

**PERFORMANCE ENHANCEMENT OF A REGULATORY
MODEL USING BACKGROUND CONCENTRATION AND
SIMULATED METEOROLOGICAL INPUTS**

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**CENTRE FOR ATMOSPHERIC SCIENCES
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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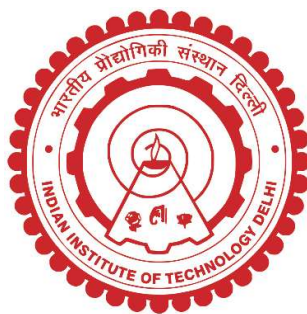
Centre for Atmospheric Sciences

Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

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Dedicated to

My Parents

*(Smt. Shakuntala Chaurasia &
Shri Rajiv Nayan Chaurasia)*

CERTIFICATE

This is to certify that the thesis entitled “**Performance Enhancement of a Regulatory Model using Background Concentration and Simulated Meteorological Inputs**” being submitted by **Mr. Rahul Chaurasia** to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy**, is a record of original bonafide work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis.

The results presented in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

Professor Manju Mohan, F.N.A.Sc

Centre for Atmospheric Sciences
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progress of my research but also to ask about my health and well-being. Their unwavering love and care have been a profound source of my emotional sustenance, providing me with an abundant reservoir of strength and comfort throughout this journey.

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Rahul Chaurasia

ABSTRACT

Air pollution is one of the major urban problems in both developed and developing countries. The rapid increase in urban population, industrialization, and the exponential growth in vehicular fleets collectively culminate in the emission of gaseous and particulate pollutants into the atmosphere. In order to implement pollution mitigation policies, it is imperative to study the source of emission and its dispersion in the environment, especially in developing countries where monitoring stations are not in sufficient numbers, which are economically burdensome and occasionally impractical. In this context, regulatory atmospheric dispersion models play a vital role in the assessment of ambient air quality. Dispersion modelling offers a solution by being able to estimate the impact of point, line, volume, and area sources on surface air quality in any given airshed, given accurate emission source characteristics, land use, terrain, meteorological data, and a measure of the total atmospheric concentration of the metrics in the model domain. However, previous studies have identified various irregularities in the prediction of pollutants, such as overestimation or underestimation across different scenarios. Many studies have suggested improving the performance of regulatory models for operational use by introducing improvements in various model inputs, including detailed atmospheric chemistry. The objective of this thesis is to improve the performance of the AERMOD model, a widely used time and cost-effective regulatory dispersion model.

Apart from being an important model input, emission inventories are helpful in keeping track of the most significant emission sources, facilitating the identification and prioritization of mitigation strategies, and informing policymakers and stakeholders about trends and patterns in emissions. Thus, an accurate emission inventory is a fundamental component for simulating pollutant dispersion and concentration in regulatory models. Therefore, the first objective of the thesis is to prepare a fine-resolution emission inventory for the study area, ie. Delhi NCT. The emission inventory for the year 2019-2020 has been prepared at a spatial resolution of $1\text{km} \times 1\text{km}$ using top to bottom approach. The inventory has comprehensively accounted for the most significant sectors contributing to the highest levels of emissions within the study area, e.g., industry, transportation, household and restaurant industries, MSW burning, aircraft emissions, etc. The emission hotspots were detected for Delhi NCT, and the emission inventory was validated using the AERMOD model, whereby the model performance was assessed using various statistical parameters, and the results were found to be satisfactory. The estimated emission data were also compared with various previous studies, which are covered in Chapter 2.

To develop effective regulatory policies, it is necessary to gain a better understanding of the regional background concentrations of pollutants. The models tendency to underestimate pollutants concentration can also be attributed to unaccounted emission sources in the emission inventory. Background Concentration is also defined as the concentration of a pollutant in a given air mass when there is no mixing of impurities due to local anthropogenic sources and natural and anthropogenic sources from outside the air shed. Thus, background concentration apart from being an important model input is also a measure of the minimum pollutant concentration level to which a population is exposed to. In this study the background concentration of the study area is estimated using meteorological filtering and statistical techniques and is covered in chapter 3. The meteorological filtering factored in the phenomena involving stagnation caused by low wind speed and temperature inversion. Whereas spectral analysis and the Kolmogorov-Zurbenko (KZ) filter were used in combination to reduce the influence of synoptic fluctuation in the time series. The estimated background concentrations were compared with the concentration obtained during Covid Lockdown period.

Later in chapter 4, the background concentration estimated using statistical method was validated using WRF Chem model. The chapter also attempts to quantify the pollutants contribution due to long-range transport in a severe pollution event. Long range transport is one of the major contributors to air Pollution in Delhi National Capital region. However, limited attempts have been made to study the characteristic of the long-range transport and its contribution during severe pollution events across the seasons. In this study, the WRF Chem model was used to quantify the contribution of regional transport to severe pollution events across the seasons and estimate the background concentration. This experimental design was used to estimate the background concentration levels for the study region. This determination is a crucial aspect of environmental monitoring and research, as it establishes a baseline level for each ambient pollutant.

Finally, the last working chapter 5 compares the the AERMOD model performance using emission inventory with and without background concentration, with meteorological data prepared using WRF model and with model simulations from WRF-Chem. It was observed that the AERMOD model underpredicted the particulate pollutants and overpredicted the gaseous pollutants in default case (using high resolution emission inventory). The AERMOD model tends to overpredict pollutants under stable atmospheric conditions. Enhancements in boundary layer parameterization could improve performance during these conditions. The model's accuracy improved for particulate pollutants during summer and monsoon seasons when using estimated background concentrations. For gaseous pollutants, performance was

somewhat better during monsoons. In the WRF-AERMOD coupled system, the model performed better in winter across all pollutants compared to summer and monsoon months. Using meteorological data from monitoring stations yielded results comparable to those using WRF model forecasts. The default WRF-AERMOD scenario showed promise in overcoming limitations related to unavailable meteorological parameters.

सारांश

वायु प्रदूषण विकसित और विकासशील दोनों देशों में प्रमुख शहरी समस्याओं में से एक है। शहरी आबादी में तेजी से वृद्धि, औद्योगीकरण, और वाहनों के बेड़े में तेजी से वृद्धि सामूहिक रूप से वायुमंडल में गैसीय और कण प्रदूषकों के उत्सर्जन में परिणत होती है। प्रदूषण शमन नीतियों को लागू करने के लिए, उत्सर्जन के स्रोत और पर्यावरण में इसके फैलाव का अध्ययन करना जरूरी है, खासकर विकासशील देशों में जहां निगरानी स्टेशन पर्याप्त संख्या में नहीं हैं, जो आर्थिक रूप से बोज़िल और कभी-कभी अव्यावहारिक हैं। इस संदर्भ में, नियामक वायुमंडलीय फैलाव मॉडल परिवेशी वायु गुणवत्ता के मूल्यांकन में महत्वपूर्ण भूमिका निभाते हैं। फैलाव मॉडलिंग सटीक उत्सर्जन स्रोत विशेषताओं, भूमि उपयोग, इलाके, मौसम संबंधी डेटा और माप के आधार पर किसी भी एयरशेड में सतह की वायु गुणवत्ता पर बिंदु, रेखा, मात्रा और क्षेत्र स्रोतों के प्रभाव का अनुमान लगाने में सक्षम होकर एक समाधान प्रदान करता है। मॉडल डोमेन में मेट्रिक्स की कुल वायुमंडलीय सांद्रता। हालाँकि, पिछले अध्ययनों ने प्रदूषकों के पूर्वानुमान में विभिन्न अनियमितताओं की पहचान की है, जैसे विभिन्न परिदृश्यों में अधिक अनुमान या कम अनुमान। कई अध्ययनों ने विस्तृत वायुमंडलीय रसायन विज्ञान सहित विभिन्न मॉडल इनपुट में सुधार करके परिचालन उपयोग के लिए नियामक मॉडल के प्रदर्शन में सुधार करने का सुझाव दिया है। इस थीसिस का उद्देश्य AERMOD मॉडल के प्रदर्शन में सुधार करना है, जो व्यापक रूप से उपयोग किया जाने वाला समय और लागत प्रभावी नियामक फैलाव मॉडल है।

एक महत्वपूर्ण मॉडल इनपुट होने के अलावा, उत्सर्जन सूची सबसे महत्वपूर्ण उत्सर्जन स्रोतों पर नज़र रखने, शमन रणनीतियों की पहचान और प्राथमिकता को सुविधाजनक बनाने और नीति निर्माताओं और हितधारकों को उत्सर्जन में रुझान और पैटर्न के बारे में सूचित करने में सहायक होती है। इस प्रकार, नियामक मॉडल में प्रदूषक फैलाव और एकाग्रता का अनुकरण करने के लिए एक सटीक उत्सर्जन सूची एक मौलिक घटक है। इसलिए, थीसिस का पहला उद्देश्य अध्ययन क्षेत्र के लिए एक बढ़िया-रिज़ॉल्यूशन उत्सर्जन सूची तैयार करना है, अर्थात् दिल्ली एनसीटी. वर्ष 2019-2020 के लिए उत्सर्जन सूची ऊपर से नीचे दृष्टिकोण का उपयोग करके 1 किमी x 1 किमी के स्थानिक रिज़ॉल्यूशन पर तैयार की गई है। सूची में अध्ययन क्षेत्र के भीतर उत्सर्जन के उच्चतम स्तर में योगदान देने वाले सबसे महत्वपूर्ण क्षेत्रों, जैसे, उद्योग, परिवहन, घरेलू और रेस्तरां उद्योग, एमएसडब्ल्यू दहन, विमान उत्सर्जन, आदि का व्यापक रूप से हिसाब लगाया गया है। उत्सर्जन हॉटस्पॉट का पता दिल्ली एनसीटी के लिए लगाया गया था। और उत्सर्जन सूची को AERMOD मॉडल का उपयोग करके मान्य किया गया था, जिसके तहत विभिन्न सांख्यिकीय मापदंडों का उपयोग करके मॉडल के प्रदर्शन का मूल्यांकन किया गया था, और परिणाम संतोषजनक पाए गए थे। अनुमानित उत्सर्जन डेटा की तुलना विभिन्न पिछले अध्ययनों से भी की गई, जो अध्याय 2 में शामिल हैं।

प्रभावी नियामक नीतियां विकसित करने के लिए, प्रदूषकों की क्षेत्रीय पृष्ठभूमि सांद्रता की बेहतर समझ हासिल करना आवश्यक है। प्रदूषकों की सांद्रता को कम आंकने की मॉडल की प्रवृत्ति को उत्सर्जन सूची में बेहिसाब उत्सर्जन स्रोतों के लिए भी जिम्मेदार ठहराया जा सकता है। पृष्ठभूमि सांद्रता को किसी दिए गए वायु द्रव्यमान में प्रदूषक की सांद्रता

के रूप में भी परिभाषित किया जाता है, जब स्थानीय मानवजनित स्रोतों और वायु शेड के बाहर से प्राकृतिक और मानवजनित स्रोतों के कारण अशुद्धियों का कोई मिश्रण नहीं होता है। इस प्रकार, पृष्ठभूमि सांद्रता एक महत्वपूर्ण मॉडल इनपुट होने के अलावा न्यूनतम प्रदूषक सांद्रता स्तर का एक माप भी है जिसके संपर्क में कोई आबादी आती है। इस अध्ययन में अध्ययन क्षेत्र की पृष्ठभूमि सांद्रता का अनुमान मौसम संबंधी फ़िल्टरिंग और सांख्यिकीय तकनीकों का उपयोग करके लगाया गया है और इसे अध्याय 3 में शामिल किया गया है। मौसम संबंधी फ़िल्टरिंग कम हवा की गति और तापमान उलटाव के कारण होने वाले ठहराव से जुड़ी घटनाओं में शामिल है। जबकि समय श्रृंखला में सिनॉप्टिक उतार-चढ़ाव के प्रभाव को कम करने के लिए वर्णक्रमीय विश्लेषण और कोलमोगोरोव-जुर्बेको (KZ) फ़िल्टर का संयोजन में उपयोग किया गया था। अनुमानित पृष्ठभूमि सांद्रता की तुलना कोविड लॉकडाउन अवधि के दौरान प्राप्त एकाग्रता से की गई।

बाद में अध्याय 4 में, सांख्यिकीय पद्धति का उपयोग करके अनुमानित पृष्ठभूमि एकाग्रता को डब्ल्यूआरएफ केम मॉडल का उपयोग करके मान्य किया गया था। अध्याय किसी गंभीर प्रदूषण घटना में लंबी दूरी के परिवहन के कारण प्रदूषकों के योगदान को मापने का भी प्रयास करता है। लंबी दूरी का परिवहन दिल्ली राष्ट्रीय राजधानी क्षेत्र में वायु प्रदूषण के प्रमुख योगदानकर्ताओं में से एक है। हालाँकि, लंबी दूरी के परिवहन की विशेषता और सभी मौसमों में गंभीर प्रदूषण की घटनाओं के दौरान इसके योगदान का अध्ययन करने के सीमित प्रयास किए गए हैं। इस अध्ययन में, डब्ल्यूआरएफ केम मॉडल का उपयोग सभी मौसमों में गंभीर प्रदूषण की घटनाओं में क्षेत्रीय परिवहन के योगदान को मापने और पृष्ठभूमि एकाग्रता का अनुमान लगाने के लिए किया गया था।

इस प्रायोगिक डिज़ाइन का उपयोग अध्ययन क्षेत्र के लिए पृष्ठभूमि एकाग्रता स्तर का अनुमान लगाने के लिए किया गया था। यह निर्धारण पर्यावरण निगरानी और अनुसंधान का एक महत्वपूर्ण पहलू है, क्योंकि यह प्रत्येक परिवेश प्रदूषक के लिए एक आधारभूत स्तर स्थापित करता है।

अंत में, अंतिम कामकाजी अध्याय 5 पृष्ठभूमि एकाग्रता के साथ और बिना उत्सर्जन सूची का उपयोग करते हुए, डब्ल्यूआरएफ मॉडल का उपयोग करके तैयार किए गए मौसम संबंधी डेटा और डब्ल्यूआरएफ-केम से मॉडल सिमुलेशन के साथ एईआरएमओडी मॉडल के प्रदर्शन की तुलना करता है। यह देखा गया कि AERMOD मॉडल ने कण प्रदूषकों का कम अनुमान लगाया और डिफॉल्ट मामले में (उच्च रिज़ॉल्यूशन उत्सर्जन सूची का उपयोग करके) गैसीय प्रदूषकों का अधिक अनुमान लगाया। AERMOD मॉडल स्थिर वायुमंडलीय परिस्थितियों में प्रदूषकों की अधिक भविष्यवाणी करता है। सीमा परत मानकीकरण में संवर्द्धन से इन स्थितियों के दौरान प्रदर्शन में सुधार हो सकता है। अनुमानित पृष्ठभूमि सांद्रता का उपयोग करते समय गर्मी और मानसून के मौसम के दौरान कण प्रदूषकों के लिए मॉडल की सटीकता में सुधार हुआ। गैसीय प्रदूषकों के लिए, मानसून के दौरान प्रदर्शन कुछ हद तक बेहतर था। WRF-AERMOD युग्मित प्रणाली में, मॉडल ने गर्मी और मानसून के महीनों की तुलना में सर्दियों में सभी प्रदूषकों में बेहतर प्रदर्शन किया। निगरानी स्टेशनों से मौसम संबंधी डेटा का उपयोग करने से डब्ल्यूआरएफ मॉडल पूर्वानुमानों का उपयोग करने वाले परिणामों की तुलना की जा सकती है। डिफॉल्ट WRF-AERMOD परिदृश्य ने अनुपलब्ध मौसम संबंधी मापदंडों से संबंधित सीमाओं पर काबू पाने का वादा दिखाया।

TABLES OF CONTENTS

CERTIFICATE	<i>i</i>
ACKNOWLEDGEMENTS	<i>ii</i>
ABSTRACT	<i>iv</i>
LIST OF FIGURES.....	<i>xiii</i>
LIST OF TABLES.....	<i>xvi</i>
LIST OF ABBREVIATIONS.....	<i>xviii</i>
Chapter 1 : Introduction	<i>1</i>
1.1 Introduction	<i>1</i>
1.2 Ambient Pollutants	<i>4</i>
1.3 Emission Inventory	<i>5</i>
1.3.1 Bottom-up Approach for emission inventory Preparation	<i>6</i>
1.3.2 Top-Down Approach for emission inventory Preparation	<i>6</i>
1.4 Background Concentration	<i>6</i>
1.5 Numerical modelling use in Air Pollution.....	<i>7</i>
1.5.1 AERMOD.....	<i>7</i>
1.5.2 WRF/WRF-Chem Modelling System	<i>8</i>
1.6 Literature Review	<i>10</i>
1.7 Objectives and Outline of present work	<i>14</i>
Chapter 2 : Preparation of Anthropogenic Emission Inventory of Delhi NCT and Validation using Regulatory Air Quality Model AERMOD	<i>16</i>
2.1 Introduction	<i>16</i>
2.2 Study Area	<i>18</i>
2.3 Methodology	<i>19</i>
2.3.1 Emissions from Domestic and Restaurants Sector:	<i>20</i>
2.3.2 Emission from vehicles:	<i>20</i>
2.3.3 Emissions from Industries:	<i>24</i>
2.3.4 Emissions from Aircraft:	<i>25</i>
2.3.5 Emissions by MSW Burning:	<i>26</i>
2.3.6 Emissions from Power Plants:	<i>28</i>
2.4 Results and discussion.....	<i>29</i>
2.4.1 Spatial Distribution of Emissions and Identification of Emission Hotspots	<i>29</i>
2.4.2 Comparing the increment in emission for the period 2015 to 2019-2020.....	<i>34</i>
2.4.3 Validation of AERMOD Model using the High Resolution Emission Inventory	<i>36</i>
2.5 Conclusions.....	<i>44</i>
Chapter 3 : Estimation of background concentration of Ambient Pollutants for Delhi NCT, India	<i>45</i>
3.1 Introduction	<i>45</i>
3.2 Data and Methodology	<i>48</i>
3.2.1 Study Area and Data Collection.....	<i>48</i>

3.2.2 Method employed to calculate background concentration	51
3.3 Results and Discussion:	60
3.3.1 Concentration under background and non-background periods	60
3.3.2 Spectral analysis and KZ filtering	63
3.3.3 Background concentration of Delhi NCT	63
3.3.4 Validation of the estimated concentration by 2020 Lockdown Event	66
3.4 Conclusions	68
<i>Chapter 4 Estimation of Background Concentration Using a Chemical Transport Model, WRF-Chem and comparison with Statistically Estimated Background Concentration</i>	70
4.1 Introduction	70
4.2 Data and Methodology	72
4.2.1 The WRF-Chem model setup.....	72
4.3 Results and Discussions.....	75
4.3.1 Model Evaluation.....	75
4.3.2 Background Concentration for the Study area	83
4.4 Severe Pollution Events	84
4.4.1 Occurrence of dust storm June 07 to 17, 2018	84
4.4.2 October Crop Burning Event.....	90
4.4.3 Winter Severe Pollution Event.....	92
4.5 Conclusion	93
<i>Chapter 5 Assessment of Overall performance of AERMOD Model with background concentration, high resolution Emission Inventory and WRF model simulated meteorology</i>	94
5.1 Introduction	94
5.2 Study Area	96
5.3 Data and Methodology	96
5.3.1 Emission Inventory	97
5.3.2 Estimation of Background Concentration.....	97
5.3.3 AERMOD Model	98
5.3.4 WRF Model.....	98
5.3.5 WRF-AERMOD coupled modelling framework.....	99
5.4 Results and Discussions.....	99
5.4.1 Comparisons of model performance for AERMOD Default (without Background concentration) and AERMOD using Background Concentration.....	100
5.4.2 Comparisons of model performance for AERMOD Default (without Background concentration) and AERMOD-WRF coupled system	111
5.4.3 Results for Default AERMOD and using WRF-Chem	118
5.5 Conclusions.....	122
<i>Chapter 6 Conclusions and Future Work</i>	124
6.1 Conclusions.....	124
6.2 Scope of future work.....	128
<i>CURRICULUM VITAE</i>	153

LIST OF FIGURES

Figure 1.1 Particulate matter exposure around the world (Source: IQAir,2019).....	(3)
Figure 1.2 Third world countries more prone to air pollution (Source: State of Global Air, 2020).....	(3)
Figure 1.3 Figure 1Flowchart depicting the AERMOD modelling system.....	(8)
Figure 1.4 WRF Chem Modelling System (Source: Peckham et al., 2012).....	(10)
Figure 2.1 Map showing Study Domain.....	(19)
Figure 2.2 Figure showing the growth of vehicular population in Delhi NCT (2000-2020).....	(22)
Figure 2.3. Percent of Vehicles and corresponding Fuel type.....	(22)
Figure 2.4. Map showing Major road networks and Heavy traffic congestion Points for Delhi NCT.....	(24)
Figure 2.5 Map showing Industrial areas of the Study Domain.....	(25)
Figure 2.6 Graph showing annual passenger travelled and air traffic over IGI Airport (2005-2020).....	(26)
Figure 2.7 A map showing settlement types based on Socio-Economic conditions for study domain.....	(28)
Figure 2.8 (a-e). <i>Sector-wise contribution of various sectors to PM₁₀, PM_{2.5}, SO₂, NO_x and CO</i>	(29)
Figure 2.9: Spatial Distribution of PM ₁₀ , PM _{2.5} , SO ₂ , NO _x and CO over Delhi NCT (kg/day).....	(32)
Figure 2.10 Q-Q plots for Observed vs Predicted concentration using high-resolution emission inventory for May Month (Summer Season).....	(40)
Figure 2.11 Q-Q plots for Observed vs Predicted using high-resolution emission inventory for July Month (Monsoon Season).....	(41)
Figure 2.12 Q-Q plots for Observed vs Predicted daily averaged concentrations of December (Winter Season).....	(42)
Figure 3.1 Map showing study area and stations considered for the study.....	(49)
Figure 3.2 The plot showing average decadal wind speed at the surface (10m) and 100m height.....	(51)
Figure 3.3 Comparison of average monthly concentration of PM ₁₀ , PM _{2.5} , NO ₂ , SO ₂ and CO for 2018 at various monitoring stations in Delhi.....	(51)
Figure 3.4 A Monthly wind rose diagram at Ayanagar Station for the year 2018.....	(53)

Figure 3.5 Air mass backward trajectories culmination over Delhi, for the year 2018, on a daily basis (a, c): distribution of 24-h air mass backward trajectories for the entire year; b: 24-h air mass backward trajectories showing high concentration load from north-west dust sources June 10, 2018 d: 24-h air mass backward trajectories from Punjab and Haryana region November 27, 2018. These trajectory plots (b, d) and similar ones were omitted for background concentration estimation.....	(54)
Figure 3.6. (a) Hourly interval mass concentrations of PM _{2.5} and PM ₁₀ during a dust storm over Delhi (b) 7-day air mass back trajectory at different altitudes on June 15, 2018 (c) 2-Week Wind-Rose during the dust storm event (June 10 to June 24, 2018) at Ayanagar station.....	(55)
Figure 3.7. (a-e) Power Spectra of PM _{2.5} , NO ₂ , PM ₁₀ , SO ₂ and CO concentration at Ayanagar air quality Monitoring Station.....	(56)
Figure 3.8. (a-e) Concentration of PM ₁₀ , PM _{2.5} , NO ₂ , SO ₂ and CO under background and non-background periods at Ayanagar station in Delhi NCT after meteorological filtering....	(61)
3.9 (a-e) Plot showing the estimated monthly background and non-background concentration for PM ₁₀ , PM _{2.5} , NO ₂ , SO ₂ and CO.....	(63)
Figure 3.10. Comparison of Estimated Background Concentration Values with concentration recorded during the Lockdown period.....	(67)
Figure 4.1: WRF ARW v3.8 model domain and study area.....	(73)
Figure 4.2: Comparison of observed to modelled Temperature at ANVT and Punjabi Bagh Station.....	(76)
Figure 4.3: Comparison of observed to modelled Relative Humidity at ANVT and Punjabi Bagh Station.....	(77)
Figure 4.4: Comparison of observed to modelled wind speed at ANVT and Punjabi Bagh Station.....	(78)
Figure 4.5: Comparison of observed to modelled PM _{2.5} at ANVT and Punjabi Bagh Station.....	(79)
Fig. 4.6. The observed and simulated daily PM _{2.5} concentration (in µg m ⁻³) over Delhi NCT during the 9-10 days window. The dashed vertical line indicate the episode day(s).....	(83)
Fig. 4.7. Day to Day variation in surface level pressure and wind vectors over the model domain from 10 June to 13 June. The wind vectors are shown at 550hPa.....	(84)
Fig. 4.8: The seasonal trajectories (a) for Delhi NCT at 1000 and 1500 mt altitudes. Figure (b) showing trajectories at 2500 and 3000 mt height, for the period 8 June to 15 June 2018....	(85)

Fig.4.9. Plot showing the peak and dissipation phase of the dust storm event. The peak was observed on 11th June 2018. This CTRL case was performed with all the emissions turned on.....	(86)
Fig.4.10. Spatial distribution of the distribution of the daily average near surface PM _{2.5} concentration on 11th June simulated by the CTL (a), LC (b) and RT (c) experiments.....	(87)
Fig 4.11. WRF-Chem simulated concentrations with attribution to local and RT (Within city boundaries and outside of the city boundary) transport and local during (a) Dust storm event (June, 2019), (b) Crop Residue Burning (October, 2019) and (c) Severe Pollution Event in winter month (December, 2019).....	(88)
Figure 4.12: (a-b) Comparison of the total cases of crop burning during the months (a) September (b) October. (c) Showing cumulative number of fire incidents from September to November.....	(90)
Figure 4.13: Spatial distribution of the distribution of the daily average near surface PM _{2.5} concentration on 18th October simulated by the CTL (a), LC (b) and RT (c) experiments.....	(90)
Figure. 5.1 (a-e) Comparison of observed vs Predicted concentrations for ANVT station for May month.....	(101)
Figure. 5.2 (a-e) Comparison of observed vs Predicted concentrations for ANVT station for July month.....	(102)
Figure. 5.3 (a-e) Comparison of observed vs Predicted concentrations for ANVT station for December month.....	(103)
Figure.5.4 Q-Q plots for Observed vs Predicted in Default Aermოდ Run and Run using Estimated Background Concentration for May Month.....	(104)
Figure.5.5 Q-Q plots for Observed vs Predicted in Default Aermოდ Run and Run using Estimated Background Concentration for July Month.....	(105)
Figure.5.6 Q-Q plots for Observed vs Predicted in Default Aermოდ Run and Run using Estimated Background Concentration for December Month.....	(106)
Figure. 5.7 (a-e) Q-Q plots for Observed vs Predicted using WRF-Meteorology for May Month.....	(112)
Figure. 5.8 (a-e) Q-Q plots for Observed vs Predicted using WRF-Meteorology for July Month	(113)
Figure. 5.9 (a-e) Q-Q plots for Observed vs Predicted using WRF-Meteorology for December Month.....	(114)

LIST OF TABLES

Table 2.1. Vehicle type and population for the year 2019-2020.....	(23)
Table 2.2. Annual Average Vehicle-Km Traveled (Delhi NCT).....	(23)
Table 2.3. Comparison of the Estimated Emission with Previous studies.....	(30)
Table 2.4. Table comparing the change in emission during the period 2015-2019-20.....	(36)
Table 2.5. Sales of Energy products in Delhi for the period 2015-2020.....	(36)
Table 2.6. Statistical indicators AERMOD Run in default mode for May.....	(39)
Table 2.7. Statistical indicators Aermod Run in default mode for July.....	(39)
Table 2.8. Statistical indicators AERMOD Run in default mode for December.....	(39)
Table 3.1. Filter configuration with different window length (m) and iteration (p).....	(58)
Table 3.2. Comparison of estimated background concentration of the current study with Annual average concentration, NAAQS, and estimated baseline concentration during lockdown period.....	(64)
Table 3.3. The seasonal average Background concentration values for the Aya Nagar Station.....	(65)
Table 4.1: Parameterization schemes used for the simulation.....	(74)
Table 4.2. The sensitivity experiments used in study.....	(74)
Table 4.3. Model statistics for Temperature.....	(80)
Table 4.4. Model statistics for Relative Humidity.....	(80)
Table 4.5. Model statistics for Wind Speed.....	(81)
Table 4.6. Model statistics for PM _{2.5}	(81)
Table 4.7. Table comparing the background concentration obtained using statistical method and using WRF-Chem Model.....	(82)
Table 4.7 The list of events and periods considered for case study.....	(83)
Table 5.1. Table 5.1. Comparison of statistical indicators for two distinct run scenarios i.e. AERMOD Run in default mode (D-AER) and Aermod run using Background concentrations (BC) for May (2019).....	(107)
Table 5.2. Comparison of statistical indicators for two distinct run scenarios i.e. AERMOD Run in default mode (D-AER) and Aermod run using Background concentrations (BC) for July (2019).....	(107)
Table 5.3. Comparison of statistical indicators for two distinct run scenarios i.e. AERMOD Run in default mode (D-AER) and AERMOD run using Background concentrations (BC) for December (2019)).....	(108)

Table 5.4. Comparison of Correlation Coefficient obtained in present study with previous studies for July Month (All the studies are done in default mode).....(108)

Table 5.5. Comparison of Fractional Bias obtained in present with previous studies for July (Default mode).....(109)

Table 5.6. Comparison of statistical indicators for Aermod Run in default mode and Aermod-WRF coupled system for May Month [D-AER: Default AERMOD; AER-WRF: AERMOD with WRF Meteorolog.....(111)

Table 5.7. Comparison of statistical indicators for Aermod Run in default mode and Aermod-WRF coupled system for July Month.....(111)

Table 5.8. Comparison of statistical indicators for Aermod Run in default mode and Aermod WRF coupled system for December Month.....(111)

Table 5.9. Comparison of Correlation Coefficient obtained in present study with inclusion of WRF simulated meteorology with earlier studies for July Month.....(115)

Table 5.10. Comparison of Fractional Bias obtained in present study with inclusion of WRF simulated meteorology with earlier studies for July Month.....(115)

LIST OF ABBREVIATIONS

AAI	: Airports Authority of India
AERMOD	: American Meteorological Society-Environmental Protection Agency Regulatory Model
ARAI	: Automotive Research Association of India
BC	: Background Concentration
BSIV	: Bharat Stage IV
CAGR	: Compound Annual Growth Rate
CNG	: Compressed Natural Gas
CO	: Carbon Monoxide
CPCB	: Central Pollution Control Board
CRB	: Crop Residue Burning
EF	: Emission Factor
FB	: Fractional Bias
HCV	: Heavy Commercial Vehicle
HSDO	: High Speed Diesel Oil
IMD	: Indian Meteorological Department
IOA	: Index of Agreement
ISBT	: Inter State Border Transport
ISCST3	: Industrial Source Complex Short Term Model 3
KZ filter	: Kolmogorov-Zurbenco Filter
LCV	: Light Commercial Vehicle
LDO	: Light Diesel Oil
LPG	: Liquified Petroleum Gas
LRT	: Long Range Transport
LTO	: Landing and Take off Cycle
MSW	: Municipal Solid Waste
MYJ	: Mellor-Yemada-Janic scheme
NCR	: National Capital Region
NCT	: National Capital Territory
NMSE	: Normalised Mean Square Error
NO ₂	: Nitrogen dioxide
NO ₃ ⁻	: Nitrates

NRMSE : Normalized Root Mean Square Error

O₃ : Ozone

PM : Particulate Matters

r : Correlation Coefficient

RT : Regional Transport

RMSE : Root Mean Squared Error

SO₂ : Sulphur dioxide

USEPA : US Environmental Protection Agency

WHO : World Health Organisation

YSU : The Yonsai University Sche