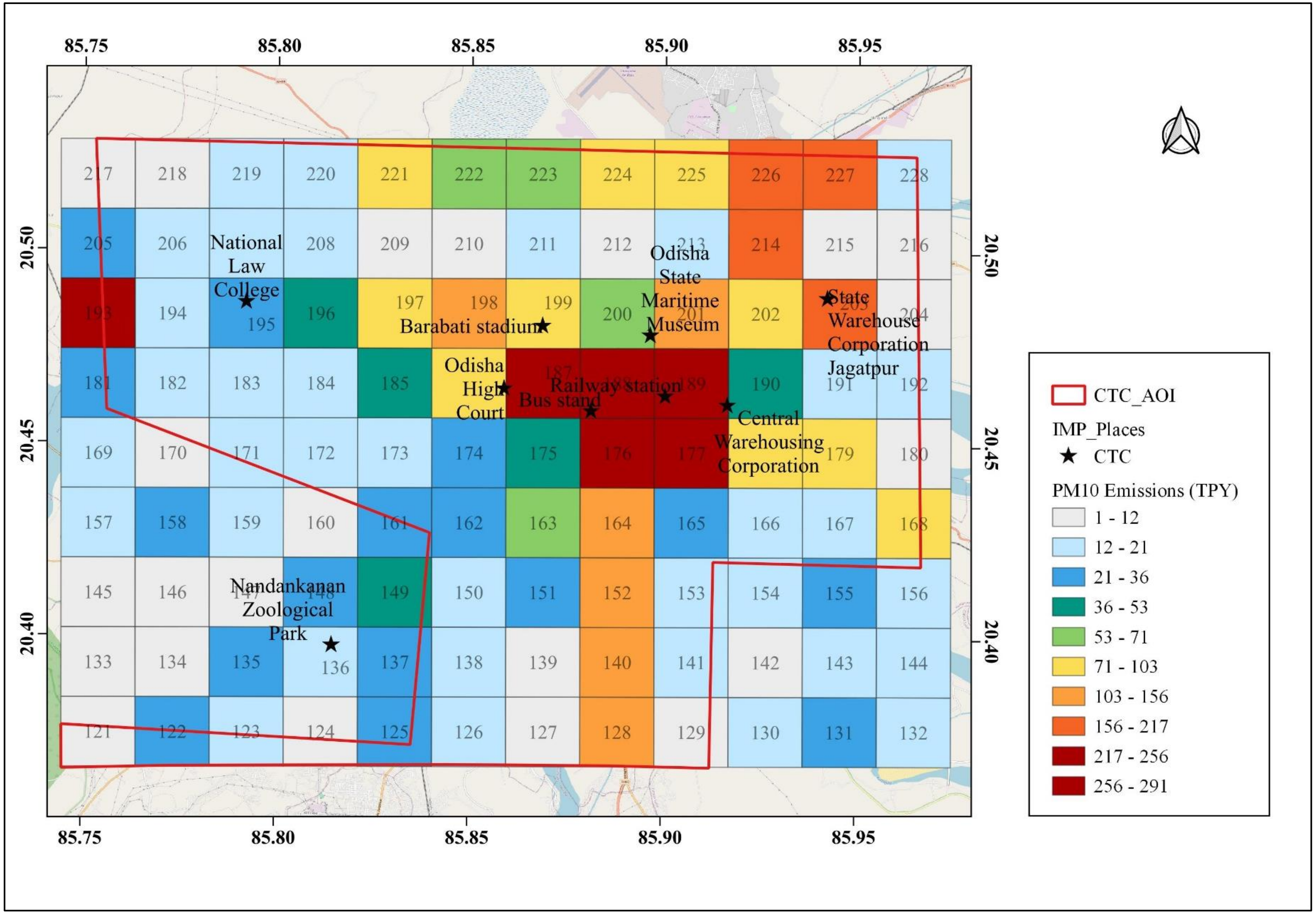

Figure 80: Spatial distribution of PM_{10} *emissions (tonnes per year) in Cuttack region for year 2022*

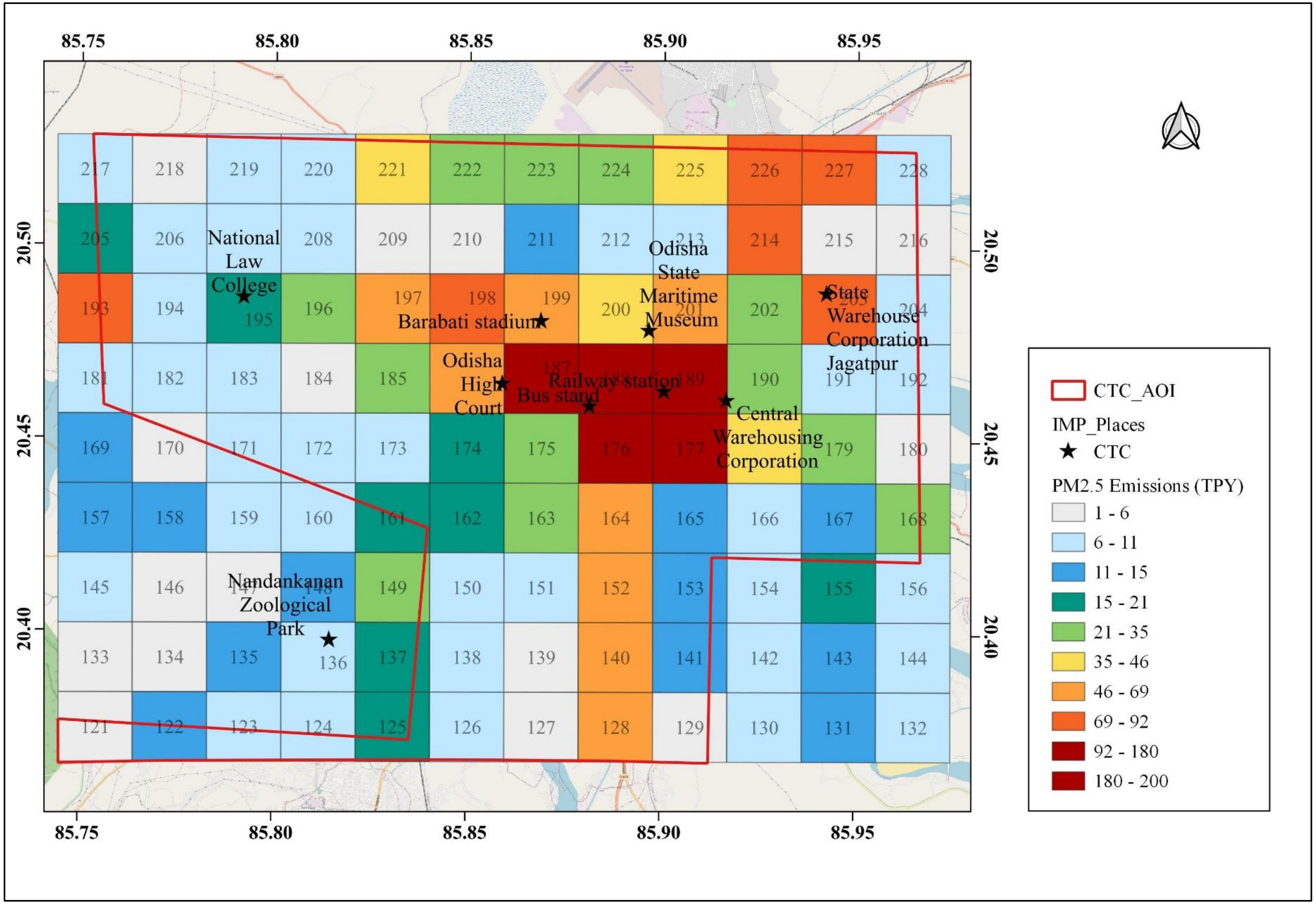

Figure 81: Spatial distribution of $PM_{2.5}$ *emissions (tonnes per year) in Cuttack region for year 2022*

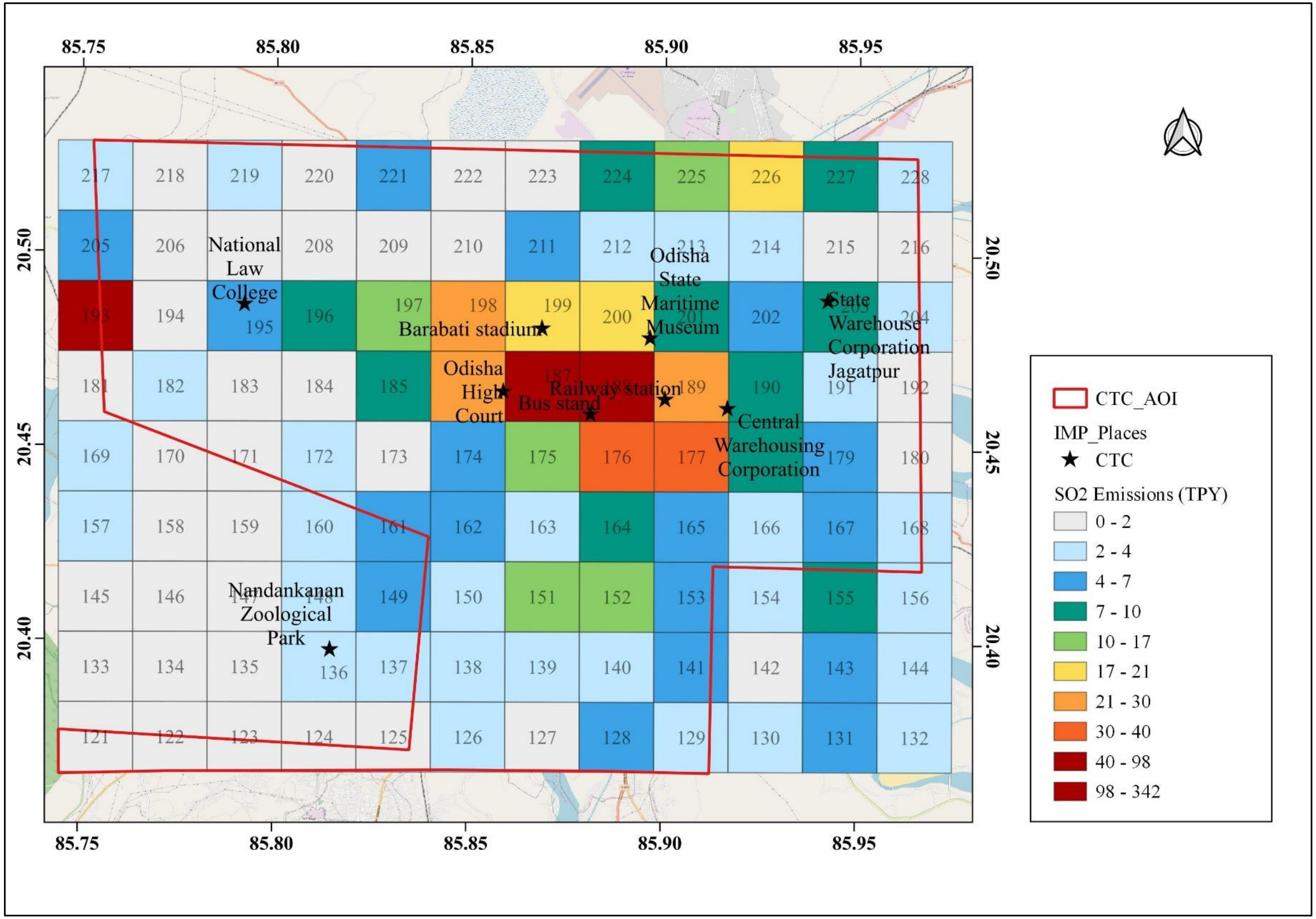

Figure 82 Spatial distribution of SO_2 *emissions (tonnes per year) in Cuttack region for year 2022*

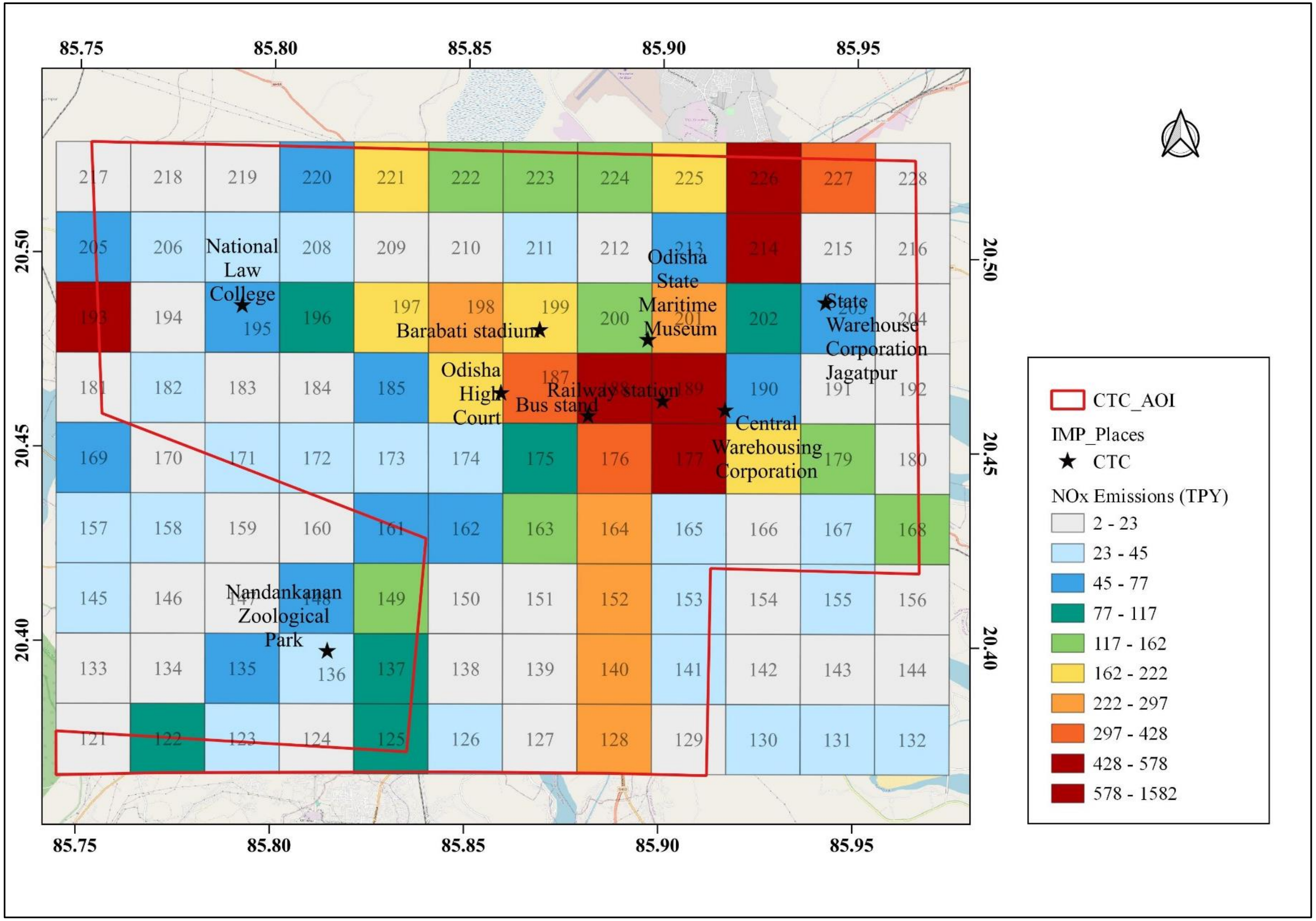

Figure 83 Spatial distribution of NO_X emissions (tonnes per year) in Cuttack region for year 2021

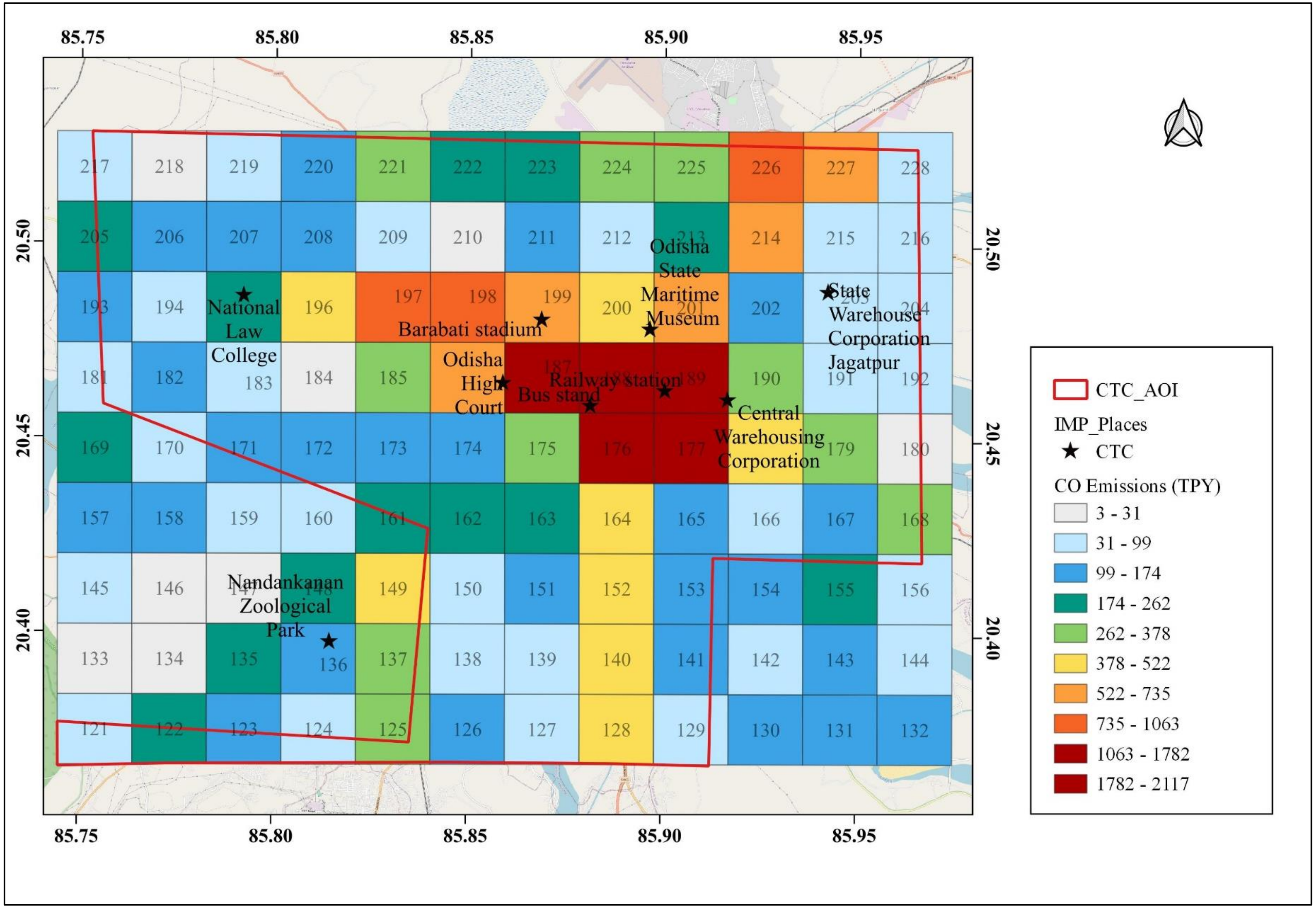

Figure 84 Spatial distribution of CO emissions (tonnes per year) in Cuttack region for year 2021

Chapter 4: Dispersion Modelling

4.1. Background

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

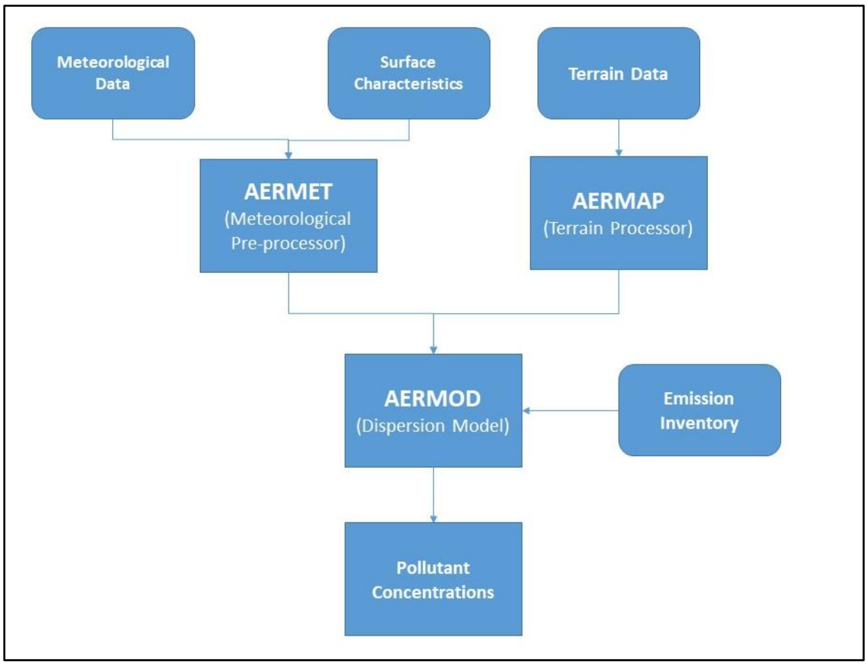

Figure 85 Flow diagram of AERMOD Modelling System used in this study to simulate the air pollutant concentrations

Fig. 85 shows the flow diagram of AERMOD modelling system. AERMOD is a steady-state gaussian plume model and consists of a dispersion model i.e. AERMOD and two pre-processors (AERMET and AERMAP). The major purpose of meteorological pre-processor i.e. AERMET, is to calculate boundary layer parameters for use by AERMOD. Surface characteristics in the form of albedo, surface roughness, and Bowen ratio, plus standard meteorological observations (wind speed, wind direction, temperature, and cloud cover), are input to AERMET. AERMET then calculates the PBL parameters: friction velocity (u*), Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (θ*), mixing height (zi), and surface heat flux (H). The terrain pre-processor i.e. AERMAP uses gridded terrain data to calculate a representative terrain-influence height, also referred to as the terrain height scale. The terrain height scale, which is uniquely defined for each receptor location, is used to calculate the dividing streamline height. The gridded data needed by AERMAP is selected from Digital Elevation Model (DEM) data. AERMAP is also used to create receptor grids. The elevation for each specified receptor is automatically assigned through AERMAP. For each receptor, AERMAP passes the following information to AERMOD: the receptor's location, its height above mean sea level, and the receptor specific terrain height scale.

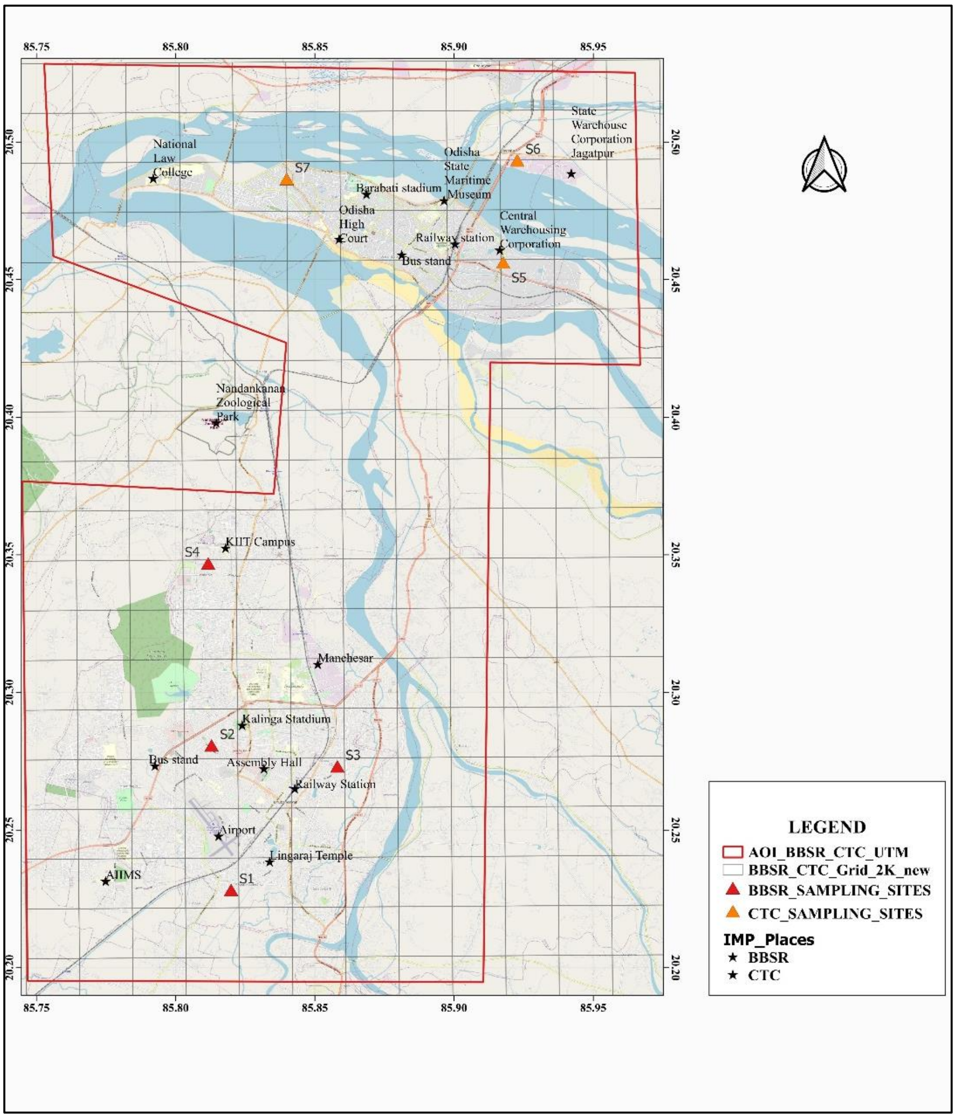

Figure 86 Map showing dispersion modelling domain i.e. Bhubaneswar and Cuttack (Combined) region and surrounding areas

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 86). Due to proximity and importance of regional sources, Bhubaneswar and Cuttack regions are modelled together in AERMOD System.

4.2. Meteorological Data

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

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 Bhubaneswar and Cuttack 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 Bhubaneswar and Cuttack 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

Additionally, the surface meteorological observations at Bhubaneswar and Cuttack are obtained from the observatory located at Biju Patnaik International Airport (Refer Figure 87). This data is available from Integrated Surface Database (ISD) maintained by National Oceanic and Atmospheric Administration (NOAA). The meteorological parameters including: wind speed and direction, ambient temperature and cloud cover are ingested into AERMET files via ONSITE pathway. The sub-hourly meteorological observations of specified weather parameters obtained from ISD data for year 2022 are processed using customized python scripts following data quality assurance.

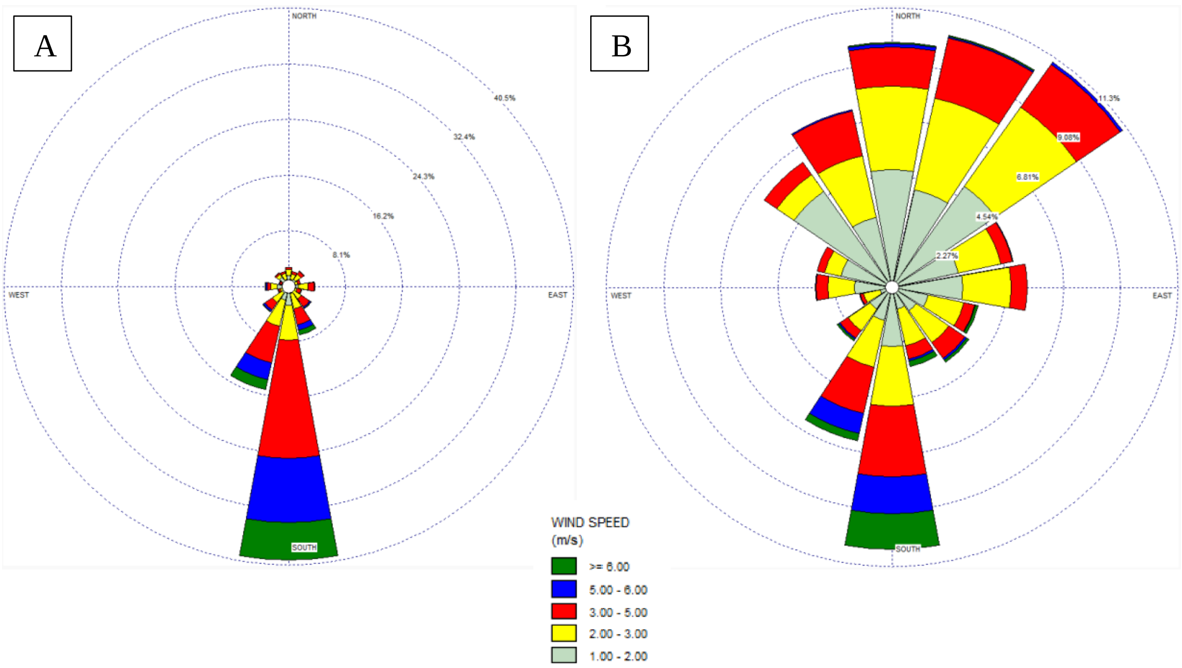

Figure 87 Windrose diagrams showing the wind speed and direction frequency distribution over Bhubaneswar and Cuttack region during summer (A) and winter (B) seasons of year 2022

Fig. 87 shows the wind speed and direction frequency distribution over Bhubaneswar and Cuttack region during summer (A) and winter (B) seasons of year 2022. The predominant wind directions during the summer season over Bhubaneswar and Cuttack region are observed to be from south (S, >40%); followed by south of south west (SSW, ~16%). The calm winds i.e. < 1 m/s, are observed for 2.47% of time, during summer season.

In the winter season, the winds are observed to blow from north-east and south quadrant, with maximum from north east (NE, > 11%), followed by north of north east (NNE, >10%), south (S, >10%), and north (N, >10%) directions. Calm winds i.e. < 1 m/s, constituted a significant portion i.e. 6.35%, 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 Bhubaneswar and Cuttack region was downloaded and processed using AERMAP processor.

Fig. 88 shows the contour map showing terrain elevations over Bhubaneswar-Cuttack (Combined) 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 ~11 m (above MSL) towards southern part to a maximum of ~82 m (above MSL) towards western part of the modelling domain.

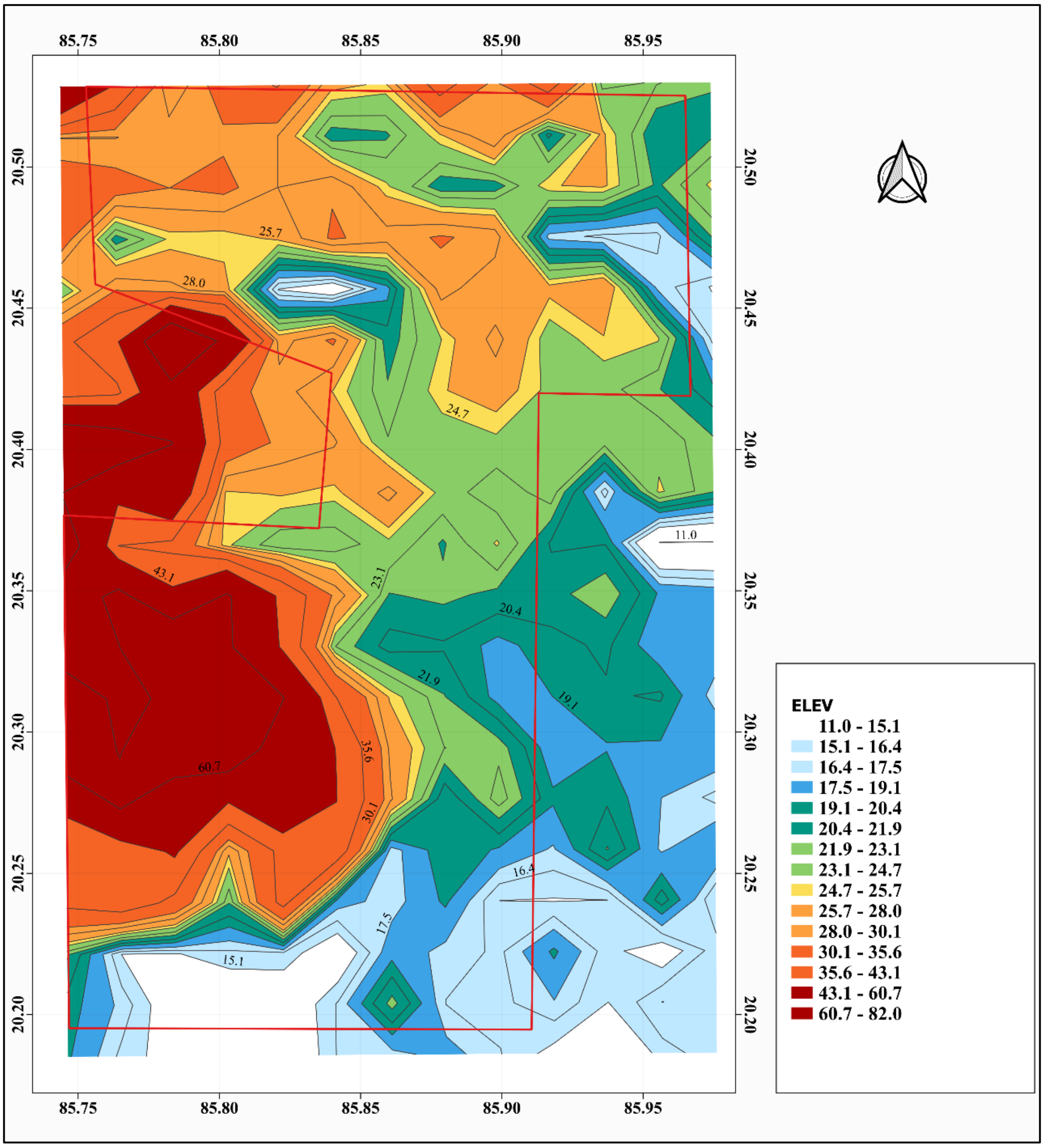

Figure 88 Contour map showing terrain elevations extracted by AERMAP using SRTM DEM dataset having a spatial resolution of 1 arc-second (~30 m)

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 and thermal powerplants, crematoria, industrial fugitive dust and brick kilns. The stack emissions from industries, thermal powerplants, 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.

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 260 gridded receptors. Additionally, seven 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 89 shows map of the modelling domain overlaid by gridded and discrete receptors configured in this study.

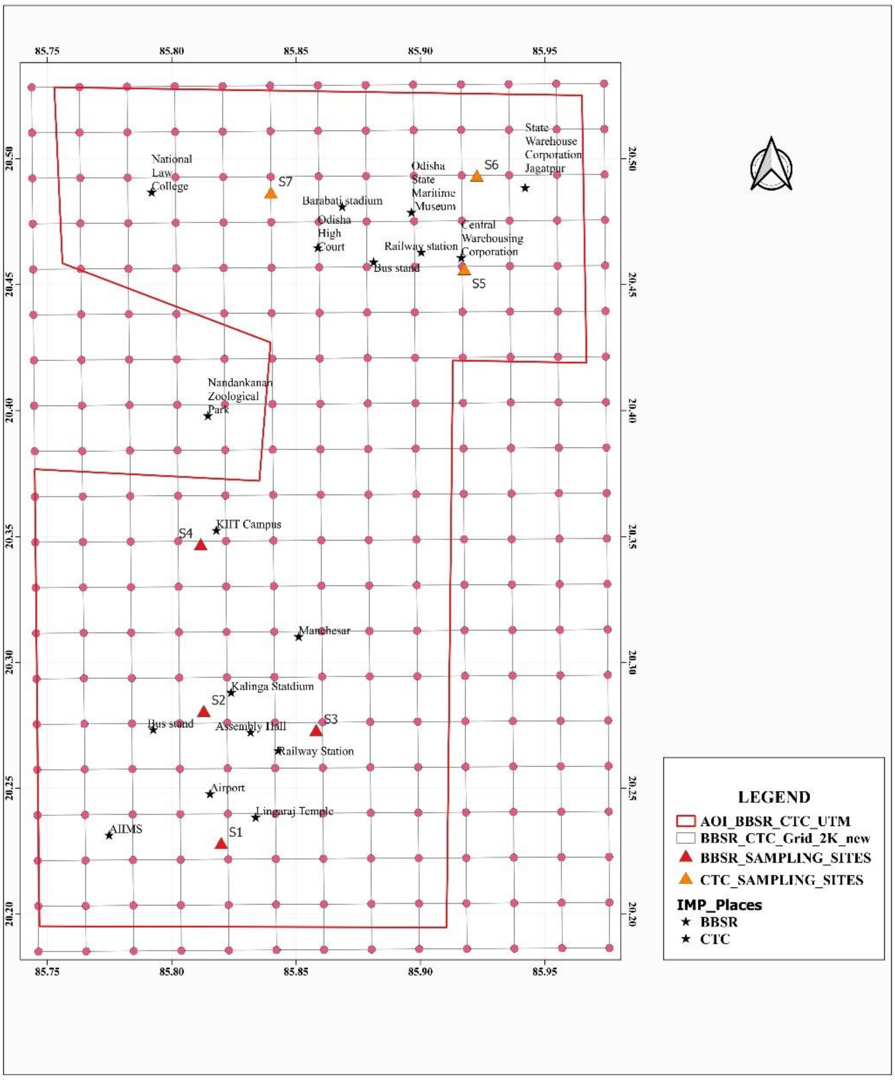

Figure 89 Map showing modelling domain overlaid by gridded and discrete receptors configured in this study.

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	24 km
2.	Length of modelling domain in Y-direction	Y	38 km
3.	X-direction receptor grid resolution	ΔX	2000 m
4.	Y-direction receptor grid resolution	ΔY	2000 m
5.	Receptor height	H_R	1.5 m
6.	Total number of gridded receptors	N_{GRD}	260
7.	Total number of discrete receptors	N_{DISC}	7
8.	Source configuration in AERMOD	--	• Industries, TPP, 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: • Dry bulb temperature • Wet bulb temperature • Cloud cover • Wind speed at 10 m • Wind direction at 10 m Onsite Meteorological data: • Dry bulb temperature • Wet bulb temperature • Cloud cover • Wind speed • Wind direction
10.	Meteorology: Upper air soundings	--	ERA5 fifth generation ECMWF reanalysis • Dry bulb temperature • Wet bulb temperature • Wind speed • Wind direction
11.	Terrain data	--	NASA's Shuttle Radar Topography Mission (SRTM) global product having 1 arc second (~30 meter) spatial resolution

4.6. Background Concentrations

The background pollutant concentrations play an important role in dispersion model validation. Continuous air quality monitoring stations were not operational during baseline year 2022, hence NAMP observations were used to derive the background concentrations. NAMP monitoring stations are operated manually and the background concentrations are derived using annual average concentrations reported at NAMP stations with suitable assumptions.

Based on literature review, previous studies in the region, results of receptor modelling in this study, and expert judgement, the background pollutant concentrations are reported to contribute between 15 and 30% (Urban Emissions Info, 2024). A series of sensitivity AERMOD simulations were conducted with varying background concentrations to cover the previously reported range of 15% to 30%. The best model results were obtained when the background concentrations were ~20% for both particulates and gases, hence this value is used to get the monthly background concentrations. The derived background concentration is added to the modelled concentrations estimated by AERMOD to get total concentration of pollutant under consideration.

4.7. Dispersion Model Validation

Due to lack of CAAQM measurements in Bhubaneswar and Cuttack region, the AERMOD simulated concentrations of pollutants including PM2.5, PM10, and NO2, are compared against monthly mean of reported observations at NAMP stations in Bhubaneswar and Cuttack. The Pearson correlation coefficient (R) is found to be greater than 0.7 for PM10 and PM2.5. 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. 90 - 94 shows the spatial distribution of modelled pollutant annual mean concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_2 and CO for year 2021, respectively. The spatial distribution of modelled pollutant concentrations in the study domain, is generally governed by emissions, terrain, land-use and meteorological factors. The highest estimated concentrations of particulate matter i.e. PM_{10} and $PM_{2.5}$ are observed towards central parts of Bhubaneswar and Cuttack regions 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. 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 SO_2 (Refer Fig. 92) is mainly governed by the use of solid fuels such as coal in residential sector and hotels, restaurants and bakeries. The NO_2 and CO concentrations are found to be distributed across the domain. The vehicular exhaust emissions, industries and thermal powerplants in the peripheral parts are main sources of NOx. In addition to industries and traffic, incomplete combustion of solid fuels such as coal and wood for domestic and commercial purposes in the region, explains the persistent CO concentrations.

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

The estimated concentrations show distinct seasonal pattern, being higher in winter and comparatively lower in summer, except a few locations very close to 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.

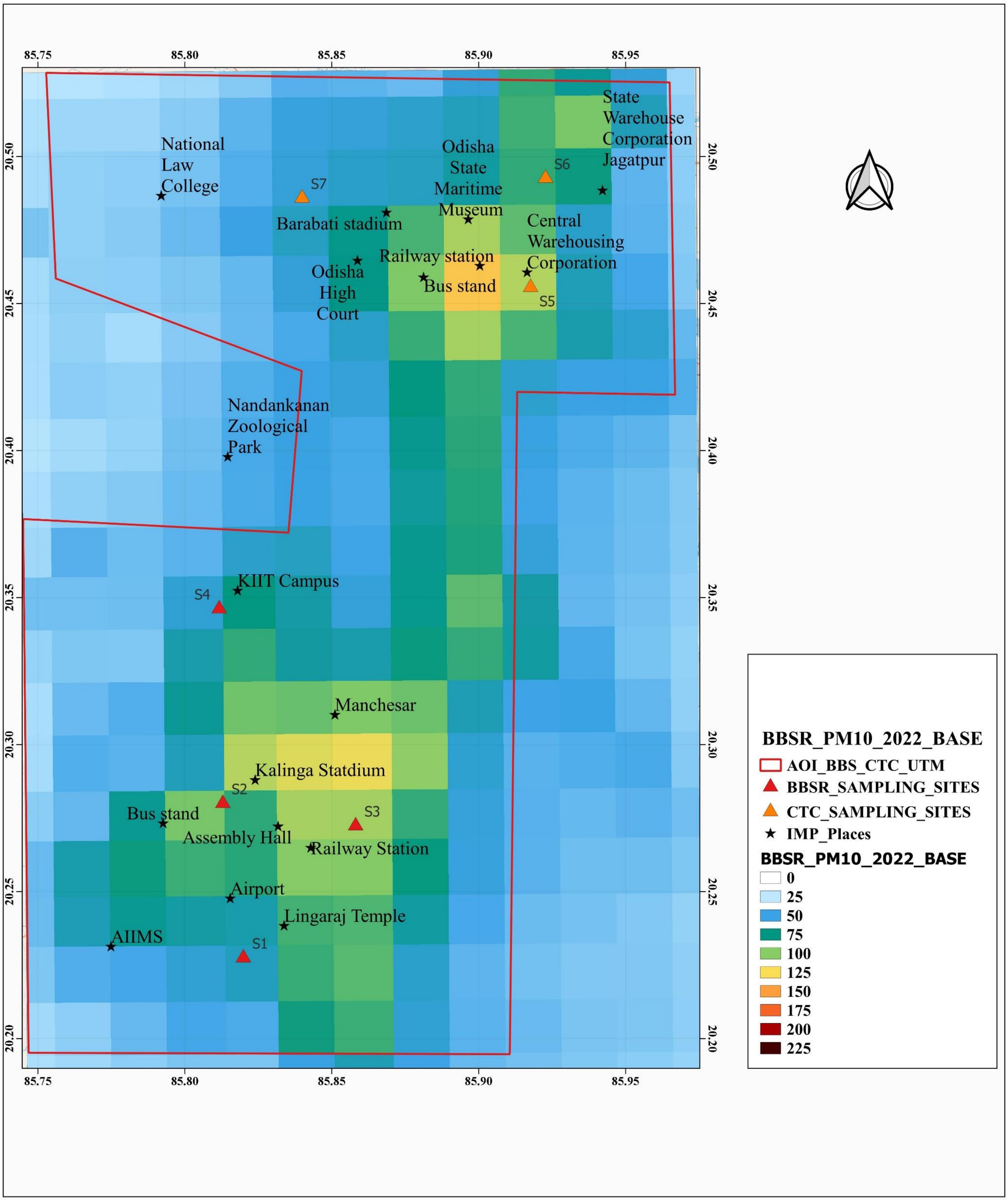

Figure 90 Map showing spatial distribution of annual mean PM_{10} concentrations (µg/m[3]) over Bhubaneswar-Cuttack region for year 2021

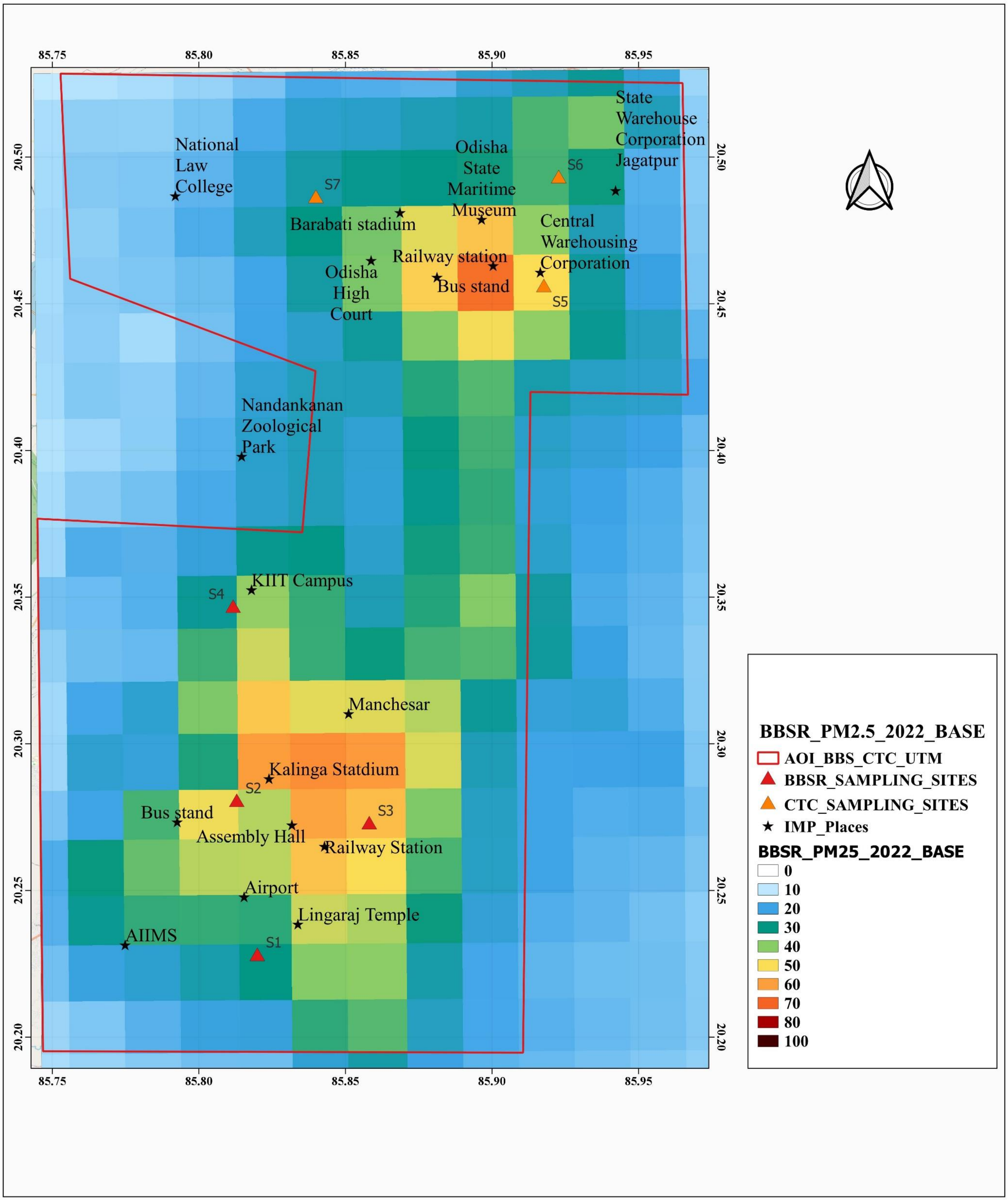

Figure 91 Map showing spatial distribution of annual mean $PM_{2.5}$ concentrations ($\mu g/m^3$) over Bhubaneswar-Cuttack region for year 2021

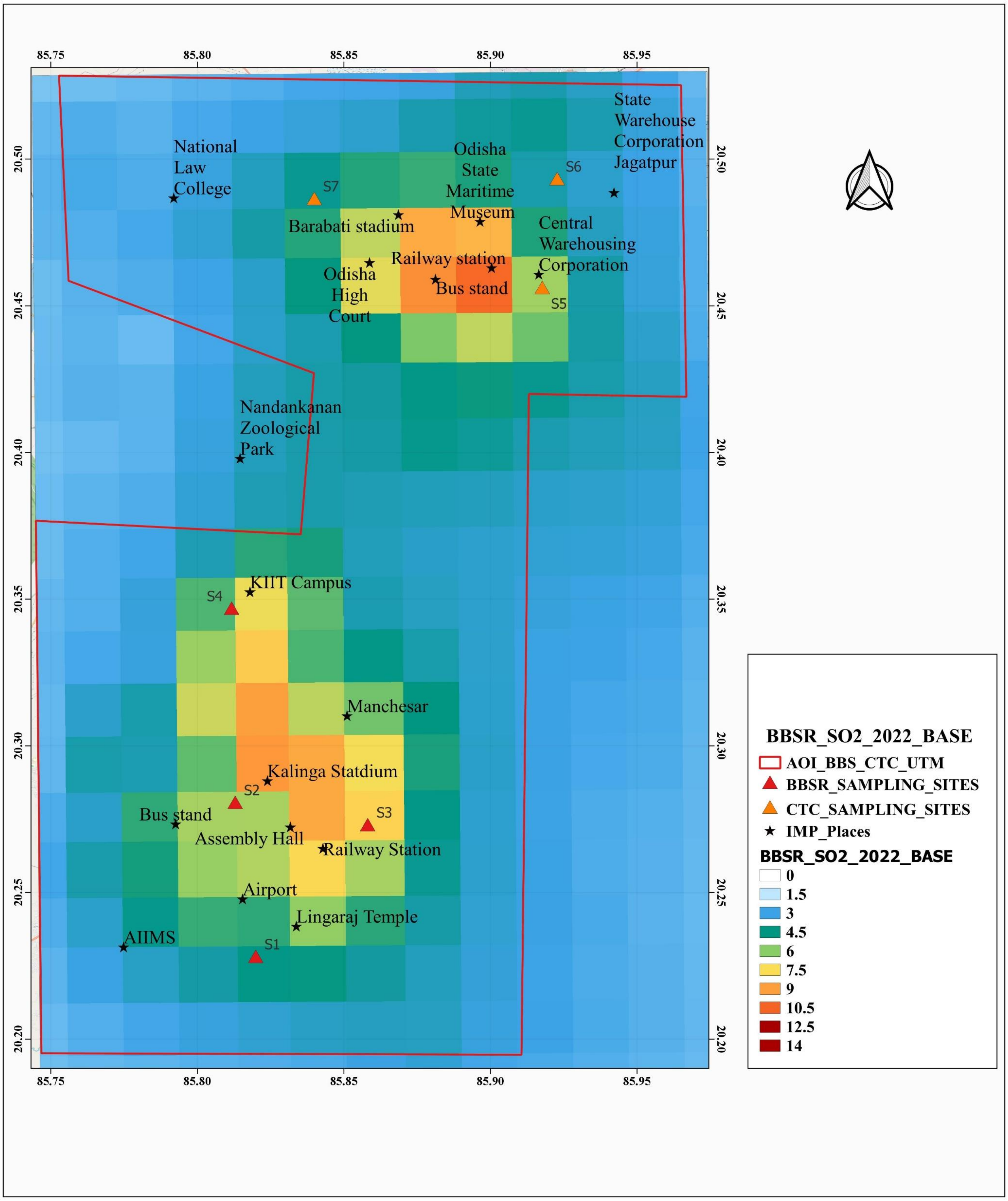

Figure 92 Map showing spatial distribution of annual mean SO_2 concentrations (µg/m^3) over Bhubaneswar-Cuttack region for year 2021

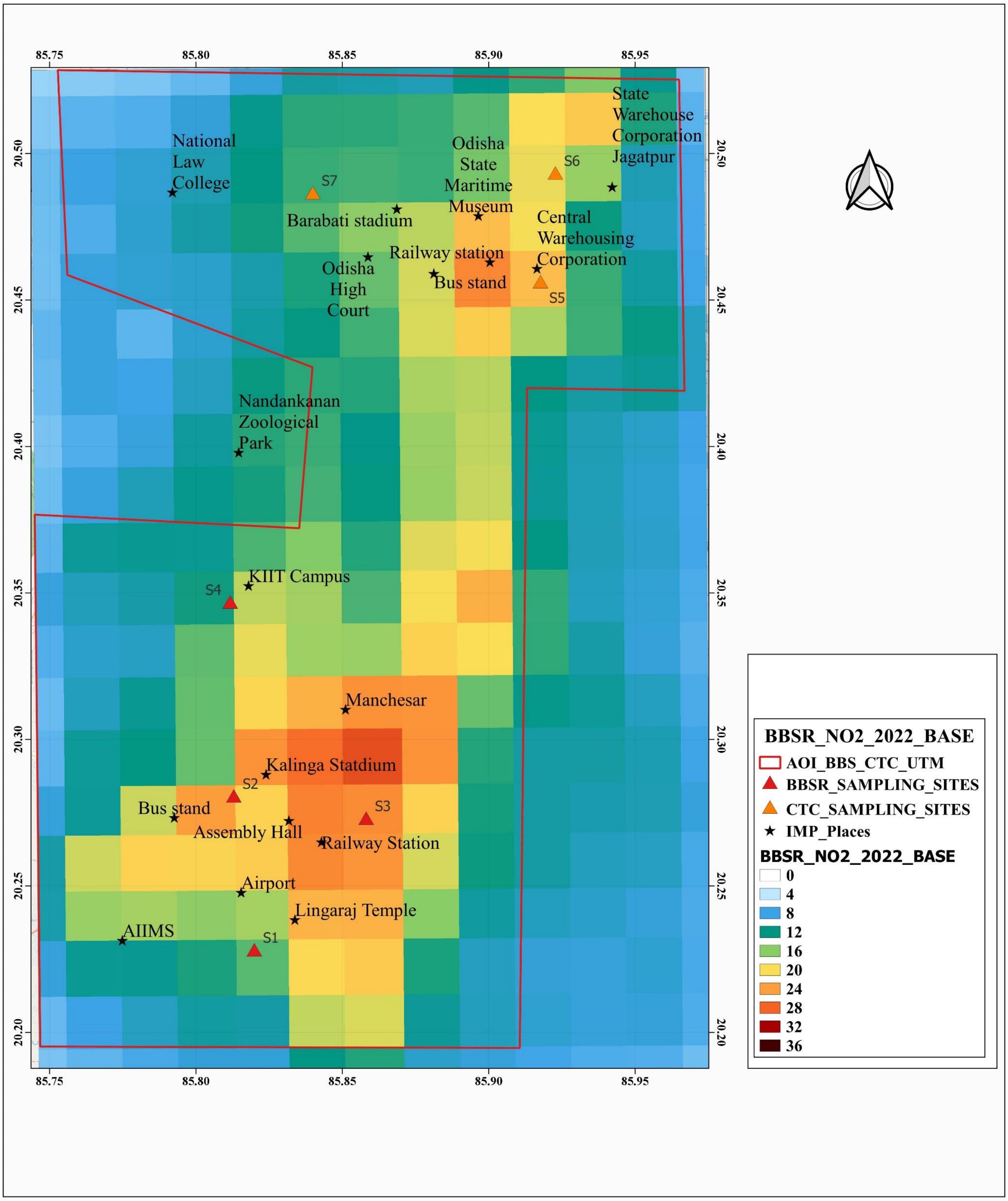

Figure 93 Map showing spatial distribution of annual mean NO_2 concentrations (µg/m^3) over Bhubaneswar-Cuttack region for year 2021

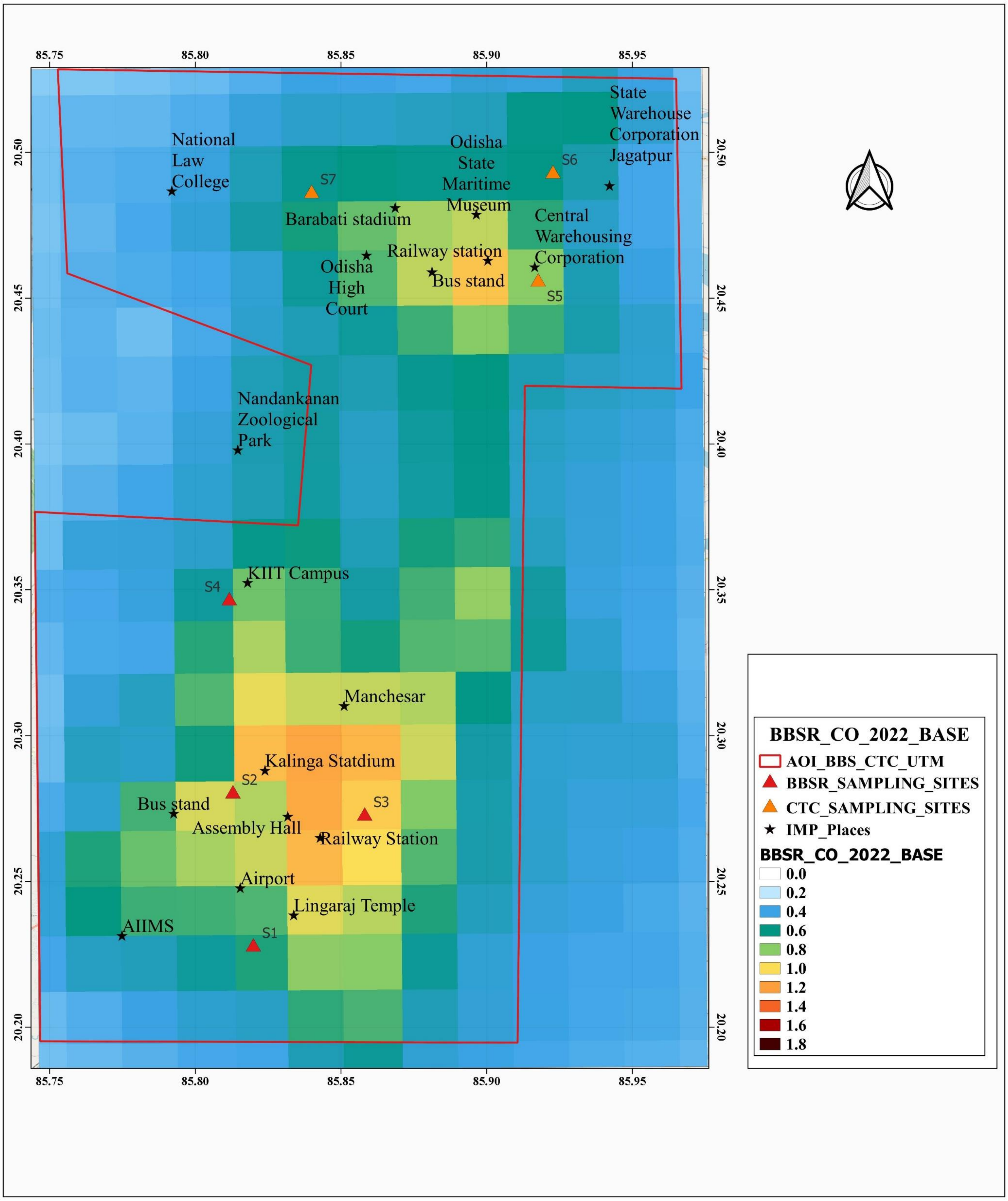

Figure 94 Map showing spatial distribution of annual mean CO concentrations (mg/m3) over Bhubaneswar-Cuttack region for year 2021

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Chapter 5: Future Projections

5.1. Future Projections of Emissions and Air Quality Benefits

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 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 Cuttack 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), 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 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 Cuttack 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 Cuttack 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 Cuttack region as well, which will in turn lead to significant reduction in vehicular exhaust emissions. The effect of increased EV penetration in Cuttack 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 Bhubaneswar 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 Cuttack 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. Mass Rapid Transit System (MRTS)

Bhubaneswar Metro is a metro rail based rapid transit system under construction to serve the city of Bhubaneswar. The phase-I of the proposed system comprise of one line with a total length of ~26 km. This line is proposed to operate from Bhubaneswar Airport to Trisulia Square. The operation of metro rail is likely to have a positive impact on peripheral grids of Cuttack region as well. The phase I of Bhubaneswar MRTS is likely to be operational from 2028.

Figure 95 shows the map of two proposed MRTS line and their zone of influence considered in future scenario analysis. The details of daily ridership, and average trip length of Bhubaneswar MRTS are used in this study for assessment of emissions in future scenario years. MRTS implementation would subsequently reduce the vehicular kilometres travelled in the zone of influence (ZIF), as people will shift from their current mode of transport to MRTS. In the present study, the methodology for estimation of emissions reduced due to shifting of on-road vehicles after the introduction of metro rail system has been adopted from Sharma et al. (2010; 2014).

5.2.6. 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.

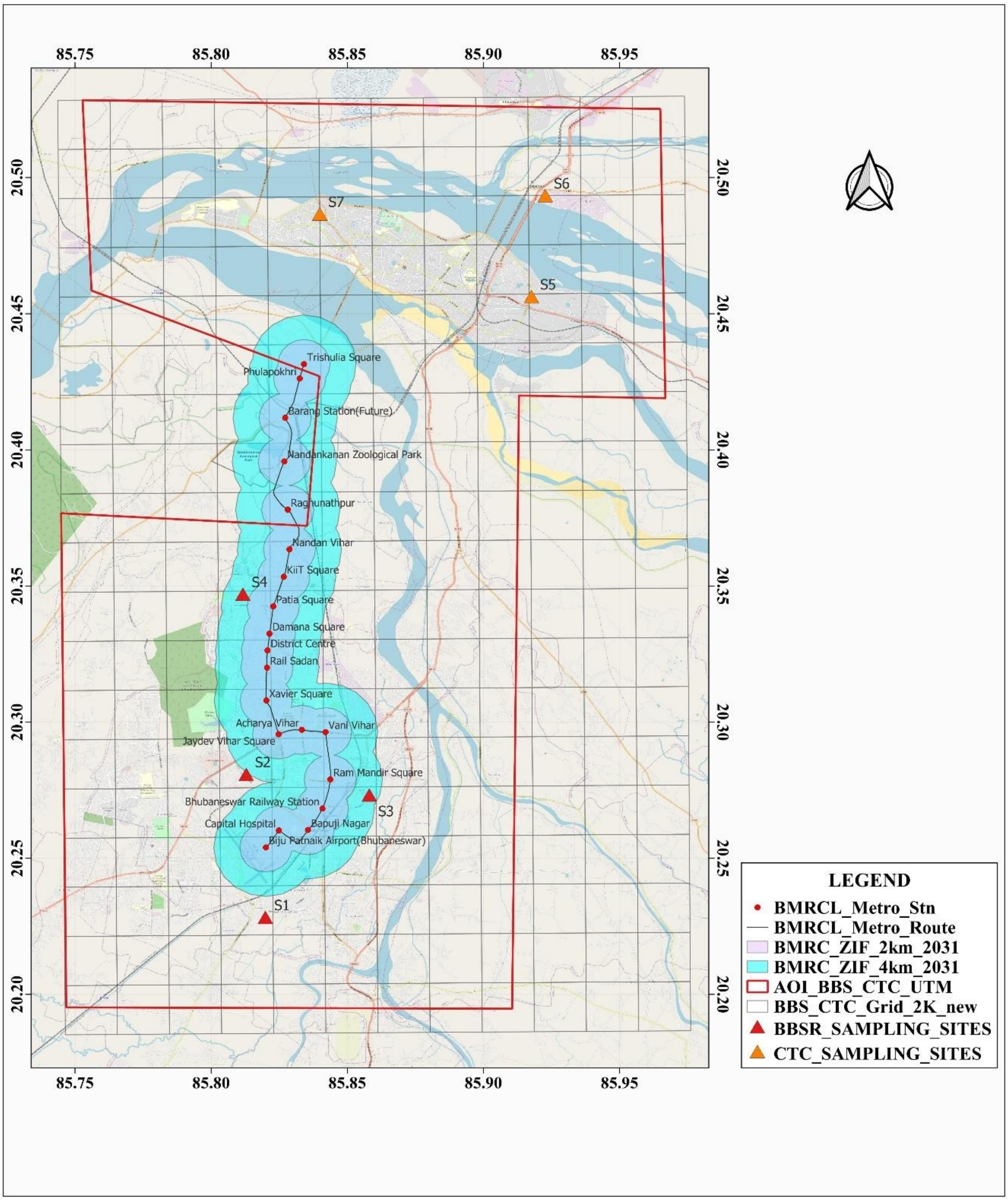

Figure 95 Map showing proposed Mass Rapid Transit System (MRTS) in Bhubaneswar-Cuttack region along with zones of influence (ZIF; 1 km radius and 2 km radius) around each station

5.3. Re-suspended Road Dust

As discussed earlier, road dust re-suspension is a major source of PM emissions in Cuttack 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 Cuttack region however there are two coal-based thermal powerplants located at the north-east and north-west periphery of the study area and few industrial units located in Jagatpur 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. Thermal Powerplants

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

For compliance to Sulphur dioxide (SO2) emission norms, all Thermal Power Plants within 10 km radius of the Non-attainment cities are directed to install Flue Gas Desulphurisation (FGD) control equipment by 31st December, 2025 vide MoEF&CC notification dated 05.09.2022. Considering these timelines, in the present study, it is assumed that Flue gas desulphurization (FGD) systems will be in-place by start year 2027 for control of SO2 emissions in all thermal powerplants in the Cuttack region.

Apart from SO2, it is important to reduce the emissions of other pollutants as well. The present study assesses the air quality improvement in the region by assuming reduction in other pollutant emissions ranging from 5% (intermediate scenarios) to 50% (under the highest aggressive scenario).

5.6. Residential, HRBE and Open Waste Burning Sectors

The quantification of emissions for future years, from residential sector mainly considers the increase in population and changes in fuel usage pattern in Cuttack region. The LPG penetration is estimated to increase gradually based on historic trends in the region whereas use of solid fuels such as wood and coal, for domestic cooking and heating applications is discouraged. Similar to residential sector, hotels and restaurants are assumed to reduce the solid fuel usage while promoting use of LPG for cooking and tandoor related applications. The open waste burning is assumed to decline in future years under different scenarios, except NFC owing to improved collection efficiency and effective solid waste management.

5.7. Brick Kilns Sector

Currently, the FCBTK type brick kilns are operational in the Cuttack 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.

5.8. Construction Sector

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

5.9. Crematoria Sector

Although, the emissions originating from crematoria contribute less than 0.5% of total PM emissions at regional-scale, these emissions are very important for local scale air pollution problems. Hence, it is proposed to gradually shift the existing wood -based crematoria to 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.

5.10. No Further Control (NFC) Scenario

The NFC scenario considers the activities in each sector would increase following the sectoral growth rates and no additional controls would be implemented till years 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	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • The major control measures considered for the transport sector include: o Increased penetration of BS-VI vehicles • Refer Annexure-H for more details on penetration and applicability of each control measure listed above.	VAHAN database, Odisha EV Policy, 2019 Assumptions
2.	RDST	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • No change in the silt loading on different road types in 2027 and 2032.	Assumptions
3.	INDU	• Industrial emissions are assumed to grow at an annual rate of 8.5% while thermal powerplants are assumed to operate at same capacity as base year (2022). • No additional emission reduction measures in-place i.e. same as baseline year 2022	Odisha Economic Survey 2022-23, Assumptions
4.	RESI	• 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

Sr. No.	Sector	Assumptions, considerations and controls	References
5..	WAST	• The population is estimated based on historic population growth rate. • The MSW collection efficiency in the study area for years 2027 and 2032 would remain same as baseline year.	Assumptions
6.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • The fuel usage characteristics and technology would remain same as the baseline year.	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	• 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	• 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	• 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	• Thermal powerplants are assumed to operate at same capacity as base year (2022) • No additional controls in future years	Assumptions
11.	DSGN	• 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

5.11. 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	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • The major control measures considered for the transport sector include: o Increased penetration of BS-VI vehicles o Introduction of E20 fuel o Increased electric vehicles (EV) penetration o Increased CNG penetration o Reduction in VKT due to increase in Non-motorized transport (NMT) share o Introduction of Mass Rapid Transit System (MRTS) in Bhubaneswar region o Improvement in public transport o 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	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • The silt loading on different road types calculated by assuming following: o Year 2027: 15% silt load reduction @ Highways and Major roads and 10% silt	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		load reduction @ Inter, Minor and residential roads ○ Year 2032: 30% silt load reduction @ Highways and Major roads and 20% silt load reduction @ Inter, Minor and residential roads	
3.	INDU	• Industrial emissions are assumed to grow at an annual rate of 8.5% while thermal powerplants are assumed to operate at same capacity as base year (2022). • Thermal powerplants to install Flue gas Desulphurization (FGD) systems for control of SO2 emissions. • Assumed an emission reduction for Industries: ○ 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	• The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: ○ Year 2027: 1. CMC HH: 85% 2. Rural HH: 70% 3. Slum HH: 65% ○ Year 2032: 1. CMC HH: 90% 2. Rural HH: 70% 3. Slum HH: 70%	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5..	WAST	• The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency:	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
		○ Year 2027: 1. CMC Area: 90% 2. Rural Area: 65% 3. Slum Area: 65% ○ Year 2032: 1. BMC HH: 90% 2. Rural HH: 70% 3. Slum HH: 70%	
6.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%. • 10% and 20% facilities would be converted from wood/coal to LPG in years 2027 and 2032, respectively.	Odisha Economic Survey 2022-23, Assumptions
7.	BRIC	• 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	• The construction activities are assumed to increase at growth rate of 6.4% till 2032 • 5% reduction in PM due to adoption of Good construction practices and stricter enforcement.	Odisha Economic Survey 2022-23, Assumptions
9.	CREM	• The deaths in 2027 and 2032 are estimated using the crude death rate. • The 10% 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	• Thermal powerplants are assumed to operate at same capacity as base year (2022) • 10% PM emission reduction compared to corresponding NFC scenarios in years 2027 and 2032.	Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References
11.	DSGN	• 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 – 2 hours depending on locality	Odisha Economic Survey 2022-23, Assumptions

5.12. Scenario – I (SC-I)

The SC-I scenario considers the activity changes due to already planned policies/interventions by the government in years 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	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • The major control measures considered for the transport sector include: ○ Increased penetration of BS-VI vehicles ○ Introduction of E20 fuel ○ Increased electric vehicles (EV) penetration ○ Increased CNG penetration ○ Reduction in VKT due to increase in Non-motorized transport (NMT) share ○ Introduction of Mass Rapid Transit System (MRTS) in Bhubaneswar region ○ 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	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • The silt loading on different road types calculated by assuming following: ○ 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	• Industrial emissions are assumed to grow at an annual rate of 8.5%	Odisha Economic

Sr. No.	Sector	Assumptions, considerations and controls	References
		• Thermal powerplants to install Flue gas Desulphurization (FGD) systems for control of SO2 emissions. • Assumed an emission reduction for Industries and thermal power plants: ○ 2027: 10% reduction in all pollutants w.r.t. corresponding NFC ○ 2032: 25% reduction in all pollutants w.r.t. corresponding NFC	Survey 2022-23, Assumptions
4.	RESI	• The population is estimated based on historic population growth rate. • The assumed LPG penetration in study area: ○ Year 2027: 1. CMC HH: 90% 2. Rural HH: 75% 3. Slum HH: 70% ○ Year 2032: 1. BMC HH: 95% 2. Rural HH: 80% 3. Slum HH: 85%	ARAI Surveys, 2021 Census 2011 and NFHS 2019-2021 report Assumptions
5.	WAST	• The population is estimated based on historic population growth rate. • The assumed MSW collection efficiency: ○ Year 2027: 1. BMC Area: 95% 2. Rural Area: 75% 3. Slum Area: 75% ○ Year 2032: 1. BMC HH: 95% 2. Rural HH: 80% 3. Slum HH: 80%	Assumptions
6.	HRBE	• The hotel and restaurants are assumed to follow an annual growth rate of 9.96%.	Odisha Economic

Sr. No.	Sector	Assumptions, considerations and controls	References
		• 20 and 40% facilities would be converted from wood/coal to LPG in years 2027 and 2032, respectively.	Survey 2022-23, Assumptions
7.	BRIC	• The brick kilns are estimated to follow a growth rate of 6.4% till 2032. • All Clamp type brick kilns within CMC area would be converted to Zig-Zag kilns by 2027. • All brick kilns within AOI are converted to Zig-Zag technology by 2032.	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	• 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	• The deaths in 2027 and 2032 are estimated using the crude death rate. • The 25% and 75% 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	• Thermal powerplants are assumed to operate at same capacity as base year (2022) • 20% and 25% PM emission reduction compared to corresponding NFC scenarios in years 2027 and 2032.	Assumptions
11.	DSGN	• 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 0.75 – 1.5 hours depending on locality	Odisha Economic Survey 2022-23, Assumptions

5.13. Scenario – II (SC-II)

The SC-II scenario considers the activity changes due to already planned policies/interventions by the government in years 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	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • The major control measures considered for the transport sector include: o Increased penetration of BS-VI vehicles o Introduction of E20 fuel o Increased electric vehicles (EV) penetration o Increased CNG penetration o Reduction in VKT due to increase in Non-motorized transport (NMT) share o Introduction of Mass Rapid Transit System (MRTS) in Bhubaneswar region o Improvement in public transport o 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	• The vehicles in Cuttack region are estimated to grow at a CAGR of 6.1% till 2032. • The silt loading on different road types calculated by assuming following: o Year 2027: 50% silt load reduction @ Highways and Major roads and 30% silt load reduction @ Inter, Minor and residential roads o Year 2032: 90% silt load reduction @ Highways and Major roads and 60% silt load reduction @ Inter, Minor and residential roads	Assumptions
3.	INDU	• Industrial emissions are assumed to grow at an annual rate of 8.5%	Odisha Economic Survey 2022-23, Assumptions

Sr. No.	Sector	Assumptions, considerations and controls	References

		• Thermal powerplants to install Flue gas Desulphurization (FGD) systems for control of SO2 emissions.
		• Assumed an emission reduction for Industries:
		  ○ 2027: 25% reduction in all pollutants w.r.t. corresponding NFC
		  ○ 2032: 50% reduction in all pollutants w.r.t. corresponding NFC	

4.	RESI	• The population is estimated based on historic population growth rate.
		• The assumed LPG penetration in study area:
		  ○ Year 2027:
		    1. CMC HH: 95%
		    2. Rural HH: 80%
		    3. Slum HH: 80%
		  ○ Year 2032:
		    1. CMC HH: 100%
		    2. Rural HH: 90%
		    3. Slum HH: 95%
			ARAI Surveys, 2021
			Census 2011 and NFHS 2019-2021 report
			Assumptions

5.	WAST	• The population is estimated based on historic population growth rate.
		• The assumed MSW collection efficiency:
		  ○ Year 2027:
		    1. CMC Area: 98%
		    2. Rural Area: 80%
		    3. Slum Area: 80%
		  ○ Year 2032:
		    1. CMC HH: 98%
		    2. Rural HH: 90%
		    3. Slum HH: 95%
			Assumptions

6.	HRBE	• 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

Sr. No.	Sector	Assumptions, considerations and controls	References
7.	BRIC	• The brick kilns are estimated to follow a growth rate of 6.4% till 2032. • All brick kilns within BMC area would be converted to VSBK/Zig-Zag kilns by 2027. • All brick kilns within study area would be converted to VSBK/Zig-Zag technology by 2032.	Odisha Economic Survey 2022-23, Assumptions
8.	CONS	• 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	• The deaths in 2027 and 2032 are estimated using the crude death rate. • The 50% and 100% of the crematoria 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	• Thermal powerplants are assumed to operate at same capacity as base year (2022) • 25% and 50% PM emission reduction compared to corresponding NFC scenarios in years 2027 and 2032.	Assumptions
11.	DSGN	• 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 0.5 to 1 hours depending on locality	Odisha Economic Survey 2022-23, Assumptions

5.14. 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 Cuttack region. As discussed earlier, these scenarios consider implementation of various control measures explained in Section 5.12 in Cuttack region with varying factors for 2027 and 2032. Table 25 and Figures 96 to 100 presents the summary of estimated emissions (tonnes per year) of selected pollutants for four scenarios in Cuttack 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 Cuttack region indicate a potential increase in PM_{10} emissions to 7709 tonnes per year in 2027 i.e. an increase of 20.4% w.r.t. baseline year 2022 and to 9798 tonnes per year in 2032 i.e. an increase of 53.0% w.r.t. baseline year 2022. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to reach to 3794 (20.0%) and to 4552 tonnes per year (i.e. 43.9%) in 2027 and 2032, respectively. The projected emissions of SO_2 indicate a potential increase to 2028 tonnes per year in 2027 i.e. an increase of 13.2% w.r.t. baseline year 2022 and to 2290 tonnes per year in 2032 i.e. an increase of 27.9% w.r.t. baseline year 2022. The projected emissions of NO_X indicate a potential increase to 16815 tonnes per year in 2027 i.e. an increase of 12.9% w.r.t. baseline year 2022 and to 17718 tonnes per year in 2032 i.e. an increase of 18.9% w.r.t. baseline year 2022. The CO emissions are expected to increase to 37588 tonnes per year in 2027 i.e. an increase of 26.3% and 45108 tonnes per year in 2032 i.e. an increase of 51.6% w.r.t. baseline year 2022.

The BAU projections in Cuttack region indicate a potential decrease of PM_{10} emissions to 6837 tonnes per year in 2027 i.e. a decrease of 11.3 % w.r.t. NFC 2027 and to 7545 tonnes per year in 2032 i.e. a decrease of 23.0% w.r.t. NFC 2032. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 3368 (-11.2%) and to 3505 tonnes per year (i.e. -23.0%) in 2027 and 2032, respectively. Sulphur dioxide (SO_2) emissions are projected to decrease by 45.3% (i.e. 1109 tonnes per year) and decrease by 44.6% (i.e.1268 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 16222 tonnes per year in 2027 i.e. an decrease of 3.5% w.r.t. NFC_2027 and to 15141 tonnes per year in 2032 i.e. an decrease of 14.5% w.r.t. NFC 2032. The CO emissions are expected to decrease to 35072 tonnes per year in 2027 i.e. a decrease of 6.7% w.r.t. NFC 2027 and 39139 tonnes per year in 2032 i.e. a decrease of 13.2% w.r.t. NFC 2032.

The SC-I projections in Cuttack region indicate a potential decrease of PM_{10} emissions to 5868 tonnes per year in 2027 i.e. a decrease of 23.9% w.r.t. NFC 2027 and to 5392 tonnes per year in 2032 i.e. a decrease of 45.0% % w.r.t. NFC 2032. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 2847 (-25.0%) and to 2609 tonnes per year (i.e. -42.7%) in 2027 and 2032, respectively. Sulphur dioxide emissions are projected to decline by 51.4% (i.e. 986 tonnes per year) and 59.7% (i.e. 923 tonnes per year) in 2027 and 2032, respectively, relative to their respective NFC scenarios. Similarly, projected emissions of NOx indicate a potential reduction to 14937 tonnes per year in 2027 i.e. a decrease of 11.2% w.r.t. NFC 2027 and to 13478 tonnes per year in 2032 i.e. a decrease of 15.9% w.r.t. NFC 2032. The CO emissions are expected to decrease to 34425 tonnes per year in 2027 i.e. a decrease of 23.7% w.r.t. NFC 2027 and 68211tonnes per year in 2032 i.e. a decrease of 18.3% w.r.t. NFC 2032.

The SC-II projections in Cuttack region indicate a potential decrease of PM_{10} emissions to 4744 tonnes per year in 2027 i.e. a decrease of 38.5% w.r.t. NFC 2027 and to 2999 tonnes per year in 2032 i.e. a decrease of 69.4% w.r.t. NFC 2032. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 2349 (i.e. -38.1%) and to 1608 tonnes per year (i.e. -64.7%) in 2027 and 2032, respectively. Sulphur dioxide (SO_2) emissions are projected to decline by 60.9% (i.e. 793 tonnes per year) and 71.0% (i.e. 665 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 13338 tonnes per year in 2027 i.e. a decrease of 20.7% w.r.t. NFC 2027 and to 11171 tonnes per year in 2032 i.e. a decrease of 37.0% w.r.t. NFC 2032. The CO emissions are expected to decrease to 28377 tonnes per year in 2027 i.e. a decrease of 24.5% w.r.t. NFC 2027 and 28890 tonnes per year in 2032 i.e. a decrease of 36.0% w.r.t. NFC 2032.

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

Year	Scenario	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
2022	BASE	6,404	3,163	1,791	14,898	29,758
2027	NFC	7,709	3,794	2,028	16,815	37,588
	BAU	6,837	3,368	1,109	16,222	35,072
	SC_I	5,868	2,847	986	14,937	31,610
	SC_II	4,744	2,349	793	13,338	28,377
2032	NFC	9,798	4,552	2,290	17,718	45,108
	BAU	7,545	3,505	1,268	15,141	39,139
	SC_I	5,392	2,609	923	13,478	34,425
	SC_II	2,999	1,608	665	11,171	28,890

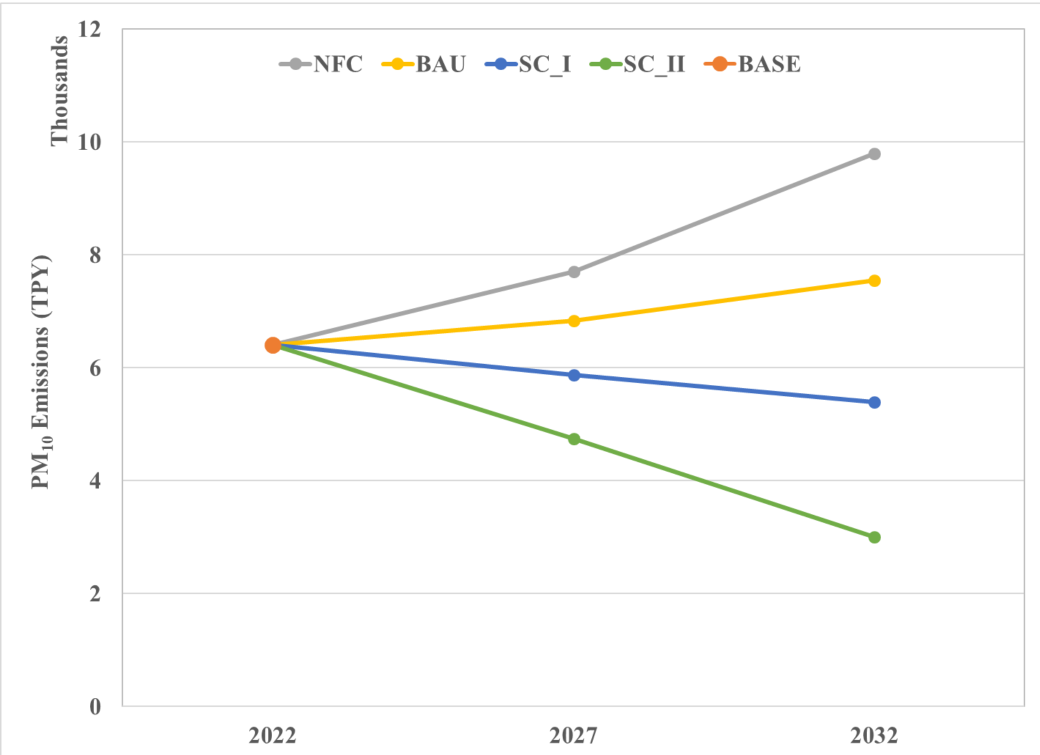

Figure 96 PM10 Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

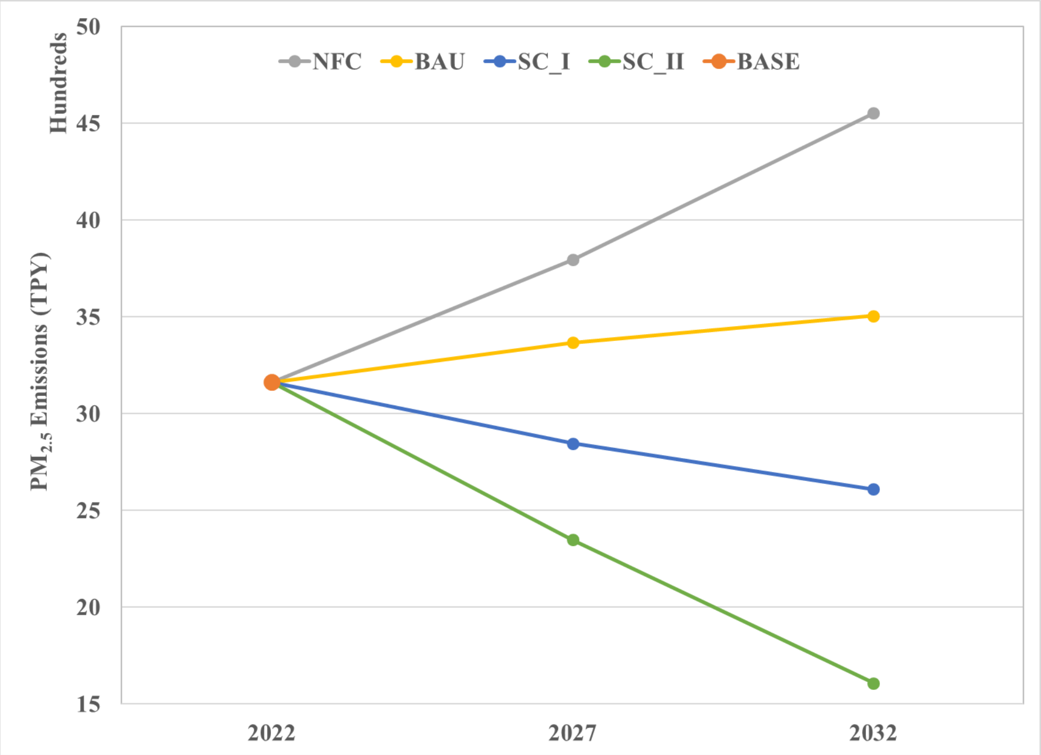

Figure 97 PM2.5 Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

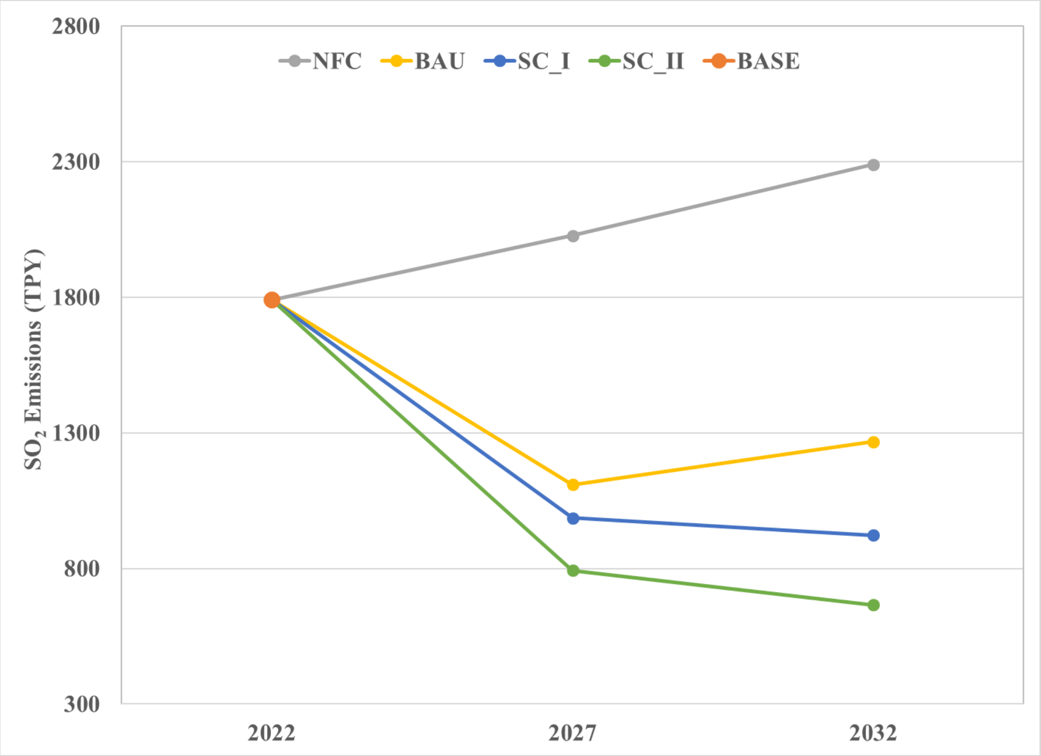

Figure 98 SO2 Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

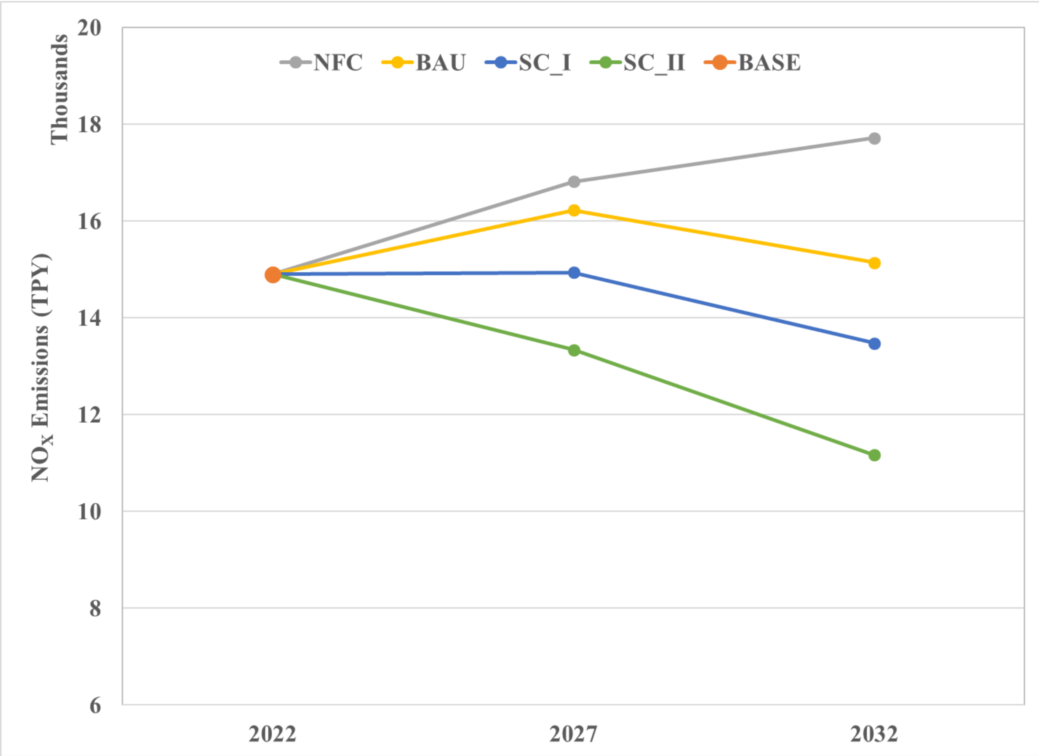

Figure 99 NO_X Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

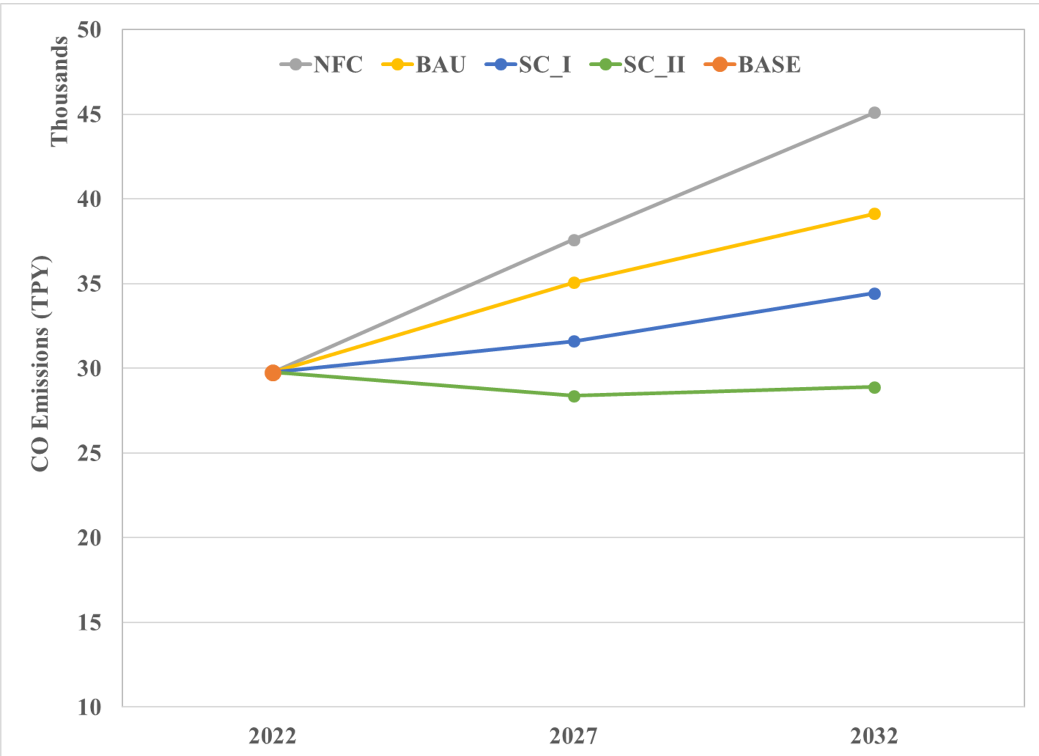

Figure 100 CO Projected emissions (tonnes per year) under NFC, BAU, SC-I and SC-II scenario in 2027 and 2032

5.14.1. Sector-wise emission reduction potentials

Table 26 and Fig. 101-105 shows sector-wise and total estimated emission reduction potential (%) of pollutants w.r.t. respective NFC scenarios in Cuttack region for years 2027 and 2032. The total emissions of particulate matter in 2027 can be reduced upto maximum 38.5% and 38.1% in PM_{10} and $PM_{2.5}$, respectively w.r.t. NFC 2027 scenario. Similarly, total emissions of particulate matter in 2032 can be reduced upto maximum 69.4% and 64.7% in PM_{10} and $PM_{2.5}$, respectively w.r.t. NFC 2032 scenario. In year 2032 the sectoral emission reduction potential for PM_{10} in decreasing order of reduction are road dust (upto 38.71%), residential (upto 5.73%), industries and powerplants (upto 5.44%), and open waste burning (upto 5.16%). Remaining PM_{10} emission sources together contribute 6.83% reduction in PM_{10}. Similarly, for $PM_{2.5}$ significant emission reductions can be obtained in re-suspended road dust (upto 22.27%), residential (upto 10.56%), open waste burning (upto 10.31%) and hotels, restaurants, bakeries and eateries (upto 7.70%).

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

Year	Sector	PM_{10}			$PM_{2.5}$		
		BAU	SC-I	SC-II	BAU	SC-I	SC-II
2027	INDU	-0.63%	-1.25%	-3.13%	-0.4%	-0.9%	-2.25%
	TRAN	-0.07%	-0.43%	-0.98%	-0.1%	-0.8%	-1.79%
	RDST	-5.23%	-10.36%	-17.25%	-2.8%	-5.6%	-9.37%
	RESI	-1.94%	-3.94%	-5.96%	-2.6%	-5.4%	-7.88%
	WAST	-1.46%	-3.51%	-4.43%	-2.8%	-6.6%	-8.35%
	HRBE	-0.91%	-1.82%	-2.73%	-1.2%	-2.3%	-3.46%
	CONS	-0.06%	-0.13%	-0.25%	0.0%	-0.1%	-0.13%
	BRIC	0.00%	-0.10%	-0.19%	0.0%	-0.2%	-0.18%
	DSGN	-0.69%	-1.68%	-2.45%	-1.1%	-2.9%	-4.24%
	CREM	-0.06%	-0.15%	-0.30%	-0.1%	-0.1%	-0.30%
	WBDT	0.00%	0.00%	0.00%	0.0%	0.0%	0.00%
	FUGT	-0.26%	-0.52%	-0.78%	-0.1%	-0.1%	-0.15%
	Total	**-11.3%**	**-23.9%**	**-38.5%**	**-11.2%**	**-25.0%**	**-38.1%**
2032	INDU	-1.09%	-2.72%	-5.44%	-0.83%	-2.07%	-4.14%
	TRAN	-0.34%	-0.77%	-1.48%	-0.65%	-1.50%	-2.87%
	RDST	-12.48%	-25.18%	-38.71%	-7.18%	-14.49%	-22.27%
	RESI	-2.98%	-5.24%	-7.52%	-4.51%	-7.41%	-10.56%
	WAST	-1.77%	-3.45%	-5.16%	-3.54%	-6.90%	-10.31%
	HRBE	-1.91%	-3.82%	-5.73%	-2.57%	-5.14%	-7.70%
	CONS	-0.06%	-0.18%	-0.36%	-0.03%	-0.10%	-0.19%
	BRIC	-0.19%	-0.37%	-0.48%	-0.19%	-0.23%	-0.38%
	DSGN	-1.73%	-2.35%	-2.99%	-3.19%	-4.35%	-5.53%
	CREM	-0.25%	-0.37%	-0.50%	-0.26%	-0.39%	-0.52%
	WBDT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	FUGT	-0.21%	-0.51%	-1.03%	-0.04%	-0.11%	-0.21%
	Total	**-23.0%**	**-45.0%**	**-69.4%**	**-23.0%**	**-42.7%**	**-64.7%**

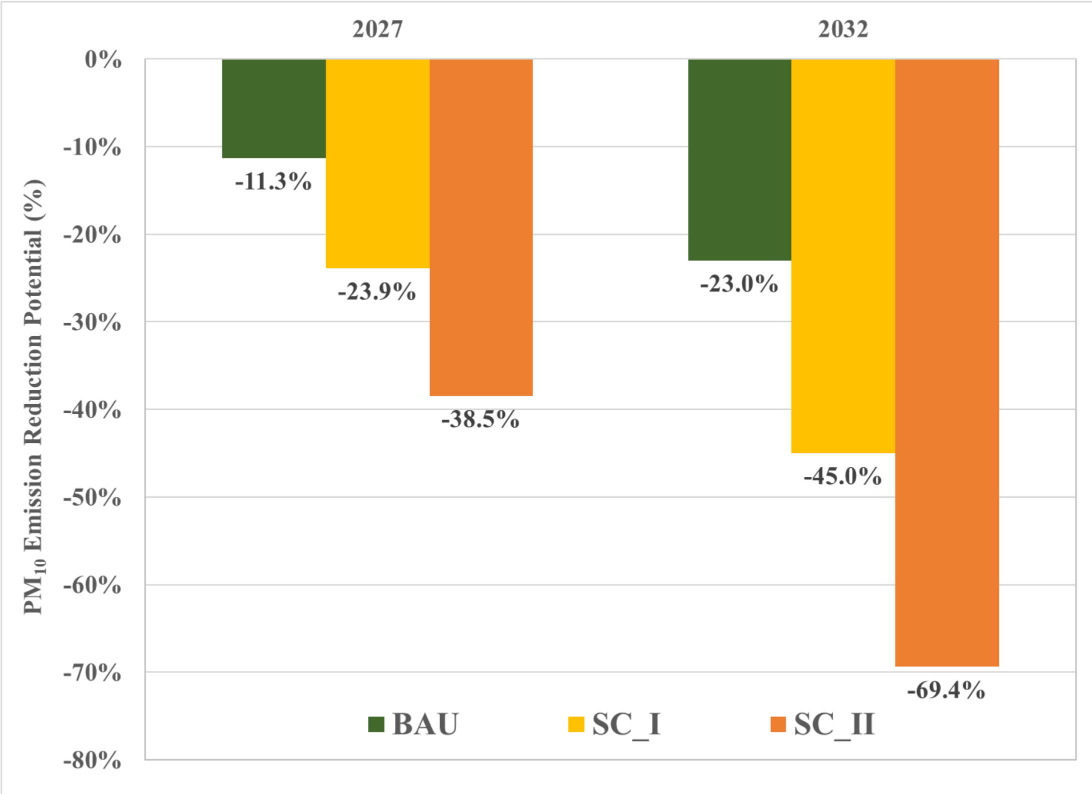

Figure 101 PM10 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

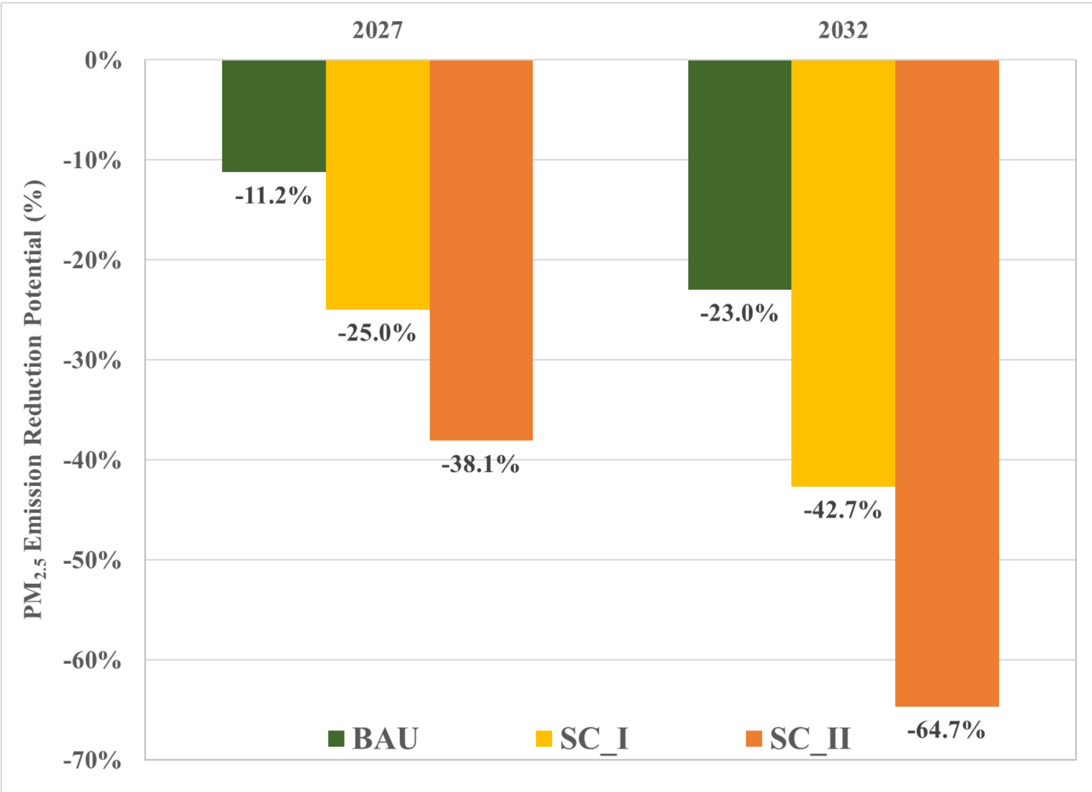

Figure 102 PM2.5 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

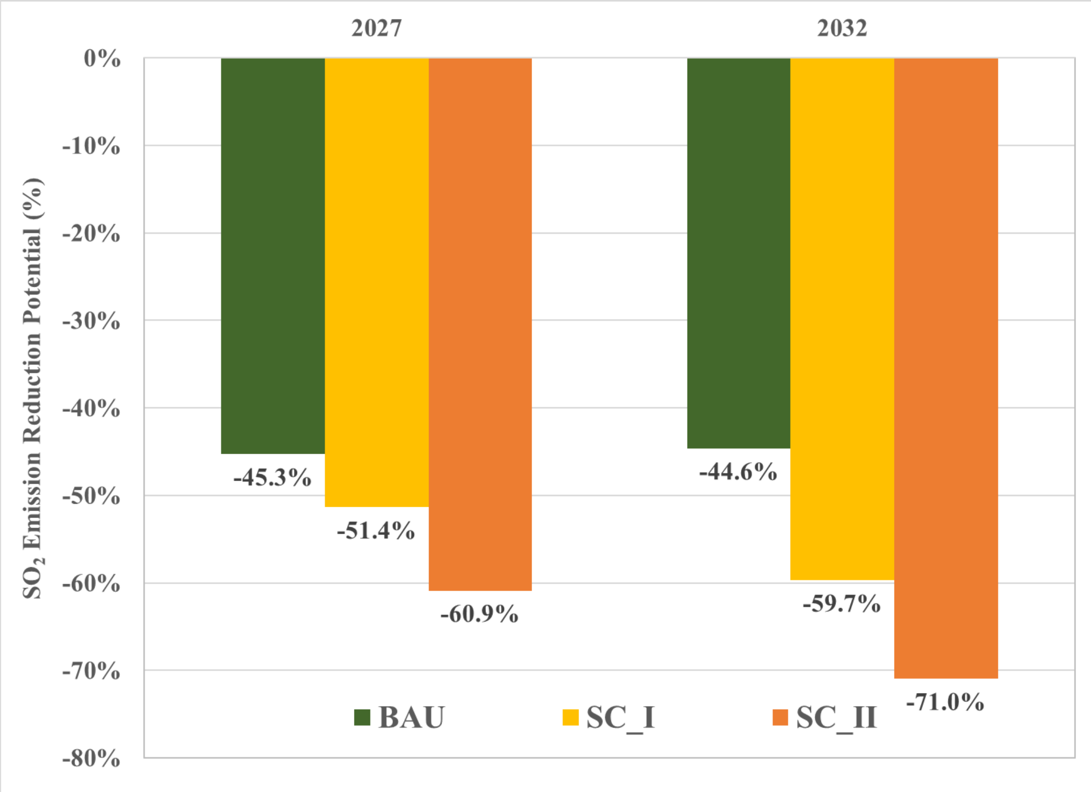

Figure 103 SO2 Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

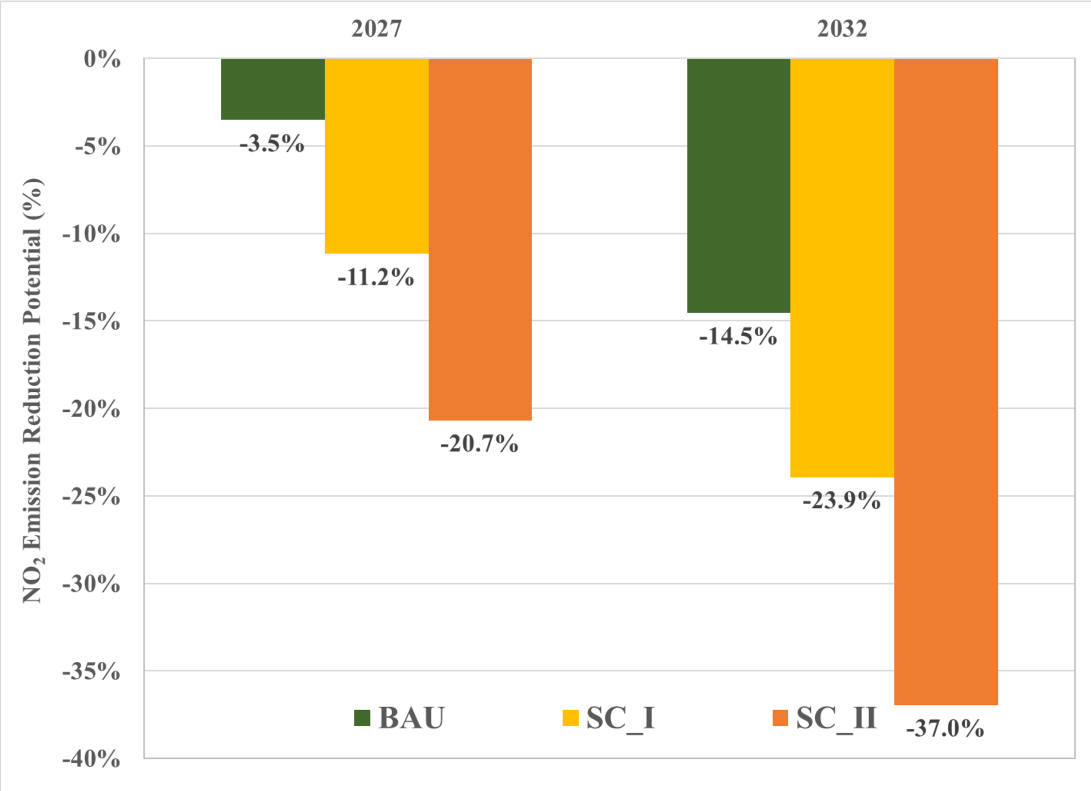

Figure 104 NO_X Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

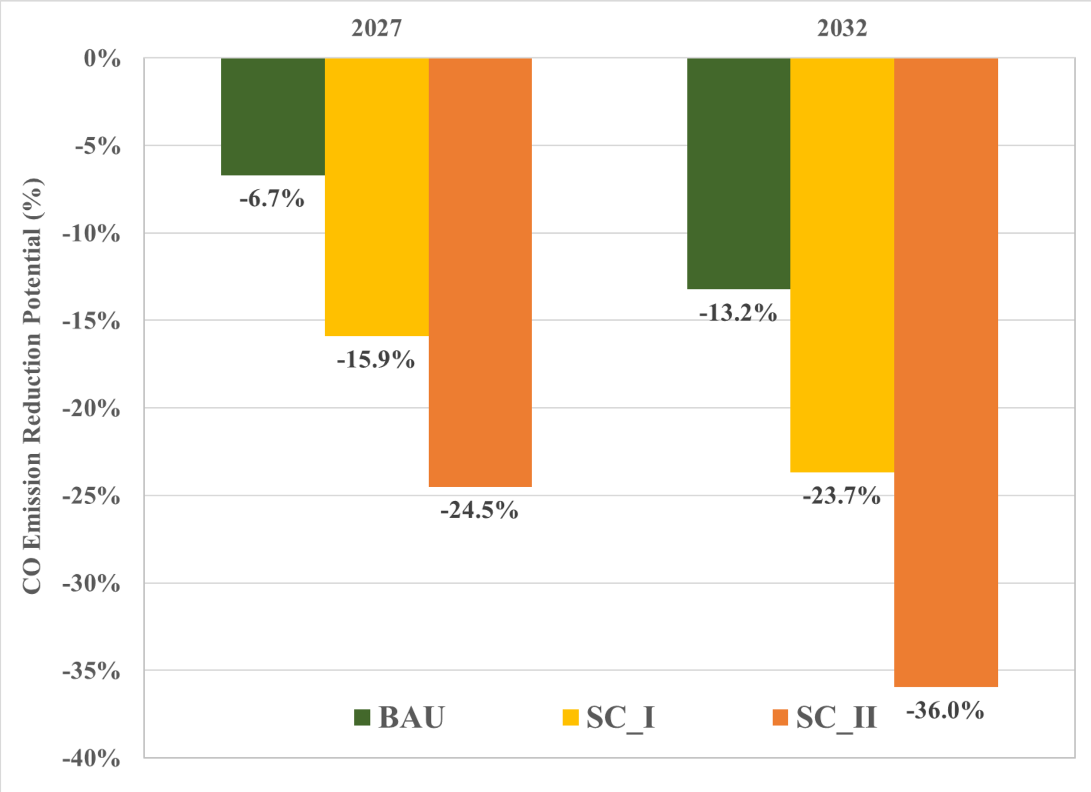

Figure 105 CO Emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II) of 2027 and 2032

5.15. 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 Bhubaneswar-Cuttack region. The spatial distribution of pollutant (PM_{10}, $PM_{2.5}$. SO_2, NO_2, CO) concentration levels over Bhubaneswar-Cuttack 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 PM2.5 are observed towards central parts of Bhubaneswar and Cuttack regions 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 106-107, the PM_{10} concentrations for NFC scenario in 2027 and 2032, are mainly concentrated in the central parts of the Bhubaneswar and Cuttack regions. The domain-averaged annual PM_{10} concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 64.4, 59.7, 54.3, and 48.3 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual PM_{10} concentrations during year 2032 are estimated to be 78.2, 64.0, 52.3, and 38.5 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 6.7%, 14.3%, and 22.8% in 2027 and 16.3%, 30.2%, and 46.3% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 108-109, the $PM_{2.5}$ concentrations, are also concentrated in central parts of the Bhubaneswar and Cuttack regions. The domain-averaged annual $PM_{2.5}$ concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 29.0, 27.0, 24.5, and 22.0 µg/m^3 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 33.4, 28.0, 23.1, and 17.8 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 6.3%, 14.4%, and 22.4% in 2027 and 15.0%, 28.7%, and 43.4% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 110-111, the SO_2 concentrations, are concentrated in the central parts of the Bhubaneswar and Cuttack regions. The domain-averaged annual SO_2 concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 4.3, 4.2, 3.7, and 3.4 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual SO_2 concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) are estimated to be 4.9, 4.6, 3.9 and 3.2 µg/m^3 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 3.0%, 11.8%, and 17.7% in 2027 and 4.7%, 17.2%, 31.2% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 112-113, the NO_2 concentrations, are also concentrated in central parts of the Bhubaneswar and Cuttack regions. Ambient NO_2 concentrations are mainly driven by ground-level line sources and are found to be highest in the vicinity of highways and major rods where heavy vehicle movement is high. The domain-averaged annual NO_2 concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 13.5, 13.4, 13.2, and 12.9 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios in year 2027, respectively. The domain-averaged annual NO_2 concentrations during year 2032 are estimated to be 13.5, 13.2, 12.8 and 12.3 µg/m^3 for NFC, BAU, SC-I and SC-II scenarios, respectively. With implementation of control measures considered in different scenarios, an estimated reduction of 0.2%, 1.8%, and 3.8% in 2027. With implementation of control measures considered in different scenarios, an estimated reduction of 1.7%, 4.5%, and 8.0% in 2032, could be achieved for BAU, SC-I and SC-II scenarios, respectively.

As shown in Fig 114-115, the CO concentrations, are also concentrated in the central, parts of the Bhubaneswar and Cuttack regions. The domain-averaged annual CO concentrations (i.e. mean of annual concentrations of 260 receptors in the study domain) estimated by AERMOD during four scenarios are 0.586, 0.570, 0.546, and 0.523 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 260 receptors in the study domain) estimated to be 0.657, 0.619, 0.581, and 0.539 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 2.5%, 6.2%, and 9.8% in 2027 and 5.3%, 10.6%, 16.6% 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.

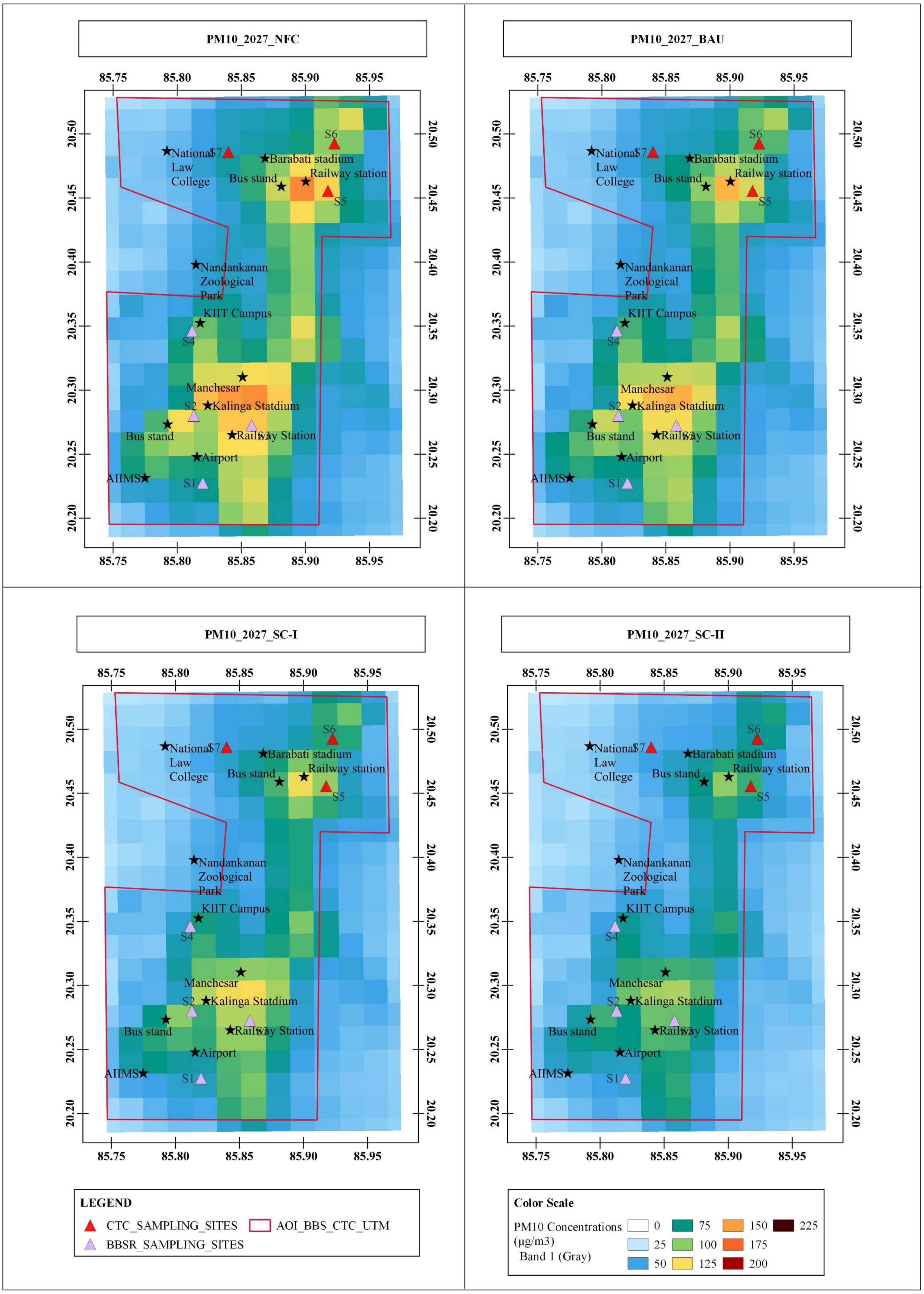

Figure 106 Spatial distribution of annual mean PM_{10} *concentrations* (µg/m^3) *for four scenarios in year 2027 over Bhubaneswar-Cuttack region*

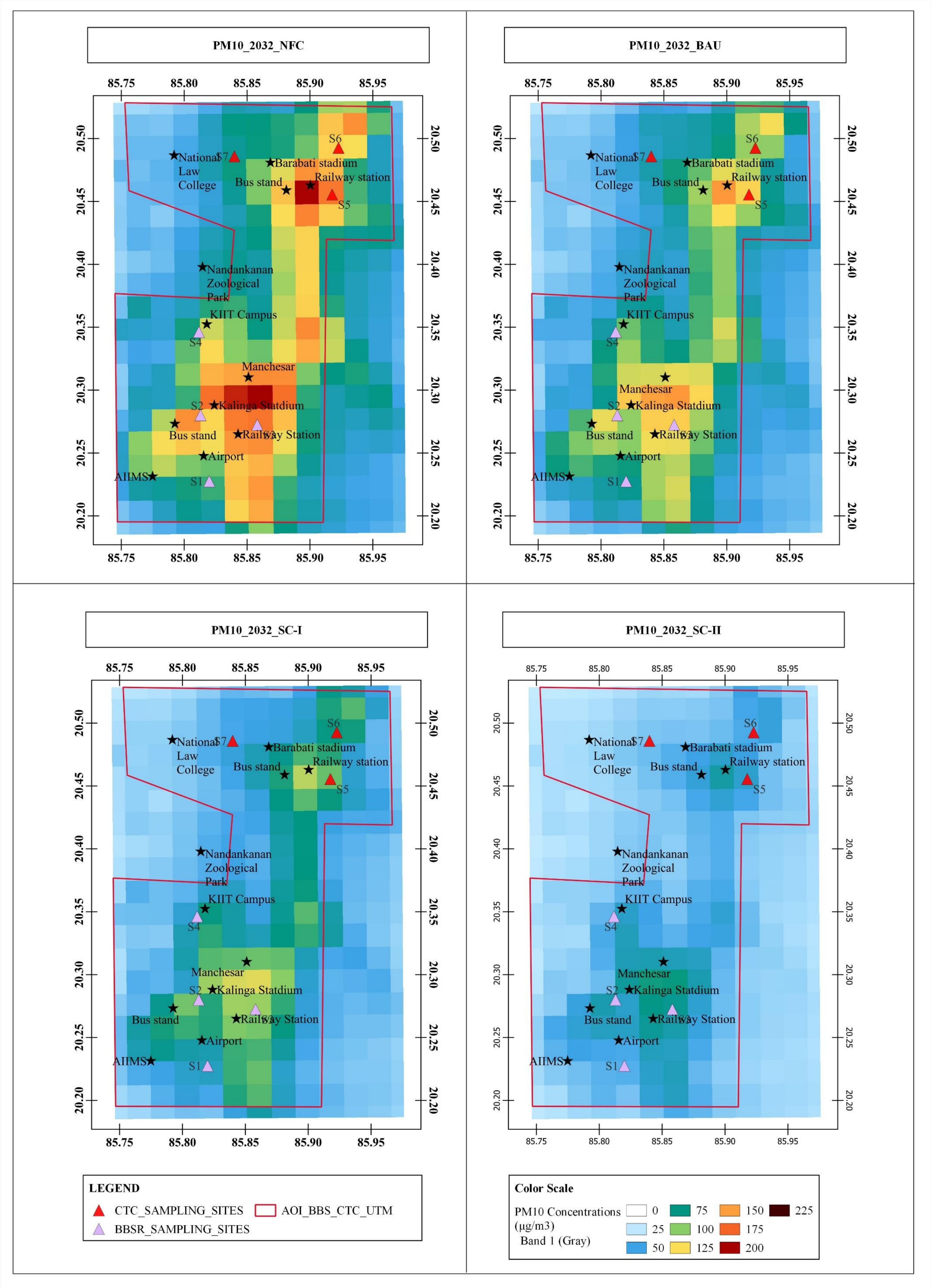

Figure 107 Spatial distribution of annual mean PM$_{10}$ *concentrations* (µg/m^3) *for four scenarios in year 2032 over Bhubaneswar-Cuttack region*

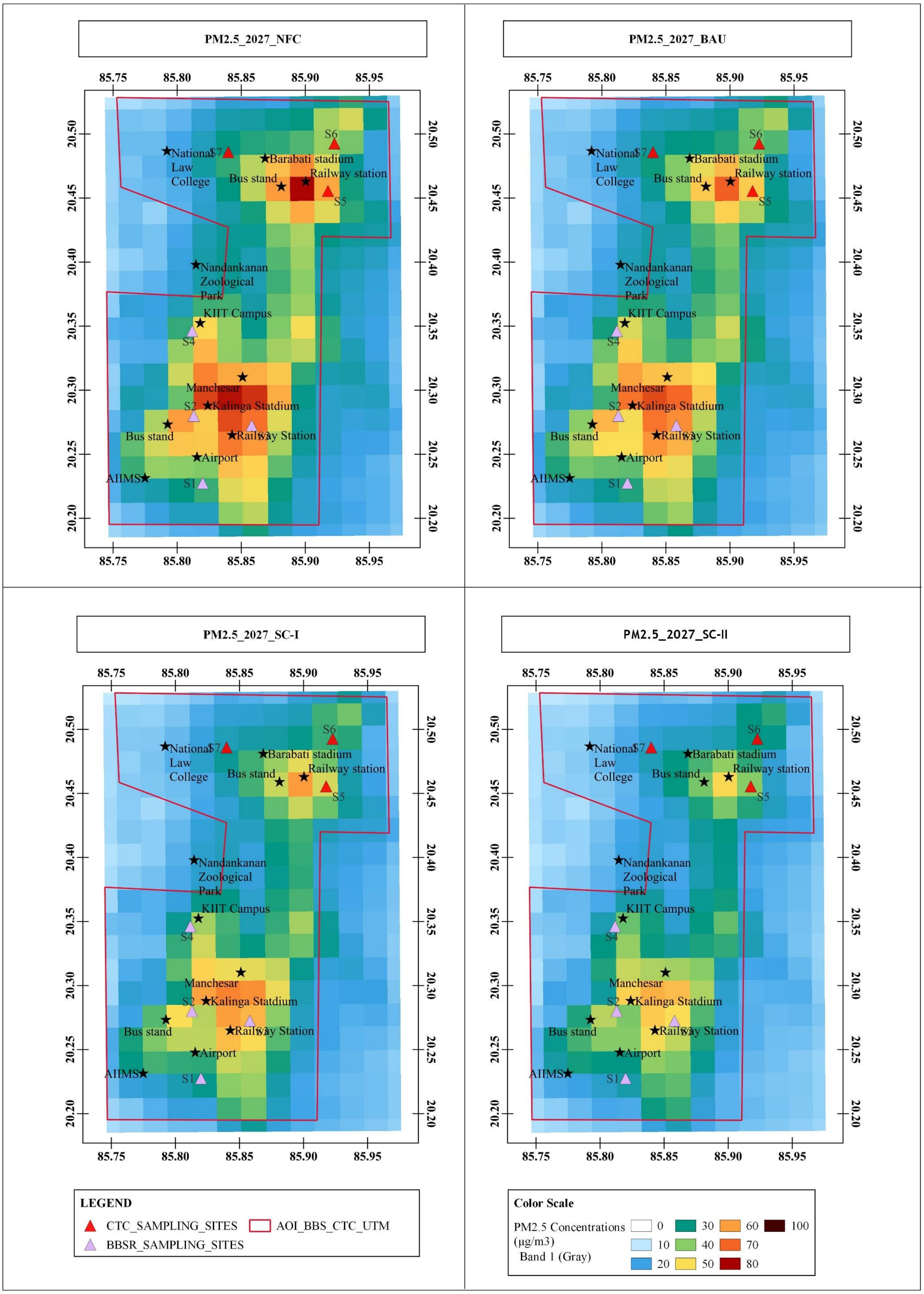

Figure 108 Spatial distribution of annual mean $PM_{2.5}$ *concentrations* (µg/m^3) *for four scenarios in year 2027 over Bhubaneswar-Cuttack region*

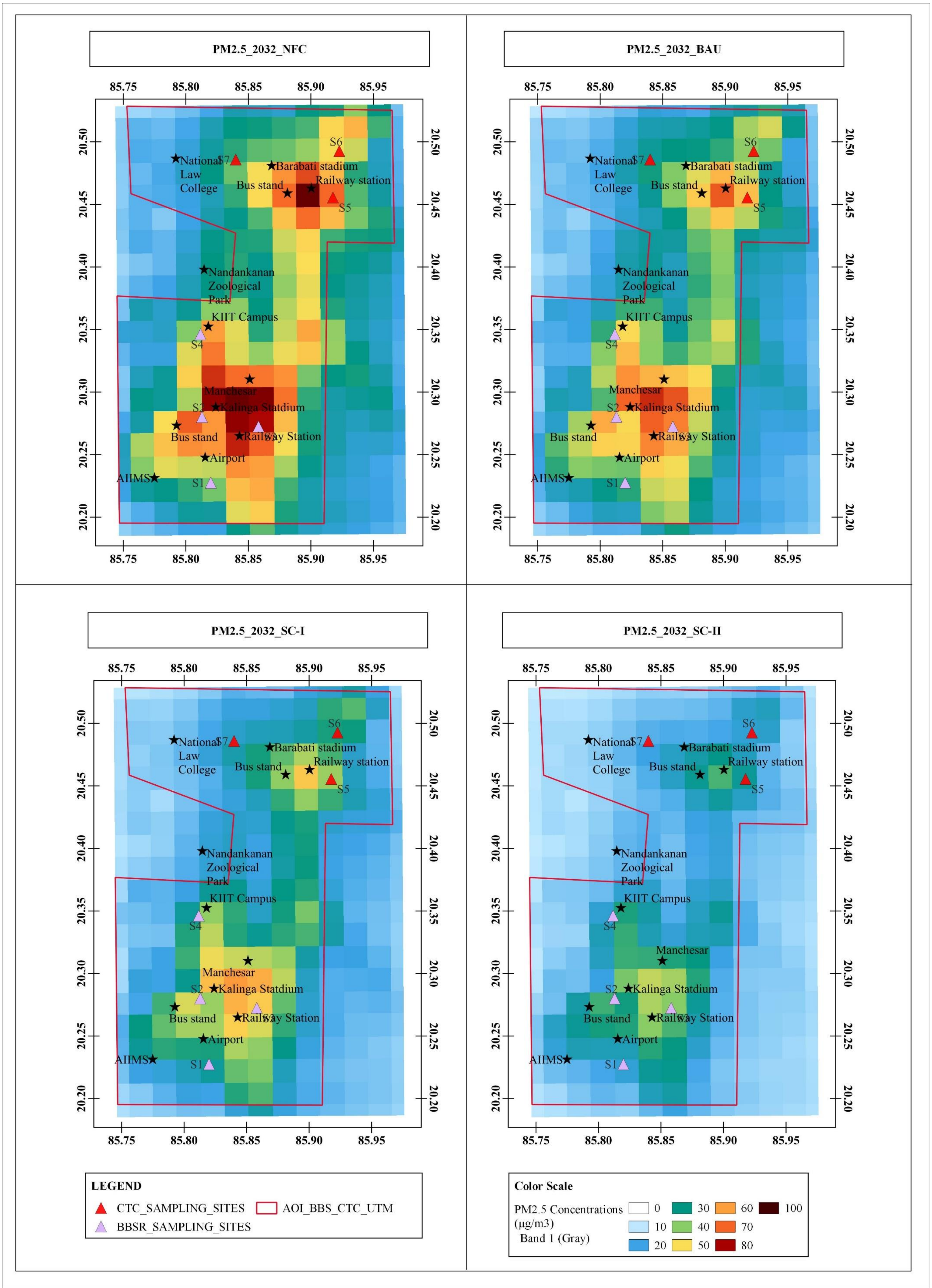

Figure 109 Spatial distribution of annual mean $PM_{2.5}$ *concentrations* ($\mu g/m^3$) *for four scenarios in year 2032 over Bhubaneswar-Cuttack region*

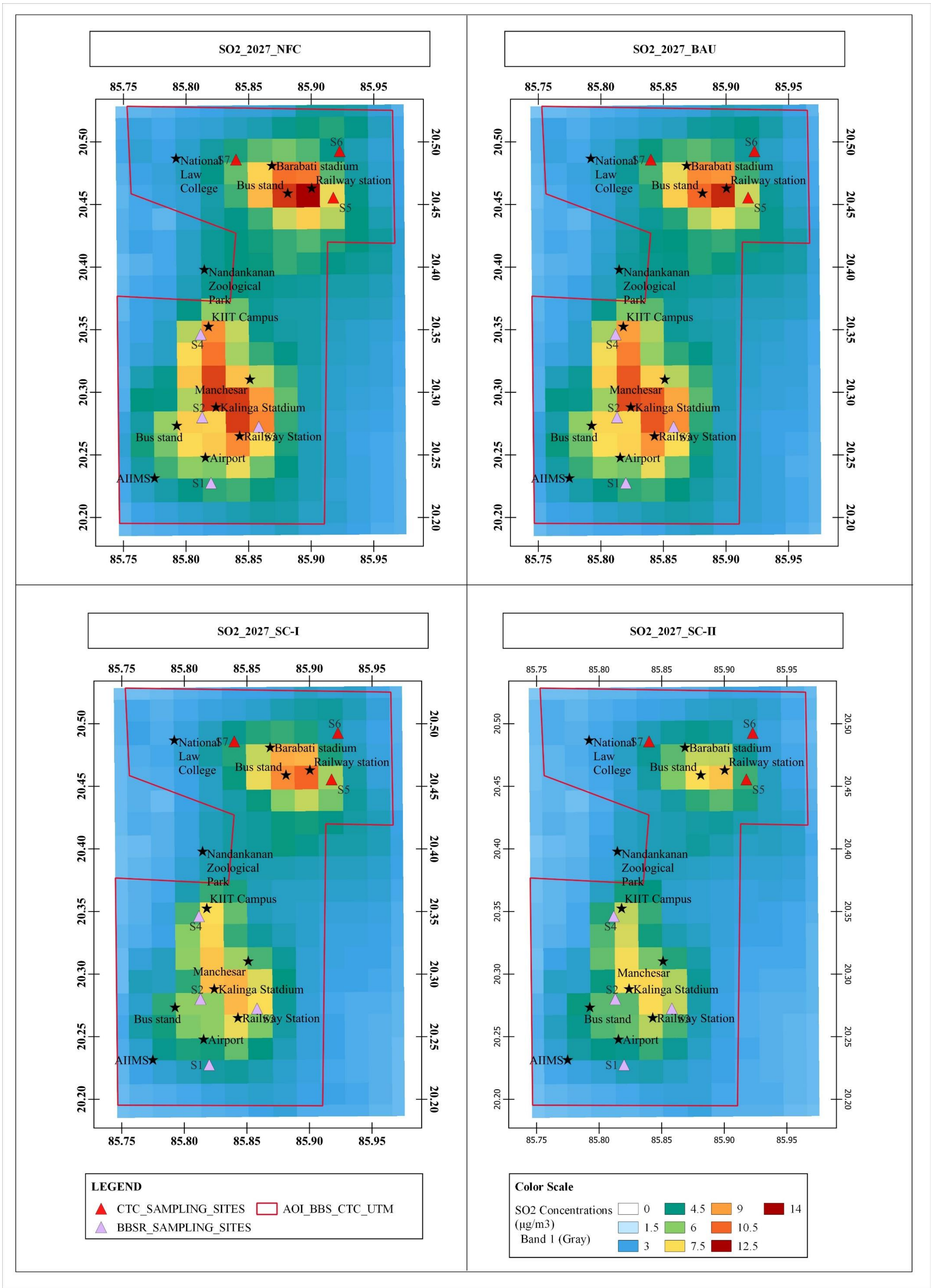

Figure 110 Spatial distribution of annual mean SO_2 *concentrations* ($\mu g/m^3$) *for four scenarios in year 2027 over Bhubaneswar-Cuttack region*

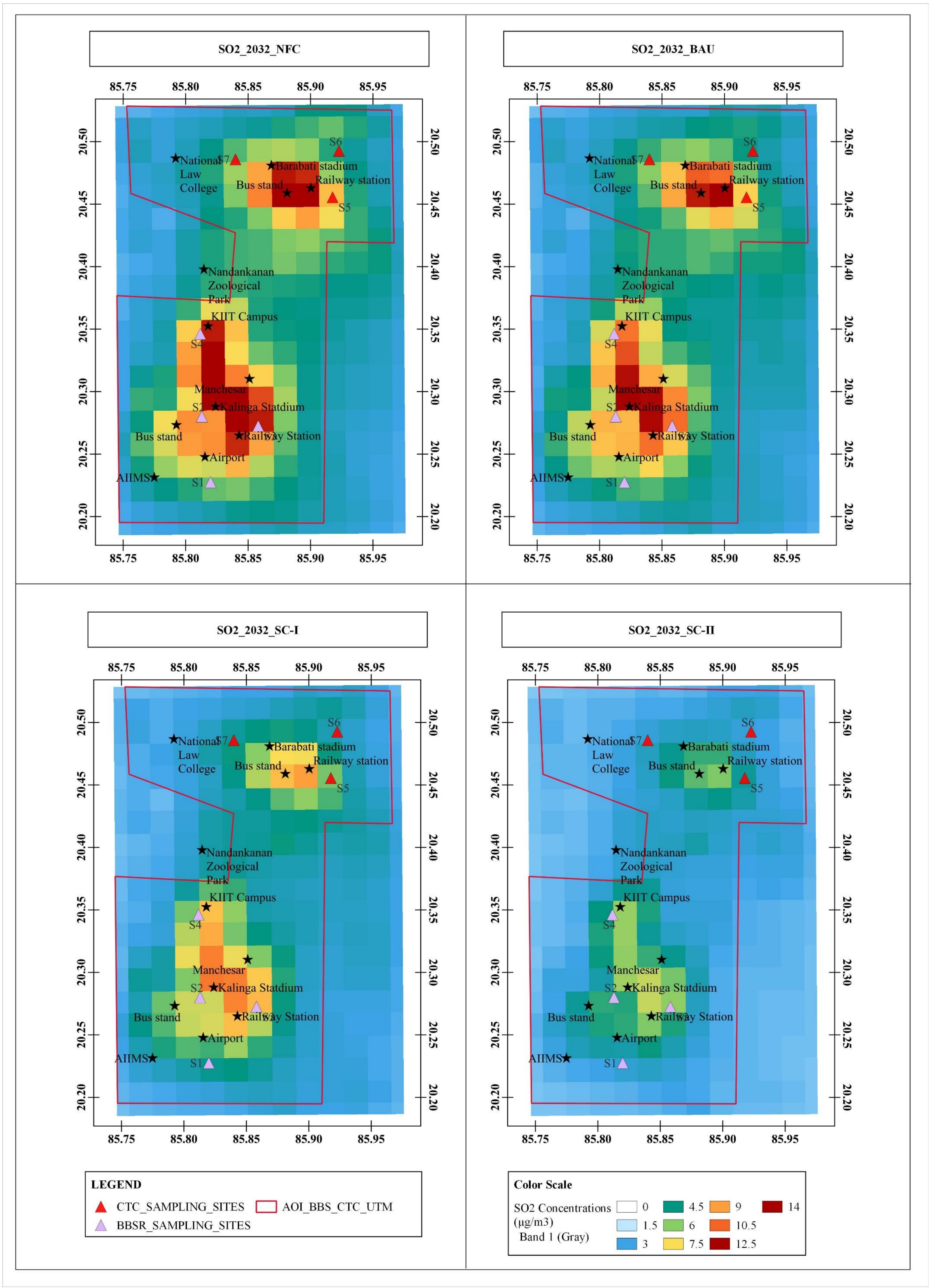

Figure 111 Spatial distribution of annual mean** SO_2 **concentrations** ($\mu g/m^3$) **for four scenarios in year 2032 over Bhubaneswar-Cuttack region

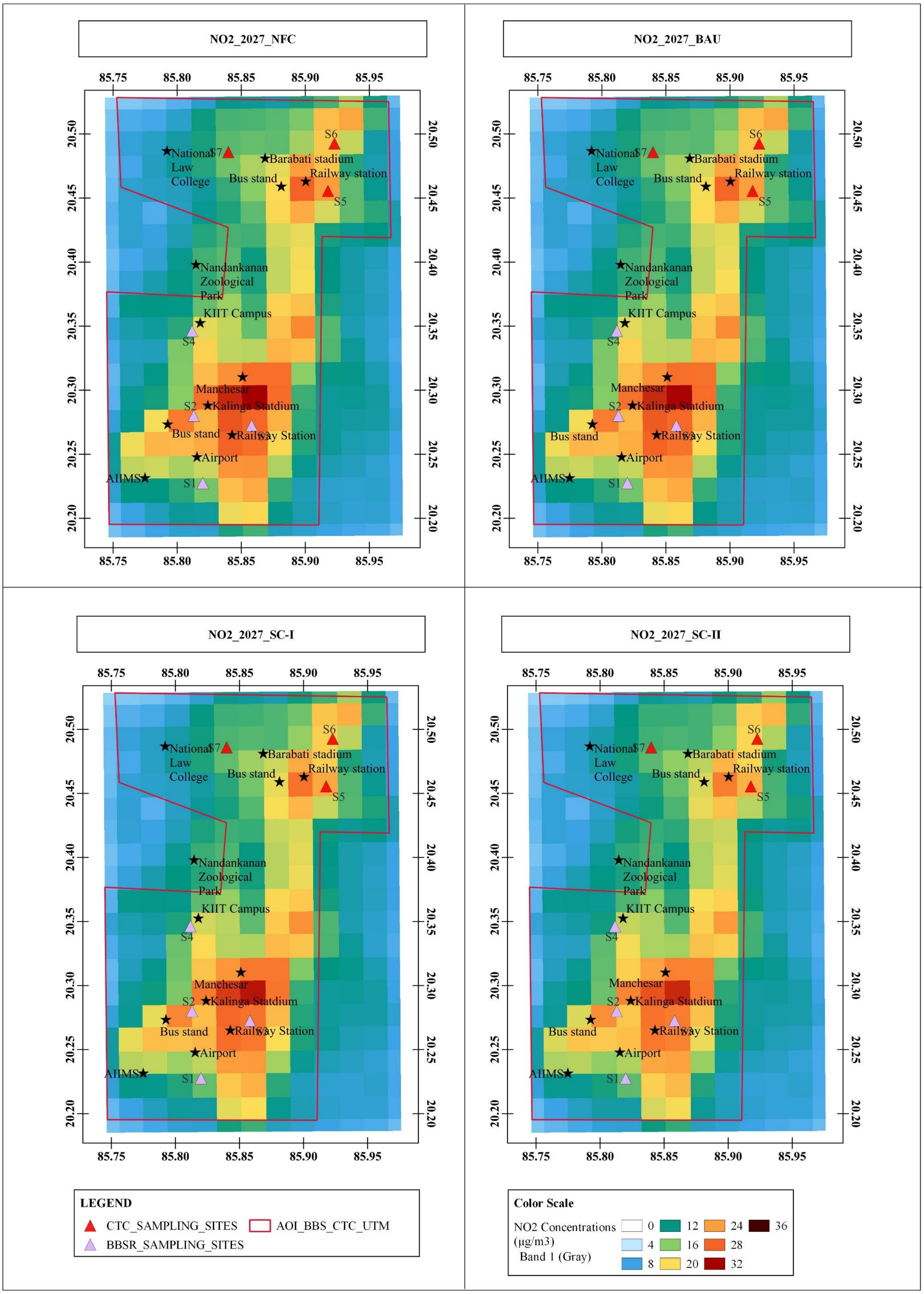

Figure 112 Spatial distribution of annual mean NO_2 *concentrations* ($\mu g/m^3$) *for four scenarios in year 2027 over Bhubaneswar-Cuttack region*

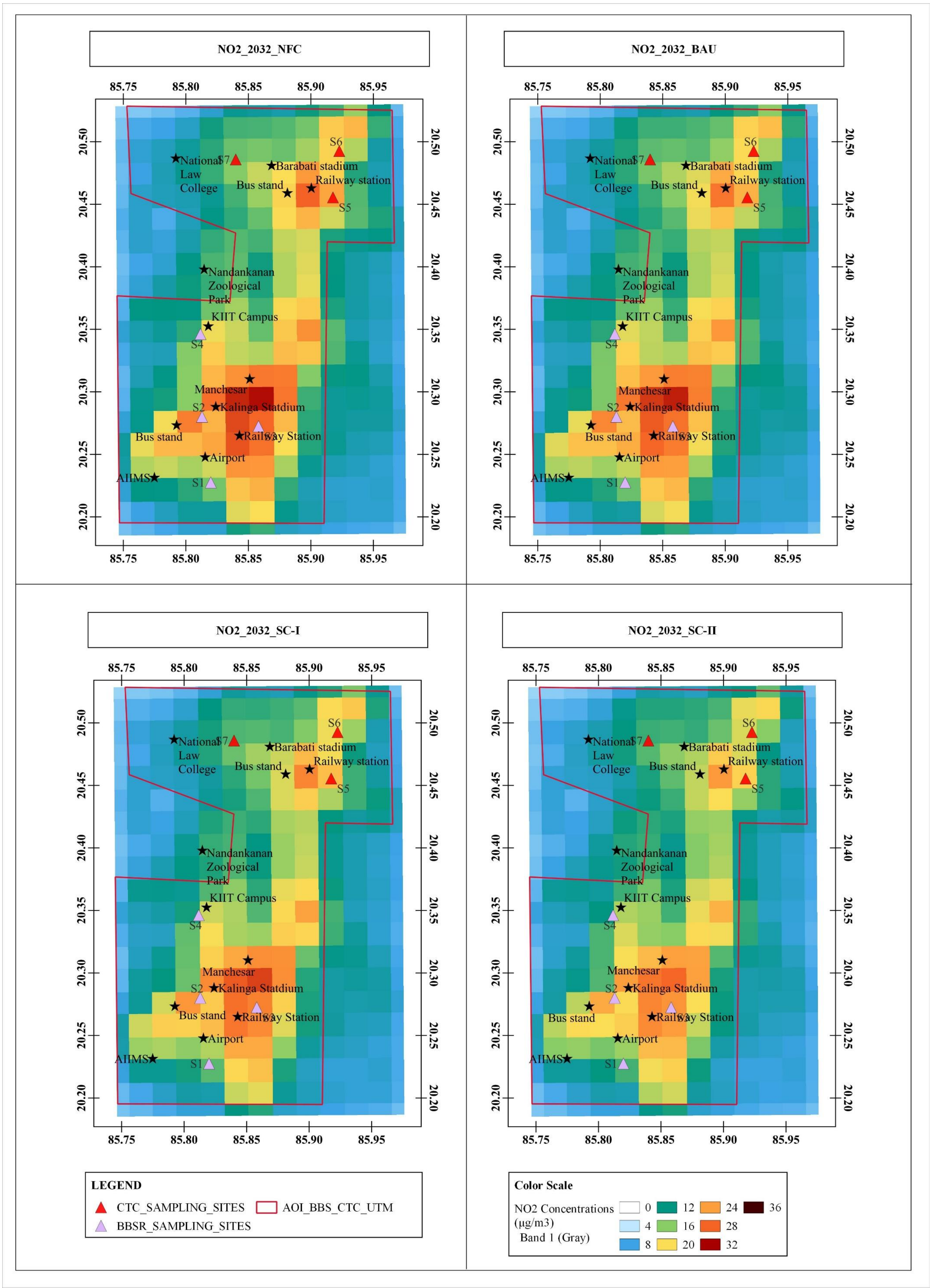

Figure 113 Spatial distribution of annual mean NO_2 *concentrations* (µg/m^3) *for four scenarios in year 2032 over Bhubaneswar-Cuttack region*

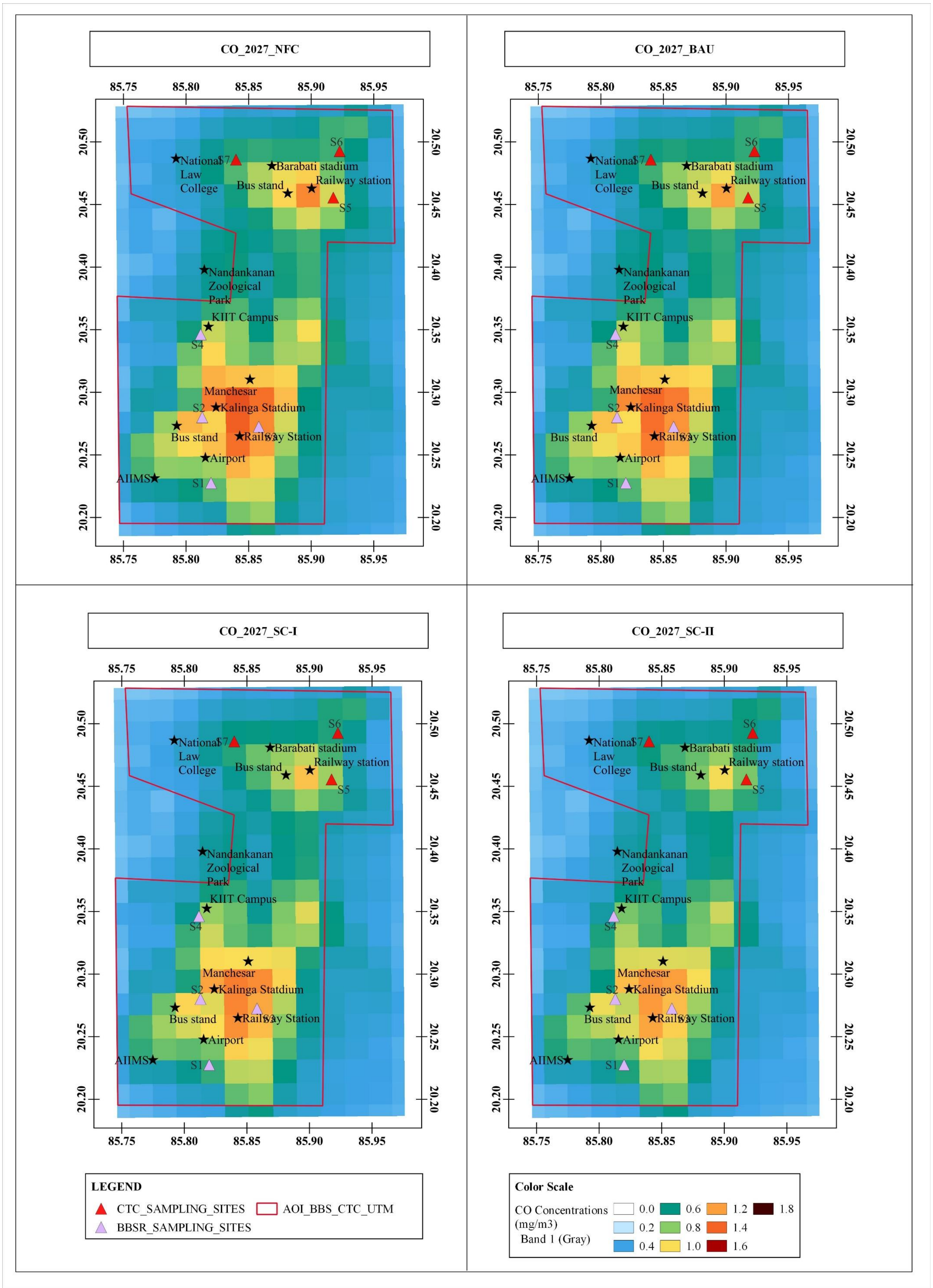

Figure 114 Spatial distribution of annual mean CO concentrations (mg/m^3) for four scenarios in year 2027 over Bhubaneswar-Cuttack region

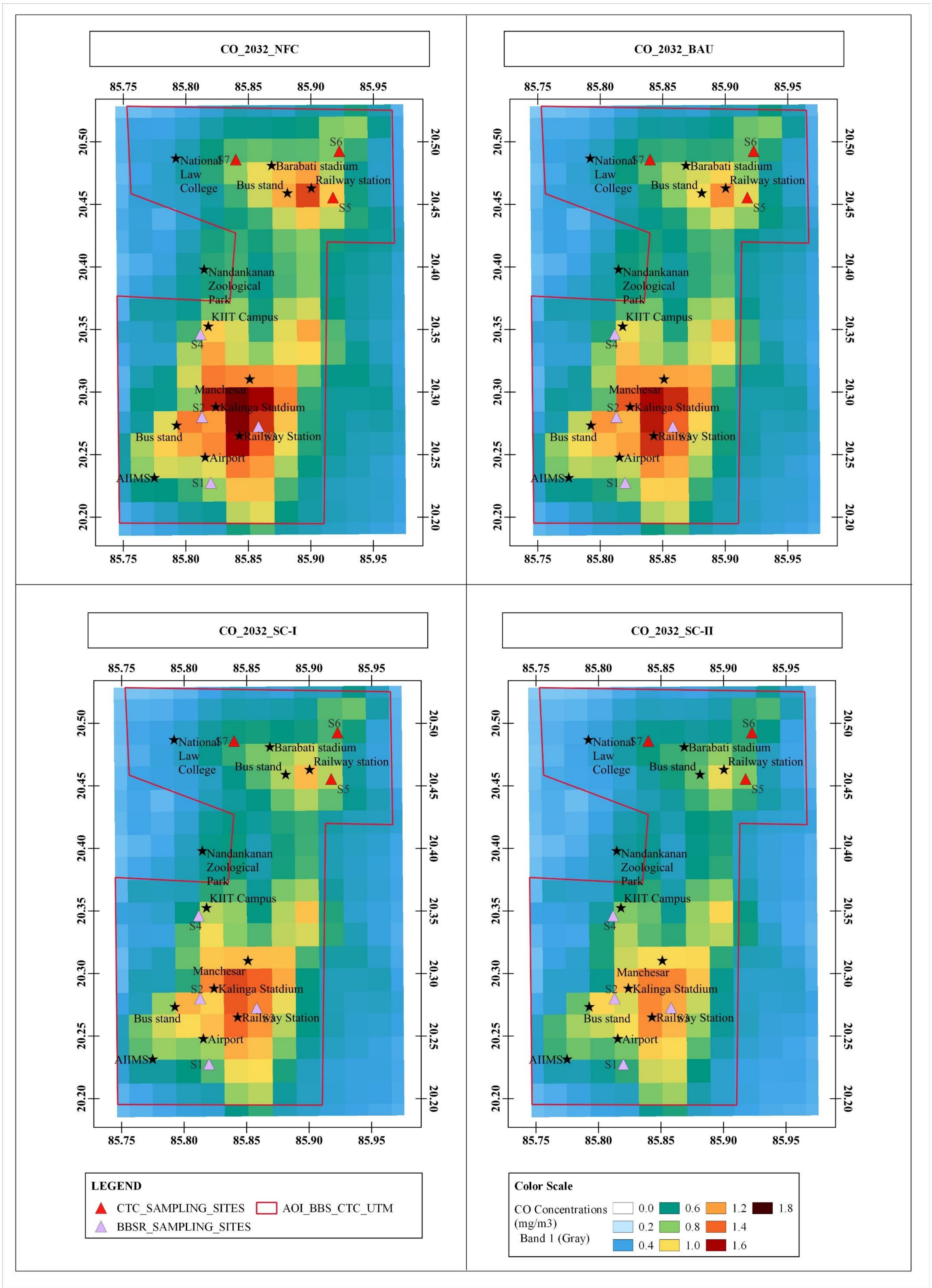

Figure 115 Spatial distribution of annual mean CO concentrations (mg/m^3) for four scenarios in year 2032 over Bhubaneswar-Cuttack region

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 (S5-S7), 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 Cuttack region.

Table 27 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S5 i.e. BDO Office, Naya Bazar sampling location

Year/Scenario	2027			2032		
Pollutant	**BAU**	**SC-I**	**SC-II**	**BAU**	**SC-I**	**SC-II**
PM_{10}	-10.0%	-20.5%	-33.0%	-21.6%	-42.4%	-64.7%
$PM_{2.5}$	-9.3%	-19.8%	-31.0%	-20.5%	-39.1%	-58.8%
SO_2	-5.6%	-11.8%	-26.8%	-5.5%	-28.7%	-46.8%
NO_2	-0.8%	-2.7%	-5.1%	-3.2%	-6.3%	-10.8%
CO	-4.4%	-9.8%	-15.6%	-9.3%	-16.5%	-24.4%

Table 28 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S6 i.e. Varun Beverages Ltd. - Jagatpur sampling location

Year/Scenario	2027			2032		
Pollutant	**BAU**	**SC-I**	**SC-II**	**BAU**	**SC-I**	**SC-II**
PM_{10}	-9.2%	-18.7%	-30.8%	-20.1%	-40.4%	-62.6%
$PM_{2.5}$	-7.8%	-16.8%	-27.3%	-17.8%	-35.4%	-54.9%
SO_2	-6.3%	-11.0%	-19.6%	-7.1%	-20.1%	-31.0%
NO_2	-0.4%	-2.0%	-4.2%	-2.3%	-4.9%	-8.9%
CO	-2.3%	-5.7%	-9.3%	-4.5%	-8.7%	-13.9%

Table 29 Percentage change in annual air pollutant concentrations, w.r.t. corresponding NFC scenarios in 2027 and 2032 at S7 i.e. Baimundi Nursing Home, Bidanasi sampling location

Year/Scenario	2027			2032		
Pollutant	**BAU**	**SC-I**	**SC-II**	**BAU**	**SC-I**	**SC-II**
PM_{10}	-7.9%	-16.4%	-25.7%	-17.1%	-32.5%	-48.6%
$PM_{2.5}$	-8.3%	-17.8%	-27.0%	-17.5%	-32.3%	-47.7%
SO_2	-5.3%	-11.8%	-25.7%	-5.3%	-27.4%	-44.8%
NO_2	-1.0%	-2.4%	-4.5%	-2.8%	-5.4%	-8.8%
CO	-4.0%	-9.2%	-15.0%	-8.8%	-16.0%	-24.0%

5.15.1. Air quality benefits in terms of Air Quality Indices

Air quality index (AQI) is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (*Ott, 1978*). In this study, a two-step methodology recommended by CPCB is used to calculate daily AQI values (*CPCB, 2015*). A sub-index (*CPCB, 2015*; refer Eq. (17)) was first calculated for each pollutant based on its observed and breakpoint concentrations using linear segmented principle. Then the individual sub-indices were aggregated using a maxima function to obtain an overall daily AQI (*CPCB, 2015*; refer Eq. (18)). The AQI values were then categorized into six different classes: Good (AQI <=50), Satisfactory (50 < AQI <=100), Moderate (100 < AQI <=200), Poor (200 < AQI <=300), Very poor (300 < AQI <=400) and Severe (400 < AQI <=500). The breakpoint concentrations used to calculate the AQI are provided in Annexure-J. In this study, we calculated the AQI using 24-hour mean concentrations of $PM_{2.5}$, PM_{10}, NO_2 and SO_2 and maximum 8-hour concentrations of CO for the corresponding day.

$$\mathbf{I_i} = \left[\left\{\frac{(\mathbf{I_{HI}} - \mathbf{I_{LO}})}{(\mathbf{B_{HI}} - \mathbf{B_{LO}})}\right\} * (\mathbf{C_P} - \mathbf{B_{LO}})\right] + \mathbf{I_{LO}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{18})$$

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

$$\mathbf{I} = \max_{\mathbf{i}=1,2,3\ldots,n} (\mathbf{I_i}) \ldots\ldots\ldots\ldots\ldots (\mathbf{19})$$

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. BDO Office, Nayabazar (S5) 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. 116 shows the distribution of six AQI categories at BDO Office, Nayabazar (S5) in Cuttack region for modelled concentrations in year 2022, while Fig. 117 and Fig. 118 shows the distribution of AQI categories for different scenarios in 2027 and 2032, respectively.

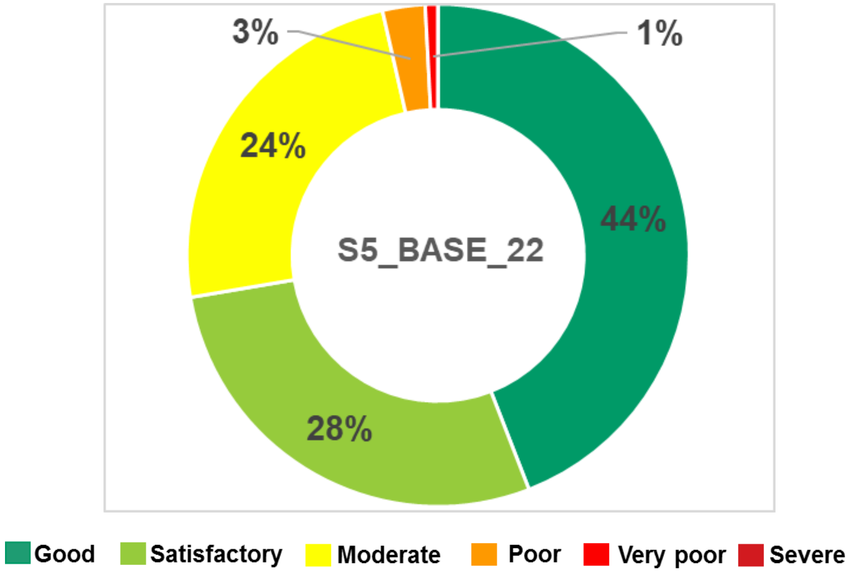

Figure 116 Distribution of six AQI categories at BDO Office, Nayabazar (S5) in Cuttack region for modelled pollutant concentrations for baseline year 2022

The AQI at the selected location during baseline scenario in 2022 is mainly driven by PM_{10} and on few occasions by $PM_{2.5}$. An examination of modelled AQI for the baseline scenario revealed that air quality index, is mainly distributed in Good (44%), Satisfactory (28%), and moderate (24%) classes.

The AQI distribution in NFC scenarios during year 2027 shows degraded air quality compared to baseline year with 37% Good, 22% satisfactory, 30% moderate, 8% poor, and 2% 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 27% Good, 22% satisfactory, 35% moderate, 10% poor, 5% very poor and 1% severe days.

The air quality situation can gradually improve with implementation of proposed control measures. The combined proportion of Good and Satisfactory AQI classes are estimated to be substantially higher compared to the corresponding do-nothing or NFC scenario. For example, the combined proportion of Good and Satisfactory AQI classes in NFC is 59% and 48% in 2027 and 2032, respectively. This combined proportion of Good and Satisfactory AQI classes improves to 68% and 60% in 2027 and 2032, respectively under BAU scenario, to 76% and 82% in 2027 and 2032, respectively under SC-I, to 85% and 99% in 2027 and 2032, respectively under SC-II scenario. Fig 117 and 118 represents the distribution of AQI categories in four scenarios at BDO Office, Nayabazar (S5) for years 2027 and 2032, respectively.

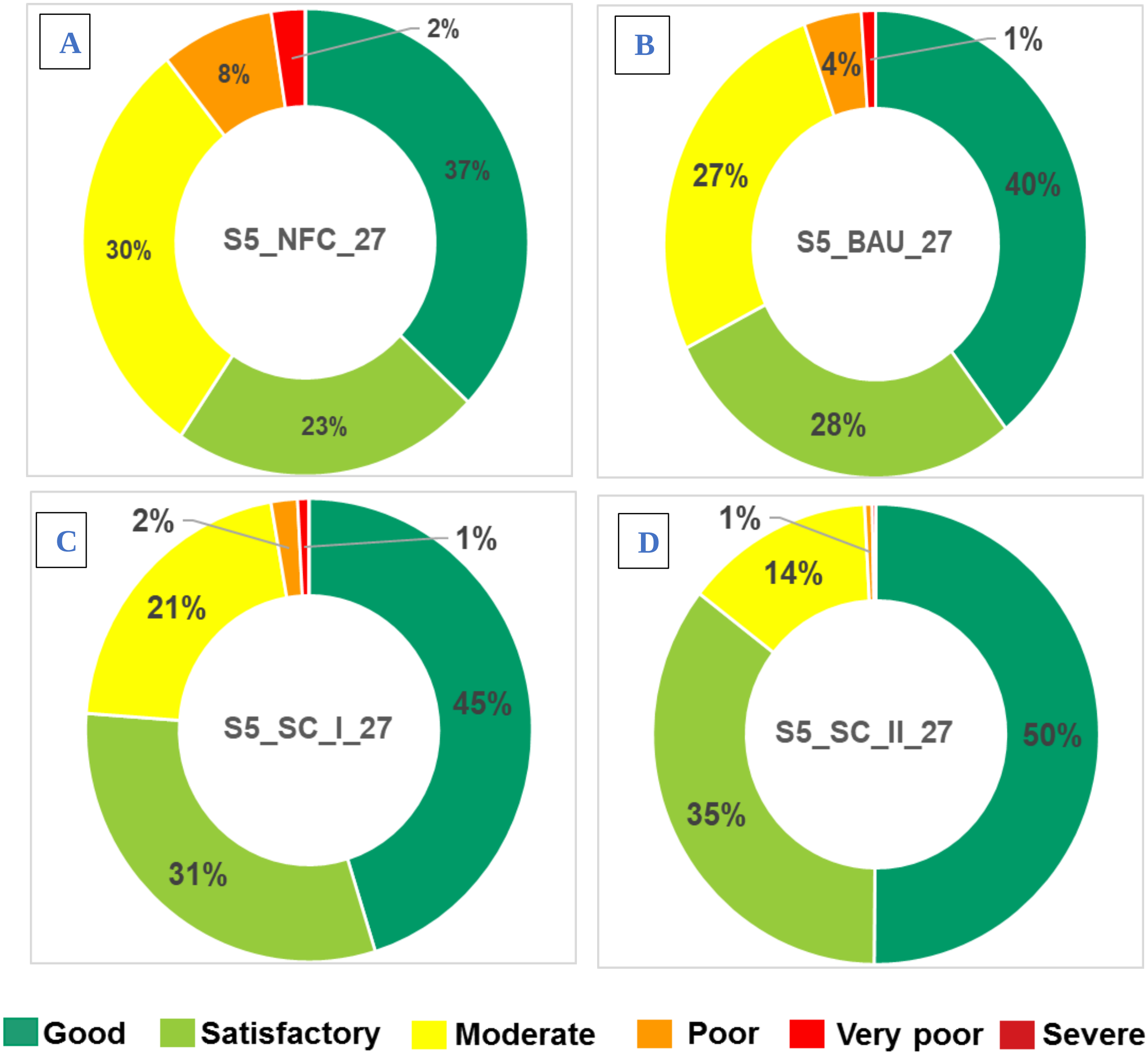

Figure 117 Distribution of six AQI categories at BDO Office, Nayabazar (S5) in Cuttack region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2027

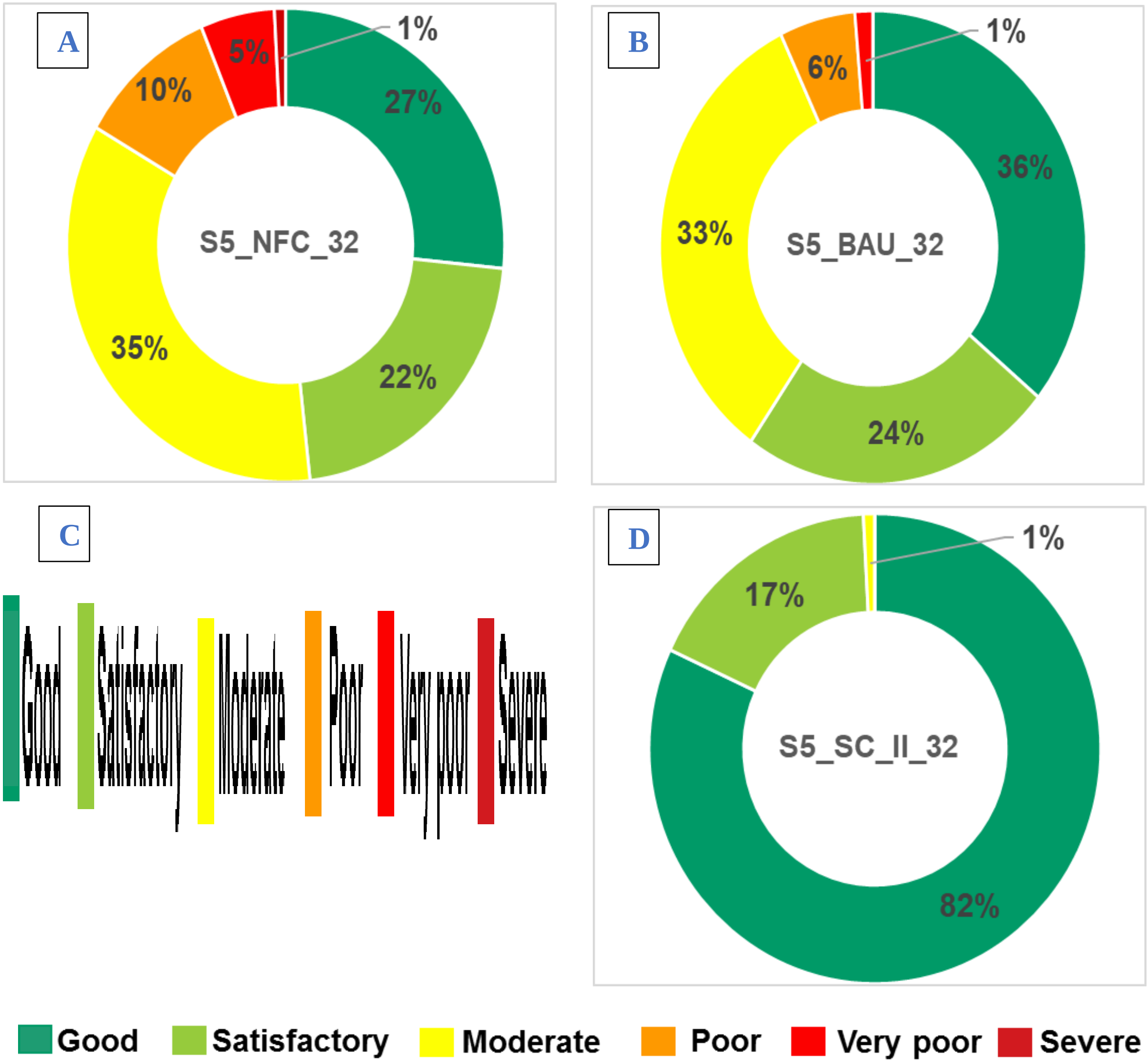

Figure 118 Distribution of six AQI categories at BDO Office, Nayabazar (S5) in Cuttack region for four scenarios i.e. NFC (A), BAU (B), SC-I (C) and SC-II (D) in year 2032

It is important to note that, Although the AQI changes presented here are location specific, a similar improvement is expected in other locations of Cuttack 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: Action Plan

6.1. Air Quality Action Plan for Cuttack Region

Table 30 presents the proposed air quality action plan for Cuttack region. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions.

Table 30 Proposed Air quality action plan for Cuttack 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.	Municipal Corporation / 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.	Municipal Corporation	3 years
	Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	Municipal Corporation	1 -2 years
	Declare NO-vehicle zones in hot-spots, university / school premises.	Municipal Corporation / University / School	6 months
	Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Examine existing framework for removing broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.	Municipal Corporation/ Local Govt. Body	6 months
	B) Technology		
	Improve and strengthen PUC program. (SMS based system to alerts, Linking of PUC centres with remote server and elimination of manual intervention in PUC testing, Fitness and calibration audits of PUC centres adopted with defined team for verification, Integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, Linking of PUC certificates with annual vehicle insurance, etc.)	RTO	1 year
	Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	Oil Companies/ GAIL / State Government	3 years
	The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	Municipal Corporation/ 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 / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	Municipal Corporation/ Local Govt. Body	6 months
	All the canals/nallah's side roads should be concrete / brick lined.	Municipal Corporation/ Local Govt. Body	1 year

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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	Adoption of Cleaner Fuels: • Cleaner fuel implementation to be encouraged and incentivized. • Discourage the fuels with high sulphur content. • A favourable taxation and pricing policy for mass adoption.	OSPCB	1 year
	Ensuring installation/Up-gradation and operation of air pollution control devices in industries	OSPCB	6 months
	Disposal of all non-hazardous wastes into the designated dumping sites	OSPCB	Continuous
	Industry shall prepare plant wise inventory of vents and ensure that it is routed to vapour recovery system followed by flare system, wherever applicable.	OSPCB	6 months
	Regeneration frequency of Adsorption / absorption system / Activated carbon bed should be clearly defined as per the trend data of previous cycles and should be documented.	OSPCB	6 months
	Industry should include a special training module regarding "fugitive emissions and its health impacts on individual and surrounding communities" for its staff, operating personnel & Drivers to spread awareness about risk/hazard associated with spills and leaks of various chemicals.	OSPCB	Continuous
	Bank guarantee should be taken for the compliance of conditions imposed in CTO/CTE for control of Environmental Pollution from industries.	OSPCB	6 months
	Industrial units to install water spraying system of internal roads and washing of tyres of vehicles	OSPCB	6 months
	Development of mobile facility/van for continuous ambient air quality monitoring for different localities.	OSPCB	6 months
Thermal Power Plants	• Implementation of new thermal power plant standards in all power plants by an early date. The power plants need to comply with the new emission standards. • Check status of compliance and prepare a transition plan for each plant to meet the new standards. This should apply to all state owned, private and captive power plants:	OSPCB	2 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	• Plants found not meeting set emission reduction targets to be penalized. • Prepare plan for full utilization of flyash, and also carry out monitoring, sprinkling of water (recycled water) especially during summer months to curtail wind-blown ash. • Progressively close the older and more polluting thermal power plants and to move to cleaner natural gas • Installation of Flue Gas Desulfurization (FGD) units to reduce the SO_2 emissions. (Efficiency 50 to 99.8% based on age of plant, sulfur content in coal etc) • Prepare a roadmap for cleaner plants and Incentivize their operation by giving them the priority over other polluting plants.		
Open Waste Burning	Improving door to door waste collection efficiency to 100%.	Municipal Corporation/ Local Govt. Body	1 year
	Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	Municipal Corporation/ 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, Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	Municipal Corporation/ Local Govt. Body	Immediate / Continuous
	Encouraging the reduce, recycle and reuse policy for waste in city	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body	1 year
	Effective management of landfill sites through increasing the recycling rate, installing waste to energy conversion plants, restricting illegal waste	Municipal Corporation/ Local Govt. Body	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	dumping, proper disposal of hazardous waste, as per Hazardous waste management rule 2016, to prevent greenhouse gas emissions from site		
	Reduce the VKT of waste collection vehicles with route optimisation technique.	Municipal Corporation/ 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	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body / OSPCB	Continuous
	Ensure transportation of construction materials in covered vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Restriction on storage of construction materials along the road side.	Municipal Corporation/ Local Govt. Body	Immediate
	Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	Municipal Corporation/ Local Govt. Body / OSPCB	Immediate
	To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	Municipal Corporation/ Local Govt. Body / Site Developer	Immediate
	Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	Municipal Corporation/ Local Govt. Body / Site Developer	3 months
	Develop and implement dust control measures such as site covering, fugitive emission control, installing air pollution controlling devices for all types of construction activities i.e. buildings and infrastructure.	Municipal Corporation/ 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.	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body / OSPCB	1 Year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
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	Municipal Corporation/ Local Govt. Body / State Electricity Board	Immediate
	Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	Municipal Corporation/ 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	Municipal Corporation/ Local Govt. Body / State Government	5 years
	Leverage rooftop solar programme to reduce dependence on DG sets.	Municipal Corporation/ Local Govt. Body	1 year
	Installation of Retrofitted Emission Control Devices (RECD) to diesel generators as per CPCB guidelines	OSPCB	1 year
Residential	Ensure easy availability of affordable cleaner cooking fuels (LPG/ PNG/biogas) for all to achieve 100% LPG adoption.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP/BP, etc.)	1-3 years
	Expanding coverage of LPG under Pradhan Mantri Ujjwala Yojana (PMUY).	State / Central Government	1-2 years
	Introduce schemes for providing subsidized LPG connections as well as providing means of finance to small tea vendors/hawkers who are using kerosene stoves in order to reduce emissions from burning of kerosene	State / Central Government	1-2 years
	Introduction of improved *Chullahs* (low emission *Chullahs*) in rural areas	Municipal Corporation/ 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	Municipal Corporation/ Local Govt. Body	1 year
	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

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Hotel, restaurant and bakeries	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.	Municipal Corporation/ 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	Municipal Corporation/ 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.	Municipal Corporation/ 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.	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
	Encourage the use of public transport for daily commute.	Municipal Corporation/ 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	Municipal Corporation/ Local Govt. Body, OSPCB, NGOs	Immediate
IT enabled services	Use of mobile application for complaint registration and grievance redressal regarding air pollution	Municipal Corporation/ 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 PM2.5 particulates in non-attainment cities.
- **Volatile organic compounds (VOCs) and Ozone monitoring:** Unlike primary pollutants, which are emitted directly, tropospheric ozone forms photochemically, involving precursors such as carbon monoxide (CO), volatile organic compounds (VOCs) and oxides of nitrogen (NOx), supplemented by transport from the stratosphere (e.g. Crutzen, 1974; Atkinson, 2000; Monks et al., 2015). It can be transported over long distances resulting in enhanced concentrations even in areas remote from the sources of precursors (Cox et al., 1975). It is suggested to augment current monitoring network, to include monitoring of VOCs and Ozone in non-attainment cities.
- **Advanced source apportionment:** Near real time advanced source apportionment using set of state-of-the-art equipment. This can typically include an aerosol chemical speciation monitors (ACSM) to monitor organic aerosols and selected ions (such as sulfate, nitrate, ammonium, and chlorides); along with a black carbon

and a metals analyzer. This set-up can provide high resolution near real time data measurements which can be then followed by PMF analysis to identify sources of air pollution in near real time and on a longer time scale.

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

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Annexures

Annexure-A: Air Quality Monitoring

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

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

1.0 Scope

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

2.0 Referred Documents

2.1 SOP MLD 055 by California Air Research Board

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

3.0 Significance and Use

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

4.0 Apparatus

Following apparatus/ instruments will be used: -

4.1 Multi-channel/dual channel speciation samplers

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

4.3 Filter papers (Teflon/ Quartz)

4.4 Proper (blunt) forceps

4.5 Labelled Filter paper petri dish for storing Filter paper

4.6 Sample Storage Kit

5.0 Chemicals/ consumables:

5.1 High Vacuum Grease

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

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

6.0 PPEs TO BE USED:

Cotton hand gloves, safety shoes

7.0 Procedure:

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

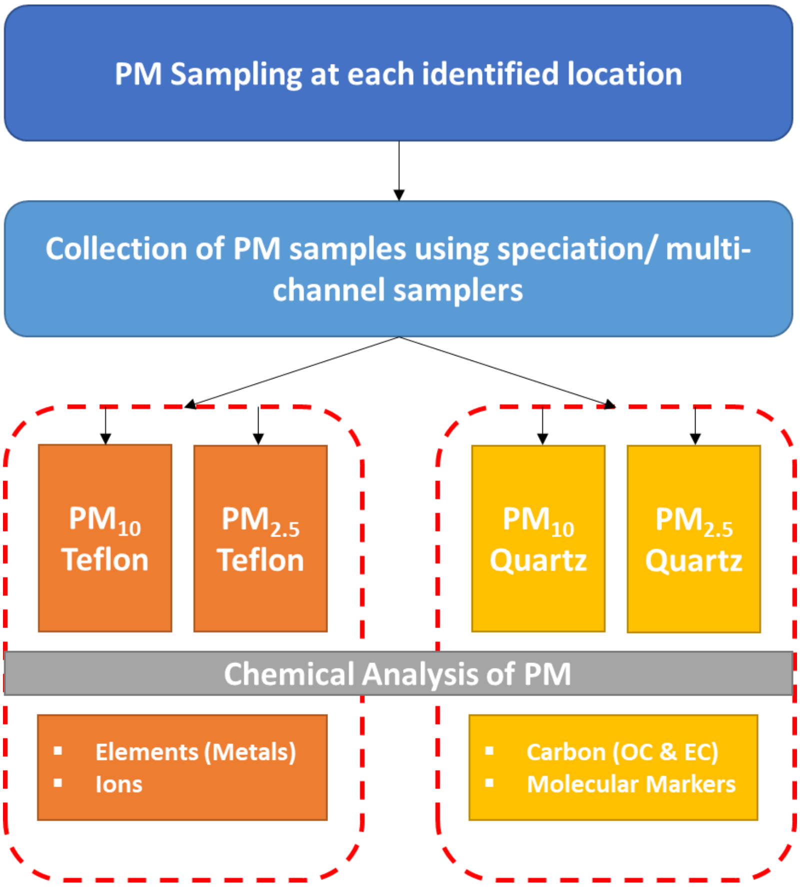
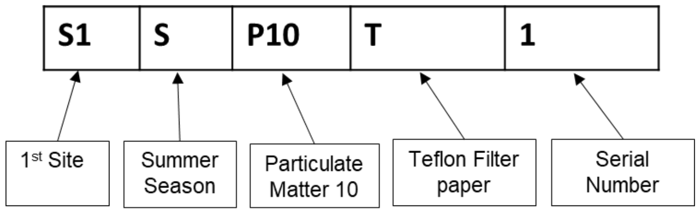


Fig. A-1: Arrangement of filter papers for multi-channel speciation samplers

7.2 Check Temperature and Humidity sensor connections.

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



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

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

7.5 Load filter paper in cartridge as per below table:

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

7.6 Start Speciation sampler as per standard procedure.

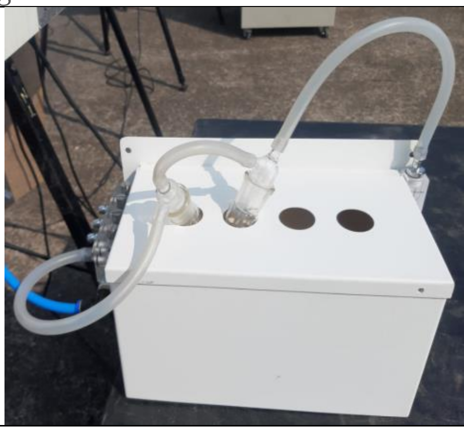
8.0 Sampling Site photographs

BDO Office

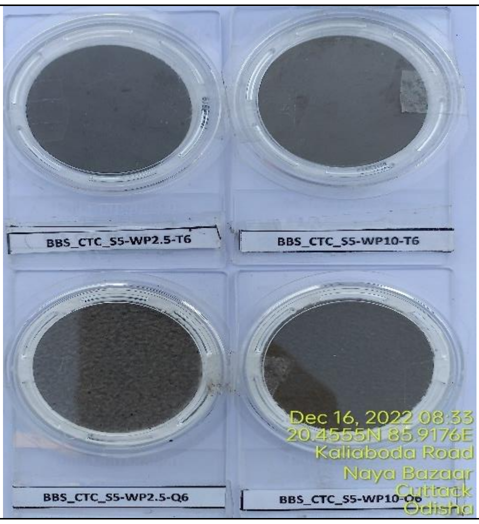
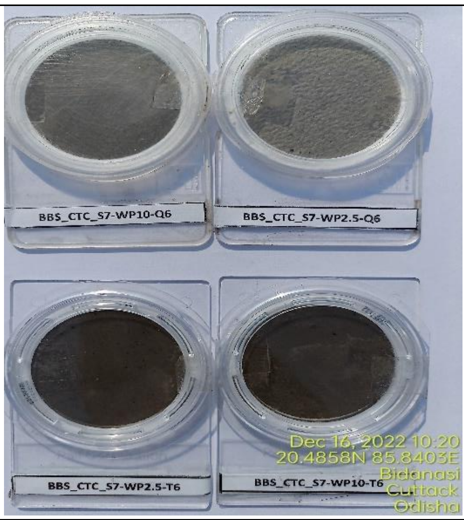
Varun Beverages Ltd (Pepsi)

Baimundi Nursing Home

VOC Sampling Collection through Tenax Sorbent Tubes



Gaseous Sampling Collection (SO_2 &NOx)

	
Loading of filter papers post sampling	

Annexure-B: Filter sample preparation, handling and weighing

1.0 Scope

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

2.0 Referred Documents

2.1 Weighing balance Operation Manual

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

2.3 Furnace

3.0 Significance and Use

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

4.0 Apparatus

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

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

4.2 Teflon coated forceps

4.3 Millipore Petrislides

4.4 Cool kit

4.5 Filter Paper used for Sampling:

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

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

5.0 Procedure

5.1 Guidelines for Conditioning of Filter Papers:

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

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

5.2 Filter Inspection and Stability

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

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

6.0 Filter Conditioning

6.1 Pre-firing of Quartz-Fiber Filters

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

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

6.2 Weighing of Teflon-Membrane Filters before and after sampling

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

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

Annexure-C: Analysis of Ions

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

1.0 Scope

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

2.0 Reference Document

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

2.2 Operation manual of Dionex make Ion Chromatograph.

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

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

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

3.0 Summary of Test Procedure

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

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

4.0 Apparatus:

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

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

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

4.2 IC Operating Conditions:

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

Sample loop volume:	**25 µl for anions and cations**
Acquisition Software	Chromeleon Software Version 7.2.9
Pressure	Max. 5000 Psi
Suppressor for anion Suppressor for Cation	AERS type 600 (4mm) suppressor CERS type 600 (4mm) suppressor
Analysis Time: Anion Cation	 20min 35min

4.3 Other Equipment:

- Ultrasonicator
- Analytical balance

4.4 Glassware:

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

5.0 Reagents:

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

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

6.0 Procedure:

Preparation of Eluents-

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

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

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

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

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

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

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

6.5 Filter Analysis:

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

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

- Transfer the contents of sample into autosampler vials and cap each vial. Run the sequence of samples as mentioned above and operate the IC Software for analysis of anions and cations at above instrumental conditions. The results are given in ppm or mg / lit.

7.0 Calculations:

7.1 Calculation of Volume of Air Sampled

V = QT

V = Volume of air sampled in m^3

Q = Mean flow rate in m^3/minute

T = Total sampling time in minute

7.2 Calculation of Anions and Cations in PM in Ambient Air

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

Where,

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

V_1 = Volume of aliquot (ml)

B = total µg or mg of Ion in blank

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

V = Volume of air sampled

Report

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

9.0 Calibration Records:

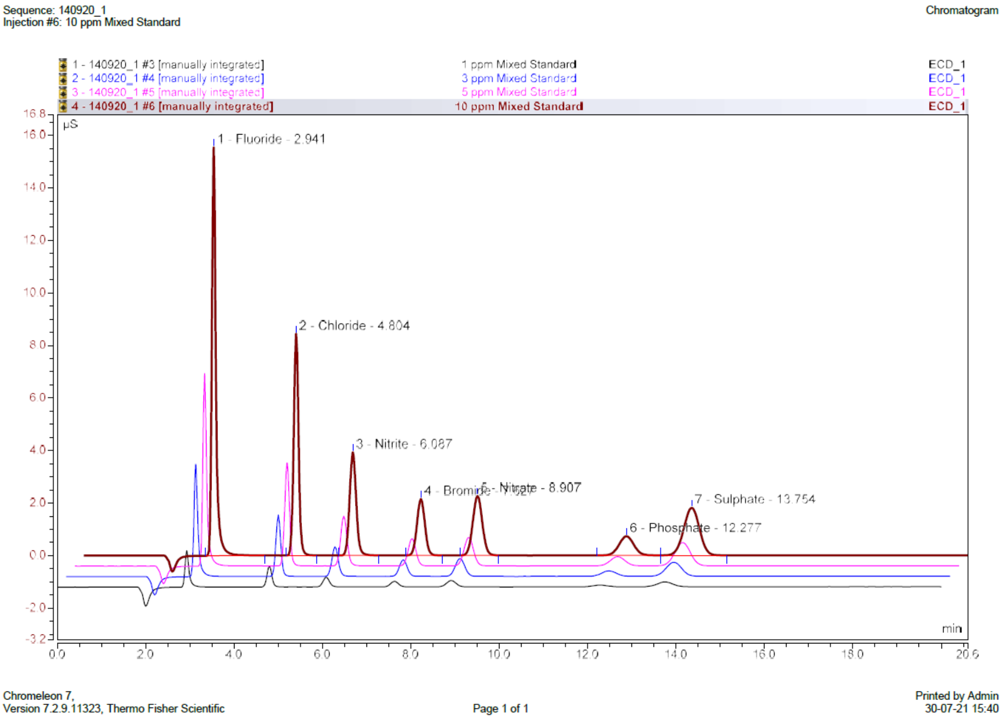


Fig. C-1: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Anion

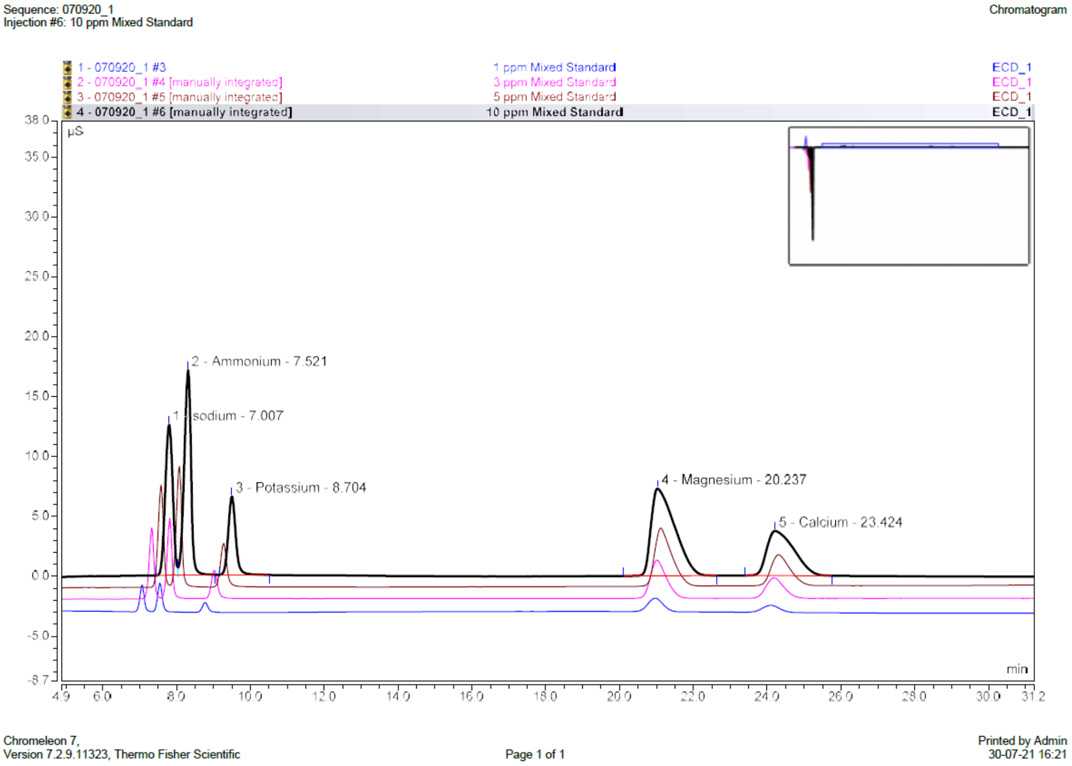


Fig. C-2: Overlay of Calibration Run of 1 ppm, 3 ppm, 5 ppm and 10 ppm run of Cation

Annexure-D: Analysis of Elements

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

1.0 Scope

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

2.0 Reference Document

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

3.0 Summary of Test Procedure

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

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

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

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

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

4.0 Apparatus

X-ray Fluorescence Spectrometer

5.0 Certified Reference Material

5.1 Single-element Thin-film calibration standards from Micromatter

6.0 Procedure

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

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

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

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

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

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

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

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

6.9 Take out the sample from the sample chamber.

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

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

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

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

6.13 Calibration:

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

7.0 Calculations

7.1 Concentration of the elements in the sample are calculated by the software in $\mu g/cm^2$.

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

8.0 Reporting

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

Annexure-E: Carbon Analysis

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

1.0 Scope

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

2.0 Referred Documents

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

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

3.0 Summary of test Procedure

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

4.0 Apparatus

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

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

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

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

4.4 Flat-tip tweezers.

4.5 Flat glass plate.

4.6 Tissue paper

4.7 Glassware

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

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

5.0 Chemicals:

5.1 Potassium Hydrogen Phthalate (KHP)

5.2 Sucrose

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

6.0 Procedure

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

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

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

6.2 Leak Check test

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

6.3 Oven Baking

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

6.4 Auto-calibration

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

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

6.5 Sample analysis

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

6.6 Filter blank

- Filter blank analysis is performed similar to sample analysis with pre-baked blank filter paper punch loaded instead of sample punch.
- Pre-baking of blank filter paper is carried out by heating the blank filter paper in furnace at 900°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

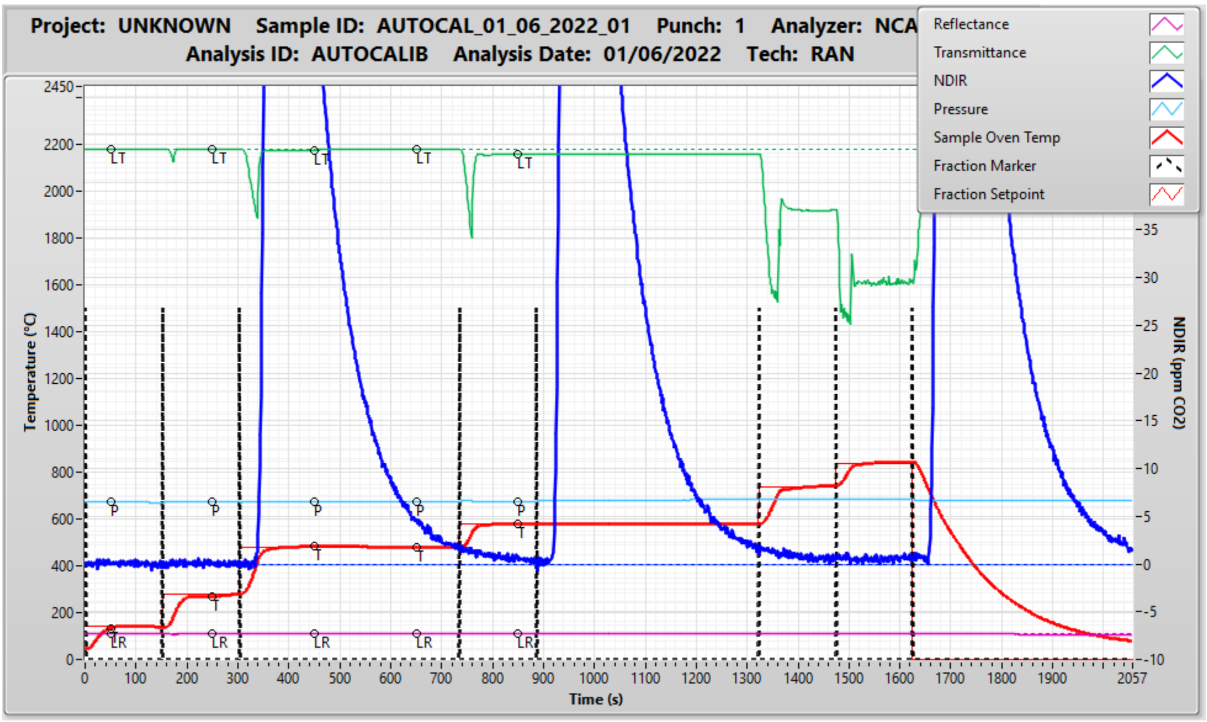


Fig. E-1: Typical example of Auto-calibration run taken on every day before actual testing starts

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 eights	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

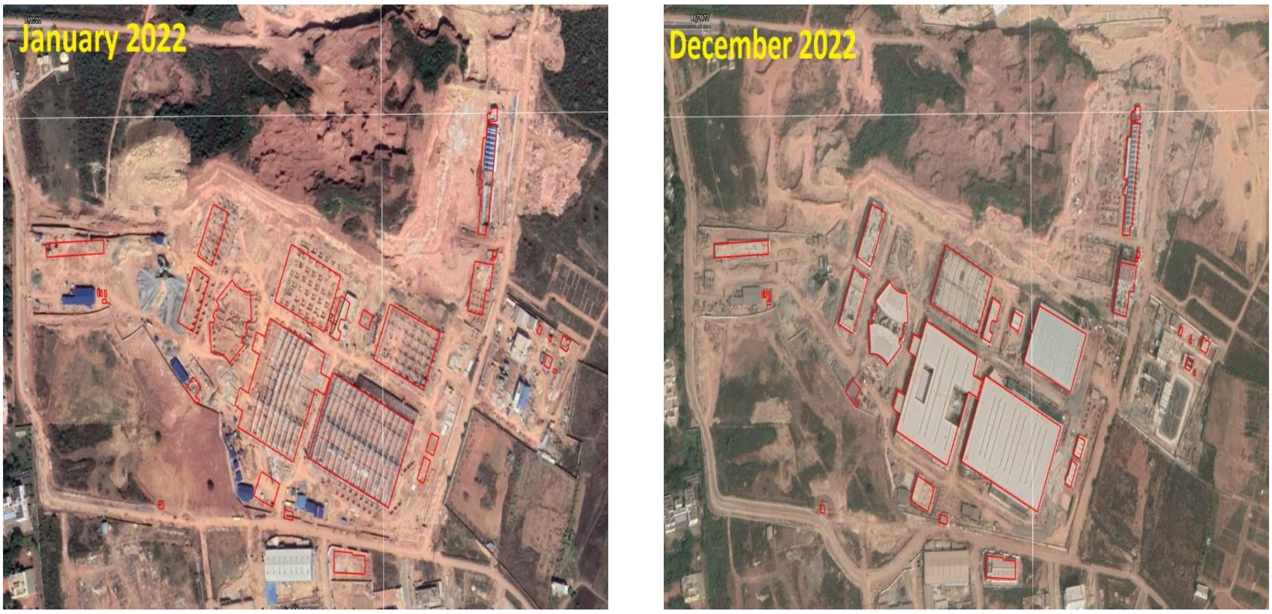


Figure G.119 Construction activity in Cuttack region in January 2022 and December 2022

Photographs taken during primary data collection surveys in Cuttack region


28-Dec-2022 1:49:05 pm
20.4500543N 85.9266971E
679 Cuttack - Paradeep Road
Naya Bazaar
Cuttack
Odisha
Altitude:-35.6m
Speed:0.0km/h


Govt
28-Dec-2022 10:39:05 am
20.45017741N 85.92682807E
679 Cuttack - Paradeep Road
Naya Bazaar
Cuttack
Odisha
Speed:0.0km/h


Power Generation
JAKSON
29-Dec-2022 10:31:07 am
20.45564472N 85.91806344E
Naya Bazaar
Cuttack
Odisha


KIRLOSKAR
29-Dec-2022 1:34:21 pm
20.45024986N 85.92676701E
Inner Service Road
Naya Bazaar
Cuttack
Odisha
Altitude:-35.1m
Speed:0.0km/h

Photographs taken during road dust sampling at Cuttack region

Photographs showing activities in Cuttack region

Road Dust

Open Waste

Analysis of satellite derived fires data

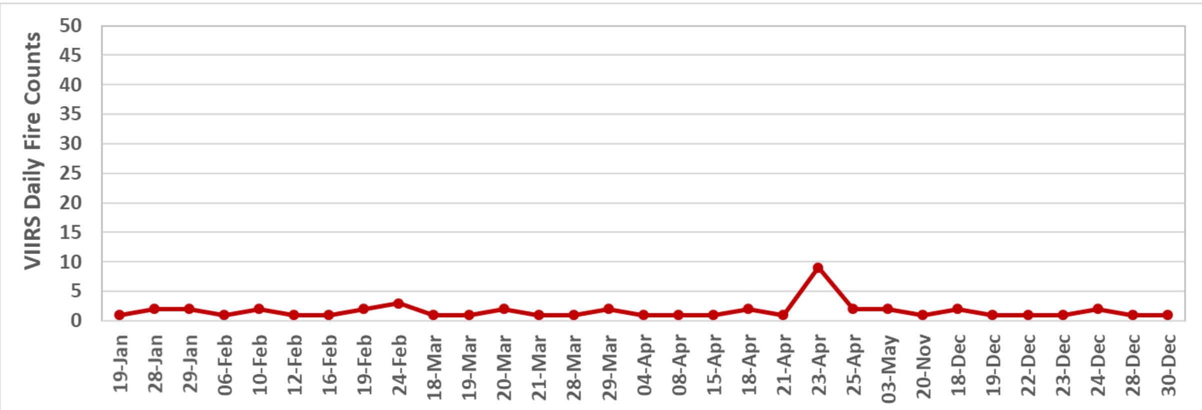


Figure G6: Time-series of daily fire counts observed over Bhubaneswar-Cuttack region during baseline year 2022.

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 Sceanrios**	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) 5% between 2021-25 b) 5% between 2026-32	EV penetration in newly registered vehicles a) 5% between 2021-25 b) 10% between 2026-32	NA	NA	NA	NA	NA
		BAU 2027	EV penetration in newly registered vehicles a) 11% between 2021-25 b) 15% between 2026-32	EV penetration in newly registered vehicles a) 18% between 2021-25	EV penetration in newly registered vehicles a) 2% between 2021-25	EV penetration in newly registered vehicles a) 3% between 2021-25	NA	NA	EV penetration in newly registered vehicles a) 1% between 2021-25

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				b) 19% between 2026-32	b) 5% between 2026-32	b) 9% between 2026-32			b) 5% between 2026-32
		SC_I_2027	EV penetration in newly registered vehicles a) 14% between 2021-25 b) 24% between 2026-32	EV penetration in newly registered vehicles a) 20% between 2021-25 b) 28% between 2026-32	EV penetration in newly registered vehicles a) 2% 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) 20% between 2021-25 b) 42% between 2026-32	EV penetration in newly registered vehicles a) 28% between 2021-25 b) 45% between 2026-32	EV penetration in newly registered vehicles a) 4% between 2021-25 b) 13% between 2026-32	EV penetration in newly registered vehicles a) 6% between 2021-25 b) 27% between 2026-32	NA	NA	EV penetration in newly registered vehicles a) 6% between 2021-25 b) 18% between 2026-32
3	**Increased CNG Penetration**	**NFC 2027**	NA	CNG penetration in newly registered vehicles a) 23% between	CNG penetration in newly registered vehicles a) 2% between	CNG penetration in newly registered vehicles a) 9% between	NA	NA	NA

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				2021-25 b) 23% between 2026-32	2021-25 b) 2% between 2026-32	2021-25 b) 9% between 2026-32			
		BAU 2027	NA	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 15% between 2026-32	CNG penetration in newly registered vehicles a) 1% between 2021-25 b) 5% 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) 1% between 2021-25 b) 5% between 2026-32	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) 20% between 2021-25 b) 20% between 2026-32	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 15% 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) 3% between 2021-25 b) 10% between 2026-32	NA	CNG penetration in newly registered vehicles a) 3% between 2021-25 b) 10% between 2026-32
		SC_II_2027	NA	CNG penetration in newly registered vehicles a) 25%	CNG penetration in newly registered vehicles a) 3%	CNG penetration in newly registered vehicles a) 15%	CNG penetration in newly registered vehicles a) 5%	NA	CNG penetration in newly registered vehicles a) 5%

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
				between 2021-25 b) 30% between 2026-32	between 2021-25 b) 20% between 2026-32	between 2021-25 b) 30% between 2026-32	between 2021-25 b) 15% between 2026-32		between 2021-25 b) 15% 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
5	**Improved Public Transport/ VKT Reduction (%)**	**NFC 2027**	No improvement in public transport						
		BAU 2027	0.39% VKT reduction by year 2027	1.84% VKT reduction by year 2027	0.80% VKT reduction by year 2027	1.34% VKT reduction by year 2027	NA	NA	25 buses per lakh population and all new buses

Sr. No	Intervention	Scenario	2W	Autos	Cars-P	Cars-C	LCV	HDV	Buses
									procured would be Electric vehicles
		SC_I_2027	0.47% VKT reduction by year 2027	2.22% VKT reduction by year 2027	0.96% VKT reduction by year 2027	1.61% VKT reduction by year 2027	NA	NA	30 buses per lakh population and all new buses procured would be Electric vehicles
		SC_II_2027	0.63% VKT reduction by year 2027	2.96% VKT reduction by year 2027	1.28% VKT reduction by year 2027	2.15% VKT reduction by year 2027	NA	NA	40 buses per lakh population and all new buses procured would be Electric vehicles
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) 5% between 2021-25 b) 5% between 2026-32	EV penetration in newly registered vehicles a) 5% between 2021-25 b) 17% between 2026-32	NA	NA	NA	NA	NA
		BAU 2032	EV penetration in newly registered vehicles a) 11% between 2021-25 b) 17%	EV penetration in newly registered vehicles a) 18% between 2021-25 b) 19%	EV penetration in newly registered vehicles a) 2% 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) 14% between 2021-25 b) 31% between 2026-32	EV penetration in newly registered vehicles a) 20% between 2021-25 b) 34% between 2026-32	EV penetration in newly registered vehicles a) 2% between 2021-25 b) 11% between 2026-32	EV penetration in newly registered vehicles a) 6% between 2021-25 b) 25% 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) 20% between 2021-25 b) 60% between 2026-32	EV penetration in newly registered vehicles a) 28% between 2021-25 b) 62% between 2026-32	EV penetration in newly registered vehicles a) 4% between 2021-25 b) 21% between 2026-32	EV penetration in newly registered vehicles a) 6% between 2021-25 b) 48% between 2026-32	NA	NA	EV penetration in newly registered vehicles a) 6% between 2021-25 b) 28% between 2026-32	
3	**Increased CNG Penetration**	**NFC**	NA	CNG penetration in newly registered vehicles a) 23% between 2021-25	CNG penetration in newly registered vehicles a) 2% between 2021-25	CNG penetration in newly registered vehicles a) 9% between 2021-25	CNG penetration in newly registered vehicles a) 2% between 2021-25	NA	NA	

				b) 23% between 2026-32	b) 2% between 2026-32	b) 9% between 2026-32	b) 2% between 2026-32		
		BAU 2032	NA	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 20% between 2026-32	CNG penetration in newly registered vehicles a) 1% between 2021-25 b) 10% between 2026-32	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 20% between 2026-32	CNG penetration in newly registered vehicles a) 1% between 2021-25 b) 10% between 2026-32	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) 20% between 2021-25 b) 30% between 2026-32	CNG penetration in newly registered vehicles a) 2% between 2021-25 b) 20% between 2026-32	CNG penetration in newly registered vehicles a) 10% between 2021-25 b) 30% between 2026-32	CNG penetration in newly registered vehicles a) 3% between 2021-25 b) 15% between 2026-32	NA	CNG penetration in newly registered vehicles a) 3% between 2021-25 b) 15% between 2026-32
		SC_II_2032	NA	CNG penetration in newly registered vehicles a) 25% between 2021-25 b) 36%	CNG penetration in newly registered vehicles a) 3% between 2021-25 b) 30%	CNG penetration in newly registered vehicles a) 15% between 2021-25 b) 42%	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 20%	NA	CNG penetration in newly registered vehicles a) 5% between 2021-25 b) 20%

				between 2026-32	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	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 1 km c) Daily ridership: 47717	NA	NA	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 1 km c) Daily ridership: 47717	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 1 km c) Daily ridership: 47717	NA	NA
		SC_I_2032	Operational MRTS	NA	NA	Operational MRTS	Operational MRTS	NA	NA

			a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 95434			a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 95434	a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 95434		
		SC_II_2032	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 102797	NA	NA	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 102797	Operational MRTS a) No. of Operational lines: 1 b) Zone of Influence: 2 km c) Daily ridership: 102797	NA	NA
5	**Improved Public Transport/ VKT Reduction (%)**	**NFC**	No improvement in public transport						
		BAU 2032	0.37% VKT reduction by year 2032	1.78% VKT reduction by year 2032	0.75% VKT reduction by year 2032	1.26% VKT reduction by year 2032	NA	NA	30 buses per lakh population and all new buses procured would be Electric vehicles
		SC_I_2032	0.56% VKT reduction by year 2032	2.69% VKT reduction by year 2032	1.13% VKT reduction by year 2032	1.89% VKT reduction by year 2032	NA	NA	45 buses per lakh population and

									all new buses procured would be Electric vehicles
		SC_II_2032	0.76% VKT reduction by year 2032	3.63% VKT reduction by year 2032	1.53% VKT reduction by year 2032	2.55% VKT reduction by year 2032	NA	NA	60 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: Breakpoints for AQI

Table J.1: Breakpoints for Air Quality Index (AQI) Scale 0 to 500 (Source: CPCB, 2015)

AQI Category	AQI Range	$PM_{2.5}$	PM_{10}	NO_2	SO_2	O3	CO
	Unit less	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**mg/m3**
Good	0-50	0-30	0-50	0-40	0-40	0-50	0-1
Satisfactory	51-100	31-60	51-100	41-80	41-80	51-100	1.1-2.0
Moderate	101-200	61-90	101-250	81-180	81-380	101-168	2.1-10.0
Poor	201-300	91-120	251-350	181-280	381-800	169-208	10.1-17.0
Very poor	301-400	121-250	351-430	281-400	801-1600	209-748	17.1-34.0
Severe	401-500	251+	431+	401+	1601+	748+	34.1+

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