Environmental Carrying Capacity (Air) Study for Non-attainment Town Byrnihat in Ri-Bhoi Dist. of Meghalaya

Sponsor

Meghalaya State Pollution Control Board

CSIR-National Environmental Engineering Research Institute (NEERI)

March 2025

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Report by

CSIR-National Environmental Engineering Research Institute (NEERI)

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FOREWORD

The relentless pursuit of industrial and economic progress often casts a long shadow on environmental quality. This report, "Environmental Carrying Capacity (Air) Study for Non-attainment Town Byrnihat in Ri-Bhoi District of Meghalaya," stands as a critical examination of this complex interplay in the study region in Byrnihat, Meghalaya. Situated strategically along the Guwahati-Shillong road and hosting the Export Promotion Industrial Park (EPIP), Byrnihat in Meghalaya faces environmental pressures associated with both urban development and industrial activity. CSIR-NEERI was engaged by Meghalaya State Pollution Control Board (MSPCB) to execute the Carrying Capacity (Air) study of Byrnihat.

This study represents a significant step towards understanding the intricate dynamics of air quality in Byrnihat and its broader airshed. It quantifies pollutant emissions from various sources, employs sophisticated air dispersion modeling, and provides a clear, data-driven assessment of the region's Atmospheric Carrying Capacity (ACC). The findings presented herein paint a concerning picture, revealing that current particulate matter emissions severely exceed acceptable ACC, jeopardizing air quality, environmental health and well-being of the local community.

However, this report is not merely a diagnosis of the problem; it is a call to action. By meticulously mapping source-specific pollution loads, delineating seasonal airsheds, and projecting the impact of various emission scenarios, this study provides policymakers and environmental stakeholders with the essential information needed to formulate targeted and effective mitigation strategies. The recommendations outlined within offer pathways towards achieving compliance with National Ambient Air Quality Standards (NAAQS) and fostering a more sustainable trajectory for development in the Byrnihat region.

We believe that the insights contained within this report will serve as a valuable resource for local authorities, industrial operators, community leaders, and researchers alike. It is our hope that this study will catalyze a renewed commitment to environmental stewardship, inspiring collaborative efforts to safeguard the air quality of Byrnihat in Meghalaya and ensure a healthier, more sustainable future for its residents. This document emphasises the urgency of addressing air pollution challenges and advocates for a balanced approach that prioritizes both economic growth and environmental protection.

DIRECTOR, NEERI

Acknowledgements

CSIR-NEERI expresses gratitude to the Meghalaya State Pollution Control Board (MSPCB), various line departments of Govt. of Megahalaya, DCIC Nongpoh, Umling Block Office, Gram Pradhans (Gamburas), District Statistical Office, MeECL, Director CASFOS, Soil Conservation and Training Institute, MIDC, the Principal of Don Bosco School, industrial representatives of Byrnihat for all cooperation and assistance, data-sharing and various logistic arrangements and lastly the general public, who assisted in the study with their opinion and responses during field surveys. CSIR-NEERI also thanks CPCB Regional Directorate, Shillong for all inputs. CSIR-NEERI would like to express its deepest appreciation to MSPCB for their financial aid and other forms of assistance in carrying out this project.

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Executive Summary

The "Environmental Carrying Capacity (Air) Study for Non-attainment Town Byrnihat in Ri-Bhoi District of Meghalaya" provides a comprehensive assessment of air quality dynamics and pollution sources in Byrnihat, revealing critical insights into its atmospheric carrying capacity (ACC) and pollutant emissions.

Byrnihat is located in the Ri-Bhoi district of Meghalaya, bordering Assam, along the Guwahati–Shillong Road. It is approximately 82 km from Shillong and has a population of 5,444 as per the 2011 Census, covering an area of 49.5 km². The region features the Export Promotion Industrial Park (EPIP), which spans 256 acres and houses 29 operational industries. The carrying capacity study designated Byrnihat and the surrounding villages within the Byrnihat Circle, which includes 20 villages, to assess the anthropogenic and commercial activities that overlap within the area.

The study begins with the development of an emission inventory that categorizes air pollution sources into point, line, and area sources, all geo-tagged for precise spatial mapping of emissions. Significant findings indicate that the current emission loads from various sources significantly exceed the ACC for particulate matter (PM_{10} and $PM_{2.5}$), marking a severe environmental concern. The emissions from point, area, and line sources average 24.5 tons of PM_{10} and 9.92 tons of $PM_{2.5}$ per day, contributing to predicted ground-level concentrations (GLCs) that surpass the National Ambient Air Quality Standards (NAAQS).Also, the proximity of urban, peri-urban, and rural areas complicates the establishment of administrative boundaries for managing air pollution sources, as many significant polluters, like industrial facilities, fall outside city limits. Effective regional air quality management requires understanding both internal and external sources of pollution and determining the airshed, which is the area from which air pollutants are transported to a city. For Byrnihat, two analyses were conducted: one for winter and one for summer airsheds. The winter airshed covers approximately 119,445 km², with Meghalaya representing 6.64% of it, while the summer airshed is more extensive at about 426,253 km², with Meghalaya making up 4.4%. However, the most actively polluted areas (hosting >90% of air trajectory frequencies) are more

significant in winter. Seasonal variations in the airshed's dimensions and pollution patterns are expected.

In both summer and winter, the study identifies alarming GLC levels: during summer, PM_{10} and $PM_{2.5}$ concentrations reach 273 µg/m³ and 202 µg/m³, respectively, well above the NAAQS limits of 100 µg/m³ for PM10 and 60 µg/m³ for $PM_{2.5}$. The situation intensifies in winter, with GLCs soaring to 360 µg/m³ and 262 µg/m³. These findings underline the urgent need for mitigation strategies, with estimates indicating a required two to three-fold reduction in PM_{10} emissions in summer and a three to four-fold reduction in $PM_{2.5}$ emissions in winter. Notably, the analysis demonstrates that emissions of PM_{10} and $PM_{2.5}$ have now rendered residual carrying capacity (RCC) negative, meaning no additional emissions can be tolerated without breaching air quality standards. In contrast, emissions from gaseous pollutants such as SO_2 and NO_x remain below their respective ACC, suggesting potential for controlled expansion of these sources. However, given the significant exceedance of particulate matter concentrations and the associated health risks, expanding sources of SO_2 and NO_x are cautioned against, as these reactive gases can exacerbate particulate pollution through secondary aerosol formation.

The study further employs AERMOD air dispersion modeling to compare business-as-usual (BAU) scenarios with controlled carrying capacities. For sustained compliance with the NAAQS, summer emissions must be amended to 8.9 T/d for PM_{10} and 2.9 T/d for $PM_{2.5}$, while winter limits must be reduced to 6.8 T/d for PM_{10} and 2.3 T/d for $PM_{2.5}$.

In conclusion, this study highlights an urgent need for targeted air quality management strategies in Byrnihat, focusing on reducing particulate emissions effectively while exercising caution with gaseous emissions to safeguard public health and the environment. The insights gained from this study are pivotal for local policymakers and environmental stakeholders aiming to comply with established air quality standards and the community's overall well-being by framing a robust and sustainable development plan considering the carrying capacity of the region.

Chapter 1

General Introduction

1.0 Introduction:

Byrnihat, a small town located in the northern part of Meghalaya's Ri-Bhoi district (25.9°N and 91.88°E, with an elevation of 66 meters above sea level), marks the border of Assam and Meghalaya along the Guwahati-Shillong Road (NH-6). Byrnihat and adjacent EPIP area together has been declared a non-attainment town in terms of ambient particulate matter (PM_{10}) concentration that exceeded Indian National Ambient Air Quality Standard for 5 consecutive years during 2011-2015(NAAQStatus_Trend_Report_2012). Umtrew river bifurcates Byrnihat from adjacent EPIP area located at south-western part of Byrnihat. The weather during the summer months tends to be humid and hot, while the winter months are pleasant and warm. Rainfall has a great normalizing influence on the temperature of the district, which makes it pleasant even when temperature is high.

The EPIP, covering an area of approximately 256 acres and situated alongside the Umtrew River on the southwestern side of Byrnihat within the Ri-Bhoi District, hosts various types of industries such as metaliks, ferro-alloys, cement, plastics, beverages, breweries, distillery etc. The EPIP is included along with Byrnihat in the study area for present study. This entire study region encounters humid and hot conditions during summer, while winters are pleasant. The peak rainfall months are June to August in decreasing order of magnitude.

Environmental carrying capacity (ECC) is "a concept and tool for sustainable development of human settlements. It is a threshold level of anthropopressure, which the environment is able to balance and withstand without irreversible changes and serious degradation. One of the most frequently recommended solutions for ECC assessment is the use of environmental indicators as Ecological Footprint and biocapacity (Świąder, 2018). The gaps amid the comprehended and desired carrying capacity are pulled through a collection of technological and policy related schemes aimed at changes in dissimilar driving forces and the adaptability that establish the level of desired carrying capacity. Environmental carrying capacity based developmental planning involves regional systems identification, generation of alternate developmental scenarios, their outcome assessment, appraisal of scenarios across sustainability criteria. The method is involving in nature and supports resolution of dispute in the region. Based on the recommendation of CPCB, the Carrying Capacity Study at Byrnihat, including the EPIP area was planned by MSPCB. A Request for Proposal (RfP) was sent to CSIR-NEERI with TOR and scope of work. In response, a project proposal on Carrying Capacity Study for the non-attainment city of Byrnihat, including the EPIP area, was submitted by CSIR-NEERI which was accepted and funded by MSPCB in November, 2022. The following objectives and scope were earmarked for the study:

1.1 Objective:

The objective of the study will be to undertake carrying capacity assessment based on atmospheric (air) assimilation capacity, taking into consideration the emission loads from various sources and region-specific meteorological conditions and terrain characteristics.

1.2 Scope of Work:

- Assessment of emissions and carrying capacity within the defined system boundary (city/town). Evaluation of the air emissions status for current year and projection till 2035.
- To conduct field survey/inspection for collecting the relevant information including industries, commercial areas, residential areas, dumpsites, landfill sites, discussion with government officials, surveys on local residents, migrants and tourists, etc for understanding the real scenario of the area under study.
- Development of inventory for the system (city) based on information provided in development plan, discussion with authorities, literature review and field inspection.
- Population of the region will be evaluated by data exploration using the census data. Further factors such as birth rate, death rate can be deduced from historical information and empirical data and available literature/reports. Population migration rate to be predicted based factors such as analysis of labour supply and demand balance, etc. Tourist activity (if significant), then tourist flow will be calculated by data extrapolation of peak tourist inflow in peak season.
- Survey of traffic volume will be carried out during weekends and weekdays not limited to the factors like Estimation of number and type of vehicles, type of fuel consumption and travel time data. Mode wise traffic composition at hotspot area of the region. Fuel station survey inside the study area road network (identification the type of fuel, fuel saving, quantity and frequency of fuel filling and their mileage, type of engine, age profile and the composition of fuel types in total fleet). Estimate traffic demand based on Origin and Destination Survey,

Number of vehicle inflow and number of local vehicles, Estimate average trip lengths for different vehicle categories (truck, car, and two-wheeler), Meteorological survey

- Inventory of emission sources like biomass burning, open waste burning, stubble burning, construction activities, commercial establishments (factories, coal based tandoors used in hotels, restaurants, dhabas), legal and illegal industries and type of industries with fuel use, boilers, DG set emissions, open burning, crematoria, municipal waste incinerators, biomedical incinerators and hazardous waste incinerators and evaluate their efficiency, road dust & unpaved road.
- Determination of Environmental Indicators viz. Population + Migration rate, Traffic volume, Urban Land, Air Emission such as Industrial emissions, DG set emission, and emission from coal based tandoors, construction activities, open burning, transport (commercial & local), biomass burning, road dust, crematoria's residential and incinerators.
- City specific carrying capacity assessment based on atmospheric assimilation capacity covering taking into consideration region-specific meteorological conditions, terrain characteristics and emission loads from different sources.

1.3 Concept of Atmospheric Carrying Capacity or Assimilative Capacity

Assimilative capacity of the atmosphere is defined as the maximum load of pollutants that can be added without compromising any of the resources in the concerned region (Goyal et al., 2006). Development activities, anthropogenic activities related to dense population, mobility, industrial and urban growth together have resulted in high emissions of air pollutants that are putting increasing pressure on regional air quality of some areas. In many cases, air pollution breaches carrying or assimilative capacity of atmosphere that is reflected in high and above-safe-level ground level concentrations of air pollutants (Su et al., 2020). The emitted pollutants are transported, dispersed and deposited influenced by meteorological and topographical conditions. Therefore, the assessment of assimilative capacity of heavily polluted and their adjacent regions is urgently required so that regional pollution load can be optimally managed by limiting number and individual load from each manageable source.

Carrying capacity is generally estimated by two different methods. The first approach uses meteorological parameters such as wind speed and mixing height to calculate the assimilative potential of the atmosphere. The ventilation coefficient (VC) is a parameter quantified by multiplying the horizontal wind velocity with mixing height. According to IMD, environment can be considered as of low contamination potential when VC > 12000 m^2/sec, of medium contamination potential with VC ≈ 6000–12000 m^2/s and of high contamination potential when VC <6000 m^2/sec.

The second method uses pollution dispersion potential, and this is done by using dispersion models for calculating the ground-level concentration of pollutants. Dispersion models use multiple emission sources to predict the spatial and temporal distribution of pollutants by using quantitative approach of emission inventory to quantify atmospheric carrying capacity. Decisive carrying capacity can be characterized as the maximum emissions (tonne/day) that the atmosphere of an area can take within a given time frame without surpassing the ambient air quality standards. Determination of decisive carrying capacity can be done by reducing or raising the current emissions by 5% (reduce if there should be an occurrence of higher concentrations of pollutants than the prescribed standards and raised when concentration of air pollutants were within the respective prescribed standard values).

1.4 Methodology

As stated in earlier section, assimilative capacity quantification of air/atmosphere is done by various approaches in different parts of the world. Widely used assimilative capacity approaches are as follows:

(i) Approach based on ventilation coefficient

(ii) Method based on Dispersion & quantitative Pollution Load estimation

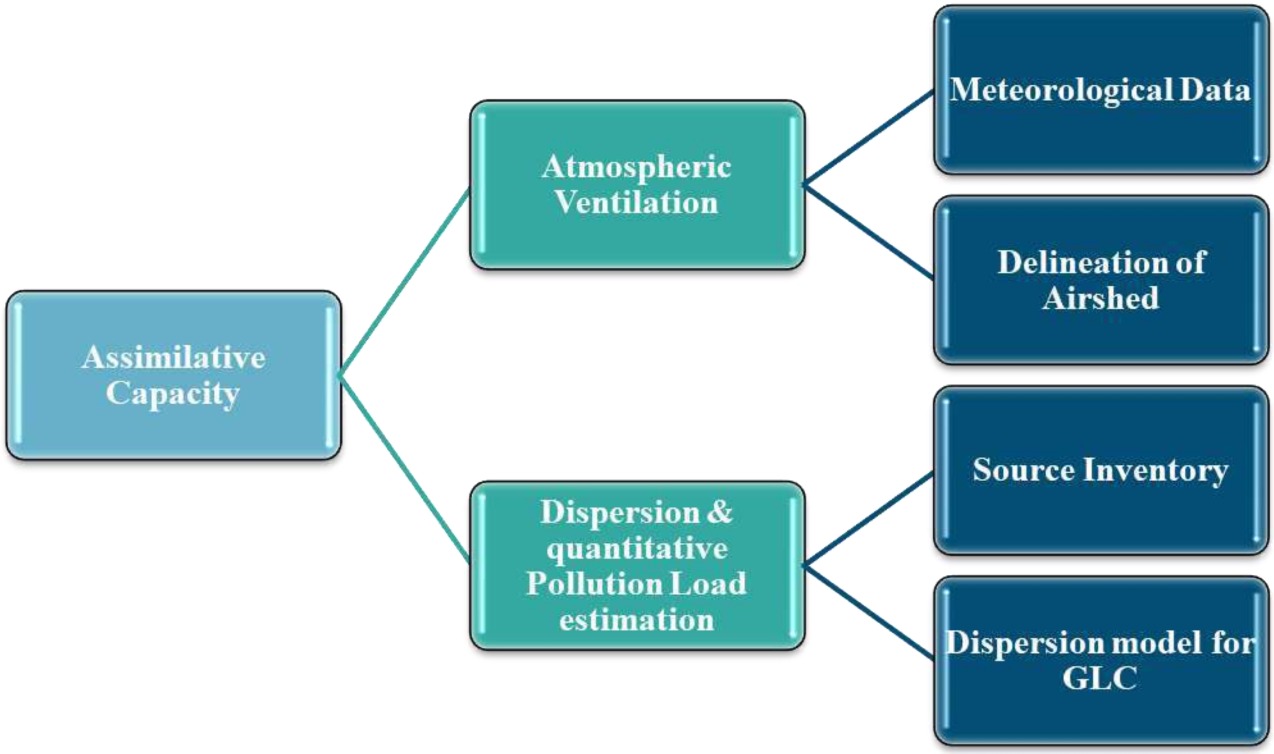


Fig 1: A flow chart showing estimation of assimilative capacity in bipartite methods

1.4.1 Approach based on Ventilation Coefficient

In atmospheric science, the assimilative capacity of the atmosphere is intricately linked to the ventilation coefficient, a parameter directly influenced by both the mixing height and the transport?? wind speed within the mixing layer. The ventilation coefficient serves as a key indicator of the atmosphere's ability to assimilate pollutants, with its expression derived from the product of the mixing height and transport wind speed.

In the assessment of the assimilative capacity over Byrnihat, a comprehensive analysis employs hourly meteorological data spanning the year 2023. The computation of hourly Ventilation Coefficient (VC) values is undertaken to gauge the assimilative capacity, given its direct proportionality to the VC. This approach leverages atmospheric stability considerations, particularly in relation to mixing height and transport wind dynamics, providing valuable insights into the assimilative behavior of the atmosphere in the specified region.

In this study, the assimilative capacity of the environment was quantified employing the ventilation coefficient approach, as outlined in equation (1.1).

Ventilation Coefficient (m^2/s) = Wind Speed (m/s) × MMD (m) ------------------------- (eq. 1.1)

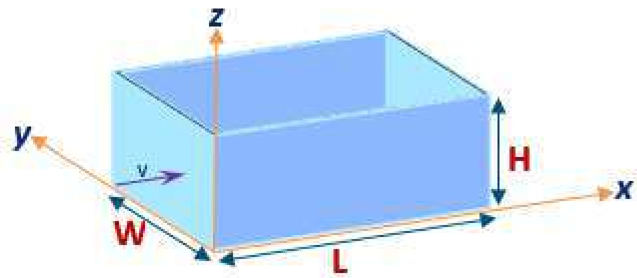
Where,

MMD = Maximum Mixing Depth

The United States National Meteorological Center and Atmospheric Environment Services of Canada have established a classification framework for assimilative capacity based on key parameters. In accordance with this classification, the assimilative capacity of the atmosphere is designated as 'low' when the ventilation coefficient falls below 6000 m^2/s (during the afternoon), mean wind speeds are less than 4 m/s and mixing depths are below 500 m (during the morning) (Prakash et al, 2017)

1.4.2 Approach based on Dispersion &Quantitative Pollution Load estimation

Estimation of atmospheric assimilative capacity using a simple box model based on mass balance is utilized in this approach. This model assumes that all pollutants in the box are uniformly mixed. Although it has several limitations, it can provide broad estimates of carrying capacity to demonstrate the framework and conduct preliminary analysis. The model is mathematically described by an equation representing mass balance, taking into account parameters such as volumetric flow rate, influent and effluent concentrations of pollutants, dry deposition velocity, chemical reaction constants, source emission rate, and wind speed. The volume of the city is also considered in the model. This approach allows for a preliminary estimation of the carrying capacity of the environment in terms of its ability to assimilate pollutants.



Mathematically it is represented as (Eqn. 1.2):

$$\boldsymbol{V}\frac{dc}{dt} = qC_{in} - qC_{out} + S - K_{dd}CLW - K_{cr}C_{out}V \quad \text{--------------------- (eq. 1.2)}$$

Where,

V = Volume of the city in cubic meters (m^3)

i.e. V = L.W.H; (L is length (m), W is Width (m), H is height (m))

q = Volumetric flow rate of air in and out of the box in cubic meters per second (m^3/s)

C_{in} = Concentration of the pollutant in the inflowing air in grams per cubic meter (g/m^3)

C_{out} = Concentration of the pollutant in the outflowing air in grams per cubic meter (g/m^3)

K_{dd}= Dry deposition velocity of the pollutant in meters per second (m/s)

K_{cr} = First-order chemical reaction constant of the pollutant in per second (1/s)

S = Emission rate of the pollutant in grams per second (g/s)

K_{dd} .C.L.W = Concentration of the pollutant removed by dry deposition in grams per cubic meter (g/m^3)

K_{cr}.C.V = Concentration of the pollutant converted by chemical reaction in grams per cubic meter (g/m^3)

u = Wind speed in meters per second (m/s)

The model is streamlined through the following assumptions:

- Steady-state condition, implying concentration remains time-invariant (dc/dt = 0).
- No deposition of pollutants in the box (K_{dd} = 0).
- No chemical transformation of pollutants (K_{cr}= 0).

The estimation of carrying capacity (Q_{cc}) follows the equation:

$$Q_{cc} = (C - C_o) \times u.W.H \quad \text{---} \text{ (eq. 1.3)}$$

For this calculation, the following parameters are essential: the Width (W) of the system boundary, the mixing height (H) averaged for both winter and summer within the system boundary, the Wind Speed (u) within the system boundary. Additionally, the Background Concentration (Co) entering the system boundary is a requisite component for the calculation. These parameters collectively contribute to a comprehensive assessment of the environmental dynamics within the specified system boundary.

Alternatively, the estimation of atmospheric assimilative capacity can be facilitated through a multi-source simulation model. This model incorporates air quality modelling techniques that account for region-specific meteorological conditions, terrain characteristics, and emission loads originating from diverse sources. This approach provides a more nuanced and context-specific understanding of assimilative capacity within the atmospheric environment. Building upon the methodology outlined by Goyal and Rao (2007), the assimilative capacity of the region is determined by identifying the discharged emission load that results in reaching the maximum allowable concentration under predefined critical conditions. This approach offers a practical and scenario-specific assessment of assimilative capacity, considering the interplay between emission loads and critical environmental conditions. The forecasting of ground-level pollutant concentrations the AEROMOD simulation model, approved by the US EPA (EPA, 1995a, 1995b) was employed. It's important to highlight that the atmospheric assimilative capacity exhibits a spectrum of values, influenced by the diverse emission characteristics under specific meteorological and topographical conditions.

Chapter 2

Study Area

2.0 Demography

Byrnihat (25.9°N 91.88°E and 66 m above the sea level) village under Umling Community & Rural Development (C&RD) Block, Umling, is situated at the northern side of Meghalaya in the district of Ri-Bhoi located at the border of Assam and Meghalaya on Guwahati-Shillong roadways (GS road) NH-40. Byrnihat is about 82 km away from Shillong. Byrnihat village, one of the villages of study area, had 62 families and a population of 298, of which 146 were males and 152 were females, as per the Population Census of 2011. In the age group of 0-6, Byrnihat has a population of 25, accounting for 8.39% of the total village population. The village exhibits a commendable Average Sex Ratio of 1041, surpassing the Meghalaya state average of 989. However, the Child Sex Ratio in Byrnihat is 471, which is lower than the Meghalaya average of 970.

Byrnihat boasts a higher literacy rate than the Meghalaya state average. In 2011, the village's literacy rate was recorded at 91.21%, in contrast to Meghalaya's 74.43%. The male literacy rate in Byrnihat is 94.57%, while the female literacy rate stands at 88.19%. Administratively, Byrnihat is governed by a Sarpanch, elected as the head of the village, in accordance with the Constitution of India and the Panchayati Raj Act. A significant fraction of Byrnihat's population belongs to the Scheduled Tribe (ST) category, constituting 50.00%, while Scheduled Caste (SC) members make up 14.09% of the total population.

Regarding employment, out of the total population, 86 individuals in Byrnihat are engaged in various work activities. Impressively, 98.84% of these workers are involved in Main Work, indicating employment or earning for more than six months. Only 1.16% are engaged in marginal activities, providing livelihood for less than six months. Among the main workers, 4 are cultivators (owners or co-owners), and none are agricultural laborers.

Byrnihat is situated on the northern part of Meghalaya in the district of Ri-Bhoi located at the border of Assam and Meghalaya on Guwahati–Shillong roadways (GS road) NH-40 and falls under the Umling Community & Rural Development (C&RD) Block, Umling. It is about 82 km from Shillong and located at co-ordinates 25.9°N & 91.88°E and 66m above sea level. Normally minimum and maximum temperatures are around 12.3°C and 35.2°C, respectively. The total population of twenty villages within Byrnihat Circle **(Table 2.1)** was 8321 as per data shared by Umling Block Office. These twenty villages in Byrnihat Circle covers an area of about 63.24 km^2 as per study area map re-constructed from the geospatial data shared by Umling Block Office.

Byrnihat has an industrial area known as Export Promotion Industrial Park (EPIP) covering an area of about 256 acres and located by the side of the river Umtrew in Byrnihat, Ri-Bhoi District. A number of industrial units have come up in the area since its establishment. The region is mostly surrounding by industrial units from Meghalaya as well as Assam side. Presently, there are 29 industries operating in EPIP, Byrnihat. Out of 29 industries, 3 belong to red, 25 to orange and 1 to green category.

The study area for this carrying capacity study was designated as Byrnihat and EPIP as per the scope earmarked by MSPCB. The Byrnihat village is very small in the entire activity zone and cannot be practically disjointed as a separate zone from the surrounding areas with similar activities. The anthropogenic and commercial activities of Byrnihat encompass and overlap several other adjacent villages. Hence, study area designation was carefully made to include some of these villages along with the Byrnihat village, coming under some designated administrative boundaries with similar activity profiles. It came to light from the Umling Block office that a designated administrative area called the Byrnihat Circle comes under the Byrnihat Area Employment Council under Umling Block. The Byrnihat circle consists of 5 centres having 20 villages in all, including Byrnihat **(Table 2.1)**. Therefore, the Byrnihat Circle boundary was chosen as the boundary of the Byrnihat study area. The population of the study area is presented in **Fig. 2.1**.

Table 2.1 List of villages coming under Byrnihat Circle in Ri-Bhoi District

Name of Circle	Centre	Village
Byrnihat	Ampher	1. Amphrangiri
		2. Ampher
		3. Matchogre
		4. Tamuli Kuchi
	Borbhuin	5. Amjok
		6. Borbhuin
		7. Nongkylla Khasi
		8. Upper Amjok
	Harli Bagan	9. Byrnihat

		10. Dehal
		11. Harli Bagan
		12. Nongkylla Mikir
		13. Upper Bagan
	Lum Nongthymmai	14. Lumnongrim
		15. Lum Nongthymmai
		16. Ranghona
		17. Umdoh 18th Mile
		18. Pahamlang 17th Mile
	15th Mile Nongthy-mmai	19. Rangsakuna
		20. Nongthymmai15th Mile

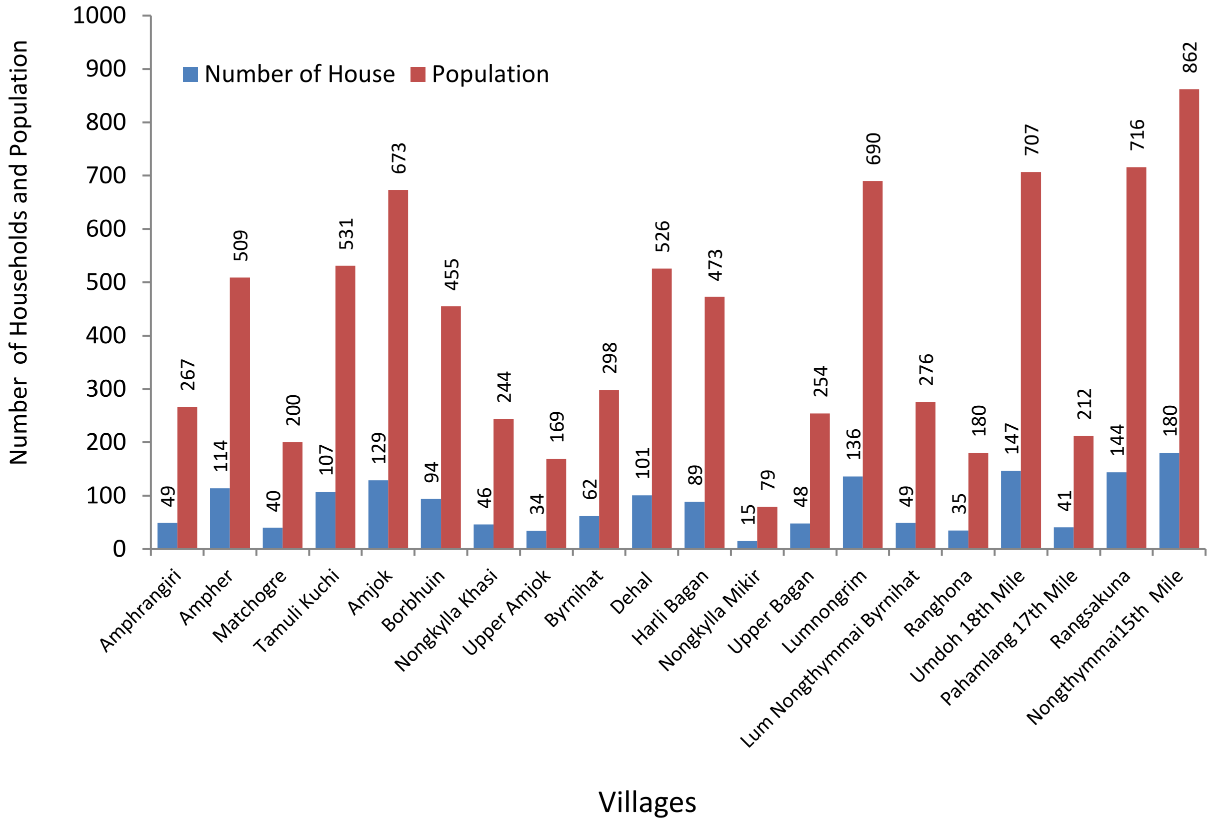


Fig. 2.1 Number of households and population in villages under the study area

The EPIP area comes under DCIC (District Commerce and Industries Centre), Nongpoh, and is composed of small and medium industries and manufacturing units. The Byrnihat-EPIP study area was earmarked along the boundary of Byrnihat Circle consisting of Byrnihat village and other 19 villages and also the EPIP area that flanks the Byrnihat Circle on the South-Western side (**Fig. 2.2**). The GS road divides the study region from Assam in the Northern part and divides the study region into two halves in the Southern part. Umtrew River runs through the study area and serves as an important source of water for domestic, commercial, and industrial uses. The river also has an Umtrew dam constructed over it, where the region receives as part of its electric supply.

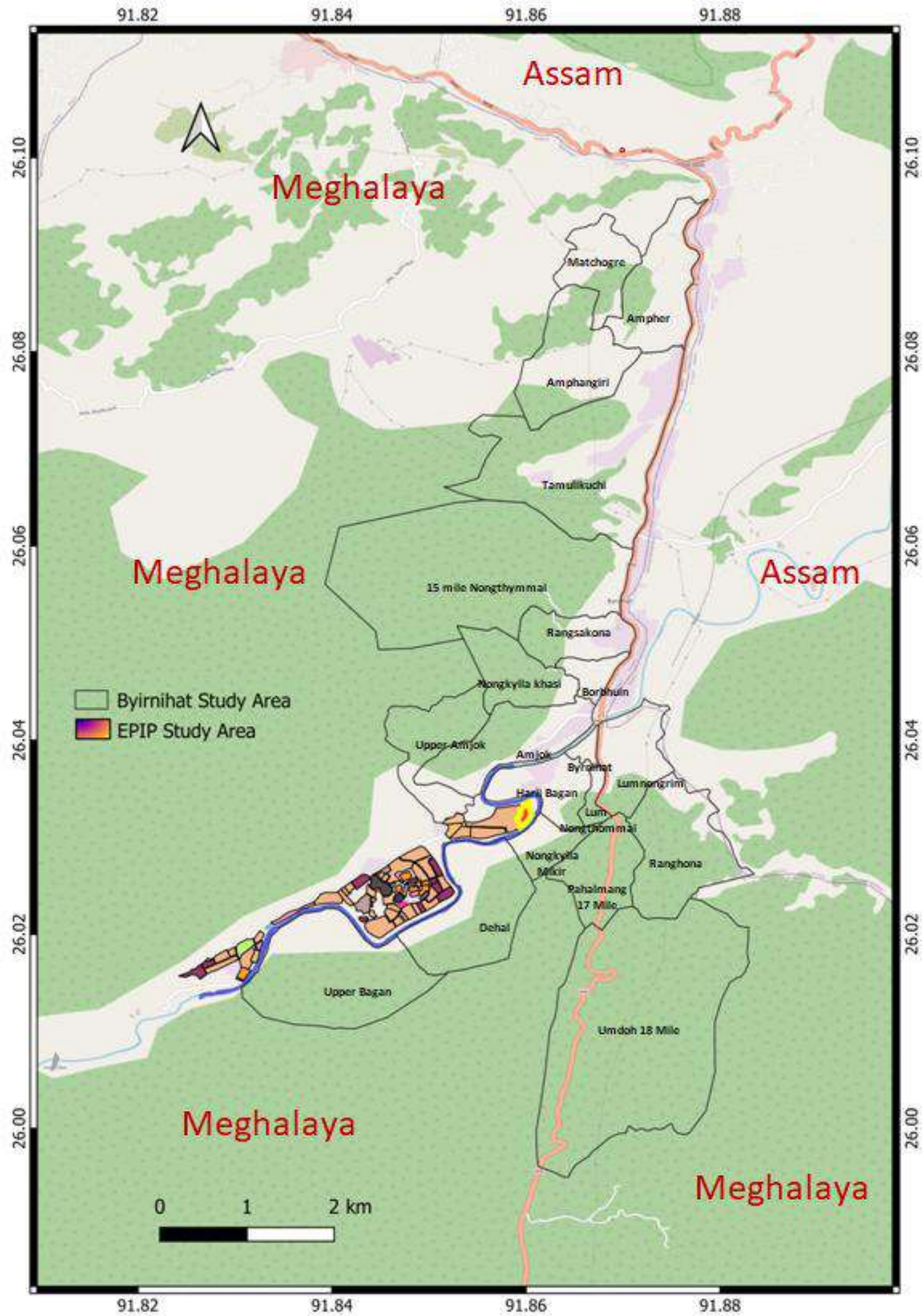


Fig. 2.2 Byrnihat-EPIP Study area

2.1 Land use & Land cover

The LULC map of the study area and surroundings indicate that area under vegetation has highest coverage in the study area and surroundings, as the majorly of area is occupied by vegetated land, forested hills and valleys (**Fig. 2.3**). A significant portion of the selected study boundary comprises of urban area and regions outside the urban land use comprise mostly dense and open forests, a few patches of scrub forests, and croplands. Small and scattered patches of agricultural land are present in some valleys. There are barren lands too in a few patches within and just adjacent to the study area. The built-up area is concentrated along the Guwahati-Shillong (GS) Road (both on Meghalaya and Assam sides on GS road) that runs along the eastern border of the study area, EPIP area and also, in small patches where hamlets are located. The built-up areas long GS road includes commercial areas, offices, schools, manufacturing premises, hotels and restaurants, houses etc. The built-up area in the EPIP zone mainly comprises industrial sheds, other industrial buildings, paved/concrete roads, staff quarters, shops and some private houses. These built-up areas can be considered as the prime sources of air pollution from industries, roads (road dust and vehicles), burning of fuels in households and eateries, open burning of garbage etc.

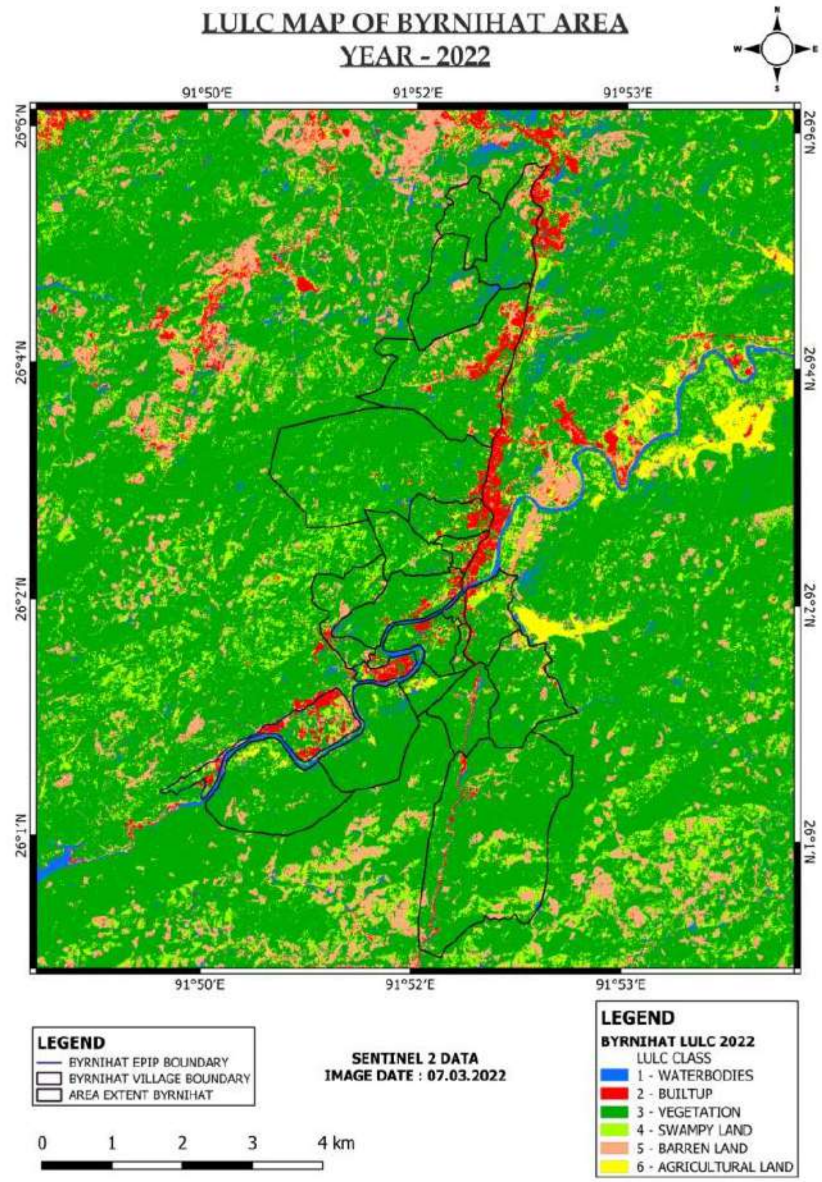


Fig. 2.3 The LULC of the study area and surroundings

The terrain in the study area was studied by the Digital Elevation Model (DEM), which is a representation of the bare ground (bare earth) topographic surface of the earth excluding trees, buildings, and any other surface objects. The terrain or topography of an area is significant as it influences wind movements, wind shear, trapping of air pollutants in low lying areas and dispersion over the flat terrain. The terrain in the study area is undulating and has several hills and valleys, especially in the EPIP area. Most industrial units are located in the EPIP area in valleys whereas the hilltops are mostly unoccupied or have hamlets or has stone crushing units. The elevation profile map (**Fig. 2.4**) shows that highest elevated areas are located in some patches in the western and southern parts. EPIP is located on almost a plain land (about 50 meters above msl), guarded by small hills on the southern, south-western and eastern parts. The highest elevation in the study area is about 530 m above msl.

The drainage channels in the area (**Fig. 2.4**) are mainly linked to Umtrew River, with various stream orders ranging from 1-5. In drainage basin analysis, designation of stream orders is done by a system introduced by Horton (1945). Stream order is a measure of the relative size of streams. The streams have been ranked following Strahler's (1964) stream ordering system, based on hierarchic ranking of streams. The number of streams of each order was computed with the application of GIS. First-order streams are perennial streams that carry water throughout the year with no permanently flowing tributaries, implying that no other streams "feed" them. First- through third-order streams are usually called headwater streams whereas streams classified as fourth-through sixth-order are considered medium streams (West Virginia Conservation Agency, https://www.wvca.us/envirothon/a7.cfm). The drainage primarily ends up in the river Umtrew, which is one of the major drainage systems in Meghalaya Plateau. Umtrew originates from the west of the Sohpetbneng range in East Khasi Hills District, near Lum Raitong. It flows towards the west till it meets the waters from the Umiam River which is being diverted by the Umiam Hydel Project. It then turns northwest and emerges at Byrnihat where the GS road crosses this river. The river flows past EPIP region where it becomes one of the primary sources of water used in industries. The DEM of the study area and surroundings, indicate to the presence of hilly terrain in and around the study area and relatively lower elevation in the major part of study area.

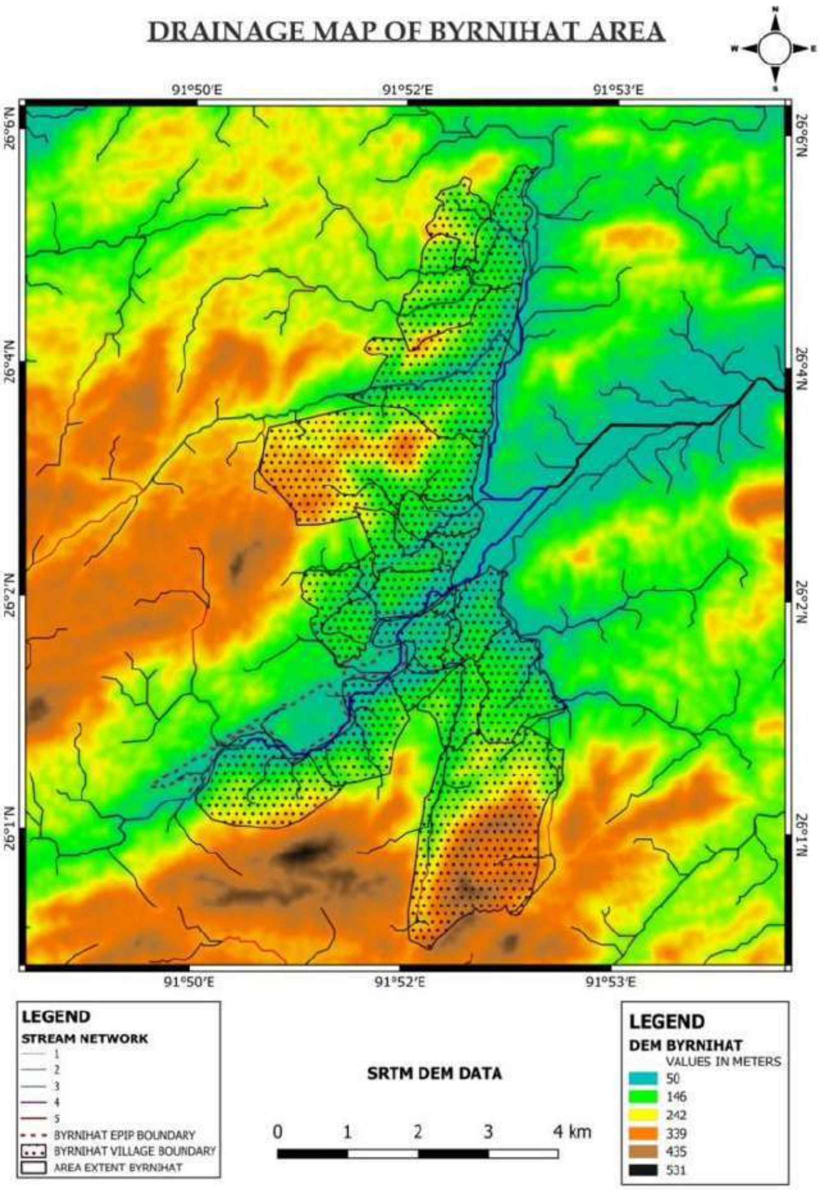


Fig. 2.4 The elevation profile (DEM) and drainage map of the study area

2.2 Weather and Climate

The Byrnihat area, situated within the Ri Bhoi district of Meghalaya, exhibits a sub-tropical climate, delineated by distinct seasonal variations. The climatic classification, essential for understanding the atmospheric dynamics, highlights a semi-dry summer and a cold winter. These climatic nuances wield significant influence over local ecosystems and environmental processes. The annual precipitation, a critical component of the local climate, ranges between 1500 mm to 2000 mm. This precipitation pattern plays a pivotal role in sustaining the ecological balance, affecting soil moisture, and influencing vegetation dynamics. Understanding the distribution of rainfall across different months is imperative for comprehending the seasonal variations within the region.

The month of January stands out as the driest and coldest month, marked by lower temperatures and minimal precipitation. In contrast, July experiences the highest rainfall, contributing to a wetter climate. The month of August emerges as the warmest, showcasing the diversity of seasonal variations within Byrnihat. The undulated topography, characterized by mountains and hillocks, adds a layer of complexity to the microclimatic dynamics. This diverse topographical layout contributes to variations in temperature gradients, wind patterns, and precipitation distribution. These interactions create microclimates within the region, influencing local weather conditions.

2.3 Meteorological features

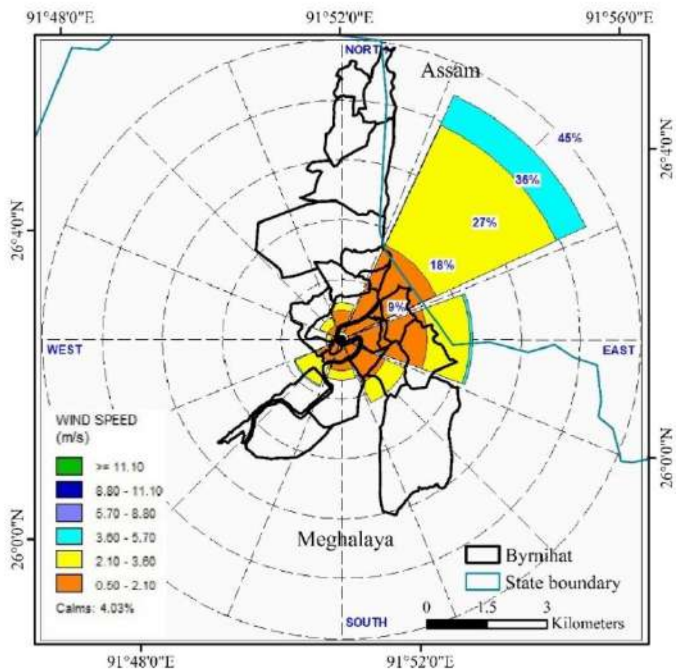
Byrnihat, nestled in the Umling Block of the Ri Bhoi district, Meghalaya, boasts a sub-tropical climate and varied topography, presenting a fascinating tapestry of meteorological conditions. Various seasonal patterns during winter and summer shape atmospheric dynamics shaping this region. During the winter months, temperature in Byrnihat ranges from 9.8°C to 30.2°C, portraying a spectrum of mild to cool conditions. Notably, high humidity levels, peaking at 93.7%, contribute to the perceived cold. Winter precipitation remains minimal or nil, indicating a dry and relatively stable atmospheric state.

Transitioning to summer, there is a discernible uptick in wind speed, reaching a maximum of 10.0 m/s. This signifies increased atmospheric activity, potentially influenced by regional climatic phenomena. Temperature exhibits a broader range, fluctuating between 16.5°C and 39.0°C. The warmer temperatures align with expectations for the summer season. Reduced humidity, bottoming out at 0.0%, highlights drier air masses prevailing during this period. Notably, summer precipitation sees a modest increase, averaging 1.9 mm/h, indicative of the influence of the monsoon and the associated convective processes.

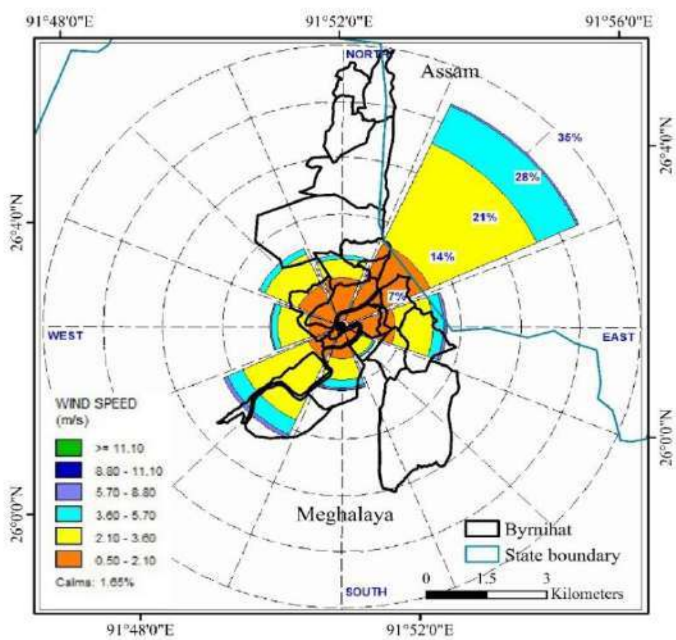
Table 2.2 Meteorological parameters of Byrnihat during Winter and Summer

Season/Description		Wind speed (m/s)	Temperature (°C)	Relative Humidity (%)	Precipitation rate (mm/h)
Winter	Maximum	5.24	30.15	93.67	0.00
	Minimum	0.02	9.85	16.66	0.00
	Average	1.94	18.57	50.37	0.00
Summer	Maximum	10.00	39.00	100.0	28.3
	Minimum	1.00	16.50	12.7	0.0
	Average	2.3	28.00	57.8	0.1

Beyond the aesthetic charm of its landscapes, understanding the meteorology of Byrnihat holds practical significance for ecological assessments and regional planning. A nuanced comprehension of local climate patterns informs decision-making processes, particularly in sectors sensitive to weather variations. During winter, the majority of wind is blowing from the NE direction towards Byrnihat with an average wind speed of 1.94 m/s and approx. 4% calm wind condition. While the summer season exhibits the majority of winds from NE and ENE directions, low frequency (<5%) winds with higher speed (>5 m/s) are also coming from SW and WNW directions (**Fig. 2.5**). The percentage of calm wind in summer (1.6%) is less than that in winter season. The seasonal average near-surface wind speed (**Fig. 2.6**) in Byrnihat is found to be varying from 3.6-4.2 m/s in winter (Dec, Jan, 2022-23) and 4.4-4.9 m/s in summer (April–June 2023). Surface pressure values are comparatively higher in winter (946–1014 hPa) than that in summer (940–1007 hPa) which indicates presence of high pressure subsidence and chances of inversion layer during winter period (**Fig. 2.7**).

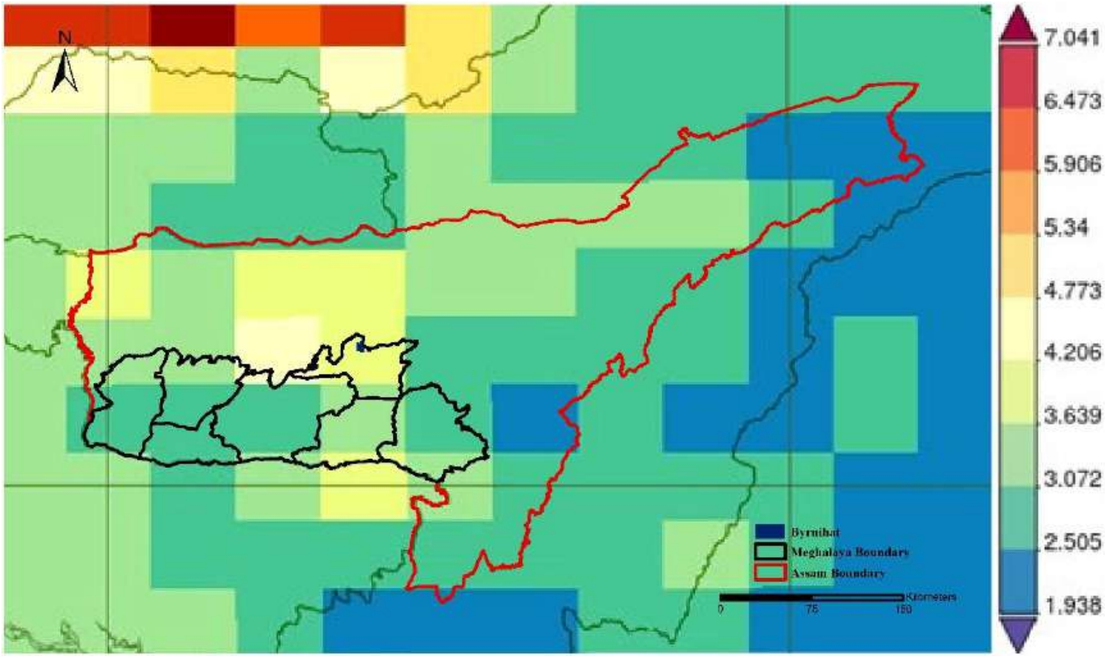


(a) Winter

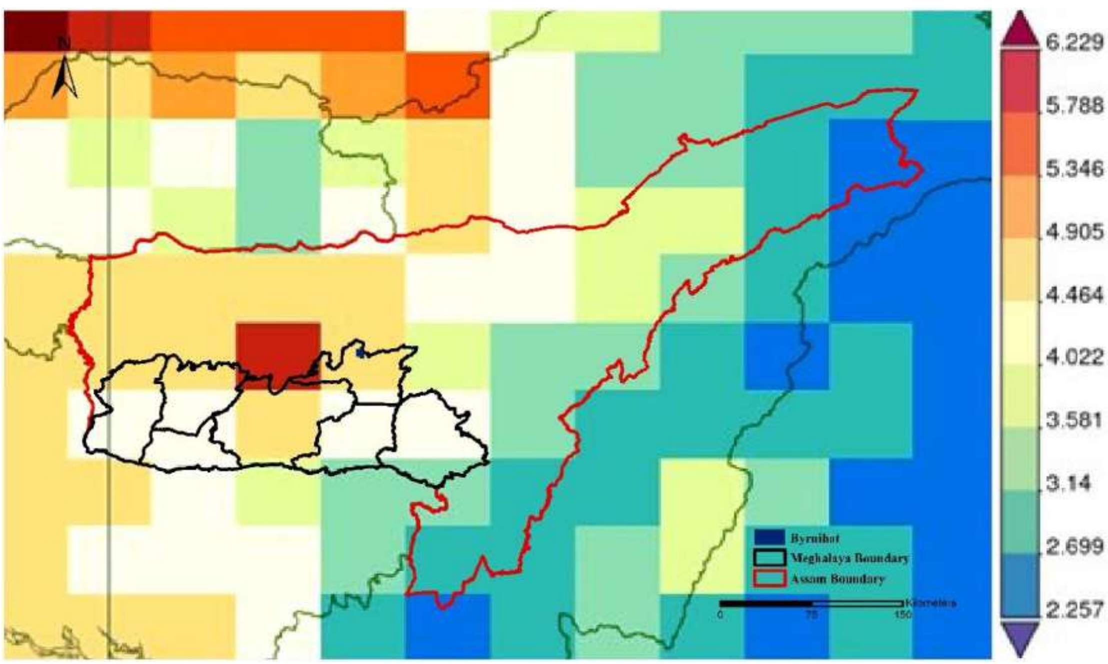


(b) Summer

Fig. 2.5 The Windrose of Byrnihat during (a) Winter (Dec-Jan-Feb) and (b) Summer (April-May-June)

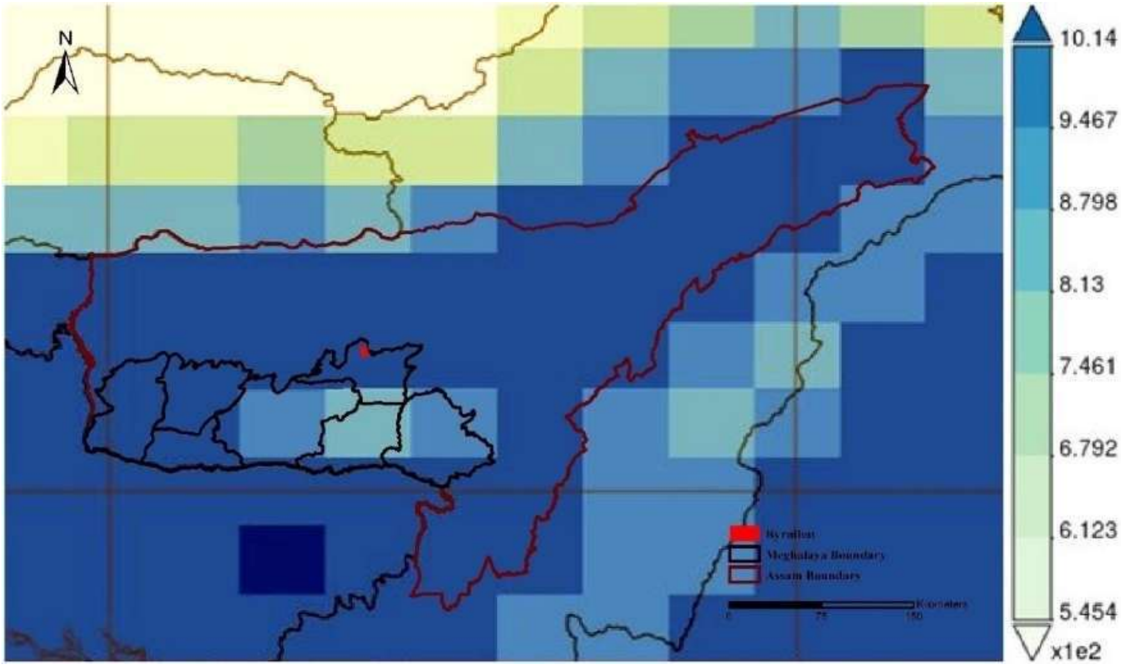


(a)

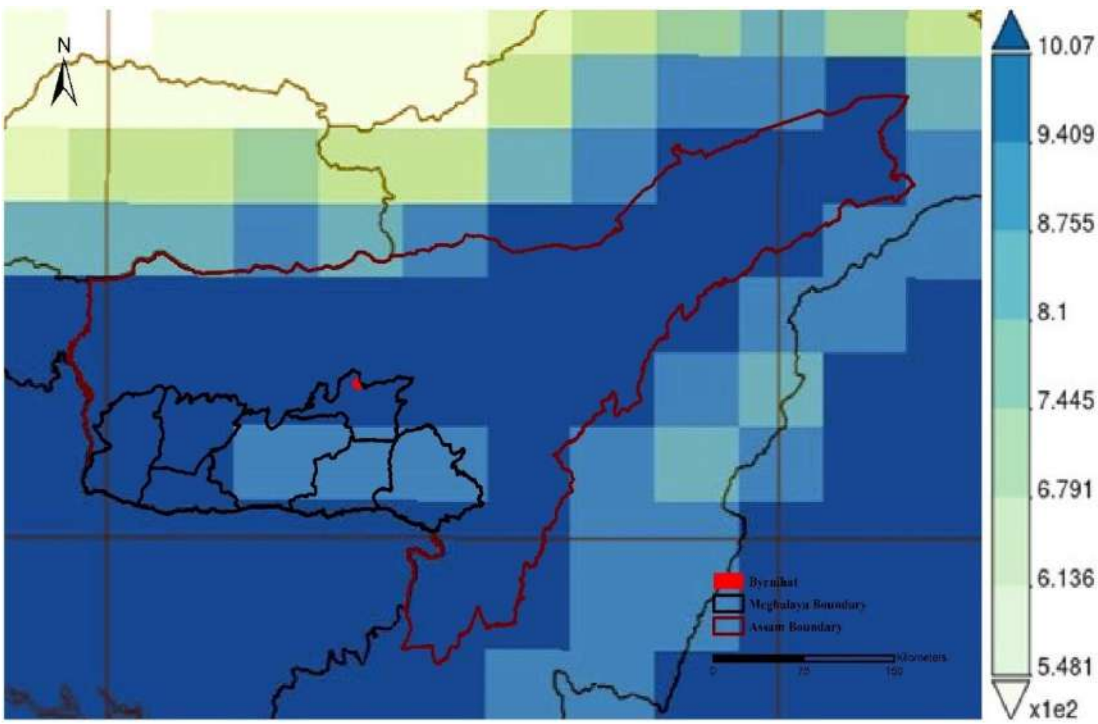


(b)

Fig. 2.6 Seasonal average near-surface wind speed (m/s) during (a) winter and (b)summer in the airshed of Byrnihat.



(a)



(b)

Fig. 2.7 Seasonal surface pressure (Pa) during (a) winter and (b)summer in the airshed of Byrnihat.

2.3.1 Planetary Boundary Layer Height (PBLH)

The planetary boundary layer (PBL) depth or mixing height describes the vertical extent of the lowest part of the atmospheric boundary layer where forcings due to surface roughness are exerted and turbulence is dominant. In the PBL, atmospheric processes reach equilibrium and the air becomes well mixed again in a time range of about one hour after a disturbance. The PBL is often bounded at the top by a temperature inversion (i.e. a layer where temperature increases with height instead of decreasing as usually). The inversion acts as a barrier to atmospheric exchange and may effectively limit the transport of gases and particles from the PBL into the free troposphere. Therefore, PBL depth or mixing (layer) height (MH) is a fundamental parameter in many dispersion models which strongly influences the concentration of atmospheric substances (Deutscher Wetterdienst -Zentrale, https://www.dwd.de/EN/research/weatherforecasting/num_modelling/03_environmental_forecasts/mischungsschichthoehen_en.html). The thickness of the PBL is not constant. At night and in the winter months, PBL tends to be lower in thickness while during the day and in the warm season, it tends to have a higher thickness. The two reasons for this are the wind speed and thickness of the air as a function of temperature. Strong wind speeds allow for more convective mixing. This convective mixing will cause the PBL to expand. At night, the PBL contracts due to a reduction of rising thermals from the surface. Cold air is denser than warm air, therefore the PBL will tend to be shallower in the cool season. The planetary boundary layer height (PBLH) therefore has a significant influence on vertical convection currents and vertical distribution of air pollutants in a region, therefore influencing near ground level air pollution significantly. Due to higher temperature and wind speed in summer, the PBLH tends to expand vertically, effectively increasing vertical dispersion of air pollutants whereas in winter, the reverse is witnessed, leading to higher air pollutant build up near ground level. Therefore, in atmospheric carrying capacity or assimilative capacity, PBLH becomes a critical limiting factor.

The PBLH characteristics over the Byrnihat airshed, encompassing Meghalaya and Assam states, were ascertained for summer (April-June 2023) and winter (December-January, 2022-23) from atmospheric reanalysis records. It was observed that PBLH over Byrnihat study area ranged from about 909.6 to 1003 meters above ground level in summer (**Fig. 2.8**) and about 601.8 to 775.8 meters above ground level in winter (**Fig. 2.9**). In summer, PBLH in most parts of R-Bhoi district also had similar values while in most parts of Assam, PBLH increased. In winter also, PBLH in most parts of R-Bhoi district had similar values while in some parts of Assam, PBLH decreased further while in some other parts, it was comparable or higher.

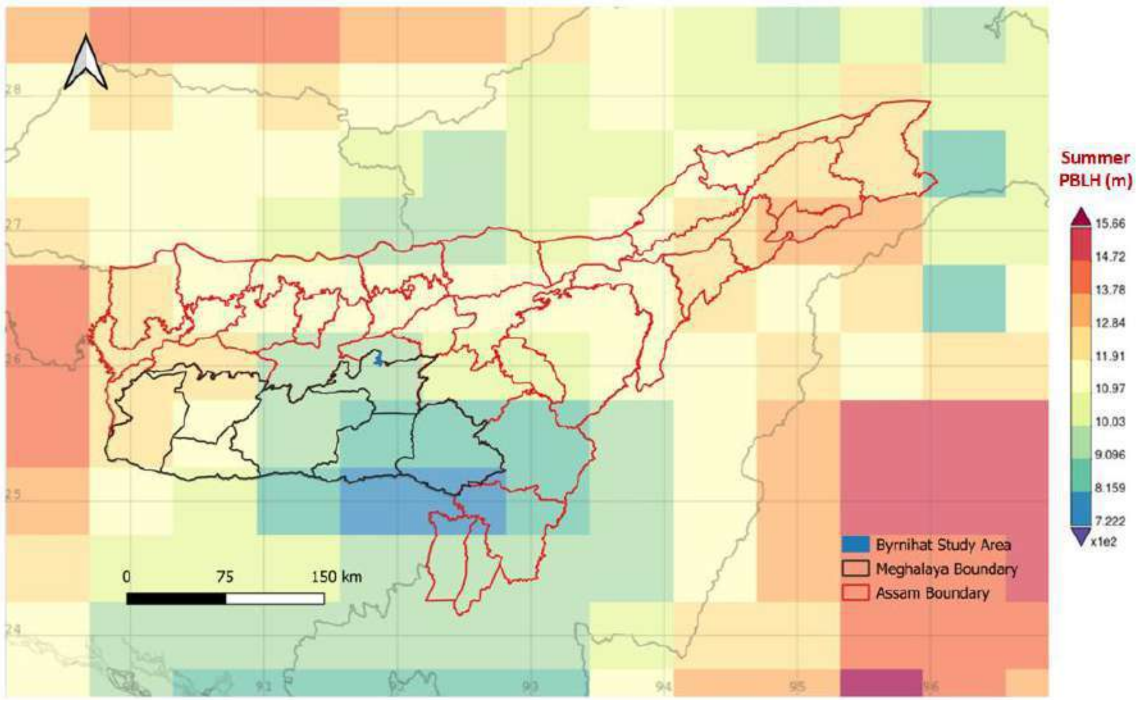


Fig. 2.8 PBLH over the Byrnihat airshed in summer (April-June, 2021)

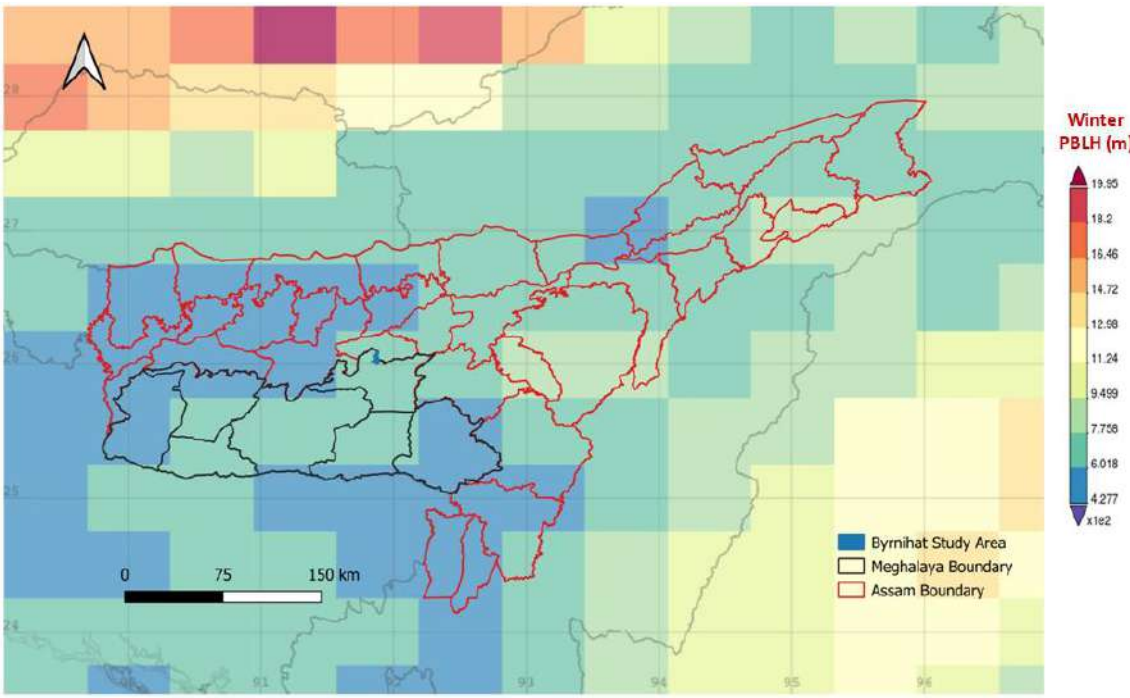


Fig. 2.9 PBLH over the Byrnihat airshed in winter (Dec-January, 2021-22)

Chapter 3

Delineation of Byrnihat Airshed

3.0 Byrnihat Airshed

An 'Airshed' is defined by the USDA Forest Service as a geographic area that, because of topography, meteorology and/or climate, is frequently affected by the same air mass (USDA Forest Service, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3795477.pdf). In another definition, an 'Airshed' is a geographical area where local topography and meteorology limit the dispersion of pollutants away from the area. They are formed by air masses moving across a landscape, thus influencing the atmospheric composition of that area. Their boundaries are loosely defined, but can be quantified (Sparling, 2016).

Due to the proximity of cities and polluted urban/peri-urban/rural areas that feed each other commercially and economically, it is sometimes impractical to draw an administrative boundary that hosts all the sources of air pollution affecting the region. Delimitation of affected regions into administrative urban boundary limits air pollution sources like road transport, rail transport, waste management, road dust, greening, and domestic cooking. But often, large and medium scale industrial sources such as coal-fired power plants and brick kilns are located outside city boundaries and fall outside enforcement responsibilities of the city administration. The situation is similar in all clusters of cities on Indian landmass. To estimate atmospheric assimilative capacity or carrying capacity of a region, it is important to delineate the regional airshed which is also instrumental in streamlining effective urban air quality management. Understandings on the sources inside and outside the cities/towns, potential hot spots (industrial, transport, landfills, and residential), and physical characteristics of the airshed is necessary for studying atmospheric assimilative capacity. For determining a city's airshed size, a general thumb rule is that the area should include all the diffused and point sources in the immediately vicinity, that are likely to influence the city's air quality by working as the receiving zone of regional wind/air masses that bring air pollutants.

The entire periphery of winter airshed of Byrnihat is enclosed into a rectangular area encompassing 4.7 (Lat) × 5.4 (Lon) degrees [1 degree Lat ≅ 110.948 km and 1 degree Lon ≅ 106 km] (**Fig. 3.1**). The airshed in itself covers an area of about 119445 sq. km in which Meghalaya state comprises about 7938 km^2 (6.64% of total airshed). But, the most active part of the airshed that hosted over >90% of air trajectory frequencies, has an area of about 13800 km^2 in which Meghalaya comprises about 1205 km^2 which is 8.73% of this active airshed. This airshed analysis has been conducted with the data of Dec-Jan 2021-22. It may be noted that the airshed periphery and area are expected vary seasonally and yearly.

The entire periphery of summer airshed of Byrnihat can be enclosed into a rectangular area encompassing about 10.5 (Lat) × 14.7 (Lon) degrees [1 degree Lat ≅ 110.948 km and 1 degree Lon ≅ 106 km] (**Fig. 3.2**). The airshed in itself covers an area of about 426253 km^2 in which Meghalaya comprises about 18733 km^2 (4.4% of total airshed). But, the most active part of the airshed that hosted over >90% of air trajectory frequencies, has an area of about 2105 km^2 in which Meghalaya comprises about 707 km^2 which is 33.6% of this active airshed. This airshed analysis has been conducted with the data of April-May 2021. It may be noted that airshed periphery and area is expected to vary seasonally and yearly.

Therefore, summer airshed is much more expansive than winter airshed in terms of area covered by all wind trajectories, but the most active part of airshed (hosting over >90% of air trajectory frequencies) is larger in winter. Further, the position of the most active part of airshed shifted westwards in summer.

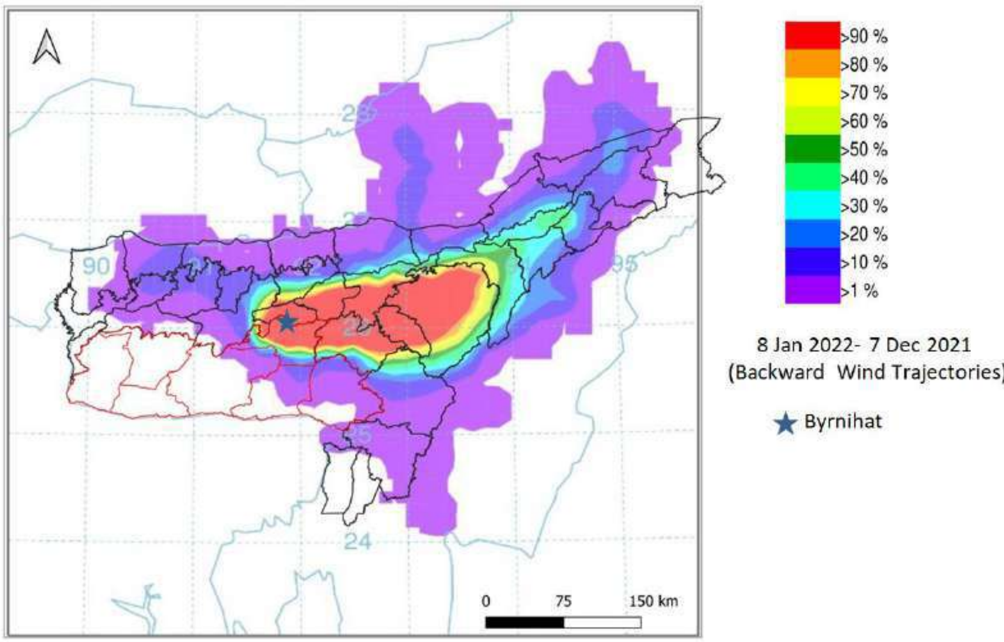


Fig. 3.1 Winter (Dec 2021-Jan 2022) airshed of Byrnihat [Assam and its districts demarcated by black border and Meghalaya and its districts by red border]

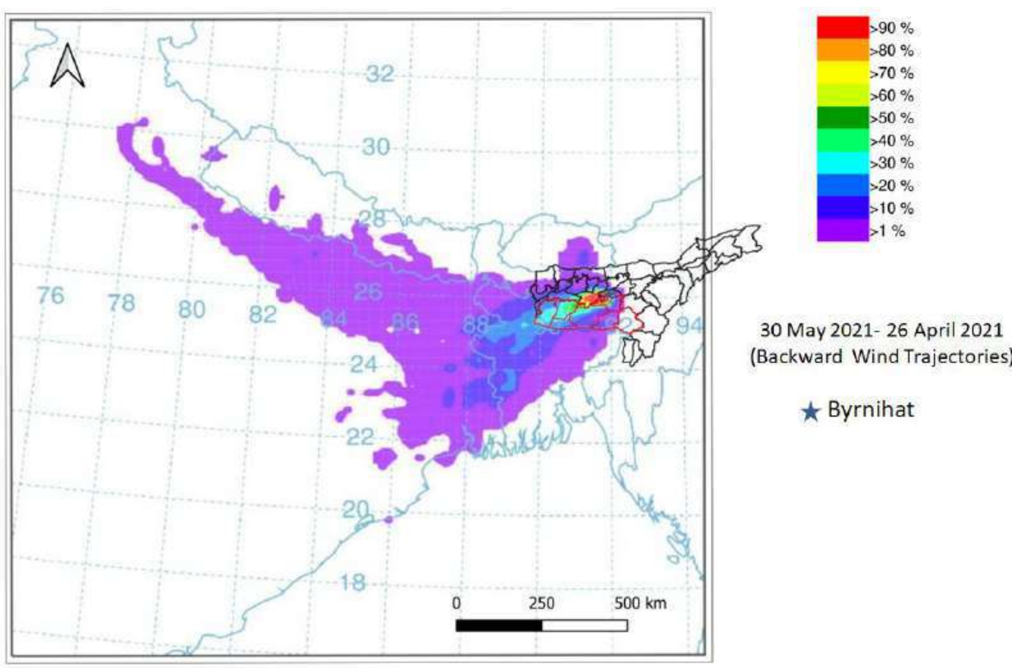


Fig. 3.2 Summer (April-May, 2021) airshed of Byrnihat [Assam and its districts demarcated by black border and Meghalaya and its districts by red border]

Chapter 4

Ambient Particulate Matter (PM_{10} and $PM_{2.5}$) and Gridded Emission Inventory

4.0 Ambient Particulate Matter

Ambient $PM_{2.5}$ and PM_{10} levels are important indicators of the air quality of a region. The atmospheric carrying capacity report is integrally linked to prevalent ambient $PM_{2.5}$ and PM_{10} levels and whenever their concentration breach the specified safe limits (National Ambient Air Quality Standard or NAAQS) in a specific area, the regional atmosphere is considered to exceed its atmospheric carrying capacity or atmospheric assimilative capacity. Therefore, it is important to carry out ambient air quality assessment on ground level atmosphere, where human activities take place and human exposure to air pollution is maximum, to understand and assess atmospheric carrying capacity. The ambient air quality monitoring and assessment was undertaken at specific sites that are considered representative to the study area and its dominant activities.

Ambient air quality monitoring ($PM_{2.5}$ and PM_{10}) at near ground level (2-5 m above GL in) was undertaken by CSIR-NEERI in winter 2023 and summer 2023 at five designated air quality monitoring sites (**Table 4.1, Fig. 4.1**) in Byrnihat-EPIP study area. The concentration of ambient $PM_{2.5}$ and PM_{10} obtained from these monitoring campaigns are presented in **Fig. 4.2–4.5 and Tables 4.2 a-d**.

Table 4.1 The summary of air quality monitoring sites in Byrnihat-EPIP area

Site No.	Site Name	Latitude	Longitude	Site classification
1	CASFOS Officers' Quarters	26.07	91.87	Residential and Industrial
2	MeECL Inspection Bungalow	26.04	91.87	Commercial and Kerbside
3	MIDC Inspection Bungalow (EPIP)	26.02	91.84	Industrial
4	Don Bosco School	26.04	91.86	Residential
5	Soil & Water Conservation Department, CTI	26.09	91.87	Control site (Winter Upwind station)

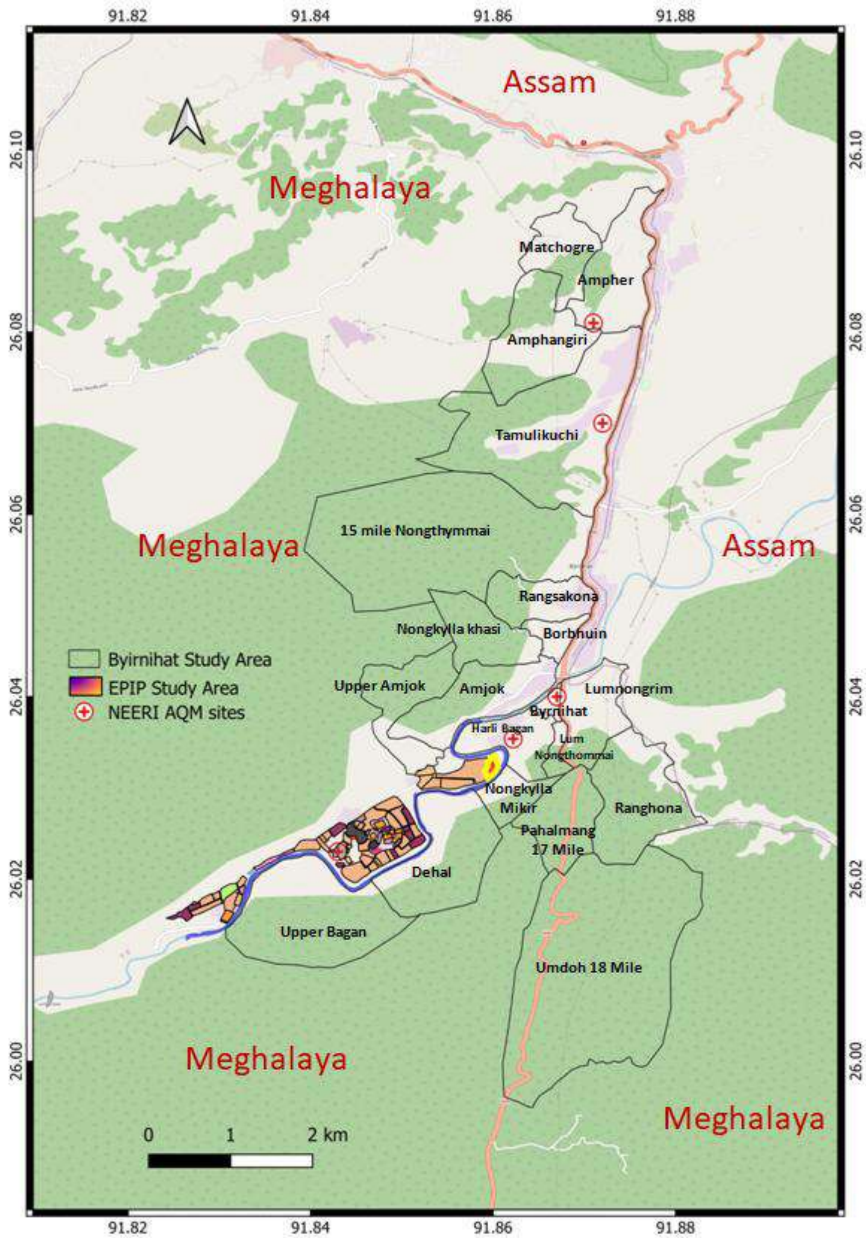


Fig. 4.1 The locations of five air quality monitoring (AQM) stations of CSIR-NEERI selected for ambient air quality monitoring at Byrnihat

Table 4.2a: Site-wise $PM_{2.5}$ concentration in winter

$PM_{2.5}$ (Winter)						
Date	**CASFOS**	**MeECL**	**MIDC**	**Date**	**Soil Consv**	**Don Bosco**
1/10/2023	158.15	259.95	85.21	1/20/2023	175.74	99.67
1/11/2023	343.90	209.62	139.27	1/21/2023	156.44	292.27
1/12/2023	193.07	255.85	124.56	1/22/2023	178.85	242.95
1/13/2023	177.51	188.25	144.62	1/23/2023	142.08	240.86
1/14/2023	211.89	250.23	137.11	1/24/2023	181.71	359.85
1/15/2023	194.42	242.26	149.63	1/25/2023	220.32	281.89
1/16/2023	201.25	231.43	113.74	1/26/2023	203.42	250.48
1/17/2023	160.51	274.95	65.62	1/27/2023	118.09	249.04
1/18/2023	122.26	124.46	123.75	1/28/2023	157.16	256.59
1/19/2023	178.41	154.29	128.87	1/29/2023	161.82	256.03

Table 4.2b: Site-wise $PM_{2.5}$ concentration in summer

$PM_{2.5}$ (Summer)						
Date	**CASFOS**	**MeECL**	**MIDC**	**Date**	**Soil Consv**	**Don Bosco**
4/28/2023	75.67	134.33	70.24	5/8/2023	134.99	137.39
4/29/2023	41.12	164.99	122.73	5/9/2023	117.27	266.59
4/30/2023	64.77	111.42	63.09	5/10/2023	136.54	201.40
5/1/2023	76.06	120.66	168.23	5/11/2023	139.77	149.42
5/2/2023	97.83	60.28	168.96	5/12/2023	111.42	107.05
5/3/2023	120.18	149.26	164.93	5/13/2023	147.36	204.65
5/4/2023	85.56	103.24	126.62	5/14/2023	109.54	105.95
5/5/2023	154.22	137.57	184.67	5/15/2023	50.77	41.39
5/6/2023	114.26	102.09	105.49	5/16/2023	141.13	75.03
5/7/2023	72.33	104.33	82.68	5/17/2023	66.29	102.21

Table 4.2c: Site-wise PM_{10}concentration in winter

PM_{10} (Winter)						
Date	CASFOS	MeECL	MIDC	Date	Soil Consv	Don Bosco
1/10/2023	232.98	322.81	159.64	1/20/2023	214.69	182.28
1/11/2023	395.89	310.50	163.76	1/21/2023	188.73	307.22
1/12/2023	246.18	331.46	188.81	1/22/2023	211.48	326.41
1/13/2023	223.18	344.36	188.80	1/23/2023	159.58	399.34
1/14/2023	369.93	280.70	244.29	1/24/2023	205.92	433.67
1/15/2023	253.79	258.17	186.17	1/25/2023	274.56	370.55
1/16/2023	231.49	350.89	162.92	1/26/2023	226.18	349.44
1/17/2023	176.32	339.80	218.69	1/27/2023	234.95	337.64
1/18/2023	162.35	155.09	261.90	1/28/2023	205.35	338.89
1/19/2023	205.44	244.83	211.65	1/29/2023	281.72	327.32

Table 4.2d: Site-wise PM_{10}concentration in summer

PM_{10}(Summer)						
Date	CASFOS	MeECL	MIDC	Date	Soil Consv	Don Bosco
4/28/2023	104.01	159.99	107.65	5/8/2023	202.91	338.69
4/29/2023	83.50	202.28	185.44	5/9/2023	207.47	294.99
4/30/2023	100.95	139.98	94.99	5/10/2023	181.01	305.74
5/1/2023	105.04	190.35	213.55	5/11/2023	190.52	314.21
5/2/2023	195.40	97.11	257.84	5/12/2023	163.14	198.69
5/3/2023	150.30	202.71	216.52	5/13/2023	198.04	315.05
5/4/2023	136.13	142.41	237.44	5/14/2023	140.87	131.85
5/5/2023	265.91	158.94	221.40	5/15/2023	69.94	62.89
5/6/2023	221.46	158.74	222.21	5/16/2023	185.20	109.49
5/7/2023	115.57	135.80	145.01	5/17/2023	123.82	155.44

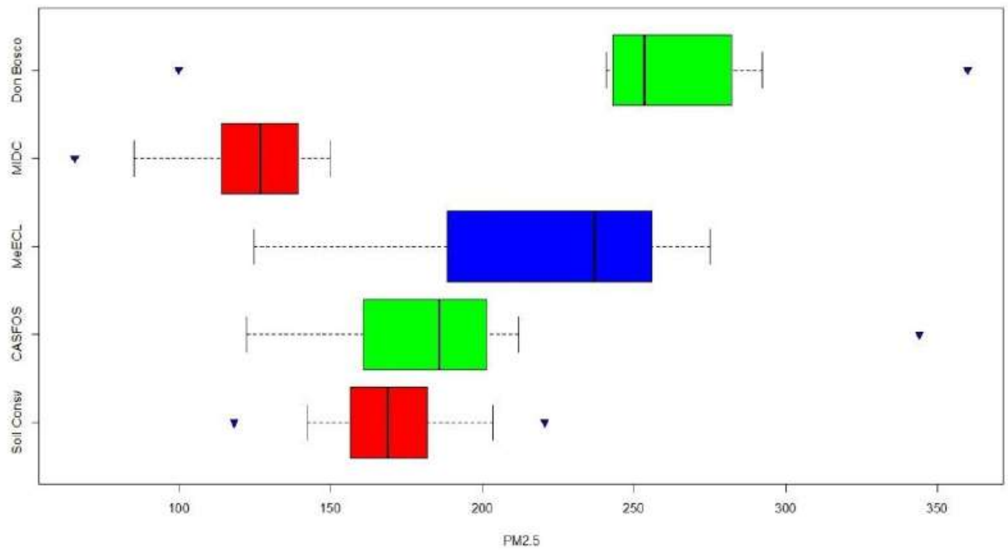


Fig. 4.2 Site-wise variation in $PM_{2.5}$ in Byrnihat (winter, 2023) [outliers marked by tiny triangles and median marked by line within bars]

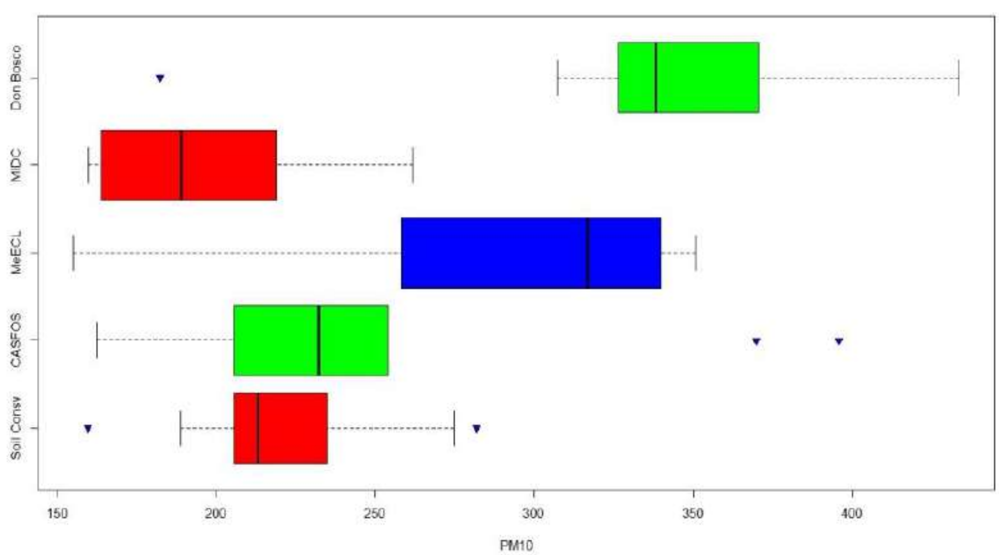


Fig. 4.3 Site-wise variation in PM_{10} in Byrnihat (winter, 2023) [outliers marked by tiny triangles and median marked by line within bars]

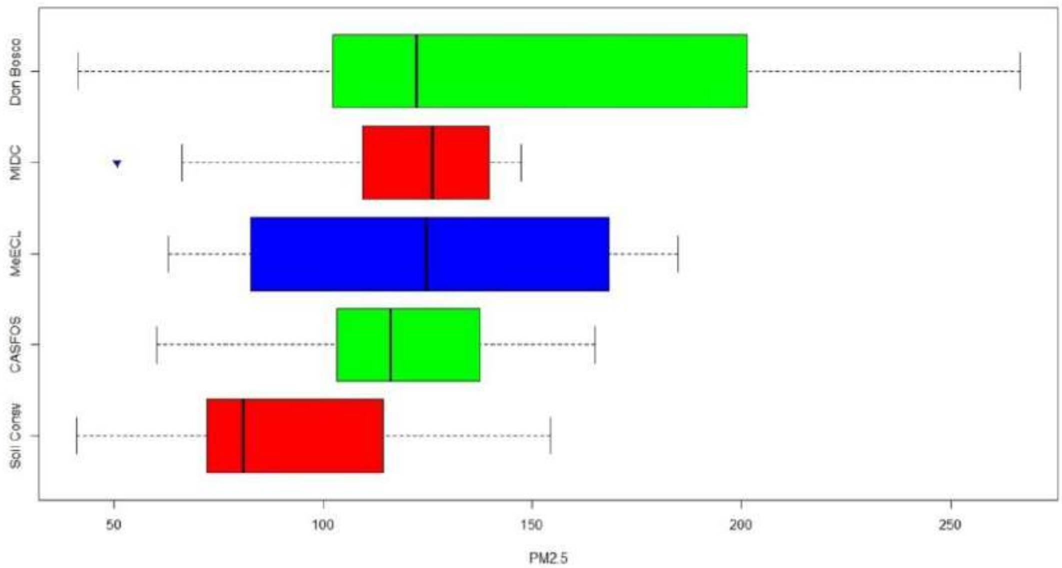


Fig. 4.4 Site-wise variation in $PM_{2.5}$ in Byrnihat (summer, 2023) [outliers marked by tiny triangles and median marked by line within bars]

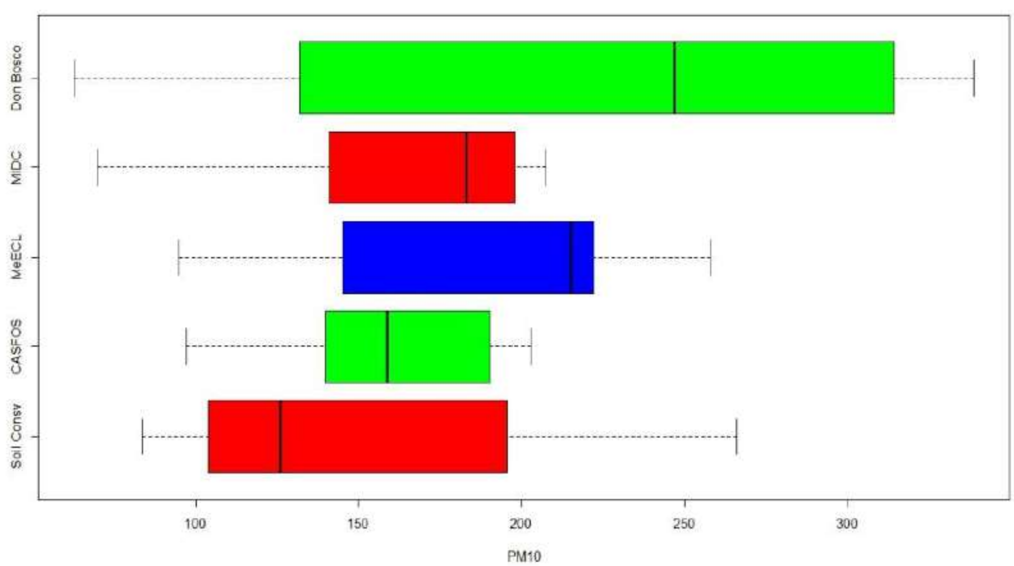


Fig. 4.5 Site-wise variation in PM_{10} in Byrnihat (summer, 2023) [outliers marked by tiny triangles and median marked by line within bars]

The geospatial spread of ambient $PM_{2.5}$ and PM_{10} over the entire study area was assessed by a statistical interpolation technique (IDW) from the monitored data at specific sites during the study, to evaluate likely levels of ambient $PM_{2.5}$ and PM_{10}over those areas also where actual air quality monitoring was not undertaken. This analysis presents a robust geospatial perspective on likely levels of air pollutants over the entire study area coinciding with the period of actual air quality monitoring. This perspective helps one to undertake informed decisions on air quality management. The levels of predicted air pollutants also give a clear perspective where the prescribed National Ambient Air Quality Standard (NAAQS) is breached and atmospheric assimilative capacity (ACC) is exceeded. This technique is one of the ways ACC can be perceived.

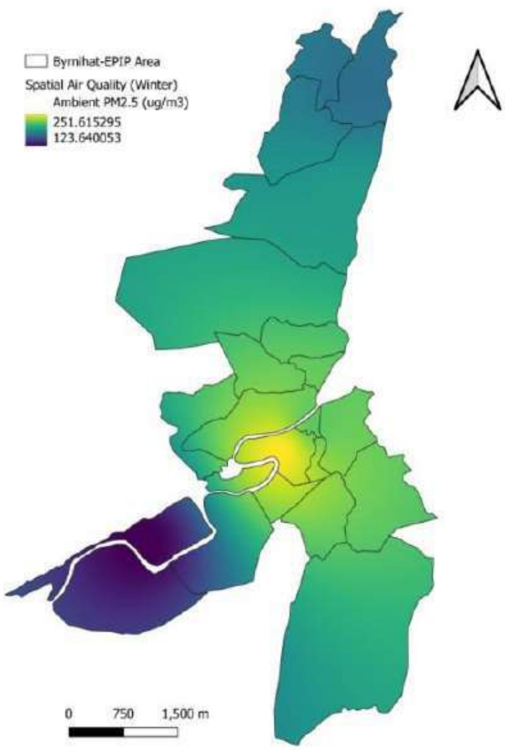


Fig. 4.6 The geospatial spread of ambient $PM_{2.5}$ ($\mu g/m^3$) in Byrnihat-EPIP study area in winter 2023

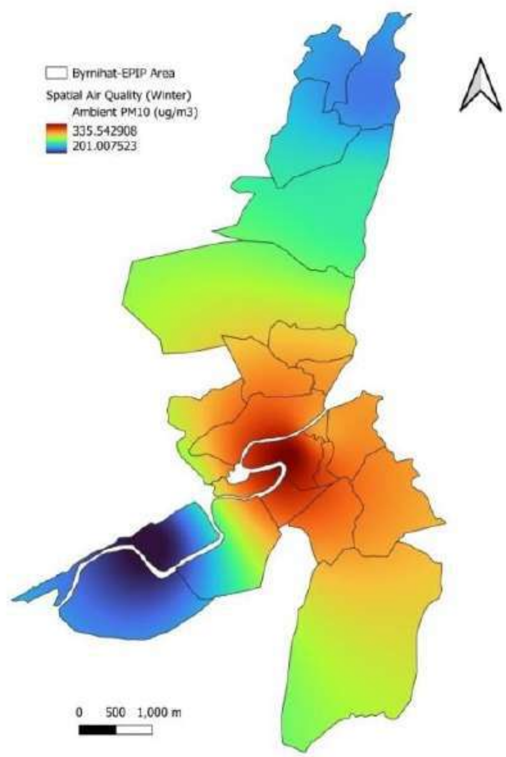


Fig. 4.7 The geospatial spread of ambient PM_{10} ($\mu g/m^3$) in Byrnihat-EPIP study area in winter 2023

The **Fig. 4.6-4.7** show that in winter 2023, the epicenter of high ambient air pollution in terms of $PM_{2.5}$ (~200-250 $\mu g/m^3$) and PM_{10} (~300-335 $\mu g/m^3$) was the central zone of the study area that includes Harli Bagan, Byrnihat, Nyokhla Mikir, Lum Nongthommai, Pahalgam 17th Mile, Amjok, Dehal, Lumnongrim villages while in all other villages, ambient $PM_{2.5}$ and PM_{10} breached 24-hrly NAAQS (60 and 100 μg/m^3, respectively).

In summer 2023 also, the epicenter of high ambient air pollution in terms of$PM_{2.5}$ (~100-138 μg/m^3) and PM_{10} (~200–221 μg/m^3) was again the central zone of the study area that includes Harli Bagan, Byrnihat, Nyokhla Mikir, Lum Nongthommai, Pahalgam 17th Mile, Amjok, Dehal villages while in all other villages, ambient $PM_{2.5}$ and PM_{10} breached 24-hrly NAAQS (60 and 100 μg /m^3, respectively) (**Fig. 4.8–4.9**).

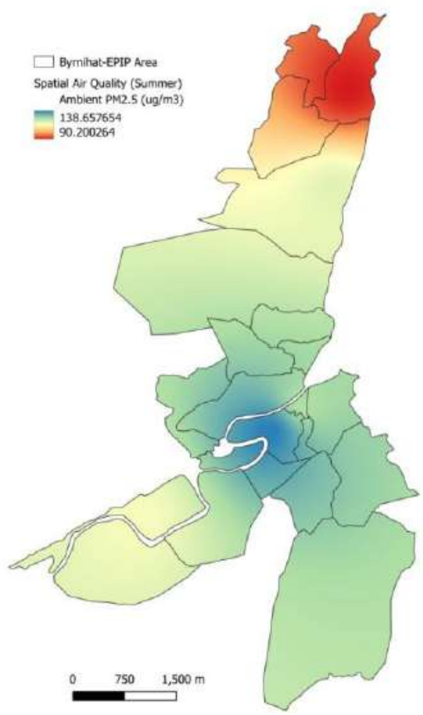


Fig. 4.8 The geospatial spread of ambient $PM_{2.5}$ (μg/m^3) in Byrnihat-EPIP study area in summer 2023

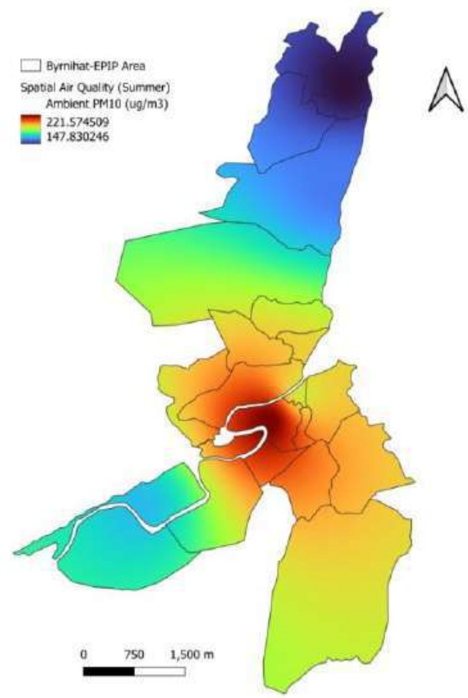


Fig. 4.9 The geospatial spread of ambient PM_{10} (μg/m^3) in Byrnihat-EPIP study area in summer 2023

4.1 Gridded-Emission Inventory

Emission inventory provides a broad estimation of source-wise emission of target air-pollutants. Emission Inventory is an essential tool for streamlining source-wise and sector-wise air quality management practices in a region. This in-depth exercise attempts to identify sector-wise air polluting sources and activities within a given area in a particular time frame and estimates likely emissions from each of the sources, activities or sectors e.g. transport, industry, roads, eateries, households, construction etc. Source-wise emissions of target air pollutants are estimated with the help of source and activity-specific data or activity data (population, fuel consumption, energy usage, length of road, number and types of vehicles running on roads etc.) and respective emission coefficients or emission factors. Gridded emission loads estimated by emission inventory technique can assist in simulating dispersion of pollutants by acting as an input parameter in the dispersion model.

The first step to preparing a emission inventory is to identify major and minor air pollution sources in the region and classify them into point (identifiable by points like industrial stacks), line (linear sources like roads and vehicles running on roads) and area (identifiable by measurable area like eateris, houses, burning areas, areas under construction, areas of earth removal) sources. The sources also need to be geo-tagged to designate their geo-spatial locations for enabling location-wise mapping of likely emission loads. Then, sector-wise activity data (e.g. mileage, vintage, number and types of vehicles, rates of consumption of raw materials for production of commodities, rates of production of commodities, types and number on industries in the study area and their hours of operation per year, area of digging/construction etc. population, number of eateries and households with their fuel consumption etc.) are collected from existing secondary databases maintained by various state/private agencies or by conducting primary survey or direct estimation. These data are then integrated with suitable source-specific and activity-specific emission factors for each target pollutant (i.e. emission per amount of fuel burnt, emission per km travelled for vehicles, emission per unit of a commodity produced etc.) to calculate the most likely emissions of pollutants from the given activity/source/sector. The general formula for emission estimation from activity data and emission factor is as following:

$E = A \times EF \times (1 - ER / 100)$ --- (eq. 4.1)

Where: E = Emissions; A = Activity rate, EF = Emission factor, and ER = Overall emission reduction efficiency, % (if any)

Emission factors (EF) are coefficients representing emission of a particular air pollutant per unit of fuel combusted, raw material consumed, product produced, area dug up, vehicle-km traveled etc. that are multiplied with the activity data (amount and type of fuel combusted, raw material used, product produced, area dug, vehicle number) to calculate emissions originating from the given activity or sector. Emissions measured on vehicle using chassis dynamometers are expressed in grams of pollutant per unit of distance travelled (g/km). For transport sector (tailpipe emissions), EFs reported by ARAI and/or CPCB were used to calculate total on-road vehicular emissions. For the other sectors, emission factors were sourced from USEPA, CPCB, WHO or from open-access reports on source apportionment studies of various cities prepared by NEERI, ARAI, TERI, IITs and other organizations.

4.2 Collection of Activity Data for Byrnihat-EPIP area

Gathering of activity data was undertaken through collection of secondary data from various state agencies, relevant reports and conducting primary surveys and studies where data was not available from any of the above agencies. In the household sector, information and data on existing village population, cooking practices and household fuel usage were collected from surveys conducted in each village of Byrnihat-EPIP area. Village-wise population data (Census, 2011) was collected from Umling Block office which was upscaled for each village to account for the population growth rate of Meghalaya state (27.95%) (https://dcmsme.gov.in/old/dips/state_wise_dips/MEGHALAYA%20STATE%20PROFILE%20REVISED.pdf). The number of restaurants and eateries, their location, coordinates and fuel usage data were collected by field surveys. In the construction sector, data such as the base area of construction as per number of ongoing constructions was not available from any agency and therefore, satellite images were examined to demarcate and delineate recognizable areas showing earth cutting and removal. Data on the numbers, types and vintage of on-road vehicles was collected through videography while proportion of vehicle types in entire fleet, kilometers travelled (VKT) per unit time by each type of vehicle and fuel type were collected from petrol pump and parking lot surveys. Registered vehicle data was also collected from the RTO situated in Nongpoh for necessary understanding on registered vehicle types in the area. The curb weight of each vehicle type was obtained from literature while loads of passengers and materials transported by respective vehicles were found from primary survey, which were suitably added up to get gross weight of vehicle types. Road dust load on various types of roads were collected for estimation of road dust loading on roads. Data on road length and width were collected from surveys and study of maps. The silt content in collected road dust was measured in laboratory to calculate silt loads on roads. For industrial sector, data on consumption of raw materials, fuels, production capacity, captive power generation, DG set usage, air pollution control device (APCD) etc. were obtained from a list of air polluting industries shared by Meghalaya State Pollution Control Board (MSPCB) and also, through a questionnaires survey routed through MSPCB. Official data on waste generation in the study area was not available during survey and hence, solid waste generation was estimated by extrapolation from population of study area by using per capita waste generation factor for Indian cities reported by CPCB. **Table 4.3** summarizes the types of data collected for preparation of emission inventory across different sectors.

Table 4.3 Summary of sector-wise identified data required for emission Inventory

Sector	Data type	Data source	Remarks
Household	Location, fuel usage, Number of houses per village/area, Number of members per family etc.	Village Heads (Gamburas), District Statistics office, Primary surveys etc.	Primary survey was done by CSIR-NEERI
Population	Village and household population etc.	Umling Block Office, Census data, Meetings with Gamburas (village heads), population growth rate of Meghalaya from report etc.	Primary survey was done by CSIR-NEERI
Eateries/ Restaurants	Number, Location, number of working hours and days, fuel usage etc.	Primary survey by NEERI	CSIR-NEERI survey

Earth Removal	Base area of earth removal, wind speed etc.	Village surveys, Satellite data	Earth cutting and removal in villages and industrial area observed
Hot mix plants	-	-	Not found
Vehicular	No. of registered vehicles and their type (small, medium, heavy and sub categories) with emission compliance category (Bharat/Euro etc.), vintage, on-road numbers, VKT	RTO office at Nongpoh, Primary surveys through videography, petrol pump and parking lot surveys etc.	Apart from local vehicles, vehicles from other states pass through the study area along GS road
Industry	Type of industry, Production capacity, Operating hrs/day and days/year, Type of Fuel, Fuel usage per day and where used, control equipment with efficiency, emission reports etc.	Questionnaire survey, MSPCB data	Collection of secondary data from air-polluting industries (identified by MSPCB) through a questionnaire survey routed through MSPCB
Industrial Captive Power Plant (CPP)	Production capacity, Operating hrs/day and days/year, Type of Fuel, Fuel usage per day or year, control equipment with efficiency	Questionnaire survey, MSPCB data	-do-

DG sets (industrial)	Operating hrs/day and days/y, Type of Fuel, Fuel usage per day	Questionnaire survey, MSPCB data	-do-
Roads	Dust and silt load on roads, On-road vehicle numbers against each type, Vehicle weight, Vehicle kilometer traveled	Primary surveys and videography for vehicle number, types and vintage, reports for vehicle weight etc.	Road dust collected by CSIR-NEERI at several locations, Petrol pump and parking lot survey for vintage and VKT estimation
Open burning of solid waste	Waste generation and dumping practices, Open burning locations	Primary surveys by NEERI, Information on waste management from Block office	No organized waste collection activity exists, and no designated dumping site is present in the study area at the time of field study. Waste mostly dumped wantonly and frequently burnt. Open burning of MSW/ leaf/garden waste documented by NEERI

4.3 Source-Category Specific Gridded Emission Inventory

The gridded emission inventory of Byrnihat-EPIP study area was prepared by taking 2023 as the base year for activity data. For calculating source-category specific emission loads of each target pollutant under each area grid (1 km × 1 km), each individual source (i.e., eateries, households, open burning, vehicles, roads, industries, earth removal/construction) contributing to air pollution in the study region were categorized into point, line or area source categories. Emission load of each target pollutant from each source per grid were estimated on the basis of density of each source and their extent/size in individual grids and total pollution load in the study area (**Table 4.4**). Subsequently, source-category wise total emission load of each target pollutant was calculated (in MT per year) [MT= metric ton or tonne] per 1 km ×1 km grids by clubbing grid-wise and pollutant-wise emission loads of each source category. The obtained emission loads of

PM_{10}, $PM_{2.5}$, SO_2 and NO_x coming from point, line and area sources individually and per grid were mapped into 1 km ×1 km grids on the Byrnihat-EPIP area through a GIS platform. The gridded emission-load maps for PM_{10}, $PM_{2.5}$, SO_2 and NO_x in Byrnihat-EPIP area are presented in **Fig. 4.10-4.21**.

These category-specific gridded emission loads were subsequently used as input parameters in dispersion modeling exercise undertaken through Aermod View software. Aermod View simulates the dispersion of emitted pollution loads from grids by using local meteorological (wind speed and direction) data, as pollutant dispersion in horizontal direction after their emission is governed by prevalent wind speed and direction in the region. The dispersion of pollutants would go on to govern the ambient ground-level concentrations of dispersed pollutants. The results and outputs of dispersion modeling for assessment of atmospheric carrying capacity are presented in **Chapter 5.**

Table 4.4 Total emissions ([a]MT/year) from various sectors

Sector	**Emission ([a]MT/year)**			
	PM_{10}	**$PM_{2.5}$**	**SO_2**	**NO_x**
Road Dust	5676.82	1357.5	-	-
Industry[b]	2469.87	1575.21	188.33	922.32
Transport (tailpipe emissions)	475.14	470.39	7.26	4533.30
Residential / Households	284.65	193.53	3.41	21.72
Eateries	23.04	15.67	0.33	2.03
Earth Removal / Construction	9.33	4.53	-	-
Open burning	3.23	3.00	0.21	0.46
Total	***8942.08***	***3619.83***	***199.54***	***5479.83***

[a] MT or Tonne = 1000 kg

[b] It was assumed that the reported Air Pollution Control (APC) systems were continuously operated with design efficiency (Ref. Table 6.2 of the Report on *Emission Inventory and Source Apportionment Study of Byrnihat & EPIP Area in Ri-Bhoi Dist. Of Meghalaya*). The APC design efficiencies were factored in for the estimation of industrial emissions. However, it may be noted that actual industrial emission could be much higher if either (i) APCs were not operated continuously or (ii) APCs had lower than the design efficiency as detailed in Table 6.2 or (iii) if part of emissions somehow bypassed the APC systems

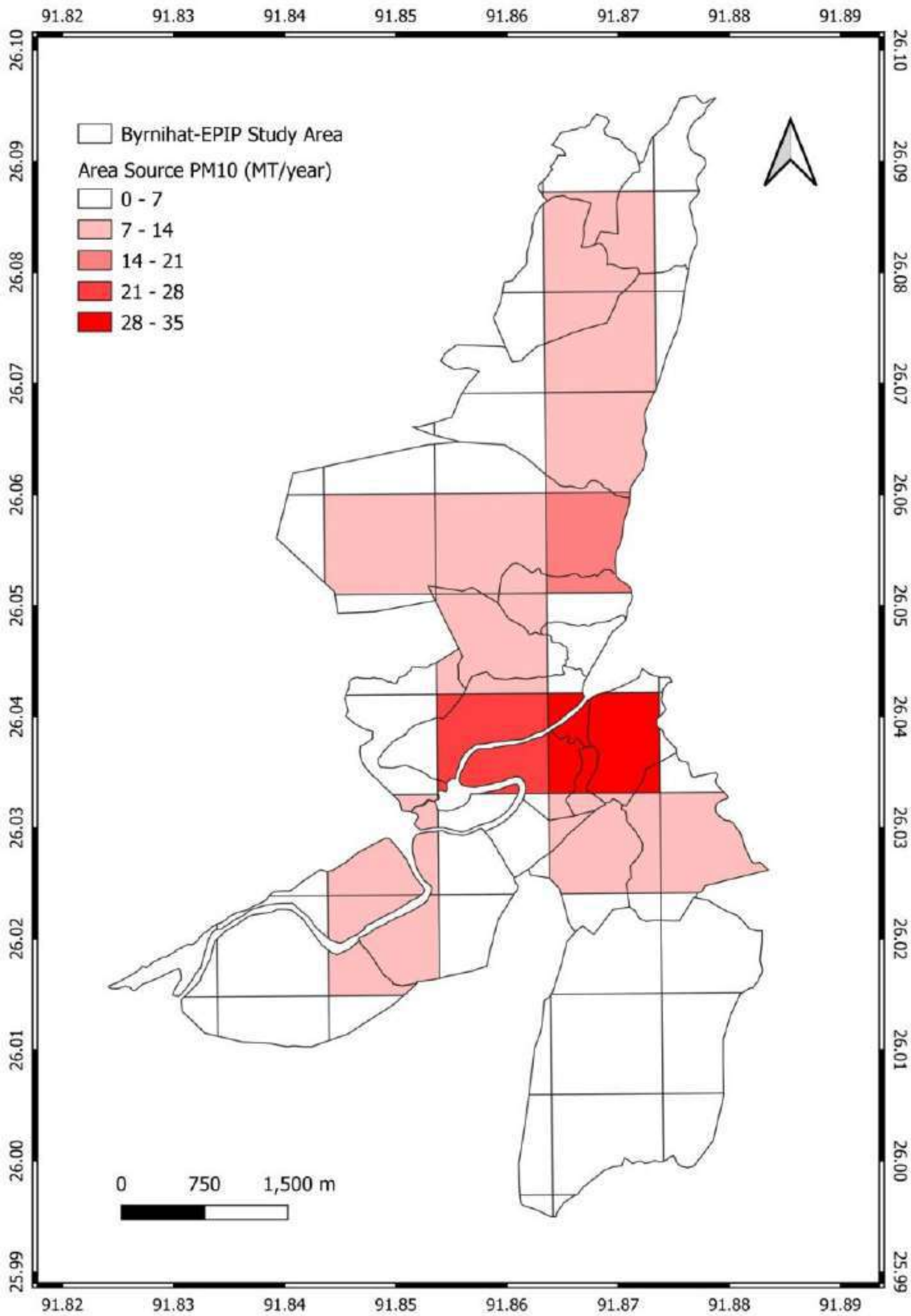


Fig. 4.10 Gridded (1 km × 1 km) emission loads of PM_{10} from area sources in Byrnihat-EPIP study area

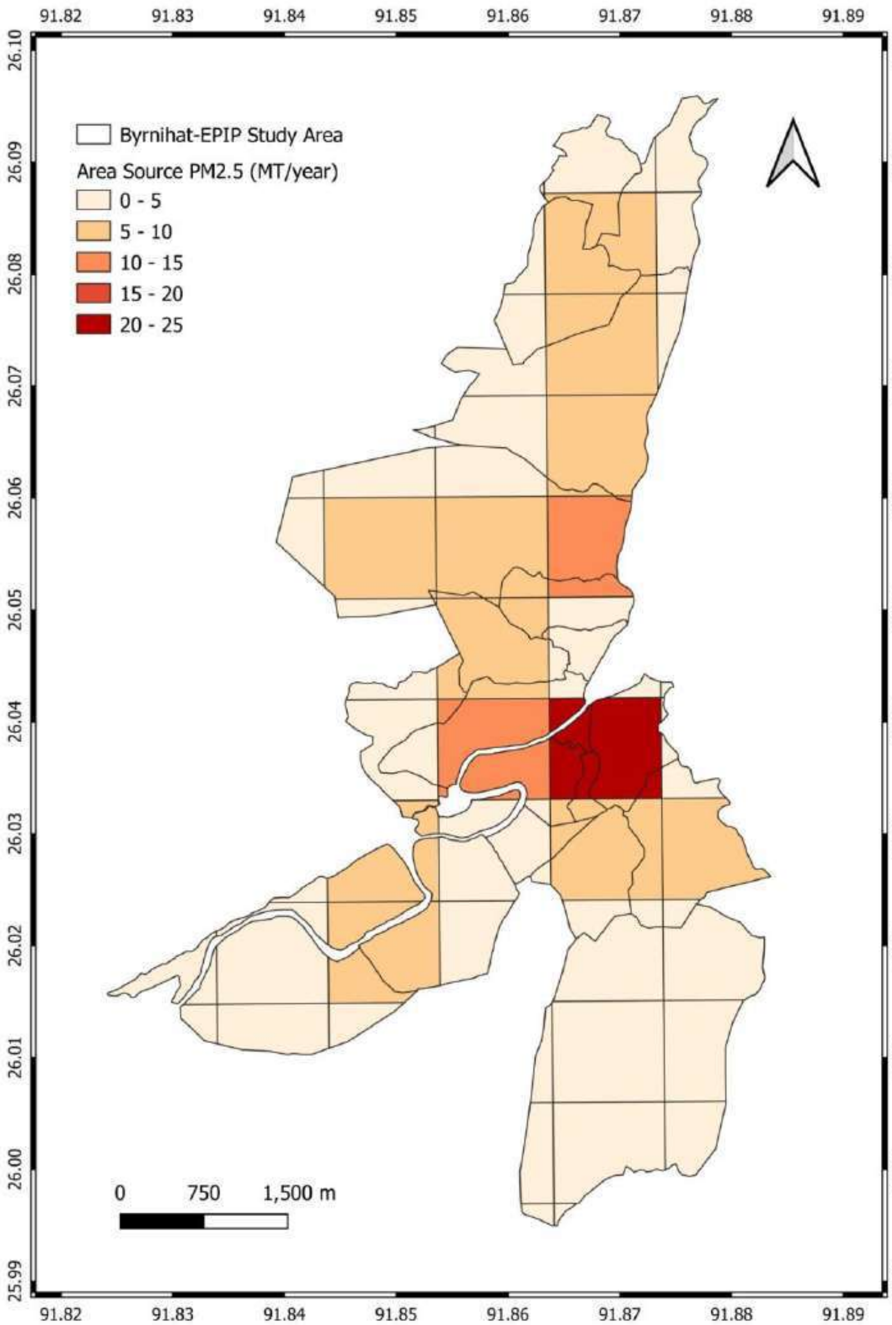


Fig. 4.11 Gridded (1 km × 1 km) emission loads of $PM_{2.5}$ from area sources in Byrnihat-EPIP study area

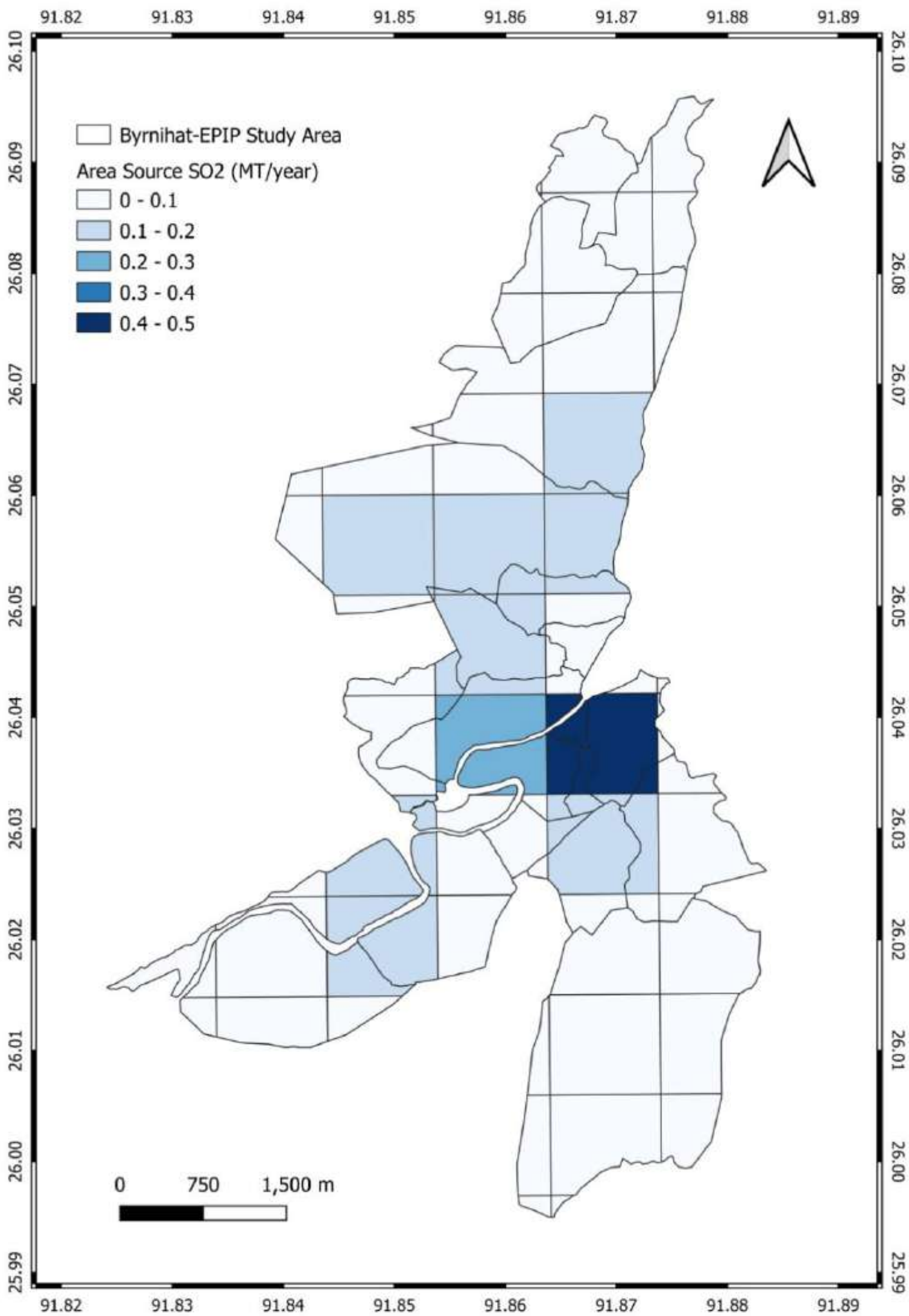


Fig. 4.12 Gridded (1 km × 1 km) emission loads of SO_2 from area sources in Byrnihat-EPIP study area

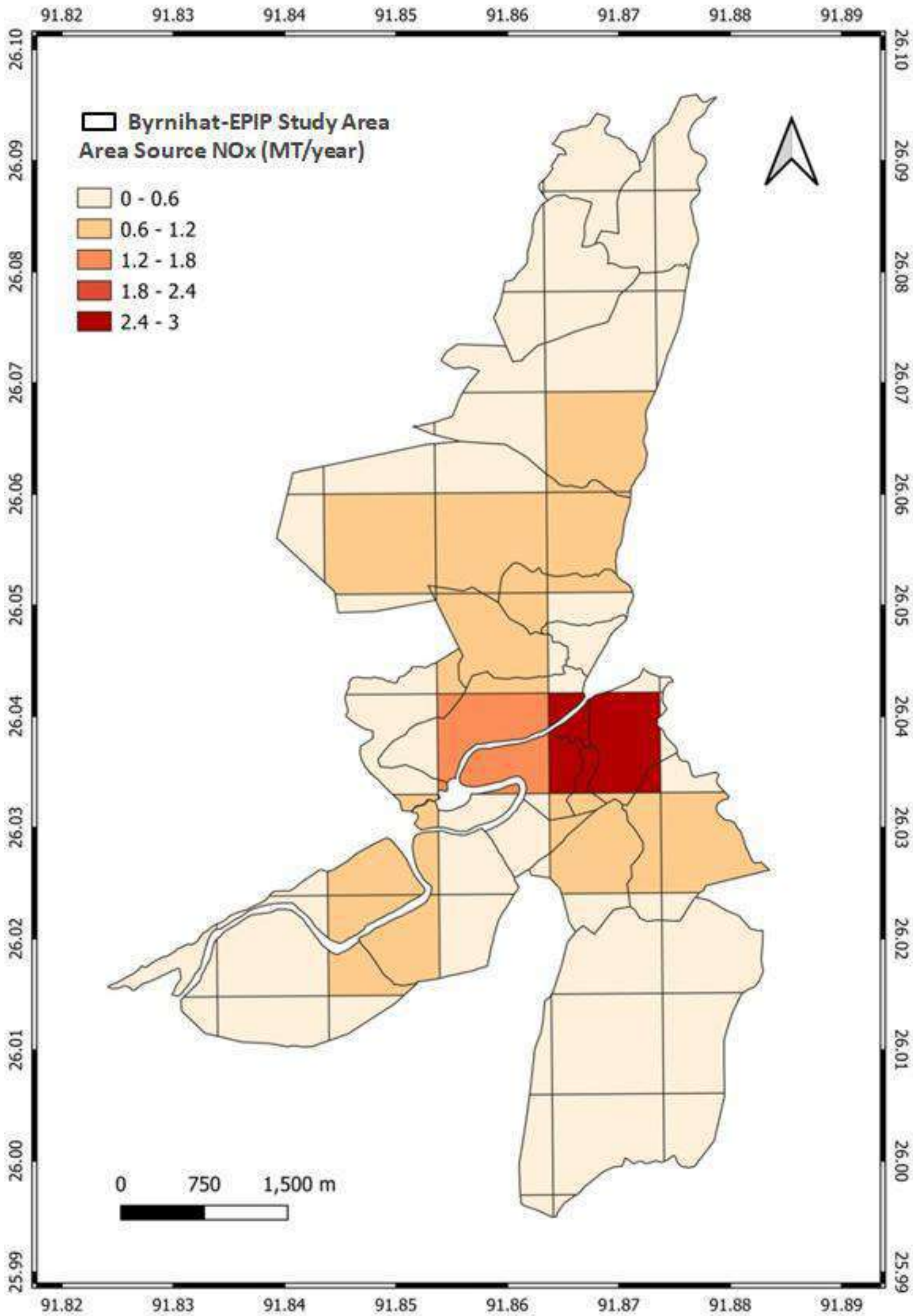


Fig. 4.13 Gridded (1 km × 1 km) emission loads of NO_x from area sources in Byrnihat-EPIP study area

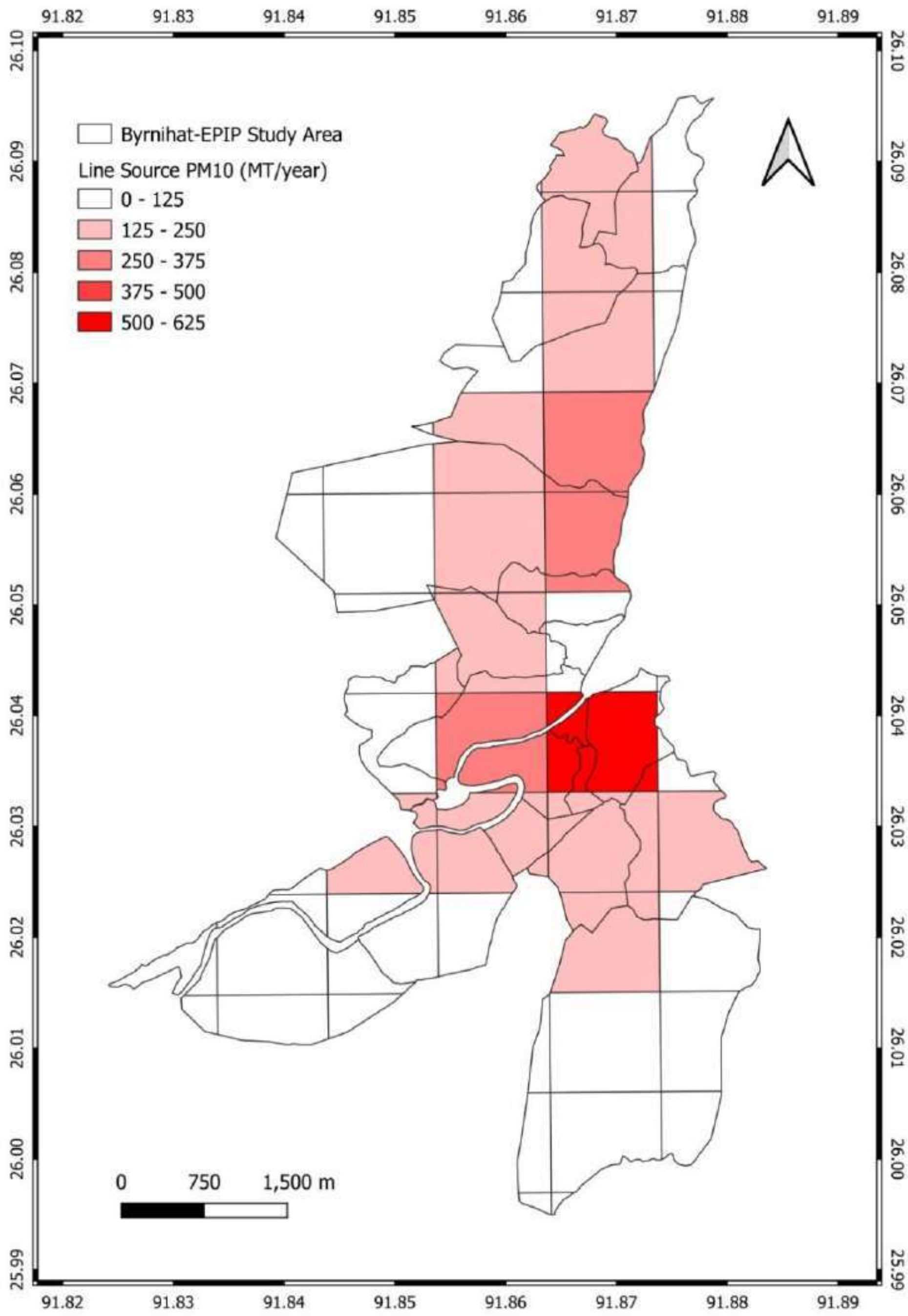


Fig. 4.14 Gridded (1 km × 1 km) emission loads of PM_{10} from line sources in Byrnihat-EPIP study area

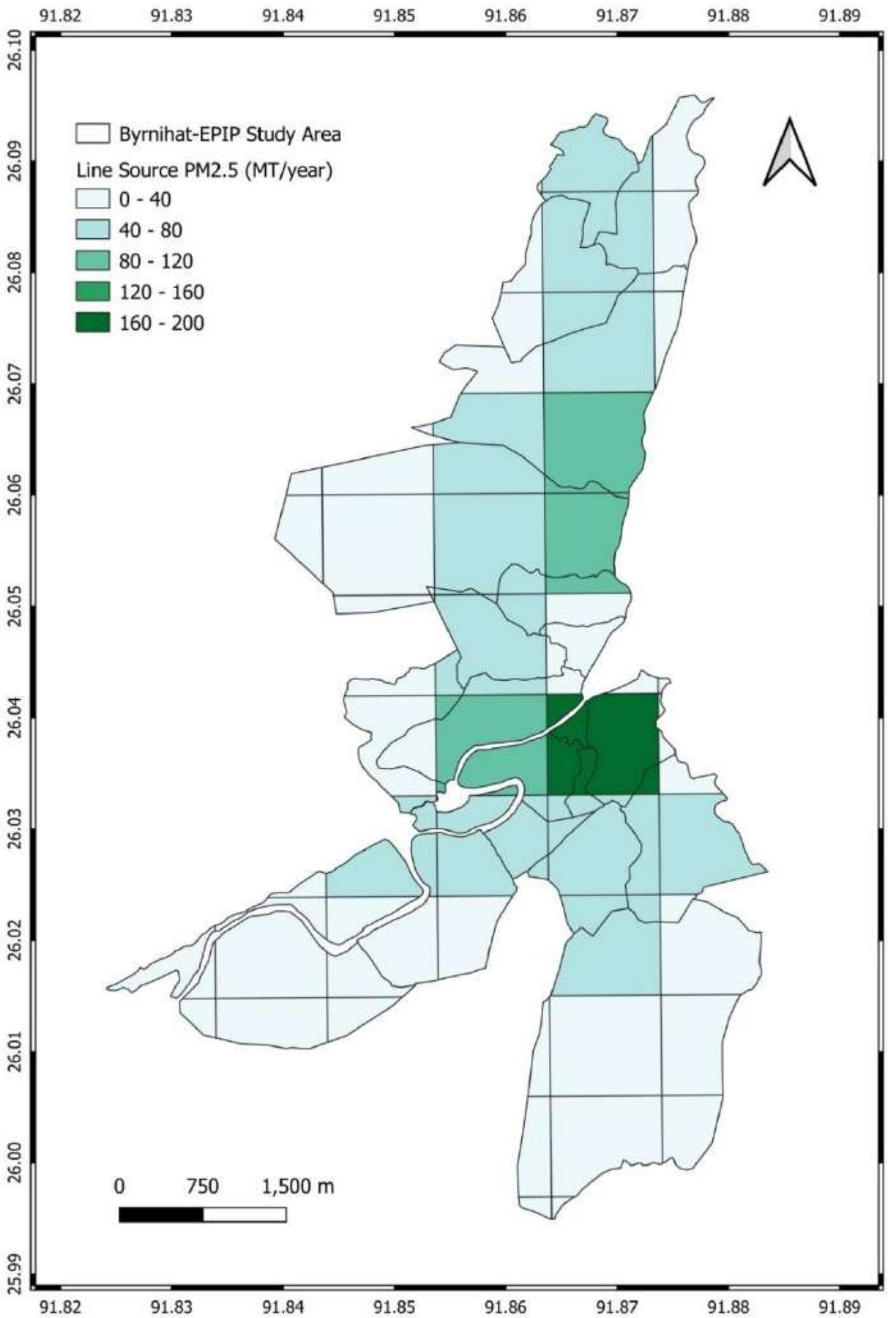


Fig. 4.15 Gridded (1 km × 1 km) emission loads of $PM_{2.5}$ from line sources in Byrnihat-EPIP study area

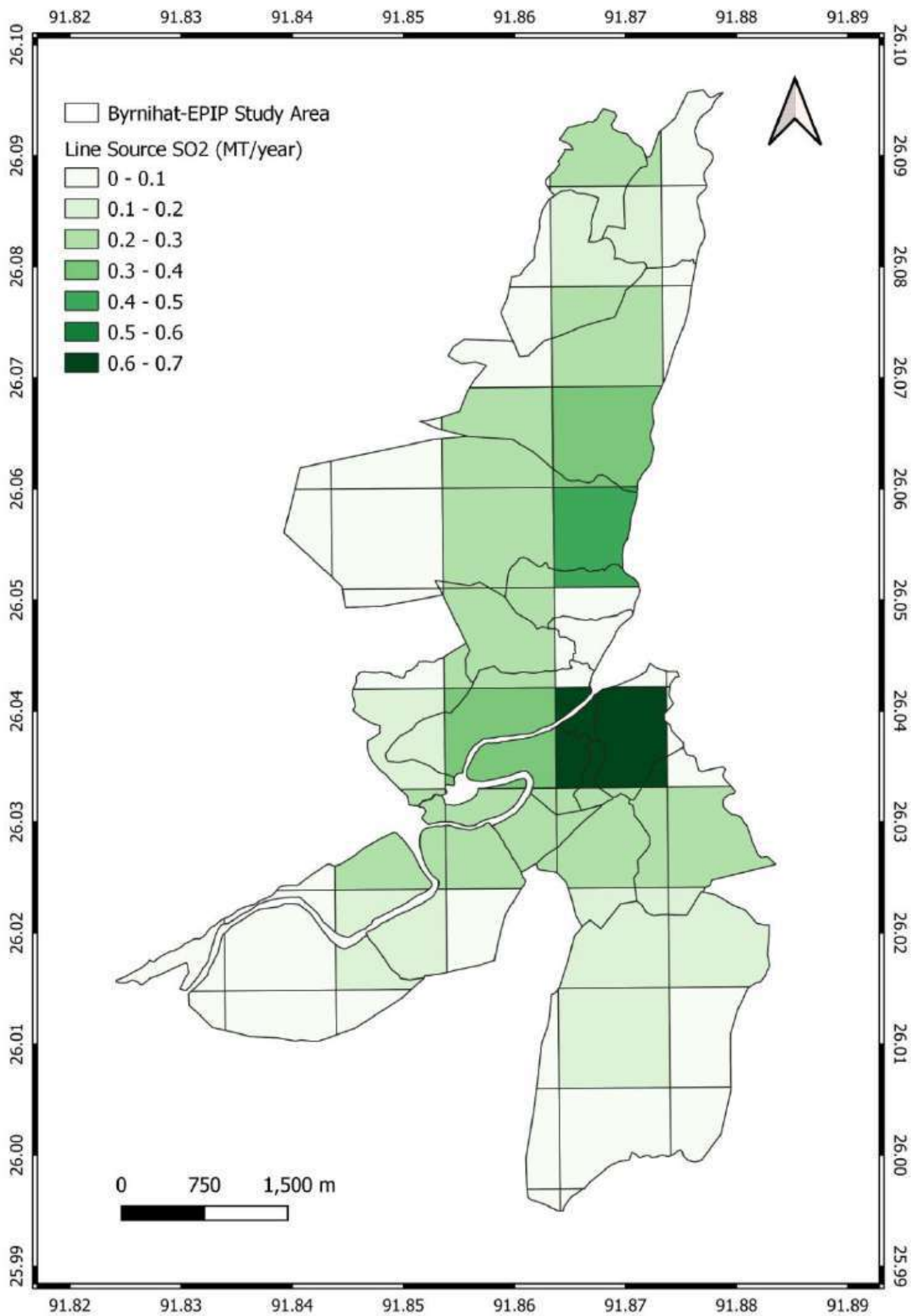


Fig. 4.16 Gridded (1 km × 1 km) emission loads of SO_2 from line sources in Byrnihat-EPIP study area

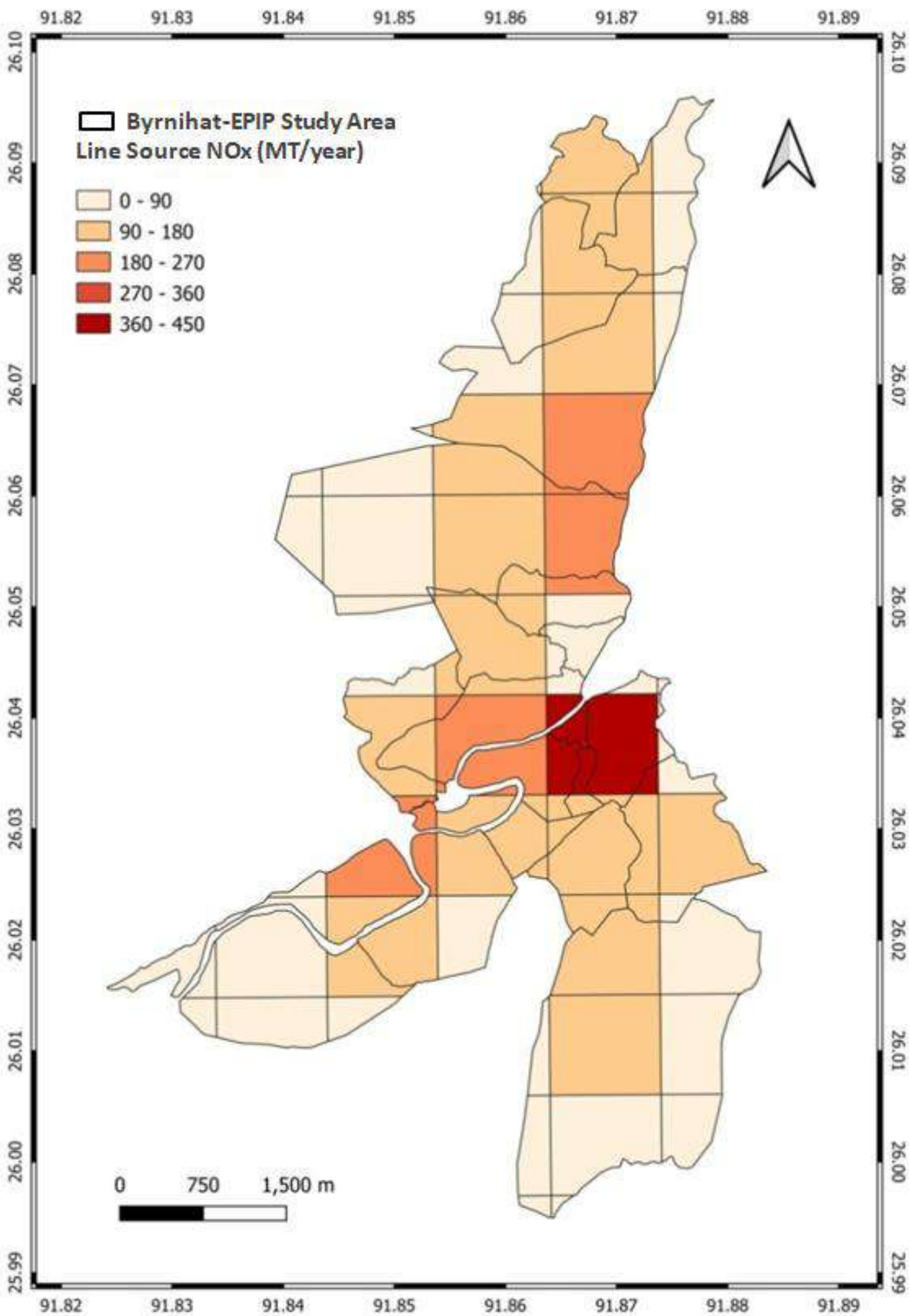


Fig. 4.17 Gridded (1 km × 1 km) emission loads of NO_x from line sources in Byrnihat-EPIP study area (revised figure attached)

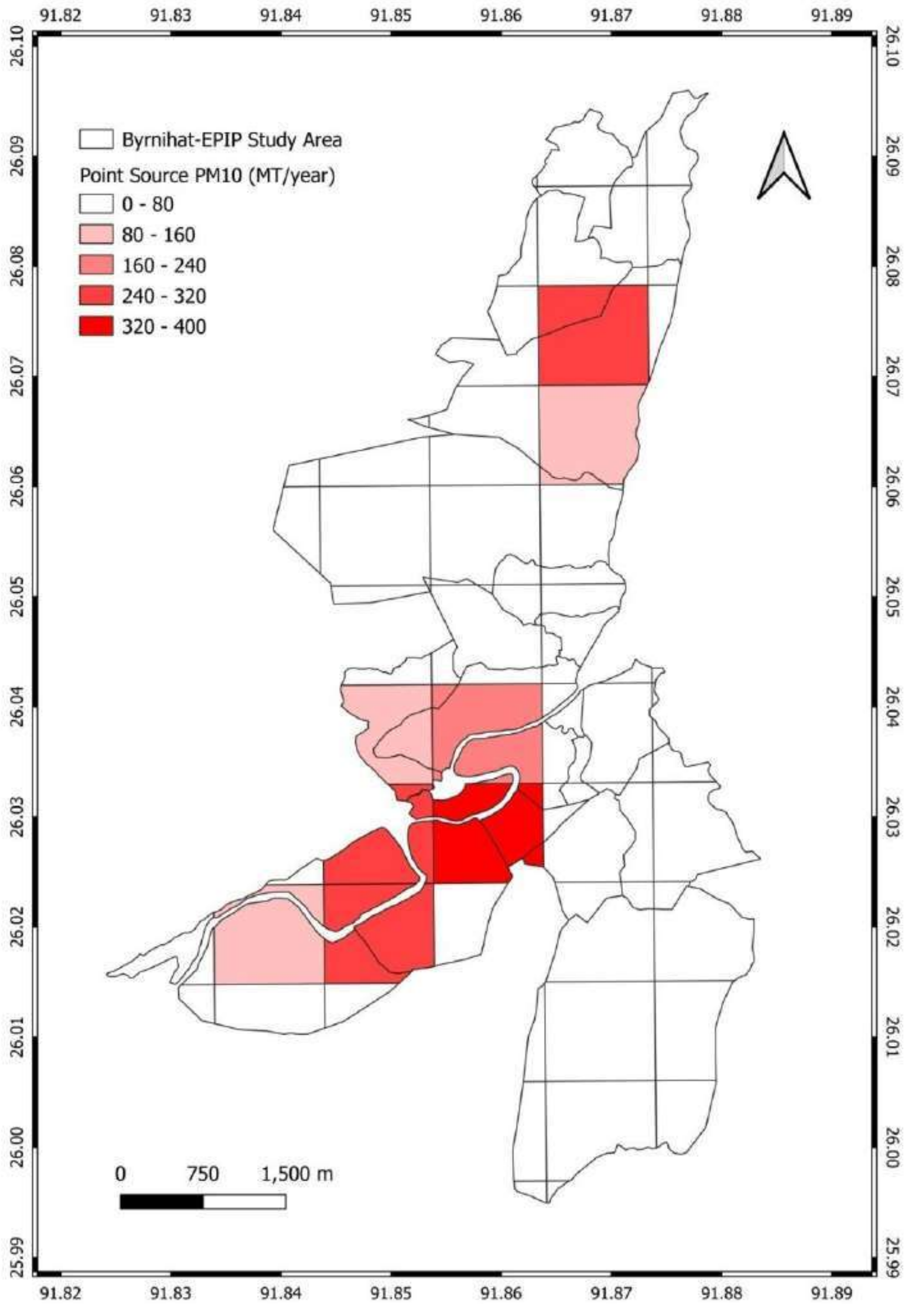


Fig. 4.18 Gridded (1 km × 1 km) emission loads of PM_{10} from point sources in Byrnihat-EPIP study area

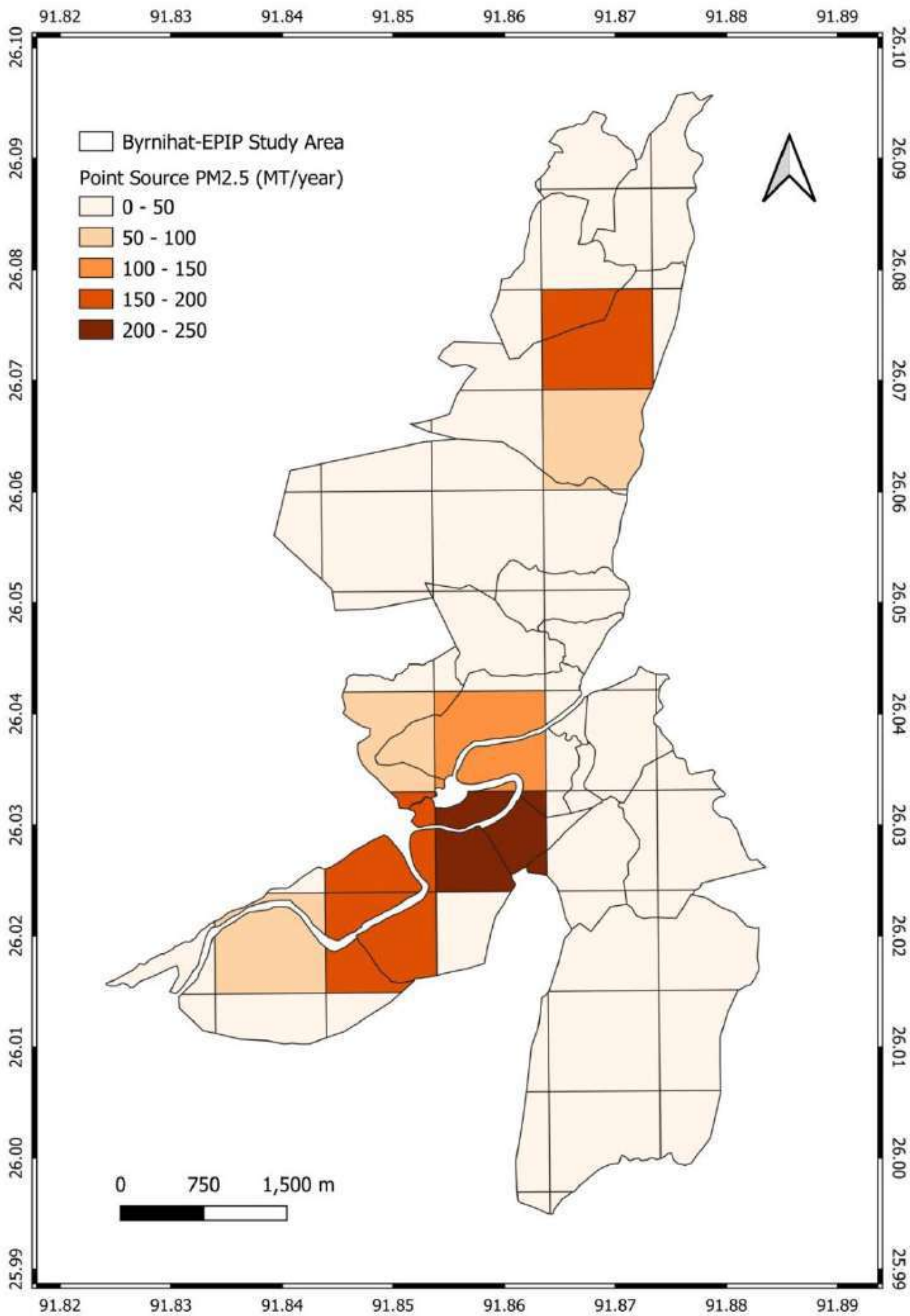


Fig. 4.19 Gridded (1 km × 1 km) emission loads of $PM_{2.5}$ from point sources in Byrnihat-EPIP study area

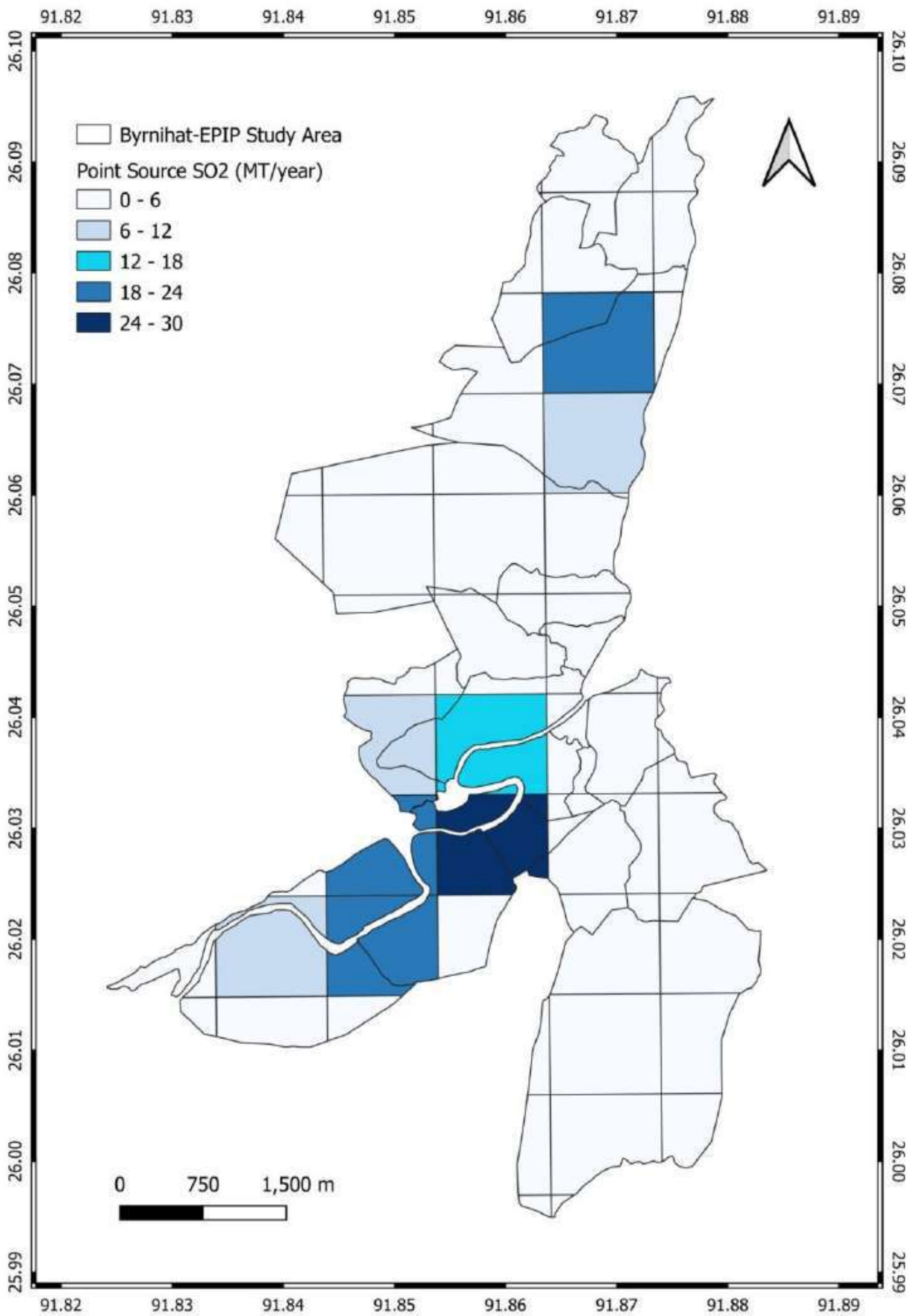


Fig. 4.20 Gridded (1 km × 1 km) emission loads of SO_2 from point sources in Byrnihat-EPIP study area

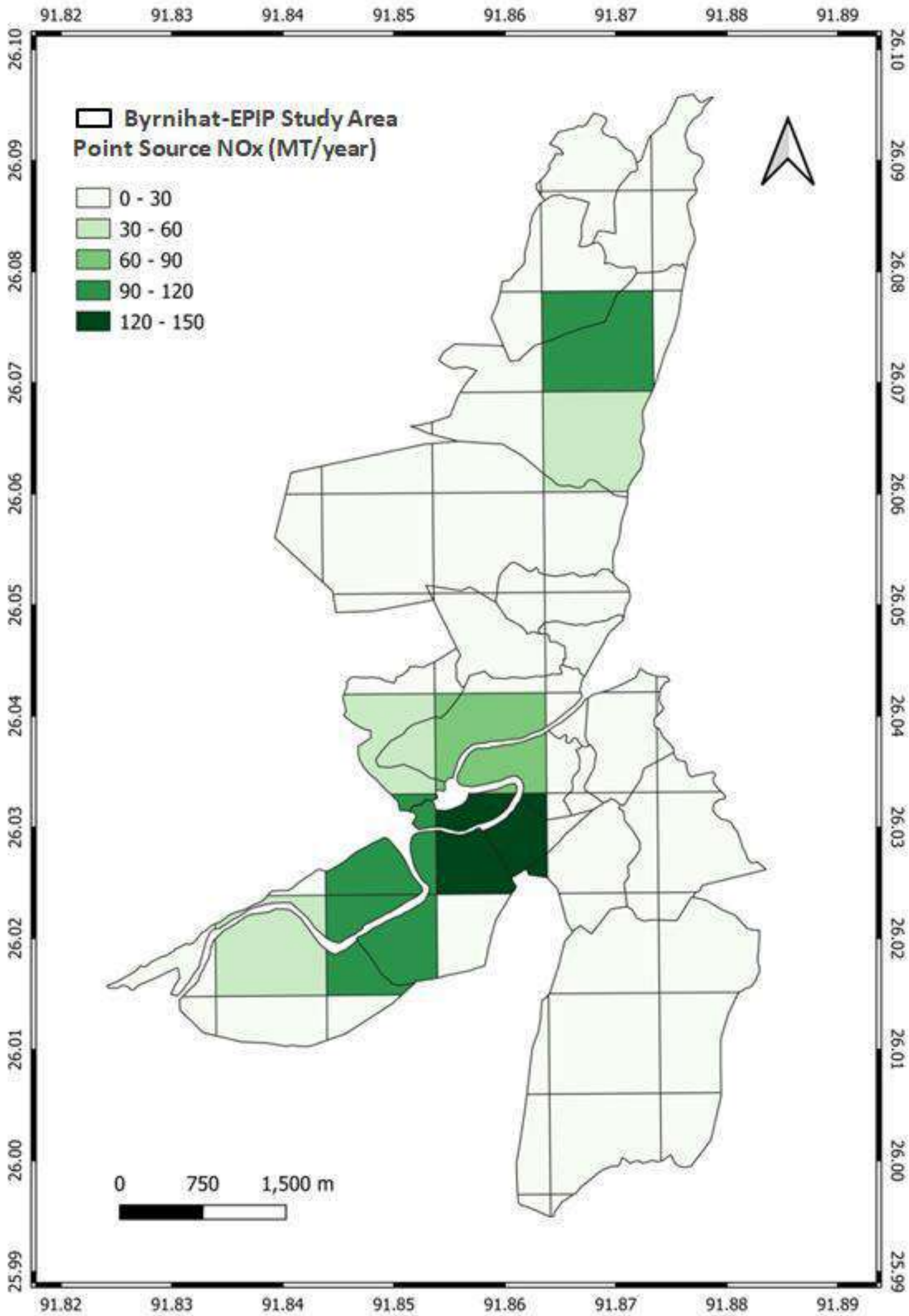


Fig. 4.21 Gridded (1 km × 1 km) emission loads of NO_x from point sources in Byrnihat-EPIP study area

The grid-wise **(1 km × 1 km)** emission inventory estimates indicate that the hot spots of point-source emissions or the grids with high emissions of pollutants from point sources (industry) were located in and around the EPIP area and also, the area near another industrial cluster near Tamuli Kuchi and Amphrangiri villages. These areas are estimated to register substantial emissions from industrial operations due to the presence of most industries. The grids with the highest line source (vehicle, road dust) emissions are located along the GS road and a few other arterial roads, while the grid with the highest estimated emission was situated on GS road near Byrnihat village, where the maximum on-road vehicle density was noticed during the study. The grids with the highest emissions from area sources (eatery, residents, shops, construction and open burning) are located over Byrnihat, Amjok, Harli Bagan and Lumnongrim villages, which are the most active areas in terms of combined commercial (eatery, shops), residential, earth removal and open burning activities together.

Chapter 5

Atmospheric Carrying Capacity (ACC)

5.0 Assessment of Atmospheric Carrying Capacity (ACC)

Byrnihat is a rapidly growing town in Meghalaya, India. With its increasing population and economic activity, it is essential to assess the atmospheric carrying capacity of the town to ensure good air quality and sustainable development.The aim of Atmospheric Carrying Capacity (ACC) analysis of Byrnihat town is to evaluate the air pollutant aassimilative capacity of atmosphereby taking inputs from emission loads from prominent sources, ambient air pollution levels *vis a vis* PM_{10}, $PM_{2.5}$, SO_2, and NO_x, and overall environmental quality, to support regional sustainable development and informed policy decisions with respect to air quality management.

The ACC of Byrnihat was assessed by using the following methods:

(a) Using Ventilation Coefficient

(b) Air Dispersion model using emission load

5.1 Ventilation Coefficient Approach

Atmospheric Carrying Capacity (ACC) or Atmospheric Assimilative Capacity (AAC) as assessed by the ventilation coefficient approach is reported here. The regional ACC/AAC of a region is directly proportional to the ventilation coefficient and was estimated through the product of the average wind speed and mixing height of the region, as follows.

Ventilation coefficient, VC (m^2/s) = MMH× U   ------------------------------------- (eq. 5.1)

Where, MMH = maximum mixing height (atmospheric boundary layer) (m) and U = average wind speed (m/s)

The meteorological parameter, the average wind speed, was taken from the installed meteorological station at the CASFOS site, and the maximum mixing height was taken from planetary boundary layer height (PBL) data of Modern-Era Retrospective analysis for Research and Applications, NASA Goddard Earth Observing System (GEOS) model reanalysis product.

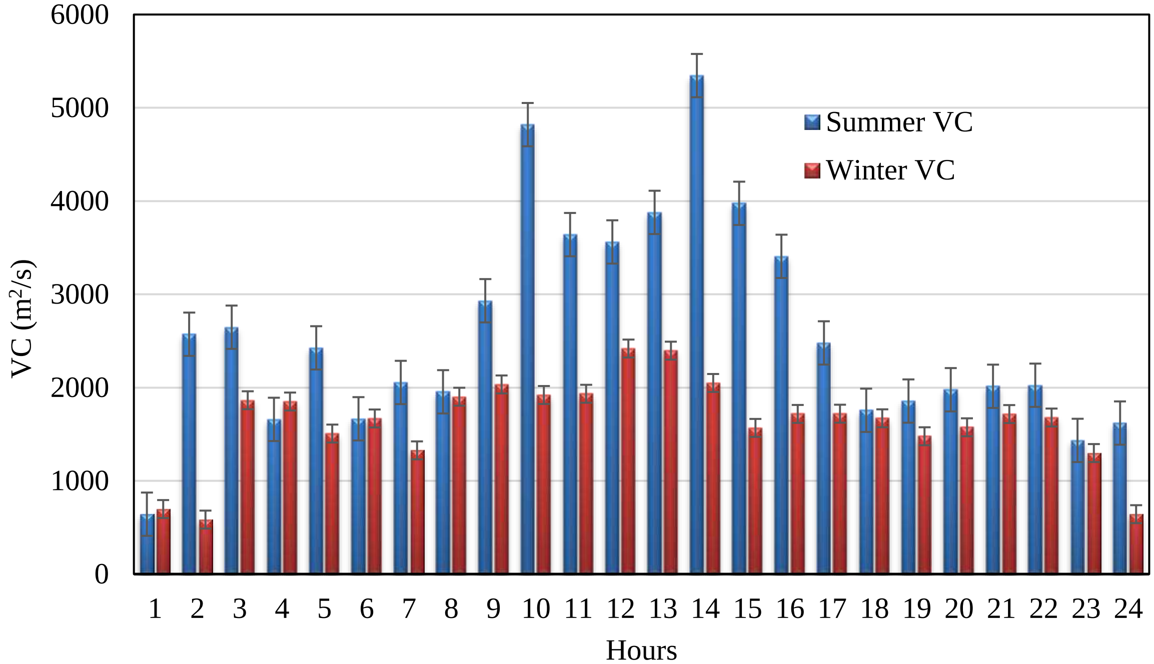


Fig. 5.1 Diurnal variation in ventilation coefficient (VC) during summer and winter seasons at Byrnihat

The summer-time VC in Byrnihat shows the highest value of 5345 m^2/s which is greater than winter-time VC (2418 m^2/s). This is commensurate with the classification that designates atmosphere of high contamination potential and low assimilative capacity when VC remains lower than <6000 m^2/sec (Prakash et al., 2017). Therefore, VC values indicate that in both summer and winter (note: much higher in winter), the atmosphere at Byrnihat remained low in assimilative capacity and highly exposed to contamination. This implies that ACC was exceeded in both summer and winter. As the mixing height stays low (due to lower temperature) during the early morning and late night hours, low convective activity gives rise to an extension in the stagnation of pollution. However, as the day advances, with the rise in the surface temperature, mixing height increases, and so does the ventilation coefficient. The assimilative potential of the atmosphere increases further with an increase in average wind speed in the boundary layer. The lower values of VC during winter affirm the stagnation and low assimilative potential of the regional atmosphere, which facilitates the production pollution built-up, specifically during night and early morning.

Table 5.1 Summer season avg. particulate matter concentrations and their exceedance with VC

Parameter	Soil Conv. Inst.	CASFOS	MeECL	MIDC	Don Bosco	Avg. VC (m^2/s) (min-max)
$PM_{2.5}$ (in µg/m^3)	90.20	118.81	125.76	115.50	139.10	2598 (642–5345)
$PM_{2.5}$ Exceedance (%) from standard (60 µg/m^3)	50.33	98.03	109.60	92.51	131.84	
PM_{10} (in µg/m^3)	147.82	158.83	190.20	166.29	222.70	
PM_{10} Exceedance (%) from standard (100 µg/m^3)	47.82	58.83	90.20	66.29	122.70	

Table 5.2 Winter season avg. particulate matter concentrations and their exceedance with VC

Parameter	Soil Conv. Inst.	CASFOS	MeECL	MIDC	Don Bosco	Avg. VC (m^2/s) (min-max)
Avg. $PM_{2.5}$ (in µg/m^3)	169.56	194.13	219.12	121.23	252.96	1634 (584–2418)
$PM_{2.5}$ Exceedance (%) from the standard (60 µg/m^3)	182.60	223.56	265.21	102.06	321.60	
Avg. PM_{10} (in µg/m^3)	220.31	249.75	293.86	198.66	337.27	
PM_{10} Exceedance (%) from the standard (100 µg/m^3)	120.31	149.75	193.86	98.66	237.27	

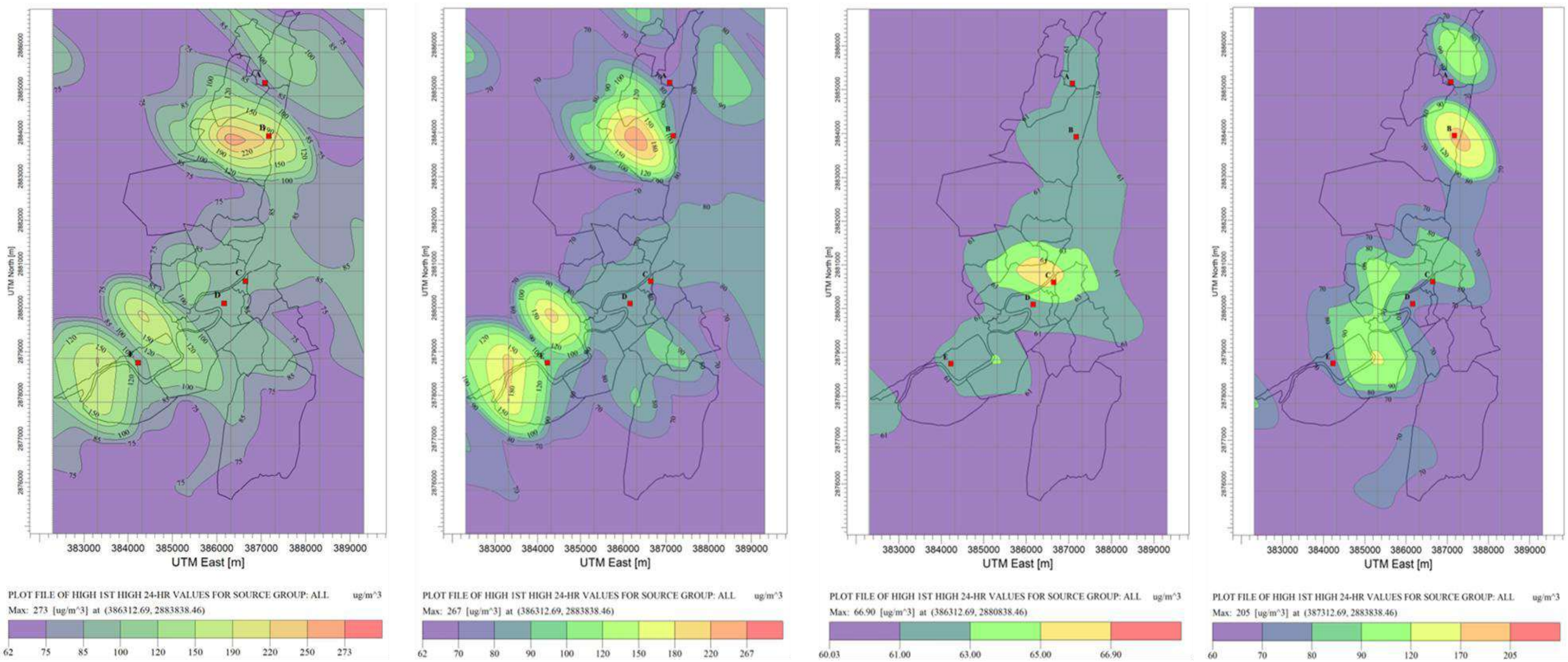
Further, particulate matter concentrations (PM_{10} and $PM_{2.5}$) and their exceedance from the respective prescribed values in NAAQS varied remarkably in two seasons, concurrent with the changes in VC values (**Table 5.1 and 5.2**). In winter, the VC values ranged from 584–2418 m^2/s with an average of 1634 m^2/s, and the exceedance in particulate matter (PM_{10} and $PM_{2.5}$) concentration at all the air quality stations were 2-3 folds over that observed in the summer season. The high receptor level exceedance in $PM_{2.5}$ and PM_{10} can be well linked to low atmospheric assimilation capacity (AAC) or ACC during the winter period, as evidenced by much lower VC values than in summer. However, considering the standards (regulatory values) of particulate matter and the existing concentrations at receptors, it is evident that AAC or ACC was already outstripped in both the seasons.

5.2 Carrying Capacity using Air Dispersion model and Emission load

Estimating the atmospheric carrying capacity of a town like Byrnihat involves understanding how pollutants disperse in the air and how much pollution the environment can handle without causing harm to public health or the ecosystem. This can be achieved through the use of air dispersion models and an emission inventory. Atmospheric carrying capacity refers to the ability of a specific area to accommodate pollutants without leading to adverse environmental and health impacts. It is influenced by several factors, including meteorological conditions (wind speed, direction, temperature, and humidity, etc.), topography, and emission sources (Industrial activities, vehicular emissions, and other anthropogenic sources contribute to the overall pollutant load).

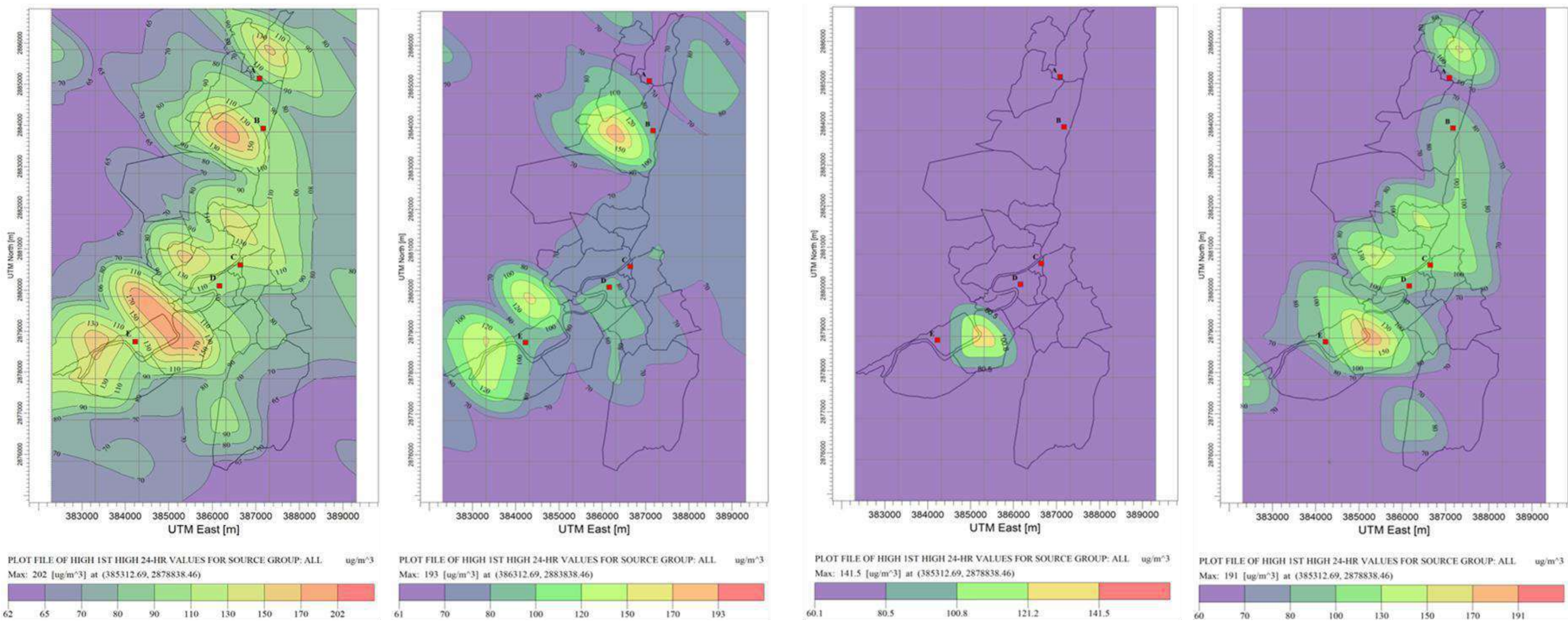
To determine the atmospheric carrying capacity of Byrnihat, AERMOD dispersion modeling was performed using the existing emission load of the pollutants (PM_{10}, $PM_{2.5}$, SO_2 and NO_x) for the summer and winter seasons. The predicted maximum GLCs are compared with each pollutant's permissible level (NAAQS). The carrying capacity (T/d) is then predicted using the ascertained emission load for which maximum GLCs come within NAAQS.To provide an insightful analysis of Ground Level Concentrations (GLCs) of point, area, and line sources for Byrnihat town using the AERMOD dispersion modelling system, it's essential to structure the existing emission inventory of the region into four distinct categories viz. (a) all sources, (b) point sources, (c) area sources, and (d) line sources. The predicted GLCs for these four categories are shown in **Fig. 5.2–5.5** (summer) and **Fig. 5.6–5.9** (winter). GLCs for PM_{10} and $PM_{2.5}$ consistently exceeded NAAQS while considering business-as-usual conditions (all sources), point sources, and line sources. While in the case of area sources, only $PM_{2.5}$ in winter showed GLC values exceeding NAAQS. It is also evident from these categorical predictions of GLCs that the contributions of point (industries) and line (traffic, roads etc.) sources play a key role in outmatching the NAAQS over the region. The predicted GLCs of PM_{10} and $PM_{2.5}$ both during summer (**Fig. 5.2-5.3**) and winter (**Fig. 5.6-5.7**) showed way above values compared to the permissible limit (NAAQS) for individual source categories of point sources and line sources. From all the categorical predictions, it is apparent that the region has exhausted its carrying capacity in terms of business-as-usual (BAU) PM_{10} and $PM_{2.5}$

emissions. On the contrary, the predicted GLCs for SO_2 and NO_x for all the categories remain well within the permissible limit which indicates positive residual carrying capacity.



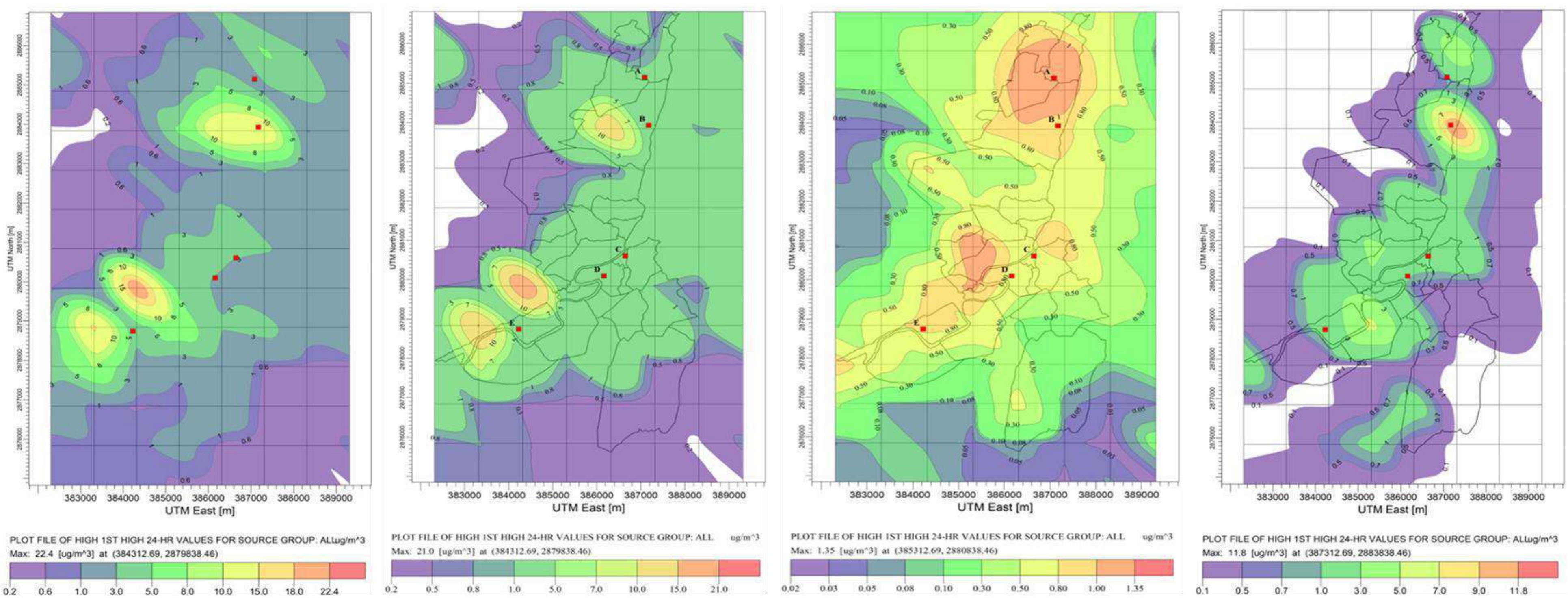
(a) All sources (b) Point Sources (c) Area sources (d) Line sources

Fig. 5.2 Predicted GLCs of PM_{10} ($\mu g/m^3$) during the summer season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources



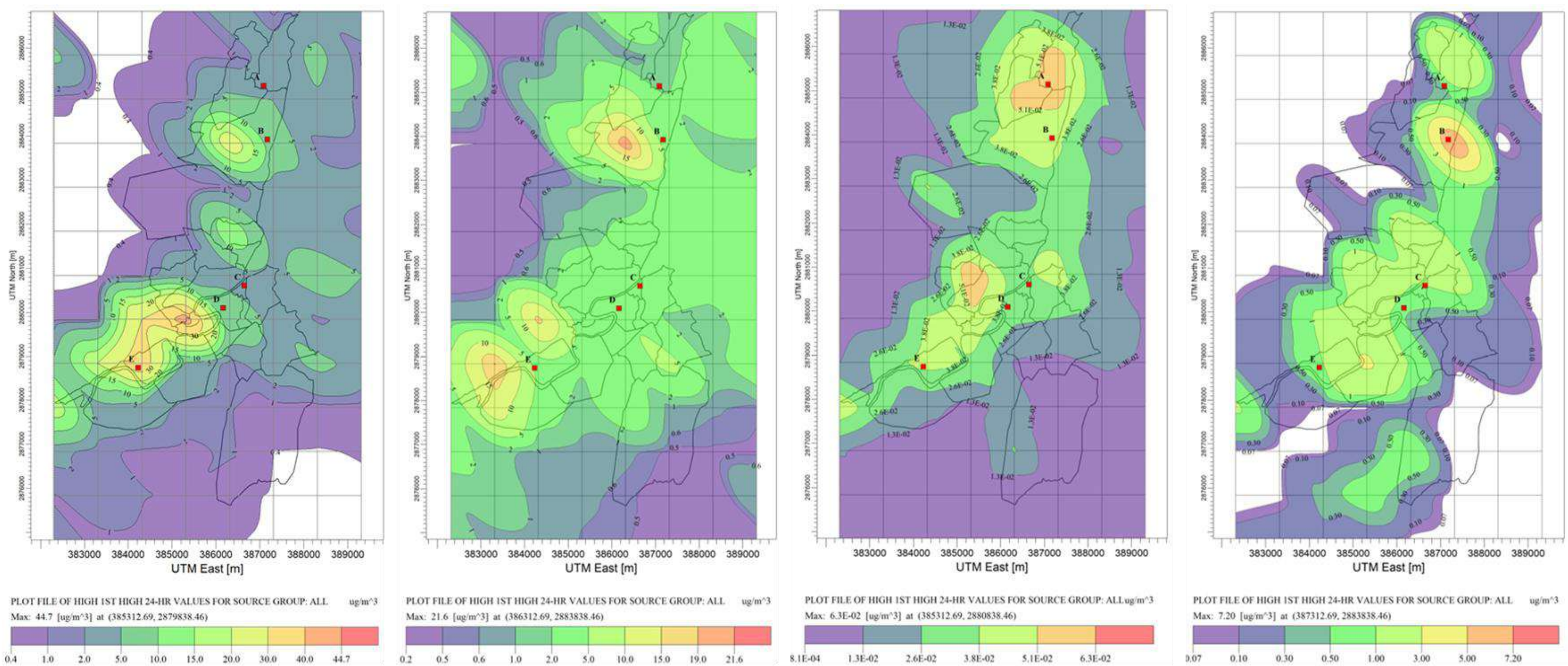
(a) All sources (b) Point Sources (c) Area sources (d) Line sources

Fig. 5.3 Predicted GLCs of $PM_{2.5}$ ($\mu g/m^3$) during the summer season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources



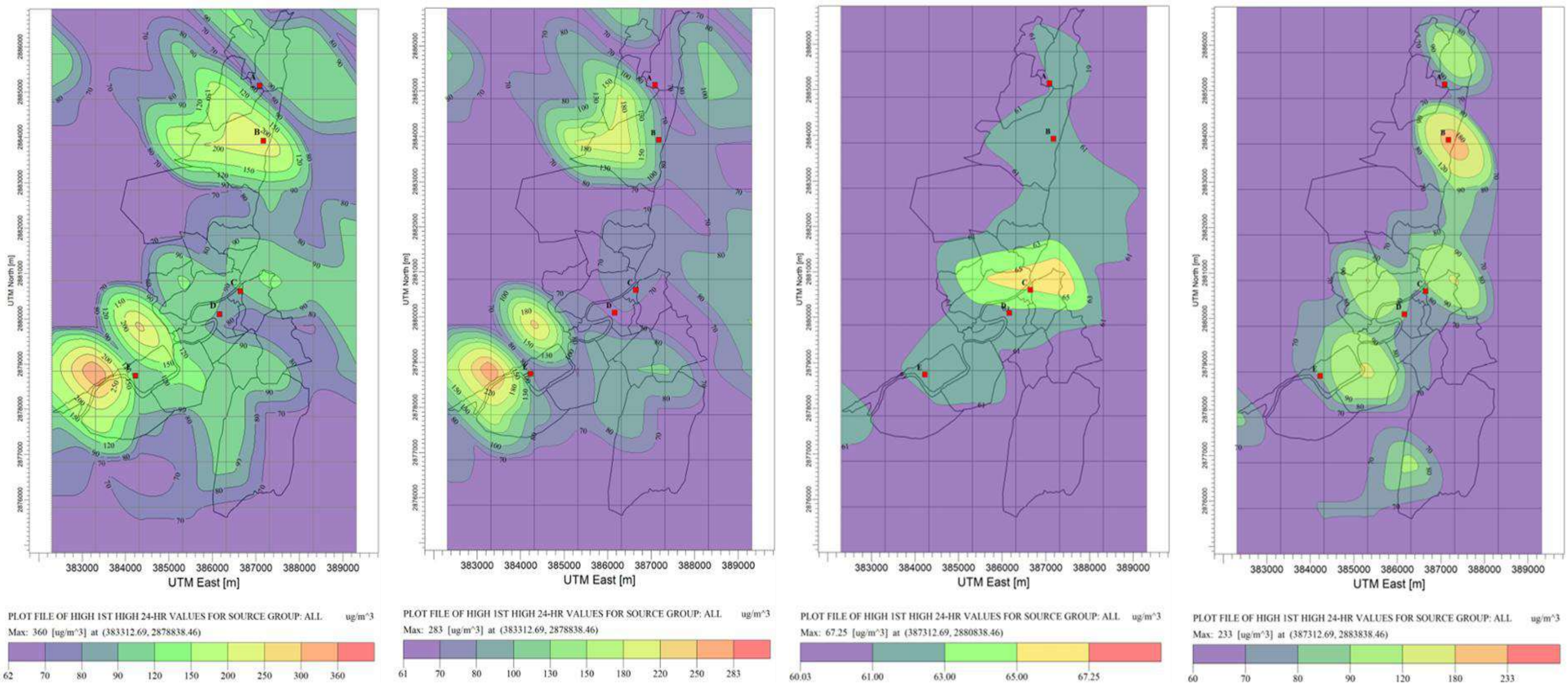
(a) All sources (b) Point Sources (c) Area sources (d) Line sources

Fig. 5.4 Predicted GLCs of SO_2 ($\mu g/m^3$) during the summer season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources



(a) All sources (b) Point Sources (c) Area sources (d) Line sources

Fig. 5.5 Predicted GLCs of NO_x ($\mu g/m^3$) during the summer season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources



(a) All sources (b) Point Sources (c) Area sources (d) Line sources

Fig. 5.6 Predicted GLCs of PM_{10} ($\mu g/m^3$) during the winter season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources

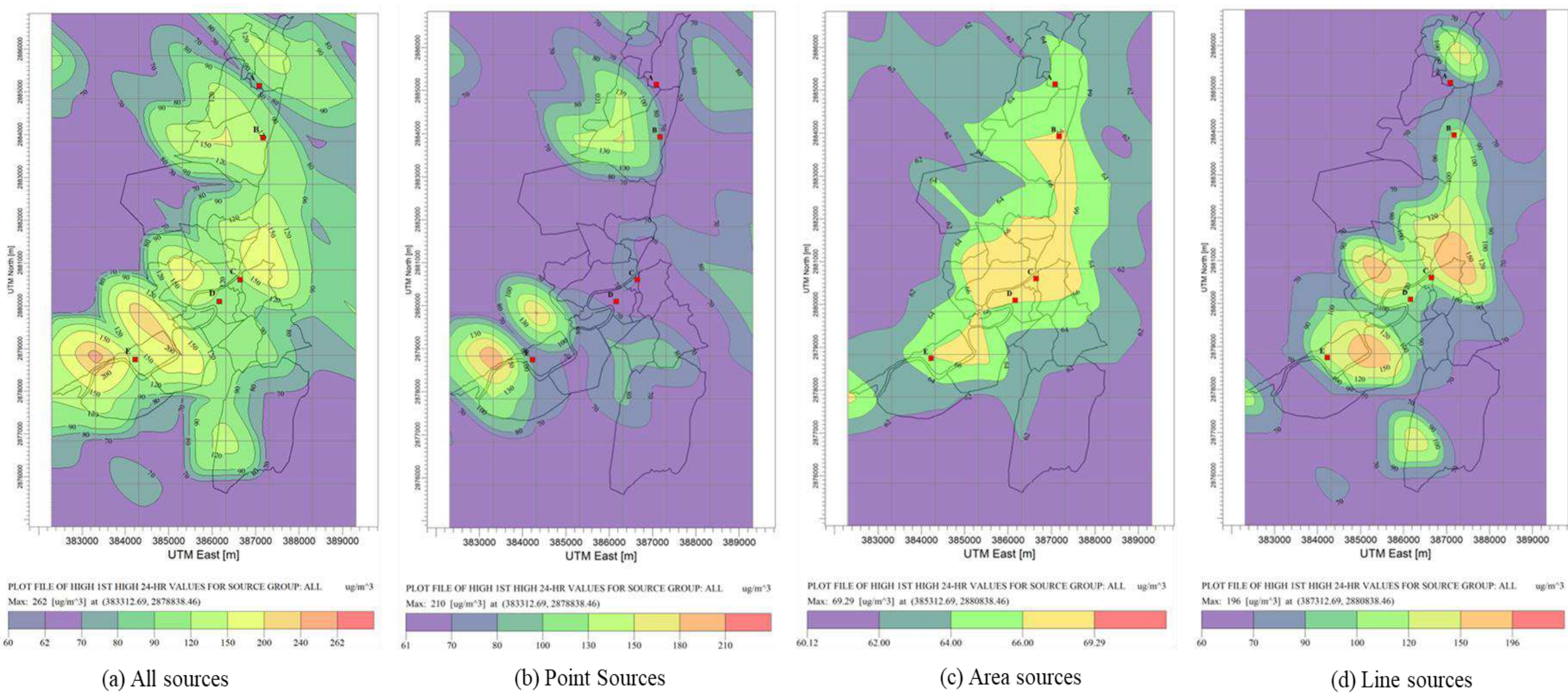
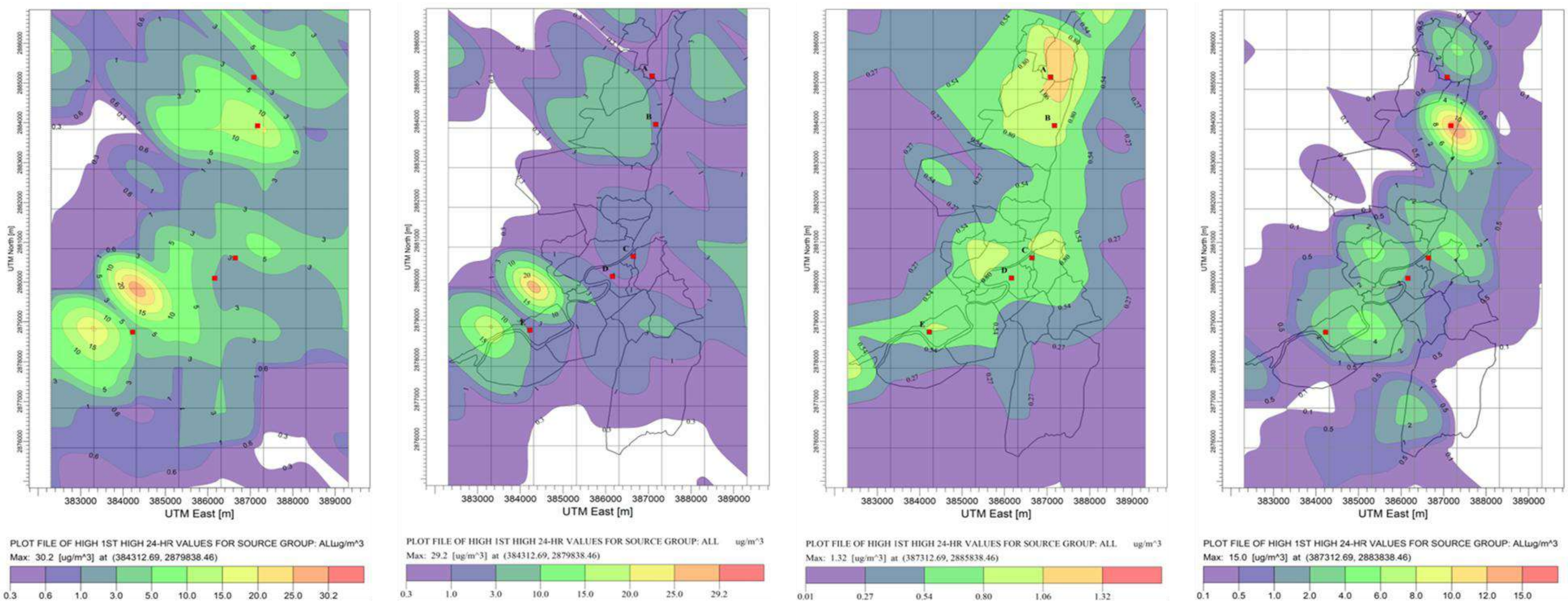
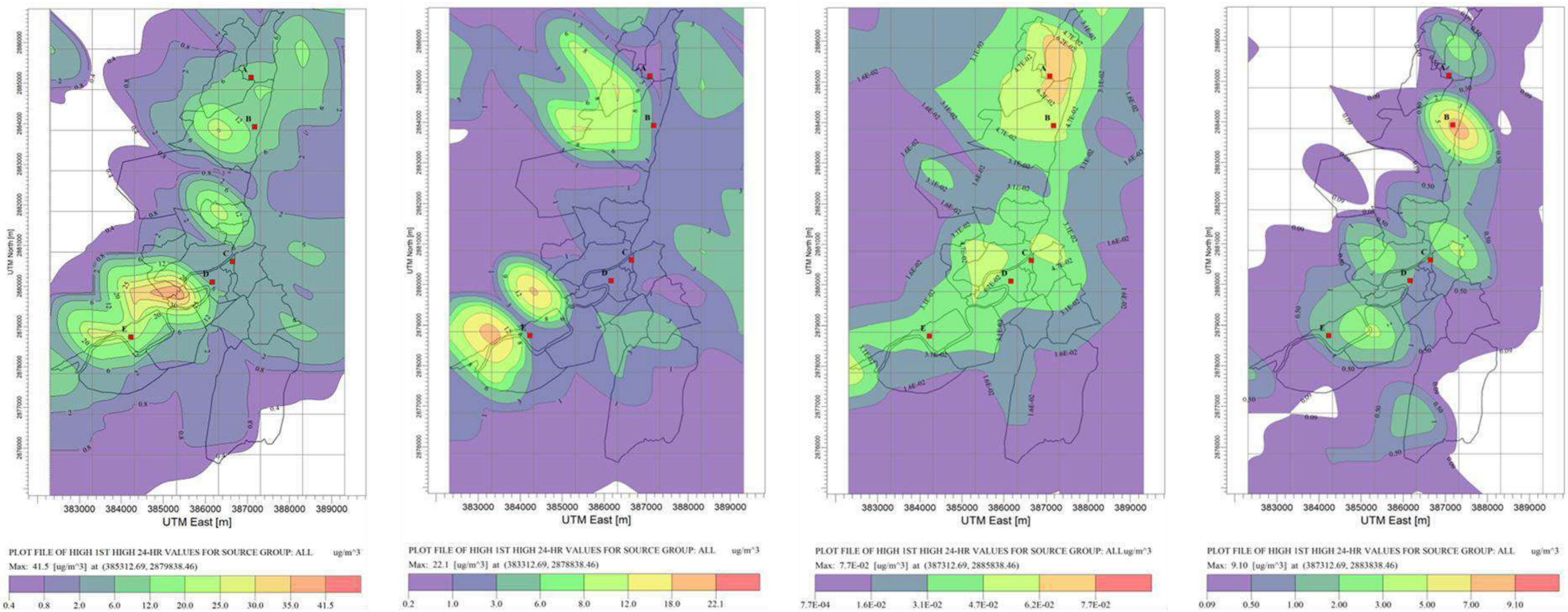


Fig. 5.7 Predicted GLCs of $PM_{2.5}$ ($\mu g/m^3$) during the winter season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources



(a) All sources (b) Point Sources (c) Area sources (d) Line sources

Fig. 5.8 Predicted GLCs of SO_2 ($\mu g/m^3$) during the winter season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources



(a) All sources (b) Point Sources (c) Area sources (d) Line sources

Fig. 5.9 Predicted GLCs of NO_x (µg/m3) during the winter season over Byrnihat study area using the emissions from (a) All sources, (b) Point sources, (c) Area sources and (d) Line sources

5.3 Analysis of Carrying Capacity and Residual Carrying Capacity

The atmospheric carrying capacity (ACC) of an air pollutant represents the highest emission rate that can be maintained without exceeding a specific ambient air quality standard, known as the National Ambient Air Quality Standards (NAAQS). Residual carrying capacity (RCC), on the other hand, refers to the additional emission rate that can be incorporated into current business-as-usual emissions to align with the allowable emission rate determined by the CC.

Mathematically, the relationship between ACC and RCC can be expressed as:

$ACC = EL_{(BAU)} + RCC$ -- (eq. 5.2)

Where, ACC = Atmospheric Carrying Capacity; $EL_{(BAU)}$ = Emission load in business-as-usual (BAU) scenario; RCC = Residual Carrying Capacity

In case of exhausted carrying capacity for a particular pollutant (i.e., $EL_{(BAU)} > CC$), the RCC becomes negative. Category-wise existing emission loads (T/d) and their corresponding AERMOD predicted maximum GLCs are presented along with their CC and RCC in **Tables 5.3 – 5.6**. An analysis of the carrying capacity has determined that the air quality has reached its maximum allowable level for particulate matter (PM_{10} and $PM_{2.5}$) emissions during both the summer and winter seasons. This indicates that the town's atmosphere is unable to absorb any further emissions of these pollutants without exceeding established environmental standards. Under current operating conditions (business-as-usual, or BAU), various emission sources release substantial amounts of particulate matter (PM) into the atmosphere. Specifically, point, area, and line sources collectively emit 24.5 tons of PM_{10} and 9.92 tons of $PM_{2.5}$ per day (T/d). These emissions significantly impact regional air quality, contributing to predicted ground-level concentrations (GLCs) that exceed regulatory standards. During the summer months, the estimated GLCs for PM_{10} and $PM_{2.5}$ reached 273 $\mu g/m^3$ and 202 $\mu g/m^3$, respectively. These elevated levels pose a significant health concern, as they exceed the NAAQS recommended limits of 100 $\mu g/m^3$ for PM_{10} and 60 $\mu g/m^3$ for $PM_{2.5}$. The situation worsens in the winter, with predicted GLCs for PM_{10} and $PM_{2.5}$ rising to 360 $\mu g/m^3$ and 262 $\mu g/m^3$, respectively. These levels are even further above the NAAQS recommended limits and indicate a severe air pollution problem that requires urgent attention. Analysis indicates that a two to three-fold reduction in PM_{10} emissions is necessary during the summer months to maintain air quality standards. Conversely, a more substantial reduction, ranging from three to four-fold, is required for $PM_{2.5}$ emissions during the winter. These figures highlight the critical need for effective strategies to mitigate the impact of particulate matter on air quality, particularly during periods of seasonal variation. Also, the National Clean Air Program (NCAP) suggested control of a 40% reduction of PM_{10}level in ambient air, which is considered to calculate carrying capacity (**Table 5.3**) revealed the existing emission load should be lowered three to four times to comply with the ambitious control scenario in the region.

In the context of distinct individual source categories, such as point and line sources (refer to **Tables 5.4 and 5.5**), the current emission levels for PM_{10} and $PM_{2.5}$ have surpassed the Atmospheric Carrying Capacity (ACC), resulting in a negative Residual Carrying Capacity (RCC) for both summer and winter seasons. But then, in the case of gaseous pollutants (SO_2, NO_x), the existing emission loads are well below the ACC and the predicted GLCs are also well within the NAAQS, which implies the scope of increase in sources of those gaseous pollutants in the Byrnihat study area.

The comfortable margin between current emission loads and established air quality standards points to a capacity for increasing sources of SO_2 and NO_x in the Byrnihat area. This aspect warrants a careful examination of potential industrial expansions, urbanization, or other activities that could lead to heightened emissions. However, looking at the extreme exceedance of particulate matter (PM_{10} and $PM_{2.5}$) predicted concentrations and exhaustion of ACC, the expansion/increase of gaseous pollutant (SO_2 and NO_x) sources is not advisable. The reactive gases (SO_2 and NO_x) participate in secondary aerosol formation and can increase the particulate matter (PM_{10} and $PM_{2.5}$) concentrations in the region.

AERMOD air dispersion modeling was performed for two contrast emission loads viz. business-as-usual (BAU) and controlled carrying capacity (which leads to predicted GLCs under NAAQS) of PM_{10} and $PM_{2.5}$using all sources for summer and winter seasons (**Fig. 5.10 to 5.13**). During the summer months, the typical emissions expected under Business as Usual (BAU) conditions are 24.5 tonnes per day (T/d) for PM10 and 9.92 tonnes per day (T/d) for $PM_{2.5}$. However, in order to uphold Ground Level Concentrations (GLCs) within the limits outlined by the National Ambient Air Quality Standards (NAAQS), a reduction in the permissible emission levels is necessary. The controlled carrying capacity for PM_{10} must be adjusted to 8.9 T/d, while for $PM_{2.5}$, it should be set at 2.9 T/d. During the winter season, it is essential to reduce the BAU emission loads further to specified limits. To comply with the National Ambient Air Quality Standards (NAAQS), emissions must be curtailed to 6.8 T/d for PM_{10} and 2.3 T/d for $PM_{2.5}$.

Table 5.3 Existing emission load, carrying capacity and residual carrying capacity considering all emission sources

Pollutants		Existing emission load (T/d)	NAAQS (µg/m³)	Predicted Maximum GLC (µg/m³)		Atmospheric Carrying Capacity (T/d)		Residual carrying capacity (T/d)	
				Summer	Winter	Summer	Winter	Summer	Winter
PM_{10}	Present	24.50	100	273	360	8.9	6.8	Exceeded (-15.5)	Exceeded (-17.7)
	NCAP Control (40%)			83 µg/m³ (40% reduction from 2019 annual average*:138.1µg/m³)		7.4	5.7	Exceeded (-16.6)	Exceeded (-18.3)
$PM_{2.5}$		9.92	60	202	262	2.9	2.3	Exceeded (-6.9)	Exceeded (-7.6)
SO_2		1.55	80	32.5	33.1	3.8	3.74	2.27	2.19
NO_x		15.01	80	44.7	41.5	26.8	28.9	11.8	12.8

**Annual Average PM10 at EPIP Byrnihat (Source CPCB, 2022)*

Table 5.4 Existing emission load, carrying capacity and residual carrying capacity considering point sources

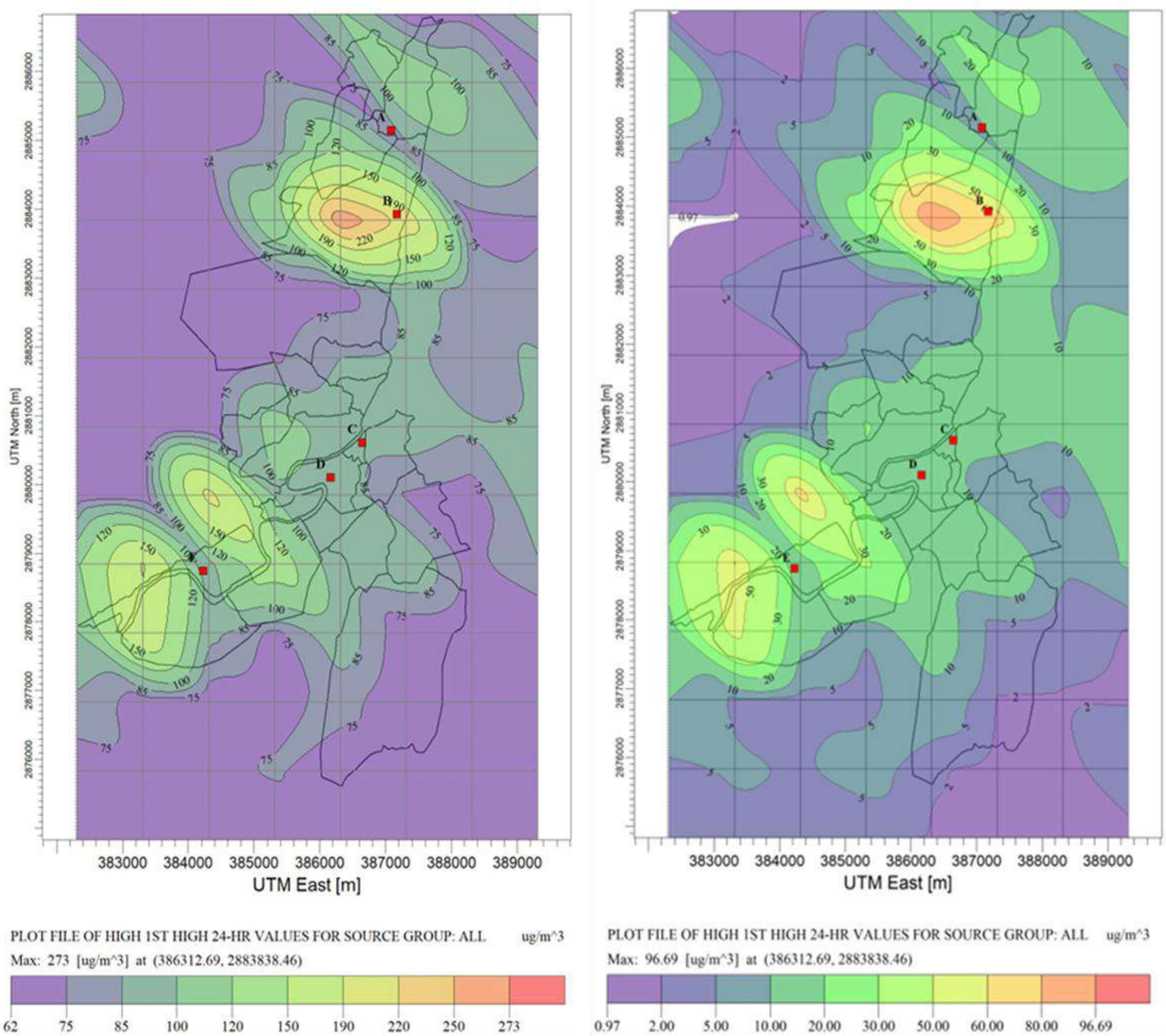
Pollutants	Existing emission load (T/d)	NAAQS (µg/m³)	Predicted Maximum GLC (µg/m³)		Atmospheric Carrying Capacity (T/d)		Residual carrying capacity (T/d)	
			Summer	Winter	Summer	Winter	Summer	Winter
PM_{10}	6.76	100	267	283	2.53	2.39	Exceeded (-4.23)	Exceeded (-4.4)
$PM_{2.5}$	4.31	60	193	210	1.34	1.23	Exceeded (-2.97)	Exceeded (-3.08)
SO_2	0.51	80	21	29.2	1.94	1.39	1.43	0.88
NO_x	2.50	80	21.6	22.1	9.25	9.04	6.75	6.54

Table 5.5 Existing emission load, carrying capacity and residual carrying capacity considering line sources

Pollutants	Existing emission load (T/d)	NAAQS (µg/m³)	Predicted Maximum GLC (µg/m³)		Atmospheric Carrying Capacity (T/d)		Residual carrying capacity (T/d)	
			Summer	Winter	Summer	Winter	Summer	Winter
PM_{10}	16.85	100	205	233	8.20	7.20	Exceeded (-8.63)	Exceeded (-9.62)
$PM_{2.5}$	5.00	60	191	196	1.50	1.50	Exceeded (-3.43)	Exceeded (-3.47)
SO_2	1.02	80	30.9	30.03	2.60	2.70	1.62	1.7
NO_x	12.42	80	7.2	9.1	25.30	23.80	12.8	11.4

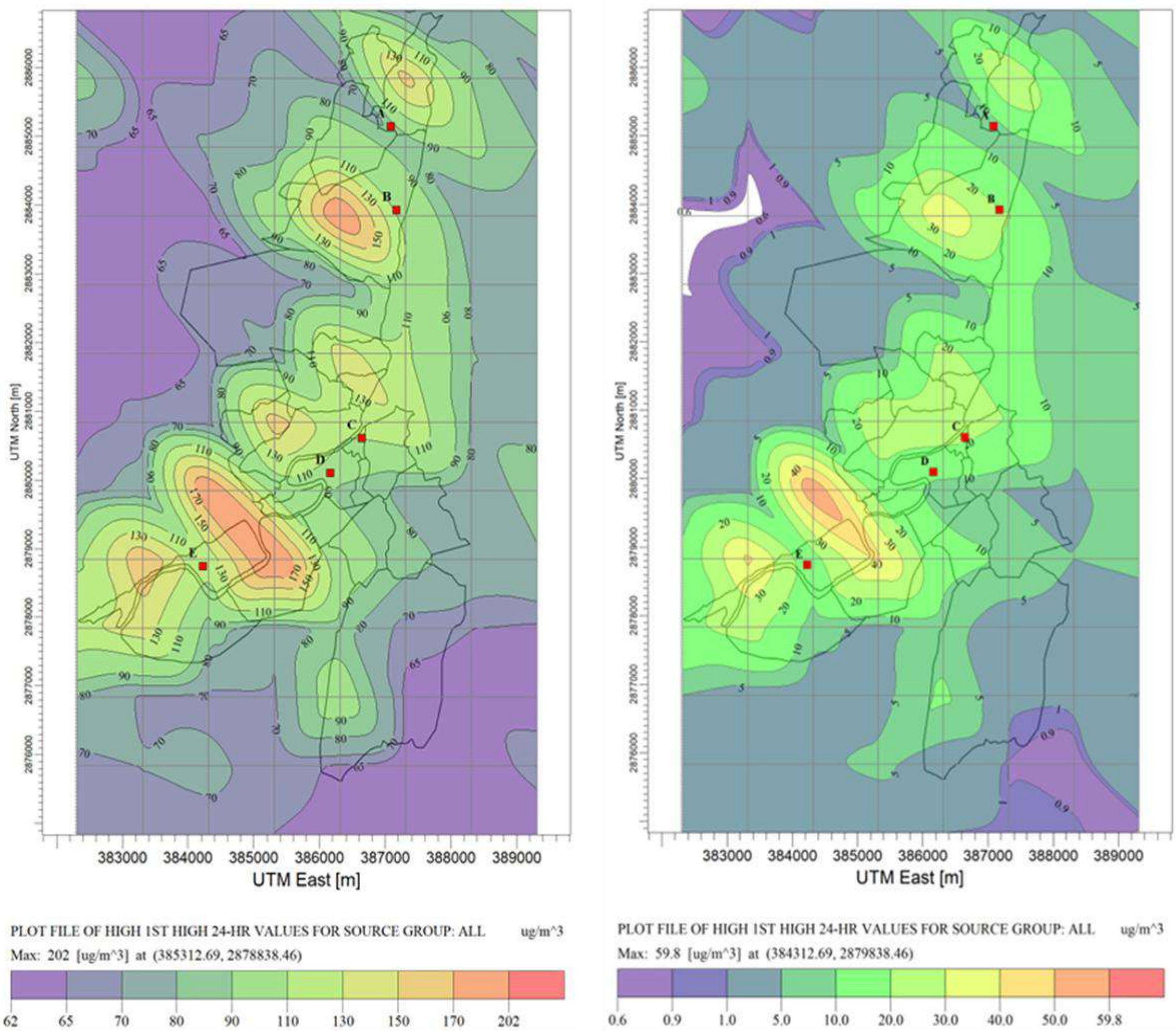
Table 5.6 Existing emission load, carrying capacity and residual carrying capacity considering area sources

Pollutants	Existing emission load (T/d)	NAAQS (µg/m³)	Predicted Maximum GLC (µg/m³)		Atmospheric Carrying Capacity (T/d)		Residual carrying capacity (T/d)	
			Summer	Winter	Summer	Winter	Summer	Winter
PM_{10}	0.88	100	66.9	67.25	1.31	1.30	0.43	0.42
$PM_{2.5}$	0.59	60	141.5	69.3	0.25	0.51	Exceeded (-0.34)	Exceeded (-0.08)
SO_2	0.01	80	1.35	1.32	5.92	0.60	5.91	0.59
NO_x	0.07	80	0.06	0.08	93.30	70.00	93.23	69.93



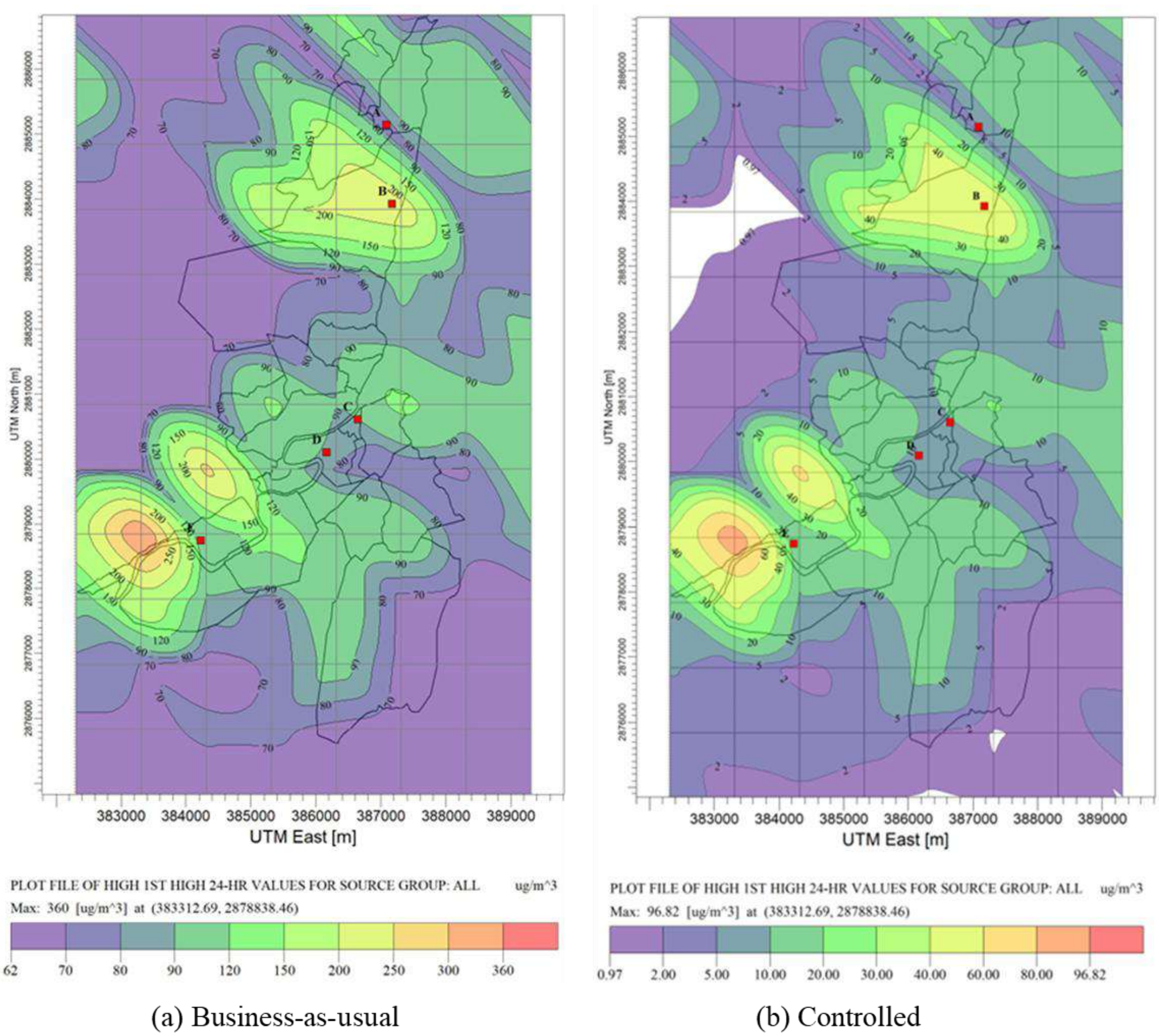
(a) Business-as-usual (b) Controlled

Fig. 5.10 Predicted GLCs of PM_{10} during summer for (a) Business-as-usual (24.5 T/d) and (b) Controlled (8.9 T/d) carrying capacity



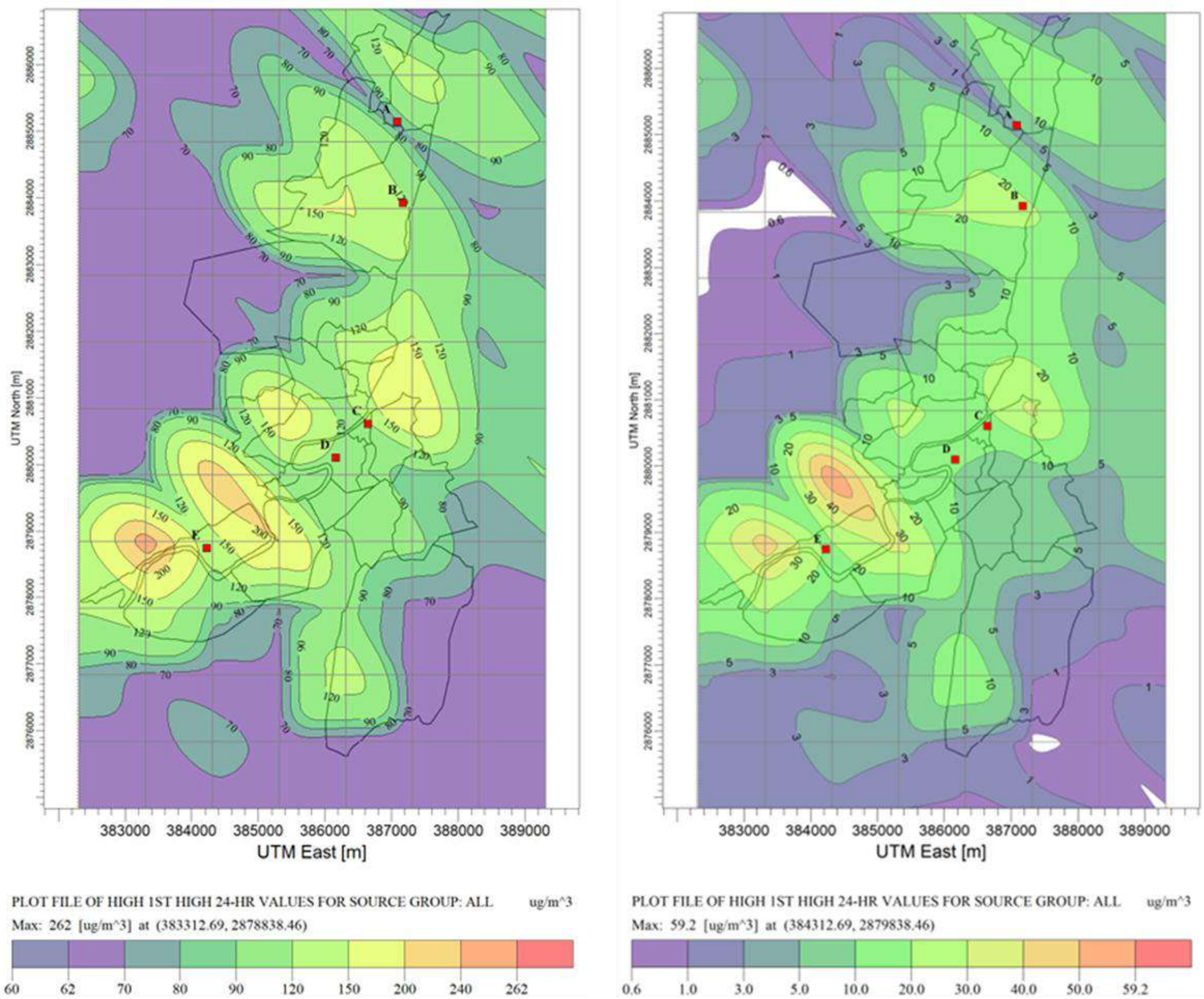
(a) Business-as-usual (b) Controlled

Fig. 5.11 Predicted GLCs of $PM_{2.5}$ during summer for (a) Business-as-usual (9.92 T/d) and (b) Controlled (2.9 T/d) carrying capacity



(a) Business-as-usual (b) Controlled

Fig. 5.12 Predicted GLCs of PM_{10} during winter for (a) Business-as-usual (24.5 T/d) and (b) Controlled (6.8 T/d) carrying capacity



(a) Business-as-usual (b) Controlled

Fig. 5.13 Predicted GLCs of $PM_{2.5}$ during winter for (a) Business-as-usual (9.92 T/d) and (b) Controlled (2.3 T/d) carrying capacity

Chapter 6

Summary
and
Recommendations

6.0 Summary

The carrying capacity of air pollution in Byrnihat town and the EPIP area demonstrates the need for an urgent and coordinated approach to air quality management. This study presents recommendations that encompass regulatory, technological, urban planning, and community engagement strategies. Implementation of these recommendations is not only expected to facilitate safeguarding health and well-being of residents but also, promote sustainable industrialization and urban development. Comprehensive air quality management is crucial for ensuring a healthier and happier future for Byrnihat and its surrounding areas.

6.1 Salient findings

- The carrying capacity assessment revealed that the town's air environment had exhausted the capacity to accommodate additional emissions of PM_{10}& $PM_{2.5}$ for both summer and winter seasons.
- Considering all sources (point, area and line), the business-as-usual (BAU) emission load for PM_{10} and $PM_{2.5}$ were 24.5 and 9.92 T/d respectively, which contributed to the predicted GLCs of 273 µg/m^3 and 202 µg/m^3 in summer and 360 µg/m^3 and 262 µg/m^3 in winter.
- During the summer season, the expected emissions under Business as Usual (BAU) scenarios amount to 24.5 tons per day (T/d) for PM_{10} and 9.92 tons per day (T/d) for $PM_{2.5}$. To ensure that Ground Level Concentrations (GLCs) remain within the thresholds defined by the National Ambient Air Quality Standards (NAAQS), it is essential to reduce the emissions limits. Specifically, the maximum emission of PM_{10} must be revised to 8.9 T/d, while the emission limit of $PM_{2.5}$ should be adjusted to 2.9 T/d.
- During the winter season, it is essential to reduce the BAU emission loads further to specified limits. To comply with the National Ambient Air Quality Standards (NAAQS), emissions must be curtailed to 6.8 T/d for PM_{10} and 2.3 T/d for $PM_{2.5}$.These findings emphasize the urgent need for effective measures to mitigate the impact of particulate matter on air quality, particularly during seasonal shifts.
- The discrepancy in required reductions between PM_{10} and $PM_{2.5}$, and between summer and winter, underscores the importance of tailored approaches to combat particulate matter pollution. Seasonal variations in weather patterns, industrial activity, and domestic heating

practices contribute to varying PM emission levels. Therefore, a comprehensive understanding of these factors is essential in developing targeted and effective strategies for reducing PM emissions and achieving NAAQS compliance.

- In the framework of different types of emission source categories, specifically point and line sources (as detailed in **Tables 5.4 and 5.5**), the present levels of PM_{10} and $PM_{2.5}$ emissions have exceeded what the Atmospheric Carrying Capacity (ACC) can sustain. This excess has led to a negative Residual Carrying Capacity (RCC) observed during both the summer and winter seasons.
- The present situation regarding SO_2 and NO_x emissions in the Byrnihat study area is within acceptable ranges, but the potential for increased emissions poses a risk that must be managed proactively. Ongoing assessments and adaptive management strategies will be necessary to sustain air quality as development progresses.
- Given the extreme levels of predicted particulate matter concentrations and the depletion of the atmosphere's capacity to accommodate additional pollutants, it is unwise to expand or increase emissions of gaseous pollutants like SO_2 and NO_x. These reactive gases are known contributors to the formation of secondary aerosols, which further intensify the concentration of particulate matter in the air. As such, any decision to augment sources of these gaseous pollutants could profoundly worsen the air quality and elevate health risks within the region.

6.2 Recommendations for improved air quality management

The keep the level of air pollution within the ACC or AAC of Byrnihat-EPIP region, it is imperative that emissions need to be reduced significantly. Targeting emission reduction from the highest emitters like industries, road and transport sectors of the region can make the biggest different to overall emission load rather than targeting small emitters. The sector wise emission load can be found in the Emission Inventory and Source Apportionment report of Byrnihat for ready reference. To sustainably manage air quality and ensure safety for the residents of Byrnihat and the EPIP area, the following, but not limited to, multi-faceted air quality management measures are suggested:

(a) Regulatory Measures

- Implementing Emission Standards: Ensure continuous vigil and periodic third-party audit for enforcing round-the-clock operation of emission control systems in industries for regulating emissions from industries
- The vehicles in the region need to be checked on a regular basis for fitness and emission compliance status.
- Regular Compliance Audits: Conduct regular monitoring and air quality audits to ensure compliance with ambient air quality standards.
- Surprise stack emission audits must be conducted in local industries to ensure emission compliance.
- All loose and dust generating fuel/raw materials like coal, ore, rice husk must be kept under covered sheds or kept covered with large tarpaulin sheets within industrial premises, to reduce resuspension of loose materials in air with wind movement.

(b) Technological Interventions

- Adoption of Cleaner Technologies: Encourage all local industries to adopt cleaner production processes and efficient emission control technologies, such as bag houses and ESPs.
- Pollution Control Devices: Implement mandatory installation of air pollution control devices in all factories, based on technical feasibility report.
- Multiple cameras with real-time video transmission to a designated ULB in the region, must be installed inside all large industrial premises (mainly manufacturing plants) to cross-check housekeeping, raw material and waste handling and operation of emission control systems.

(c) Urban Planning

- Green Buffer Zones: Enforce installation of tall green belts as barriers to lateral dispersion of fugitive particulates around all industrial premises and designated industrial areas can enhance air quality in micro-regions.
- Zoning Regulations: Implementation of guidelines and best practices for zoning air-polluting industries near residential areas and villages.

- New industry: Permission may be denied for any highly polluting (air) new installation of manufacturing units in the study area (Byrnihat and EPIP area, ref. Fig. 2.2)
- Industrial expansion: Expanding the production capacity of existing red and orange category industries may be restricted.
- Ensuring clean and paved roads all over the region will not only streamline smooth mobility but also can reduce road dust emissions substantially.
- All parking lots and vehicle movement zones in the region on both sides of GS road and within industrial premises, need to be paved immediately to restrict loose dust emissions from such parking lots.
- Unauthorized denudation of forest / vegetative cover in the local hills must be stopped to ensure the proper functioning of purification of air pollutants by vegetative cover in the region
- All roads and alleys leading to industries located inside villages must immediately be paved, wherever remained unpaved so far.

(d) Public Awareness and Community Involvement

- Awareness Campaigns: Initiate educational campaigns in schools, colleges, local gatherings and clubs highlighting the effects of air pollution on health and the environment. Most importantly, students and general public should be sensitized on potential individual duties in curbing air pollution
- Community Monitoring Programs: Engage local communities in monitoring and keeping vigil on activities that degrade air quality and reporting violations thereof through mobile apps. A mobile app needs to be developed, and therefore, it is expected to take a few months, whereas reports on violations can be sent directly by the public to 1-2 dedicated WhatsApp numbers to start the initiative immediately.

(e) Policy Integration

- Cross-Sector Collaboration: Establish a framework for collaboration among various government departments, industries, local communities, churches and clubs to ensure a holistic approach to air quality management.

- Sustainable Development Policies: Integrate air quality objectives into broader urban planning and development policies at state, district as well as the block levels.
- Ensuring widespread LPG supply and use in the household sector, even into the villages, can improve air quality of the region and hence, must be brainstormed in terms of feasibility and ways to achieve.
- Organized waste collection and management (especially combustibles) is of utmost importance and needs to be started immediately in the entire block including study region. This might ensure minimization of widespread practice of putting combustibles to fire.

Some recommendations under the potential ambit of regional airshed approach for air quality management are furnished below:

- All industries present in EPIP, Byrnihat and CEPI and other nearby areas on Assam side of GS road need to be brought under an ambit of strict emission control and periodic emission audits, if the entire Byrnihat airshed is put under a combined AQM action plan.
- All particulate generating industries (all types of metallurgical and alloy making, cement, coke etc.) need to install bag house for PM control from operations.
- Strict on-site fugitive emission control systems like de dusting houses, sprinklers, shed for storage etc. need to be installed in all industries handling coal, coke, loose earth, any kind of ore, cement, quartz etc.
- 24x7 operations of emission control systems in all industries in air shed needs to be ensured
- Also, a few brick kilns present on Assam side within 2 km from GS road needs to be put under the vigil for emission compliance and should be enforced to shift to zig-zag firing, if not done so far

- All soil and stone mining activities in the entire airshed need to be monitored on regular basis for particulate emissions and air quality management system needs to implemented on these
- All eateries on both sides of GS road need to be converted to LPG only
- All barren truck parking lots and industrial premises need to be paved on both sides of GS road
- All large industries in the airshed need to develop greenbelt around the periphery to minimize particulate dispersion outside premises
- Alley plantation along GS road needs to be planned for minimizing road dust dispersal and sound wave propagation on both sides
- Holding frequent events on the benefits cleanliness, sanitation, waste management, environmental education and awareness in public through religious centres (Church/Temple/Masjid) and schools and colleges in the entire airshed

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