ANALYZING LONG-TERM AIR QUALITY TRENDS IN DIFFERENT ZONES OF INDIA USING HYSPLIT MODEL

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Submitted

by

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TO WHOMSOEVER IT MAY CONCERN

This is to certify that Ms. Atirah Nisar has successfully completed her Dissertation under the Co-Supervision at **Indian Institute of Technology, Delhi**, as a student of Thapar Institute of Engineering & Technology, Patiala from 6th June 2023 and concluded on 7th June 2024.

During the course of her work, she actively participated in the project titled **"Analyzing long-term air quality trends in different zones of India using HYSPLIT model"**. Her dedication, enthusiasm, and commitment to learning were evident throughout the period. She displayed strong analytical skills, attention to detail, and the ability to work effectively both independently and as part of a team.

Ms. Atirah Nisar exhibited a keen interest in Air Quality Modelling and demonstrated a willingness to learn and explore new concepts. She consistently met deadlines and effectively applied the knowledge gained from her academic coursework to practical scenarios. It is our belief that the skills, experience, and knowledge acquired during this period will serve Ms. Atirah Nisar well in her future endeavours. We wish her all the best for her future academic pursuits and professional career.

Dated: 11th June 2024

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DECLARATION CUM CERTIFICATE

I hereby declare that the project work titled **"Analyzing long-term air quality trends in different zones of India using HYSPLIT model"** is an authentic record of my own work carried out at **Indian Institute of Technology, Delhi** as requirements of one-year project internship for the award of degree of Masters in Technology in Environmental Science & Technology at Thapar Institute of Engineering & Technology, Patiala, under the co-guidance of Dr. Sri Harsha Kota and guidance of Dr. Amit Dhir and Dr. N. Tejo Prakash, during June 2023 to June 2024.

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Certified that the above statement made by the student is correct to the best of our knowledge and belief.

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ABSTRACT

Based on statistical analysis using the Hybrid Single–Particle Lagrangian Integrated Trajectory (HYSPLIT) model, driven by meteorological data from the National Oceanic and Atmospheric Administration (NOAA) reanalysis archives, along with concentration monitoring data from Central Pollution Control Board (CPCB) of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 in six zones of India from 2011 to 2019, the primary transport pathways and potential sources of air pollutants were investigated. The trajectory classification method revealed that air masses from certain directions significantly contributed to high pollutant concentrations in the respective zones, while air masses from other directions were associated with cleaner air. Consistent with Concentration-Weighted Trajectory (CWT) results, the Potential Source Contribution Function (PSCF) analysis indicated that potential sources leading to elevated concentrations of PM_{10} and $PM_{2.5}$ were primarily located in Indo-Gangetic Plains of Gorakhpur, north-western regions of Jodhpur and Vadodara. These areas exhibited PM_{10} concentrations exceeding 300 $\mu g/m^3$ and $PM_{2.5}$ concentrations surpassing 60 $\mu g/m^3$. On the other hand, sources of sulphur and nitrogen dioxides were predominantly influenced by local emissions. Reduction of both local and regional pollution is required to yield a significant reduction in pollution of all cities. Since the selected sites for the monitoring of the ambient air quality were the tourist hotspots thus in depth studies regarding the reduction of tourist inflow is also reviewed. It is clearly seen that the destinations like Jammu, Jalandhar and Guwahati is affected the most because these places show a reduction of about 15 % in tourist inflow. All these issues can be dealt by improving the air quality using policy implementations and green initiatives. Many services can be provided to people that influence the communities to travel to these destinations in rest of the year when the air quality is comparatively better.

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CHAPTER 1

INTRODUCTION

Air pollution is the major problem in India, affecting both rural and urban areas. The main causes of air pollution in India are thermal plants, pollution from vehicles, industrial emissions and burning of wood and dirty fuels for cooking and heating. The effects of air pollution are devastating, causing more than 2 million deaths in a year in India, with respiratory and cardiovascular diseases being the most common health problems [1]. India has one of the highest levels of air pollution in the world with 22 of the world's 30 cities with the worst air pollution [2]**.** The economic impact of air pollution is also significant, with lost output from premature deaths and morbidity attributable to air pollution [2].

Rapid urbanization and globalization have resulted in megacities in developing countries experiencing serious health problems because of ambient air pollution. Concerns about urban air quality are becoming more pressing in both developed and developing nations [3]**.** Among the main contributions are sulphur dioxide (SO_2), nitrogen oxides (NO_x) and fine particulate matter (PM). These pollutants seriously endanger vulnerable populations and cause respiratory and cardiovascular problems. In addition, air pollution damages ecosystems, leading to a decline in biodiversity and accelerating climate change by releasing greenhouse gases into the atmosphere. Even in areas that are quickly urbanizing, there are still difficulties implementing rules, despite efforts to ameliorate this situation. In order to assure cleaner air for the present and future generations, addressing air pollution requires coordinated worldwide efforts to embrace sustainable behaviours, technological developments and strong regulatory frameworks.

Commencing in 1987, India established a national ambient surface monitoring network that has progressively expanded its reach and capacity. Notably, between 2015 and 2019, there was a significant augmentation in the number and spatial distribution of both continuous and manual monitoring stations. Currently, the Central Pollution Control Board (CPCB), in collaboration with State Pollution Control Boards (SPCBs), oversees the most extensive monitoring network in the country through the National Air Quality Monitoring Program (NAMP). By 2019, the cooperative efforts of NAMP, CPCB, and SPCBs resulted in the operation of more than 750 manual monitoring stations. This marks a substantial increase from the initial 20 stations in 1987 and 450 stations in 2015. These stations play a crucial role in publicly archiving annual average concentrations of pollutants such as PM_{10}, $PM_{2.5}$, SO_2 and NO_2, with the data accessible on the CPCB's official website [4]. As of 2019, over 220 Continuous Ambient Air Quality Monitoring (CAAQM) stations operated (compared with less than 50 stations in 2015 when our analysis starts). CPCB archives publicly available, real-time data, every 15 minutes, from over 220 stations across India of an extensive list of criteria and non-criteria air pollutants and meteorological variables [5]. Stations vary in the air pollutant species and meteorological data they collect. The manual monitors provide better spatial coverage than the continuous monitors, but provide data on fewer air pollutants at much lower temporal resolution (annual average values versus every 15 minutes). Despite the recent expansion of urban monitoring stations throughout India, large areas still lack monitoring coverage, leaving a significant data gap in non-urban locations. With limited information available, except for satellite data for a few pollutants, the surface concentrations of air pollutants in rural areas across India remain largely unmonitored [6]. This lack of comprehensive monitoring becomes particularly relevant in light of the observed extreme levels of fine particulate air pollution in India, coupled with an increasing awareness of the adverse health impacts associated with elevated air pollution. Responding to these concerns, the Indian government initiated the National Clean Air Programme (NCAP) in 2019, as outlined by the Ministry of Environment, Forests, and Climate Change. The NCAP aims to achieve a 20–30% reduction in PM_{10} and $PM_{2.5}$ concentrations by 2024 relative to 2017 levels. A key aspect of the NCAP is the enhancement of the national monitoring network, and significant financial support was allocated for this purpose in the 2020 Union Budget. This strategic move signifies a commitment to addressing air quality issues on a broader scale, emphasizing the importance of a more extensive and inclusive monitoring system to better understand and combat air pollution across diverse geographic settings in the country.

Despite a growing monitoring network and the need for analysis, prior to our work, no study holistically analysed existing government surface air pollutant monitoring data across India. Most research studies analysing ground monitoring data have focused on Delhi and the surrounding National Capital Region (NCR) and other major cities. There is a need for a comprehensive analysis of all surface data collected by manual NAMP and continuous CAAQM monitoring networks for other parts of India. The current work outlines the sources, factors and variables that contribute to the Himalayan region's rising air pollution levels and their variation trends [7].

The South Asian region, particularly India, grapples with the most elevated mean annual $PM_{2.5}$ levels globally, primarily due to soaring population rates and emissions stemming from industries, vehicles, households, and the combustion of bio-fuels like wood, dung, and agricultural residue. As highlighted in the World Health Organization's 2016 report, four out of the top 10 cities with the highest $PM_{2.5}$ concentrations were situated in India. The detrimental effects of heightened $PM_{2.5}$ exposure include chronic obstructive pulmonary disease, ischemic heart conditions, lung cancer, stroke, and various other severe health risks [8].

Numerous studies have highlighted the significant spatial variability of $PM_{2.5}$ concentrations across India, with higher levels predominantly found in the Indo-Gangetic Plains and notably lower levels in the southern states. Major Indian cities consistently exceed annual standards for both PM_{10} and $PM_{2.5}$ concentrations, irrespective of their geographical location. The effective implementation of control and mitigation policies by authorities is crucial to addressing this issue. For instance, in 2015, air pollution-related deaths in India surpassed those in China, partly due to a reduction in $PM_{2.5}$ concentrations resulting from a government crackdown on heavily polluting industries in China. Establishing guidelines for control and mitigation requires the identification of factors contributing to high $PM_{2.5}$ concentrations. Emissions and meteorology are two key factors influencing pollutant concentrations. Emissions directly introduce pollutants into the atmosphere, while meteorology influences their transport, transformation, and deposition. For example, emissions from various sources such as manufacturing, construction, household combustion, road dust, and industrial activities significantly contribute to PM_{10} and $PM_{2.5}$ concentrations in the Indo-Gangetic Plains, Western India, and southern India. Meteorological factors such as temperature, wind speed, and relative humidity play crucial roles in pollutant dispersion, deposition, and chemistry. Effective pollution control often involves stringent regulation laws and mitigation policies at the local level. However, addressing long-lived pollutants requires regional cooperation between states and countries. This collaborative approach is essential to reducing pollution effectively, particularly in areas affected by sources beyond their immediate control [8].

In the realm of air quality assessments, environmental planning, and emergency response, coupled atmospheric and dispersion models play a pivotal role. These models rely on meso-scale atmospheric dynamic models to provide essential variables such as flow field and mixing height for dispersion calculations. However, the accuracy of these simulations is subject to various factors such as initial conditions, representation of sub-grid scale processes, and model configurations. Numerous studies have underscored the significant impact of different model parameters and configurations on meteorological forecasts, particularly in short-range weather prediction scenarios. Variations in physical parameterizations, such as planetary boundary layer (PBL) and land surface processes, can lead to diverse simulations of temperature profiles, wind fields, and atmospheric stratification layers [9]**.**

Modern dispersion models have evolved to incorporate sophisticated calculations accounting for complex turbulence mechanisms and transport processes in the lower atmosphere, relying heavily on input fields from meso-scale models. Yet, the choice of model physics formulations can introduce variability in meteorological fields, consequently influencing dispersion results. To address this variability and obtain a more robust estimate of model uncertainty, its common practice to conduct a series of meteorological model runs with perturbed physics formulations. This approach helps in quantifying the performance deviations of dispersion models, largely attributed to uncertainty in input fields. However, evaluating model performance can be challenging due to limited observational data availability. Therefore, it becomes imperative to conduct sensitivity studies to assess uncertainty in air quality simulations. This study aims to explore the intricacies of coupled atmospheric and dispersion models, their sensitivity to model configurations, and the implications for air quality assessments [9].

A wealth of research on this topic advocates for an ensemble approach, among other methodologies, to address the inherent uncertainties in dispersion modelling. This approach involves conducting statistical analyses on multiple dispersion simulations of a shared case study, aiming to elucidate the influence of factors such as atmospheric circulation, dispersion methods, and source characteristics on dispersion patterns. By doing so, it becomes possible to identify the most probable dispersion patterns and establish an envelope of uncertainty surrounding them. One method employed to study the sensitivity of dispersion models is to utilize a single atmospheric circulation model while generating different ensemble members through the implementation of various physics variants for sub-grid scale physical processes. For instance, a researcher utilized a high-resolution meteorological model equipped with diverse physics options and initial data fields to furnish input meteorological fields for a dispersion model. Subsequently, dispersion probabilities were estimated at each grid point within the model domain. The endeavours to delve into the efficacy of ensemble approaches in addressing uncertainty in dispersion modelling, shedding light on the dependency of dispersion patterns on critical factors. By exploring various methodologies, including the utilization of different physics variants within a single atmospheric circulation model, this study aims to enhance our understanding of dispersion modelling sensitivity and its implications for environmental assessment and emergency response planning [9]**.**

In urban-intensive regions, the phenomenon of cross-regional transportation of air pollution is glaringly apparent. Contaminants traverse between cities via airflow dynamics, leading to the overlapping of pollution layers above urban centres and exacerbating the challenge of pinpointing potential source areas. By delving into the regional transport dynamics of pollutants, it becomes possible to analyze the varied influence of different regions on pollutant contributions. Central to this analysis are air quality models and receptor models, which play a crucial role in elucidating the intricate pathways of pollutant dispersion. Concurrently, research efforts in the realm of air quality predominantly revolve around investigating the temporal and spatial fluctuations of pollutants, alongside the factors shaping meteorological conditions [10]**.**

This thesis aims to delve into the complexities of cross-regional air pollution transportation, exploring the interplay between urban centres and surrounding regions. Through the utilization of advanced air quality and receptor models, this study seeks to unravel the intricate dynamics governing pollutant dispersion. Additionally, it endeavours to shed light on the temporal and spatial variations of pollutants, with a keen focus on understanding the underlying meteorological influences.

1.1 HYSPLIT Description: A Lagrangian Dispersion Model

The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model, jointly developed by NOAA and the Australian Weather Bureau, offers real-time calculations and comprehensive analysis of the transport origins of various atmospheric pollutants. With its robust capabilities in atmospheric transport, diffusion, and deposition, HYSPLIT stands out as a versatile tool for understanding the movement of pollutants in the atmosphere. Its ability to handle multiple pollutant types, diverse meteorological inputs, and varied emission sources makes it a go-to choice for researchers investigating the transport, dispersion, and settling patterns of atmospheric pollutants. It possesses the capability to handle multiple atmospheric and physical transport processes, diverse meteorological input fields, and emissions from various categories simultaneously [11].

In an Eulerian modeling approach, concentrations of air pollutants are determined for each grid cell by integrating the fluxes of pollutants across grid cell boundaries, considering both diffusion and advection. Conversely, in a Lagrangian modeling approach, concentrations are computed by aggregating the contributions of individual pollutant "puffs" as they traverse through the grid cell following their trajectories. This method allows for simulating dispersion either by tracking the evolution of the pollutant puff's size or by explicitly modeling the dispersion of a cluster of particles. Despite its name, HYSPLIT can simulate the distribution of pollutants starting from a single particle or puff, or by tracking the dispersed motion of numerous particles. Some of the model's over prediction issues were linked to its sensitivity to parameters like the threshold friction velocity and the surface soil texture coefficient (representing the soil emission factor), posing challenges for their accurate representation within the model. The vertical mass flux is derived from the friction velocity and the threshold friction velocity [12].

When the wind field exhibits horizontal and vertical variations, a single trajectory puff fails to accurately depict the expansion of a pollutant cloud. In such scenarios, the model must either divide the single puff into multiple puffs or utilize numerous pollutant particles for simulation. HYSPLIT offers three primary configurations to represent the dispersive growth of pollutant elements. In "puff" mode, a fully 3-D cylindrical puff is employed, featuring a defined concentration distribution both vertically and horizontally. Puffs expand both horizontally and vertically based on dispersion rules and split if they exceed a certain size threshold. Alternatively, in "particle" mode, an infinitesimally small particle serves as the contaminant element. A fixed number of particles are released and are subject to movement by wind with mean and random components, without any growth or splitting. In the "hybrid" approach, the element takes the form of a circular 2-D object (planar mass) with zero vertical depth, featuring a puff distribution horizontally. In the vertical dimension, a fixed number of these elements act as particles, while in the horizontal dimension, they expand following puff dispersion rules and split if necessary. To compute air concentrations, it's essential to track all particles explicitly or understand the particle distribution (puff definition) around the mean trajectory. This is achieved in the particle approach by introducing a random component to the mean advection velocity, defining the dispersion of the pollutant cloud [12].

Analysis of backward trajectories using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model revealed that the prevailing synoptic conditions facilitated the transportation of pollutants. Backward trajectory analysis serves as a potent tool extensively employed to comprehend phenomena associated with the long-distance transport of aerosols [13]. By integrating calculation techniques for both horizontal and vertical atmospheric motion, the HYSPLIT model offers comprehensive capabilities in pollutant transport, diffusion, and settling. It finds widespread application in simulating pollution trajectories, identifying pollution sources, and quantitatively estimating pollutant concentrations. Additionally, the model extends its utility to fields such as analyzing the transport routes of water vapour and sand-dust [10].

Dispersion computation involves three key elements: particle transport driven by the mean wind, turbulent transport, and the determination of air concentration. Pollutant particles are released from the source and passively follow the wind field, with their average trajectory obtained through the integration of their spatial and temporal position vectors. Turbulent motion contributes to the dispersion of the pollutant cloud, achieved by introducing random components to the mean advection velocity across all three dimensions of wind. Vertical turbulence is derived from wind and temperature profiles, while horizontal turbulence stems from velocity deformation. The meteorological fields required by the model encompass horizontal (u, v) and vertical (w) wind components, temperature (T), height (Z) or pressure (P), surface pressure (Po), and optionally, moisture and vertical motion. These gridded three-dimensional fields undergo linear interpolation in both space and time to match the position of the particles [9].

CHAPTER 2
LITERATURE REVIEW

Table 1-A review of various studies done statistically and using modelling

Serial Number	Parameters studied	City/State	Observations	Ref.
1.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	Beijing, Shanghai & Guangzhou (China)	Seasonal trends. $PM_{2.5}$, PM_{10}, CO, SO_2 & NO_2 exhibited max. concentrations in winter & min. in summer, while O_3 showed the opposite pattern. Results underscore the crucial role of meteorological parameters in air pollution formation, with significant variations across seasons & geographical locations (2013-2014)	[14]
2.	SO_2, NO_x, PM_{10}, SPM	Delhi, Mumbai, and Kolkata	Declining SO_2 levels from reduced sulphur in fuels, but increasing NO_x levels due to more vehicles and CNG engines. Kolkata shows the highest SPM and PM_{10} emissions, while Delhi has the highest ambient concentrations. The study underscores the regional and global impact of megacity emissions and evaluates the effectiveness of government air quality policies.	[15]
3.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2	Varanasi, India	Air quality trends from 2013 to 2016 using Mann-Kendall and Sen's slope methods. It forecasts future pollutant levels with ARIMA models, finding ARIMA (1,1,1) most suitable. Results show PM_{10} levels are increasing, predicted to reach 273 µg/m^3 by 2030, while $PM_{2.5}$, CO, NO_2, and SO2 levels are decreasing, with CO, NO_2, and SO_2 expected to remain below permissible limits, but PM_{10} and $PM_{2.5}$ likely to exceed them.	[16]
4.	RSPM, $PM_{2.5}$, NO_2 and SO_2	India	From June 2017 to May 2018, finding higher pollutant concentrations at high-traffic sites, especially during summer and winter is analyzed. Summer shows elevated RSPM and $PM_{2.5}$ levels, while winter has peak NO_2 & SO_2 concentrations.	[17]

			The lowest levels are during the monsoon. Principal Component Analysis identifies vehicular emissions, crustal re-suspension, & activities like burning wood & coal as major pollution sources. The study emphasizes addressing these sources to improve air quality.	
5.	NO_2 & NO_x	India	By employing a rolling window regression method, it more accurately captures true trends compared to simple averaging. Simulations confirmed its effectiveness, and its application to London roadside data (2000–2017) revealed a significant downward trend in NOx concentrations, contrasting with minimal changes suggested by averaging. This method enhances trend analysis accuracy, especially for datasets with limited or varying lengths.	[18]
6.	SO_2 & NO_2	Gwalior	This study assessed urban residential zones, focusing on spatial and temporal variations at four sites. Results showed the highest pollutant concentrations in commercial areas and high-traffic locations, adhering to India's national ambient air quality guidelines.	[19]
7.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	China	This study uses spatial interpolation to analyze air pollutant and meteorological data from 896 stations (2014-2019). Results show a significant decline in most air pollutants, except for ozone (O_3), which increased due to reduced particulate matter and NO_2 levels. Meteorological conditions, such as wind speed, precipitation, and relative humidity, generally negatively correlate with pollutant concentrations, while atmospheric pressure has a positive correlation. Temperature impact varies with latitude, emphasizing the need to understand air pollution-meteorology interactions for effective air quality control.	[20]
8.	NO_2, PM_{10},	Jammu	Data revealed consistent reductions in $PM_{2.5}$ &	[21]

	$PM_{2.5}$ & O_3		PM_{10} by -11.71% & -12.18%, respectively, during weekend restrictions compared to weekdays.NO_2 & O_3 exhibited notable variations, registering decreases of -8.37% & -17.01%, contributing to an overall change in AQI by -15.09% (2020)	
9.	PM_{10}, $PM_{2.5}$	Bulandshahr, Nainital & Patiala	Proportions of PM_{10} formed by $PM_{2.5}$ for Patiala & Bulandshahr were similar – varying from about 25% to 90% of PM_{10}. PM concentration levels reached the maximum in the mornings, and the minimum in the afternoons	[22]
10.	PM_{10}, $PM_{2.5}$, SO_2, NO_2 & O_3	Delhi, Kolkata, Mumbai, Hyderabad & Chennai	Particulate pollution dominates pollution mix in northern India exceeding the annual average PM_{10} & $PM_{2.5}$ residential NAAQS by 150% & 100% respectively, & in southern India exceeding the PM_{10} standard by 50% & $PM_{2.5}$ standard by 40% (2015-2019)	[6]
11.	$PM_{2.5}$	Delhi	With the exception of December & January, all months exhibit a decreasing trend in $PM_{2.5}$ concentration, indicating a gradual reduction in particle pollution. Meteorological variables show trends during the study period, with a rising trend observed for relative humidity, surface pressure & a declining trend for wind speed (2007-2021)	[23]
12.	SO_2, NO_2 & PM_{10}	Dehradun, Haridrwar & Rishikesh	Meteorological parameter variations reveal robust positive correlation between SO_2 & NO_2 Linear regression plots depict the relationships between SO_2 , NO_2 & PM_{10} (2011-2020)	[24]
13.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	Delhi	Addresses air pollution beyond Delhi, focusing on 20 other Indian cities through the APnA city program. By establishing a high-resolution multi-pollutant emissions inventory and utilizing the WRF-CAMx chemical transport model, it estimates spatial pollutant concentrations and generates 3-day air quality forecasts. This research provides valuable insights for policymakers on the	[7]

			sources and impacts of air pollution in these urban areas.	
14.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	Delhi, Mumbai, Indore, and Chandigarh	This review examines the NCAP initiative in India, launched in 2019 to improve air quality in 131 non-attainment cities. By February 2023, only 39 cities completed source apportionment studies. The study emphasizes enhancing ambient air monitoring networks, recommending 2118 sampling sites across 104 airsheds, covering 164 cities with 295 million people. Key steps include determining optimal airshed sizes, sampling frequencies, and incorporating hybrid monitoring networks with low-cost sensors. Effective airshed-level management plans and robust monitoring infrastructures are crucial for achieving NCAP goals.	[7]
15.	$PM_{2.5}$	New Delhi, Kolkata, Mumbai, Hyderabad, & Chennai	TTAinterfaceTrendAnalysis, an R-based GUI package evaluates $PM_{2.5}$ trends from 2014 to 2020. It finds significant annual declines in $PM_{2.5}$ levels, ranging from -0.27 to -5.2 µg/m³ per year, but month-wise trends are not statistically significant. The study also examines the impact of the COVID-19 lockdown, with trend changes between -0.13 & 2.29 µg/m³ per year. This research highlights the package's utility in assessing long-term air quality trends & the influence of external factors like lockdowns.	[25]
16.	PM_{10}	Spain	HYSPLIT model is used to determine the sources of PM_{10} during a March 2003 dust outbreak. It finds that 20-30% of PM_{10} came from Mauritania and Western Sahara, 15-20% from Mali and the Ahaggar Mountains, and 55-60% from other north-western African sources.	[12]
17.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	US	WRF & HYSPLIT models analyze air pollutant dispersion from Mississippi Gulf coastal sources. It explores sensitivity to meteorological	[9]

			conditions through varying WRF configurations, highlighting the significant impact of model settings on concentration predictions.	
18.	$PM_{2.5}$, PM_{10}	Delhi	The study examines smog from 2010 to 2012, noting especially high pollution levels during a severe event in November 2012 compared to Diwali. It highlights the significant impact of regional pollution on air quality.	[13]
19.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	Central Himalayan region	The study analyzes aerosol distribution in the Central Himalayas and surrounding plains (2007-2016) using satellite data. It finds elevated aerosol layers in winter and post-monsoon seasons, with long-range transport affecting higher altitudes and more localized air masses in summer. Increasing aerosols in winter and post-monsoon correlate with reduced snow cover, suggesting a link between aerosols and snow variability.	[26]
20.	PM_{10}, $PM_{2.5}$, SO_2, & NO_2	Shenyang	The study analyzes 2017 air pollutant sources using the HYSPLIT model and TrajStat method. It identifies northeast and northwest air masses as major contributors to high PM_{10} & $PM_{2.5}$ levels, with key sources in southern Hebei, northern Shandong, and Inner Mongolia. Local sources mainly influence nitrogen sulfide. These insights help target mitigation strategies.	[10]
21.	$PM_{2.5}$	Patna, Kolkata, Bangalore, Chennai, Hyderabad, Mumbai, New Delhi & Lucknow	$PM_{2.5}$-related mortality was studied (2015-2016) using HYSPLIT analysis. It identifies higher health risks in northern and eastern cities, particularly for stroke. UP significantly impacts winter mortality in Delhi, Lucknow & Patna, while Kolkata faces high $PM_{2.5}$ from West Bengal & Bangladesh. Regional pollution from the Indian Ocean affects west & south cities in winter. The study emphasizes reducing both local & regional pollution to mitigate health risks, with variations in dominant pollution sources noted in Delhi &	[27]

			Lucknow.	
22.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	Shenyang	Heating season (November 2017 to March 2018), focused on PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, and CO across 11 monitoring stations. PM_{10} and $PM_{2.5}$ are primary pollutants, with highest concentrations at Taiyuan Street station and elevated levels in south-western Shenyang. Backward trajectory simulations highlight inland sources impacting local air quality during this period.	[11]
23.	$PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 & O_3	Jaipur, Kanpur, and Ballia.	Kanpur consistently had the highest aerosol optical depth (AOD) values, with biomass burning characterized by finer particles. AOD trends increased during biomass burning (most notably in Ballia) and varied during the dusty season, with anthropogenic aerosols prevalent in Kanpur and Ballia during biomass burning and desert dust dominant in Kanpur and Ballia during the dusty season. Source analyses identified local and upper/middle IGB regions as significant contributors to aerosol levels.	[28]
24.	$PM_{2.5}$	Thimphu, Bhutan	From 2018-2020, ground data & HYSPLIT analysis, finds high $PM_{2.5}$ levels above WHO guidelines, with major contributions from neighboring countries. Despite a COVID-19 lockdown, $PM_{2.5}$ reduction was minimal, indicating significant nonlocal emissions. Targeted interventions are crucial to manage elevated $PM_{2.5}$	[8]

In India, there is limited availability of the literature that deals with the multi-city comparison of the trends of air pollution scenario among tier 2 cities (non-attainment cities) and sub urban area. Hence to fill this gap, this study has been conducted to analyse the trends in relation of meteorological parameters.

CHAPTER 3
OBJECTIVES & SCOPE

3.1 Objectives

The objectives of this study are mentioned below:

1. The comparative study of hexagonal binning and trajectory clustering of the 18 monitoring sites in 6 zones of India.
2. The comparative study of CWT and PSCF analysis in two sections of the study period of 9 years i.e., 2011-2014 and 2015-2019.
3. The comparative study of the CWT and PSCF analysis of different seasons during the study period (2011-2014 & 2015-2019).
4. Theoretical analysis of the effects of the air pollution on the tourist hotspots in tier 2 and tier 3 cities and their reduction thereof.

3.2 Scope

The aim of the work reported here is to evaluate Concentration Weighted Trajectories and Potential Source Contribution Function of different cities. The work serves to demonstrate the air quality assessment done by manual methods in tier 2 and tier 3 cities which are surrounded by several industrial clusters, and are connected to other major economic hubs. All the places hold a significant importance in terms of the best tourist destinations because of their stunning natural beauty and an eloquent place for pilgrimages.

CHAPTER 4
METHODOLOGY

4.1 Study Area

India is situated north of equator between 8°4’ N (the mainland) to 37°6’ N latitude and 68°7’ E to 97°25’ E longitude. It is the seventh largest country in the world, with a total area of 3,287,263 km^2. India being one of the most populous countries in the world, its effect on the generation of air pollutants is a major concern at the regional and global level both. India is divided into different physiographic zones such as Himalayas, Indo Gangetic Plains, North-eastern, North-western, Central and Southern zones [7]**.** Due to the meteorological factors and topographical features, the generation, transportation and residual patterns of pollutants vary.

In the Himalayan region, the selected air quality monitoring sites for the present study are Maulana Azad Stadium, Jewel Chowk at Jammu in Jammu & Kashmir; Nagar Palika Parishad at Rishikesh in Uttarakhand and Kotwali Bazaar at Dharamshala in Himachal Pradesh. The site selected in Jammu is Maulana Azad Stadium, Jewel Chowk with geographical co-ordinates 32°43’42’’N and 74°51’41’’E. The site selected in Rishikesh is Nagar Palika Parishad with geographical co-ordinates 30°5’59.604’’N and 78°17’21.516’’E. The site selected in Dharamshala is Kotwali Bazar with geographical co-ordinates of 32°13’12’’ N and 76°19’’6’’E.

In the Indo-Gangetic Plains, the current study's chosen sites for monitoring air quality include Jalkal Bhawan, Gorakhpur in Uttar Pradesh; Albert Ekka Chowk, Ranchi in Jharkhand and MC Tubewell, Jalandhar in Punjab. The site selected in Gorakhpur is Jalkal Bhawan with geographical co-ordinates 26°45’21.996”N and 83°22’22.98”E. The site selected in Ranchi is Albert Ekka Chowk with geographical co-ordinates 23°18’31.3”N and 85°17’27.5”E. The chosen location in Jalandhar is MC Tubewell using coordinates from a geographic location as 31°19’30.3924”N and 75°34’55.3584”E.

In North-east region, the sites selected for air quality monitoring in the current investigation include Khanapara C. Diary at Guwahati in Assam; Opposite War Cemetery, Kohima in Nagaland and Boards Office Premises, Lumpyngngad at Shillong in Meghalaya. The location chosen in Guwahati is Khanapara C. Diary with co-ordinates 26°07’N and 91°48’E. The chosen spot in Kohima is Opposite War Cemetery with co-ordinates 25°40’N and 94°6.04’E.

The site selected in Shillong is Boards Office Premises, Lumpyngngad with geographical co-ordinates 25°33’30.4092”N and 91°54’2.9016”E.

In North-west region, the sites selected for air quality monitoring include Sojati Gate, Jodhpur in Rajasthan; Dandia Bazar, Vadodara in Gujarat and Mashal Chowk, Daman in Dman and Diu. The site selected in Rajasthan has geographical coordinates as 26°17’18.6”N and 73°1’26.04”E. The chosen spot in Gujarat has the geographical coordinates as 22°17’59.5644”N and 73°12’5.9976”E. the site selected in Daman has coordinates as 20°25’15.8628”N and 72°50’25.764”E.

In the central region of India, the sites selected are IRC Village, Bhubaneshwar in Odisha; Rajkamal Square, Vanita Samaj Building at Amravati in Maharashtra and Waidhan, Singrauli in Madhya Pradesh. The coordinates of the site selected in Bhubaneshwar are 20°17’34.51074”N and 85°48’23.81891”E. The site selected in Amravati has coordinates as 20°55’44.94”N and 77°45’8.71”E. The selected in Singrauli has coordinates as 24°4’38.442”N and 82°36’41.1192”E.

In southern region, the site selected is AVM Jewellery at Tuticorin in Tamil Nadu; Kozhikode city, Kozhikode in Kerala and Rani channamma Circle, Hubli in Karnataka. The coordinates of the site selected in Tuticorin are 84°8’18”N and 78°9’11.16”E. The coordinates of the spot selected in Kozhikode are 15°52’2.0748”N and 74°30’41.7816”E. In Hubli, the coordinates of the site are 11°15’2.16”N and 75°46’58.8”E.

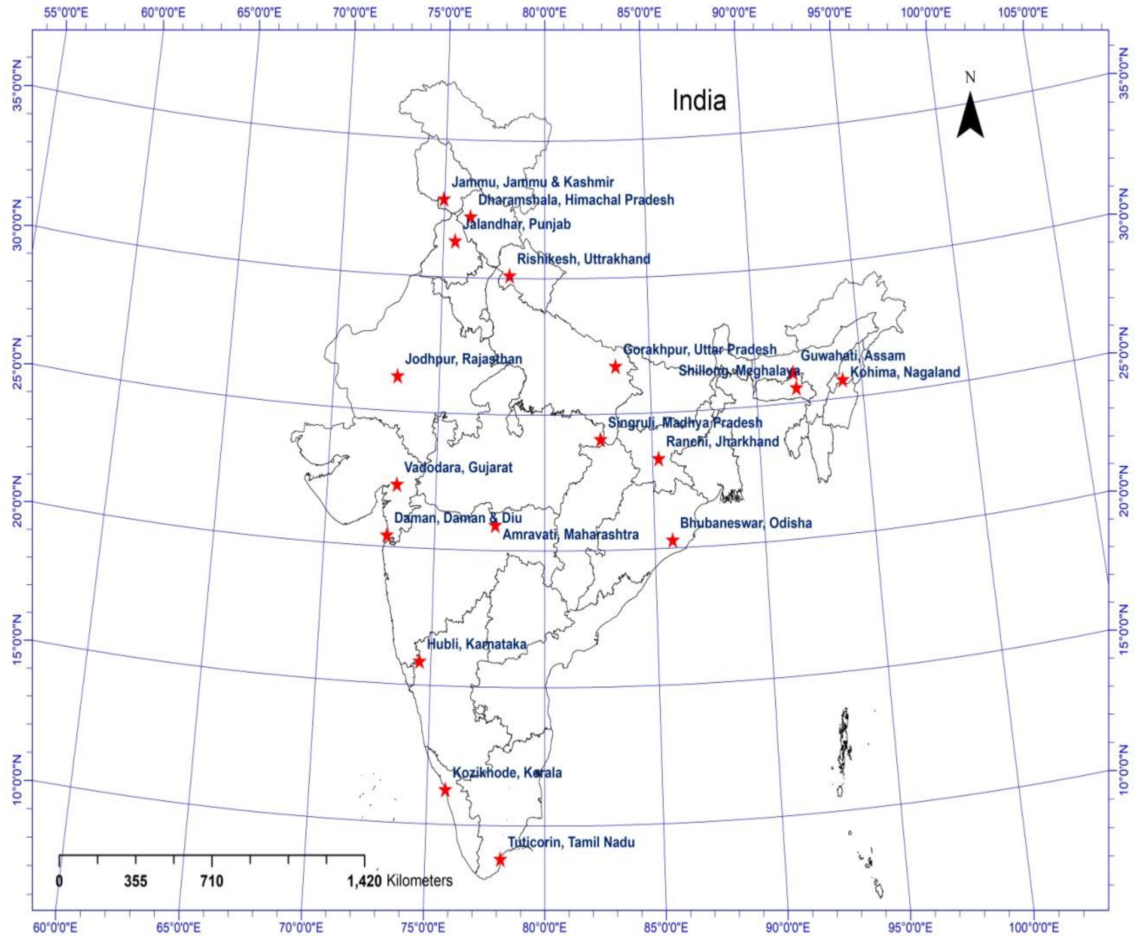

Figure 1-Study area map showing the cities of the monitoring stations

4.2 Data Collection

Ambient air quality data was taken from the site [4] from 2011-2019 every month in every zone for the selected sites. The meteorological data for the HYsplit model is taken in the form of global (.gbl) files from the website [29]. The seasons are classified as winter (January-February), summer (March-May), monsoon (June-September) and post-monsoon (October-December) as per Indian Meteorological Department [30].

A dust sampler can detect both SO_2 and NO_2 gaseous pollutants at the same time. The modified West and Gaeke method are used to quantify SO_2. Using this technique, SO_2 was absorbed at an average flow rate of 1 per minute in a sodium tetrachloromercurate solution. The SO_2 concentration has a detection range of 4–1050 $\mu g/m^3$. The Modified Jacobs and Hochheiser method are used to quantify nitrogen dioxide (NO_2). Sodium hydroxide and sodium arsenite solution are used to air bubble ambient NO_2 to collect it. In order to determine the concentration of NO_2 in the sample, a spectrophotometer with a range of 9-750 μg/m^3 at a length of 540 nm is used to monitor a chemical reaction produced by the absorption of a highly coloured dye. The filtration-gravimetric approach was employed to assess the PM_{10} concentration using a respirable dust sampler. The device remained in place two metres above the floor. The device used a Whatman filter paper (20.3 × 25.4 cm) to gather the particles [24].

4.3 Research Methodology

4.3.1 Back Trajectory Analysis

Back trajectories are extremely beneficial in the study of air pollution and can yield valuable data regarding the origins of air masses. Even with their obvious benefits, back trajectories are mostly utilized inside the scientific community. Back trajectories are useful for a variety of tasks, such as longer-term analysis and comprehending the origins of air masses over several days. In order to enable more in-depth analysis of air pollution, such as trends in concentration by air mass origin, they are frequently employed to filter air mass origins. They are frequently paired with more complex analyses, including cluster analysis, to assist in classifying related types of air masses according to their place of origin.

The fact that back trajectory analysis can be time-consuming to do could be one of the reasons it is not done more frequently. This is especially true if one want to think about spending several years at various locations. Additionally, retrieving back trajectory data can be challenging. Openair provides much functionality to access and examine pre-calculated back trajectories, aiming to address some of these problems and increase the potential for data analysis [31].

These functions now provide some trajectory plotting functions; several pre-define locations, and the ability to import pre-calculated back trajectories. All of these features will eventually be improved to enable the execution of increasingly complex studies. It should be acknowledged that these functions are still in their infancy and may continue to evolve and improve [31].

Using the HYSPLIT trajectory model (Hybrid Single Particle Lagrangian Integrated Trajectory Model [32], this importTraj function imports pre-calculated back trajectories. Trajectories are saved in annual files and run every three hours. Starting at 10 metres above the earth, the trajectories propagate backward in time. Similar to importKCL, the data are kept on online servers at King's College London, making it incredibly simple to import trajectory data that has already been pre-processed for a variety of locations and years [31].

Note: The back trajectories are saved as .RData objects and have already been pre-calculated for particular places. If users would like additional locations included, they should get in touch with David Carslaw. Users can currently access only a small number of receptors, but with time, this will change [31].

4.3.2 Trajectory gridded frequencies

There are multiple analytical techniques available in the HYSPLIT model itself for gridding trajectory data. Comparable features can also be found in openair, where additional openair capabilities can be used to expand the studies. Understanding the origins of trajectories is helpful. Over-plotting occurs frequently when trajectories are shown as lines or points over the course of a year. Consequently, it is helpful to grid the trajectory data and compute different statistics while taking latitude-longitude intervals into account.

The first study looks at how many different paths there are in a specific grid square. Using the trajLevel function and selecting "frequency" as the statistic option will accomplish this. Hexagonal binning can also be used to obtain a sense of trajectory frequencies. In this instance, the counting is done using each 3-hour point along each route.

4.3.3 Trajectory source contribution functions

Receptor modeling can be done using back trajectories to pinpoint the locations of the main emission sources. Numerous back trajectories (spanning months to years) can reveal the geographic origin most frequently linked to increased concentrations when they are examined in particular ways. When there are sufficient (dissimilar) trajectories, the regions with the highest concentrations start to become visible. Plotting back trajectory data over an entire year can result in individual trajectories that span thousands of kilometres.

4.3.4 Potential Source Contribution Function (PSCF)

Plotting of the Potential Source Contribution Function (PSCF) occurs if statistic = "pscf". The likelihood that a source is situated at latitude i and longitude j is determined by the PSCF [33]. The PSCF and the CPF function, which take local wind direction probabilities into account, are similar in certain ways. The two strategies have really been demonstrated to complement one another nicely [34]. The analysis of air mass return trajectories has made extensive use of the PSCF technique. The idea behind PSCF is that material from a source can be collected and conveyed to the receptor site along the trajectory if the source is located at (i, j) and an air parcel back trajectory passes through that point. PSCF solves

$$\text{PSCF} = \frac{m_{ij}}{n_{ij}} \quad \textbf{(1)}$$

where n_{ij} is the number of times that the trajectories passed through the cell (i, j) and m_{ij} is the number of times that a source concentration was high when the trajectories passed through the cell (i, j). The percentile, which is set to 90 by default, controls the criterion used to determine m_{ij}. Also take note of the weighting factor given to cells with little data to lessen their impact [35], [31].

4.3.5 Concentration Weighted Trajectory (CWT)

Grid cells may have the same PSCF value when sample concentrations exceed the requirement by a small amount or by a large amount, which is a restriction of the PSCF approach [10]. It can be challenging to discern between strong and moderate sources as a result [8]. The calculated concentration fields to pinpoint pollution source locations. This method is also known as the concentration field (CF) or CWT. Similar to the PSCF approach, a grid domain was employed. The concentration of a pollutant species was determined for each grid cell using the mean (CWT) or logarithmic mean (used in the Residence Time Weighted Concentration (RTWC) approach) as follows:

$$\ln(Cij) = 1 / \sum_{k=1}^{N} \tau\text{ijk} = \sum_{k=0}^{N} \ln\text{ (Ck) } \tau\text{ijk} \quad \textbf{(2)}$$

where i and j are the indices of grid, k the index of trajectory, N the total number of trajectories used in analysis, ck the pollutant concentration measured upon arrival of trajectory k, and τ_{ijk} the residence time of trajectory k in grid cell (i, j). A high value of C_{ij} means that, air parcels passing over cell (i, j) would, on average, cause high concentrations at the receptor site.

4.3.6 Back trajectory cluster analysis with the trajCluster function

Cluster analysis on the back trajectories is often helpful in combining comparable air mass origins. Post-processing data based on cluster origin is the main goal of clustering back trajectories. Information on pollutant species with comparable chemical histories can be obtained by combining data with similar geographic origins. There are multiple approaches to clustering as well as multiple metrics for comparing the similarity of various groups. The calculation of the distance matrix, which assesses how similar or unlike various back trajectories are, is a crucial problem. The Euclidean distance is the most basic measurement. But an angle-based measurement is also frequently applied. Because calculating the distance matrices in openair requires a lot of processing power, C++ code is used for this purpose. Keep in mind that the HYSPLIT can also be used directly for these computations, model in its own right.

4.3.7 Selection of starting height for HYSPLIT trajectories

Similar CWT plots were produced for the chosen cities with trajectory beginning heights of 100, 500, and 1000 metres. This may be the rationale behind the majority of previous research choice of 500 metres as the beginning height. Therefore, only the outcomes of a 72-hour back trajectory simulation with a 500-meter beginning height are displayed, despite the fact that analysis was done for all three trajectory heights [27].

CHAPTER 5

RESULTS AND DISCUSSION

5.1 HYSPLIT Data Analysis

5.1.1 Himalayan region

I. Jammu city

Jammu is a city in the Indian-administered union territory of Jammu and Kashmir, located in the south-western part of the Himalayas along the Tawi River. The city is situated on uneven ridges of low heights at the Shivalik hills and has an average elevation of 350 meters (1148 feet), having an area of 189 km^2 with an annual average precipitation of 1088 mm. The temperature of this city varies from cold in winter with minimum temperature dipping up to -2°C to heat wave in summers when temperature shoots up to 46°C. The population of Jammu city within municipal limits is 6,07,181, with population density of 3205 persons/sq.km, whereas, there is a floating population of additional 1.5-2.0 lac, due to pilgrimage en-route to Katra, other state tourism destinations. It is also known as the city of temples. Due to its floating population, with tourist and pilgrim influx, Jammu business, hotels/restaurants/dhabas, transport facilities via roadways, railways, airways, education sector (Universities, Medical colleges, Engineering colleges, B.Ed./Degree Colleges, Schools), private and government offices, the air pollution load increases by several folds. The site selected in Jammu is Maulana Azad Stadium, Jewel Chowk with geographical co-ordinates 32°43’42’’N and 74°51’41’’E.

It was observed from the trajectories in the period 2011-2014 that the trajectories originated from Pakistan, Afghanistan and India (J&K and Himachal Pradesh. While during 2015-2019, trajectories originated from Pakistan, Afghanistan and India (J&K and Himachal Pradesh).

Table 2-Trajectory clustering Jammu

	Duration	**Afghanistan**	**Pakistan**	**Himachal Pradesh**
Contribution	2011-2014	55 %	19 %	26 %
Contribution	2015-2019	50 %	20 %	30 %

In seasonal plots during the period 2013-2014, it was observed that in monsoon season the trajectories originated from Afghanistan, Pakistan and India (North and north-west). The maximum trajectories originate from Afghanistan (~39%), followed by Rajasthan (~24%), Pakistan (~19%) and Himachal Pradesh (~17%). In post-monsoon, the trajectories originated from Afghanistan, Pakistan, India (J&K and Himachal Pradesh). The maximum trajectories emerged from Pakistan (~42%), Afghanistan (~24%), Himachal Pradesh (~23%) and J&K (~ 11%). In summer, trajectories stem from Afghanistan, Pakistan and India (North). The highest trajectories from Afghanistan (~ 57%), accompanied by accompanied by Himachal Pradesh (~ 28%) and Pakistan (~15%). In winter, it was monitored that the trajectories rise from Pakistan and India (North). The most trajectories from Himachal Pradesh (~ 37%), Afghanistan (~ 31%), Punjab (~18%) and Pakistan (~14%).

In seasonal plots during 2015-2019, it was observed that in monsoon season the trajectories originated from Afghanistan, Pakistan and India (North and north-west). The maximum trajectories originate from Pakistan (~36%), followed by Rajasthan (~35%) and Himachal Pradesh (~ 29%). In post-monsoon, the trajectories originated from Afghanistan and India (North). The maximum trajectories emerged from Afghanistan (~64%) and Himachal Pradesh (~36%). In summer, trajectories stem from Afghanistan, Pakistan, India (North). The highest trajectories from Afghanistan (~ 57%), accompanied by accompanied by Himachal Pradesh (~ 31%) and Pakistan (~ 12%). In winter, it was monitored that the trajectories rise from Afghanistan, Pakistan, Iran and India (North). The most trajectories from Himachal Pradesh (~38%), Afghanistan (~35%), Pakistan (~17%) and Iran (~11%).

(A) CWT Analysis

The CWT analysis of Jammu from 2013-2014 reflects the concentration of NO_2 is found to be 17 $\mu g/m^3$ mainly from China and Afghanistan. This concentration of is dominated by the sources regions of Pakistan, China, Afghanistan, Tajikistan, Nepal, India (North, IGP and north-west) and winds blowing from Arabian Sea. The concentration of PM_{10} is around 150 $\mu g/m^3$ mainly from China, Pakistan, Afghanistan, Tajikistan, Kyrgyzstan and India (North and north-west). The SO_2 concentration is found to be 21 $\mu g/m^3$ in Jammu during 2013-2014 which is occurring due to Pakistan, China, Afghanistan and India (North, north-west and IGP).

The CWT analysis of Jammu from 2015-2019 reflects the concentration of NO_2 is found to be 20 $\mu g/m^3$ mainly from China, Nepal, Pakistan and Afghanistan. The concentration of PM_{10} is around 190 $\mu g/m^3$ mainly from China, Pakistan, Afghanistan, Tajikistan, Kyrgyzstan and India (North and north-west). The SO_2 concentration is found to be 5 $\mu g/m^3$ in Jammu during

2015-2019 which is occurring due to Pakistan, China, Afghanistan and India (North, north-west and IGP).

The CWT analysis of different seasons from 2013-2014 shows that the concentration of NO_2 in monsoon is shown to be around 15 µg/m^3, SO_2 is 15 µg/m^3 mainly from Tajiskistan, Afghanistan and Pakistan and PM_{10} is 150 µg/m^3 coming mainly from Tajiskistan, China and the rest of 100 µg/m^3 coming from IGP, north India and the neighbouring countries and winds blown across Arabian sea. In post-monsoon, the SO_2 and NO_2 concentration is around 25 µg/m^3 & 20 µg/m^3 and that of PM_{10} is 180 µg/m^3 mainly from north-east and north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 2 µg/m^3 & 15 µg/m^3 and PM_{10} concentration was 150 µg/m^3 which is influenced by north India, IGP, north-west India, Pakistan, Afghanistan and Tajikistan. The concentration of NO_2 and SO_2 in winter is about 15 µg/m^3 & 20 µg/m^3 and of PM_{10} is 170 µg/m^3 from Pakistan, Afghanistan, Tajikistan and India (North and IGP).

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 20 µg/m^3, SO_2 is 5 µg/m^3 mainly from Tajiskistan, Afghanistan and Pakistan and PM_{10} is 150 µg/m^3 and $PM_{2.5}$ is 55 µg/m^3 coming mainly from Tajiskistan, China and the rest of 100 µg/m^3 coming from IGP, north India and the neighbouring countries and winds blown across Arabian sea. In post-monsoon, the SO_2 and NO_2 concentration is around 5 µg/m^3 & 20 µg/m^3 and that of PM_{10} is 160 µg/m^3 and $PM_{2.5}$ is 45 µg/m^3 mainly from north-east and north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 5 µg/m^3 & 20 µg/m^3 and PM_{10} concentration was 160 µg/m^3 and PM2.5 was 55 µg/m^3 which is influenced by north India, IGP, north-west India, Pakistan, Afghanistan and Tajikistan. The concentration of NO_2 and SO_2 in winter is about 20 µg/m^3 & 5 µg/m^3 and of PM_{10} was 200 µg/m^3 and $PM_{2.5}$ was 50 µg/m^3 from Pakistan, Afghanistan, Tajikistan and India (North and IGP).

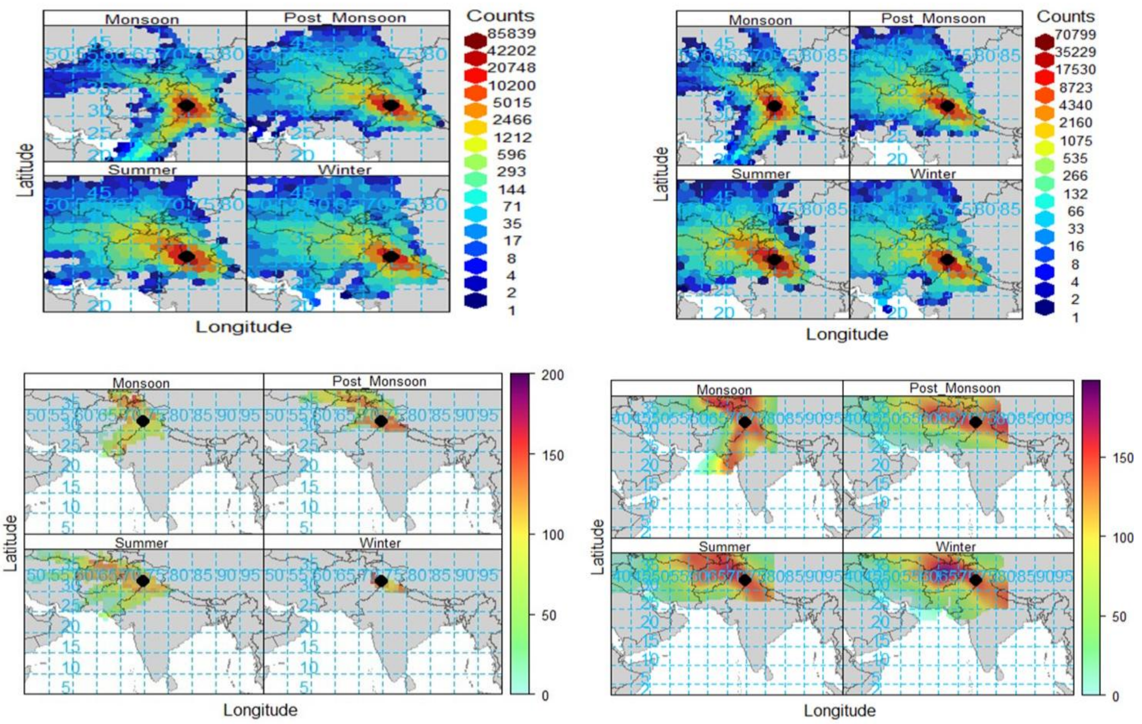

Figure 2- During the period of 2011-2014 & 2015-2019 in Jammu resp. (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

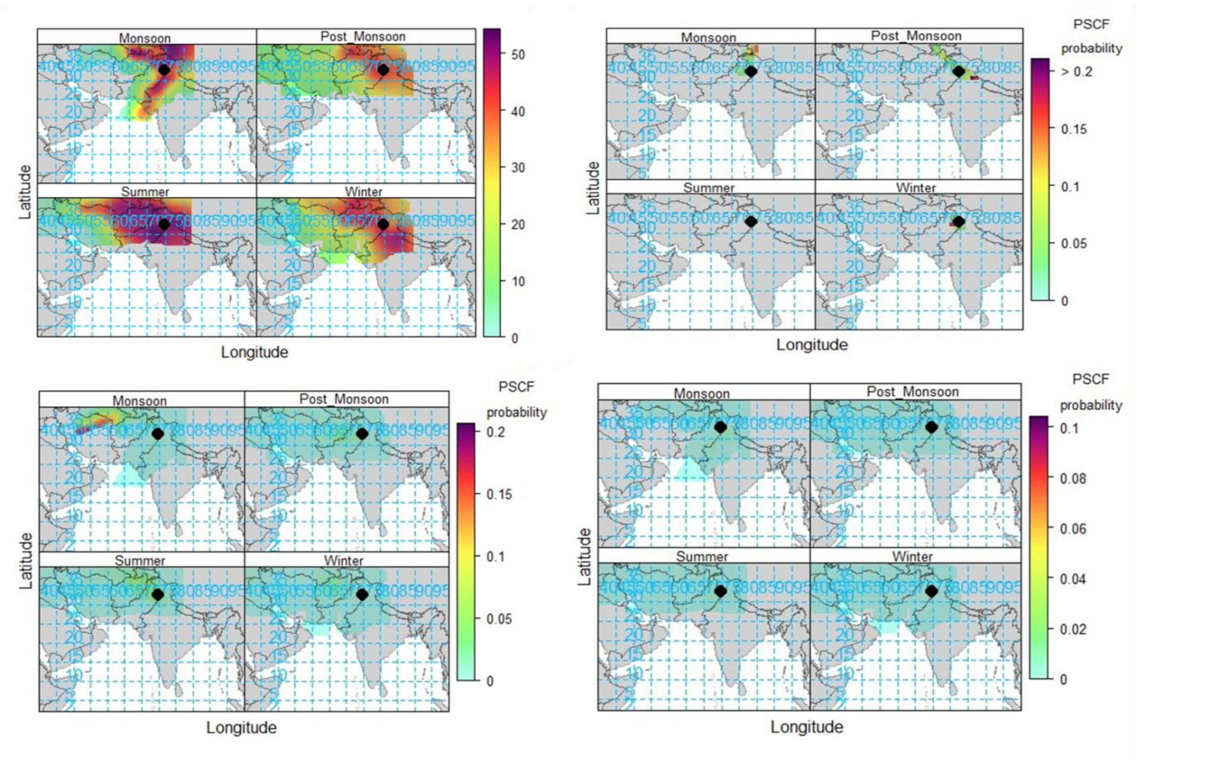

Figure 3-During the period of 2011-2014 & 2015-2019 in Jammu (a) Seasonal CWT of $PM_{2.5}$, (b) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 pollution in Jammu from 2013-2014 is Ladakh and Kazakhstan (~ 0.15), the main source of SO_2 pollution is Ladakh and China (~0.15) and the main source of PM_{10} pollution is Pakistan and Rajasthan (~ 0.13) followed by IGP and north India (~ 0.06).

The potential source of NO_2 pollution in Jammu from 2015-2019 is Pakistan and Afghanistan (~ 0.05), the main source of SO_2 pollution is Pakistan (~0.15) and the main source of PM_{10} pollution is Russia and Afghanistan (~ 0.13) followed by IGP and north India (~0.06).

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of NO_2 is Ladakh and Afghanistan (~ 0.09) and of PM_{10} pollution is Uttrakhand (~ 0.05). In post-monsoon, Uttrakahnd and Pakistan is the main source of NO_2 (~0.09) and SO_2 pollution from Pakistan (~0.2), Uttrakhand is the main source of PM_{10} (~0.3) followed by IGP (~0.25). In summer season, SO_2 is originating mainly from Pakistan and Punjab (~0.15) and Tajiskistan for NO2 (~0.09) and the PM_{10} sources were not widespread with high potential in Pakistan and Iran (~0.17), followed by J&K and Himachal Pradesh (~0.1). In winter season, Pakistan is the main source of SO_2 and PM_{10} pollution (~0.15) and (~0.2) and Afghanistan for NO2 (~ 0.08).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2 is IGP (~ 0.03) and of PM_{10} and SO_2 pollution is Iran (~ 0.2) and (~ 0.2). In post-monsoon, Uttrakhand and Pakistan is the main source of NO_2 (~0.07) and SO_2 pollution from Pakistan (~ 0.09), Pakistan and Afghanistan is the main source of PM_{10} (~0.05). In summer season, NO_2 originates from Tajikistan and Afghanistan (~0.05), SO_2 is originating mainly from Pakistan and Punjab (~0.01). In winter season, NO_2 originates from Afghanistan (~0.08), Pakistan is the main source of SO_2 and PM_{10} pollution (~ 0.01) and (~ 0.03). PM2.5 concentration is observed to be mainly from Pakistan, Afghanistan and India (IGP, north, and north-west) in all the seasons (~0.01)

II. Rishikesh City

Rishikesh is a city in the Dehradun district of the Indian state Uttarakhand, situated in the foothills of the Garhwal Himalayan Range and the Shivalik range. The elevation of Rishikesh generally ranges from 372 meters (1,220 feet) to 2,136 feet (651 meters), having an area of 11.5 km^2 with an annual precipitation of 2136.7 mm. The weather of Rishikesh often becomes unpredictable. In the months of summer, the temperature in Rishikesh varies from 35° to 45°C. The temperature ranges from 10° to 30°C in the months of winter. The total population of the city as per 2011 census is 70,499 and urban agglomeration of 1,02,138 with population density of 8851 persons/sq.km. Rishikesh is popularly known as the 'Yoga Capital of the World' and receives a tremendous flow of tourists in the city every year, coming for spiritual activities and adventure sports which puts a lot of pressure on city's natural environment and city administration responsible for maintaining suitable living conditions for all. The equivalent daily floating population in Rishikesh is considered as 12,344. The site selected in Rishikesh is Nagar Palika Parishad with geographical co-ordinates 30°5'59.604''N and 78°17'21.516''E.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Pakistan, Afghanistan and India (J&K, Himachal Pradesh, Punjab, Haryana and Rajasthan) that is almost same during 2015-2019.

Table 3-Trajectory clustering Rishikesh

	Duration	**Pakistan**	**Nepal**	**JK**	**Uttrakhand**	**Rajasthan**
Contribution	2011-2014	63 %			22 %	15 %
Contribution	2015-2019	48 %	25 %	12 %		15 %

In seasonal plots, it was observed that in monsoon season the trajectories originated from Afghanistan, Pakistan, China, Nepal and India (North India, Indo-Gangetic Plains and north-west India). The maximum trajectories originate from J&K (~30%), followed by Punjab (~ 27%), Rajasthan (~ 26%) and north-west Nepal (~ 8%). In post-monsoon, the trajectories originated from Afghanistan, Pakistan, India (J&K, Punjab, Himachal Pradesh, Haryana and Uttrakhand). The maximum trajectories emerged from Pakistan (~50%), Uttrakhand (~22%), Afghanistan (~21%) and Punjab (~7%). In summer, trajectories stem from Pakistan, China, India (North India and Indo-Gangetic Plains). The highest trajectories from Pakistan (~ 75%), accompanied by accompanied by Uttrakhand (~ 13%) and China (~ 11%). In winter, it was monitored that the trajectories rise from Pakistan, Nepal and India (North and IGP). The most trajectories from Pakistan (~47%), Nepal (~44%) and J&K (~9%).

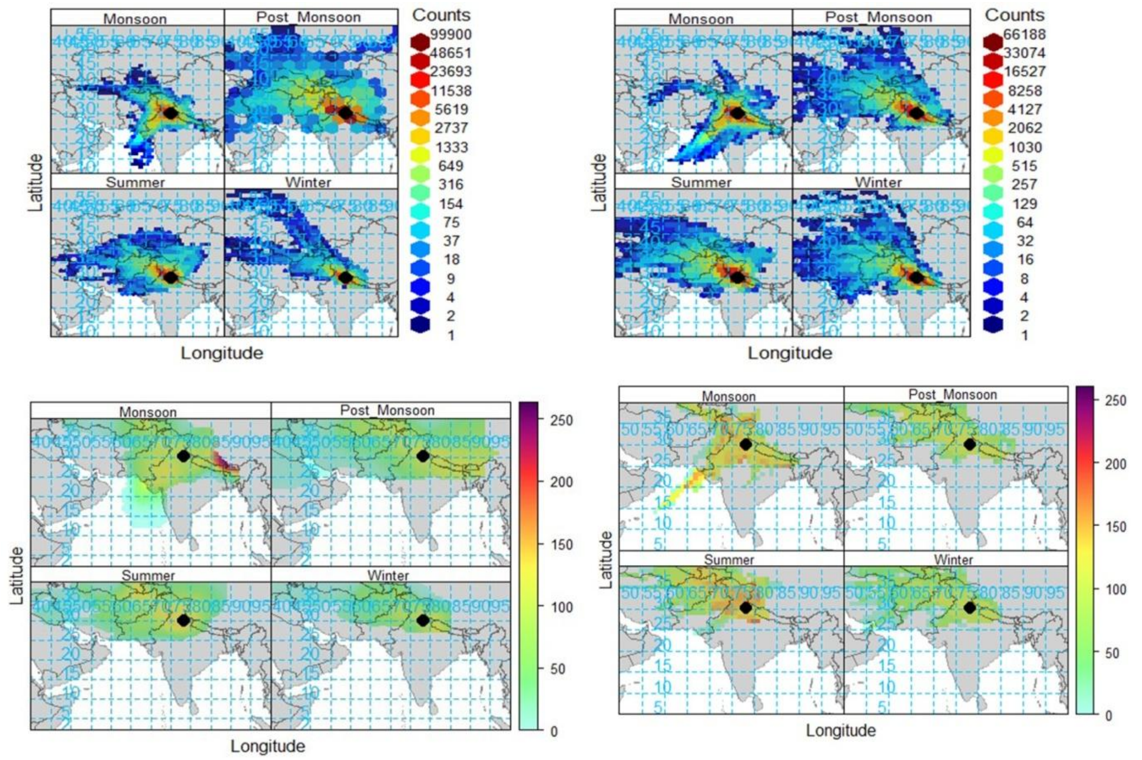

Figure 4-During the period of 2011-2014 & 2015-2019 resp. in Rishikesh (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM10

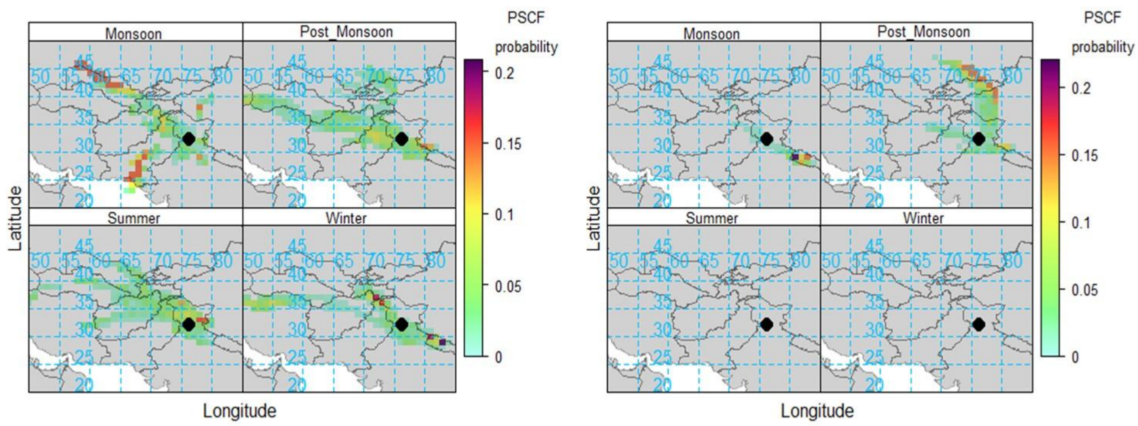

Figure 5-During the period of 2011-2014 & 2015-2019 in Rishikesh (a) Seasonal PSCF of PM10

(A) CWT Analysis

The CWT analysis of Rishikesh from 2011-2014 reflects the concentration of NO_2 in Rishikesh is found to be 40 µg/m^3. This concentration of is dominated by the sources regions of Pakistan, China, Afghanistan, Tajikistan, Nepal, India (North, IGP and north-west) and winds blowing from Arabian Sea. The concentration of PM_{10} is around 140 µg/m^3 from China, Nepal, Pakistan, Tajikistan, Kyrgyzstan and India (North and north-west). The concentration from the surrounding areas is limited to 100 µg/m^3. The SO_2 concentration is found to be 25 µg/m^3 in Rishikesh during 2011-2014 which is occurring due to Pakistan, China, Afghanistan and India (North, north-west and IGP).

The CWT analysis of NO_2 from 2015-2019 in Rishikesh clearly reveals that around 30 µg/m^3 concentration is present in Rishikesh and that is due to Northern India, IGP, North-west India, Pakistan, Afghanistan and China. The SO_2 concentration is observed to be around 25 µg/m^3 during the period 2015-2019. The source locations of this pollutant are almost the same as described above for NO_2. The PM_{10} concentration is observed to be around 130 µg/m^3. This concentration is attributed to various regions in the northern, IGP, north-west, wind blowing from Arabian sea, Pakistan, Afghanistan, China Tajikistan and Turkmenistan.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 50 µg/m^3, of SO_2 is 50 µg/m3 and of PM_{10} is 250 µg/m^3 coming mainly from Nepal and the rest of 30 µg/m^3 coming from IGP, north-west, north-east, north India and the neighbouring countries and winds blown across Arabian sea. In post-monsoon, the SO_2 and NO_2 concentration is around 25 µg/m^3 and that of PM_{10} is 125 µg/m^3 mainly from north-east and north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 25 µg/m^3 which is influenced by north India, IGP, north-west India, Pakistan, Afghanistan, Tajikistan, China and Nepal. The concentration of NO_2 and SO_2 in winter is about 30 µg/m^3 and of PM_{10} is 140 µg/m^3 but this pollution concentration is not much widespread.

(B) PSCF Analysis

The potential source of NO_2 from 2011-2014 in Rishikesh is Pakistan (~0.04) and rest of the sources are from other places like Afghanistan, J&K, Himachal Pradesh and Punjab (~ 0.015). The potential source of SO_2 is Pakistan and northern India (~ 0.04). The potential source of PM_{10} is J&K (~0.05) followed by Pakistan and Punjab (~0.04).

The potential source of NO_2 pollution in Rishikesh from 2015-2019 is Pakistan and North India (~ 0.12), the main source of SO2 pollution is China (~ 0.11) followed by Pakistan, Afghanistan and India (north and IGP) and the main source of PM10 pollution is Pakistan, China and winds blowing from Arabian sea (~ 0.06) followed by Iran, Afghanistan, Turkmenistan and India (J& K and Bihar) (~0.045) and north India and IGP (~0.02).

In the seasonal analysis, from 2011-2014 in Rishikesh NO_2 pollution is monitored mainly in the summer season which indicated that the potential source is Pakistan, Afghanistan, Turkmenistan and India (Uttrakhand, Punjab and Haryana) (~0.03). The SO_2 pollution has the main potential source concentrated in J&K, Pakistan, Afghanistan and Turkmenistan (~0.04) in monsoon and Uttrakhand, Punjab and J&K (~0.03) in post-monsoon and in summer from Pakistan (~0.1) and Afghanistan, Pakistan, Turkmenistan and India (North). The sources of PM_{10} were Pakistan, Afghanistan, China, Nepal, Bangladesh, Bhutan, India (North, IGP, north-east and north-west) and winds blowing from Arabian Sea. (~0.015) in monsoon. In post-monsoon, the sources are widespread China, Nepal, Pakistan, Afghanistan, Iran, Iraq, Saudi Arabia and India (North, IGP and north-east) (~0.015). In summer, the main sources are Himachal Pradesh, Punjab, J&K and Haryana (~ 0.09) followed by the neighbouring countries (~0.02). In winter season the pollution is not widespread but concentrated from Pakistan, China, Nepal, Pakistan, Afghanistan, Tajikistan and India (North and IGP) (~0.015).

III. Dharamshala City

Dharamshala is a town in the Indian state of Himachal Pradesh, located on a lower slope of the Himalayas in the Kangra Valley, at an altitude of 1,457 meters (4,780 feet), with an approximate area of 8.51 km^2 with precipitation of around 2350 mm per year. Dharamshala has a population of 22,586 as per census 2011. However, the area under the administration of municipal body expanded in 2015, with a revised population of 53,000. The drifting population is also very high due to the pleasant weather conditions. The temperature typically varies from 2°C to 30°C throughout the year. It serves as the winter capital of the state and the administrative headquarters of the Kangra district. The site selected in Dharamshala is Kotwali Bazar with geographical co-ordinates of 32°13’12’’ N and 76°19’’6’’E.

It was observed from the hexagonal counts in 2014 that the trajectories originated from Pakistan, Afghanistan, Tajikistan, Turkmenistan, China, Nepal and India (J&K, Himachal Pradesh, Punjab, Haryana, Uttrakhand, New Delhi and Rajasthan). However, in the period 2015-2019 trajectories originated from Pakistan, Afghanistan, Tajikistan, Turkmenistan, Kyrgyzstan, Uzbekistan, China, Nepal and India (J&K, Himachal Pradesh, Punjab, Haryana, Uttrakhand, New Delhi and Rajasthan).

Table 4-Trajectory clustering Dharamshala

	Duration	Afghanistan	Pakistan	Tajikistan	Punjab	Uttrakhand
Contribution	2011-2014	23 %	30 %		26 %	21 %
Contribution	2015-2019	35 %		16 %	24 %	25 %

In seasonal plots in 2014, it was observed that in monsoon season the trajectories originated from Afghanistan, Pakistan and India (North India and Indo Gangetic Plains). The maximum trajectories originate from Afghanistan (~ 43%), followed by Pakistan (~ 29%), Punjab (~ 23%) and China (~ 6%). In post-monsoon, the trajectories originated from Afghanistan, Pakistan, Tajikistan and India (J&K, Punjab, Himachal Pradesh, Haryana and Uttrakhand). The maximum trajectories emerged from Pakistan (~ 41%), Afghanistan (~ 30%), Punjab (~ 18%) and Uttrakhand (~ 11%). In summer, trajectories stem from Pakistan, Afghanistan, India (North India and Indo-Gangetic Plains). The highest trajectories from Afghanistan (~ 28%), accompanied by accompanied by Pakistan (~ 24%), Uttrakhand (~ 28%) and Himachal Pradesh (~ 20%). In winter, it was monitored that the trajectories rise from Pakistan, Nepal and India (North and IGP). The most trajectories from Himachal Pradesh (~31%), Uttrakhand (~24%), Afghanistan (~23%) and Pakistan (~22%).

In seasonal plots in the period 2015-2019, it was observed that in monsoon season the trajectories originated from Afghanistan, Pakistan, China and India (North, north-west India and Indo Gangetic Plains). The maximum trajectories originate from Pakistan (~ 60%), followed by Rajasthan (~ 32%) and Uttrakhand (~ 17%). In post-monsoon, the trajectories originated from Afghanistan, Pakistan, Tajikistan, Nepal and India (J&K, Punjab, Himachal Pradesh, Haryana and Uttrakhand). The maximum trajectories emerged from Afghanistan (~ 36%), Uttrakhand (~26%), Turkmenistan (~21%) and Punjab (~ 17%). In summer, trajectories stem from Pakistan, Afghanistan, Tajikistan, Nepal, China and India (North India and Indo-Gangetic Plains). The highest trajectories from Afghanistan (~ 55%), accompanied by accompanied by Pakistan (~ 20%) and Uttrakhand (~ 25%). In winter, it was monitored that the trajectories rise from Pakistan, Afghanistan, Turkmenistan, Nepal and India (North India and IGP). The most trajectories from Uttrakhand (~36%), Turkmenistan (~28%), Afghanistan (~19%) and Punjab(~22%).

(A) CWT Analysis

The CWT analysis in 2014 reflects the concentration of NO_2 is found to be 13 μg/m^3 mainly from J&K, Pakistan and Afghanistan. The concentration of PM_{10} is around 50 μg/m^3 mainly from Nepal and India (North and IGP). The SO_2 concentration is found to be below detection level.

The CWT analysis in 2015-2019 reflects the concentration of NO_2 is found to be 13 μg/m^3 mainly from Tajikistan, Pakistan and Kyrgyzstan. The concentration of PM_{10} is around 55 μg/m^3 mainly from Nepal. And $PM_{2.5}$ about 50 μg/m^3 from China. The SO_2 concentration is found to be below detection level.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 25 μg/m^3 and PM_{10} is 60 μg/m^3 coming mainly from Tajiskistan, China and the rest of 60 μg/m^3 coming from IGP, north India and the neighbouring countries and winds blown across Arabian sea. In post-monsoon, NO_2 concentration is around 5 μg/m^3 and that of PM_{10} is 60 μg/m^3 mainly from north-east and north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of NO_2 is observed to be 11 μg/m^3 which is influenced by north India, IGP, north-west India, Pakistan, Afghanistan, Tajikistan, China and Nepal. The concentration of NO_2 in winter is about 26 μg/m^3 and of PM_{10} is 70 μg/m^3 but this pollution concentration is not much widespread.

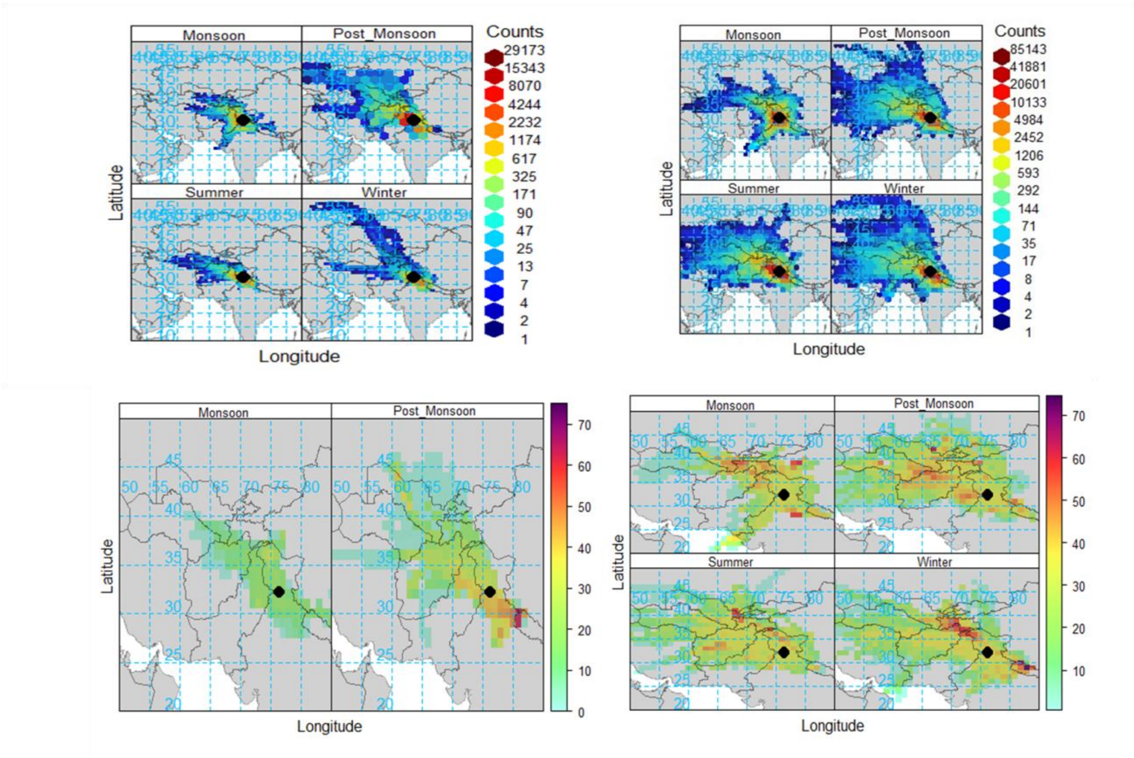

Figure 6-During the period of 2011-2014 & 2015-2019 resp. in Dharamshala (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

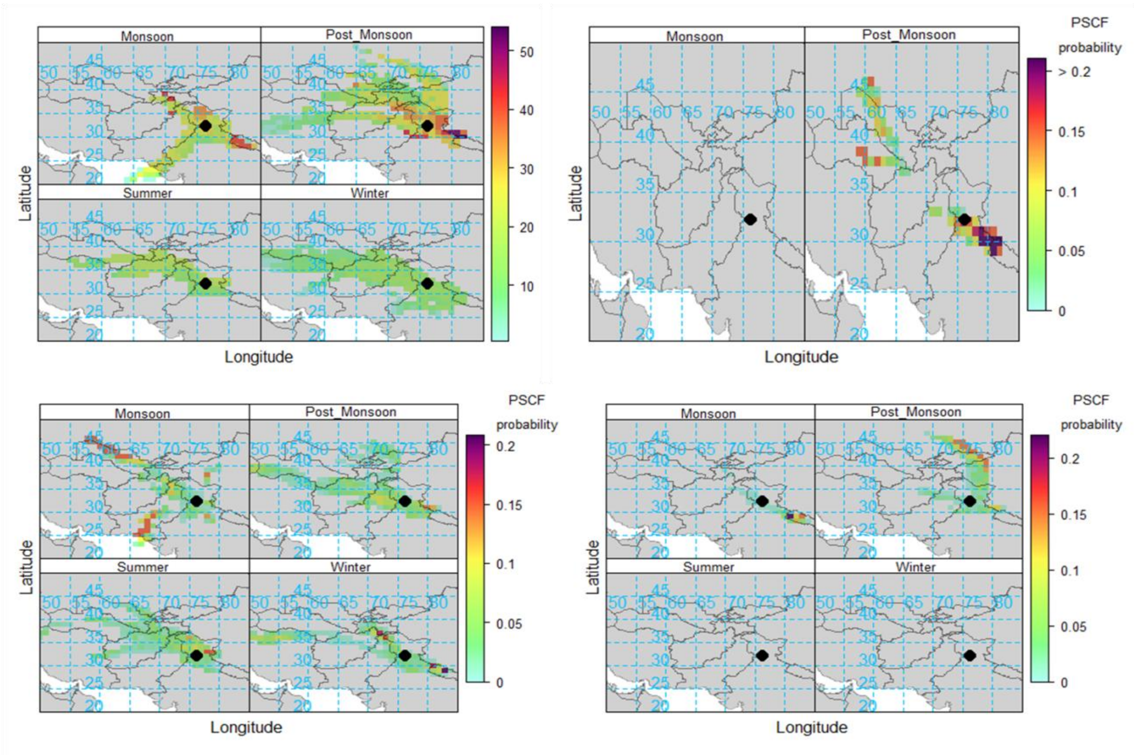

Figure 7-During the period of 2011-2014 & 2015-2019 in Dharamshala (a) Seasonal CWT of $PM_{2.5}$, (b) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 in 2014 in Dharamshala is Uttrakhand and Nepal (~0.16) and rest of the sources are from North India (~ 0.12). The potential source of PM_{10} is Uttrakhand and Nepal (~0.14) followed by North India (~0.1).

The potential source of NO_2 from 2015-2019 in Dharamshala is Pakistan and Iran (~0.16) and rest of the sources are from North India (~ 0.08). The potential source of PM_{10} is Pakistan (~ 0.14) followed by North India (~0.08). The potential source of $PM_{2.5}$ is Kyrgyzstan (~0.14) followed by North India (~0.08).

The PSCF analysis of different seasons in Dharamshala from 2015-2019 for NO_2 pollution is monitored in the monsoon season which indicated that the potential source is Pakistan (~0.3), followed by Afghanistan, Tajikistan and India (Uttrakhand, Punjab and J&K) (~0.1). In post-monsoon, Pakistan, Afghanistan, Iran, Turkmenistan and India (Punjab and Uttrakhand) (~ 0.1). In summer, the pollution source is Pakistan, Afghanistan, Tajikistan and India (Uttrakhand and J&K). In winter, the pollution is quite sweeping across Punjab (~ 0.25), Pakistan and Iran (~ 0.15) and Afghanistan and India (Uttrakhand and J&K). The PM_{10} pollution has the main potential source concentrated in Iran and Turkmenistan (~0.2), J&K, Pakistan, Afghanistan and Turkmenistan (~0.025) in monsoon and Pakistan and Afghanistan (~0.075) followed by Uttrakhand, Punjab and J&K (~0.03) in post-monsoon and in summer from Afghanistan, Pakistan, Turkmenistan and India (North) (~0.025).

5.1.2 Indo-Gangetic Plains

I. Ranchi City

Jharkhand, with Ranchi as its capital, experiences diverse topographical and climatic conditions throughout the year. Jharkhand is characterized by a varied topography including hills, plateaus, and valleys. The state is rich in mineral resources, with extensive forests covering a significant portion of its land. Ranchi, situated at an average elevation of about 651 meters (2136 feet) above sea level, lies amidst the Chota Nagpur Plateau, which dominates much of Jharkhand's landscape. The climate in Ranchi and Jharkhand is generally moderate due to its elevation and geographical location. Here's a breakdown of the climatic conditions throughout the year. Winter (January-February): Winter in Ranchi and Jharkhand is relatively mild and dry. Temperatures typically range from 10°C to 25°C (50°F to 77°F). January is usually the coldest month. Summer (March-May): Summers are warm and can be relatively humid. Temperatures range from 20°C to 35°C (68°F to 95°F) or higher during peak summer months. May is often the hottest month with temperatures sometimes exceeding 40°C (104°F). Monsoon (June-September): Jharkhand experiences a monsoon season characterized by heavy rainfall. Rainfall is vital for agriculture and the region receives substantial precipitation during this period. Humidity levels increase significantly. Post-Monsoon (October-December): After the monsoon season, the weather begins to transition towards winter. October and November are generally pleasant months with mild temperatures and clear skies. Overall, Ranchi and Jharkhand offer a mix of pleasant weather conditions throughout most of the year, with distinct seasons contributing to the state's agricultural productivity and natural beauty.

It was observed from the hexagonal counts from 2011-2014 that the trajectories originated from Bangladesh, Nepal and India (Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Odisha, Chattisgarh, New Delhi and winds blowing from Bay of Bengal). However, from 2015-2019 that the trajectories originated from Bangladesh, Nepal and India (Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Gujarat, Maharashtra, Odisha, Chattisgarh, New Delhi and winds blowing from Bay of Bengal).

Table 5-Trajectory clustering Ranchi

	Duration	**Haryana**	**MP**	**Bihar**	**Bay of Bengal**
Contribution	2011-2014	47 %	24 %	11 %	18 %
Contribution	2015-2019		100 %		

In seasonal plots from 2011-2014, it was observed that in monsoon season the trajectories originated from Bangladesh and India (Indo Gangetic Plains, north-east and north-west India). The maximum trajectories originate from Rajasthan (~37%), followed by Gujarat (~ 26%), Odisha (~25%) and Bihar (~13%). In post-monsoon, the trajectories originated from Nepal, Bangladesh, India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Uttar Pradesh (~81%), Bihar (~10%) and Andhra Pradesh (~9%). In summer, trajectories stem from Nepal, Bangladesh and India (North, north-east and Indo-Gangetic Plains). The highest trajectories from UP (~ 67%), accompanied by winds blowing from Bay of Bengal (~33%). In winter, it was monitored that the trajectories rise from Pakistan, Nepal and India (North, north-east and IGP). The most trajectories from Rajasthan (~96%) and Odisha (~4%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from Bangladesh and India (Indo Gangetic Plains, north-east and north-west India). The maximum trajectories originate from Gujarat (~33%), followed by Maharashtra (~ 24%), Andhra Pradesh (~22%) and Bay of Bengal (~20%). In post-monsoon, the trajectories originated from Nepal, Bangladesh, India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Uttar Pradesh (~100%). In summer, trajectories stem from Nepal, Bangladesh, India (North, north-east and Indo-Gangetic Plains) and winds blowing from Bay of Bengal. The highest trajectories from Bay of Bengal (~ 40%), accompanied by UP (~32%) and Madhya Pradesh (~28%). In winter, it was monitored that the trajectories rise from Pakistan, Nepal and India (North, north-east and IGP). The most trajectories from UP (~93%) and Odisha (~7%).

(A) CWT Analysis

The CWT analysis of NO_2 from 2011-2014 in Ranchi clearly reveals that around 60 µg/m^3 concentration is present in Ranchi and that is due to Telangana and Chattisgarh, Pakistan, Afghanistan, Bangladesh and Nepal. The SO_2 concentration is around 30 µg/m^3 mainly from Pakistan, Turkmenistan and North-west India. The PM_{10} concentration is about 300 µg/m^3 mainly from Pakistan, Turkmenistan, Nepal, Rajasthan, UP, Bihar and New Delhi.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 55 µg/m^3, of SO_2 is 40 µg/m3 and of PM_{10} is 250 µg/m^3 coming mainly from Maharashtra, UP, Rajasthan and New Delhi and the rest coming from IGP, north-west, north-east, north India and the neighbouring countries and winds blown across Arabian sea. In post-monsoon, the SO_2 and NO_2 concentration is around 25 & 40 µg/m^3 and that of PM_{10} is 250 µg/m^3 mainly from north-east and north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 20 & 40 µg/m^3 and PM_{10} concentration is around 250 µg/m^3 which is influenced by north India, IGP, north-west India, Bangladesh, Nepal and Bay of Bengal. The concentration of NO_2 and SO_2 in winter is about 40 & 25 µg/m^3 and of PM_{10} is 250 µg/m^3 but this pollution concentration is not much widespread.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 40 µg/m^3, of SO_2 is 20 µg/m^3 and of PM_{10} is 200 µg/m^3 coming mainly from Maharashtra, UP, Rajasthan and New Delhi and the rest coming from IGP, north-west, north-east, north India, winds blown across Arabian sea and Bay of Bengal.

In post-monsoon, the SO_2 and NO_2 concentration is around 30 & 45 µg/m^3 and that of PM_{10} is 225 µg/m^3 mainly from north-east and north India along with Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 20 & 40 µg/m^3 and of PM_{10} is about 225 µg/m^3 which is influenced by north India, IGP, north-west India, Bangladesh, Nepal and Bay of Bengal. The concentration of NO_2 and SO_2 in winter is about 40 & 20 µg/m^3 and of PM_{10} is 225 µg/m^3 but this pollution concentration is not much widespread.

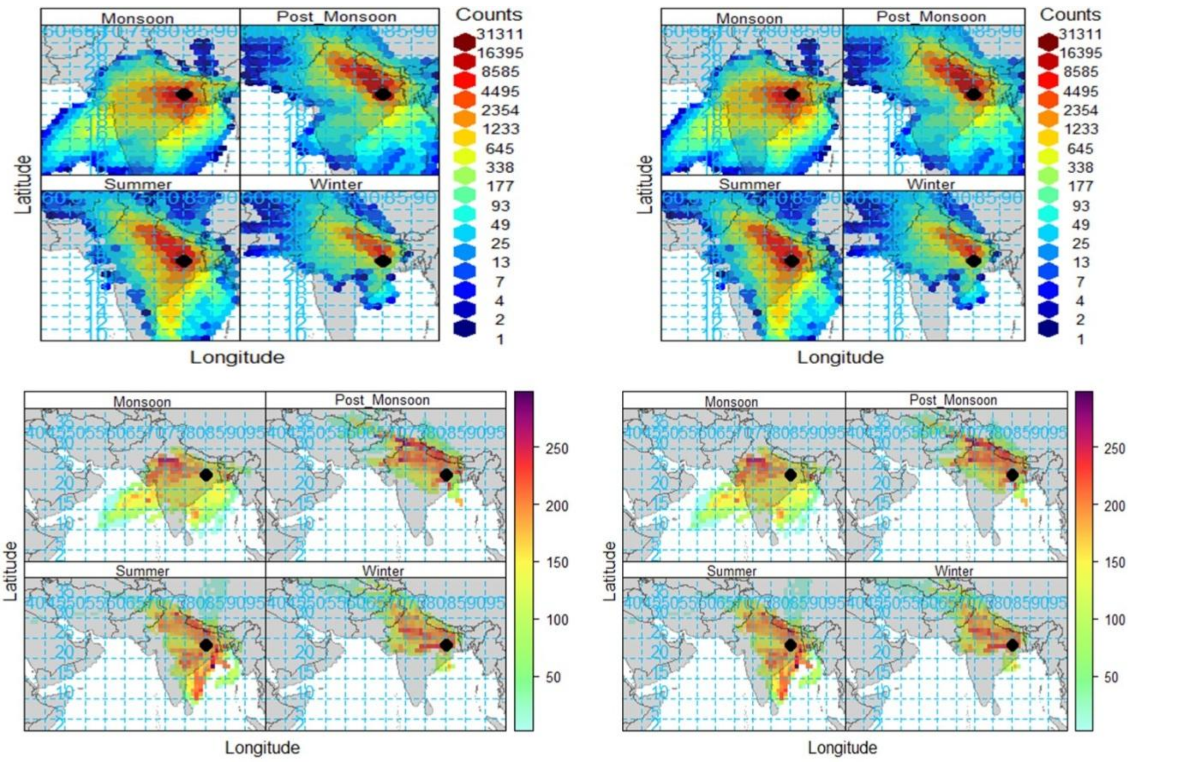

Figure 8-During the period of 2011-2014 & 2015-2019 resp. in Ranchi (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

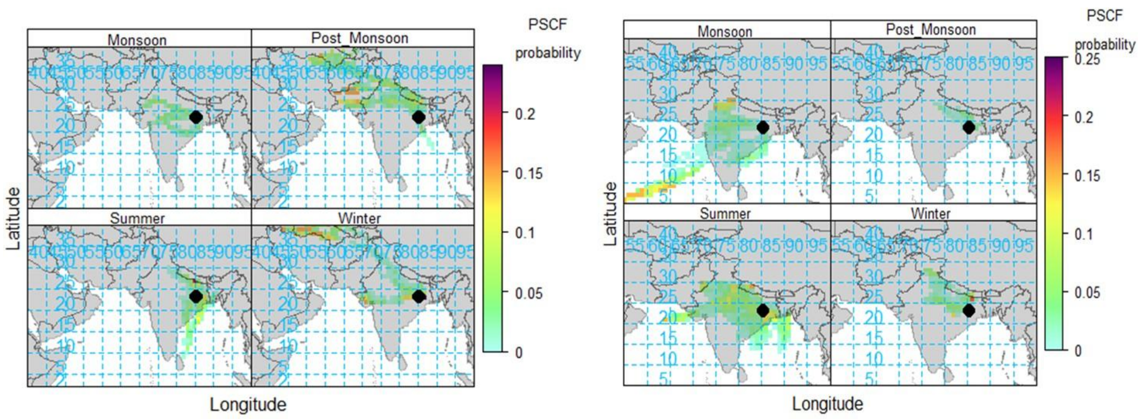

Figure 8-During the period of 2011-2014 & 2015-2019 in Ranchi (a) Seasonal PSCF of PM_{10}

(B) PSCF Analysis

The potential source of NO_2 pollution in Ranchi from 2011-2014 is Bangladesh and Nepal (~ 0.15), the main source of SO_2 pollution is Nepal (~0.17) followed by Pakistan, Afghanistan and India (IGP and central) and the main source of PM_{10} pollution is Pakistan, Afghanistan, Nepal (~ 0.18) followed by Iran, Turkmenistan and India (UP, Delhi, Rajasthan, Odisha and Bihar) (~0.06).

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of NO_2 & SO_2 is the Bay of Bengal (~0.15), followed by Central India (~0.1) and of PM_{10} pollution is IGP and North-west India (~0.08). In post-monsoon, Nepal is the main source of NO_2 and SO_2 pollution (~0.22), Pakistan is the main source of PM_{10} (~0.17) followed by Nepal and IGP (~0.05). In summer season, SO_2 & NO_2 is originating mainly from Central India (~0.1) and the PM_{10} sources were not widespread with high potential in Bihar (~0.23), followed by Odisha, West Bengal (~0.07). In winter season, it is observed that Nepal is the main source of NO_2 pollution (~0.25) and Turkmenistan is the major source of SO_2 (~0.18). Turkmenistan and Gujarat (India) has the potential probability of PM_{10} pollution (~0.17) followed by IGP (~ 0.05).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2 & SO_2 is the Bay of Bengal and Arabian Sea (~0.15), followed by Central India (~0.1) and of PM_{10} pollution is IGP & Arabian Sea (~0.18) and North-west India (~0.08). In post-monsoon, Bangladesh and West Bengal is the main source of NO_2 and SO_2 pollution (~0.22), Bihar and UP is the main source of PM_{10} (~0.07). In summer season, SO_2 & NO_2 is originating mainly from Central India (~0.1) and the PM_{10} sources were widespread with high potential in Nepal (~0.15), followed by Odisha, West Bengal (~0.07). In winter season, it is observed that Odisha is the main source of NO_2 pollution (~0.2) and IGP and Pakistan is the major source of SO_2 (~0.08). Bihar has the potential probability of PM_{10} pollution (~0.18) followed by IGP (~0.05).

II. Jalandhar City

Jalandhar, located in the state of Punjab in north-western India, has its own distinct topographical and climatic characteristics throughout the year. It is situated on the fertile plains of the Punjab region. The city is part of the IGP, which is known for its agricultural productivity due to the fertile soil brought by the rivers flowing through the region, primarily the Sutlej and Beas rivers. This place can be described as a typical north Indian plains climate, influenced by its location and topography. Winter here is chilly and can be foggy, particularly in the early mornings. Temperatures range from around 5°C to 20°C (41°F to 68°F). January tends to be the coldest month with temperatures occasionally dropping below 5°C (41°F). Summers here are hot and dry, typical of the northern plains. Temperatures rise significantly, ranging from 25°C to 45°C (77°F to 113°F) during the peak months of May. Heat waves are not uncommon during this period. It experiences a monsoon season characterized by moderate to heavy rainfall. The southwest monsoon brings much-needed rain to the region, which is crucial for agriculture. Humidity levels increase significantly during this time. After the monsoon retreats, the weather becomes more pleasant. October and November are transition months with decreasing temperatures and clearer skies. Temperatures typically range from 15°C to 30°C (59°F to 86°F) during this period. Overall, here the climate is influenced by its geographical setting on the plains of Punjab, with distinct seasons contributing to agricultural cycles and local lifestyles. The summers are hot and dry, while winters are chilly with occasional fog, and the monsoon season brings vital rainfall for the region's agriculture.

It was observed from the hexagonal counts in 2012-2014 that the trajectories originated from Pakistan, Afghanistan, Tajikistan, Turkmenistan, China, Nepal and India (J&K, Himachal Pradesh, Punjab, Haryana, Uttrakhand, New Delhi and Rajasthan). However, in 2015-2019 trajectories originated from Pakistan, Afghanistan, Tajikistan, Turkmenistan, China, Nepal and India (J&K, Himachal Pradesh, Punjab, Haryana, Uttrakhand, New Delhi, Gujarat and Rajasthan).

Table 6-Trajectory clustering Jalandhar

	Duration	**Afghanistan**	**Pakistan**	**Uttrakhand**	**Rajasthan**
Contribution	2011-2014	26 %	31 %	25 %	18 %
Contribution	2015-2019		100 %		

(A) CWT Analysis

The CWT analysis of Jalandhar from 2011-2014 reflects the concentration of NO_2 in Jalandhar is found to be 35 µg/m^3 mainly from UP and Nepal. This concentration of is dominated by the sources regions of Pakistan, China, Afghanistan, Tajikistan, Nepal, India (North, IGP and north-west) and winds blowing from Arabian Sea. The concentration of PM_{10} is around 225 µg/m^3 mainly from Nepal & UP followed by China, Pakistan, Tajikistan, Kyrgyzstan and India (North and north-west). The concentration from the surrounding areas is limited to 100 µg/m^3. The SO_2 concentration is found to be 18 µg/m^3 in Jalandhar during 2011-2014 which is occurring due to Pakistan, China, Afghanistan and India (North, north-west & IGP).

The CWT analysis of Jalandhar from 2015-2019 reflects the concentration of NO_2 in Jalandhar is found to be 25 µg/m^3 mainly from UP and Nepal. This concentration of is dominated by the sources regions of Pakistan, China, Afghanistan, Tajikistan, India (North, IGP and north-west) and winds blowing from Arabian Sea. The concentration of PM_{10} is around 300 µg/m^3 mainly from Nepal and UP followed by China, Pakistan, Tajikistan, Kyrgyzstan and India (North and north-west). The concentration from the surrounding areas is limited to 150 µg/m^3. The SO_2 concentration is found to be 15 µg/m^3 in Jalandhar during 2015-2019 which is occurring due to Pakistan, China, Afghanistan and India (North, north-west and IGP).

The CWT analysis of different seasons from 2012-2014 shows that the concentration of NO_2 in monsoon is shown to be around 25 µg/m^3, SO_2 is 14 µg/m^3 mainly from Pakistan and IGP and PM_{10} is 130 µg/m^3 coming mainly from Afghanistan, Pakistan and from IGP, north India and the neighbouring countries and winds blown across Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 14 µg/m^3 & 32 µg/m^3 and that of PM_{10} is 210 µg/m^3 mainly from north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 14 µg/m^3 & 27 µg/m^3 which are influenced by north India, IGP, north-west India, Pakistan, Afghanistan, Tajikistan and Nepal and that of PM_{10} is around 100 µg/m^3 from Pakistan, Afghanistan and India (North and IGP). The concentration of NO_2 and SO_2 in winter is about 29 µg/m^3 & 15 µg/m^3 and of PM_{10} is 140 µg/m^3 but this pollution concentration is not much widespread.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 25 µg/m^3, SO_2 is 14 µg/m^3 mainly from Pakistan and IGP and PM_{10} is 300 µg/m^3 coming mainly from India (North-west, IGP and North), Afghanistan, Pakistan and from IGP, and the neighboring countries and winds blown across Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 14 µg/m^3 & 32 µg/m^3 and that of PM_{10} is 210 µg/m^3 mainly from north India along with Pakistan, Afghanistan and Turkmenistan. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 14 µg/m^3 & 27 µg/m^3 which are influenced by north India, north-west

India, Pakistan, Afghanistan, Tajikistan and Nepal and that of PM_{10} is around 150 µg/m^3 from Pakistan, Afghanistan and India (North and IGP). The concentration of NO_2 and SO_2 in winter is about 29 µg/m^3 & 15 µg/m^3 and of PM_{10} is 300 µg/m^3 but this pollution concentration is not much widespread.

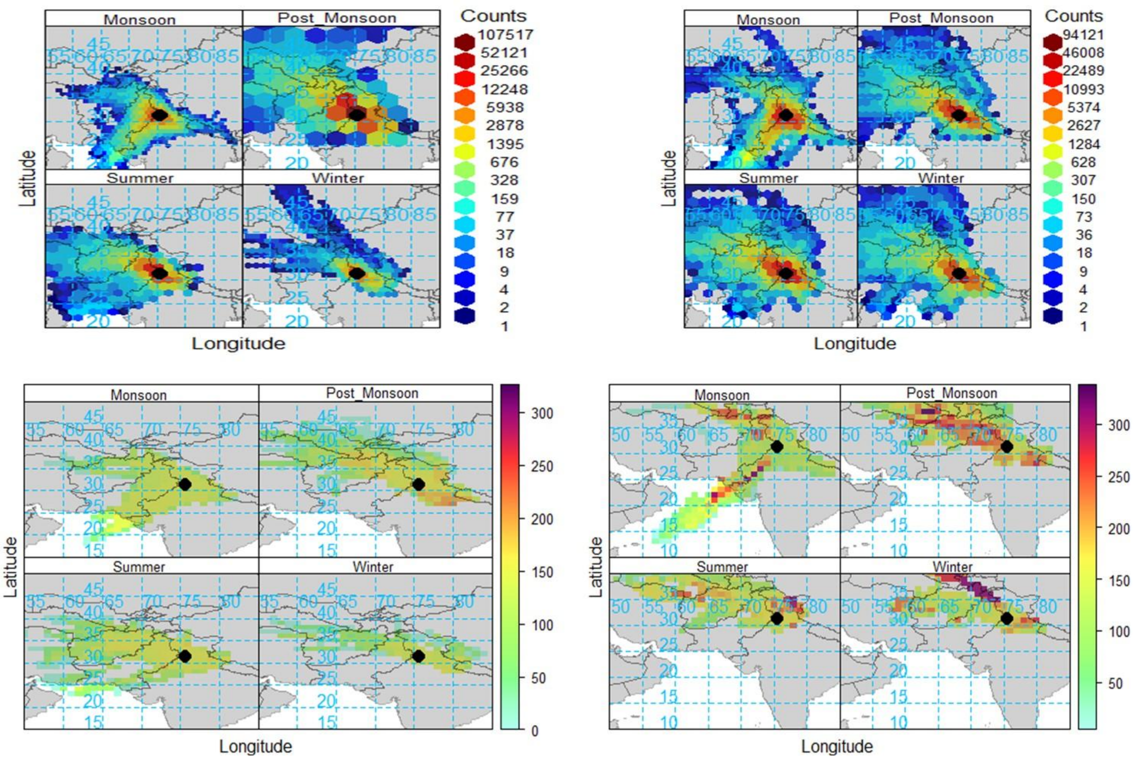

Figure 9-During the period of 2011-2014 & 2015-2019 resp. in Jalandhar (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

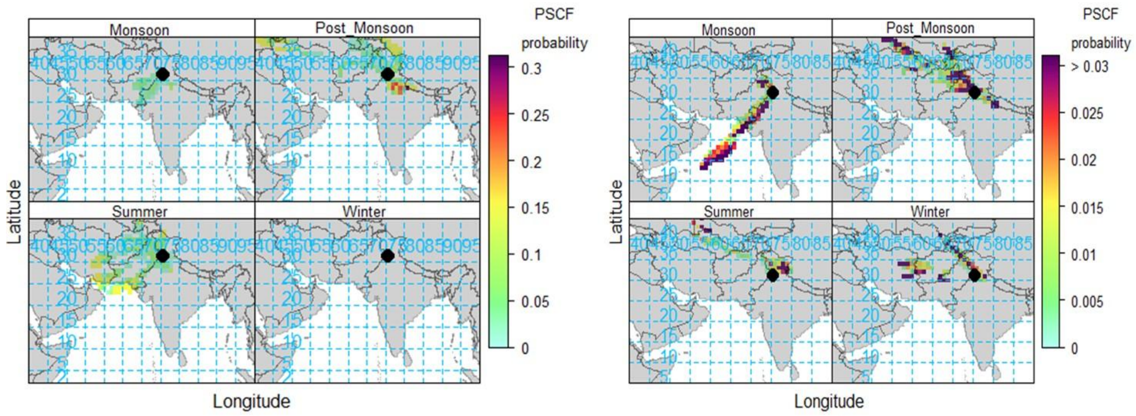

Figure 10-During the period of 2011-2014 & 2015-2019 in Jalandhar (a) Seasonal PSCF of PM_{10}

(B) PSCF Analysis

The potential source of NO_2 pollution in Jalandhar from 2012-2014 is UP and Uttrakhand (~ 0.2), the main source of SO_2 pollution is Kazakhstan (~ 0.15) followed by Pakistan, Afghanistan and India (north and IGP) and the main source of PM_{10} pollution is UP (~ 0.16) followed by Iran, China (~0.14) and north India, IGP, Pakistan, Afghanistan & Turkmenistan (~0.07).

The potential source of NO_2 pollution in Jalandhar from 2015-2019 is Uttrakhand, J&K and Pakistan (~ 0.08), the main source of SO_2 pollution is Kazakhstan, Afghanistan, Pakistan, India (North and IGP) (~0.05) and the main source of PM_{10} pollution is winds blowing from Arabian Sea (~ 0.15) followed by Rajasthan (~ 0.1) and north India, IGP, Pakistan, Afghanistan & Turkmenistan (~0.03).

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of NO_2 & SO_2 is Rajasthan (~ 0.05) and of PM_{10} pollution is Uttrakhand (~ 0.05). In post-monsoon, Uttrakahnd is the main source of NO_2 (~ 0.03) and SO_2 pollution from Iran (~ 0.14), Uttrakhand is the main source of PM_{10} (~ 0.3) followed by IGP (~ 0.25). In summer season, SO_2 & NO_2 is originating mainly from Pakistan and Afghanistan (~ 0.04) and the PM_{10} sources were not widespread with high potential in Pakistan and Iran (~ 0.17), followed by J&K and Himachal Pradesh (~ 0.1). In winter season, pollutants are not recorded in this season.

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2 is Uttrakhand (~ 0.03) & SO_2 is Rajasthan and J&K (~ 0.05) and of PM_{10} pollution is Rajasthan, Himachal Pradesh, Pakistan and winds blowing from Arabian Sea (~0.035). In post-monsoon, Uttrakahnd, J&K and Pakistan is the main source of NO_2 (~ 0.03) and SO_2 pollution from Nepal (~0.14), Uttrakhand, Pakistan, Afghanistan, Nepal is the main source of PM_{10} (~0.035). In summer season, SO_2 is originating mainly from J&K (~ 0.04) and the PM_{10} sources were not widespread with high potential in J&K and Kazakhistan (~ 0.035. In winter season, Pakistan is the potential source of SO_2 (~ 0.14) and PM_{10} is Himachal Pradesh, Iran, Afghanistan, Pakistan and J&K (~0.035).

III. Gorakhpur City

Gorakhpur, located in the north-eastern part of the Indian state of Uttar Pradesh, exhibits unique topographical and climatic features throughout the year. It is situated on the eastern plains of UP, near the border with Nepal. It is characterized by flat terrain and fertile agricultural land. The region is crisscrossed by several rivers and is known for its rich alluvial soil. The climate is influenced by its location in the northern plains of India and experiences distinct seasons. Winters in Gorakhpur are generally cool and dry. Temperatures range from around 8°C to 25°C (46°F to 77°F). January is typically the coldest month, with temperatures occasionally dropping below 5°C (41°F) during the night. Summers are hot and humid. Temperatures can soar, ranging from 25°C to 45°C (77°F to 113°F) or higher during the peak months of May. Heat waves are common during this period. Monsoon experiences a monsoon season characterized by heavy rainfall. The southwest monsoon brings substantial precipitation, vital for agriculture in the region. Humidity levels are high during this time, and occasional flooding may occur in low-lying areas. After the monsoon season, the weather starts to transition towards winter i.e., post-monsoon. October and November are relatively pleasant months with decreasing temperatures and clear skies. Temperatures typically range from 15°C to 30°C (59°F to 86°F) during this period. Overall, climate is influenced by its geographical location in the IGP, with hot summers, relatively mild winters, a distinct monsoon season with heavy rainfall, and a transitional period between seasons. These climatic variations play a significant role in the agricultural activities and overall lifestyle of the region's inhabitants.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Pakistan, Afghanistan, Nepal, China, Bangladesh and India (J&K, Himachal Pradesh, Punjab, Haryana, Bihar, Madhya Pradesh, UP, Uttrakhand, Jharkhand, West Bengal and Rajasthan). While in the period 2015-2019, the trajectories originated from Pakistan, Afghanistan, Nepal, China, Bangladesh and India (J&K, Himachal Pradesh, Punjab, Haryana, Bihar, Madhya Pradesh, UP, Uttrakhand, Jharkhand, West Bengal and Rajasthan).

Table 7-Trajectory clustering Gorakhpur

	Duration	**Haryana**	**Punjab**	**MP**	**HP**	**Bihar**
Contribution	2011-2014		58 %	11 %	10 %	21 %
Contribution	2015-2019	48 %		15 %	7 %	30 %

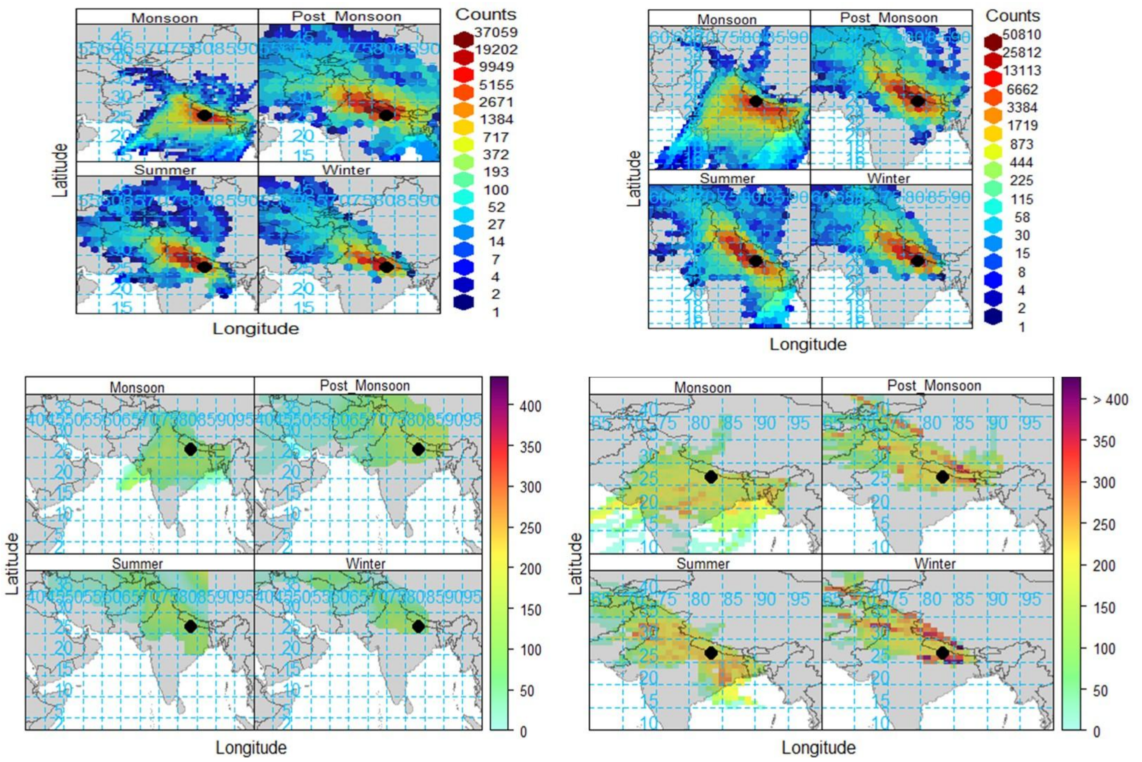

Figure 11-During the period of 2011-2014 & 2015-2019 resp. in Gorakhpur (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

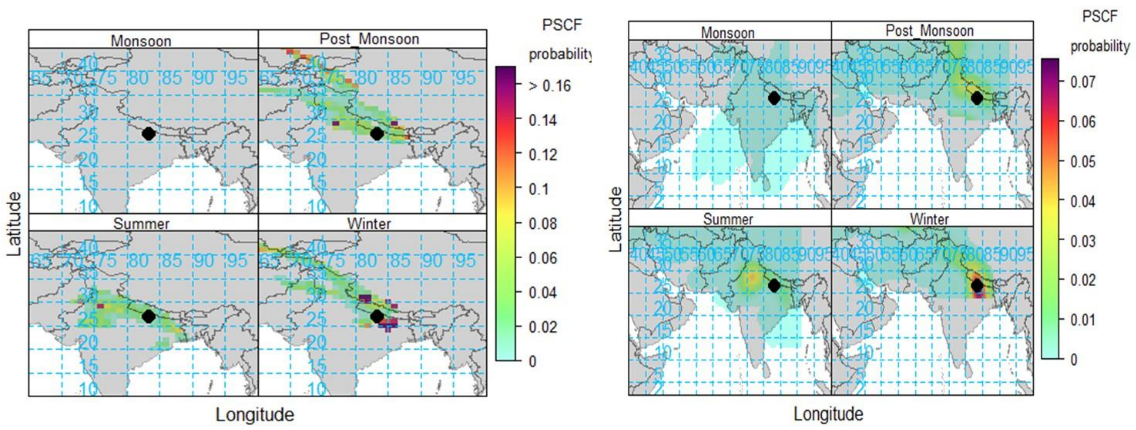

Figure 12-During the period of 2011-2014 & 2015-2019 in Gorakhpur (a) Seasonal PSCF of PM_{10}

(A) CWT Analysis

The CWT analysis of Gorakhpur from 2011-2012 reflects the concentration of NO_2 is found to be 45 μg/m^3 mainly from UP, Bihar and Meghalaya. This concentration of is dominated by the sources regions of Pakistan, China, Afghanistan, Nepal, Bhutan and India (North, IGP and north-west) and winds blowing from Arabian Sea. The concentration of PM_{10} is around 150 μg/m^3 mainly from Nepal, Bangladesh, Bhutan, China and UP followed by Tajikistan, Kyrgyzstan and India (North and north-west). The concentration from the surrounding areas is limited to 150 μg/m^3. The SO_2 concentration is found to be 20 μg/m^3 in Gorakhpur during

2011-2012 which is occurring due to Pakistan, China, Afghanistan, Nepal, Bangladesh, Bhutan and India (North, north-west, north-east and IGP).

The CWT analysis of Gorakhpur from 2015-2019 reflects the concentration of NO_2 is found to be 65 μg/m^3 mainly from China, Nepal and J&K. This concentration of is dominated by the sources regions of Pakistan, China, Afghanistan, Bangladesh, Bhutan and India (North, IGP, north-east and north-west) and winds blowing from Arabian Sea and Bay of Bengal. The concentration of PM_{10} is around 350 μg/m^3 mainly from Nepal, China, Pakistan, J&K and UP followed by Tajikistan, Kyrgyzstan and India (North, central, IGP and north-west). The concentration from the surrounding areas is limited to 200 μg/m^3. The SO_2 concentration is found to be 30 μg/m^3 in Gorakhpur during 2015-2019 which is occurring due to Pakistan, China, Afghanistan, Nepal, Bangladesh, Bhutan and India (North, north-west, north-east, central and IGP).

The CWT analysis of different seasons from 2011-2012 shows that the concentration of NO_2 in monsoon is shown to be around 45 μg/m^3, SO_2 is 25 μg/m^3 mainly from North, North-west, North-east, IGP and Nepal and PM_{10} is 150 μg/m^3 coming mainly from North, North-west, North-east, IGP, Bangladesh, Nepal and the neighbouring countries and winds blown across Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 20 μg/m^3 & 30 μg/m^3 and that of PM_{10} is 170 μg/m^3 mainly from north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 30 μg/m^3 & 45 μg/m^3 which are influenced by north India, IGP, north-west India, Pakistan, Afghanistan, Tajikistan, China and Nepal. The concentration of NO_2 and SO_2 in winter is about 50 μg/m^3 & 35 μg/m^3 and of PM_{10} is 175 μg/m^3 but this pollution concentration is not much widespread.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 45 μg/m^3, SO_2 is 25 μg/m^3 mainly from North, North-west, North-east, IGP, Bangladesh and Nepal and PM_{10} is 250 μg/m^3 coming mainly from North, North-west, North-east, IGP, Bangladesh, Nepal and the neighbouring countries and winds blown across Arabian Sea and Bay of Bengal. In post-monsoon, the SO_2 and NO_2 concentration is around 50 μg/m^3 & 70 μg/m^3 and that of PM_{10} is 350 μg/m^3 mainly from north India along with Pakistan, Afghanistan, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 30 μg/m^3 & 60 μg/m^3 which are influenced by north India, IGP, north-west India, Pakistan, Afghanistan, Tajikistan, China, Bangladesh and Nepal and PM10 is from Pakistan, Odisha, Bihar, West Bengal, Jharkhand, IGP and northwest India along with Nepal, Bangladesh, China, Pakistan, Afghanistan. The concentration of NO_2 and SO_2 in winter is about 65 µg/m^3 & 50 µg/m^3 and of PM_{10} is 375 µg/m^3 but this pollution concentration is mainly from Jharkhand, J&K, China, Nepal, Pakistan and Afghanistan.

(B) PSCF Analysis

The potential source of NO_2 pollution in Gorakhpur from 2011-2012 is Haryana, Delhi and Assam (~ 0.075), the main source of SO_2 pollution is Andhra Pradesh and Madhya Pradesh (~0.15) and the main source of PM_{10} pollution is Pakistan and China (~ 0.14).

The potential source of NO_2 pollution in Gorakhpur from 2015-2019 is J&K, Nepal, China, Kazakhstan(~ 0.075), the main source of SO_2 pollution is Haryana and Punjab (~0.08) and the main source of PM_{10} pollution is Pakistan, Kazakhstan and China (~ 0.09).

The seasonal PSCF analysis from 2011-2012 in Gorakhpur clearly reveals that the main source of NO2 is North-east India, Bhutan and Bangladesh (~ 0.07), for SO2 is Andhra Pradesh (~0.18). In post-monsoon, the main source of NO2 is Punjab, Haryana and Rajasthan (~0.025), that of SO2 is Pakistan, Afghanistan, Iran, China, Nepal and India (North, IGP and north-west) (~ 0.02) and PM10 is mainly coming from Haryana and China (~ 0.17). In summer, the main source of NO2 is North India (~0.035), for SO2 is Pakistan, Afghanistan China, Nepal, Tajikistan and India (~ 0.02) and PM10 is mainly coming from Haryana (~ 0.15). In winter season, NO2 & SO2 pollution is from Pakistan, Afghanistan, Tajikistan, China, Nepal and India (north and IGP) (~0.01) and PM10 is mostly from Bihar and China (~ 0.17).

The seasonal PSCF analysis from 2015-2019 in Gorakhpur clearly reveals that the main source of NO_2, SO_2 and PM_{10} is India, China, Nepal, Bhutan and Bangladesh (~ 0.01). In post-monsoon, the main source of NO_2 is UP and Nepal (~ 0.05), that of SO_2 and PM_{10} is Nepal and India (North and IGP) (~0.04). In summer, the main source of NO_2 is central India (~ 0.025), for SO_2 & PM_{10} is North India (~ 0.03). In winter season, NO2, SO_2 and PM_{10} is mostly from Bihar, UP, Nepal and China (~0.07).

5.1.3 North-East India

I. Guwahati City

Guwahati, the largest city in Assam and the gateway to north-eastern India, has distinctive topographical and climatic characteristics shaped by its location in the Brahmaputra Valley. It is situated on the south bank of the Brahmaputra River, nestled between the foothills of the Shillong Plateau and the Brahmaputra Valley. The city's terrain varies from flatlands near the river to hilly terrain as one move towards the Meghalaya border. It is surrounded by lush green hills and tea gardens, typical of Assam's landscape. The climate in here is influenced by its proximity to the Brahmaputra River, the surrounding hills, and the tropical monsoon climate of the region. Winters are mild and dry. Daytime temperatures range from around 10°C to 25°C (50°F to 77°F). Nights can be cool, with temperatures occasionally dropping to around 5°C to 10°C (41°F to 50°F). Clear skies are common during this season. Summers are warm and humid. Day time temperatures range from 25°C to 35°C (77°F to 95°F) or higher, especially in May. Humidity levels are high, making the weather feel hotter than the actual temperature. Nights provide some relief but remain warm with temperatures around 20°C to 25°C (68°F to 77°F). It experiences a heavy monsoon season influenced by the southwest monsoon. The region receives substantial rainfall during this period, with July and August being the wettest months. Intense rainfall can lead to occasional flooding in low-lying areas. After the monsoon season, the weather gradually becomes drier in post-monsoon. October and November are pleasant months with decreasing temperatures and clear skies. Daytime temperatures range from 25°C to 30°C (77°F to 86°F), while nights become cooler. Overall, here climate is characterized by its tropical monsoon climate, featuring mild winters, warm and humid summers, a significant monsoon season with heavy rainfall, and a pleasant post-monsoon period. The climate influences agriculture, the local economy, and the rich biodiversity of the region.

It was observed from the hexagonal counts in the period 2012-2014 that the trajectories originated from Bhutan, Nepal, China, Bangladesh, Myanmar, Bay of Bengal and India (North-east, IGP and North India). However, in the period 2015-2019 trajectories originated from Bhutan, Nepal, China, Bangladesh, Myanmar, Bay of Bengal and India (North-east, IGP and North India).

Table 8-Trajectory clustering Guwahati

	Duration	China	Myanmar	UP	Bay of Bengal
Contribution	2011-2014	10 %	22 %	29 %	39 %
Contribution	2015-2019		100 %		

In seasonal plots from 2012-2014, it was observed that in monsoon season the trajectories originated from Bangladesh, Myanmar, Bay of Bengal and India (north-east India). The maximum trajectories originate from Bay of Bengal (~59%), followed by Myanmar (~41%). In post-monsoon, the trajectories originated from Nepal, China, Bangladesh, India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Assam (~35%), UP (~29%), China (~21%) and Bangladesh (~15%). In summer, trajectories stem from Nepal, Bangladesh and India (North, north-east and Indo-Gangetic Plains). The highest trajectories from Uttrakhand (~ 38%), accompanied by winds blowing from Bay of Bengal (~31%), Bihar (~17%) and Mizoram (~14%). In winter, it was monitored that the trajectories rise from Pakistan, China, Bangladesh and India (North, north-east and IGP). The most trajectories from UP (~55%), Pakistan (~37%), Bangladesh (~14%) and China (~6%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from Bangladesh, Myanmar, Bay of Bengal and India (north-east India). The maximum trajectories originate from Bay of Bengal (~56%), followed by Myanmar (~44%). In post-monsoon, the trajectories originated from Nepal, China, Bangladesh, India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Assam (~56%), Nepal (~24%) and China (~20%). In summer, trajectories stem from Nepal, Bangladesh and India (North, north-east and Indo-Gangetic Plains). The highest trajectories from winds blowing from Bay of Bengal (~ 55%), accompanied by Nepal (~26%) and Assam (~19%). In winter, it was monitored that the trajectories rise from China, Bangladesh and India (North, north-east and IGP). The most trajectories from Nepal (~100%).

(A) CWT Analysis

During 2012-2014, the concentration of NO_2 & SO_2 is around 15 µg/m^3 & 8 µg/m^3 mainly from Nepal, China, Bangladesh, Myanmar and India (north-east and IGP).The concentration of PM_{10} is found to be 260 µg/m^3 mainly from Madhya Pradesh.

During 2015-2019, the concentration of NO_2 & SO_2 is around 15 µg/m^3 & 9 µg/m^3 mainly from Nepal, China, Bangladesh, Myanmar, Bay of Bengal and India (north-east and IGP).The concentration of PM_{10} is found to be 230 $\mu g/m^3$ mainly from Madhya Pradesh but the concentration of $PM_{2.5}$ was observed to be nearly 40 $\mu g/m^3$ mainly from North-east India.

The CWT analysis of different seasons from 2012-2014 shows that the concentration of NO_2 in monsoon is shown to be around 20 $\mu g/m^3$, SO_2 is 8 $\mu g/m^3$ and PM_{10} is 150 $\mu g/m^3$ mainly from North-east, Myanmar, Bangladesh and winds blowing from Bay of Bengal. In post-monsoon, the SO_2 and NO_2 concentration is around 7 $\mu g/m^3$ & 15 $\mu g/m^3$ and that of PM_{10} is 250 $\mu g/m^3$ mainly from north India along with Pakistan, Bangladesh, Myanmar, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 8 $\mu g/m^3$ & 15 $\mu g/m^3$ which are influenced by north India, IGP, north-east India, Pakistan, China, Bangladesh and Nepal and PM_{10} is about 200 $\mu g/m^3$ from Odisha, Bihar, West Bengal, Jharkhand, IGP and northeast India along with Nepal, Bangladesh, China and Myanmar. The concentration of NO_2 and SO_2 in winter is about 15 $\mu g/m^3$ & 7 $\mu g/m^3$ and of PM_{10} is 260 $\mu g/m^3$. This pollution concentration is mainly from India (North, IGP, northeast and northwest), China, Nepal and Bangladesh.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 25 $\mu g/m^3$, SO_2 is 14 $\mu g/m^3$, PM_{10} is 90 $\mu g/m^3$ mainly from North-east, Myanmar, Bangladesh and winds blowing from Bay of Bengal and $PM_{2.5}$ is 40 $\mu g/m^3$ mainly from North-east, Bangladesh, Myanmar and Bay of Bengal. In post-monsoon, the SO_2 and NO_2 concentration is around 14 $\mu g/m^3$ & 22 $\mu g/m^3$ and that of PM_{10} is 100 $\mu g/m^3$ mainly from IGP, north, north-east India along with Pakistan, Bangladesh, Myanmar, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 14 $\mu g/m^3$ & 22 $\mu g/m^3$ which are influenced by north India, IGP, north-east India, China, Bangladesh and Nepal and PM_{10} is about 200 $\mu g/m^3$ from Odisha, Bihar, West Bengal, Jharkhand, IGP and northeast India along with Nepal, Bangladesh, China and Myanmar. The concentration of NO_2 and SO_2 in winter is about 30 $\mu g/m^3$ & 11 $\mu g/m^3$ and of PM_{10} is 200 $\mu g/m^3$. This pollution concentration is mainly from India (North, IGP, northeast and northwest), China, Nepal, Bangladesh and Bay of Bengal.

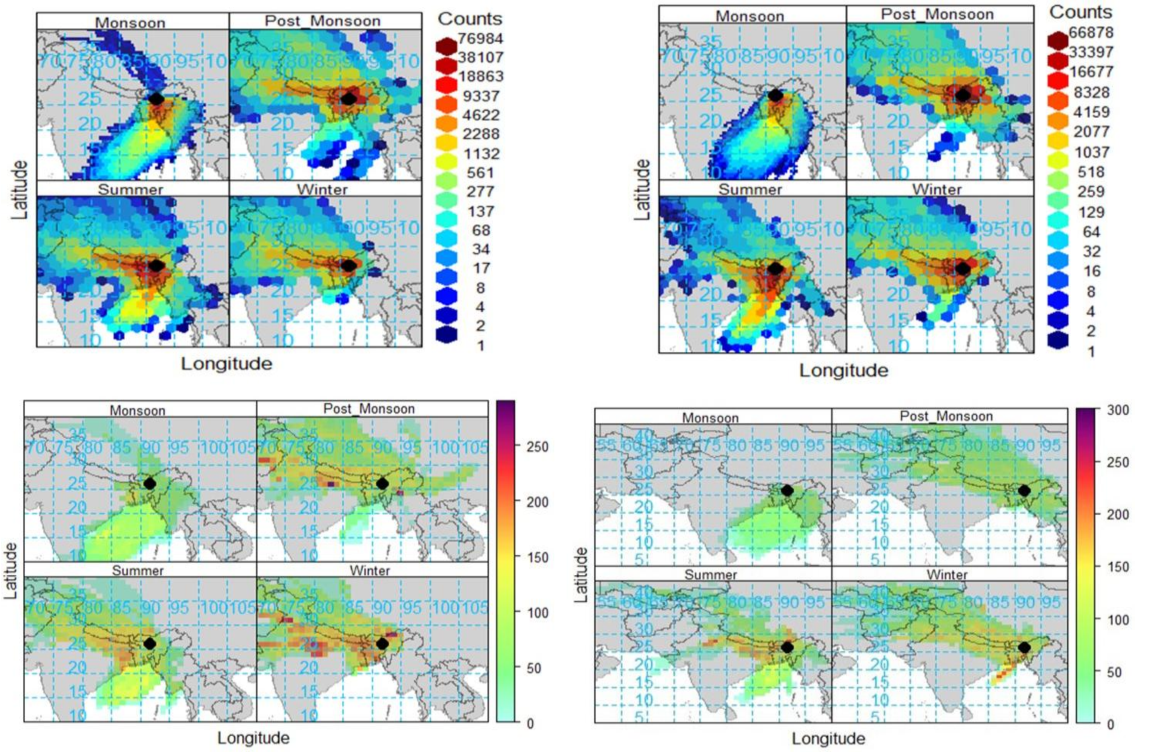

Figure 13-During the period of 2011-2014 & 2015-2019 resp. in Guwahati (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

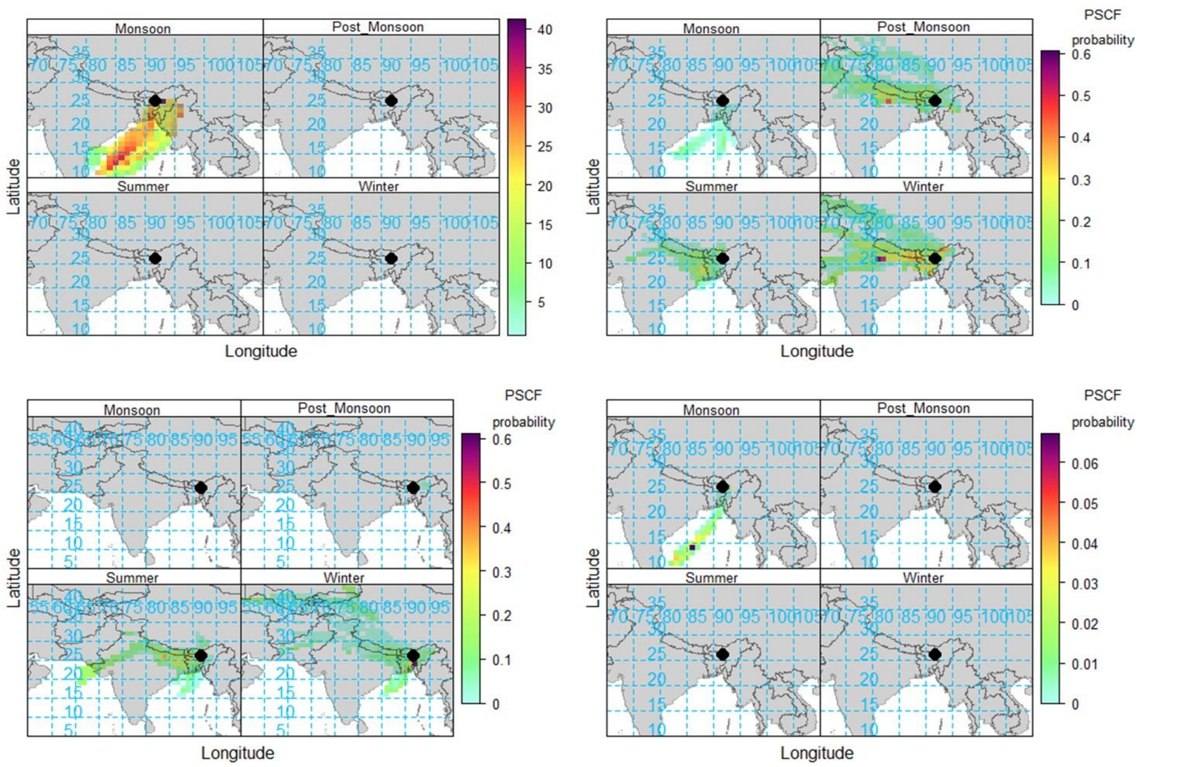

Figure 14-During the period of 2011-2014 & 2015-2019 in Guwahati (a) Seasonal CWT of $PM_{2.5}$, (b) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 pollution in Guwahati from 2012-2014 is Myanmar, Bangladesh, China and Bay of Bengal (~ 0.18), the main source of SO_2 pollution is Myanmar and Bay of Bengal(~0.15) and the main source of PM_{10} pollution is UP (~ 0.3).

The potential source of NO_2 pollution from 2015-2019 is Iran, West Bengal, UP, Rajasthan and Gujarat (~ 0.14), the main source of SO_2 pollution is Iran (~0.15) followed by China and Myanmar (~ 0.11), the main source of PM_{10} pollution is UP and Bihar (~ 0.23) and the potential source of $PM_{2.5}$ is largely Bay of Bengal (~0.035), followed by Assam (~0.01) and Mizoram and Tripura (~0.005).

The seasonal PSCF analysis from 2012-2014 in Guwahati clearly reveals that the main source of NO_2 & SO_2 is Myanmar (~0.35) & (~0.23) followed by north-east India (~0.13) and PM_{10} is Bay of Bengal and Bangladesh (~0.2). In post-monsoon, the main source of NO_2 is China (~ 0.27), that of SO_2 is Myanmar and China (~0.15) and of PM_{10} is UP (~0.4). In summer, the main source of NO_2 is Bangladesh, Bay of Bengal and India (IGP, north-west and north-east) (~ 0.2), for SO_2 is Tripura, Bangladesh and Bay of Bengal (~ 0.2) & PM_{10} is Bangladesh, Nepal, Bhutan and India (North-east and IGP) (~0.4). In winter season, NO_2 is mainly from Bangladesh (~0.35), SO_2 coming from Bangladesh (~0.19) and PM_{10} is mostly from UP (~ 0.6).

The seasonal PSCF analysis from 2015-2019 in Guwahati clearly reveals that the main source of NO_2 & SO_2 is north-east India (~0.05) & $PM_{2.5}$ is Bay of Bengal & Bangladesh (~0.06). In post-monsoon, the main source of NO_2 is Afghanistan and India (North-east & north) (~0.15), that of SO_2 is Myanmar & Bhutan (North & IGP) (~0.25) & of PM_{10} is Assam (~0.1). In summer, the main source of NO_2 is Tajikistan, China and India (IGP, north-west and north-east) (~ 0.13), for SO_2 (~ 0.16) & PM_{10} is Bangladesh, Nepal, Bhutan and India (Nort-east &IGP) (~0.4). In winter season, NO_2 (~0.15), SO2 (~0.1) & PM_{10} is mostly from Tripura (~ 0.6).

II. Kohima City

Kohima, the capital city of Nagaland in north-eastern India, has distinct topographical and climatic characteristics influenced by its location in the Naga Hills. It is situated at an altitude of approximately 1,444 meters (4,738 feet) above sea level in the Naga Hills. The city is surrounded by steep hills and deep valleys, characterized by dense forests and terraced fields.

The rugged terrain contributes to its scenic beauty and unique geographical setting. The climate is influenced by its high altitude and the northeast monsoon, resulting in moderate temperatures throughout the year. Winters in here are cool and dry. Daytime temperatures range from around 10°C to 20°C (50°F to 68°F). Nights can be cold, with temperatures occasionally dropping to around 5°C to 10°C (41°F to 50°F). Clear skies are common during this season, offering crisp, pleasant weather. Summers are mild and comfortable compared to the plains of India. Daytime temperatures range from 15°C to 25°C (59°F to 77°F). Humidity levels are moderate, making the weather feel relatively cooler than lower altitudes. Occasional rainfall occurs during this period, particularly towards June. It experiences a significant monsoon season influenced by the southwest monsoon. The region receives moderate to heavy rainfall during this period, which is crucial for agriculture. July and August are the wettest months, with frequent rain showers and occasional thunderstorms. After the monsoon season, the weather gradually becomes drier. October and November are pleasant months with mild temperatures and clear skies in post-monsoon. Daytime temperatures range from 15°C to 25°C (59°F to 77°F), while nights become cooler. Overall, climate is characterized by its high altitude in the Naga Hills, featuring mild winters, comfortable summers, a significant monsoon season with moderate to heavy rainfall, and a pleasant post-monsoon period. The climate plays a vital role in shaping the region's agriculture, biodiversity, and cultural practices of the indigenous Naga tribes.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Bhutan, Nepal, China, Bangladesh, Myanmar, Bay of Bengal and India (North-east, IGP and North India). However, in the period 2015-2019 trajectories originated from Bhutan, Nepal, China, Bangladesh, Myanmar, Bay of Bengal and India (North-east, IGP and North India).

Table 9-Trajectory clustering Kohima

	Duration	**Bangladesh**	**Mizoram**
Contribution	2011-2014	100 %	
Contribution	2015-2019		100 %

In seasonal plots from 2011-2014, it was observed that in monsoon season the trajectories originated from Bangladesh, Myanmar, Bay of Bengal and India (north-east India). The maximum trajectories originate from Bay of Bengal (~59%), followed by Myanmar (~41%).

In post-monsoon, the trajectories originated from Nepal, China, Bangladesh, India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Nagaland (~100%). In summer, trajectories stem from Nepal, Bangladesh, Myanmar, Bay of Bengal and India (North-east and Indo-Gangetic Plains). The highest trajectories from Nepal (~ 36%), accompanied by winds blowing from Bay of Bengal (~ 23%), Myanmar (~ 21%) and Bangladesh (~ 19%). In winter, it was monitored that the trajectories rise from Myanmar, China, Bangladesh and India (North-east and IGP). The most trajectories from Bangladesh and Bihar (~31%), China (~26%), Assam (~21%) and Myanmar (~21%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from Bangladesh, Myanmar, Bay of Bengal and India (north-east India). The maximum trajectories originate from Bay of Bengal (~ 100%). In post-monsoon, the trajectories originated from Nepal, China, Bangladesh and India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Myanmar (~49%), Nagaland (~27%) and China (~15%). In summer, trajectories stem from Nepal, Bangladesh, Myanmar, Bay of Bengal and India (North-east and Indo-Gangetic Plains). The highest trajectories from Tripura (~ 100%). In winter, it was monitored that the trajectories rise from Myanmar, China, Bangladesh and India (North-east and IGP). The most trajectories from Assam and Arunachal Pradesh (~100%).

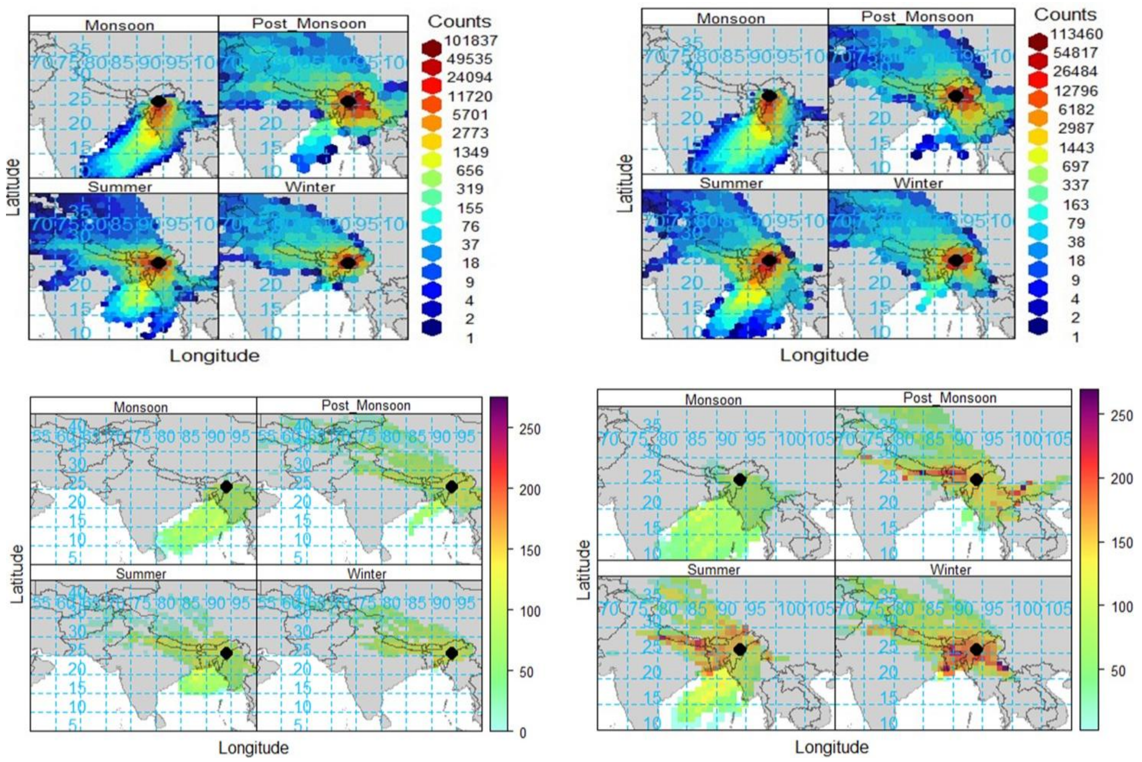

Figure 15-During the period of 2011-2014 & 2015-2019 resp. in Kohima (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 is around 6 µg/m^3 mainly from Nepal, China, Bhutan, Bangladesh, Myanmar, Bay of Bengal and India (north-east and IGP).The concentration of PM_{10} is found to be 140 µg/m^3 mainly from UP, Bihar, Jharkhand, Assam, Arunachal Pradesh, Nagaland, West Bengal, Bay of Bengal, Nepal, China, Bhutan, Bangladesh and Myanmar.

During 2015-2019, the concentration of NO_2 is around 7 µg/m^3 mainly from Nepal, China, Bhutan, Bangladesh, Myanmar, Bay of Bengal and India (north-east and IGP).The concentration of PM_{10} is found to be 150 µg/m^3 mainly from UP, Bihar, Jharkhand, Assam, Arunachal Pradesh, Nagaland, West Bengal, Bay of Bengal, Nepal, China, Bhutan, Bangladesh and Myanmar.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 4 µg/m^3 and PM_{10} is 100 µg/m^3 mainly from North-east, Myanmar, Bangladesh and winds blowing from Bay of Bengal. In post-monsoon, NO_2 concentration is around 4 µg/m^3 and that of PM_{10} is 100 µg/m^3 mainly from IGP, north-east

India along with Bangladesh, Myanmar, Nepal and China. In summer, NO_2 is observed to be 3 μg/m^3 which are influenced by north India, IGP, north-east India, China, Bangladesh and Nepal and PM_{10} is about 120 μg/m^3 from Odisha, Bihar, West Bengal, Jharkhand, IGP and northeast India along with Nepal, Bangladesh, China and Myanmar. The concentration of NO_2 in winter is about 3 μg/m^3 and of PM_{10} is 130 μg/m^3. This pollution concentration is mainly from India (IGP & northeast), China, Nepal, Bangladesh, Myanmar and Bay of Bengal.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 6 μg/m^3 and PM_{10} is 100 μg/m^3 mainly from North-east, Myanmar, Bangladesh and winds blowing from Bay of Bengal. In post-monsoon, NO_2 concentration is around 7 μg/m^3 and that of PM_{10} is 250 μg/m^3 mainly from north-east India along with Bangladesh, Myanmar, Nepal and China. In summer, NO_2 is observed to be 6 μg/m^3 which are influenced by IGP, north-east India, China, Bangladesh and Nepal and PM_{10} is about 200 μg/m^3 from Odisha, Bihar, West Bengal, Jharkhand, IGP and northeast India along with Nepal, Bangladesh, China and Myanmar. The concentration of NO_2 in winter is about 3 μg/m^3 and of PM_{10} is 260 μg/m^3. This pollution concentration is mainly from India (IGP & northeast), China, Nepal, Bangladesh and Myanmar.

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 is China (~ 0.14) followed by Kyrgyzstan (~ 0.12) and the main source of PM_{10} pollution is Uzbekistan and Arunachal Pradesh (~ 0.16).

The potential source of NO_2 pollution from 2015-2019 is China (~ 0.12), the main source of SO_2 pollution is below detection level and the main source of PM_{10} pollution is Pakistan and North-east (~ 0.2).

The seasonal PSCF analysis from 2011-2014 in Kohima clearly reveals in monsoon that the main source of PM_{10} is Myanmar & Tripura (~ 0.12). In post-monsoon, the main source of NO_2 is China, Myanmar and North-east India (~ 0.13) & that of PM_{10} is Myanmar, China, Bhutan and India (North & North-east) (~ 0.15). In summer, PM_{10} is Bangladesh, Nepal & India (North-east) (~0.1). In winter season, PM_{10} is mostly coming from Myanmar and Assam (~0.3).

The seasonal PSCF analysis from 2015-2019 in Kohima clearly reveals in monsoon that the main source of PM_{10} is Myanmar and Tripura (~0.1). In post-monsoon, the main source of NO_2 is China, Myanmar and North-east India (~0.12) and that of PM_{10} is Myanmar, China, Bhutan and India (North and North-east) (~0.15). In summer, the main source of PM_{10} is Bangladesh (~0.2). In winter season, PM_{10} is mostly coming from Bangladesh and Tripura (~ 0.3).

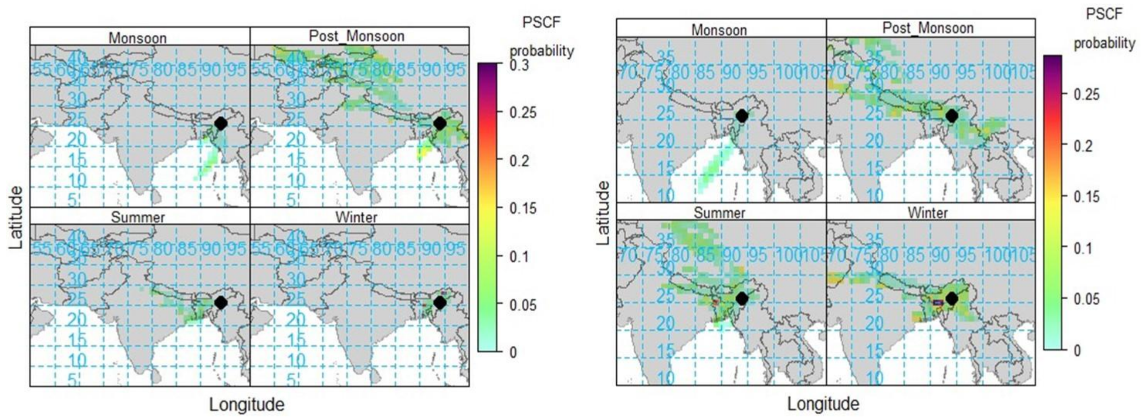

Figure 16-During the period of 2011-2014 & 2015-2019 in Kohima (a) Seasonal PSCF of PM_{10}

III. Shillong City

Shillong, the capital city of Meghalaya in north-eastern India, exhibits unique topographical and climatic characteristics owing to its location in the Khasi Hills. It is situated at an average altitude of about 1,496 meters (4,908 feet) above sea level in the East Khasi Hills district. It is known for its picturesque hills, valleys, and lush green landscapes. The city is surrounded by pine forests and numerous waterfalls, contributing to its scenic beauty. Climatic Conditions: The climate is influenced by its altitude, geographical location, and the northeast monsoon. Winters are cool and dry. Daytime temperatures range from around 10°C to 20°C (50°F to 68°F). Nights can be chilly, with temperatures occasionally dropping to around 2°C to 5°C (36°F to 41°F). Clear skies are common during this season. Summers are mild and pleasant compared to other parts of India. Daytime temperatures range from 15°C to 25°C (59°F to 77°F). Nights are generally cool and comfortable. The region experiences occasional rainfall during this period. It experiences a significant monsoon season characterized by heavy rainfall. The southwest monsoon brings abundant rainfall to the region, transforming the landscape into lush greenery. July and August are the wettest months, with frequent rainfall and occasional thunderstorms. In post-monsoon the weather gradually becomes drier. October and November are pleasant months with cool temperatures and clear skies. Daytime temperatures range from 15°C to 25°C (59°F to 77°F), while nights become cooler. Overall, climate is moderate throughout the year due to its elevation and geographical setting in the hills. It experiences relatively mild winters, pleasant summers, a substantial monsoon season with heavy rainfall, and a beautiful post-monsoon period. The climate plays a crucial role in shaping the lush green environment and the unique cultural heritage of the region.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Bhutan, Nepal, China, Bangladesh, Myanmar, Bay of Bengal and India (North-east, IGP and North India). However, in the period 2015-2019 the trajectories originated from Bhutan, Nepal, China, Bangladesh, Myanmar, Bay of Bengal and India (North-east, IGP and North India).

Table 10-Trajectory clustering Shillong

	Duration	Bangladesh	West Bengal
Contribution	2011-2014		100 %
Contribution	2015-2019	100 %	

In seasonal plots from 2012-2014, it was observed that in monsoon season the trajectories originated from Bangladesh, Myanmar, Bay of Bengal and India (north-east India). The maximum trajectories originate from Bay of Bengal (~88%), followed by Myanmar (~12%). In post-monsoon, the trajectories originated from Nepal, China, Bangladesh, India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Sikkim (~100%). In summer, trajectories stem from Nepal, Bangladesh and India (North, north-east and Indo-Gangetic Plains). The highest trajectories from Nepal (~ 35%), accompanied by winds blowing from Bay of Bengal (~30%), Myanmar (~25%) and West Bengal (~19%). In winter, it was monitored that the trajectories rise from Bhutan, China, Bangladesh and India (North, north-east and IGP). The most trajectories from UP (~ 55%), Himachal Pradesh (~ 22%), Bangladesh (~13%) and Bhutan (~10%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from Bangladesh, Myanmar, Bay of Bengal and India (north-east India). The maximum trajectories originate from Bay of Bengal (~85%), followed by Myanmar (~15%). In post-monsoon, the trajectories originated from Nepal, China, Bangladesh, India (Indo Gangetic Plains and north-east). The maximum trajectories emerged from Bhutan (~100%).

In summer, trajectories stem from Nepal, Bangladesh and India (North, north-east and Indo-Gangetic Plains). The highest trajectories from winds blowing from Bay of Bengal (~ 56%), accompanied by Bihar (~ 23%) and Assam (~ 21%). In winter, it was monitored that the trajectories rise from Bhutan, China, Bangladesh and India (North, north-east and IGP). The most trajectories from UP (~ 31%), Arunachal Pradesh (~ 29%), Bangladesh (~ 21%) and Himachal Pradesh (~19%).

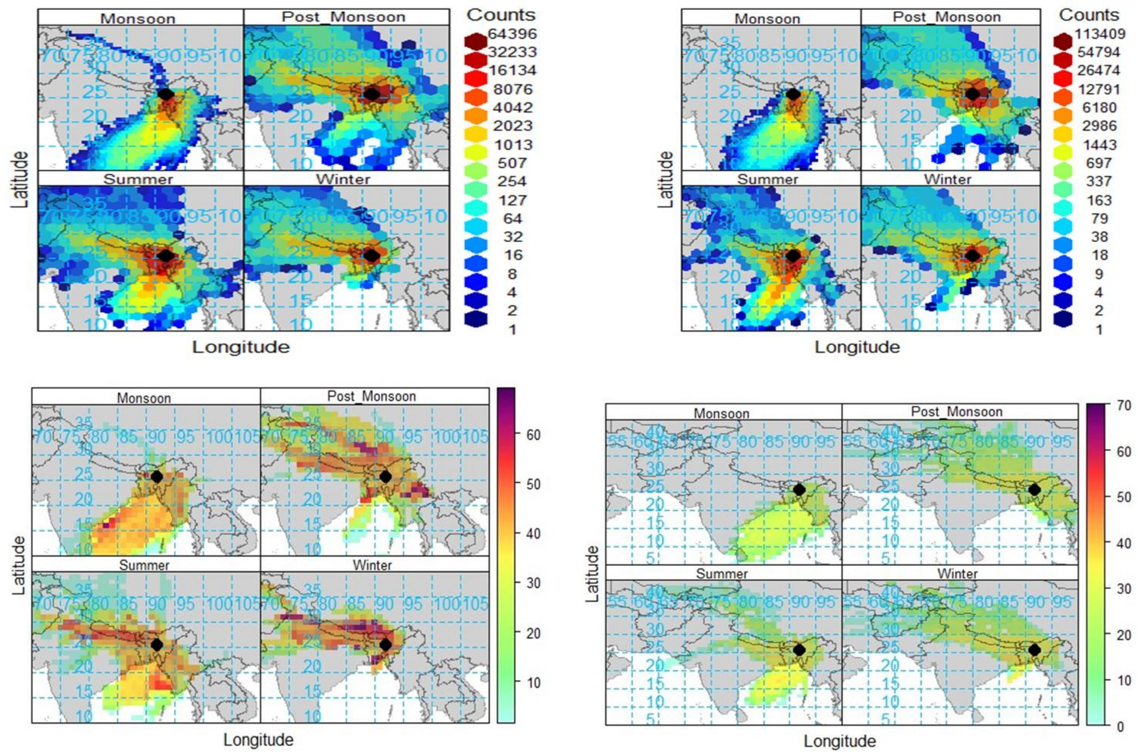

Figure 17-During the period of 2011-2014 & 2015-2019 resp. in Shillong (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 & SO_2 is around 7 µg/m^3 & 4 µg/m^3 mainly from Nepal, China, Myanmar, Bay of Bengal and India (North, north-east and IGP).The concentration of PM_{10} is found to be 70 µg/m^3 mainly from UP, Bihar, Jharkhand, Assam, Arunachal Pradesh, Nagaland, West Bengal, Bay of Bengal, Nepal, China, Bhutan, Bangladesh and Myanmar.

During 2015-2019, the concentration of NO_2 & SO_2 is around 7 µg/m^3 & 2 µg/m^3 mainly from Nepal, China, Myanmar, Bay of Bengal and India (North, north-east and IGP).The concentration of PM_{10} is found to be 40 µg/m^3 mainly from UP, Bihar, Jharkhand, Assam, Arunachal Pradesh, Nagaland, West Bengal, Bay of Bengal, Nepal, China, Bhutan, Bangladesh and Myanmar. The concentration of $PM_{2.5}$ was found to be 17 $\mu g/m^3$ mainly from IGP followed by Nepal, Bangladesh, China, Bhutan, and Myanmar.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 10 $\mu g/m^3$, SO_2 is 2 $\mu g/m^3$ and PM_{10} is 65 $\mu g/m^3$ mainly from North-east, Myanmar, Bangladesh and winds blowing from Bay of Bengal. In post-monsoon, the SO_2 and NO_2 concentration is around 3 $\mu g/m^3$ & 6 $\mu g/m^3$ and that of PM_{10} is 65 $\mu g/m^3$ mainly from (north, IGP, north-east) India along with Bangladesh, Myanmar, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 2 $\mu g/m^3$ & 7 $\mu g/m^3$ which are influenced by (north, IGP, north-east) India, Bangladesh, Bhutan, Myanmar and Nepal and PM_{10} is about 60 $\mu g/m^3$ from Odisha, Bihar, West Bengal, Jharkhand, IGP and northeast India along with Nepal, Bangladesh, Bhutan and Myanmar. The concentration of NO_2 and SO_2 in winter is about 10 $\mu g/m^3$ & 2.5 $\mu g/m^3$ and of PM_{10} is 70 $\mu g/m^3$. This pollution concentration is mainly from India (IGP & northeast), China, Nepal, Bangladesh and Myanmar.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 8 $\mu g/m^3$, SO_2 is 2 $\mu g/m^3$, PM_{10} is 30 $\mu g/m^3$ and $PM_{2.5}$ is 13 $\mu g/m^3$ mainly from North-east, Myanmar, Bangladesh and winds blowing from Bay of Bengal. In post-monsoon, the SO_2 and NO_2 concentration is around 3 $\mu g/m^3$ & 9 $\mu g/m^3$, that of PM_{10} is 30 $\mu g/m^3$ and $PM_{2.5}$ is 12 $\mu g/m^3$ mainly from (north, IGP, north-east) India along with Bangladesh, Myanmar, Nepal and China. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 2 $\mu g/m^3$ & 7 $\mu g/m^3$ which are influenced by (north, IGP, north-east) India, Bangladesh, Bhutan, Myanmar and Nepal, PM_{10} is about 30 $\mu g/m^3$ and $PM_{2.5}$ is about 14 $\mu g/m^3$ from Odisha, Bihar, West Bengal, Jharkhand, IGP and northeast India along with Nepal, Bangladesh, Bhutan and Myanmar. The concentration of NO_2 and SO_2 in winter is about 10 $\mu g/m^3$ & 2.5 $\mu g/m^3$, PM_{10} is 30 $\mu g/m^3$ and $PM_{2.5}$ is 17 $\mu g/m^3$. This pollution concentration is mainly from India (IGP & northeast), China, Nepal, Bangladesh and Myanmar.

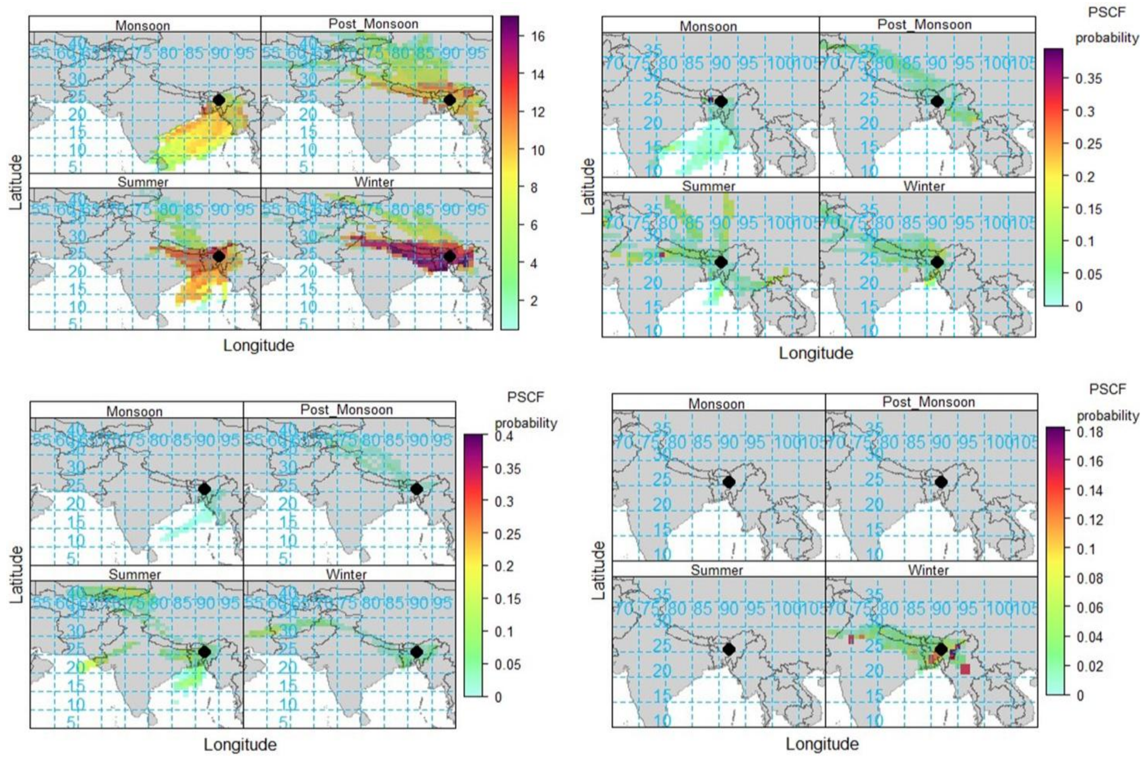

Figure 18-During the period of 2011-2014 & 2015-2019 in Shillong (a) Seasonal CWT of $PM_{2.5}$, (b) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 is IGP and south India (~ 0.14), the main source of SO_2 pollution is China (~0.04) followed by India (North, IGP and north-east) (~0.05) and the main source of PM_{10} pollution is China and UP (~ 0.2).

The potential source of NO_2 pollution from 2015-2019 is IGP and south and north-east India (~ 0.1), the main source of SO_2 pollution is north-east India (~0.02), the main source of PM_{10} pollution is Gujarat, West Bengal and Bihar (~ 0.17) and $PM_{2.5}$ pollution is Iran (~0.14) followed by north-east and IGP (~0.06)

The seasonal PSCF analysis from 2011-2014 in Shillong clearly reveals in monsoon that the main source of NO_2 is Tripura, Manipur, Mizoram, Andhra Pradesh and Myanmar (~0.1) and PM_{10} is West Bengal (~0.35) followed by Tripura, Manipur, Mizoram and Andhra Pradesh. In post-monsoon, the main source of NO_2 is Nepal, Myanmar and UP (~0.15), that of SO_2 is China (~0.08) and of PM_{10} is Myanmar, China, Bhutan and India (North and North-east) (~ 0.5). In summer, the main source of NO_2 is mainly Bay of Bengal (~0.3), SO_2 is Manipur (~ 0.08) & PM_{10} is UP (~0.1). In winter season, NO_2 is coming from UP (~0.3) and PM_{10} is mostly from Nepal and India (north, IGP, north-east) (~0.15).

The seasonal PSCF analysis from 2015-2019 in Shillong clearly reveals in monsoon that the main source of NO_2 is Tripura, Manipur, Mizoram and Myanmar (~ 0.1) and PM_{10} is West Bengal, Myanmar and Bay of Bengal (~ 0.1) followed by Tripura, Manipur, Mizoram and Andhra Pradesh. In post-monsoon, the main source of NO_2 is Nepal, Myanmar, China and UP (~0.11), that of SO_2 is China (~0.08) and of PM_{10} is Myanmar, China, Bhutan and India (North and North-east) (~0.5). In summer, the main source of NO_2 is mainly Bay of Bengal, North-east India (~ 0.15) & PM_{10} is Gujarat, UP, Bihar and West Bengal (~ 0.15). In winter season, PM_{10} is mostly from Nepal, Afghanistan, Iran and India (north and north-east) (~ 0.15) and that of PM2.5 is Manipur (~0.18).

5.1.4 North-West India

I. Jodhpur City

Jodhpur, situated in the western part of Rajasthan, India, has a distinct topography and climate that characterize its weather throughout the year. It is located on the edge of the Thar Desert, also known as the Great Indian Desert. The city itself lies on a rocky plateau, surrounded by the stark landscape of desert terrain. The region is known for its arid conditions, sparse vegetation, and sand dunes. The climate is influenced significantly by its desert surroundings, resulting in extreme temperature variations between seasons. Winters are mild during the day but can be cold at night. Daytime temperatures range from around 10°C to 25°C (50°F to 77°F). Nights can be chilly, with temperatures sometimes dropping below 5°C (41°F). The weather is generally dry with clear skies. Summers are extremely hot and dry. Daytime temperatures often exceed 40°C (104°F), reaching up to 45°C (113°F) or higher in May. The region experiences intense heat waves during this period. Nights provide some relief but can still be warm, with temperatures ranging from 25°C to 30°C (77°F to 86°F). In monsoon, Jodhpur receives minimal rainfall compared to other regions of India due to its desert climate. The southwest monsoon brings sporadic and light rainfall to the area, usually occurring in July and August. Thunderstorms are occasional during this period, providing brief relief from the heat. During post-monsoon season, temperatures begin to decrease gradually. October and November are pleasant months with gradually decreasing temperatures. Daytime temperatures range from 25°C to 35°C (77°F to 95°F), while nights become cooler. Overall, Jodhpur's climate is characterized by its desert environment, featuring hot summers, mild winters, minimal rainfall, and considerable temperature variations between day and night.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Arabian Sea, Pakistan and India (North-west and North India). However, in the period 2015-2019 trajectories originated from Arabian Sea, Pakistan and India (North-west and North India).

Table 11-Trajectory clustering Jodhpur

	Duration	Pakistan	Delhi	Arabian Sea	Rajasthan
Contribution	2011-2014	35 %	15 %	50 %	18 %
Contribution	2015-2019	39 %		47 %	14 %

In seasonal plots from 2011-2014, it was observed that in monsoon season the trajectories originated from India (North-west India) and Arabian Sea. The maximum trajectories originate from winds blowing from Arabian Sea (~90%), followed by UP (~10%). In post-monsoon, the trajectories originated from Pakistan, India (North-west and central) and Arabian Sea. The maximum trajectories emerged from Pakistan (~89%), followed by (~21%). In summer, trajectories stem from Pakistan and India (North-west and Central). The highest trajectories from Arabian Sea (~ 63%), accompanied by Afghanistan (~20%) and Punjab (~ 17%). In winter, it was monitored that the trajectories rise from Pakistan and India (North-west and Central). The most trajectories from Pakistan (~53%) followed by Haryana (~31%) and Rajasthan (~1%)

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from India (North-west India) and Arabian Sea. The maximum trajectories originate from winds blowing from Arabian Sea (~90%), followed by UP(~10%). In post-monsoon, the trajectories originated from Pakistan, India (North-west and central) and Arabian Sea. The maximum trajectories emerged from Pakistan (~55%), Haryana (~25%), and Afghanistan (~20%). In summer, trajectories stem from Pakistan and India (North-west and Central). The highest trajectories from Pakistan (~84%), accompanied by Arabian Sea (~ 46 %) and Madhya Pradesh (~5%). In winter, it was monitored that the trajectories rise from Pakistan and India (North-west and Central). The most trajectories from Pakistan (~48%) followed by Afghanistan (~29%), and Rajasthan (~23%).

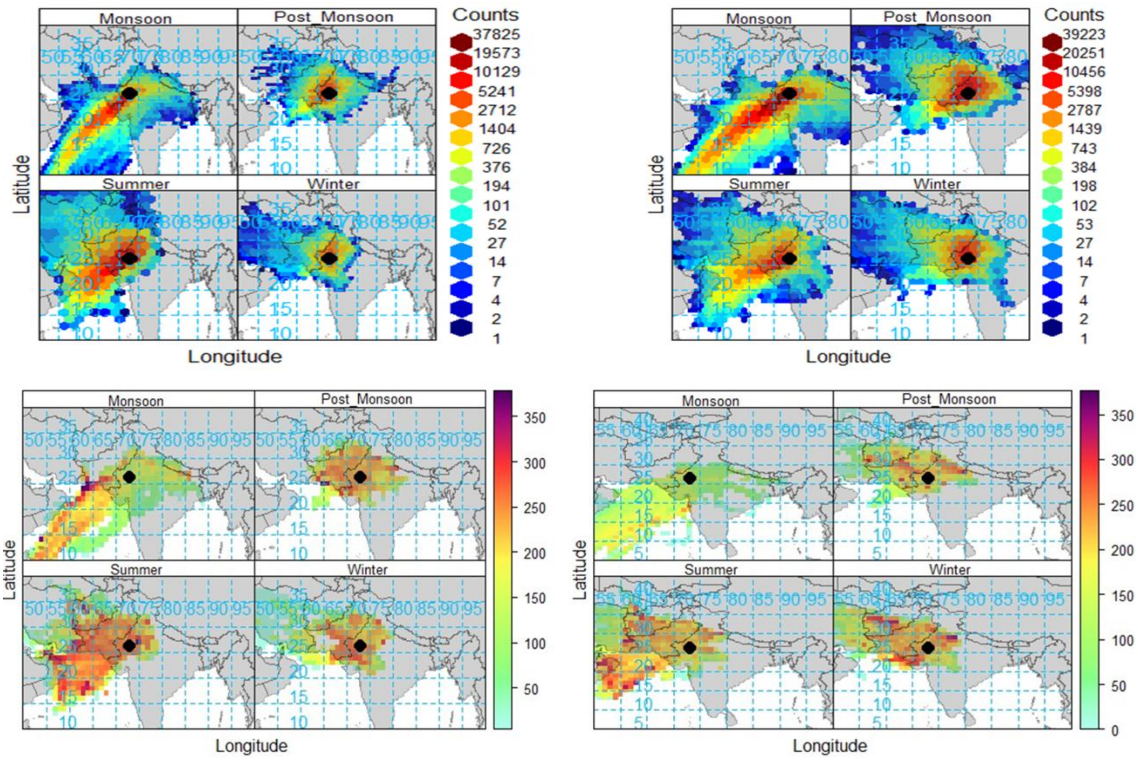

Figure 19-During the period of 2011-2014 & 2015-2019 resp. in Jodhpur (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

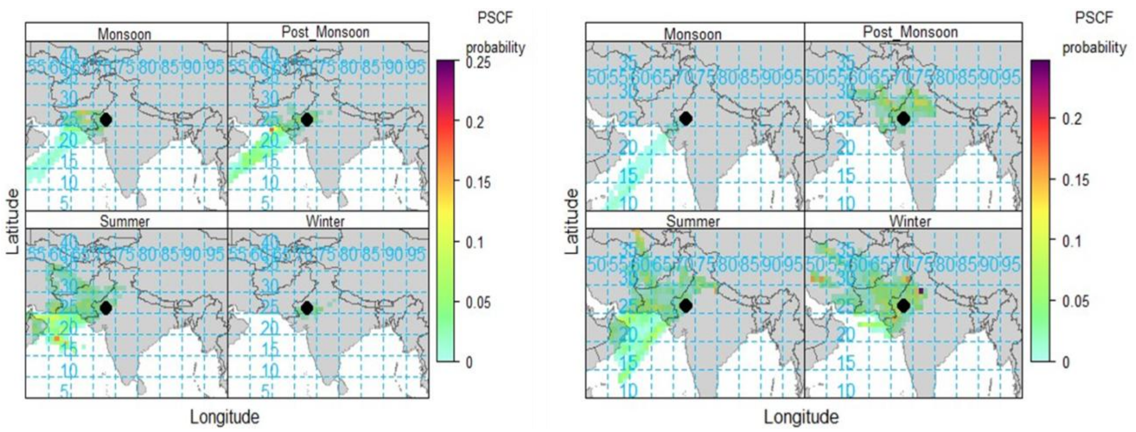

Figure 20-During the period of 2011-2014 & 2015-2019 in Jodhpur (a) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 & SO_2 is around 33 µg/m^3 & 9 µg/m^3 mainly from Pakistan, Afghanistan, Iran, Oman, Arabian Sea & India (North, north-west & IGP). The concentration of PM_{10} is found to be 325 µg/m^3 mainly from UP, Punjab, Himachal Pradesh, Haryana, Rajasthan, Gujarat, winds blowing from Arabian Sea, Pakistan, Afghanistan, Iran, Oman & Nepal.

During 2015-2019, the concentration of NO_2 & SO_2 is around 36 μg/m^3 & 10 μg/m^3 mainly from Pakistan, Afghanistan, Iran, Oman, Arabian Sea & India (North, north-west and IGP). The concentration of PM_{10} is found to be 325 μg/m^3 mainly from UP, Punjab, Himachal Pradesh, Haryana, Rajasthan, Gujarat, winds blowing from Arabian Sea, Pakistan, Afghanistan, Iran, Oman & Nepal.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 25 μg/m^3, SO_2 is 11 μg/m^3 and PM_{10} is 350 μg/m^3 mainly from North-west, Pakistan and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 8 μg/m^3 & 45 μg/m^3 and that of PM_{10} is 350 μg/m^3 mainly from (north, IGP, north-west) India along with Pakistan. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 6 μg/m^3 & 25 μg/m^3 which are influenced by (north, IGP, north-west) India and Pakistan and PM_{10} is about 300 μg/m^3 from IGP and north-west India along with Pakistan. The concentration of NO_2 and SO_2 in winter is about 35 μg/m^3 & 8 μg/m^3 and of PM_{10} is 275 μg/m^3. This pollution concentration is mainly from India (IGP & north-west) and Pakistan.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 25 μg/m^3, SO_2 is 8 μg/m^3 and PM_{10} is 250 μg/m^3 mainly from North-west, Pakistan and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 11 μg/m^3 & 45 μg/m^3 and that of PM_{10} is 350 μg/m^3 mainly from (north, IGP, north-west) India along with Pakistan and Afghanistan. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 11 μg/m^3 & 35 μg/m^3 which are influenced by (north, IGP, north-west) India, Pakistan, Afghanistan and PM_{10} is about 325 μg/m^3 from IGP and north-west India along with Pakistan. The concentration of NO_2 and SO_2 in winter is about 45 μg/m^3 & 8 μg/m^3 and of PM_{10} is 375 μg/m^3. This pollution concentration is mainly from India (IGP & north-west), Pakistan and Afghanistan.

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 in Jodhpur is Pakistan (~ 0.12) followed by IGP & north-west India (~ 0.1), the main source of SO_2 pollution is Rajasthan & Pakistan (~ 0.1), the main source of PM_{10} pollution is Pakistan & winds blowing from Arabian Sea (~ 0.08), followed by north-west India.

The potential source of NO_2 pollution from 2015-2019 in Jodhpur is Afghanistan and Pakistan (~0.12) followed by Punjab and Haryana (~ 0.1), the main source of SO_2 pollution is Afghanistan (~0.09), the main source of PM_{10} pollution is Haryana (~ 0.15), followed by Turkmenistan, north-west India, Pakistan and Afghanistan.

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of SO_2 is winds blowing from Arabian Sea (~0.03) & of PM_{10} pollution is Pakistan (~0.13). In post-monsoon, Gujarat & Pakistan is the main source of NO_2 (~0.22), SO_2 pollution from Gujarat and Pakistan (~0.2) & winds from Arabian Sea are the main source of PM_{10} (~0.3) followed by IGP (~0.25). In summer season, SO_2 is originating mainly from Rajasthan (~0.05) & the PM_{10} sources were winds blowing from Arabian Sea (~0.2), followed by Pakistan (~0.1), followed by J&K & Himachal Pradesh (~0.1). In winter season, Pakistan is the main source of NO_2 (~0.2), SO_2 pollution from Pakistan (~0.14) & Rajasthan is the main source of PM_{10} (~ 0.05).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of PM_{10} pollution is Gujarat and winds blowing from Arabian Sea (~0.05). In post-monsoon, Punjab and Pakistan is the main source of NO_2 (~ 0.22), SO_2 pollution from Uttrakhand and Afghanistan (~0.15) and Punjab and Pakistan are the main source of PM_{10} (~0.3) followed by IGP (~0.25). In summer season, SO_2 is originating mainly from Gujarat and winds blowing from Arabian Sea (~0.05) and the PM_{10} sources were Punjab, Himachal Pradesh, Afghanistan and Pakistan (~ 0.13). In winter season, Pakistan is the main source of NO_2 (~ 0.2), SO_2 pollution from Iran and Pakistan (~ 0.1) and Haryana is the main source of PM_{10} (~ 0.25) followed by Pakistan (~0.17).

II. Vadodara City

Vadodara, located in the western part of Gujarat, India, exhibits unique topographical and climatic characteristics influenced by its geographical location and landscape. It is situated on the banks of the Vishwamitri River and is surrounded by hills on the east and west sides. The city itself is located in the fertile plains of the eastern part of Gujarat, known for its agricultural productivity. The terrain is relatively flat compared to other parts of Gujarat. The climate is predominantly influenced by its proximity to the Arabian Sea and its location on the Gujarat plains. Winters are mild and pleasant. Daytime temperatures range from around 15°C to 30°C (59°F to 86°F). Nights can be cool, with temperatures occasionally dropping to around 10°C (50°F). The weather is generally dry with clear skies. Summers are hot and dry.

Daytime temperatures rise significantly, ranging from 30°C to 45°C (86°F to 113°F) or higher, especially in May. Heat waves are common during this period, with temperatures occasionally exceeding 40°C (104°F). Nights provide little relief, remaining warm with temperatures around 25°C to 30°C (77°F to 86°F). Monsoon season is characterized by moderate to heavy rainfall. The southwest monsoon brings substantial precipitation to the region, vital for agriculture. Humidity levels increase significantly during this time, making the weather relatively humid. In post-monsoon, the weather gradually becomes more pleasant. October and November are transition months with decreasing temperatures and clearer skies. Daytime temperatures range from 25°C to 35°C (77°F to 95°F), while nights become cooler. Overall, Vadodara's climate is influenced by its geographical location on the Gujarat plains, with hot summers, mild winters, a distinct monsoon season with heavy rainfall, and a transitional period between seasons.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Arabian Sea, Pakistan and India (North-west and North India). However, in the period 2015-2019 trajectories originated from Arabian Sea, Pakistan and India (North-west and North India).

Table 12-Trajectory clustering Vadodara

	Duration	**MP**	**Arabian Sea**	**Rajasthan**
Contribution	2011-2014	19 %	67 %	14 %
Contribution	2015-2019	20 %	65 %	15 %

In seasonal plots from 2011-2014, it was observed that in monsoon season the trajectories originated from India (North-west India) and Arabian Sea. The maximum trajectories originate from winds blowing from Arabian Sea (~95%), followed by Gujarat (~5%). In post-monsoon, the trajectories originated from Pakistan, India (North-west and central) and Arabian Sea. The maximum trajectories emerged from Madhya Pradesh (~42%), Rajasthan (~30%), winds blowing from Arabian Sea (~16%), Rajasthan, Gujarat and Pakistan (~12%). In summer, trajectories stem from Pakistan and India (North-west and Central). The highest trajectories from Arabian Sea (~ 81%), accompanied by Pakistan (~ 11%) and Madhya Pradesh (~7%). In winter, it was monitored that the trajectories rise from Pakistan and India (North-west and Central). The most trajectories from Arabian Sea (~ 34%) followed by Rajasthan (~27%), Pakistan (~20%) and Maharashtra (~19%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from India (North-west India) and Arabian Sea. The maximum trajectories originate from winds blowing from Arabian Sea (~97%), followed by Rajasthan (~3%). In post-monsoon, the trajectories originated from Pakistan, India (North-west and central) and Arabian Sea. The maximum trajectories emerged from Madhya Pradesh (~36%), Rajasthan (~31%), winds blowing from Arabian Sea (~19%) and Pakistan (~13%). In summer, trajectories stem from Pakistan and India (North-west and Central). The highest trajectories from Arabian Sea (~84%), accompanied by Pakistan (~11%) and Madhya Pradesh (~5%). In winter, it was monitored that the trajectories rise from Pakistan and India (North-west and Central). The most trajectories from Arabian Sea (~29%) followed by Madhya Pradesh (~27%), Pakistan (~25%) and Rajasthan (~19%).

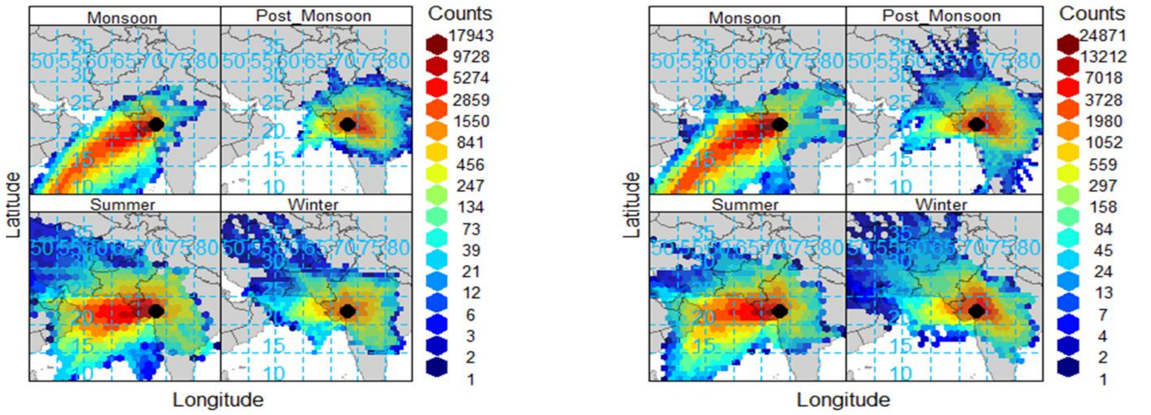

Figure 21- Seasonal distribution of trajectories in the form of hexagonal counts during the period of 2011-2014 & 2015-2019 resp. in Vadodara

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 & SO_2 is around 37 μg/m^3 & 17 μg/m^3 mainly from Pakistan, Iran and India (North-west and IGP). The concentration of PM_{10} is found to be 150 μg/m^3 mainly Rajasthan, Telangana, winds blowing from Arabian Sea, Pakistan, Iran and Nepal and that of $PM_{2.5}$ is 60 μg/m^3, mainly coming from Chattisgarh and Andhra Pradesh.

During 2015-2019, the concentration of NO_2 & SO_2 is around 37 μg/m^3 & 19 μg/m^3 mainly from Pakistan, Iran & India (North-west & IGP). The concentration of PM_{10} is found to be 150 μg/m^3 mainly Rajasthan, Telangana, winds blowing from Arabian Sea, Pakistan & Iran & that of $PM_{2.5}$ is 70 μg/m^3, mainly coming from Chattisgarh, Andhra Pradesh & Rajasthan.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 25 μg/m^3, SO_2 is 15 μg/m^3 & PM_{10} is 100 μg/m^3 mainly from North-west, Pakistan & winds blowing from Arabian Sea. $PM_{2.5}$ concentration is around 40 µg/m^3 mainly from north-west India & Arabian Sea. In post-monsoon, the SO_2 & NO_2 concentration is around 15 µg/m^3 & 35 µg/m^3 & that of PM_{10} is 100 µg/m^3 mainly from (IGP, north-west) India along with Pakistan. $PM_{2.5}$ concentration is 60 µg/m^3 arising from central India. In summer, the pollution is not widespread & the concentration of SO_2 & NO_2 is observed to be 11 µg/m^3 & 25 µg/m^3 which are influenced by (IGP, north-west) India, Pakistan & PM_{10} is about 250 µg/m^3 from IGP & north-west India along with Pakistan. $PM_{2.5}$ concentration is 80 µg/m^3 arising from Gujarat. The concentration of NO_2 & SO_2 in winter is about 40 µg/m^3 & 15 µg/m^3 & of PM_{10} is 100 µg/m^3. This pollution concentration is mainly from India (IGP & north-west) & Pakistan. $PM_{2.5}$ is about 30 µg/m^3 mainly from central & North-west India.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 35 µg/m^3, SO_2 is 25 µg/m^3 & PM_{10} is 200 µg/m^3 mainly from North-west, Pakistan & winds blowing from Arabian Sea. $PM_{2.5}$ concentration is around 70 µg/m^3 mainly from north-west India & Arabian Sea. In post-monsoon, the SO_2 & NO_2 concentration is around 30 µg/m^3 & 35 µg/m^3 & that of PM_{10} is 225 µg/m^3 mainly from (IGP, north-west & central) India along with Pakistan. $PM_{2.5}$ concentration is 70 µg/m^3 arising from central India. In summer, the pollution is not widespread & the concentration of SO_2 & NO_2 is observed to be 30 µg/m^3 & 40 µg/m^3 which are influenced by (IGP, north-west) India, Pakistan & PM_{10} is about 250 µg/m^3 from Central & north-west India along with Pakistan. $PM_{2.5}$ concentration is 100 µg/m^3 arising from Gujarat. The concentration of NO_2 & SO_2 in winter is about 45 µg/m^3 & 40 µg/m^3 & of PM_{10} is 275 µg/m^3. This pollution concentration is mainly from India (Central & north-west) & Pakistan. $PM_{2.5}$ is about 90 µg/m^3 mainly from central, North-west India & Pakistan.

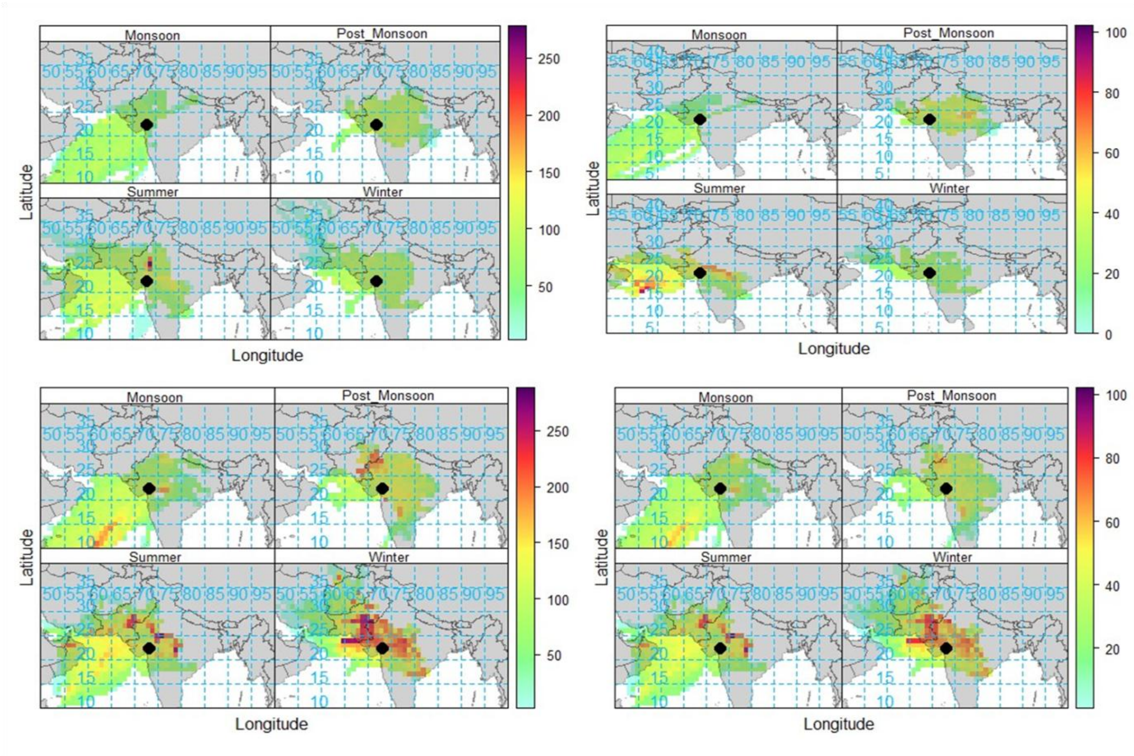

Figure 22-During the period of 2011-2014 & 2015-2019 resp. in Vadodara (a) Seasonal CWT of PM_{10} (b) $PM_{2.5}$

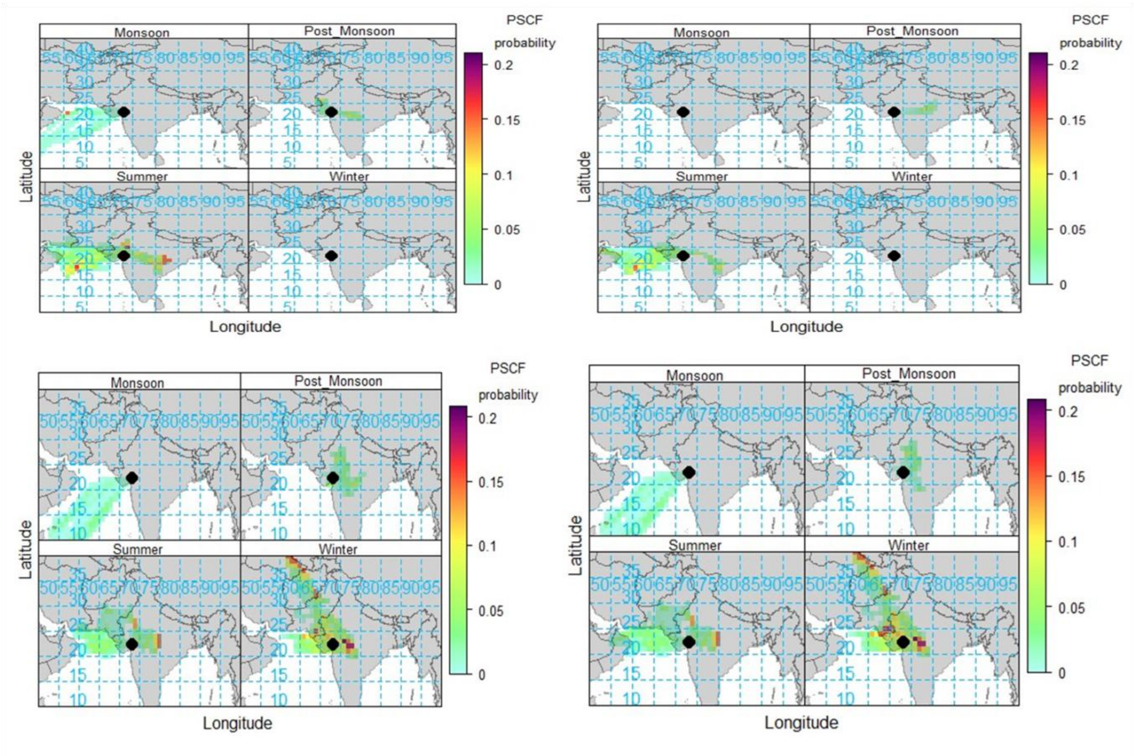

Figure 23-During the period of 2011-2014 & 2015-2019 resp. in Vadodara (a) Seasonal PSCF of PM_{10} (b) $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 in Vadodara is Rajasthan (~ 0.16) followed by north-west India (~ 0.1), the main source of SO_2 pollution is Rajasthan and UP (~0.16), the main source of PM_{10} pollution is Maharashtra (~ 0.09), followed by north-west India and that of $PM_{2.5}$ is MP and Maharashtra (~0.08).

The potential source of NO_2 pollution from 2015-2019 in Vadodara is Pakistan, Afghanistan, Tajikistan, Turkmenistan and Uzbekistan (~0.16) followed by north-west India (~ 0.1), the main source of SO_2 pollution is Afghanistan, Tajikistan, Turkmenistan and Uzbekistan (~ 0.16), the main source of PM_{10} pollution is Pakistan, Afghanistan, Turkmenistan, Uzbekistan, Rajasthan and Madhya Pradesh (~ 0.09), followed by north-west India and that of $PM_{2.5}$ is Afghanistan and Turkmenistan (~0.14).

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of PM_{10} pollution is winds blowing from Arabian Sea (~0.15). In post-monsoon, Maharashtra is the main source of NO_2 (~0.13), SO_2 pollution from Gujarat and Pakistan (~0.2), Rajasthan is the main source of PM_{10} (~ 0.1) followed by Maharashtra (~ 0.05) and $PM_{2.5}$ originates from Maharashtra (~0.07). In summer season, NO_2 is coming mainly from Gujarat and Rajasthan (~ 0.25), SO_2 is originating mainly from Rajasthan (~0.05), the PM_{10} sources was Gujarat and Rajasthan (~0.2), followed by Arabian Sea (~0.15) and $PM_{2.5}$ is mainly coming from Arabian Sea (~0.15). In winter season, Arabian Sea is the main source of NO_2 (~0.2), SO_2 pollution from Pakistan (~0.14) and Rajasthan is the main source of PM_{10} (~0.05).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2, SO_2 is Gujarat (~0.05), PM_{10} and $PM_{2.5}$ pollution is winds blowing from Arabian Sea (~0.05). In post-monsoon, Maharashtra is the main source of NO_2 (~0.13), SO_2 pollution from Gujarat and Pakistan (~0.2), Rajasthan is the main source of PM_{10} and $PM_{2.5}$ (~0.05) followed by Maharashtra (~0.05) and $PM_{2.5}$ originates from Maharashtra (~0.07). In summer season, NO_2 is coming mainly from Gujarat and Rajasthan (~ 0.25), SO_2 is originating mainly from Rajasthan (~ 0.05), the PM_{10} and $PM_{2.5}$ sources was Maharashtra and Rajasthan (~ 0.15), followed by Arabian Sea (~0.15). In winter season, Arabian Sea is the main source of NO_2 (~ 0.2), SO_2 pollution from Pakistan and Gujarat (~0.14) and Maharashtra and Pakistan is the main source of PM_{10} (~0.05) and PM2.5 (~0.2).

III. Daman City

Daman, located on the western coast of India, is a part of the union territory of Daman and Diu. It has its own unique topographical and climatic characteristics influenced by its coastal location. It is situated on a small peninsula on the southern bank of the Daman Ganga River. It is characterized by flat terrain with sandy beaches along its coastline. The region is relatively small and is known for its picturesque coastal landscape. The climate is predominantly influenced by its coastal proximity and tropical monsoon climate. Winters are mild and pleasant. Daytime temperatures range from around 20°C to 30°C (68°F to 86°F). Nights can be cooler, with temperatures occasionally dropping to around 15°C (59°F). The weather is generally dry and comfortable. Summers are hot and humid, typical of coastal areas. Daytime temperatures rise significantly, ranging from 30°C to 35°C (86°F to 95°F) or higher. Humidity levels are high, making the weather feel hotter than the actual temperature. Nights remain warm, with temperatures around 25°C to 30°C (77°F to 86°F). It experiences a monsoon season characterized by heavy rainfall. The southwest monsoon brings abundant rainfall to the region, with July and August being the wettest months. The rain cools down the temperature but increases humidity levels significantly. In post-monsoon season, the weather gradually becomes more pleasant. October and November are transition months with decreasing temperatures and clearer skies. Daytime temperatures range from 25°C to 30°C (77°F to 86°F), while nights become cooler. Overall, climate is influenced by its coastal location, featuring mild winters, hot and humid summers, a significant monsoon season with heavy rainfall, and a transitional period between seasons. The coastal environment also plays a role in shaping the local economy, tourism, and lifestyle.

It was observed from the hexagonal counts in the period 2017-2019 that the trajectories originated from Arabian Sea, Pakistan and India (North-west and North India).

Table 13-Trajectory clustering Daman

	Duration	**MP**	**Arabian Sea**	**Rajasthan**
Contribution	2015-2019	26 %	61 %	14 %

In seasonal plots from 2015-2019, it was observed that in monsoon season the maximum trajectories originate from winds blowing from Arabian Sea (~100%). In post-monsoon, the trajectories originated from India (North-west and central) and Arabian Sea. The maximum trajectories emerged from Maharashtra (~42%), Madhya Pradesh (~37%), Gujarat (~13%) and Arabian Sea (~9%). In summer, trajectories stem from India (North-west). The highest trajectories from Arabian Sea (~88%), accompanied by Rajasthan (~12%). In winter, it was monitored that the trajectories rise from Pakistan and India (North-west and Central). The most trajectories from Maharashtra (~34%) followed by Rajasthan (~29%), Arabian Sea (~22%) and Pakistan (~15%).

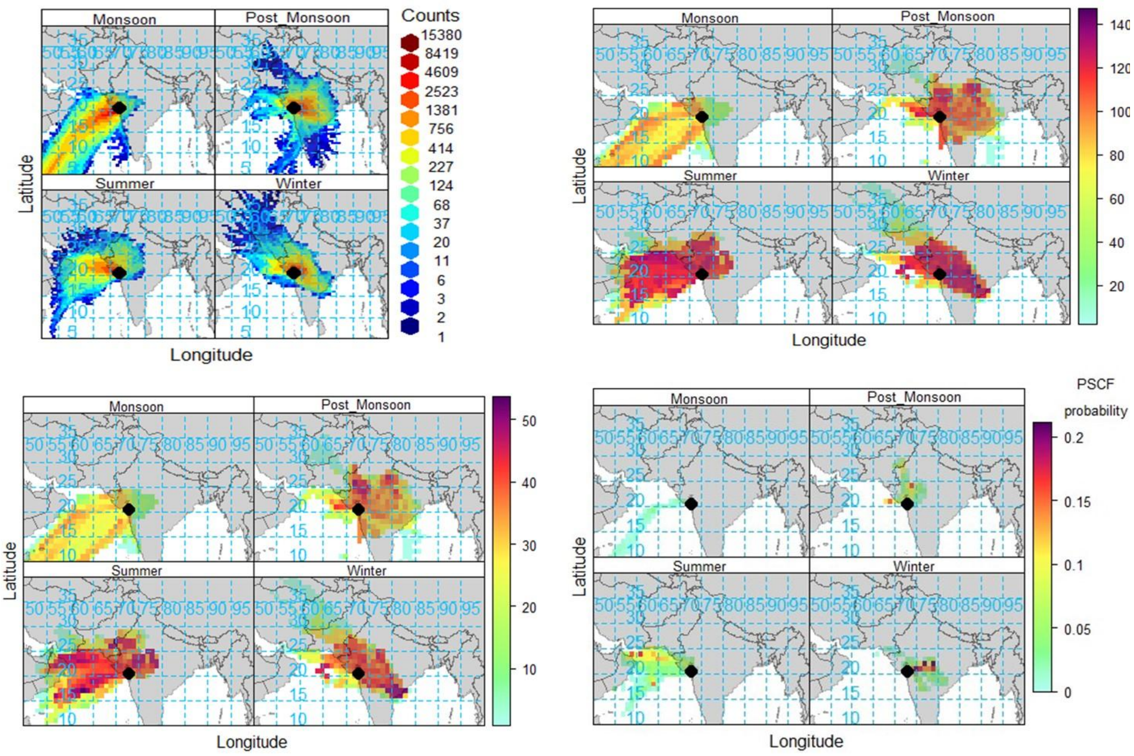

Figure 24-During the period of 2015-2019 in Daman (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10} (c) Seasonal CWT of $PM_{2.5}$ (d) Seasonal PSCF of PM_{10}

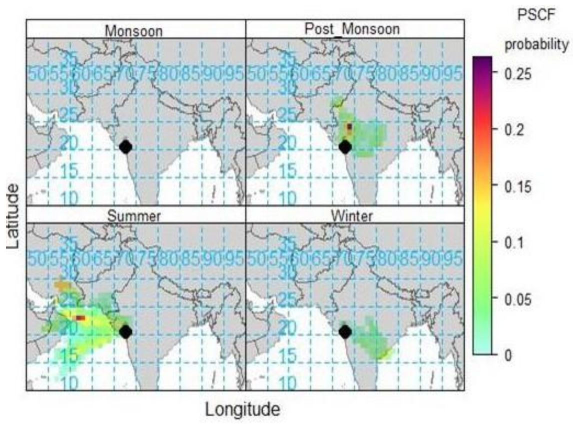

Figure 25-Seasonal PSCF of $PM_{2.5}$

(A) CWT Analysis

During 2017-2019, the concentration of NO_2 & SO_2 is around 35 µg/m^3 & 35 µg/m^3 mainly from Pakistan and India (North-west, south and IGP). The concentration of PM_{10} is found to be 130 µg/m^3 mainly Rajasthan, Telangana, winds blowing from Arabian Sea and Pakistan and that of $PM_{2.5}$ is 50 µg/m^3, mainly coming from Rajasthan and Andhra Pradesh.

The CWT analysis of different seasons from 2017-2019 shows that the concentration of NO_2 in monsoon is shown to be around 25 µg/m^3, SO_2 is 20 µg/m^3 and PM_{10} is 100 µg/m^3 mainly from North-west India and winds blowing from Arabian Sea. $PM_{2.5}$ concentration is around 40 µg/m^3 mainly from north-west India and Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 35 µg/m^3 & 35 µg/m^3 and that of PM_{10} is 120 µg/m^3 mainly from (IGP, north-west and central) India. $PM_{2.5}$ concentration is 50 µg/m^3 arising from central, IGP and north-west India. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 35 µg/m^3 & 40 µg/m^3 which are influenced by (IGP & north-west) India, Pakistan and PM_{10} is about 140 µg/m^3 from IGP and north-west India along with Pakistan. $PM_{2.5}$ concentration is 80 µg/m^3 arising from Gujarat. The concentration of NO_2 and SO_2 in winter is about 40 µg/m^3 & 40 µg/m^3 and of PM_{10} is 140 µg/m^3. This pollution concentration is mainly from India (IGP & north-west). $PM_{2.5}$ is about 50 µg/m^3 mainly from central and North-west India.

(B) PSCF Analysis

The potential source of NO_2 pollution from 2017-2019 was Arabian Sea (~0.1) followed by north-west India (~ 0.1), the main source of SO_2 pollution was UP, Afghanistan and Turkmenistan (~ 0.14), the main source of PM_{10} and $PM_{2.5}$ pollution was Arabian Sea (~ 0.12) and (~0.15).

The PSCF analysis from 2017-2019, reveals that in monsoon the potential source of PM_{10} pollution is winds blowing from Arabian Sea (~0.05). In post-monsoon, SO_2 pollution from Gujarat and Rajasthan (~0.25), Gujarat and Arabian Sea is the main source of PM_{10} (~0.15) followed by Maharashtra (~ 0.05) and $PM_{2.5}$ originates from Gujarat (~ 0.25). In summer season, NO_2 is coming mainly from Maharashtra (~ 0.2), SO_2 is originating mainly from Gujarat (~0.05), the PM_{10} sources was Arabian Sea (~0.17), followed by Gujarat (~0.05) and $PM_{2.5}$ is mainly coming from Arabian Sea (~0.2). In winter season, Gujarat is the main source of NO_2 (~0.2), SO_2 pollution from Gujarat (~0.25), Maharashtra is the main source of PM_{10} (~ 0.2) and Andhra Pradesh is the main source of $PM_{2.5}$ (~0.14).

5.1.5 Central India

I. Bhubaneshwar City

Bhubaneswar, the capital city of Odisha, is located in the eastern part of India. It lies in the coastal plains, specifically on the eastern coastal plains, which are a part of the larger Eastern Ghats range. The city is situated at an average elevation of about 45 meters (148 feet) above sea level. The topography is generally flat, with a gentle slope towards the Bay of Bengal. The region around it features a mix of urban landscapes, fertile agricultural land, and areas of forest cover. It experiences a tropical savanna climate (Köppen climate classification Aw), characterized by distinct wet and dry seasons. The climate can be divided into three main seasons: Summers are hot and humid. Temperatures can reach up to 40°C (104°F), with May being the hottest month. High humidity levels often make the heat feel more intense. In monsoon, the city receives heavy rainfall. The average annual rainfall is around 1,540 mm (60.6 inches), with the bulk of it occurring between June and September. Monsoons bring relief from the summer heat but can also lead to flooding and water logging in some areas. Winters are mild and pleasant. Temperatures range from 15°C to 28°C (59°F to 82°F). January is typically the coolest month, with occasional dips in temperature, especially during early mornings and nights.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Arabian Sea, Bay of Bengal and India (North-east, IGP and central India). However, in the period 2011-2014 trajectories originated from Arabian Sea, Bay of Bengal and India (North-east, IGP and central India).

Table 14-Trajectory clustering Bhubaneshwar

	Duration	**West Bengal**	**UP**	**MP**	**Bihar**	**Arabian Sea**	**Bay of Bengal**
Contribution	2011-2014			25 %	13 %	33 %	28 %
Contribution	2015-2019	11 %	25 %			33 %	32 %

In seasonal plots from 2012-2014, it was observed that in monsoon season the trajectories originated from Arabian Sea, Bay of Bengal and central India. The maximum trajectories originate from Arabian Sea (~ 66%), followed by Madhya Pradesh (~ 22%) and Bay of Bengal (~ 12%). In post-monsoon, the trajectories originated from Bay of Bengal and India

(Indo Gangetic Plains and north-east). The maximum trajectories emerged from UP (~66%), followed by West Bengal (~21%) and Bay of Bengal (~13%). In summer, trajectories stem from Bay of Bengal and India (central and Indo-Gangetic Plains). The highest trajectories from Bay of Bengal (~ 70%), accompanied by UP (~16%) and Maharashtra (~16%). In winter, it was monitored that the trajectories rise from Bay of Bengal and IGP. The most trajectories from UP (~40%), Jharkhand (~30%) and Bay of Bengal (~30%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from Arabian Sea, Bay of Bengal and India (North-west and central). The maximum trajectories originate from Arabian Sea (~45%), followed by Daman and Diu (~ 30%), Andhra Pradesh (~18%) and Bay of Bengal (~7%). In post-monsoon, the trajectories originated from Bay of Bengal, Bangladesh and India (Indo Gangetic Plains and central). The maximum trajectories emerged from UP (~ 68%), followed by Bangladesh (~ 19%) and Andhra Pradesh (~13%). In summer, trajectories stem from Bay of Bengal and India (central and Indo-Gangetic Plains). The highest trajectories from Bay of Bengal (~ 78%), accompanied by Maharashtra (~14%) and UP (~8%). In winter, it was monitored that the trajectories rise from Bay of Bengal and India (IGP, central and north-east). The most trajectories from MP (~34%), UP (~30%), Bay of Bengal (~30%) and West Bengal (~8%).

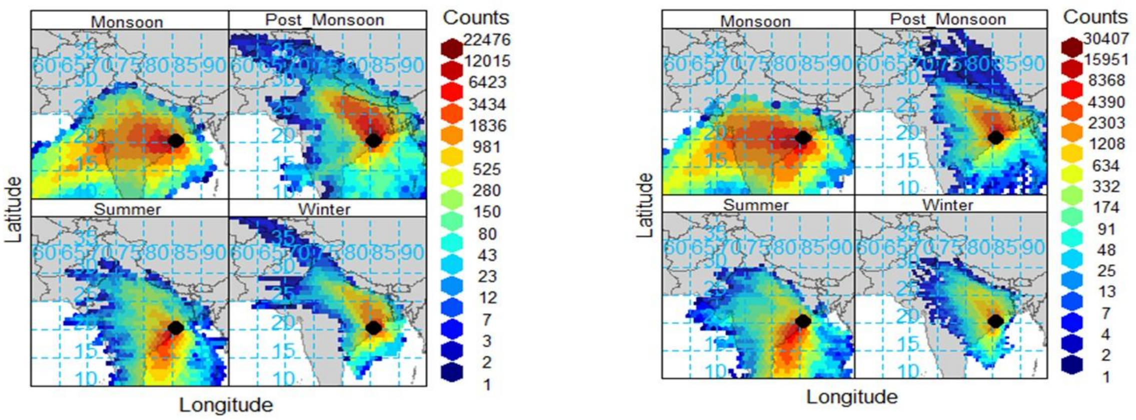

Figure 26-During the period of 2011-2014 & 2015-2019 resp. in Bhubaneshwar seasonal distribution of trajectories in the form of hexagonal counts

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 & SO_2 is around 25 µg/m^3 & 5 µg/m^3 mainly from Bay of Bengal, Nepal & India (North, north-east & IGP).The concentration of PM_{10} is found to be 150 µg/m^3 mainly from UP, Bihar, Jharkhand, West Bengal, Bay of Bengal, Nepal, Bangladesh & Myanmar. The concentration of $PM_{2.5}$ was found to be 90 µg/m^3 mainly from IGP & North-east India.

During 2015-2019, the concentration of NO_2 & SO_2 is around 35 µg/m^3 & 5 µg/m^3 mainly from Bay of Bengal, Nepal & India (North, north-east & IGP).The concentration of PM_{10} is found to be 200 µg/m^3 mainly from UP, Bihar, Jharkhand, West Bengal & Bangladesh. The concentration of $PM_{2.5}$ was found to be 120 µg/m^3 mainly from West Bengal & Bangladesh.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 15 µg/m^3, SO_2 is 2 µg/m^3, PM_{10} is 50 µg/m^3 & $PM_{2.5}$ is 50 µg/m^3 mainly from North-east, IGP, Nepal & winds blowing from Bay of Bengal. In post-monsoon, the SO_2 & NO_2 concentration is around 5 µg/m^3 & 25 µg/m^3 & that of PM_{10} is 160 µg/m^3 mainly from (north, IGP, north-east) India along with Bangladesh & Nepal. In summer, the pollution is not widespread & the concentration of SO_2 & NO_2 is observed to be 2 µg/m^3 & 25 µg/m^3 which are influenced by (north, IGP, north-east) India, Bangladesh, Bhutan, Myanmar & Nepal, PM_{10} is about 120 µg/m^3 & $PM_{2.5}$ is about 70 µg/m^3 from Odisha, Bihar, West Bengal, Jharkhand, IGP & northeast India along with Nepal & Bangladesh. The concentration of NO_2 & SO_2 in winter is about 30 µg/m^3 & 3 µg/m^3, PM_{10} is 150 µg/m^3 & $PM_{2.5}$ is 100 µg/m^3. This pollution concentration is mainly from India (IGP & northeast), Nepal & Bangladesh.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 30 µg/m^3, SO_2 is 2 µg/m^3, PM_{10} is 50 µg/m^3 and $PM_{2.5}$ is 50 µg/m^3 mainly from North-east, IGP, Nepal and winds blowing from Bay of Bengal. In post-monsoon, the SO_2 and NO_2 concentration is around 6 µg/m^3 & 30 µg/m^3 and that of PM_{10} & $PM_{2.5}$ is 250 µg/m^3 and 250 µg/m^3 mainly from (north, IGP, north-east) India along with Bangladesh and Nepal. In summer, the pollution is not widespread and the concentration of SO_2 and NO_2 is observed to be 2 µg/m^3 & 25 µg/m^3 which are influenced by (north, IGP, north-east) India, Bangladesh, Bhutan, Myanmar and Nepal, PM_{10} is about 100 µg/m^3 and $PM_{2.5}$ is about 100 µg/m^3 from Odisha, Bihar, West Bengal, Jharkhand, IGP and northeast India along with Nepal and Bangladesh. The concentration of NO_2 and SO_2 in winter is about 25 µg/m^3 & 2 µg/m^3, PM_{10} is 150 µg/m^3 and $PM_{2.5}$ is 150 µg/m^3. This pollution concentration is mainly from India (IGP & northeast), Nepal and Bangladesh.

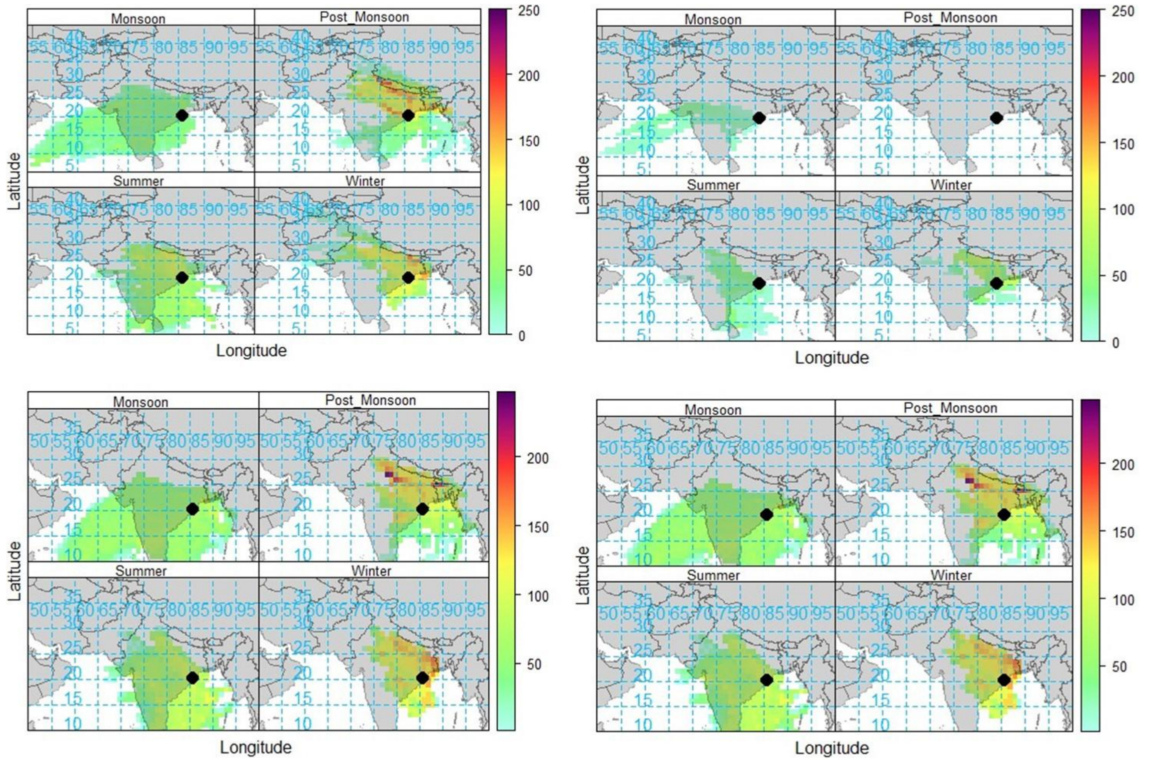

Figure 27-During the period of 2011-2014 & 2015-2019 resp. in Bhubaneshwar (a) Seasonal CWT of PM_{10} (b) Seasonal CWT of $PM_{2.5}$

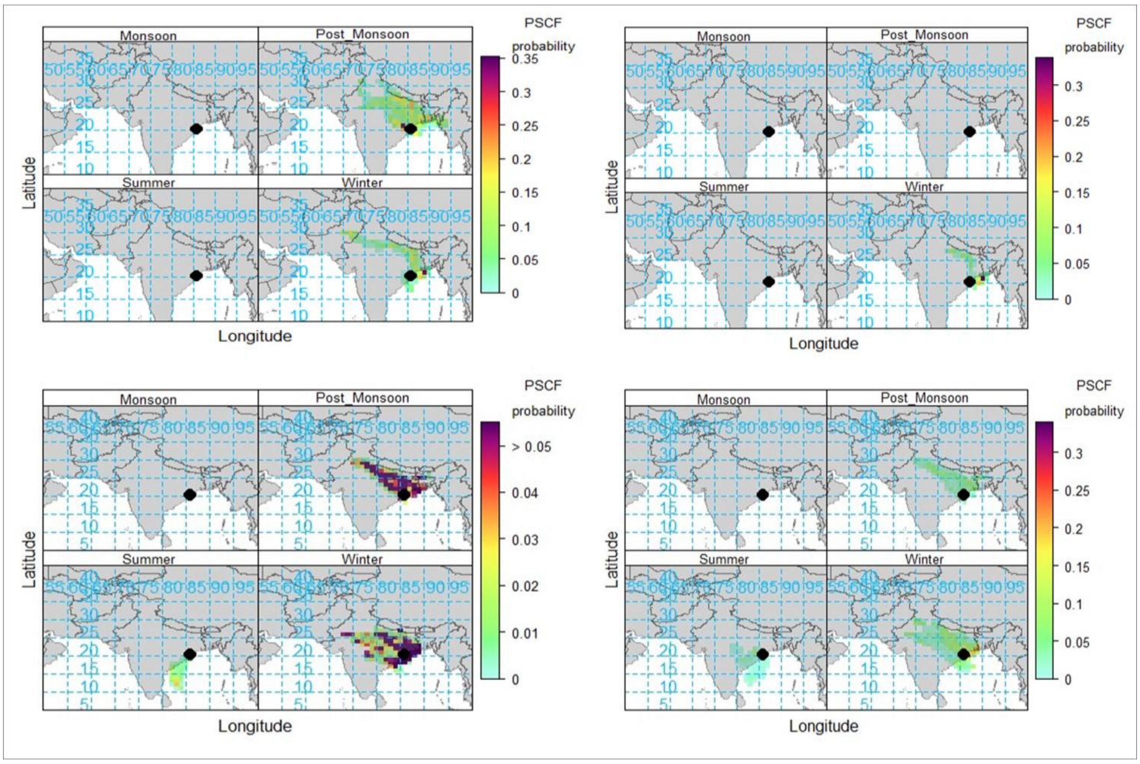

Figure 28-During the period of 2011-2014 & 2015-2019 resp. in Bhubaneshwar (a) Seasonal PSCF of PM_{10} (b) Seasonal PSCF of $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 is Pakistan, North & north-east India (~ 0.14), the main source of SO_2 pollution is Uttrakhand and Tamil Nadu (~0.025), the main source of PM_{10} pollution is Pakistan, Bangladesh and India (IGP and north-east) (~ 0.12) and $PM_{2.5}$ pollution is winds blowing across Bay of Bengal (~0.08).

The potential source of NO_2 pollution from 2015-2019 is Pakistan and Mayanmar (~ 0.15), the main source of SO_2 pollution is Bihar (~0.035), the main source of PM_{10} pollution is UP (~ 0.12) and $PM_{2.5}$ pollution is West Bengal, Bihar and Punjab (~0.08).

The seasonal PSCF analysis from 2011-2014 in Shillong clearly reveals in post-monsoon, the main source of NO_2 is Bihar (~0.18), that of SO_2 is Nepal (~0.06) and of PM_{10} is Odisha (~ 0.35). In summer, the main source of NO_2 is mainly Bay of Bengal central India (~0.08) and SO2 from Tamil Nadu (~0.04). In winter season, NO_2 is mostly from Bihar (~0.18), PM_{10} is mostly from winds blowing from Bay of Bengal (~0.35) and that of $PM_{2.5}$ is winds blowing from Bay of Bengal (~0.3).

The seasonal PSCF analysis from 2015-2019 in Shillong clearly reveals in monsoon season NO_2 mainly emerges from Odisha & Andhra Pradesh (~0.06). In post-monsoon, the main source of NO_2 is Bangladesh (~0.16), that of SO_2 is UP & West Bengal (~0.045), that of PM_{10} is Central, north-east & IGP (~0.05) & PM2.5 is from central India (~0.1). In summer, the main source of NO_2 is mainly Bay of Bengal & Rajasthan (~0.16), PM10 emerges from Bay of Bengal (~0.03) & $PM_{2.5}$ from central India (~0.05). In winter season, NO_2 is mostly from Odisha (~0.06), PM_{10} is mostly from Central & north-east India (~0.05) & that of $PM_{2.5}$ is winds blowing from Bay of Bengal & Odisha (~0.25).

II. Amravati City

Amravati is located in the Vidarbha region of Maharashtra, India. It lies at an average elevation of about 343 meters (1,125 feet) above sea level. The terrain is predominantly flat, with some undulating hills. The region is part of the Deccan Plateau, which consists of basaltic rock formations. It is also close to the Satpura mountain range, adding to the diversity of its topography. It experiences a tropical wet & dry climate. Summers are hot & dry. Temperatures can soar up to 45°C (113°F), with May being the hottest month. The region receives moderate to heavy rainfall in monsoon. The average annual rainfall is around 850 mm (33.5 inches). The monsoon brings relief from the intense summer heat, with temperatures ranging from 25°C to 35°C (77°F to 95°F). Winters are mild & pleasant. Temperatures range between 10°C to 20°C (50°F to 68°F). January is typically the coldest month. Overall, climate is characterized by hot summers, a pronounced monsoon season, & mild winters, which are typical of the tropical regions in central India.

It was observed from the hexagonal counts in the period 2011-2014 that the trajectories originated from Arabian Sea, Bay of Bengal & India (North-east, IGP & central India). However, in the period 2015-2019 trajectories originated from Arabian Sea, Bay of Bengal & India (North-east, IGP & central India).

Table 15-Trajectory clustering Amravati

	Duration	**UP**	**Rajasthan**	**Andhra Pradesh**	**Arabian Sea**
Contribution	2011-2014	18 %	15 %	13 %	54 %
Contribution	2015-2019	20 %	19 %	12 %	50 %

In seasonal plots from 2011-2014, it was observed that in monsoon season the trajectories originated from Arabian Sea, Bay of Bengal and central India. The maximum trajectories originate from Arabian Sea (~96%), followed by Madhya Pradesh (~4%) and Bay of Bengal (~ 12%). In post-monsoon, the trajectories originated from Bay of Bengal and India (Indo Gangetic Plains, north-east and north-west). The maximum trajectories emerged from UP (~ 32%), followed by Bihar (~ 29%), Rajasthan (~ 26%) and Odisha (~ 14%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 67%), Andhra Pradesh (~ 10%) and accompanied by Rajasthan (~16%). In winter, it was monitored that the trajectories rise from north-west India. The most trajectories from Bihar (~27%), Odisha (~26%), Rajasthan (~23%) and Gujarat (~ 23%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from Arabian Sea, Bay of Bengal and central India. The maximum trajectories originate from Arabian Sea (~93%), followed by Madhya Pradesh (~7%). In post-monsoon, the trajectories originated from Bay of Bengal and India (Indo Gangetic Plains, north-east and north-west). The maximum trajectories emerged from UP (~36%), followed by Odisha (~ 32%), Rajasthan (~22%) and Gujarat (~10%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 60%), Rajasthan (~16%) accompanied by Andhra Pradesh (~16%) and MP (~8%). In winter, it was monitored that the trajectories rise from north-west India. The most trajectories from Andhra Pradesh (~29%), Chattisgarh (~28%), Rajasthan (~27%) and Gujarat (~16%).

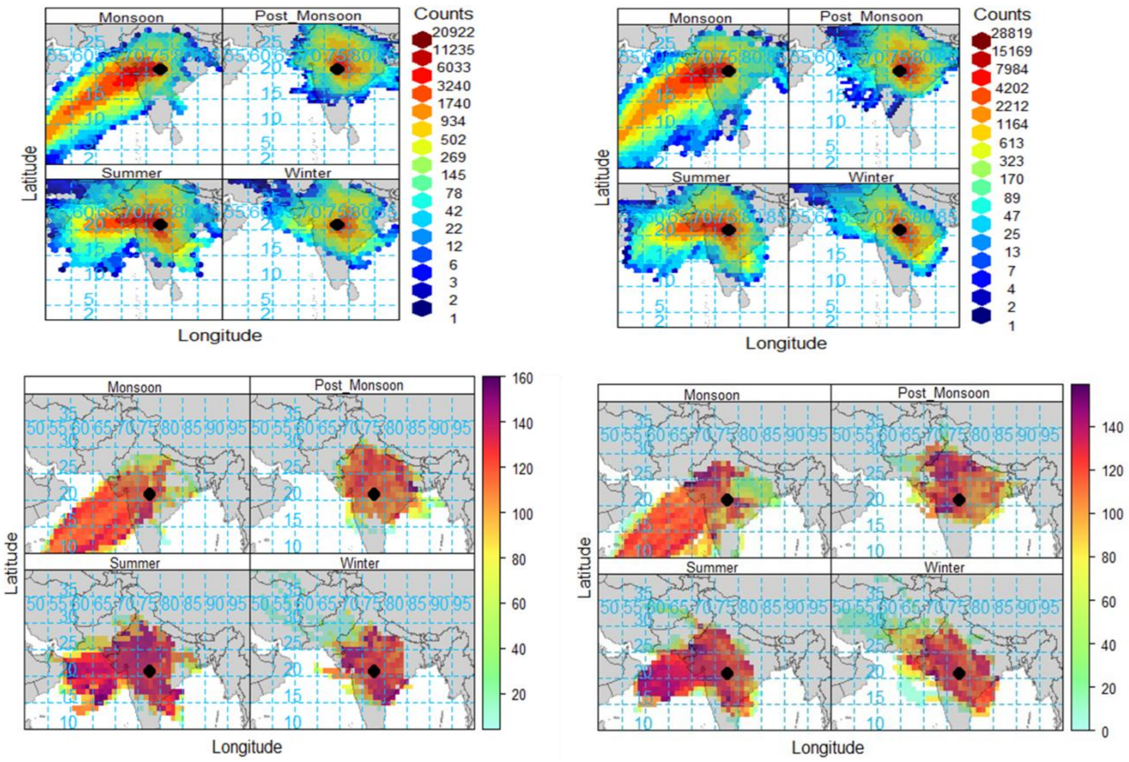

Figure 29-During the period of 2011-2014 & 2015-2019 resp. in Amravati (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

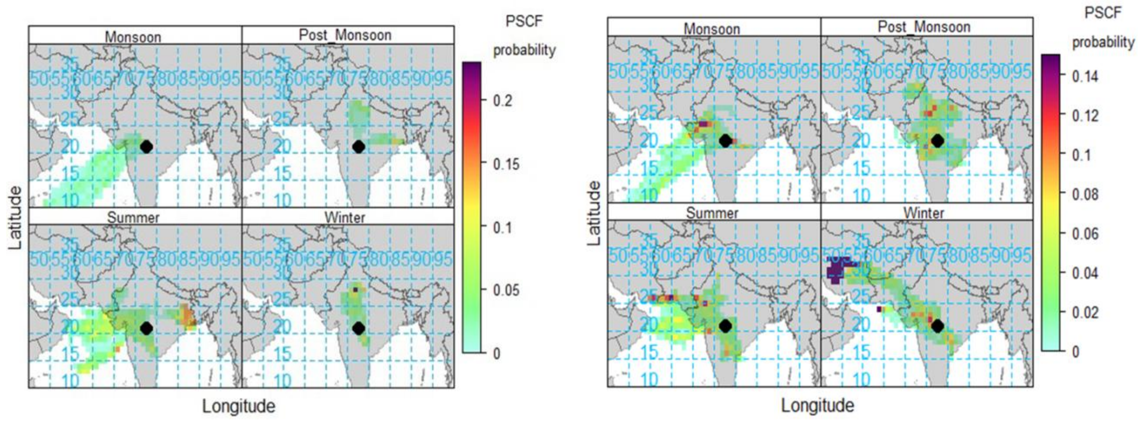

Figure 30-During the period of 2011-2014 & 2015-2019 in Amravati (a) Seasonal PSCF of PM_{10}

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 & SO_2 is around 20 µg/m^3 & 15 µg/m^3 mainly from West Bengal. The concentration of PM_{10} is found to be 160 µg/m^3 mainly from West Bengal, Karnataka, Rajasthan, Maharashtra and winds blowing from Arabian Sea.

During 2015-2019, the concentration of NO_2 & SO_2 is around 25 µg/m^3 & 15 µg/m^3 mainly from winds blowing across Bay of Bengal and Uttrakhand. The concentration of PM_{10} is found to be 160 µg/m^3 mainly from, Karnataka, Rajasthan, Maharashtra, Uttrakhand and winds blowing from Arabian Sea.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 15 µg/m^3, SO_2 is 15 µg/m^3 and PM_{10} is 160 µg/m^3 mainly from North-west, IGP and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 15 µg/m^3 & 15 µg/m^3 and that of PM_{10} is 160 µg/m^3 mainly from (IGP, north-west) India. In summer, the concentration of SO_2 and NO_2 is observed to be 15 µg/m^3 & 15 µg/m^3 which are influenced by (north, IGP, north-west) India and PM_{10} is about 160 µg/m^3 from Odisha, Bihar, West Bengal, Jharkhand, IGP and north-west India. The concentration of NO_2 and SO_2 in winter is about 15 µg/m^3 & 15 µg/m^3, PM_{10} is 160 µg/m^3. This pollution concentration is mainly from India (IGP, central & north-west).

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 17 µg/m^3, SO_2 is 17 µg/m^3 and PM_{10} is 160 µg/m^3 mainly from North-west, IGP and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 17 µg/m^3 & 17 µg/m^3 and that of PM_{10} is 160 µg/m^3 mainly from (IGP, north-west) India. In summer, the concentration of SO_2 and NO_2 is observed to be 17 µg/m^3 & 17 µg/m^3 which are influenced by (north, IGP, north-west and central) India and PM_{10} is about 160 µg/m^3 from Odisha, Bihar, West Bengal, Jharkhand, IGP and north-west India. The concentration of NO_2 and SO_2 in winter is about 20 µg/m^3 & 20 µg/m^3, PM_{10} is 160 µg/m^3. This pollution concentration is mainly from India (IGP, central & north-west).

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 was West Bengal (~0.12) followed by north-west India (~ 0.1), the main source of SO_2 pollution was West Bengal (~0.12), the main source of PM_{10} was West Bengal and Delhi (~0.13).

The potential source of NO_2 pollution from 2015-2019 was UP (~0.12) followed by north-west India (~ 0.1), the main source of SO_2 pollution was UP (~0.12), the main source of PM_{10} was Gujarat and Iran (~0.13).

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of NO_2 was Maharashtra (~ 0.06) and PM_{10} pollution was winds blowing from Arabian Sea and Maharashtra (~0.04). In post-monsoon, NO_2 emerges from UP (~0.12), SO_2 pollution from UP (~0.1) and West Bengal was the main source of PM_{10} (~0.11). In summer season, NO_2 is coming mainly from West Bengal Jharkhand and Bihar (~0.16), SO_2 is originating mainly from West Bengal Jharkhand and Bihar (~ 0.15) and the PM_{10} sources was West Bengal Jharkhand and Bihar (~0.17). In winter season, Telangana is the main source of NO_2 (~0.1) and Delhi is the main source of PM_{10} (~0.23).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2 & SO_2 was Maharashtra, Daman and Diu and Gujarat (~0.06) and (~0.06) and PM_{10} pollution was Maharashtra and Gujarat (~0.14). In post-monsoon, NO_2 emerges from UP (~0.14), SO_2 pollution from UP (~0.14) and Rajasthan and Maharashtra was the main source of PM_{10} (~ 0.12). In summer season, NO_2 is coming mainly from MP (~0.08), SO_2 is originating mainly from Andhra Pradesh and MP (~0.1) and the PM_{10} sources was Iran and Rajasthan(~0.15). In winter season, Andhra Pradesh is the main source of NO_2 (~0.16), winds blowing from Bay of Bengal (~0.12) and Iran is the main source of PM_{10} (~0.15).

III. Singrauli City

Singrauli, located in the eastern part of Madhya Pradesh, is known for its rich coal deposits and significant industrial activity. The region is part of the larger Singrauli coalfield, which extends into the neighbouring state of Uttar Pradesh. The topography is characterized by: Hilly Terrain: The area has undulating terrain with a mix of low hills and plateaus. Coal Mines and Forests: Extensive coal mining activities dominate the landscape, interspersed with patches of forested land. Rivers and Water Bodies: The region is drained by several rivers, with the Rihand River being the most prominent. The Rihand Dam creates the Govind Ballabh Pant Sagar, a large reservoir in the area. Singrauli experiences a tropical climate with distinct seasons, typical of central India. Summers are hot and dry. Temperatures can rise to around 45°C (113°F), with May being the hottest month. Heat waves are common during this period, making it the harshest season. The region receives moderate to heavy rainfall during the monsoon season. The average annual rainfall is approximately 1,200 mm (47 inches).

Monsoon rains bring relief from the intense summer heat, with temperatures ranging from 25°C to 35°C (77°F to 95°F). Winters are mild and pleasant. Temperatures range from 10°C to 25°C (50°F to 77°F). January is typically the coldest month, with cooler temperatures during early mornings and nights. Overall, climate is marked by hot summers, a monsoon season with significant rainfall, and mild winters. The topography is influenced by its hilly terrain, coal mines, and forested areas, making it a region with diverse geographical features.

It was observed from the hexagonal counts in 2012 that the trajectories originated from Arabian Sea, Bay of Bengal and India (North-east, IGP and central India). However, from 2015-2019 trajectories originated from Arabian Sea and India (North, North-west, IGP and central India).

Table 16-Trajectory clustering Singrauli

	Duration	**UP**	**Haryana**	**Odisha**	**Arabian Sea**
Contribution	2011-2014	22 %	41 %	13 %	23 %
Contribution	2015-2019	16 %	37 %	19 %	28 %

In seasonal plots in 2012 it was observed that in monsoon season the trajectories originated from Arabian Sea and central India. The maximum trajectories originate from Arabian Sea (~ 56%), followed by Chattisgarh (~ 25%) and Rajasthan (~ 19%). In post-monsoon, the trajectories originated from Bay of Bengal and India (Indo Gangetic Plains, north-east and north-west). The maximum trajectories emerged from UP (~36%), followed by Rajasthan (~ 30%), Haryana (~24%) and Odisha (~10%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Haryana (~ 39%), Uttrakahnd (~30%) accompanied by UP (~17%) and Jharkhand (~14%). In winter, it was monitored that the trajectories rise from north-west India. The most trajectories from MP (~ 42%), Delhi (~31%) and Pakistan (~28%).

In seasonal plots from 2015-2019, it was observed that in monsoon season the trajectories originated from Arabian Sea and central India. The maximum trajectories originate from Arabian Sea (~34%), followed by Gujarat (~30%), West Bengal (~19%) and Chattisgarh (~ 17%). In post-monsoon, the trajectories originated from Bay of Bengal and India (Indo Gangetic Plains, north-east and north-west). The maximum trajectories emerged from Haryana (~44%), followed by Uttrakhand (~22%), Jharkhand (~19%) and Rajasthan (~16%).

In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Haryana (~ 36%), UP (~24%) accompanied by Odisha (~21%) and MP (~19%). In winter, it was monitored that the trajectories rise from north-west India. The most trajectories from UP (~54%), Haryana (~38%) and Chattisgarh (~8%).

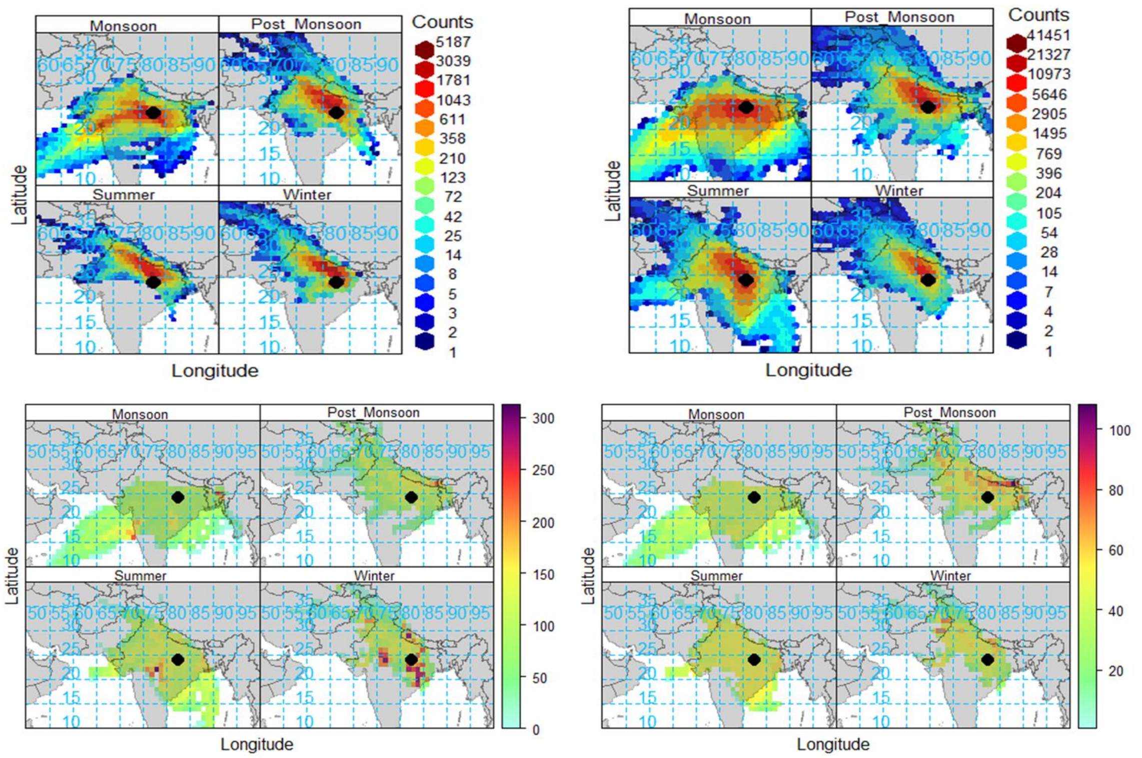

Figure 31-During the period of 2011-2014 & 2015-2019 resp. in Singrauli (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

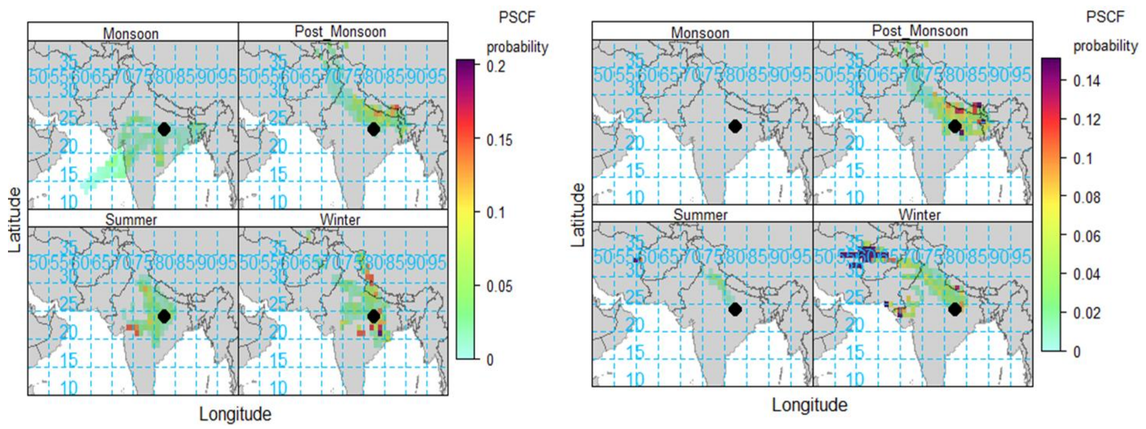

Figure 32-During the period of 2011-2014 & 2015-2019 in Singrauli (a)) Seasonal PSCF of PM_{10}

(A) CWT Analysis

During 2012, the concentration of NO_2, SO_2 and PM_{10} is around 25 µg/m^3 , 25 µg/m^3 and 75 µg/m^3 mainly from IGP, North-west and central India.

During 2015-2019, the concentration of NO_2 & SO_2 is around 35 µg/m^3 & 50 µg/m^3 mainly from Karnataka, Gujarat, Tripura and Nepal. The concentration of PM_{10} is found to be 225 µg/m^3 mainly from North-east India and Nepal. The concentration of $PM_{2.5}$ was found to be 100 µg/m^3 mainly from Sikkim and Nepal.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 80 µg/m^3, SO_2 is 45 µg/m^3, PM_{10} is 250 µg/m^3 and $PM_{2.5}$ is 50 µg/m^3 mainly from Andhra Pradesh and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 45 µg/m^3, 80 µg/m^3, PM_{10} is 250 µg/m^3 and $PM_{2.5}$ is 100 µg/m^3 mainly from (IGP, north-east) India. In summer, the concentration of SO_2 and NO_2 is observed to be 40 µg/m^3 & 70 µg/m^3 which are influenced by (north, IGP, north-west and central) India and PM_{10}, $PM_{2.5}$ is about 300 µg/m^3 & 70 µg/m^3 from Maharashtra, IGP and north-west India. The concentration of NO_2 and SO_2 in winter is about 60 µg/m^3 & 55 µg/m^3. Also PM_{10} is 300 µg/m^3 and $PM_{2.5}$ is 80 µg/m^3. This pollution concentration is mainly from India (IGP, central & north-west).

(B) PSCF Analysis

The potential source of NO_2 and SO_2 pollution from 2012 was not specific but the main source of PM_{10} was Punjab, Haryana and Delhi (~0.04).

The potential source of NO_2 pollution from 2015-2019 was UP (~0.12) followed by north-west India (~ 0.1), the main source of SO_2 pollution was Nepal, Pakistan and Kyrgyzstan (~ 0.15), the main source of PM_{10} was Gujarat and Iran (~0.13) and that of $PM_{2.5}$ is Nepal, Kyrgyzstan and Iran (~0.14).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2 and SO_2 was North-east, north-west, central and south India (~0.3) and PM_{10} pollution was winds blowing from Arabian Sea and central India (~0.05). In post-monsoon, NO_2 and SO_2 emerges from North-east, north-west, central and south India (~0.3) and IGP & Nepal was the main source of PM_{10} (~0.15). PM2.5 was observed to be coming from MP, Jharkhand and China (~ 0.14). In summer season, NO_2 and SO_2 emerges from North-east, north-west, central and south India (~0.3), PM_{10} sources was Gujarat and Maharashtra (~0.15) and $PM_{2.5}$ emerges from IGP (~). In winter season, NO_2 & SO_2 emerges from North-east, north-west, central and south India (~0.3) and Chattisgarh and Maharashtra is the main source of PM_{10} (~0.2). The potential source of $PM_{2.5}$ is Afghanistan, Iran, Pakistan and Gujarat (~0.15).

5.1.6 South India

I. Hubli City

Hubli (Hubballi), located in the north-western part of Karnataka, India, is part of the Deccan Plateau. The topography of Hubli is characterized by the area primarily features flat to gently undulating terrain typical of the Deccan Plateau. It is situated at an average elevation of about 670 meters (2,200 feet) above sea level. The region includes several small hills and is interspersed with water bodies like lakes and streams. The surrounding areas are known for their agricultural land and forest cover. It experiences a tropical savanna climate, with distinct wet and dry seasons. Summers are hot and dry. Temperatures can reach up to 40°C (104°F), with April and May being the hottest months. High temperatures and occasional heatwaves are characteristic of this season. The city receives moderate to heavy rainfall during the monsoon season. The average annual rainfall is around 838 mm (33 inches), with the majority falling between June and September. The monsoon brings relief from the summer heat, with temperatures ranging from 20°C to 30°C (68°F to 86°F). Winters are mild and pleasant. Temperatures range from 14°C to 30°C (57°F to 86°F). December and January are typically the coolest months, with pleasant weather during the day and cooler nights. Overall, climate is characterized by hot summers, a significant monsoon season with moderate to heavy rainfall, and mild winters.

It was observed from the hexagonal counts from 2011-2013 that the trajectories originated from Arabian Sea and India (North-west and central India). However, from 2017-2018 trajectories originated from Arabian Sea and India (North-west and central India).

Table 17-Trajectory clustering Hubli

	Duration	**Gujarat**	**Andhra Pradesh**	**Arabian Sea**
Contribution	2011-2014	9 %	27 %	64 %
Contribution	2015-2019		39 %	61 %

In seasonal plots from 2011-2013 it was observed that in monsoon season the trajectories originated from Arabian Sea and north-west India. The maximum trajectories originate from

Arabian Sea (~96%), followed by Gujarat (~4%). In post-monsoon, the trajectories originated from Bay of Bengal, Arabian Sea and India (central and north-west). The maximum trajectories emerged from Chattisgarh (~44%), followed by Bay of Bengal (~28%), Arabian Sea (~ 15%) and MP (~ 13%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 86%), accompanied by Andhra Pradesh (~14%). In winter, it was monitored that the trajectories rise from north-west and central India. The most trajectories from Andhra Pradesh (~42%), Arabian Sea (~40%) and Gujarat (~18%).

In seasonal plots from 2017-2018 it was observed that in monsoon season the trajectories originated from Arabian Sea and north-west India. The maximum trajectories originate from Arabian Sea (~97%), followed by Andhra Pradesh (~3%). In post-monsoon, the trajectories originated from Bay of Bengal, Arabian Sea and India (central and north-west). The maximum trajectories emerged from Andhra Pradesh (~ 55%), followed by Chattisgarh (~ 24%), Daman and Diu (~14%) and Arabian Sea (~14%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 76%), accompanied by Andhra Pradesh (~17%) and Maharashtra (~7%). In winter, it was monitored that the trajectories rise from north-west and central India. The most trajectories from Bay of Bengal (~30%), Andhra Pradesh (~29%), Telengana (~17%) and Maharashtra (~ 14%).

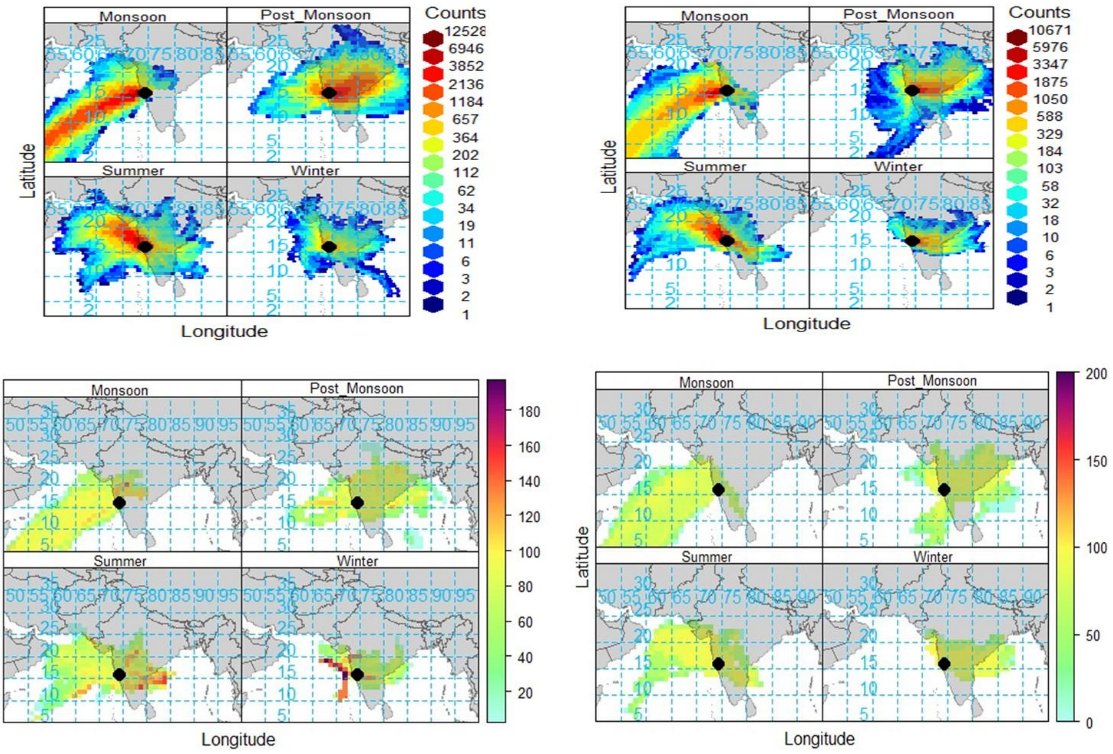

Figure 33-During the period of 2011-2014 & 2015-2019 resp. in Hubli (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

(A) CWT Analysis

During 2011-2013, the concentration of NO_2 & SO_2 is around 17 µg/m^3 & 9 µg/m^3 mainly from north-west, central and south India. The concentration of PM_{10} is found to be 150 µg/m^3 mainly from Arabian Sea and Bay of Bengal.

During 2017-2018, the concentration of NO_2 & SO_2 is around 30 µg/m^3 & 9 µg/m^3 mainly from north-west, central and south India. The concentration of PM_{10} is found to be 100 µg/m^3 mainly from Arabian Sea and Bay of Bengal.

The CWT analysis of different seasons from 2011-2013 shows that the concentration of NO_2 in monsoon is shown to be around 15 µg/m^3, SO_2 is 10 µg/m^3 and PM_{10} is 160 µg/m^3 mainly from North-west, central India and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 10 µg/m^3 & 15 µg/m^3 and that of PM_{10} is 110 µg/m^3 mainly from (central, north-west) India and winds blowing from Arabian Sea. In summer, the concentration of SO_2 and NO_2 is observed to be 8 µg/m^3 & 15 µg/m^3 which are influenced by (central, north-west) India and Arabian Sea and PM_{10} is about 140 µg/m^3 from central, south and north-west India. The concentration of NO_2 and SO_2 in winter is about 15 µg/m^3 & 6 µg/m^3, PM_{10} is around 200 µg/m^3. This pollution concentration is mainly from India (central & north-west).

The CWT analysis of different seasons from 2017-2018 shows that the concentration of NO_2 in monsoon is shown to be around 25 µg/m^3, SO_2 is 6 µg/m^3, PM_{10} is 75 µg/m^3 and $PM_{2.5}$ is 40 µg/m^3 mainly from North-west, central India and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration was around 10 µg/m^3 & 30 µg/m^3, PM_{10} is 75 µg/m^3 and that of $PM_{2.5}$ is 50 µg/m^3 mainly from (central, north-west) India and winds blowing from Arabian Sea. In summer, the concentration of SO_2 and NO_2 was observed to be 7 µg/m^3 & 30 µg/m^3 which are influenced by (central, north-west) India and Arabian Sea, PM_{10} was about 75 µg/m^3 and $PM_{2.5}$ was 45 µg/m^{3}from central, south and north-west India. The concentration of NO_2 and SO_2 in winter is about 30 µg/m^3 & 7 µg/m^3, PM_{10} was around 75 µg/m^3 and $PM_{2.5}$ was 45 µg/m^3. This pollution concentration was mainly from India (central & north-west).

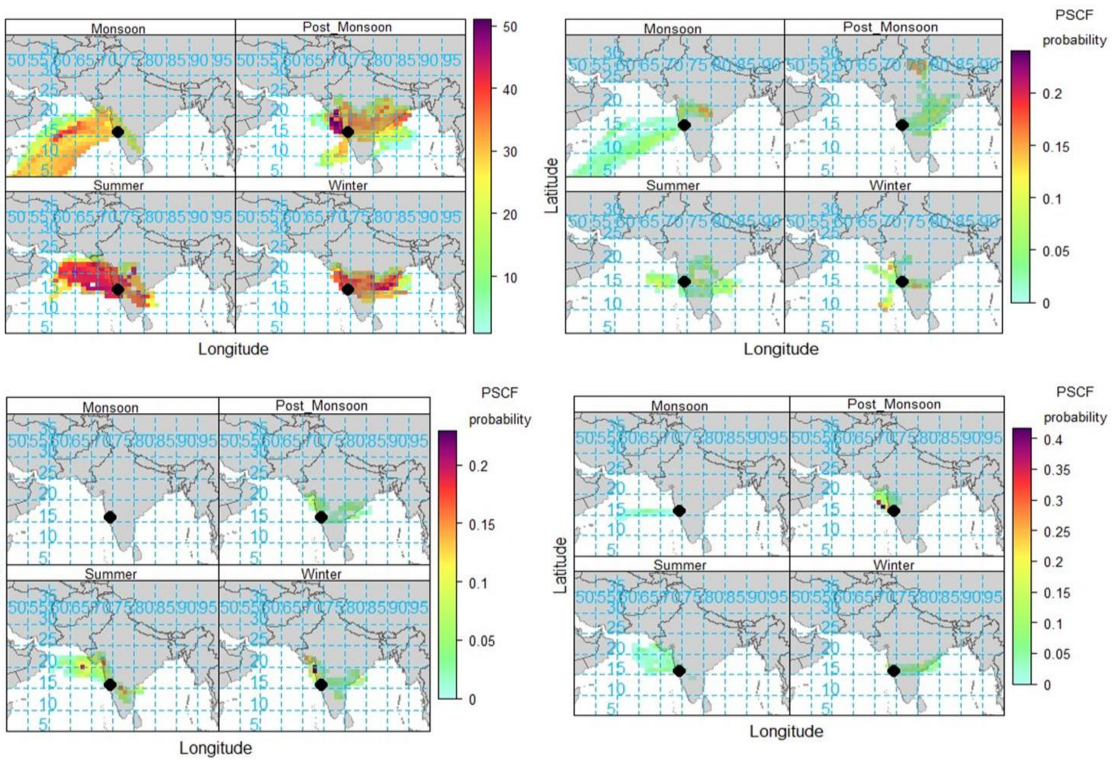

Figure 34-During the period of 2011-2014 & 2015-2019 in Hubli (a) Seasonal CWT of $PM_{2.5}$, (b) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2013 was Andhra Pradesh (~0.15) followed by central India (~ 0.1), the main source of SO_2 pollution was Arabian Sea (~0.15) and the main source of PM_{10} was Delhi and Rajasthan (~0.17).

The potential source of NO_2 pollution from 2017-2018 was Madhya Pradesh (~ 0.17) followed by central India (~ 0.09), the main source of SO_2 pollution was Gujarat (~0.18), the main source of PM_{10} was Gujarat (~0.17).

The PSCF analysis from 2011-2013, reveals that in monsoon the potential source of NO_2 and SO_2 was central India (~0.17) and PM_{10} pollution was from central India (~0.16). In post-monsoon, NO_2 emerges from central and south India (~0.21) and IGP and central India was the main source of PM_{10} (~0.16). In summer season, NO_2 emerges from central and south India (~0.15) and PM_{10} sources was central India (~0.13). In winter season, the main source of PM_{10} was central India (~0.17).

The PSCF analysis from 2017-2018, reveals that in monsoon the potential source of NO_2 and $PM_{2.5}$ was Arabian Sea (~0.05). In post-monsoon, NO_2 (~0.15) and SO_2 (~0.2) emerges from central India and Arabian Sea and north-west and central India was the main source of PM_{10} (~0.07). $PM_{2.5}$ was observed to be coming from Maharashtra and Gujarat (~0.4). In summer season, NO_2 (~0.15) and SO_2 (~0.2) emerges from central and north-west India, PM_{10} sources was central India and north-west India (~ 0.17) and $PM_{2.5}$ emerges from north-west and central India (~0.1). In winter season, NO_2 & SO_2 emerges from central, north-west India (~ 0.2), the main source of PM_{10} was central and north-west India (~0.2) and $PM_{2.5}$ was central India (~0.15).

II. Tuticorin City

Tuticorin (Thoothukudi), located in the southern part of Tamil Nadu, India, is known for its port and industrial activities. The topography is characterized by south-eastern coast of India, on the Gulf of Mannar, featuring flat coastal plains. The area has a low elevation, with an average height of about 4 meters (13 feet) above sea level. The region is notable for its extensive salt pans and patches of mangrove forests along the coast. The city’s location near the sea influences its topography, with sandy beaches and coastal dunes. It experiences a tropical maritime climate, characterized by hot summers, mild winters, and significant rainfall. Summers are hot and humid. Temperatures can reach up to 40°C (104°F), with May being the hottest month. The coastal location moderates temperatures slightly, but humidity levels are high. The city receives most of its rainfall during the northeast monsoon season. The average annual rainfall is about 660 mm (26 inches), with the majority falling between October and December. The monsoon season brings relief from the summer heat, with temperatures ranging from 25°C to 35°C (77°F to 95°F). Winters are mild and relatively dry. Temperatures range from 20°C to 30°C (68°F to 86°F). January is typically the coolest month, with pleasant weather during the day and cooler nights. Overall, climate is characterized by hot summers, a distinct northeast monsoon season with moderate rainfall, and mild winters.

It was observed from the hexagonal counts from 2011-2014 that the trajectories originated from Arabian Sea and Bay of Bengal. However, from 2015-2019 trajectories originated from Arabian Sea and Bay of Bengal.

Table 18-Trajectory clustering Tuticorin

	Duration	Arabian Sea	Bay of Bengal
Contribution	2011-2014	61 %	39 %
Contribution	2015-2019	100 %	

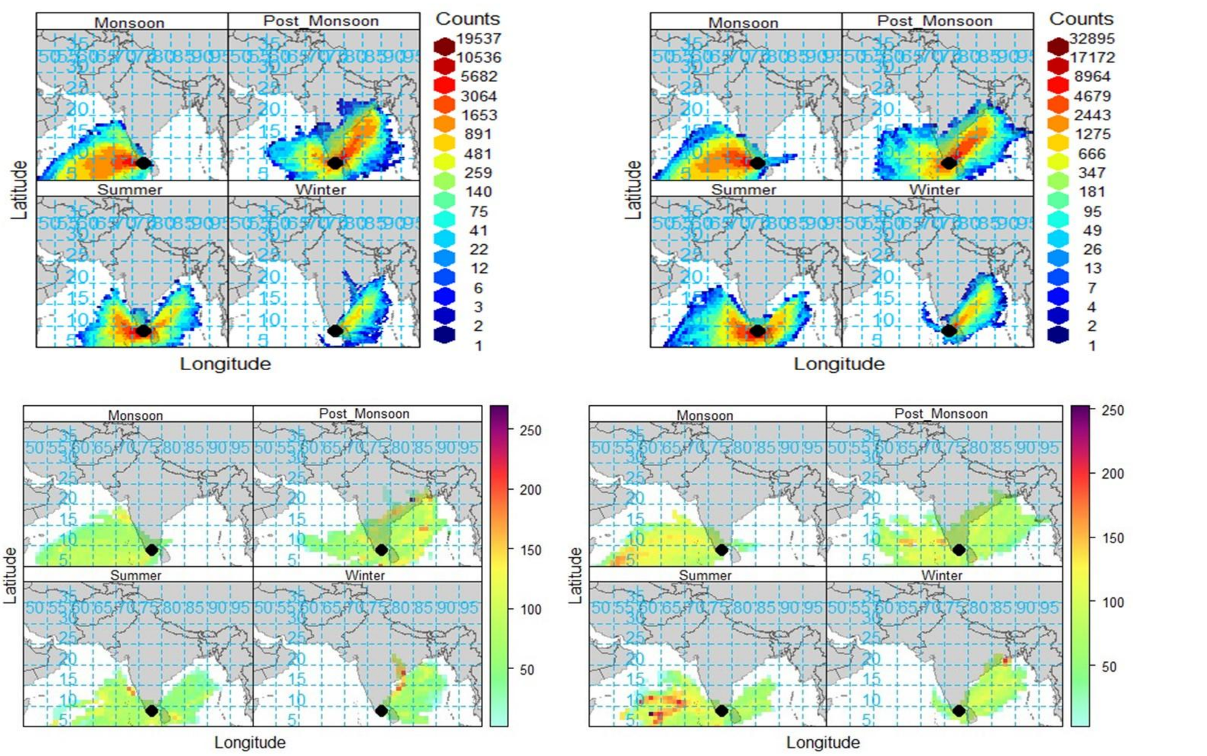

Figure 35-During the period of 2011-2014 & 2015-2019 resp. in Tuticorin (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

In seasonal plots from 2011-2014 it was observed that in monsoon season the trajectories originated from Arabian Sea (~100%). In post-monsoon, the trajectories originated from Bay of Bengal, Arabian Sea and India (central and north-west). The maximum trajectories emerged from Arabian Sea (~ 28%), followed by Bay of Bengal (~ 72%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 71%), accompanied by Bay of Bengal (~29%). In winter, it was monitored that the trajectories rise from Bay of Bengal (~100%).

In seasonal plots from 2015-2019 it was observed that in monsoon season the trajectories originated from Arabian Sea (~100%). In post-monsoon, the trajectories originated from Bay of Bengal, Arabian Sea and India (central and north-west). The maximum trajectories emerged from Bay of Bengal (~ 66%), followed by Arabian Sea (~ 34%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 100%). In winter, it was monitored that the trajectories rise from Bay of Bengal (~100%).

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 & SO_2 is around 30 µg/m^3 & 30 µg/m^3 mainly from Arabian Sea, Bay of Bengal, north-west, central and south India. The concentration of PM_{10} is found to be 250 µg/m^3 mainly from Odisha.

During 2015-2019, the concentration of NO_2 & SO_2 is around 20 µg/m^3 & 15 µg/m^3 mainly from Arabian Sea, Bay of Bengal, central and south India. The concentration of PM_{10} is found to be 150 µg/m^3 mainly from central and south India.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon is shown to be around 15 µg/m^3, SO_2 is 30 µg/m^3 and PM_{10} is 150 µg/m^3 mainly from south, central India and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 25 µg/m^3 & 15 µg/m^3 and that of PM_{10} is 250 µg/m^3 mainly from (central, south) India and winds blowing from Bay of Bengal. In summer, the concentration of SO_2 and NO_2 is observed to be 20 µg/m^3 & 40 µg/m^3 which are influenced by (central, north-west) India and Arabian Sea and PM_{10} is about 200 µg/m^3 from south India. The concentration of NO_2 and SO_2 in winter is about 20 µg/m^3 & 15 µg/m^3, PM_{10} is around 220 µg/m^3. This pollution concentration is mainly from India (central & south).

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon is shown to be around 15 µg/m^3, SO_2 is 15 µg/m^3, PM_{10} is 150 µg/m^3 and $PM_{2.5}$ is 60 µg/m^3 mainly from south, central India and winds blowing from Arabian Sea. In post-monsoon, the SO_2 and NO_2 concentration is around 15 µg/m^3 & 15 µg/m^3, that of PM_{10} is 175 µg/m^3 and $PM_{2.5}$ is 40 µg/m^3 mainly from (central, south) India and winds blowing from Bay of Bengal. In summer, the concentration of SO_2 and NO_2 is observed to be 15 µg/m^3 & 15 µg/m^3 which are influenced by (central, north-west) India and Arabian Sea, PM_{10} is about 250 µg/m^3 and $PM_{2.5}$ is 60 µg/m^3 from south India. The concentration of NO_2 and SO_2 in winter is about 15 µg/m^3 & 15 µg/m^3, PM_{10} is around 200 µg/m^3 and $PM_{2.5}$ is 45 µg/m^3. This pollution concentration is mainly from India (central & south) and Bay of Bengal.

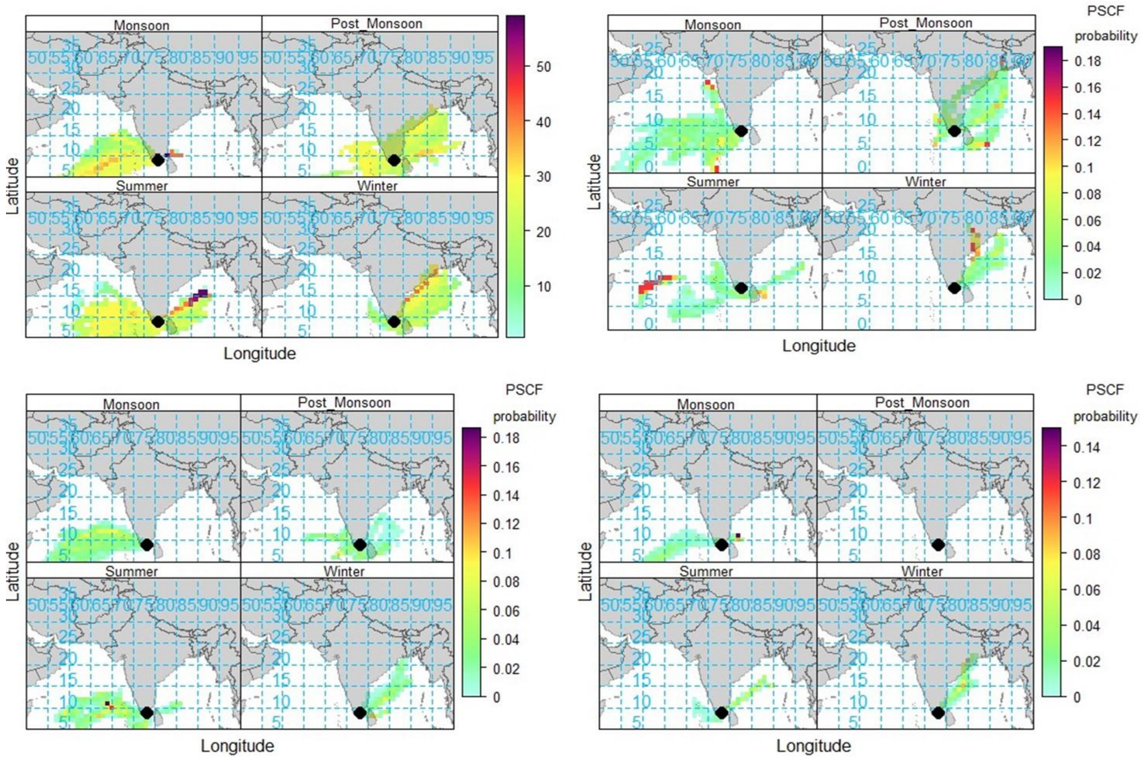

Figure 36-During the period of 2011-2014 & 2015-2019 in Tuticorin (a) Seasonal CWT of $PM_{2.5}$, (b) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 were winds blowing from Arabian Sea (~0.14) followed by south India (~ 0.06), the main source of SO_2 pollution was north-east India (~0.14) and the main source of PM_{10} was north-east India (~0.14).

The potential source of NO_2 pollution from 2015-2019 were winds blowing from Arabian Sea (~0.14) followed by south India (~ 0.06), the main source of SO_2 pollution was IGP (~0.14) and the main source of PM_{10} was winds blowing from Arabian Sea (~0.12).

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of NO_2 and SO_2 was central India (~ 0.14) and PM_{10} pollution was from south India (~ 0.16). In post-monsoon, NO_2 emerges from south India (~ 0.1), SO_2 from north-east and southern India (~ 0.18) and IGP and central India was the main source of PM_{10} (~0.16). In summer season, NO_2 emerges from the winds blowing from the Arabian Sea and south India (~ 0.25), SO_2 from southern India (~0.08) and PM_{10} sources was south India (~0.16). In winter season, the main source of NO_2 was south India (~0.05) and PM_{10} was central India (~0.16).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2 (~ 0.16) and SO_2 (~0.08) was south India and Arabian Sea, PM_{10} pollution was from south India and Arabian Sea (~ 0.1) and $PM_{2.5}$ from Bay of Bengal and south India (~ 0.14). In post-monsoon, NO_2 emerges from south India (~ 0.1), SO_2 from north-east and southern India (~ 0.14) and Arabian Sea and southern India was the main source of PM_{10} (~ 0.08). In summer season, SO_2 from southern India and Arabian Sea (~0.14), PM_{10} sources was south India and Arabian Sea (~0.18) and $PM_{2.5}$ from Bay of Bengal and south India (~0.08). In winter season, the main source of NO_2 was south India and Bay of Bengal (~0.05), SO_2 emerges from south India and Bay of Bengal (~0.06), PM_{10} was south India and Bay of Bengal (~0.16) and $PM_{2.5}$ from Bay of Bengal, south and central India (~0.1).

III. Kozhikode City

Kozhikode (Calicut), located in the southwestern state of Kerala, India, has diverse topography characterized by Malabar Coast, featuring flat coastal plains. The city is flanked by the Western Ghats on the east, which rise steeply from the plains, creating a diverse landscape with hills and valleys. The region is traversed by several rivers, including the Chaliyar, Kallayi, and Korapuzha, along with numerous backwaters and lagoons. It experiences a tropical monsoon climate, with significant rainfall throughout the year. Summers are hot and humid. Temperatures can reach up to 35°C (95°F), with high humidity making it feel warmer. The proximity to the sea moderates the temperatures to some extent, but the humidity remains high. The city receives heavy rainfall during the monsoon season due to the south-west monsoon. The average annual rainfall is around 3,266 mm (128.6 inches), with the majority falling between June and September. The monsoon season is marked by frequent and intense rainfall, leading to lush greenery and sometimes causing flooding. The post-monsoon period continues to receive moderate rainfall from the northeast monsoon until December. Winters are mild and pleasant, with temperatures ranging from 20°C to 32°C (68°F to 90°F). This period is the most comfortable, with lower humidity and cooler temperatures. Overall, climate is characterized by hot and humid summers, a prolonged and intense monsoon season, and mild winters. The topography includes flat coastal plains, the rising terrain of the Western Ghats, and numerous rivers and backwaters, contributing to its rich natural landscape.

It was observed from the hexagonal counts from 2011-2014 that the trajectories originated from south India, Arabian Sea and Bay of Bengal. However, from 2015-2019 trajectories originated from south India, Arabian Sea and Bay of Bengal.

Table 19-Trajectory clustering Kozhikhode

	Duration	**Arabian Sea**	**Bay of Bengal**
% Contribution	2011-2014	64 %	36 %
% Contribution	2015-2019	68 %	32 %

In seasonal plots from 2011-2014 it was observed that in monsoon season the trajectories originated from Arabian Sea (~100%). In post-monsoon, the trajectories originated from Bay of Bengal, Arabian Sea and India (central and north-west). The maximum trajectories emerged from Bay of Bengal (~64%), followed by Arabian Sea (~19%) and Telangana (~17%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 75%), accompanied by Bay of Bengal (~15%) and Tamil Nadu (~11%). In winter, it was monitored that the trajectories rise from Bay of Bengal (~76%), followed by Arabian Sea (~18%) and Tamil Nadu (~6%).

In seasonal plots from 2015-2019 it was observed that in monsoon season the trajectories originated from Arabian Sea (~100%). In post-monsoon, the trajectories originated from Bay of Bengal, Arabian Sea and India (central and north-west). The maximum trajectories emerged from Bay of Bengal (~66%), followed by Arabian Sea (~23%) and Karnataka (~11%). In summer, trajectories stem from Arabian Sea and India (central and north-west). The highest trajectories from Arabian Sea (~ 84%), accompanied by Bay of Bengal (~16%). In winter, it was monitored that the trajectories rise from Bay of Bengal (~82%), followed by Arabian Sea (~18%).

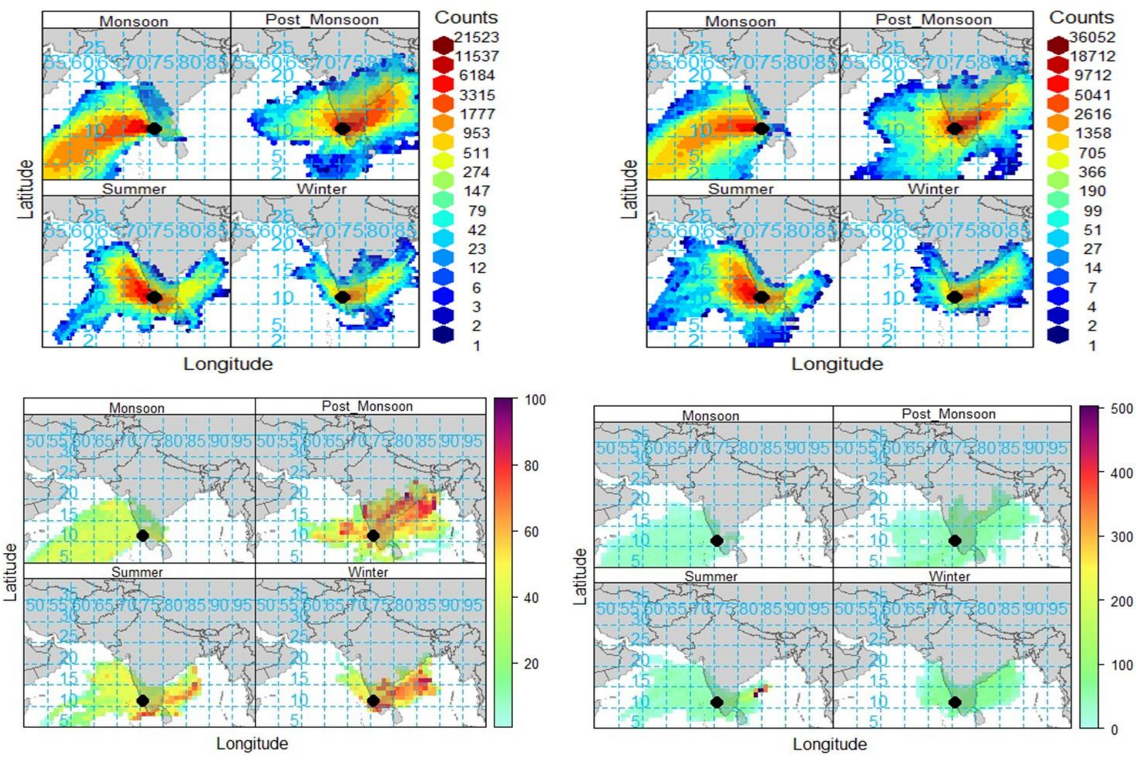

Figure 37-During the period of 2011-2014 & 2015-2019 resp. in Kozhikhode (a) Seasonal distribution of trajectories in the form of hexagonal counts (b) Seasonal CWT of PM_{10}

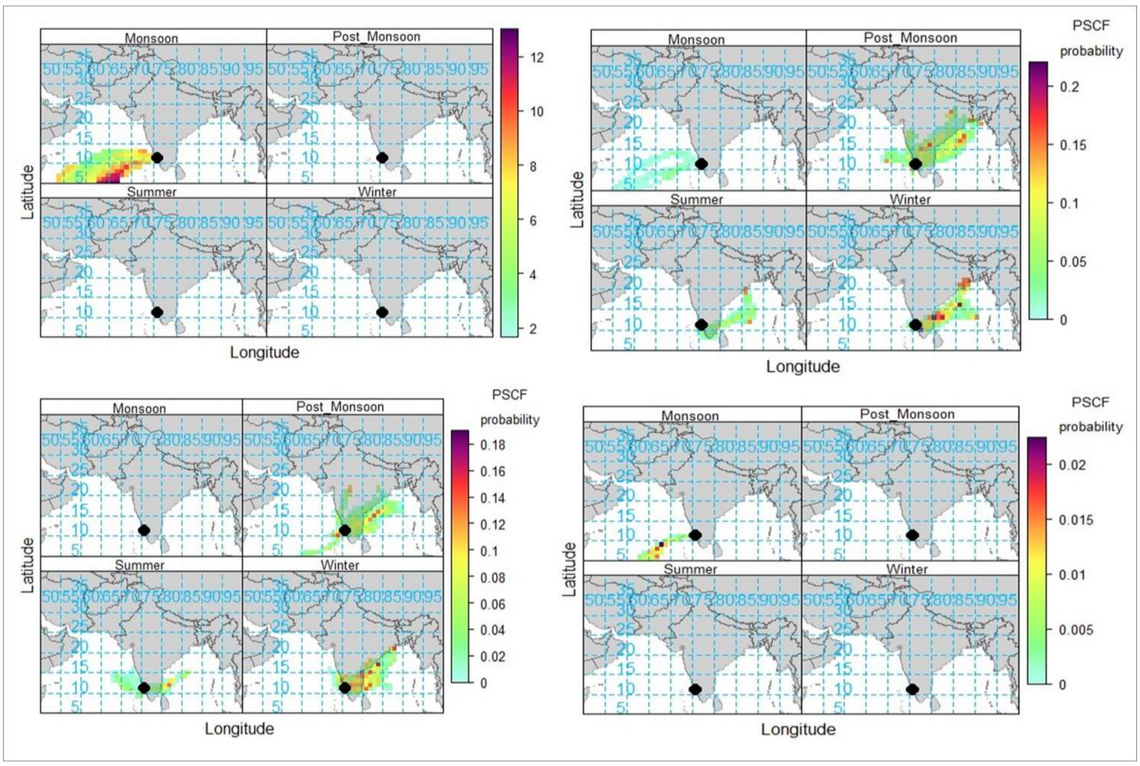

Figure 38-During the period of 2011-2014 & 2015-2019 in Kozhikhode (a) Seasonal CWT of $PM_{2.5}$, (b) Seasonal PSCF of PM_{10} & $PM_{2.5}$

(A) CWT Analysis

During 2011-2014, the concentration of NO_2 was around 30 µg/m^3 mainly from Arabian Sea, Bay of Bengal and central India & SO_2 was below detection level. The concentration of PM_{10} is found to be 100 µg/m^3 mainly from Odisha.

During 2015-2019, the concentration of NO_2 was around 25 µg/m^3 mainly from Arabian Sea, Bay of Bengal and central India & SO_2 was below detection level. The concentration of PM_{10} was found to be 100 µg/m^3 mainly from Andhra Pradesh and $PM_{2.5}$ was around 13 µg/m^3 mainly from Arabian Sea.

The CWT analysis of different seasons from 2011-2014 shows that the concentration of NO_2 in monsoon was shown to be around 25 µg/m^3 and PM_{10} is 60 µg/m^3 mainly from south, central India and winds blowing from Arabian Sea. In post-monsoon, the NO_2 concentration was around 30 µg/m^3 and that of PM_{10} is 100 µg/m^3 mainly from (central, south) India and winds blowing from Bay of Bengal and Arabian Sea. In summer, the concentration of NO_2 is observed to be 25 µg/m^3 which are influenced by (central and south) India and Arabian Sea and PM_{10} is about 80 µg/m^3 from south India. The concentration of NO_2 in winter was about 25 µg/$m^3$and PM_{10} is around 90 µg/m^3. This pollution concentration is mainly from India (central & south) and winds blowing from Bay of Bengal.

The CWT analysis of different seasons from 2015-2019 shows that the concentration of NO_2 in monsoon was shown to be around 30 µg/m^3, PM_{10} is 100 µg/m^3 and $PM_{2.5}$ was 13 µg/m^3 mainly from south, central India and winds blowing from Arabian Sea. In post-monsoon, the NO_2 concentration was around 30 µg/m^3 and that of PM_{10} was 150 µg/m^3 mainly from (central, south) India and winds blowing from Bay of Bengal and Arabian Sea. In summer, the concentration of NO_2 was observed to be 35 µg/m^3 which are influenced by (central and south) India and Arabian Sea and PM_{10} was about 400 µg/m^3 from winds blowing from Bay of Bengal and south India. The concentration of NO_2 in winter was about 30 µg/$m^3$and PM_{10} is around 150 µg/m^3. This pollution concentration was mainly from India (central & south) and winds blowing from Bay of Bengal.

(B) PSCF Analysis

The potential source of NO_2 pollution from 2011-2014 were winds blowing from West Bengal and Bangladesh (~0.14) followed by Bay of Bengal and Arabian Sea (~ 0.1) and the main source of PM_{10} was IGP (~0.14).

The potential source of NO_2 pollution from 2011-2014 were winds blowing from Tamil Nadu and Sri Lanka (~0.12) followed by Bay of Bengal and Arabian Sea (~ 0.06), the main source of PM_{10} was central India (~ 0.12) and $PM_{2.5}$ was mainly from the winds blowing from Arabian Sea (~0.14).

The PSCF analysis from 2011-2014, reveals that in monsoon the potential source of NO_2 was Arabian Sea (~ 0.08) and PM_{10} pollution was from Arabian Sea (~ 0.05). In post-monsoon, NO_2 emerges from West Bengal, central and south India (~ 0.18) and IGP and central and southern India was the main source of PM_{10} (~ 0.16). In summer season, NO_2 emerges from the winds blowing from the Arabian Sea and south India (~0.1) and PM_{10} sources was Bay of Bengal, central and south India (~ 0.16). In winter season, the main source of NO_2 was West Bengal and Odisha (~0.16) and PM_{10} was Bay of Bengal, central and south India (~0.21).

The PSCF analysis from 2015-2019, reveals that in monsoon the potential source of NO_2 was Arabian Sea (~ 0.12) and that of $PM_{2.5}$ was Arabian Sea (~ 0.02). In post-monsoon, NO_2 emerges from central and south India (~ 0.16) and Arabian Sea, Bay of Bengal, central and southern India was the main source of PM_{10} (~ 0.16). In summer season, NO_2 emerges from the south India (~ 0.18) and PM_{10} sources was Bay of Bengal and south India (~ 0.15). In winter season, the main source of NO_2 was south India (~ 0.1) and PM_{10} was Bay of Bengal, central and south India (~0.17).

5.2 Analysis on the effects of air pollution on Tourism

Many urban centers face challenges related to air quality. Poor air quality can impact the health of residents and visitors, influence tourists' perceptions, and affect overall tourism revenue.

5.2.1 Effects of Air Quality on Tourism

1. Health Concerns

i. **Respiratory Issues:** Poor air quality can lead to respiratory problems such as asthma, bronchitis, and other lung-related diseases. Tourists, especially those with pre-existing conditions, may avoid visiting areas with high pollution levels.

ii. **General Health Risks:** High levels of pollutants like $PM_{2.5}$ and PM_{10} can cause cardiovascular issues and other serious health problems. This can deter tourists who are increasingly aware of and concerned about air quality.

2. Perception and Reputation

i. **Negative Publicity:** News and reports about poor air quality can damage a city's reputation as a tourist destination. Social media and travel forums play a significant role in shaping potential visitors' perceptions.
ii. **Travel Advisories:** Governments and travel organizations may issue advisories against traveling to areas with poor air quality, impacting international tourist arrivals.

3. Economic Impact

i. **Reduced Tourist Numbers:** A decline in tourist arrivals due to air quality concerns can lead to a significant drop in revenue for the local economy, affecting businesses like hotels, restaurants, and transport services.
ii. **Increased Costs:** The tourism sector may face increased costs related to healthcare and mitigation measures, such as providing air purification systems in hotels and public areas.

I. **Air Quality Index (AQI):** The AQI in Jammu often fluctuates, with winter months typically showing higher pollution levels due to factors like vehicular emissions, industrial activities, and biomass burning. During peak pollution periods, the AQI can reach levels that are considered unhealthy for sensitive groups.
II. **Pollutant Levels:** Studies have shown that $PM_{2.5}$ and PM_{10} levels in Jammu often exceed the permissible limits set by the World Health Organization (WHO). For instance, the average $PM_{2.5}$ levels during winter months have been recorded at levels significantly above the safe limit of 25 µg/m³ [36].
III. **Tourism Statistics:**

According to the State Tourism Department, there has been a noticeable decline in tourist arrivals during periods of poor air quality. For example, during a particularly bad air quality episode in winter 2019-2020, there was a reported 15% drop in tourist visits compared to the previous year.

Table 20-Tourist statistics according to State of Tourism Department

Serial No.	City	Description	Reduction of tourists (2018-2019)	Ref.
1.	**HIMALAYAN REGION**			
I.	Jammu	It is often referred to as the "City of Temples," is a significant cultural and religious tourism hub in India [37].	15 %	[38]
II.	Rishikesh	It is known as the "Yoga Capital of the World" and a gateway to the Himalayas, attracts a significant number of domestic and international tourists annually. The city's appeal lies in its spiritual ambiance, adventure sports, and natural beauty [39].	12 %	[40]
III.	Dharamshala	It is located in the picturesque state of Himachal Pradesh, India, is renowned for its natural beauty, spiritual significance, and as the residence of the Dalai Lama [41].	10 %	[42]
2.	**INDO-GANGETIC PALINS**			
I.	Ranchi	It is the capital of Jharkhand, is known for its scenic beauty, waterfalls, and rich cultural heritage [43].	8 %	[44]
II.	Jalandhar	It is a prominent city in Punjab, India, is known for its rich history, vibrant culture, and sports industry [45].	10-15 %	[46]
III.	Gorakhpur	It is located in Uttar Pradesh, India, is known for its religious significance, historical sites, and as a gateway to Nepal [47].	10-12 %	[48]
3.	**NORTH-EAST INDIA**			
I.	Guwahati	It is the largest city in Assam and	15%	[44]

		often referred to as the "Gateway to Northeast India," is known for its rich cultural heritage, temples, and natural beauty. It attracts tourists for its historical sites, wildlife sanctuaries, and vibrant festivals [49].		
II.	Kohima	It is Kohima, the capital city of Nagaland, India, is known for its picturesque landscapes, rich cultural heritage, and historical significance. It attracts tourists for its festivals, particularly the Hornbill Festival, historical sites, and natural beauty [50].	10 %	[48]
III.	Shillong	It is the capital of Meghalaya, India, is often referred to as the "Scotland of the East" due to its rolling hills, scenic beauty, and pleasant climate. It is a popular tourist destination known for its waterfalls, lakes, and vibrant cultural festivals [51].	8 %	[48]
4.	**NORTH-WEST INDIA**			
I.	Jodhpur	It is also known as the "Blue City" and the "Sun City," is a major tourist destination in Rajasthan, India. It is famous for its palaces, forts, and temples set against the stark landscape of the Thar Desert [52].	12 %	[48]
II.	Vadodara	It is also known as Baroda, is a city in Gujarat, India, famous for its rich cultural heritage, historical monuments, and industrial development [53].	10-12 %	[48]
III.	Daman	It is located on the west coast of India, is a popular tourist destination known for its beaches, Portuguese colonial	10-12 %	[48]

		architecture, and scenic landscapes [54].		
5.	**CENTRAL INDIA**			
I.	Bhubaneshwar	It is the capital city of Odisha, is known for its ancient temples, rich cultural heritage, and burgeoning modern infrastructure. It attracts tourists for its historical sites, vibrant festivals, and natural beauty [55].	10 %	[56]
II.	Amravati	It is located in the state of Maharashtra, India, is known for its temples, wildlife sanctuaries, and historical sites [57].	8 %	[48]
III.	Singrauli	It is often referred to as the "Energy Capital of India," is known for its abundant coal reserves and power generation. While its industrial base is strong, the region also boasts natural attractions such as forests, rivers, and historical sites [58].	10-12 %	[48]
6.	**SOUTH INDIA**			
I.	Hubli	It is known for its historical significance, cultural heritage, and vibrant markets. It along with its twin city Dharwad, forms a key commercial hub in Karnataka [59].	7 %	[60]
II.	Tuticorin	It is known for its rich history, vibrant culture, and scenic beaches. The city is also an industrial hub, with significant contributions from salt pans, fishing, and shipping industries [61].	9 %	[48]
III.	Kozhikhode	It is renowned for its historical significance, cultural heritage, scenic beaches, and vibrant markets [53].	6 %	[62]

5.2.2 Mitigation Measures and Recommendations

1. Improving Air Quality

i. **Policy Implementation:** Strict enforcement of emission standards for vehicles and industries.
ii. **Green Initiatives:** Promoting the use of public transportation and electric vehicles, and increasing green cover in urban areas.

2. Tourism Sector Adaptations

i. **Health Services:** Establishing health services and air quality monitoring stations in key tourist areas to provide real-time information to visitors.
ii. **Awareness Campaigns:** Educating tourists about air quality issues and promoting off-season travel when air quality is typically better.

By addressing air quality issues through comprehensive policies and proactive measures, these cities can mitigate the negative effects on tourism and continue to attract visitors to its rich cultural and historical sites.

CHAPTER 6

CONCLUSION

When we see the results, we find that the particulate matter is emitted more as compared other gaseous pollutants. Hence, some measures are recommended for reducing the deterioration of air quality like:

a. Replacing the fuels that produce high levels of pollutants with other environment friendly fuels, such as liquefied petroleum gas (LPG), and electricity, in order to control and
b. Minimise the emissions of pollutants at their point sources.
c. In addition to this, meteorological parameters are observed to show a huge influence on the concentration of pollutants.

The monitoring sites chosen for ambient air quality assessment were primarily tourist hotspots, necessitating thorough studies on the impact of reduced tourist inflow. Destinations such as Jammu, Jalandhar, and Guwahati have been particularly affected, experiencing a decrease in tourist numbers by approximately 15%. Addressing these challenges requires:

a. Improving air quality through effective policy implementation and green initiatives.
b. Additionally, offering services that encourage travel to these destinations during periods when air quality is better can help mitigate the negative impacts.

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