A project report on

IMPACT ASSESSMENT OF GRAP SCHEME IMPLEMENTATION DURING EXTREME POLLUTION EVENTS IN DELHI

Submitted in the Partial Fulfilment of the Requirement for the Award of a Degree of

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by

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(2K22/ENE/05)

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CANDIDATE'S DECLARATION

I, **Rimaz Hassan Hussain Mohmmed, 2K22/ENE/05** student of MTech (Environmental Engineering), hereby declare that the project Dissertation titled "**Impact assessment of GRAP scheme implementation during extreme pollution events in Delhi** " which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

Place**: Delhi**

Date**: 24th June 2024**

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CERTIFICATE

Certified that the project Dissertation title "**Impact Assessment of GRAP Scheme Implementation During Extreme Pollution Events in Delhi"** which is submitted by **Rimaz Hassan Hussain Mohmmed, 2K22/ENE/05** Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by student under my supervision. To the best of my knowledge this work has not been submitted part or full for any Degree, Diploma in this university of Elsewhere.

Place**: Delhi**

Date**: June 2024**

Supervisor

Dr. Rajeev Kumar Mishra

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ABSTRACT

The high level of air pollution in the megacity of Delhi is extremely concerning and requires committed, rigorous efforts to reduce it to achieve the specified standards. The study evaluated the impact of the Graded Response Action Plan (GRAP) on air quality in Delhi, India, focusing on changes before, during, and after its implementation across various zones. Data was collected from 41 monitoring stations in Delhi, divided into two phases (2022-2023 and 2023-2024), and included concentrations of key pollutants. The data was analyzed to illustrate pollutant concentration changes across different GRAP stages within specified zones. The study found that all zones experienced increased pollutant concentrations during Phase 1, while Phase 2 showed a decreasing trend, indicating the effectiveness of Phase 2 GRAP interventions. The CO concentrations across all zones and phases, maintain stable levels. However, NH_3 and NO_x levels increased in Phase 1, while O_3 and SO_2 levels fluctuated. PM_{10} and $PM_{2.5}$ levels also increased in both phases. In Phase 1, NO_2 concentrations increased except in the east zone, while other pollutants (NO_x, NO, $PM_{2.5}$, and PM_{10}) showed an increasing trend. In Phase 2, NH_3 concentrations increased except in the north, south, and east zones, while NO_x, NO_2, NO, $PM_{2.5}$, and PM_{10} concentrations increased except in the west and central zones. On a zone basis, the study reveals that the north, south, and west zones of Delhi have the most significant increasing trends in pollutants in Phase 1 and Phase 2, respectively. The east zone shows the most consistent decreasing trends in Phase 1 and Phase 2. Compared with the standard, $PM_{2.5}$ and PM_{10} consistently exceeded the National Ambient Air Quality Standards (NAAQS) limits in both Phase 1 and 2, while NH_3, O_3, SO_2, and CO remained within acceptable limits. However, NO_x, NO_2, and NO exhibited fluctuating concentrations, suggesting that more measures are needed for effective air

pollution control. The study recommends enhancing GRAP measures, particularly targeting high-emission zones like North and South Delhi, and incorporating additional interventions to ensure more significant reductions in pollutant levels to meet air quality standards.

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LIST OF ABBREVIATIONS

GRAP	Graded Response Action Plan
NAAQS	National Ambient Air Quality Standards
PM	Particulate Matter
NCR	National Capital Region
MOEF&CC	Ministry of Environment, Forests & Climate Change
CAQM	Commission for Air Quality Management
DISCOMs	Distribution Companies
AQI	Air Quality Index
SAFAR	System of Air Quality and Weather Forecasting and Research
C&D	Construction and Demolition
MSW	Municipal Solid Waste
GNCTD	Government of National Capital Territory of Delhi
WHO	World Health Organisation
USEPA	United States Environmental Protection Agency
CAGRs	Compound Annual Growth Rates
BG vs S1	Before GRAP Versus Stage 1
S1 vs S2	Stage 1 versus Stage 2
S2 vs S3	Stage 2 versus Stage 3
S3 vs S4	Stage 3 versus Stage 4
S4 vs S3	Stage 4 versus Stage 3
S3 vs S2	Stage 3 versus Stage 2
S2 vs S3	Stage 2 versus Stage 3

S3 vs S2	Stage 3 versus Stage 2
S2 vs S1	Stage 2 versus Stage 1
S1 vs S2	Stage 1 versus Stage 2
S2 vs S1	Stage 2 versus Stage 1
S1 vs AG	Stage 2 versus After GRAP

Chapter 1

INTRODUCTION

New Delhi is the most polluted city in the world, with particle matter (PM) concentrations of smaller than 2.5 micrometers measured in diameter measuring more than 350 micrograms per cubic meter of air in May 2014(Kanawade et al., 2020). This increased PM content is due to a rise in automobile emissions and the number of coal-fired power plants in urban areas is the cause of the different sizes in the atmosphere (Guttikunda & Gurjar, 2012). There is a serious risk to human health and welfare from pollution. studies by the WHO have shown that seven Million people have perished globally due to air pollution (Shivani et al., 2019). Among these are fatalities brought on by exposure to hazardous substances both indoors and outdoors (Sharma, 2023). Automobile exhaust and industrial emissions are the primary causes of air pollution in India and the rest of the world (Sahu et al., 2011). Traces of fossil fuels, carbon particles, and metal particles from industrial and automobile sources are examples of external contaminants (Singh et al., 2018). emissions, harmful gasses like sulfur dioxide, carbon monoxide, and nitrogen dioxide, among others. Moreover, tobacco smoke, ozone, and so forth. However, hazardous gasses released by burning fuels for cooking and construction materials, such as tobacco smoke, asbestos, lead, etc (Sengupta et al., 2022). In developing nations, one of the biggest health risks is urban air pollution. The majority of megacities have rising air quality levels above the national limits or regulations for ambient air quality. Because of the rapid expansion of sources and the inadequate execution of control measures, assessing and managing the quality of the air in such megacities presents significant challenges. Urban areas are full of different combinations of activities that produce pollution, which may be dangerous and lower air quality. Delhi, the capital of India, has higher pollution levels than other large cities in developing nations. Rapid population increase also spurs the development of related dependent industries including commercial, residential, and transportation by road, which eventually raises energy consumption. In Delhi City, the number of motorized vehicles has increased dramatically during the past 15 years (from 34.56 million in 2000 to 104.83 lakh in 2017) Additionally, rapid expansion of business ventures resulted in a rise in the quantity of diesel generator (DG) sets, eateries, and lodging. This tremendous growth in the consumption of petroleum products led to the generation of high air pollution(Gulia et al., 2021). In the past, Delhi's rapid industrialization and urbanization have been major factors in the city's rising pollution levels. This change has accelerated economic expansion but has also considerably degraded air quality by increasing industrial discharges, vehicle emissions, and other pollutants. Geographical and meteorological variables worsen the issue, making Delhi's air pollution a complicated problem with wideranging effects. There has been much research done on the effects of Delhi's air pollution on health. Long-term exposure to poor air quality can result in chronic health concerns since researchers have connected it to a variety of respiratory and cardiovascular disorders. Specifically, particulate matter (PM) in Delhi's air, particularly $PM_{2.5}$ and PM_{10}, is a significant role in inhabitants' health problems(Ashutosh Deshpande et al., 2024). Additionally, research has demonstrated that vulnerable populations, such as children, the elderly, and those with pre-existing medical disorders, are disproportionately impacted by air pollution. This demographic feature emphasizes the necessity of focused interventions and legislative actions. The financial cost of Delhi's health problems caused by air pollution is another important factor. The significant direct and indirect costs—which include healthcare expenses and missed productivity—highlight the necessity of efficient pollution control measures. In conclusion, the Delhi-NCR air pollution problem is a serious public health issue in addition to an environmental concern. Because of its complex impacts on the economy, public health, and vulnerable groups, air pollution must be understood, tracked, and mitigated through a comprehensive strategy(Ashutosh Deshpande et al., 2024). A healthy life demands clean air, but air pollution has become a global problem, with cities being particularly vulnerable because of their dense populations. Asian megacities have gained international prominence while being far more polluted than before. The megacity in India's air quality at the start of winter brings news from print and media alike, including Delhi. Because of its link to early death and the weight of disease, air pollution is viewed as a modern-day curse that greatly affects developing nations with poor incomes, particularly India. The fourth most important risk factor for disease burden and premature mortality globally is now air pollution. Its negative effects might affect people anywhere in the world, regardless of where they were born. Indian cities certainly rank among the most seriously impacted polluted areas and the health hazards to the world. Twenty-two of the thirty most polluted cities in the world are located in India, with Delhi, the nation's capital, topping the list for several years due to its annual particulate matter ($PM_{2.5}$) level, which is almost ten times higher than WHO permissible limits. Delhi is also extremely involved in the harmful network of air quality and health-based standards. This resulted in dangerously high Air Quality Index (AQI) readings in Delhi, the nation's capital and largest metropolis, which have garnered significant media and political attention in recent years doubt, living in megacities is now preferable. Simultaneously, they exhibit great diversity worldwide and are vulnerable to deteriorating air quality as a result of high particulate matter (PM) concentrations. Lack of knowledge about the complexity of air pollution sources and their dynamic combination of natural and man-made sources makes combating mega-city air pollution more difficult (Sahu et al., 2023). Numerous studies have consistently shown that megacities with dangerously high levels of pollution, which mostly impact the elderly and school-age population, have higher rates of respiratory and cardiovascular problems. The wintertime deterioration of Delhi's air quality is associated with stubble burning 62 in Punjab and Haryana. To reduce the effect of pollution load, the government implemented Odd & Even vehicle ply on roadways. Still, the effect was negligible. The blame game keeps going from one state (or agency) to another, with each having an autonomous viewpoint on how to address Delhi's growing pollution levels. Researchers from across the world have taken notice of Delhi Air as it has not improved despite several efforts by stakeholders. It is confirmed that the air quality in Delhi is still dangerous to breathe and has not improved significantly. Comprehensive knowledge of the complexity and scope of pollution sources in a megacity is crucial for research on air quality, regional atmospheric chemistry, and climate perspectives. However, because of the variety of main and small factors that contribute to the problem as well as the complexity of the technology utilized during combustion operations, it becomes difficult to properly identify the unattended sources and quantify them. The variety of pollution sources and their temporal volatility make the issue even more complicated(Sahu et al., 2023).

1.1 Common air pollutants

With a variety of environmental and social implications, the decline in ambient air quality is a serious global issue. Not only pose a serious threat to the climate and ecology, but it also poses a serious risk to human health (Dalai et al., 2024).Moreover, emission inventories are compiled for various pollutants from many sectors, including nonenergy sources like road dust and fugitive emissions from fuel handling, building, and storage, and energy sources including transportation, electricity, industry, and residential areas. Criteria pollutants, which are precursors to secondary particle matter (PM) and ozone, are often included in an emission inventory. These include ammonia (NH3), volatile organic compounds (VOCs), nitrogen oxides (NOx), sulphur dioxide (SO2), carbon monoxide (CO), PM10, and PM2.5(Gupta et al., 2022). In additionthe sources of air pollutants are numerous and varied and can be either natural or man-made Among these, Common air pollutants include:

1.1.1 Sulfur dioxide (SO_2)

SO_2, a non-flammable gas, is converted into sulphates, a precursor of secondary particles. It is primarily produced by burning fossil fuels and biomass, and naturally by volcanic activity, resulting in a colourless, non-flammable gas.

1.1.2 Nitrogen Oxides (NO_x)

NO_x is a mixture of nitric oxide and nitrogen dioxide, produced by combustion. It is primarily emitted as NO, converted to NO_2 by ozone chemical reaction. NO_x composition in ambient air is highly variable, with air quality limit values for both.

1.1.3 Particulate Matter (PM)

Particulate matter is classified by particle size, including total suspended particulate matter (dust), PM_{10}, $PM_{2.5}$, and ultrafine particles. Primary PM is directly emitted into the air as solid particles, while atmospheric gas reactions form secondary PM. Sources include road dust, agricultural activities, vehicle exhaust, wood burning, forest fire smoke, and industrial activities. Secondary particulate matter, a significant fraction of $PM_{2.5}$, can be created from NO_x, SO_2, and ammonia.

1.1.4 Carbon Monoxide (CO)

CO, a colorless and odorless gas, originates from the incomplete combustion of fossil fuels, industrial processes, and natural sources like forest fires.

1.1.5 Organic Compounds (VOCs)

VOCs, organic compounds like benzene, ethylene glycol, and formaldehyde, evaporate under atmospheric conditions and are precursors to ground-level ozone and particulate matter, contributing to smog. Natural sources are larger than man-made ones.

1.1.6 Ozone (O_3)

Ozone, a naturally occurring chemical, is produced through chemical reactions between NO_x and VOCs in sunlight, blocking ultra-violet radiation in the upper atmosphere but potentially causing health issues at ground level.

1.1.7 Ammonia (NH_3)

Ammonia, a highly reactive substance, produces ammonium sulphate and ammonium nitrate, the main components of secondary PM, accounting for 94% of NH_3 emissions in Europe(European Environment Agency, 2017).

1.2 Health effects of air pollution

Air pollution is linked to various adverse health effects in the general population, including increased respiratory ailments, impaired ventilator function, eye irritation, increased cardiovascular morbidity, and a depleted immune system. It also affects short-term mortality due to respiratory and cardiovascular diseases and long-term mortality due to the carcinogenic effect of pollutants. Air pollution is a major cause of non-communicable diseases, with at least 3% of cardiopulmonary and 5% of lung cancer deaths attributable to PM. In 2016, ambient air pollution was responsible for 7.5% of global deaths, while 27.5% of deaths due to Lower Respiratory Tract Infections and 26.8% of deaths due to Chronic Obstructive Pulmonary Diseases were linked to air pollution(Mark LI & Léo MALLAT, 2018).

AIR QUALITY INDEX (AQI)	CATEGORY
0-50	Good
51-100	Satisfactory
101-200	Moderate
201-300	Poor
301-400	Very Poor
401-500	Severe

Figure.1.1 Air Quality Index (Aastha Ahuja, 2019)

1.3 The Graded Response Action Plan

The National Capital Region (NCR) of India, which encompasses Delhi and the surrounding districts, has been fighting air pollution via a series of policies and actions known as the Graded Response Action Plan (GRAP). GRAP consists of several government agencies' actions to stop the Delhi-NCR region's air quality from worsening. In 2017, the plan was notified by the Ministry of Environment Forests & Climate Change (MoEF&CC). The Graded Response Action Plan is carried out by the Commission for Air Quality Management (CAQM). GRAP is a series of emergency action plans that are carried out in four phases based on air pollution severity, which is assessed using the air quality index (AQI). As stated by the System of Air Quality and Weather Forecasting and Research (SAFAR), Stages I, II, III, and IV are titled "Poor" (AQI 201–300, "Very Poor" (AQI 301–400), "Severe" (AQI 401–450), and "Severe +" (AQI >450), in that order (Commission for Air Quality Management, 2022).

1.3.1 GRAP Stage I

Under GRAP stage 1 'Poor' Air Quality (DELHI AQI ranging between 201-300), the actions taken in this stage by the government are policies and procedures intended to reduce dust and enhance environmental management for projects involving the building and demolition (C&D) of plots larger than 500 sqm. These precautions include registering the projects on an online platform for remote monitoring, lifting and disposing of different kinds of waste, sweeping and misting roads to reduce dust, using anti-smog guns, forbidding the open burning of biomass and municipal solid waste, ensuring that traffic flow and vehicle emissions are followed, pursuing legal action against polluting industrial units, enforcing regulations on pollution control in various sectors, and encouraging the public to report pollution-related activities and provide information. A citizen charter with suggestions on how each person may help with pollution control is also included in the text(Commission for Air Quality Management, 2022).

1.3.2 GRAP Stage II

Air pollution control measures have been put in place in GRAP Stage 2. Daily Road sweeping, frequent water spraying and dust suppressants to reduce dust, stringent enforcement of dust control procedures at building and demolition sites, fuel usage limitations, power supply controls, traffic management, parking fees, public transportation, residential measures, and a citizen charter are a few of these. Dust and debris are removed by mechanical or vacuum-based sweeping, and dust control techniques include frequent watering and using dust suppressants. Clean fuel gas-based appliances or electricity are required for hotels and restaurants. Power supply mechanisms provide a continuous electricity supply, and traffic management plans movements and places workers at crossings. Radio, TV, and newspapers contribute to a greater public awareness campaign. To stop the open burning of biomass and municipal solid trash during the winter, resident welfare associations also give electric warmers to security personnel and enhance public transportation services (Commission for Air Quality Management, 2022).

1.3.3 GRAP Stage III

The National Capital Region (NCR) has taken several steps to mitigate air pollution in GRAP Stage 3. These include sanitizing roads, stepping up the provision of public transportation, outlawing the use of unapproved fuels in industry, restricting the operation of specific industries, and outlawing the construction and demolition of buildings. Carpentry, electrical work, plumbing, and other non-polluting trades are permitted to continue. There are also limitations on industrial operations, including mining, hot mix plants, stone crushers, and brick kilns. State governments may place limits on vehicles. Additionally, a citizen charter that promotes working from home, combining errands, and walking to errands is being put into practice. To prevent open burning during the winter, security personnel are given electric heaters and are advised not to use coal or wood for heating. State governments have the authority to limit LMVs that are BS III gasoline and BS IV diesel(Commission for Air Quality Management, 2022).

1.3.4 GRAP Stage IV

Several measures have been implemented in GRAP Stage 4 to regulate truck traffic in Delhi. Trucks are not permitted entry into the city except for those transporting necessities or offering necessities. Electric trucks and CNG trucks are also allowed. Delhi Registered Diesel Operated MGV and HGV are forbidden, except for individuals who deliver necessities or render necessities services. Delhi and the surrounding districts of the National Capital Region (NCR) prohibit the usage of four-wheeler diesel Light Motor Vehicles (LMVs) unless they are BS-VI vehicles or vehicles utilized for emergency or vital services. If an industry uses fuels that aren't listed on the Standard list of permitted fuels for NCR, it has to shut down. When it comes to linear public projects like highways, roads, flyovers, overpasses, electricity transmission, and pipelines, construction, and demolition (C&D) operations are forbidden. GNCTD and NCR State Governments may permit 50% staffing for public, municipal, and private workplaces, with the remaining staff members working from home. Offices of the Central Government may also allow remote work. A car plying system, non-emergency commercial operations, and the closure of schools, universities, and other educational facilities are examples of further emergency measures that are permitted. It is urged that citizens stay indoors and refrain from outside activities, especially if they are young, elderly, or suffering from a chronic illness(Commission for Air Quality Management, 2022).

1.4 Objectives of the study

The objectives of the present study are as follows:

1. Evaluating the effectiveness of GRAP in reducing air pollution levels and improving overall air quality.
2. To determine the change in ambient air quality parameters before, during, and after the implementation of GRAP.
3. Analyse air quality trends to check for any significant improvements resulting from the implementation of GRAP.

CHAPTER 2

LITERATURE REVIEW

2.1 International Studies

The research emphasizes the importance of air environmental audits in pollution control efforts and the potential for adopting similar audit systems to strengthen environmental governance. The study on air environmental audits in China reveals their significant impact on reducing air pollution. It was found that audits reduced emissions across 261 prefecture-level cities between 2004 and 2018. Audit impacts vary across pollutants, with $PM_{2.5}$ concentrations showing the most immediate reduction, while industrial sulphur dioxide and smoke emissions show delayed responses. The study also highlights the importance of tailoring audit strategies to local conditions and priorities. It recommends intensifying audits, especially focusing on reducing sulphur dioxide and industrial smoke emissions, and emphasizes the need for frequent audits, prompt action on findings, and customization of audit approaches. The study also suggests that the auditing system in China could serve as a model for other developing nations grappling with environmental sustainability amidst economic development (Rong Ge et al., 2023).

In China, the Study of Heterogeneous relations among environmental regulation, technological innovation, and environmental pollution emphasizes the importance of market-incentive and public participation regulations for environmental goals. The study found that command-and-control regulation did not significantly reduce environmental pollution. Market-incentive and public participation regulations had a negative impact, leading to pollution reduction. Technological innovations partially mediated the relationship between these regulations and pollution. Process innovation had a better effect on reducing emissions than product innovation. However, the mismatch between enterprise technology innovation and environmental regulation led to suboptimal environmental benefits. The impact of different environmental regulation tools varied across periods, with command-based regulation becoming less effective over time (You et al., 2024).

The study examines the effectiveness of joint prevention and control of air pollution in China under the Air Pollution Prevention and Control Action Plan. It uses panel data from 290 cities from 2007 to 2021 and finds a significant reduction in pollutant emissions, particularly in the Yangtze River Delta and Pearl River Delta urban agglomerations. The study recommends establishing cross-regional coordination mechanisms, clarifying cost and benefit sharing, and enhancing environmental monitoring for optimal air pollution control efforts (Wu, 2023).

The study on air pollution in East Africa reveals heterogeneous patterns, with hot spots experiencing higher pollution levels and cold spots experiencing decreases. It also identifies four major pollution periods and long-range transport from various regions. Seasonal meteorological conditions and climate factors also influence pollution concentrations. Spatial trends show variation in pollution trends, with anthropogenic and biomass burning being major drivers. Understanding pollution persistence and variability can guide policy decisions and prioritize interventions based on areas experiencing increasing pollution levels(Kalisa et al., 2023).

The study on air pollution governance in China and India reveals that China uses a centralized approach with top-down administrative enforcement, while India uses decentralized power. China's policies have led to significant improvements in air quality, while India's has been less effective. The study emphasizes the importance of strong political will, accountability, detailed initiatives, post-crisis policy windows, and prioritizing cost-effective actions. It recommends connecting high-level goals to facility-level measures, seizing opportunities, and prioritizing efficient actions(Wang et al., 2023).

The study in Malaysia on Clearing the Air Legal Strategies for Combating Smog and Pollution highlights the global crisis caused by air pollution and the importance of legal frameworks in mitigating its effects. It advocates for a collaborative approach involving policymakers, legal practitioners, and environmental advocates to safeguard air quality and promote a healthier future while adhering to WHO air quality guidelines(Muhammad Usman et al., 2023).

Pollution Mapper, a study focusing on identifying global air pollution sources, has identified major $PM_{2.5}$ sources, responsible for 80% of global deaths. The mixed-methods model, developed using NOAA's HYSPLIT wind dispersion model, accurately captured seasonal variations in $PM_{2.5}$ constituents. The model is adaptable to other cities globally, aiding policymakers in designing effective interventions. Policymakers can use Pollution Mapper to simulate the effects of policy interventions on air quality, allowing informed decision-making. Future work aims to address hyper-local factors and conduct causal analysis(Agarwal et al., 2024).

The study on implementing the air quality management program in Mexicali, Baja California, Mexico (PROAIR) reveals limited progress despite its release in 2000. The program consists of five strategies targeting various sectors, industry, commerce, services, vehicles, urban management, ecological recovery, and international agreements. Mexicali has benefited from environmental protocols such as the Border 2012 Program between Mexico and the USA. The study recommends improving environmental outcomes in Mexicali and similar regions(Quintero-Nuñez & Nieblas-Ortiz, 2008).

The study in the USA examines the spatial and temporal patterns of traffic-related air pollutants, particularly $PM_{2.5}$ and NO_x, in urban areas using a new dispersion model (RLINE) and a detailed emissions inventory. It was found that vehicle traffic is a significant source of pollutants, with the highest concentrations near major roadways. High-resolution mapping is crucial for capturing the dynamic nature of pollutant concentrations. The study also highlighted the need for detailed, real-time monitoring to understand pollution dynamics accurately. The findings have implications for policy and health(Batterman et al., 2015).

The study Indoor Air Sources of Outdoor Air Pollution, Health Consequences, Policy, and Recommendations" by experts from various fields reveals the significant impact of indoor air pollution on indoor and outdoor air quality. It suggests source control and filtration as effective measures to reduce indoor pollution and recommends switching from natural gas to electric stoves and transitioning to scent-free products(Nassikas et al., 2024).

The study reveals that air pollution perception is subjective and varies among individuals due to sensory stimuli and brain interpretation. There is a discrepancy between public perception and objective measurements, influenced by factors like socio-economic characteristics and emotions. Social media and the internet have significantly impacted risk perception. Tailored communication is needed to bridge the gap between public perception and scientific understanding. Robust frameworks and a perception index can enhance communication and understanding(Aswin Giri J & Shiva Nagendra S M, 2024).

The study on spatial patterns of $PM_{2.5}$ air pollution in Jakarta, using mobile monitoring with Google Street View cars, found temporal variability, intra-neighborhood variability, and proximity to pollution sources. The study also highlighted the importance of considering local emission sources when evaluating air pollution exposure in urban areas. The findings also revealed exposure disparities, highlighting how different socio-economic groups experience varying levels of air pollution exposure within the same city(Ghaida et al., 2024).

The study of The Impacts of air pollution on human health a critical literature review highlights a gap in research on the impact of air pollution on human health. It suggests that higher levels of air pollution can lead to cognitive decline in older adults and adverse effects on mental health. The study suggests using theoretical frameworks like Particulate Matter Theory, Oxidative Stress Theory, and Inflammatory Response Theory for future research. Healthcare systems must be prepared to address the health impacts of air pollution, and governments should allocate resources effectively(Maknae, 2024).

2.2 National Studies

The study uses a comprehensive approach to develop long-term solutions to curb air pollution in Delhi and NCR. It critically reviews existing literature and recommends new policy measures based on factors like topography, meteorology, emissions, construction activities, waste management, and coordination among authorities. The research aims to bridge the gap between political, economic, and scientific aspects of air pollution, serving as a reference document for governments and stakeholders (Bhardawaj & Bhardwaj et al., 2022).

The study aims to develop a coherent framework for effective air quality management at identified air pollution hotspots in Indian cities, focusing on emission reduction potential, ease of enforcement, scale of implementation, and socio-economic feasibility. The study focuses on reducing $PM_{2.5}$ in an urban industrial area in Delhi, using a methodology that includes data collection, emission inventorization, control scenario simulations, socio-economic assessment, and ranking of actions for implementation. The study finds that road dust emissions are the highest (45–56%), followed by multiple industries (18–21%). The maximum reduction in $PM_{2.5}$ concentrations can be achieved by actions that include mechanized vacuum machine cleaning, full-capacity industrial operations, cyclone dust collector installation, and stack height increase (Goyal et al., 2022).

A study to understand the effectiveness of control actions implemented in the past and their response to air quality found that Over 17 years, RSPM and NO 2 concentrations in Delhi has gradually increased, while SO 2 concentrations have decreased. RSPM and NO_2 consistently exceeded standards, while SO_2 remained below-specified standards. Correlations between RSPM and NO 2 were Found at specific times and locations, indicating potential sources like vehicular and industrial emissions. Compared to 2003, RSPM and NO_2 concentrations were higher due to increased sources like vehicles and energy demand. Policymakers introduced numerous control strategies, highlighting the need for systematic monitoring to assess improvements (Gulia et al., 2021).

In the study of improvements in SO_2 pollution in India, the role of technology and environmental regulations identify Central and East India as hotspots for SO_2 emissions due to the presence of thermal power plants, refineries, steel, and cement industries. Thermal power plants contribute 51% of anthropogenic SO_2 emissions, while manufacturing and construction contribute 29%. SO_2 concentrations are higher in winter and lower in pre-monsoon seasons. From 1980 to 2010, SO_2 concentrations increased due to coal burning and technological limitations but decreased from 2010 to 2020 due to environmental regulations and control technologies. India's increased renewable energy production since 2010 has reduced SO_2 emissions. Policy recommendations include a shift to renewable energy, strict environmental regulations, accurate emission inventories, and effective control technologies (Kuttippurath et al., 2022).

The study on air pollution trends in Chandigarh from 2019 to 2022, focusing on meteorological factors reveals a rise in pollution due to vehicular emissions, industrial growth, and construction activities. Pollutant concentrations surged during rice stubble burning season due to winter conditions and increased fossil fuel usage. Wheat stubble burning had minimal impact. High temperatures led to a spring peak in surface O_3, a common feature in South Asia. The COVID-19 lockdown improved air quality, emphasizing the need for comprehensive management strategies to protect public health and environmental well-being(Dalai et al., 2024).

The study on Delhi's air pollution reveals that the city's PM_{10} levels have exceeded safe limits, exceeding 10-fold the recommended level of 198µg/m3. The main contributors to pollution are vehicle emissions and industrial activities. The study also reveals a correlation between pollution levels and adverse health outcomes, including increased mortality and morbidity rates. Over the past decade, efforts have been made to lower pollution levels, but the research provides evidence-based insights into the effectiveness of these measures (Sharma et al. 2020).

Delhi, the Indian capital, faces deteriorating air quality due to a poor understanding of emissions sources. This paper develops a spatially resolved high-resolution gridded emission inventory for eight major pollutants in the Delhi region. The study estimated annual emissions for $PM_{2.5}$, PM_{10}, CO, NO_x, VOC, SO_2, BC, and OC over Delhi-NCR in 2020. The decadal growth in PM2.5 and PM10 is marginal at 31% and 3%, respectively, with the transport sector experiencing the maximum growth. The study examines the decadal shift of sectorial emissions with changing policies (Sahu et al., 2023).

The analysis involves Delhi as the treatment group and Haryana as the control group due to the lack of clean fuel implementation in Haryana during the primary survey. The study reveals that introducing clean fuel in Delhi reduced health illnesses and economic costs, improved health expenditure, reduced productivity loss, and increased willingness to pay for improved air quality. However, caution is needed in economic comparisons between

Delhi and Haryana due to socio-economic and demographic differences (Chowdhury et al., 2023).

The study compared indoor and outdoor air quality in Anand Vihar, Delhi, revealing seasonal variations, especially during winter. Results showed lower PM and RH indoors but higher CO levels outdoors. Most parameters exceeded international standards, posing health risks. The study emphasizes the need for extensive air quality monitoring, both stationary and mobile outdoors, and compact indoor sensors to mitigate health risks and promote healthier living conditions(Bhardawaj et al. 2022).

The study estimates baseline pollutant concentrations in Delhi during winter 2022 using data from intermittent rainfall and COVID-19 lockdowns. Results show higher levels in central areas. The study uses rainfall scavenging, lockdown emissions reduction, and meteorological filtering to estimate pollution baselines. $PM_{2.5}$ and NO_x levels showed positive and negative correlations with rainfall. During rain and lockdown, $PM_{2.5}$ levels were reduced by 69-73%, while NOx reductions were 26-63%. The findings provide insights into pollution management strategies and model refinement (Gulia et al., 2024).

The study reveals that the transport of transboundary pollutants significantly impacts Delhi's air quality, with winter showing high standard deviations for NO_2 (7.14–9.63%) and SO_2(4.04–7.42%) in 2019–2022. Post-monsoon seasons show increased CO levels due to stubble burning in Punjab, leading to persistent CO exceedance days (4.52–8.00%). The study also identifies hotspots in Southeast Punjab that contribute to CO levels in Delhi during the post-monsoon season of 2019. It emphasizes the importance of source apportionment studies for pollution management strategies. The study suggests that hotspot identification can inform targeted policies to reduce emissions without affecting economic growth(Nirwan et al., 2024).

The study explores the seasonal dynamics of particulate matter (PM) pollution in Delhi, India. It reveals that pollution is influenced by local sources and meteorological factors, with North and East Delhi being the most polluted areas. The study also shows that temperature and relative humidity significantly impact PM concentration. Long-range dispersion patterns vary by season, with southeasterly winds in monsoon seasons and northwestern winds in other seasons contributing to Delhi's pollution (Sharma et al. 2022).

The study examined air pollution in the Okhla industrial area of New Delhi after COVID-19. PM_{10} levels ranged from 9.73 to 640.14 µg/m³, $PM_{2.5}$ from 6.18 to 448.06 µg/m³, SO_2 from 2.72 µg/m³ to 25.78 µg/m³, and NO_2 varied from 14.75 to 219.36 µg/m³. PM_{10} and $PM_{2.5}$ significantly exceeded Central Pollution Control Board standards, while SO_2 levels were below. NO_2 levels were notably higher than standards. Wind patterns showed low speeds linked to high pollutant levels, mainly from the southeast. Overall, the study underlined a critical post-COVID pollution situation, urging immediate action to curb pollution in the area (Jha et al., 2023).

The study on $PM_{2.5}$ in Delhi found that high annual concentrations were highest in R.K. Puram, DTU, and ITO during 2018-19 and 2019-20, with seasonal variability. Winter months were the highest, with post-monsoon months showing the highest levels. Winter peaks were due to low mixing heights and calm wind conditions, while post-monsoon peaks may be due to lower ventilation coefficients, local activities, and festive emissions. The study underscored the necessity of site-specific interventions and local source influences for effective air quality management, emphasizing the significance of tailored approaches (Jha et al., 2024).

The study on surface ozone and its correlation with other pollutants in New Delhi from 2013 to 2019 found significant concentrations within specific ranges. Ozone levels averaged between 32.44 ppb to 36.57 ppb, while NO, NO_2, and NOx levels ranged from 19.46 to 28.09 ppb, 20.83 to 26.89 ppb, and 43.04 to 54.99 ppb, while CO concentrations varied from 1.67 to 1.89 ppm. The study found peak NO_x and CO concentrations in the morning and late evening, with higher ozone levels in the afternoon. It also found a negative correlation between ozone and NO_x concentrations, oxidants, temperature, and humidity, highlighting pollution sources in the Delhi National Capital Region (Sinha et al., 2021).

The study explores the sensitivity of surface ozone to nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHCs) in Delhi, India. It found seasonal variations in ozone levels, with higher levels during pre-monsoon and post-monsoon periods. The study also found that NO_x plays a critical role in controlling ozone concentrations. Ozone production conditions were more favorable during pre-monsoon and post-monsoon seasons. The study highlights the need for policies targeting NO_x reductions to mitigate ozone pollution in urban areas(Sharma et al., 2021).

The study examines NO_x and related pollutants in Delhi's heavily polluted Anand Vihar area. It reveals that meteorological factors, such as temperature and humidity, significantly affect NO_2 levels. Seasonal variations also occur, with lower levels in monsoon and higher in winter/post-monsoon periods. Vehicular activities directly impact pollution levels, with lower heights leading to higher pollution. The study also highlights the potential of electric vehicles (EVs) in reducing NO_2 pollution. Heavy vehicular traffic areas experience higher NO_2 levels, emphasizing the need for pollution control and sustainable transportation (Kaushik & Das, 2023).

A study on India's coal-fired thermal power plants found significant health impacts, including premature deaths and asthma cases. The emissions from these plants emitted pollutants like $PM_{2.5}$, sulfur dioxides, nitrogen oxides, carbon monoxide, volatile organic compounds, and carbon dioxide. The economic cost of pollution was estimated at INR 16,000 to 23,000 crores. The study emphasized the need for stringent rules for pollution control, as those pertaining to flue gas desulfurization systems. Implementing these systems could reduce $PM_{2.5}$ concentrations by 30-40%, providing health and environmental benefits. Monitoring emissions, implementing tighter emission standards, improving plant efficiency, and revising environmental impact assessment procedures are also crucial (Guttikunda & Jawahar, 2014).

The study explores the link between air pollution levels and health outcomes in Delhi-NCR, revealing persistent high levels of pollutants like $PM_{2.5}$ and PM_{10}, particularly during winter. It highlights the need for holistic pollution control strategies and a direct link between $PM_{2.5}$ levels and respiratory admissions. The findings call for targeted interventions and equitable access to healthcare, particularly in socioeconomically disadvantaged communities (Ashutosh Deshpande et al., 2024).

The study on Delhi's air pollution levels, focusing on respiratory diseases, found that all pollutants exceeded ambient air quality standards. The pollution scenario became more critical in 2008 due to stricter NAAQS. Town Hall, Mayapuri, and Najafgarh showed high pollution levels, with higher SPM and RSPM levels impacting respiratory health. Winter pollution spikes contribute to increased respiratory health problems. Long-term health risks include lung cancer due to carcinogens in pollutants. Urgent measures and lifestyle changes are needed (Malhotra et al., 2023).

A study was conducted at an agricultural farm site in Delhi, India, to assess the health risks of aerosol particles (PM_{10} and $PM_{2.5}$) and their associated heavy metals found that air pollution due to urbanization and industrialization poses health risks. The concentrations of PM_{10} and $PM_{2.5}$ were 136 to 177μg/m^3 and 56 to 162μg/m^3, respectively at the site. In the present case, the highest PM_{10} and $PM_{2.5}$ levels were reported in January, followed by December were higher than WHO guidelines for 15 and 5μg/m^3, respectively, especially in winter. Surface ozone O_3 and NO_x levels were high in February and March. The mean hazard index for metals was within acceptable limits, indicating no carcinogenic effects. The carcinogenic risk values were within USEPA standards, indicating no risks to children and adults. This information can help develop mitigation strategies(Chaudhary et al., 2023).

The study of the association of asthma and air pollution Evidence from India found that air pollution in India has increased over the past two decades, leading to worsened air quality. Indoor and outdoor air pollution are identified as important risk factors for asthma in this study, which focuses on women aged 15 to 49. Other risk factors include smoking, second-hand smoke, dietary factors, and obesity(D. Singh et al., 2023).

The study on long-term regional air pollution in Hyderabad, India, reveals significant urbanization over the past two decades, leading to changes in air quality. The study shows that columnar aerosol loading is highest during spring, with a positive trend in aerosol optical depth and $PM_{2.5}$ concentrations during winter. The northeastern and southeastern parts experience higher aerosol loading, while NO_2 and SO_2 concentrations increase in the northeast sub-region with thermal power plants and urban centers (Jayachandran & Rao, 2024).

The study reveals that particulate matter (PM) concentrations in India have increased significantly, with Uttar Pradesh showing the highest PM rate in 2021 at 5.754. The study also found that Himachal Pradesh and Jammu & Kashmir have the highest Compound Annual Growth Rates (CAGRs) of 0.429 and 0.421 respectively. However, states like Karnataka, Odisha, Punjab, Telangana, and West Bengal show stable and lower PM growth rates, suggesting effective air quality management strategies. Factors influencing PM growth include post-pandemic effects, economic changes, and local events. The study recommends state-level policies, long-term strategies, and personalized, area-specific approaches for effective air quality management(Ramakrishna.G.N. et al., 2023)

The study Air Pollution, A Major Threat to Sustainable Development identifies six major air pollutants: particulate matter, ground-level ozone, carbon monoxide, sulphur oxides, nitrogen oxides, and lead. These pollutants have widespread effects on air, soil, and water quality, negatively impacting human health and contributing to climate change, greenhouse effects, global warming, and acid rain. The study emphasizes the need for mitigation strategies, individual actions, and collective efforts to control air pollution for sustainable development(Ravichandran et al., 2021).

The study Health and Economic Impact of Air Pollution in India States that, according to the Global Burden of Disease Study 2019, air pollution was responsible for 1.67 million deaths in 2019, or 17.8% of all deaths. The study also found significant economic impacts, with estimated losses of US$36.8 billion in 2019, representing 1.36% of India's GDP. The study highlights the dual burden of health impacts and economic losses, suggesting that successful reduction strategies could improve public health and contribute to economic growth, aligning with India's goal of becoming a $5 trillion economy by 2024(Pandey et al., 2021).

The study on vehicular emissions in Kanpur City revealed that rapid urbanization and industrialization have led to increased emissions, causing significant air pollution. The study focused on three major pollutants: PM_{10}, SO_2, and NO_2. The vulnerability analysis revealed that PM_{10} concentrations consistently exceeded the National Ambient Air Quality Standards, indicating high levels of particulate matter pollution. SO_2 concentrations were within prescribed standards, while NO_2 concentrations exceeded standards at five out of eight locations(Yadav & Ganguly, 2023). The study Dispersion Modelling of Air Pollutants in a Hilly City in India found that vehicular pollution significantly contributes to air pollution in urban areas. The study evaluated two air quality dispersion models, STREET and CALINE 4, to predict PM_{10} concentrations in Shimla, Himachal Pradesh(Ganguly et al., 2021).

Chapter 3

Methodology of The Study

3.1 Site Selection

The national capital of India, Delhi, has been selected to conduct this study. GRAP was implemented to improve the air quality in Delhi regions, so it was chosen for the study. Delhi is the single largest contributor to India's urban population (about 7.6%). The land cover is about 1485 km^2, with a population distribution of about 16.8 million. In the past two decades, the population density has increased from 9340 people per sq. km in 2001 to 11,297 people per sq. km in 2011, with an increased rate of 37.6% annually (Mahato et al. 2020). Delhi is located between the semi-arid regions of Rajasthan to the southwest and the fertile, rain-washed Indo-Gangetic Plain to the east. Its high population density (11,297 people per square kilometer) makes it one of the planet's most crowded and polluted metropolitan settings. Delhi, the capital of the National Capital Territory, is situated between Uttarakhand and Haryana. The upper Gangetic plain, ridge, and flood plain comprise the city's three parts. It is distinguished by a humid subtropical climate influenced by the monsoon that borders on a hot, semi-arid environment. Pre-monsoon (March through May), monsoon (June through September), post-monsoon (October and November), and winter (December through February) are the four seasons that the city endures. The region experiences a range of air temperatures, from 4–10 °C in the winter to 42–48 °C in the summer. During the monsoon season, the region has gentle breezes flowing from the southeast, but for the rest of the year, northwest winds with an intensity of 2-3 m/s^{-1} pass across the territory. Delhi has become a hotspot for urban and regional pollution because of the region's orography, which allows for restricted wind circulation and minimal air pollution dispersion. The region's major sources of gaseous air pollution include vehicles, small-scale businesses (brick kilns), home cooking, burning biomass from seasonal agriculture, and emissions from thermal power plants (Nirwan et al., 2024).

A total of 41 operational monitoring stations in NCR and NCT Delhi have been considered for this study (Fig.3.1). The different sources of the data providers are given in (Table.3.1) The various locations selected for extracting the data are provided in Supplementary (Table.3.2).

Figure.3.1 Image showing the location of the monitoring stations in Delhi(Sharma et al., 2022).

Table.3.1 Different monitoring agencies and their respective monitoring stations

CITY	Monitoring Agency	Location name
	DPCC	Alipur, Anand Vihar, Ashok Vihar, Bawana, Dr.Karni Singh Shooting Range, Dwarka-Sector8, Jahangirpuri, Jawaharlal Nehru Stadium, Major Dhyan Chand National Stadium, Mandir Marg, Mundka, Najafgarh,

DELHI		Narela, Nehru Nagar, North Campus DU, Okhla Phase-2, Patparganj, Punjabi Bagh, Pusa, R K Puram, Rohini, Sonia Vihar, Sri Aurobindo Marg, Vivek Vihar, Wazirpur.
	IMD	Aya Nagar, Burari Crossing, IGI Airport (T3), Pusa, Lodhi Road, CRRI Mathura road.
	IITM	Chandni Chowk, Lodhi Road.
	CPCB	DTU, East Arjun Nagar, IHBAS-Dilshad Garden, ITO, NSIT Dwarka, Shadipur, Sirifort.

Table.3.2 Total number of monitoring stations in the study area

Location no	Location Name
1	Alipur, Delhi – DPCC
2	Anand Vihar, Delhi – DPCC
3	Ashok Vihar, Delhi – DPCC
4	Aya Nagar, Delhi – IMD
5	Bawana, Delhi – DPCC
6	Burari Crossing, Delhi – IMD
7	chandni chowk -IITM
8	Dr. Karni Singh Shooting Range, Delhi- DPCC
9	DTU, Delhi – CPCB
10	Dwarka-Sector 8, Delhi – DPCC
11	East Arjun Nagar, Delhi – CPCB

12	IGI Airport (T3), Delhi – IMD
13	IHBAS, Dilshad Garden, Delhi – CPCB
14	ITO, Delhi – CPCB
15	Jahangirpuri, Delhi – DPCC
16	Jawaharlal Nehru Stadium, Delhi – DPCC
17	Lodhi Road, Delhi – IMD
18	Lodhi Road, Delhi – IITM
19	MDCNS, Delhi – DPCC
20	Mandir Marg, Delhi – DPCC
21	Mathura Road, Delhi – IMD
22	Mundka, Delhi – DPCC
23	Najafgarh, Delhi – DPCC
24	Narela, Delhi – DPCC
25	Nehru Nagar, Delhi – DPCC
26	New Moti Bagh, Delhi – MHUA
27	North Campus, DU, Delhi – IMD
28	NSIT Dwarka, Delhi
29	Okhla Phase-2, Delhi – DPCC
30	Patparganj, Delhi – DPCC
31	Punjabi Bagh, Delhi – DPCC
32	Pusa, Delhi – DPCC
33	Pusa, Delhi – IMD
34	R K Puram, Delhi – DPCC
35	Rohini, Delhi – DPCC
36	Shadipur, Delhi – CPCB
37	Sirifort, Delhi – CPCB
38	Sonia Vihar, Delhi – DPCC
39	Sri Aurobindo Marg, Delhi – DPCC
40	Vivek Vihar, Delhi – DPCC
41	Wazirpur, Delhi – DPCC

3.2 Parameters for Analysis

The parameters used to assess or measure the changes in air quality in this study are $PM_{2.5}$, PM_{10}, NO_x, NO_2, NO, SO_2, NH_3, CO, and ozone because these pollutants are fundamental and commonly monitored pollutants due to their significant impact on human health and the environment.

3.3 Data Collection

The collected data during the study was a one-hour average concentration of pollutants ($PM_{2.5}$, PM_{10}, NO_x, NO_2, NO, SO_2, NH_3, CO, and Ozone) from 41 monitoring stations in Delhi. This data was subdivided into two phases: phase 1, including the data from 2022 to 2023, mentioned in Table.3.3, and Phase 2, including data from 2023 to 2024, cited in Table.3.4 (from September to March), using information from the Central Pollution Control Board. The data was reorganized and distributed to 5 zones of Delhi (North, South, East, West, and Central) to illustrate the change in air quality by zone area of Delhi city. The data was collected before, during, and after implementing the various stages (Stage 1, Stage 2, Stage 3, and Stage 4) of the Graded Response Action Plan (GRAP) in Delhi.

Table.3.3. GRAP stages and their implementation dates in Phase 1

Stage	**Implementation period**
Before GRAP	20/09/2022 to 04/10/2022
Stage 1	05/10/2022 to 18/10/2022
Stage 2	19/10/2022 to 28/10/2022
Stage 3	29/10/2022 to 02/11/2022
Stage 4	03/11/2022 to 05/11/2022
Stage 3	06/11/2022 to 13/11/2022
Stage 2	14/11/2022 to 03/12/2022
Stage 3	04/12/2022 to 14/01/2023
Stage 2	15/01/2023 to 31/01/2023
Stage 1	01/02/2023 to 15/02/2023
Stage 2	16/02/2023 to 28/02/2023
Stage 1	01/03/2023 to 08/03/2023
After GRAP	08/03/2023 to 23/03/2023

Table.3.4. Lists of the GRAP stages and the dates of phase 2 implementation.

Stage	**Implementation period**
Before GRAP	20/09/203 to 05/10/2023
Stage 1	16/10/2023 to 20/10/2023
Stage 2	21/10/2023 to 01/11/2023
Stage 3	02/11/2023 to 04/11/2023
Stage 4	05/11/2023 to 17/11/2023
Stage 3	18/11/2023 to 27/11/2023
Stage 2	28/11/2023 to 21/12/2023
Stage 3	22/12/2023 to 31/12/2023
Stage 2	01/01/2024 to 13/01/2024
Stage 3	14/01/2024 to 17/01/2024
Stage 2	18/01/2024 to 18/02/2024
Stage 1	19/02/2024 to 26/02/2024
After GRAP	27/02/2024 to 15/03/2024

3.4 Data Analysis

To analyze air quality changes before, during, and after implementing the Graded Response Action Plan (GRAP) based on zone area, the average concentrations of pollutants from 41 stations were calculated and illustrated in graphs using R Studio and Origin. These graphs show the pollutant concentrations in two phases as well as before GRAP, during various stages (Stage 1, Stage 2, Stage 3, Stage 4), and after GRAP across five zones (North, South, East, West, Central). Additionally, percentage changes were calculated to assess the variations in pollutant concentrations before, during, and after GRAP implementation. These changes are depicted in graphs showing the percentage change of all pollutant concentrations between different GRAP stages within each zone. Furthermore, a temporal analysis of pollutants across zones and stages was observed, and the comparison of pollutant concentrations with the NAAQS standards was studied. A table containing the GRAP action guidelines and the recommended guidelines from the study to enhance effectiveness was also included.

Chapter 4

RESULTS AND DISCUSSION

The results and discussion sections of this study provide a comprehensive analysis of the impact of the Graded Response Action Plan (GRAP) on air quality in Delhi, India's capital. Using data from 41 monitoring stations across the city, the study evaluates changes in the concentrations of key pollutants ($PM_{2.5}$, PM_{10}, NO_x, NO_2, NO, SO_2, NH_3, CO, and Ozone) before, during, and after GRAP implementation over two phases (2022-2023 and 2023-2024). The data is categorized into five zones (North, South, East, West, Central) to illustrate spatial variations. The analysis, conducted using R Studio and Origin, highlights the average concentrations and percentage changes of pollutants across different GRAP stages, with results presented in graphical form. The discussion delves into the effectiveness of GRAP in reducing pollutant levels and compares these levels with the National Ambient Air Quality Standards (NAAQS).

4.1 Particulate Matter (PM_{10}) Concentration Variation During Phase1 and Phase 2

Phase 1 shows a general rising trend in PM_{10} concentration across all zones. Stage 4 of the north zone had the highest concentration (570 µg/m^3), whereas the south zone before GRAP had the lowest value (102 µg/m^3). The level of PM_{10} in every zone at every stage above the permissible thresholds for PM_{10} (40 µg/m^3) established by NAAQS. Phase 2 shows a pattern of rising PM_{10} concentrations in the north and south and declining concentrations in the west, east, and central zones. Stage 3 of the north zone had the highest concentration (572 µg/m^3). In contrast, the central zone following GRAP had the lowest value (129 µg/m^3). The level of PM_{10} in every stage and zone above the NAAQS permissible limits.

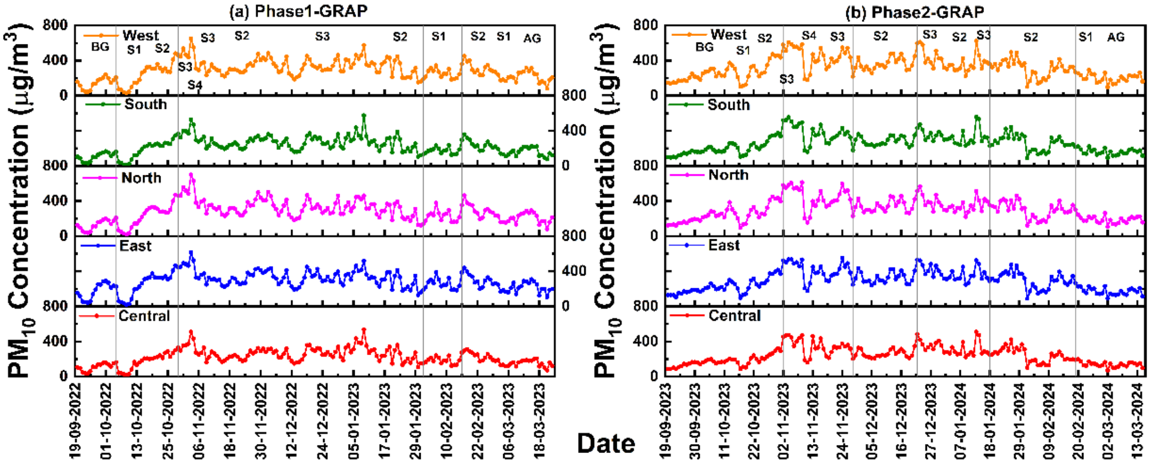

Figure.4.1 PM_{10} concentration in two phases across different zones (North, South, East, West, Central) at different GRAP stages

The study reveals significant fluctuations of PM_{10} concentration across five zones (West, South, North, East, and Central) and four GRAP stages (Fig.4.1 and Fig.4.2). In Phase 1, all zones experienced substantial increases in PM_{10} levels from pre-GRAP to Stage 4, peaking notably in the North zone at 570 µg/m³. The East zone showed the highest initial concentration, escalating to 489 µg/m³ at Stage 4. In Phase 2, the initial PM_{10} levels were generally higher than in Phase 1, with the North zone peaking at 572 µg/m³ at Stage 3. The subsequent stages reflected similar patterns of significant rise, peak, and subsequent reduction, with post-GRAP levels dropping below the initial concentrations across all zones.

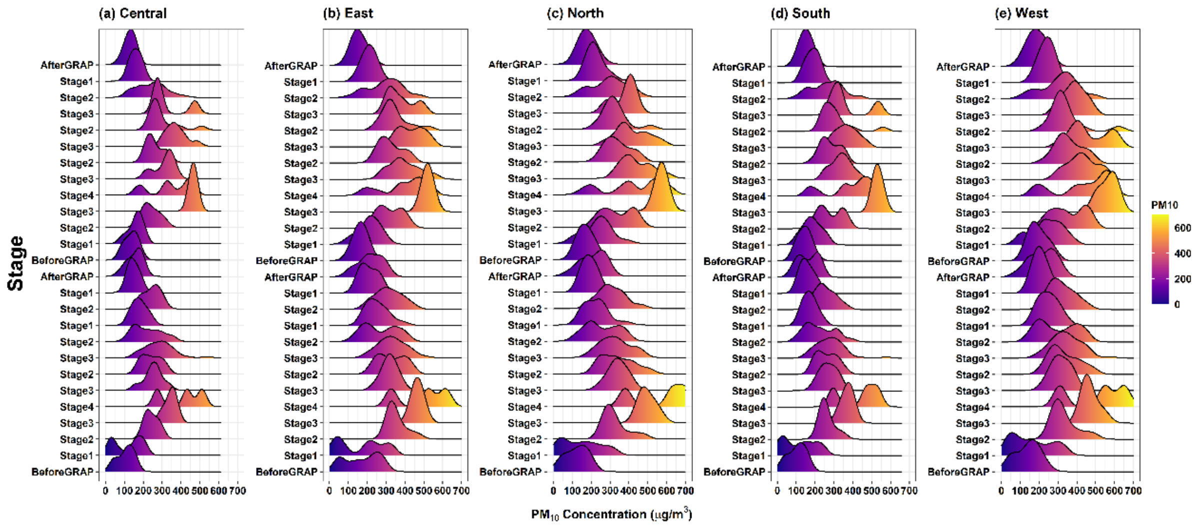

Figure.4.2 Distribution of PM_{10} Concentrations across different zones (Central, East, North, South, West) during two phases and various GRAP stages

4.2 Particulate Matter ($PM_{2.5}$) Concentration Changes During Phase1 and Phase 2

$PM_{2.5}$ concentrations are generally trending increasing in all zones throughout phase 1. The highest concentration was observed in the north zone stage 4 (357 µg/m³), while the lowest was in the south zone before GRAP (45 µg/m³). The $PM_{2.5}$ concentration in all zones in all stages Exceeds the acceptable limits (40 µg/m³) set by NAAQS for $PM_{2.5}$. In phase 2, The overall trend in $PM_{2.5}$ concentration is increasing in all zones except in the east zone shows a decreasing trend. The highest concentration was observed in the west zone stage 3 (380 µg/m³), while the lowest was in the south and central zones before GRAP (55 µg/m³). The $PM_{2.5}$ concentration in all zones in all stages Exceeds the acceptable limits (40 µg/m³) set by NAAQS for $PM_{2.5}$.

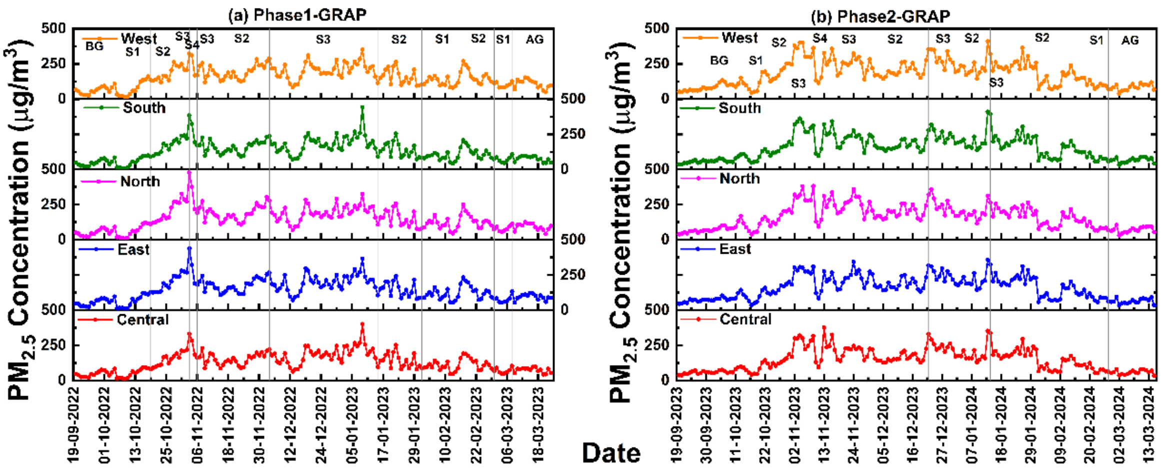

Figure.4.3 Two phases of $PM_{2.5}$ concentration in various zones (North, South, East, West, and Central) during various GRAP stages

The $PM_{2.5}$ concentrations during Phase 1(Fig.4.3 and Fig.4.4), From pre-GRAP to Stage 4, show significantly increasing levels in all zones, peaking notably in the North zone at 357 µg/m³. The West zone saw a rise from 59 µg/m³ to 267 µg/m³ at Stage 4. Following these peaks, each zone exhibited varied trends of decline and minor increases in $PM_{2.5}$ levels. In Phase 2, initial $PM_{2.5}$ levels were generally higher than in Phase 1, with the West zone peaking at 380 µg/m³ at Stage 3. The subsequent stages reflected similar patterns of fluctuation, with post-GRAP levels increasing above the initial concentrations across almost all zones.

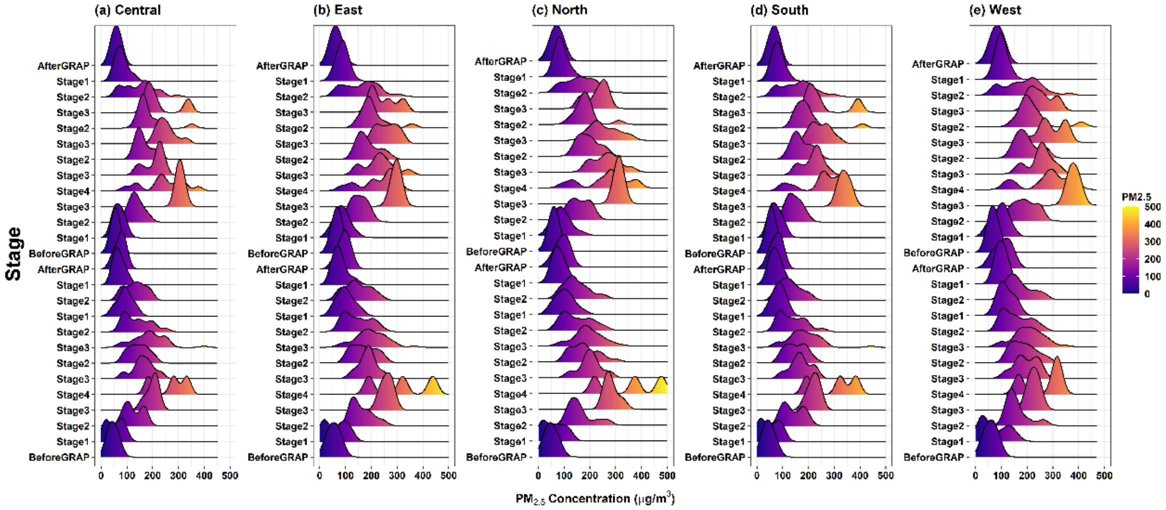

Figure.4.4 The pattern of $PM_{2.5}$ Concentrations across different zones (Central, East, North, South, West) during two phases and various GRAP stages

4.3 Temporal Analysis of Sulphur Dioxide During Phase1 and Phase 2

Throughout all zones, Phase 1 displays an overall trend of increasing SO_2 concentrations, with the exception of the central zone, where levels are declining. West zone after GRAP had the highest concentration (19 µg/m³), whilst other zones (south zone before GRAP and stage 1, north zone before GRAP) had the lowest concentrations (5 µg/m³). The NAAQS's acceptable limits of SO_2 concentration of 50 µg/m³ are met in all zones at all stages. Phase 2 shows an overall increasing trend in SO_2 concentration across all zones. The east zone prior to GRAP had the lowest concentration (5 µg/m³), while the west zone stage 2 had the highest concentration (21 µg/m³). The SO_2 concentration at every stage and in every zone within the acceptable limits (50 µg/m³) set by NAAQS for SO_2.

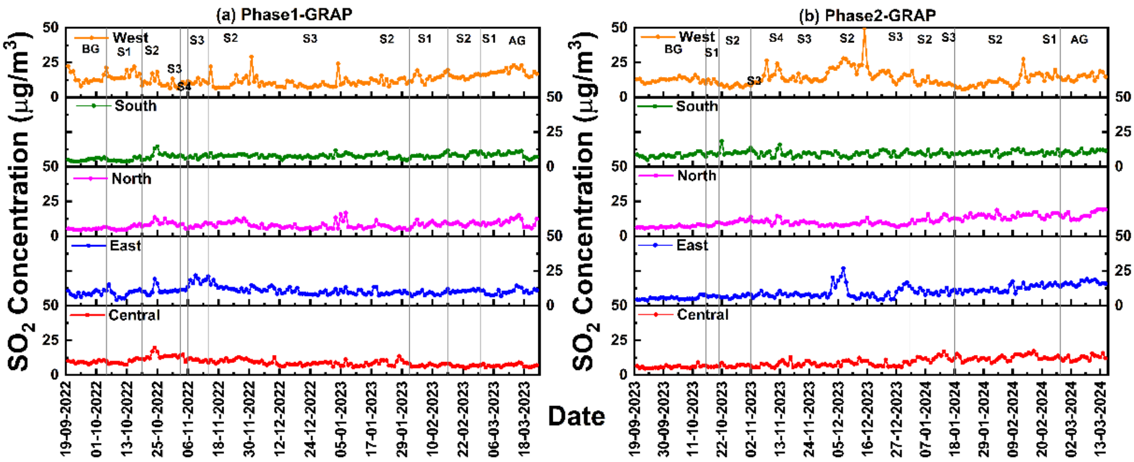

Figure.4.5 Variation in SO_2 concentration in two phases across different zones (North, South, East, West, Central) at different GRAP stages

The study found the SO_2 concentration (Fig.4.5) In Phase 1 in the West zone saw a minor initial increase, and then decrease through the middle stages, and a rise to 19 µg/m³ post-GRAP. The South zone showed stability and slight increases from the initial level to 8 µg/m³ after GRAP. The North zone displayed minor variations, ending at 10 µg/m³ post-GRAP. The East zone experienced fluctuations and increased from the initial level to 11 µg/m³ after GRAP. The Central zone had an initial rise, then decreased and stabilized at 7 µg/m³ after GRAP. In Phase 2, the West zone's SO_2 concentration fluctuated significantly, peaking at 16 µg/m³ at Stage 4 and ending at 15 µg/m³ post-GRAP. The South zone showed moderate increases and stabilization at 11 µg/m³ post-GRAP. The North zone had steady increases and fluctuation, peaking at 15 µg/m³ after GRAP. The East zone exhibited a steady rise, increasing from the initial level to reach 16 µg/m³ post-GRAP. The Central zone experienced minor fluctuations, peaking at 13 µg/m³ in stage 2 and stabilizing at 12 µg/m³ post-GRAP.

4.4 Nitrogen Oxides Concentration Comparison in Phase1 and Phase 2

NO_x concentrations in phase 1 continuously exceed the permissible limits (40 ppb) stated by NAAQS across all zones and stages, except the west zone before GRAP and stage 1 in the north zone (before GRAP, stage 1, stage 1 third implementation, and after GRAP). The concentration of NO_x is generally on the rise in all zones, starting before GRAP and continuing through the different stages till after GRAP. Before GRAP, the West zone had the lowest concentration (22 ppb), whereas the Central zone had the highest concentration (143 ppb) during Stage 3. Except for the west zone (before GRAP and stage 1 second implementation), the south (before GRAP), the north (before and after GRAP), and the east zone (before and after GRAP), the NO_x concentrations in phase 2 continuously exceeded the acceptable limits set by the NAAQS of 40 ppb across all zones and stages. Following GRAP, the West zone had the lowest concentration (25 ppb), while the Central zone had the greatest concentration (139 ppb) during Stage 3 (Second Occurrence). Except the West zone, where a declining tendency is seen, most zones have an overall trend of rising NO_x levels despite of fluctuation.

In addition, the overall trend in NO_2 concentration in phase 1 increasing in all zones except in the east zone shows a decreasing trend. The highest concentration was observed in the Central zone during Stage 2 (the second implementation of Stage 2) (76 µg/m³), while the lowest was in the North zone before GRAP (18 µg/m³). The NO_2 concentrations exceeded acceptable limits set by NAAQS of 40 µg/m³ in most stages for most zones except in the west zone (before GRAP and stage 1 the first implementation), south zone (before GRAP, stage 1 first implementation, stage 3, stage 2, stage1the second implementation, stge1 third implementation and after GRAP). east (Stage1 third implementation), central (before GRAP and stage1 third implementation) the NO_2 concentration was within the acceptable limits. In phase 2, The overall trend in NO_2 concentration is increasing in the South, North, East, and Central zones, while it is decreasing in the West zone. The highest concentration was observed in the Central zone during multiple stages (75 µg/m³), while the lowest was in the North zone before GRAP (24 µg/m³). The NO_2 concentrations exceeded acceptable limits set by NAAQS of 40 µg/m³ in most stages for most zones and stages except in the west zone(After GRAP), south zone(before GRAP,stage1 first implementation,stage2 third and fourth implementation, stage 3 fourth implementation,stage1 second implementation and after GRAP)North (before GRAP, stage 1,stage2,stage4 and after GRAP) east(before GRAP,stage1 and stage2) central(Before GRAP,stage1,stage3 third implementation) the NO_2 concentration was within the acceptable limits.

Moreover, from before GRAP through the various stages until after GRAP, the overall trend of NO concentration in phase 1 is rising in all zones. Before GRAP, the North zone had the lowest concentration (12 µg/m³), while the Central zone had the greatest concentration (111 µg/m³) during Stage 3. Except for the west zone (before GRAP, stage 1, stage 2, stage 4 second implementation, stage 1 second and third implementation, and after GRAP), north (all stages within the acceptable limits except stage 2 stage 3 and stage 2 second implementation), and east (before GRAP and stage 1, stage 1 third implementation), central (before GRAP and stage 1)NO concentration was within the acceptable limits while in the South zone (before GRAP and stage 1) the NO concentration during these stages exceeded the acceptable limits. Phase 2 shows an overall pattern of declining NO concentration in the central and west zones and rising NO concentration in the north, east, and south zones. During Stage 3, the South zone had the highest concentration (115 µg/m³), while the North zone had the lowest concentration prior to GRAP and the West zone had the lowest concentration following GRAP (10 µg/m³). The NO concentrations in the south zone exceed the acceptable limits in most stages, except before GRAP, stage 1, stage 2 third implementation, stage 1 second implementation, and after GRAP. The NO concentrations in the west zone exceed the acceptable limits NAAQS of 40 µg/m³ in (Stages 2, 3, 4, Stage 3 second and third, and Stage 2 second implementation). In north Exceeds the acceptable limits in (Stage 3, Stage 2 second implementation, Stage 3 third and fourth implementation) east exceeds the acceptable limits in (Stage 3, Stage 4Stage 3second implementation, Stage 2 second implementation, Stage 3 third and fourth implementation, Stage 2 third implementation) central Exceeds the NAAQS of 40 in most stages except (Before GRAP, Stage 2 third implementation, Stage 1 second implementation and after GRAP).

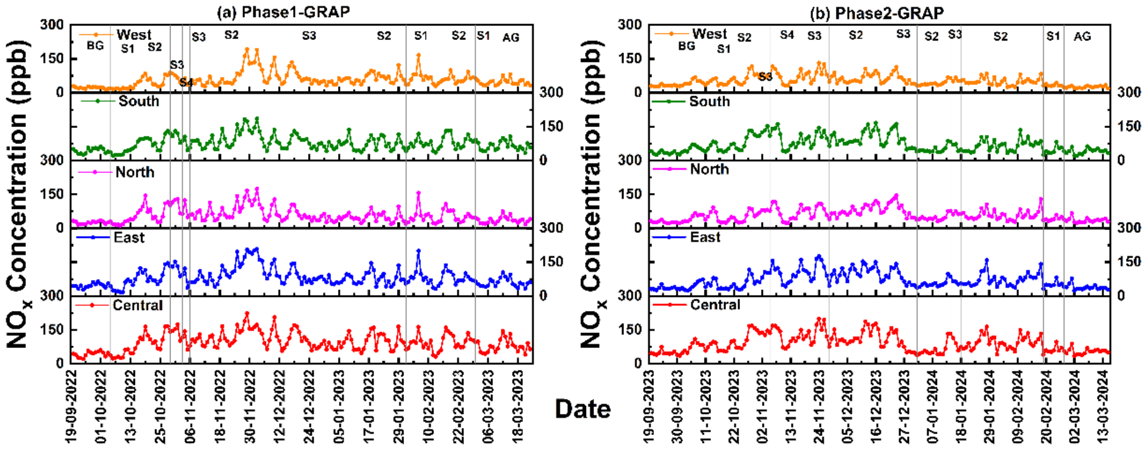

Figure.4.6 Trends in NO_x concentration in two phases across various zones (North, South, East, West, Central) and GRAP stages

The study of NOx concentrations across five zones during Phases 1 and 2 of the GRAP stages reveals significant fluctuations and trends. The study observed that the NO_x concentration I(Fig.4.6) in Phase 1 in the West zone increasing from 22 ppb pre-GRAP to a peak of 86 ppb in Stage 2 then decreased to 47 ppb post-GRAP. The South zone experienced a sharp rise from 43 ppb before GRAP to 111 ppb in Stage 3, ending at 66 ppb post-GRAP. The North zone's NO_x levels rose from 25 ppb before GRAP to a peak of 108 ppb in Stage 3 and decreased to 38 ppb after GRAP. The East zone increased from 46 ppb before GRAP to a peak of 127 ppb in Stage 3, ending at 62 ppb post-GRAP. The Central zone showed the highest variability, peaking at 143 ppb in Stage 3 and ending at 84 ppb post-GRAP. In Phase 2, the West zone's NO_x levels started at 34 ppb, peaking at 85 ppb in Stage 3, and declining to 25 ppb post-GRAP. The South zone began at 36 ppb before GRAP, peaked at 137 ppb in Stage 3, and ended at 41 ppb post-GRAP. The North zone's levels increased from 28 ppb to 80 ppb in Stage 3 and declined to 35 ppb post-GRAP. The East zone saw levels rise from 33 ppb to a peak of 119 ppb in Stage 3, ending at 38 ppb post-GRAP. The Central zone's NO_x levels began at 49 ppb, peaking at 137 ppb in Stage 3, and declined to 54 ppb post-GRAP.

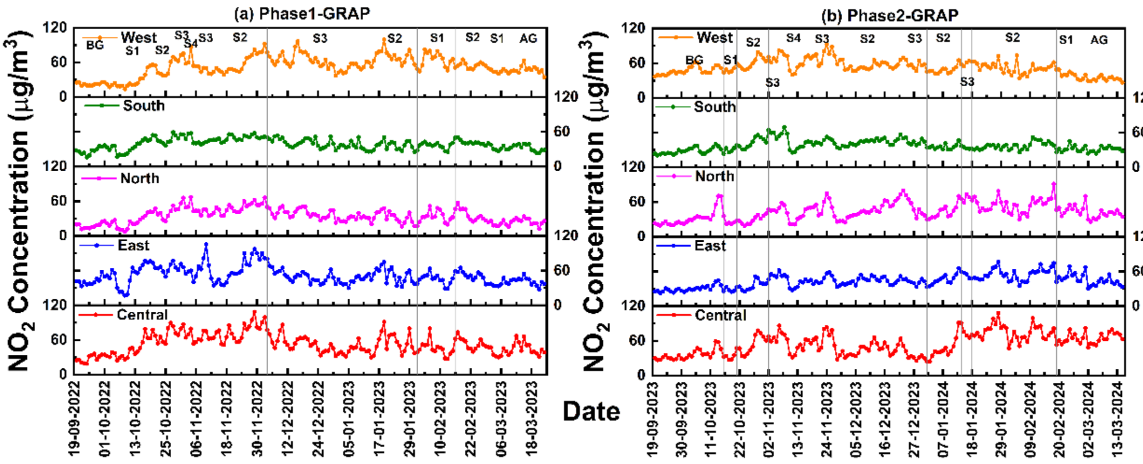

Figure.4.7 Two phases of NO_2 concentration in various zones (North, South, East, West, Central) during various GRAP stages

The NO2 concentration analysis (Fig. 4.7) Phase 1 in the West Zone revealed an increase from 22 µg/m3 to a peak of 71 µg/m3 in Stage 2, dropped to 47 µg/m3 post-GRAP. The South zone saw levels increase from 28 µg/m3 to 52 µg/m3 in Stage 3, then end at 32 µg/m3 post-GRAP. The North zone's concentrations rose from 18 µg/m3 to 53 µg/m3 in Stage 4 and decreased to 24 µg/m3 post-GRAP. The East zone experienced an increase from 44 µg/m3 to 66 µg/m3 in Stage 2, ending at 41 µg/m3 post-GRAP. The Central zone, displaying the highest variability, rose from 29 µg/m3 to 76 µg/m3 in Stage 2 and dropped to 46 µg/m3 post-GRAP. In Phase 2, the West zone's NO_2 levels increased from 45 µg/m3 to a peak of 74 µg/m3 in Stage 3 and finally decreased from the initial level to reach 33 µg/m3 post-GRAP. The South zone saw levels rise from 27 µg/m3 to 61 µg/m3 in Stage 3, and this concentration dropped to 31 µg/m3 post-GRAP. The North zone's concentrations increased from 24 µg/m3 to 66 µg/m3 in Stage 3, ending at 40 µg/m3 post-GRAP. The East zone experienced an increase from 27 µg/m3 to 52 µg/m3 in Stage 3, then the concentration declined to 43 µg/m3 post-GRAP. The Central zone shows increasing from 31 µg/m3 to 75 µg/m3 in Stage 3 and Stage 2, and ending at 65 µg/m3 post-GRAP.

Additionally, the concentration of NO in Phase 1 in the West zone witnessed an initial rise from 14 µg/m3 to a peak of 47 µg/m3 at Stage 3, followed by significant drops and fluctuations, finally stabilizing at 29 µg/m3 post-GRAP. The South zone's NO levels rose from 26 µg/m3 to 86 µg/m3 at Stage 3, then varied considerably, ending at 47 µg/m3 post-GRAP. The North zone experienced a rise from 12 µg/m3 to 69 µg/m3 at Stage 3, fluctuating before stabilizing at 18 µg/m3 post-GRAP. The East zone showed a dramatic rise from 26 µg/m3 to 107 µg/m3 at Stage 3, and decreased to 43 µg/m3 post-GRAP. In the Central zone, the concentration peaked at 111 µg/m3 at Stage 3, with subsequent fluctuations leading to a stable 55 µg/m3 post-GRAP. In Phase 2, the West zone's NO levels increased from 13 µg/m3 to 50 µg/m3 at Stage 3, followed by significant variations, and finally stabilizing at 10 µg/m3 post-GRAP. The South zone's concentration peaked at 115 µg/m3 at Stage 3, with later stages fluctuating significantly, ending at 24 µg/m3 post-GRAP. The North zone saw a rise from 10 µg/m3 to 45 µg/m3 at Stage 3, with subsequent fluctuations ending at 14 µg/m3 post-GRAP. The East zone's NO levels increased from 14 µg/m3 to 69 µg/m3 at Stage 4, the following stages saw fluctuations and finally stabilized at 19 µg/m3 post-GRAP. The Central zone showed a peak of 94 µg/m3 at Stage 3, with notable variations, ending at 24 µg/m3 post-GRAP.

4.5 Temporal Analysis of Carbon Monoxide During Phase1 and Phase 2

In Phase 1, The CO concentrations (Fig.4.8) were stable across all zones, with a slight increase in the Central zone during Stage 3 which reached 3 mg/m^3. The overall range of pollutant concentrations was from 1 to 3 mg/m^3. All zones' CO concentrations are mostly within the acceptable limits (2 mg/m^3) set by NAAQS for CO, with a single exceedance during one stage in the Central zone. In Phase 2, The CO concentrations were stable across all zones, with a slight increase in the South zone during Stage 3 reached 3 mg/m^3. The overall range of pollutant concentrations was from 1 to 3 µg/m^3. All zones' CO concentrations are mostly within the acceptable limits (2 mg/m^3) set by NAAQS for CO, with a single exceedance during one stage in the South zone.

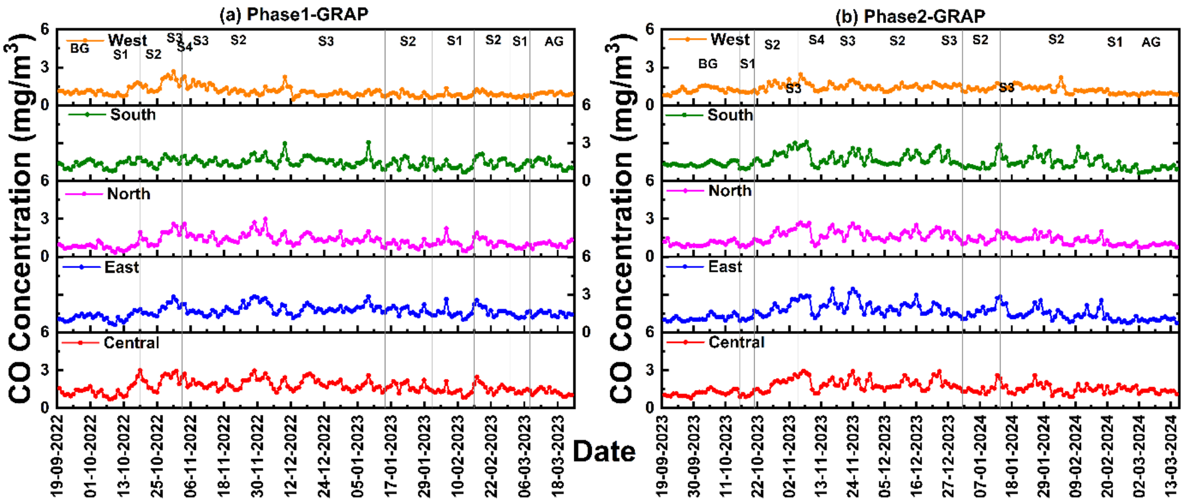

Figure.4.8 CO concentration in two phases across different zones (North, South, East, West, Central) at different GRAP stages

4.6 Ozone Concentration Changes During Phase1 and Phase 2

Phase 1 shows that the general trend of O_3 concentration in the west is rising (Fig. 4.9) in the south and north zones while decreasing in the east and central zones. The highest concentration was observed in the east zone during Stage 2 (36 µg/m³), while the lowest was in the west zone before GRAP and the east zone Stage 2 (16 µg/m³). The O_3 concentration in all zones and stages within the acceptable limits (100 µg/m³) set by NAAQS for O_3. In phase 2, The overall trend in O_3 concentration is increasing in all zones except in the west zone shows a decrease. The highest concentration was observed in different zones (south zone after GRAP, in north zone stage 1 and after GRAP, in the east zone after GRAP) (38 µg/m³), while the lowest was in different zones (in north stage 2, west stage 2, and stage)15 µg/m³. The O_3 concentration in all zones in all stages within the acceptable limits (100 µg/m³) set by NAAQS for O_3.

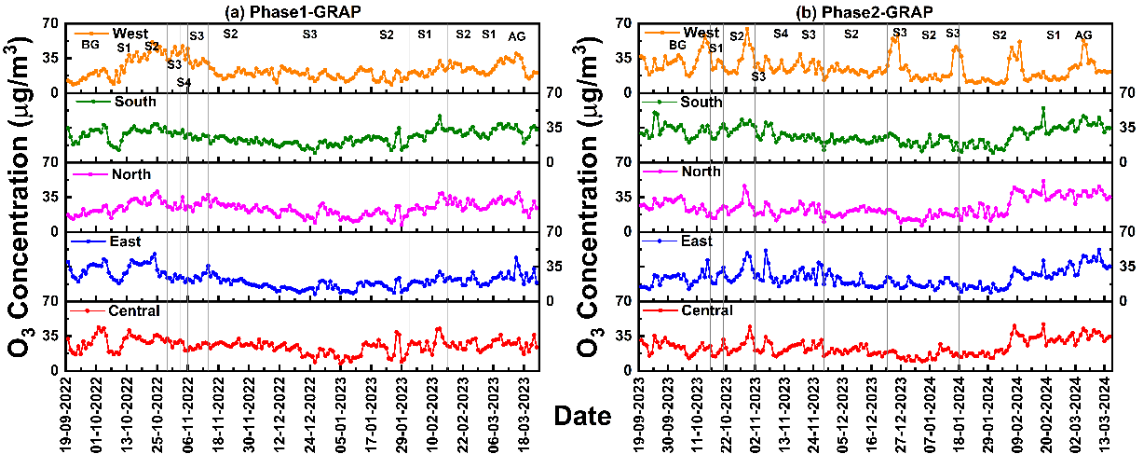

Figure.4.9 Changes in O_3 concentration in two phases and various zones (North, South, East, West, Central) and GRAP stages

The result of O_3 concentration (Fig.4.9) During Phase 1 varied across the West, South, North, East, and Central zones before and after GRAP implementation. In the West zone, O_3 started at 16 µg/m³, peaking at 42 µg/m³ during Stage 2, and finally stabilizing at 28 µg/m³ post-GRAP, with a range of 16 µg/m³ to 42 µg/m³. The South zone began at 28 µg/m³, reached a peak of 34 µg/m³ in Stage 2, and ended at 33 µg/m³ post-GRAP, in this stage the concentration fluctuated between 19 µg/m³ to 34 µg/m³. The North zone's O_3 concentration started at 19 µg/m³, peaking at 33 µg/m³ in Stage 2, and ending at 28 µg/m³ post-GRAP, the range of the concentration of 18 µg/m³ to 33 µg/m³. The East zone started at 32 µg/m³, peaked at 36 µg/m³ in Stage 2, and stabilized at 27 µg/m³ post-GRAP, with a range of 13 µg/m³ to 36 µg/m³. The Central zone's O_3 concentration began at 29 µg/m³, peaked at 31 µg/m³ in Stage 2, and declined to 27 µg/m³ post-GRAP, the concentration in this zone fluctuating between 19 µg/m³ to 31 µg/m³. In Phase 2, the West zone started at 30 µg/m³, peaked at 35 µg/m³ during Stage 3, and ended at 27 µg/m³ post-GRAP, with a range of 15 µg/m³ to 35 µg/m³. The South zone began at 35 µg/m³, peaked at 36 µg/m³ during Stage 2, and ended at 38 µg/m³ post-GRAP, the range of the concentration between 20 µg/m³ to 36 µg/m³. The North zone started at 29 µg/m³, and peaked at 38 µg/m³ post-GRAP, with significant drops during the stages, showing a range of 15 µg/m³ to 38 µg/m³. The East zone started at 21 µg/m³, peaked at 31 µg/m³ during Stage 2, and rose to 38 µg/m³ post-GRAP, with a range of concentration of 17µg/m³ to 38 µg/m³. The Central zone began at 26 µg/m³, peaked at 32 µg/m³ during Stage 1, and increased at 35 µg/m³ post-GRAP, with a range of 15 µg/m³ to 35 µg/m³.

4.7 Ammonia Concentration Changes During Phase1 and Phase 2

During the first phase, there was a general increase in NH_3 concentrations in the West, South, North, and Central zones, and a decrease in the East zone. Before GRAP, the West zone's concentration shows the minimum concentration of 23 µg/m³, while the Central zone shows the highest concentration of 95 µg/m³ during Stage 2. Every zone stayed within the 100 µg/m³ permissible limits for NH_3 set by the NAAQS. Phase 2 saw general fluctuations in NH_3 concentrations within each zone. The west zone saw a return to its initial level, while the south and north saw modest drops, the east saw noticeable increases, and the central zone saw slight decreases. The maximum concentration observed was 81 µg/m³ in the North zone during Stage 3, and the minimum was 23 µg/m³ in the West zone before and after GRAP. All zones remained within the acceptable limits (100 µg/m³) set by the NAAQS for NH3.

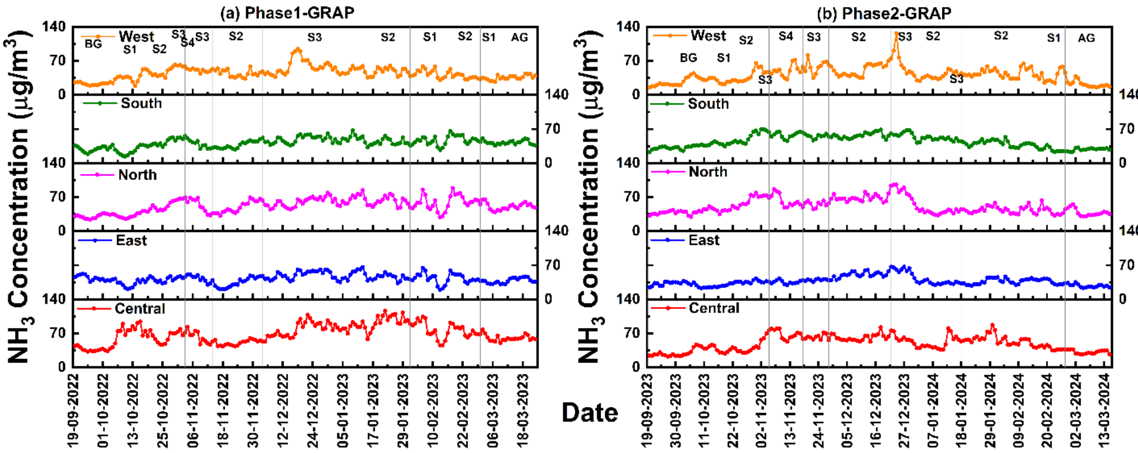

Figure.4.10 NH_3 concentration in two phases across different zones (North, South, East, West, Central) at different GRAP stages

According to the NH_3 concentration analysis (Fig. 4.10), Phase 1 in the West Zone began with a concentration of 23 µg/m³, peaking at 60 µg/m³ in Stage 3, and declined to 37 µg/m³ post-GRAP, with a range of concentration 23 µg/m³ to 60 µg/m³. The South zone started at a concentration of 29 µg/m³, peaking at 52 µg/m³ in Stage 2, and ending at 42 µg/m³ after GRAP, the range of concentration in this zone between 26 µg/m³ to 52 µg/m³. In the North zone the NH_3 concentration before GRAP was 30 µg/m³, peaked at 67 µg/m³ in Stage 2, and decreased to 51 µg/m³ post-GRAP, with a range of 30 µg/m³ to 67 µg/m³. The East zone started with an NH_3 concentration of 44 µg/m³, peaked at 51 µg/m³ in Stage 3, and declined to 40 µg/m³ post-GRAP, with a range of 32 µg/m³ to 51 µg/m³. The Central zone starts with a concentration of 37 µg/m^3, peaking at 95 µg/m^3 in Stage 2, and decreases to 59 µg/m^3 after GRAP, with a range of 37 µg/m^3 to 95 µg/m^3. The West zone's range was 23 µg/m^3 to 66 µg/m^3, with the highest level of 66 µg/m^3 in Stage 3 and dropping to 23 µg/m^3 post–GRAP in Phase 2. With a range of 28 µg/m^3 to 69 µg/m^3, the South zone started at 30 µg/m^3, rose at 69 µg/m^3 in Stage 3, and then stabilized at 28 µg/m^3 post-GRAP. The North zone fluctuated between 38 µg/m^3 and 81 µg/m^3, rising at 81 µg/m^3 in Stage 3 before ending at 39 µg/m^3. With a range of 27 µg/m^3 to 60 µg/m^3, the East zone starts at 33 µg/m^3, climbed at 60 µg/m^3 in Stage 3, and steadied at 28 µg/m^3. With a range of 25 µg/m^3 at the beginning, 69 µg/m^3 at the peak in Stage 4, and 31 µg/m^3 at the stabilization.

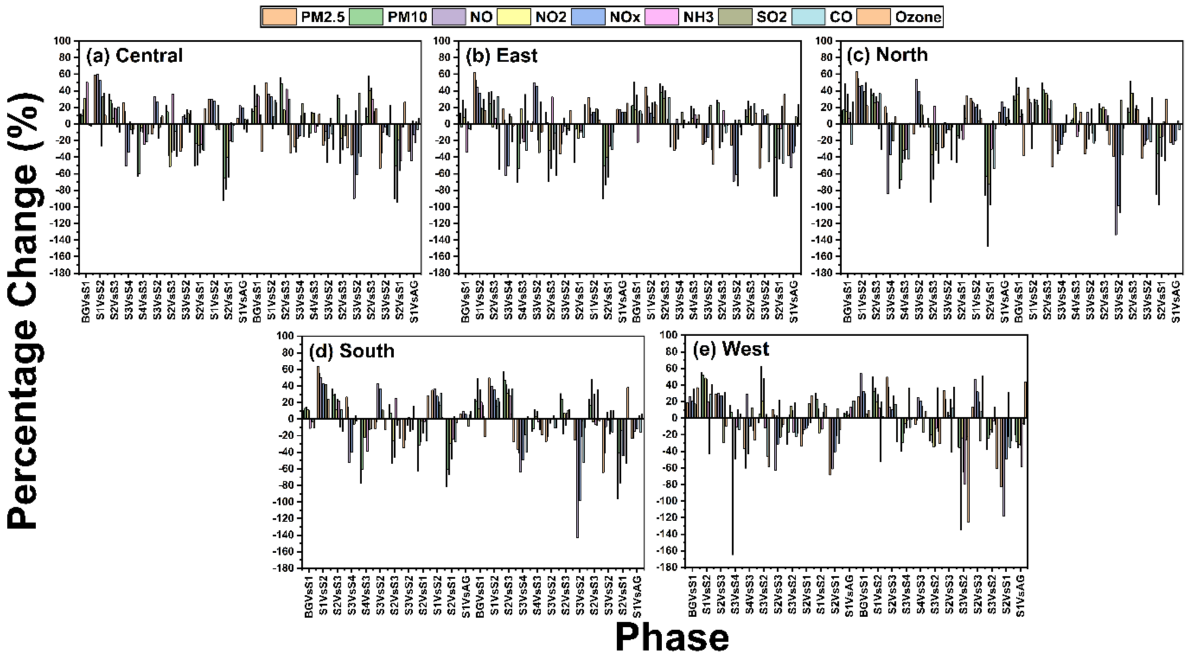

Figure.4.11 Variations in pollutant concentrations ($PM_{2.5}$, PM_{10}, NO_2, NO_x, CO, NH_3, SO_2, O_3) across two phases and various GRAP stages in different zones (Central, East, North, South, West)

4.1 Pollutant Concentration Comparison During Phase 1 and Phase 2

In the central zone (Fig.4.12), in phase 1, The overall trend of the pollutant concentration from BGvsS1 to S1vsAG is increasing in NO(17%-22%)and SO_2 (0%-5%), O_3 (-3%-5%) and show increasing albeit at a slower rate in $PM_{2.5}$ (from 12% to 6%), PM_{10} (10%-4%), NO_2(31%-15%), NO_x (23%-20%) and decreasing trend in NH_3 (50%to -6%) and CO(-2% to -9%). The Pollutant exhibiting the most significant increase in concentration during this phase is NO during S1vsS2 with a percentage change of 60%, while The Pollutant showing the most substantial decrease in concentration during this phase is $PM_{2.5}$ during S2vsS1 with a percentage change of -92%(Table.4.1).

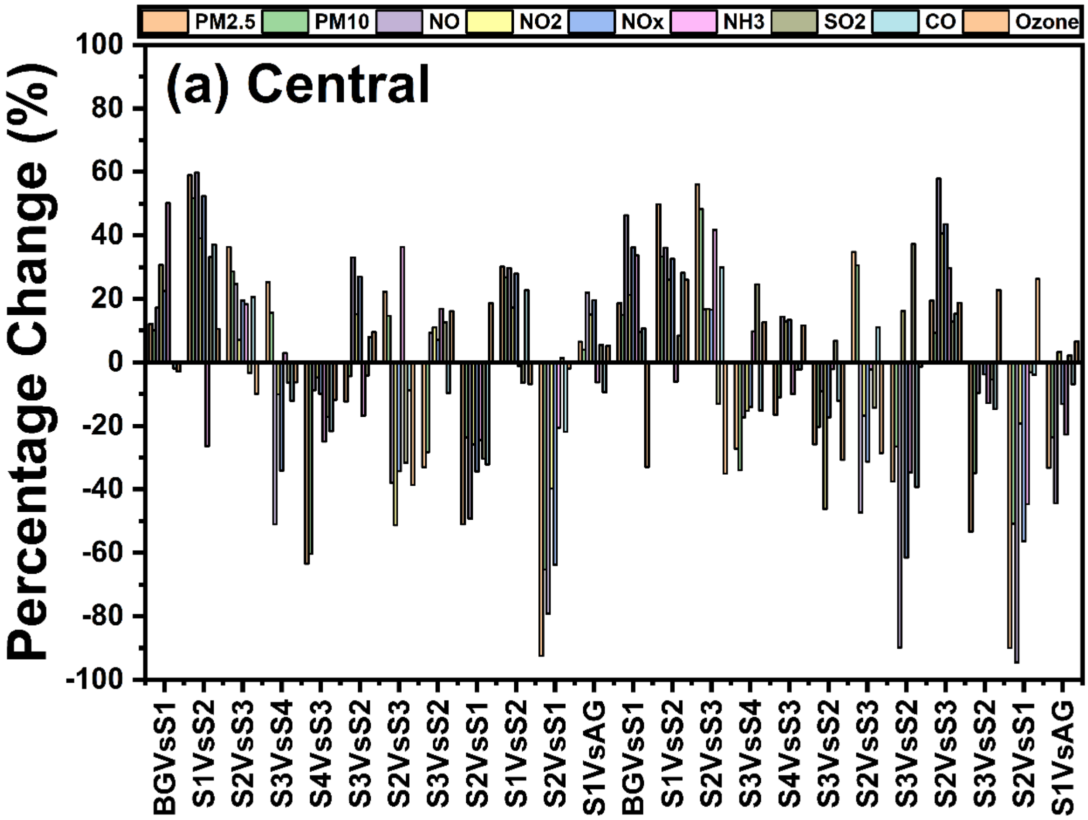

Figure.4.12 Pollutant concentration changes ($PM_{2.5}$, PM_{10}, NO_2, NO_x, CO, NH_3, SO_2, O_3) across two phases and various GRAP stages in the central zone

In phase 2, The overall trend in the pollutant concentration from BGvsS1 to S1vsAG is increasing in O_3 (-33% to 7%) and shows increasing albeit at a slower rate in SO_2 (from 9% to 2%), NO_2 (21%to 3%), and decreasing trend in $PM_{2.5}$ (19%to -33%), PM_{10} (15% to -24%), NO(46%to -44%), NO_x (36% to -13%), NH_3 (34% to -23%) and CO(11% to -7%). In this phase, The Pollutant observed the most significant increase in concentration is $PM_{2.5}$ during S2vsS3 with a percentage change of 56%, while The Pollutant showing the most substantial decrease in concentration during this phase is NO during S2vsS1 with a percentage change of -95%. Overall results revealed Phase 1 generally saw an increasing trend in most pollutant concentrations, in Phase 2 there was a decreasing trend so this is evidence of the effectiveness of interventions in Phase 2 of GRAP in reducing pollutant concentration in the central zone (Table.4.2).

Table.4.1 Pollutant concentration changes in Phase 1 ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the central zone

Phase 1									
GRAP stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	12%	10%	17%	31%	23%	50%	0%	-2%	-3%
S1vsS2	59%	52%	60%	39%	52%	-26%	33%	37%	11%
S2vsS3	36%	29%	25%	7%	19%	18%	-3%	21%	-10%
S3vsS4	25%	16%	-51%	-10%	-34%	3%	-6%	-12%	-6%
S4vsS3	-63%	-60%	-9%	-5%	-10%	-25%	-17%	-22%	-12%
S3vsS2	-12%	-4%	33%	15%	27%	-17%	-4%	8%	9%%
S2vsS3	22%	15%	-38%	-51%	-34%	36%	-32%	-9%	-39%
S3vsS2	-33%	-28%	9%	11%	7%	17%	13%	-10%	16%
S2vsS1	-51%	-24%	-49%	-26%	-34%	-24%	-30%	-32%	19%
S1vsS2	30%	27%	30%	17%	28%	-1%	-6%	23%	-7%
S2vsS1	-92%	-65%	-79%	-40%	-64%	-21%	1%	-22%	-2%
S1vsAG	6%	4%	22%	15%	20%	-6%	5%	-9%	5%

Table.4.2 Pollutant concentration changes in phase 2 ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the central zone

Phase 2									
GRAP stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	19%	15%	46%	21%	36%	34%	9%	11%	-33%
S1vsS2	50%	33%	36%	26%	33%	-6%	8%	28%	26%
S2vsS3	56%	48%	17%	17%	17%	42%	-13%	30%	-35%
S3vsS4	-27%	-34%	-17%	-15%	-14%	10%	25%	-15%	13%
S4vsS3	-17%	-11%	14%	13%	13%	-10%	-2%	-2%	12%
S3vsS2	-26%	-20%	-9%	-46%	-17%	-2%	7%	-12%	-31%

S2vsS3	35%	31%	-47%	-17%	-31%	-2%	-14%	11%	-29%
S3vsS2	-38%	-27%	-90%	16%	-61%	-35%	37%	-39%	-1%
S2vsS3	19%	9%	58%	41%	44%	30%	13%	15%	19%
S3vsS2	-53%	-35%	-10%	0%	-4%	-13%	-5%	-15%	23%
S2vsS1	-90%	-51%	-95%	-19%	-56%	-45%	-3%	-4%	26%
S1vsAG	-33%	-24%	-44%	3%	-13%	-23%	2%	-7%	7%

Phase 1 of the east zone (Fig4.13) shows an overall trend of increasing pollutant concentration from BGVsS1 to S1vsAG for all pollutants in this phase (Table.4.3). $PM_{2.5}$ during S1vsS2 exhibits the most notable concentration increase during this phase, with a percentage change of 62%, while $PM_{2.5}$ during S2vsS1 exhibits the most notable concentration decrease during this phase, with a percentage change of -90%.

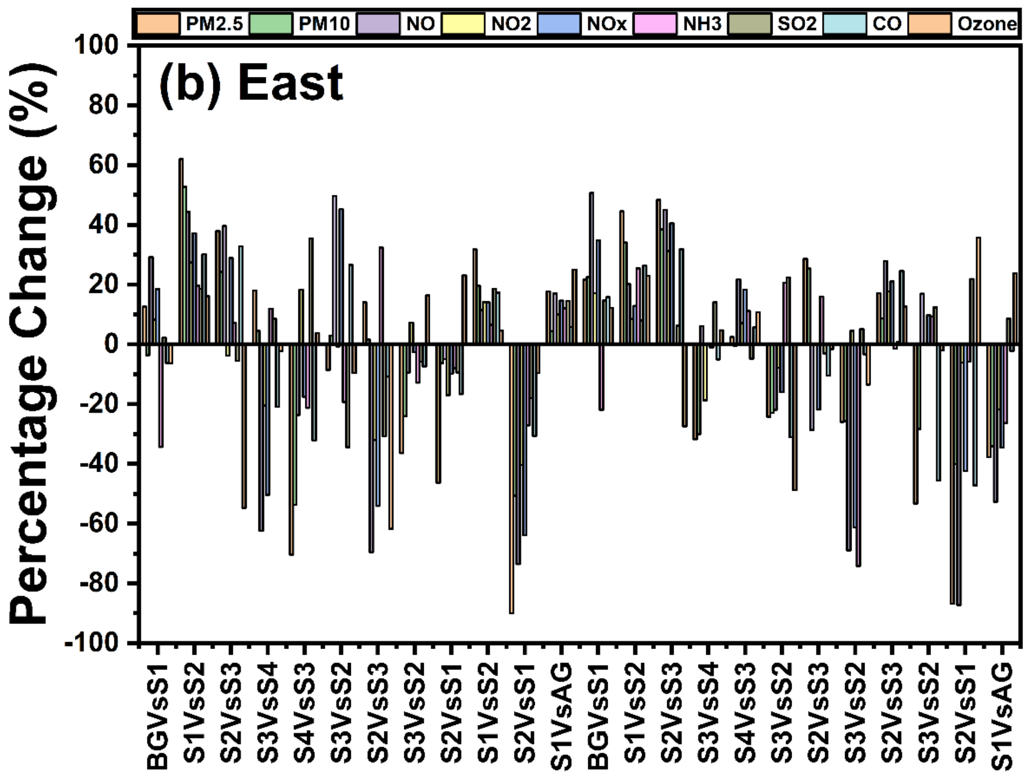

Figure.4.13 Percentage changes in pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across two phases and various GRAP stages in the east zone

Phase 2 (Table.4.4) analysis shows an overall increase in O_3 concentration from BGvsS1 to S1vsAG of 12% to 24%, an increase in SO_2 concentration from 15% to 9%, albeit at a slower rate, and a decrease in all other pollutant concentrations, including $PM_{2.5}$ (22% to -38%), PM_{10} (22% to -34%), NO (51% to -53%), NO2 (17% to -22%), NO_x (35% to-35%), NH_3(-22%to-26%), and(16%to-2%). Pollutants showing the greatest decrease in concentration during this phase are $PM_{2.5}$ and NO during S2vsS1, with a percentage change of -87%, while NO during BGvsS1 exhibits the most significant increase in concentration, with a percentage change of 51%. The east zone's pollutant concentrations increased during Phase 1 of GRAP, while Phase 2 revealed a declining trend, demonstrating the efficacy of Phase 2.

Table.4.3 Percentage values in phase 1 for all pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the east zone

Phase 1									
GRAP stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	13%	-4%	29%	8%	18%	-34%	2%	-6%	-6%
S1vsS2	62%	53%	44%	27%	37%	20%	19%	30%	16%
S2vsS3	38%	24%	40%	-4%	29%	7%	-6%	33%	-55%
S3vsS4	18%	5%	-62%	-21%	-50%	12%	9%	-21%	-2%
S4vsS3	-70%	-54%	-24%	18%	-18%	-21%	35%	-32%	4%
S3vsS2	-9%	3%	50%	-1%	45%	-19%	-34%	27%	-10%
S2vsS3	14%	2%	-70%	-32%	-54%	32%	-31%	-11%	-62%
S3vsS2	-36%	-24%	-9%	7%	-3%	-13%	-6%	-7%	16%
S2vsS1	-46%	-6%	-5%	-17%	-10%	-8%	-9%	-17%	23%
S1vsS2	32%	20%	11%	14%	14%	7%	19%	17%	5%
S2vsS1	-90%	-51%	-74%	-40%	-64%	-27%	-18%	-31%	-10%
S1vsAG	18%	4%	17%	10%	15%	12%	15%	6%	25%

Table.4.4 Percentage values in phase 2 for all pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the east zone

Phase 2									
GRAP stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	22%	22%	51%	17%	35%	-22%	15%	16%	12%
S1vsS2	45%	34%	20%	8%	13%	25%	8%	26%	23%
S2vsS3	48%	38%	45%	31%	41%	0%	6%	32%	-28%
S3vsS4	-32%	-30%	6%	-19%	0%	-1%	14%	-5%	5%
S4vsS3	2%	0%	22%	7%	18%	11%	-5%	6%	11%
S3vsS2	-24%	-23%	-22%	-8%	-16%	21%	22%	-31%	-49%
S2vsS3	29%	25%	-29%	0%	-22%	16%	-3%	-10%	-2%
S3vsS2	-26%	-26%	-69%	5%	-61%	-74%	5%	-3%	-13%
S2vsS3	17%	9%	28%	18%	21%	-1%	1%	24%	13%
S3vsS2	-53%	-28%	17%	0%	10%	9%	12%	-46%	-2%
S2vsS1	-87%	-40%	-87%	-6%	-42%	-6%	22%	-47%	36%
S1vsAG	-38%	-34%	-53%	-22%	-35%	-26%	9%	-2%	24%

The general pattern of the pollutant concentration in North Zone (Fig.4.14) Phase 1 is rising from BGvsS1 to S1vsAG in CO(-25%to 18%) and shows increasing albeit at a slower rate in $PM_{2.5}$ (from 16% to 14%), PM_{10} (17%-10%), NO(49% to 27%), NO_2 (16% to 13%), NO_x (36%to21%), SO_2 (14% to 8%) and O_3 (26% to 5%)and decreasing trend in NH_3 (7%to -1%) (Table.4.5). $PM_{2.5}$ during S1vsS2 displays the most significant concentration increase during this phase, with a percentage change of 63%, whereas NO during S2vsS1 exhibits the most noticeable drop in concentration during this phase, with a percentage change of -148%.

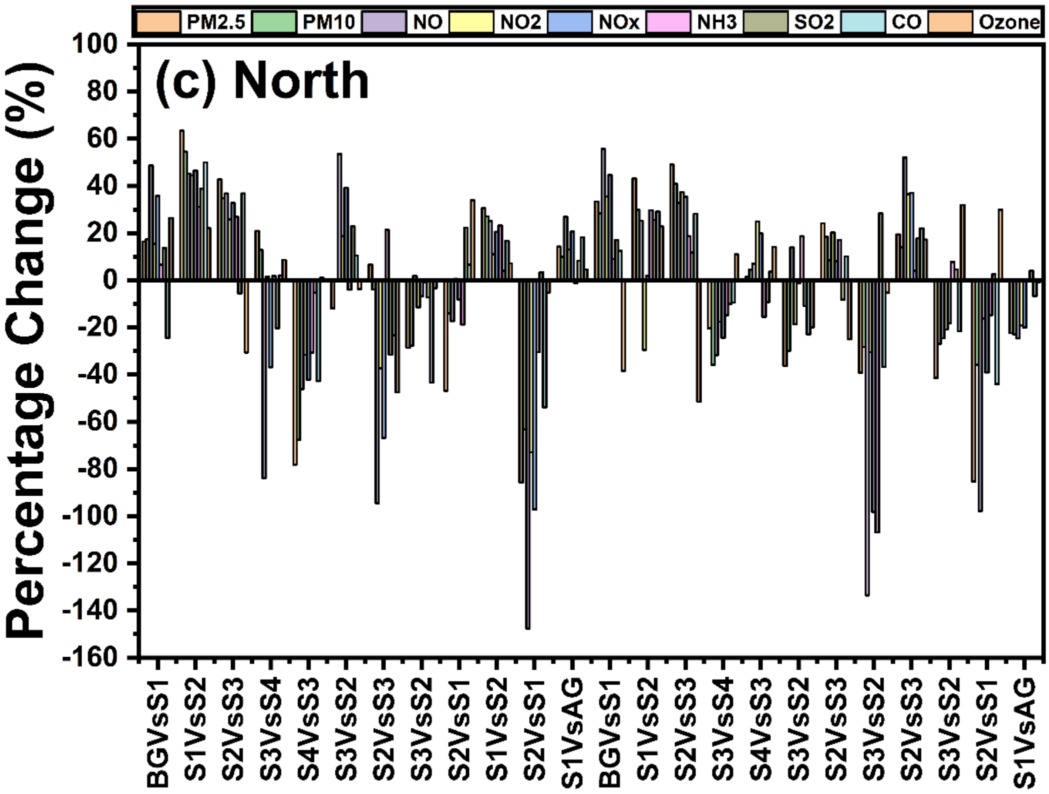

Figure.4.14 Changes in pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across two phases and various GRAP stages in the north zone

In North zone phase 2(Table. 4.6), The overall trend in the pollutant concentration from BGvsS1 to S1vsAG is shown to increase albeit at a slower rate in SO_2 (from 17% to 4%) while showing a decreasing trend in all other pollutants $PM_{2.5}$ (33%to -22%), PM_{10} (28% to -23%), NO(56% to -25%), NO_2 (35% to -19%), NO_x (45% to -20%), NH_3 (9% to 0%), CO(12% to -7%) and O_3 show decreasing but in slower rate (-38% to -1%). The Pollutant exhibiting the most significant increase in concentration during this phase is NO during BGvsS1 with a percentage change of 56%, while The Pollutant showing the most substantial decrease in concentration during this phase is NO during S3vsS2 with a percentage change of -134%. Overall, Phase 1 of GRAP showed an increase in pollutant concentrations in the north zone, while Phase 2 showed a decreasing trend, indicating the effectiveness of the interventions.

Table.4.5 Pollutant concentrations in phase 1 ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) and their variations across different GRAP implementation stages in the North zone

Phase 1									
GRAP stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	16%	17%	49%	16%	36%	7%	14%	-25%	26%
S1vsS2	63%	54%	45%	44%	46%	31%	39%	50%	22%
S2vsS3	43%	35%	37%	26%	33%	27%	-6%	37%	-31%
S3vsS4	21%	13%	-84%	1%	-37%	2%	-20%	2%	9%
S4vsS3	-78%	-68%	-46%	-32%	-42%	-31%	-5%	-43%	1%
S3vsS2	-12%	0%	54%	19%	39%	-4%	23%	10%	-4%
S2vsS3	7%	-4%	-95%	-37%	-67%	21%	-32%	-23%	-47%
S3vsS2	-29%	-28%	2%	-11%	-7%	-1%	-7%	-43%	-3%
S2vsS1	-47%	-14%	-17%	1%	-8%	-19%	22%	7%	34%
S1vsS2	31%	27%	25%	11%	21%	23%	4%	17%	7%
S2vsS1	-86%	-63%	-148%	-73%	-97%	-31%	3%	-54%	-5%
S1vsAG	14%	10%	27%	13%	21%	-1%	8%	18%	5%

Table.4.6 Pollutant concentrations in phase 2 ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) and their variations across different GRAP implementation stages in the North zone

Phase 2									
GRAP stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	33%	28%	56%	35%	45%	9%	17%	12%	-38%
S1vsS2	43%	30%	25%	-30%	2%	30%	26%	29%	23%
S2vsS3	49%	41%	33%	37%	35%	19%	12%	28%	-51%
S3vsS4	-20%	-36%	-32%	-18%	-24%	-15%	-10%	-9%	11%
S4vsS3	2%	4%	7%	25%	20%	-16%	-9%	4%	14%

S3vsS2	-36%	-30%	14%	-19%	-1%	19%	-11%	-23%	-20%
S2vsS3	24%	18%	9%	20%	8%	17%	-8%	10%	-25%
S3vsS2	-39%	-28%	- 134%	-31%	-98%	- 107%	28%	-37%	-5%
S2vsS3	19%	14%	52%	37%	37%	4%	18%	22%	17%
S3vsS2	-41%	-27%	-25%	-21%	-18%	8%	5%	-22%	32%
S2vsS1	-85%	-36%	-98%	-16%	-39%	-15%	3%	-44%	30%
S1vsAG	-22%	-23%	-25%	-19%	-20%	0%	4%	-7%	-1%

In the first phase of the south zone (Fig.4.15), the overall trend in the concentration of pollutants from BGvsS1 to S1vsAG is increasing in CO (-3% to 5%) and O_3 (-10% to 9%). The following pollutants show increasing trends, albeit at a slower rate: $PM_{2.5}$ (from 11% to 6%), PM_{10} (from 13% to 3%), NO (15% to 10%), NO_x (from 11% to 6%), and decreasing trends in NO_2 (from 11% to 0%), SO2 (-2% to -9%), and NH_3 (Table.4.7). $PM_{2.5}$ during S1vsS2 displays the most noticeable concentration increase during this phase, with a percentage change of 64%, while $PM_{2.5}$ during S2vsS1 exhibits the most notable concentration decrease during this phase, with a percentage change of -81%.

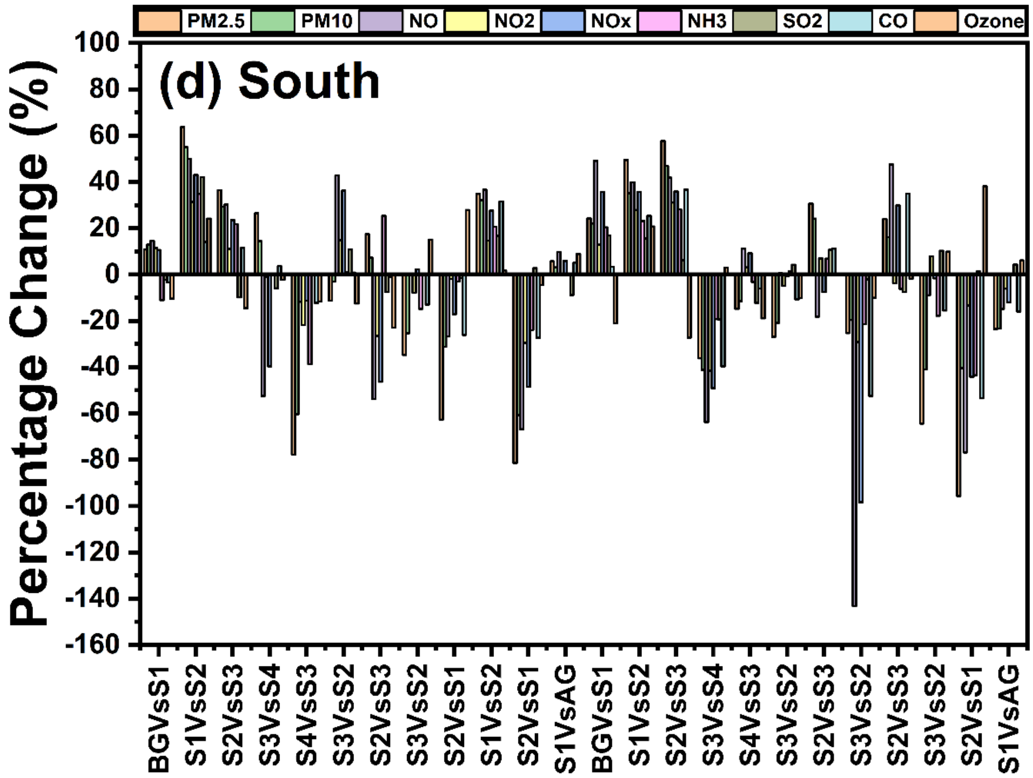

Figure.4.15 Variations in pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across two phases and various GRAP stages in the south zone

Phase2(Table.4.8) shows an overall trend of rising of O_3 (-21% to 6%) concentrations from BGvsS1 to S1vsAG.All other pollutants show a declining trend: $PM_{2.5}$ (from 24% to -24%), PM_{10} (from 22% to -23%), NO (from 49% to -15%), NO_2 (13% to -6%), NO_x (36% to 12%), and NH_3 (20% to 0%). The SO_2 indicates a rising trend but at a slower rate of (17% to 4%). $PM_{2.5}$ during S2vsS3 demonstrates the most significant concentration increase during this phase, with a percentage change of 58%, while NO during S3vsS2 reveals the most notable concentration drop during this phase, with a percentage change of –143%. within the south zone, most pollutant concentrations in phase 1 typically showed an increasing trend, but phase 2 showed a declining trend, indicating the efficacy of the interventions in phase 2 of GRAP in lowering pollutant concentration in the south zone.

Table.4.7 Percentage changes in phase 1 for all pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the south zone

Phase 1									
GRAP Stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	11%	13%	15%	11%	11%	-11%	-2%	-3%	-10%
S1vsS2	64%	55%	50%	31%	43%	35%	42%	14%	24%
S2vsS3	36%	29%	30%	11%	24%	22%	-10%	12%	-15%
S3vsS4	26%	14%	-53%	-1%	-40%	0%	-6%	4%	-2%
S4vsS3	-78%	-60%	-12%	-22%	-11%	-39%	0%	-12%	-12%
S3vsS2	-11%	-3%	43%	15%	36%	1%	11%	1%	-13%
S2vsS3	18%	7%	-54%	-26%	-46%	25%	-8%	-1%	-23%
S3vsS2	-35%	-25%	0%	-8%	2%	-15%	0%	-13%	15%
S2vsS1	-63%	-31%	-27%	-2%	-17%	-3%	-1%	-26%	28%
S1vsS2	35%	32%	37%	15%	28%	21%	17%	32%	2%
S2vsS1	-81%	-61%	-67%	-30%	-49%	-24%	3%	-27%	-5%
S1vsAG	6%	3%	10%	0%	6%	0%	-9%	5%	9%

Table.4.8 Percentage changes in phase 2 for all pollutants concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the south zone

Phase 2									
GRAP Stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3**	**SO_2**	**CO**	**Ozone**
BGvsS1	24%	22%	49%	13%	36%	20%	17%	3%	-21%
S1vsS2	49%	35%	40%	28%	36%	23%	16%	25%	21%
S2vsS3	58%	47%	42%	31%	36%	28%	6%	37%	-27%
S3vsS4	-36%	-41%	-64%	-42%	-49%	-19%	-19%	-40%	3%
S4vsS3	-15%	-11%	11%	3%	9%	-3%	-12%	-6%	-19%
S3vsS2	-27%	-21%	1%	-5%	-1%	1%	4%	-11%	-10%
S2vsS3	31%	24%	-18%	7%	-8%	7%	11%	11%	0%

S3vsS2	-25%	-20%	-143%	-29%	-98%	-21%	-2%	-53%	-10%
S2vsS3	24%	16%	48%	-4%	30%	-6%	-8%	35%	-2%
S3vsS2	-64%	-41%	-9%	8%	-2%	-18%	10%	-16%	10%
S2vsS1	-96%	-40%	-77%	-13%	-44%	-44%	1%	-53%	38%
S1vsAG	-24%	-23%	-15%	-6%	-12%	0%	4%	-16%	6%

In the west zone (Fig.4.16)phase 1, The overall trend in the pollutant concentration from BGvsS1 to S1vsAG is increasing in CO(0%to 21%), while the all other pollutant show increasing albeit at a slower rate $PM_{2.5}$ (from 19% to 6%), PM_{10} (12% to 5%), NO(26% to 8%), NO_2 (14% to 3%), NO_x (21%to5%), NH_3 (35% to 13%)SO_2 (17% to 10%)and O_3 (37% to 20%).so all pollutant in this phase show increasing trend(Table.4.9). NO during S3vsS2 presents the most recognized concentration increase during this phase, with a percentage change of 62%, whereas NO during S3vsS4 exhibits the most noticeable concentration decline during this phase, with a percentage change of -164%.

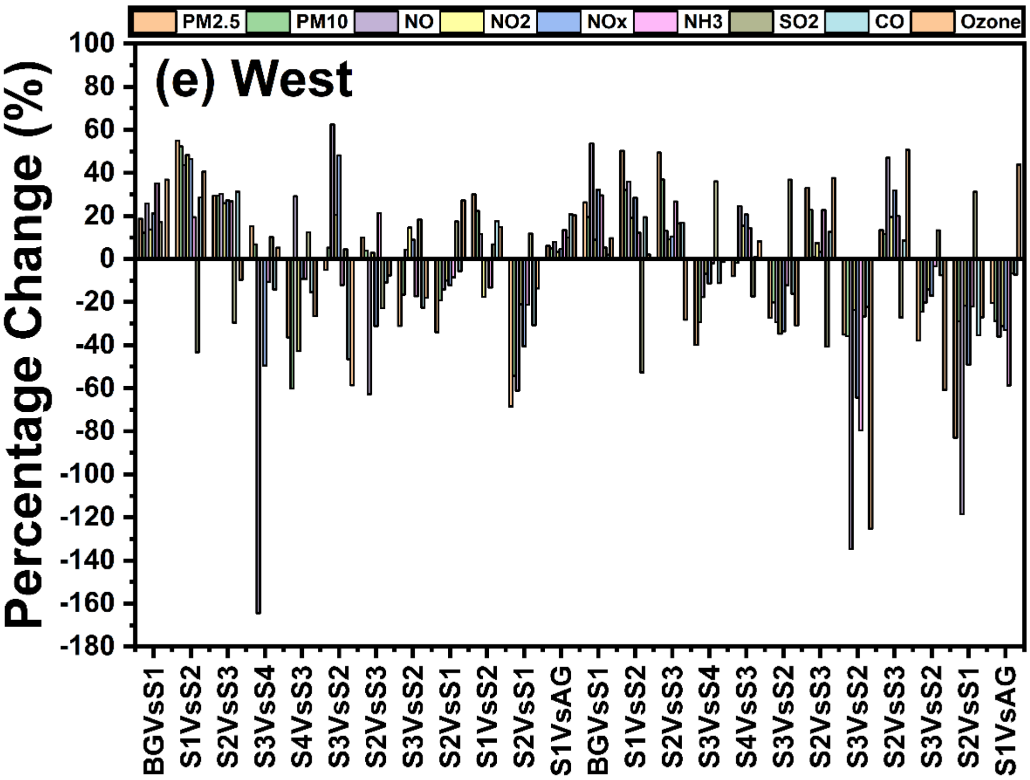

Figure.4.16 Changes in the percentage of pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) in the west zone across two phases and different GRAP stages

Phase 2(Table.4.10) From BGvsS1 to S1vsAG, the overall trend in pollutant concentration shows an increasing trend, albeit at a slower rate in O_3 (from 10% to 44%). All other pollutant shows a decreasing trend, including $PM_{2.5}$ (26 to -20%), PM_{10} (19% to -29%), NO(54% to -36%), NO_2 (9% to -31%), NO_x (32% to 33%), NH_3 (30% to -59%), SO_2 (5% to-7%), and CO(2%to-7%). PM2.5 during S1vsS2 shows the most significant concentration increase during this phase, with a percentage change of 50%, whereas NO during S3vsS2 displays the most notable reduction in concentration during this phase, with a percentage change of -135%. The Pollutant concentrations in the west zone rose during GRAP Phase 1, whereas Phase 2 exhibited a declining trend.

Table.4.9 Phase 1 pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the west zone

Phase 1									
GRAP Stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3%**	**SO_2**	**CO**	**Ozone**
BGvsS1	19%	12%	26%	14%	21%	35%	17%	0%	37%
S1vsS2	55%	52%	44%	48%	46%	19%	-43%	29%	41%
S2vsS3	29%	29%	30%	26%	27%	27%	-30%	31%	-10%
S3vsS4	15%	7%	-164%	0%	-50%	-11%	10%	-14%	5%
S4vsS3	-36%	-60%	29%	-43%	-9%	-9%	12%	-15%	-27%
S3vsS2	-5%	5%	62%	20%	48%	-12%	4%	-46%	-59%
S2vsS3	10%	4%	-63%	3%	-31%	21%	-23%	-11%	-8%
S3vsS2	-31%	-17%	4%	15%	9%	-17%	18%	-23%	-18%
S2vsS1	-34%	-19%	-14%	-10%	-12%	-8%	17%	-6%	27%
S1vsS2	30%	22%	12%	-18%	-1%	-13%	7%	18%	15%
S2vsS1	-69%	-54%	-61%	-21%	-41%	-21%	12%	-31%	-14%
S1vsAG	6%	5%	8%	3%	5%	13%	10%	21%	20%

Table.4.10 Phase 2 for all pollutant concentrations ($PM_{2.5}$, PM_{10}, NO, NO_2, NO_x, NH_3, SO_2, CO, and O_3) across different GRAP implementation stages in the west zone

Phase 2									
GRAP Stage	**$PM_{2.5}$**	**PM_{10}**	**NO**	**NO_2**	**NO_x**	**NH_3%**	**SO_2**	**CO**	**Ozone**
BGvsS1	26%	19%	54%	9%	32%	30%	5%	2%	10%
S1vsS2	50%	32%	36%	19%	29%	12%	-53%	19%	2%
S2vsS3	49%	37%	13%	9%	10%	27%	17%	17%	-28%
S3vsS4	-40%	-29%	-18%	-7%	-11%	-2%	36%	-11%	-1%
S4vsS3	-8%	-2%	25%	16%	21%	14%	-17%	1%	8%
S3vsS2	-27%	-20%	-29%	-35%	-34%	-12%	37%	-16%	-31%
S2vsS3	33%	23%	1%	7%	3%	23%	-41%	13%	38%
S3vsS2	-35%	-36%	-135%	-24%	-64%	-80%	-27%	-22%	-125%
S2vsS3	13%	12%	47%	19%	32%	20%	-27%	9%	51%
S3vsS2	-38%	-25%	-20%	-14%	-17%	-3%	13%	-8%	-61%
S2vsS1	-83%	-29%	-118%	-22%	-49%	-22%	31%	-35%	-27%
S1vsAG	-20%	-29%	-36%	-31%	-33%	-59%	-7%	-7%	44%

Chapter 5

CONCLUSION

New Delhi, India's capital, is the world's most polluted city, with PM concentrations exceeding 350 micrograms per cubic meter. This is due to increased automobile emissions and coal-fired power plants. The WHO reports seven million deaths globally due to air pollution, with fatalities resulting from exposure to hazardous substances indoors and outdoors. The national capital of India, Delhi, has been selected to conduct this study. The study collected data on the one-hour average concentration of different pollutants ($PM_{2.5}$, PM_{10}, NO_x, NO2, NO, SO_2, NH_3, CO, and Ozone) from 41 monitoring stations in Delhi, divided into two phases from 2022 to 2024. The data was distributed to five zones of Delhi to illustrate air quality changes before, during, and after the implementation of the Graded Response Action Plan (GRAP). the results revealed that all zones (North, South, East, and West) experienced an average increase in pollutant concentrations during Phase 1. Conversely, Phase 2 showed a decreasing trend in pollutant levels, demonstrating the effectiveness of interventions implemented in Phase 2 of the (GRAP) across all zones in Delhi. It also indicates that both $PM_{2.5}$ and NO concentrations fluctuated significantly, whereas NO showed more pronounced decreases across various phases and zones. In addition, the study indicates that the implementation of GRAP was highly effective in reducing CO concentrations across all zones and phases, maintaining stable levels. However, NH_3 exhibited an increasing trend in Phase 1 and fluctuations in Phase 2. NO_x showed an increasing trend in most of the zones across all phases, while NO_2 also increased consistently. NO concentrations increased in different zones and stages during Phase 1, with fluctuations observed in Phase 2. O_3 levels fluctuated in Phase 1 but increased in Phase 2. SO_2 demonstrated an increasing trend across all phases and zones. PM_{10} showed an increasing trend in Phase 1 across all stages, with fluctuations among zones in Phase 2. Lastly, $PM_{2.5}$ exhibited an increasing trend in both phases. Moreover, going through the GRAP stages, Before the implementation of the GRAP and during, both Phase 1 and Phase 2, pollutant concentrations exhibited a generally increasing trend from Stage 1 to Stage 4, followed by fluctuations. After the implementation of GRAP, the pollutants exhibited both a decreasing and increasing trend. In Phase 1, NO_2 concentrations increased in all zones except the east zone, SO_2 increased in all zones except the central zone, and O_3 increased in all zones except the east and central zones. All other pollutants (NO_x, NO, $PM_{2.5}$, and PM_{10}) increased in all zones. and CO shows a stable concentration in all zones except in the central zone, which shows increasing. In Phase 2, NH_3 concentrations increased in all zones except the north, south, and east zones. NO_x increased in all zones except the west zone, NO_2 increased in all zones except the west zone, and NO increased in all zones except the west and central zones. $PM_{2.5}$ concentrations increased in all zones except the east zone, while PM_{10} increased in all zones except the east, west, and central zones. SO_2 showed an increasing trend in all zones during Phase 2. and CO showed stable concentration in all zones except in the south zone, which showed an increase. When analyzed on a zone basis, the north, south, and west zones showed the most significant increasing trends for all pollutants in Phase 1, while the north and south zones experienced the highest increasing trends in Phase 2 except NH_3. The east zone demonstrated the most consistent decreasing trends in Phase 1. and the west zone in Phase 2. Therefore, the increase in the north zone is due to the high density of industrial activities in Bawana, Narela, and Wazirpur, combined with significant commercial activities in Chandni Chowk and ITO, and heavy residential emissions. Moreover, the increasing $PM_{2.5}$ in the north zone may be due to industrial clusters and anthropogenic emission sources like automobiles, road dust, open/garbage burning, hotels/restaurants, eateries, factories, and home cooking. Furthermore, after comparing pollutants with the National Ambient Air Quality Standards (NAAQS), it was observed that $PM_{2.5}$ and PM_{10} consistently exceeded the limits across all zones and stages from pre-GRAP to post-GRAP in both Phase 1 and Phase 2. Conversely, NH_3, O_3, and SO_2 remained within acceptable limits across all zones and stages during both phases. CO remained within acceptable limits in all zones and stages, except for the central zone in Phase 1 and the south zone in Phase 2, where concentrations exceeded the acceptable limits. However, NO_x, NO_2, and NO exhibited fluctuating concentrations across zones and stages, alternating between acceptable and exceeding levels of the NAAQS standard. the no change of most pollutant concentrations before and after GRAP means that the GRAP implementation needs more measures to be more effective in combating air pollution. The study recommends enhancing GRAP measures mentioned in (Table.5.1), particularly targeting high-emission zones like North and South Delhi, and incorporating additional interventions to ensure more significant reductions in pollutant levels to meet air quality standards.

Table.5.1 The GRAP existing guidelines and suggesting guidelines for improving the effectiveness

Stage	**Existing Guidelines**	**Suggesting Guidelines**
Stage 1	1. Ensure proper implementation of guidelines on dust mitigation measures and sound Environmental Management of Construction and Demolition (C&D) wastes.	1. Stage I of the Graded Response Action Plan (GRAP) can be enhanced to improve air quality in the NCR, by ensuring strict enforcement of dust mitigation measures at construction sites, regular monitoring and compliance checks, and increasing penalties for non-compliance to deter violations.
	2. Stop C&D activities in respect of such projects with plot size equal to or more than 500 sqm which have still not been registered on the 'web portal' of the respective state /GNCTD, for remote monitoring in accordance with Direction Nos. 11-18 dated 11.06.2021 issued by the Commission.	2. Halt all C&D operations for projects with plot sizes exceeding 500 sqm that have not registered on the designated web portal for remote monitoring. This proactive measure aims to curb unmonitored activities contributing to air pollution. Implementing penalties or incentives can further incentivize timely registration and adherence to monitoring protocols, promoting accountability and a healthier environment.
	3. Ensure regular lifting of Municipal Solid Waste (MSW), Construction & Demolition (C&D) waste, and Hazardous wastes from dedicated dump sites and ensure that no waste is dumped illegally on open land.	3. Streamlining C&D waste management, implementing a streamlined process for remote monitoring of construction projects, and enforcing strict regulations for proper containment, covering, and recycling of C&D waste.

	4. Carry out periodic mechanized sweeping and/or water sprinkling on roads and ensure disposal of dust collected in designated sites/landfills.	4. increasing mechanized road cleaning and waste disposal.
	5. Enforce guidelines for the use of anti-smog guns at construction sites.	5. Regular inspections and penalties for non-compliance are essential for strict enforcement of anti-smog regulations. Incentives like tax breaks or subsidies can encourage advanced technologies. Collaboration between government agencies, construction companies, and environmental experts is crucial for developing tailored strategies for specific pollution challenges.
	6. Stringently enforce the prohibition on open burning of biomass and municipal solid waste. Impose a heavy fine upon violation, and Strict vigil to ensure that there is no burning incidents in the landfill sites/dumpsites.	6. Implement strict regulations, local authorities' collaboration, targeted campaigns, technology investment, and environmental partnerships to combat open burning, educate communities, promote sustainable alternatives, and enforce penalties against non-compliant industrial units.
	7. Ensure strict penal/ legal action against non-compliant and illegal industrial units. moreover, ensure that only approved fuel is used by industries and stringent action is taken against violations.	7. Implement a tiered penalty system based on the severity and frequency of violations, with escalating fines, temporary shutdowns, or legal action for repeat offenders.
	8. Ensure that diesel generator sets are not used as a regular source of power supply.	8. advocates for cleaner, more efficient generator technologies, regular maintenance, and incentives for alternative power sources like solar, wind, or natural gas.

	CITIZEN CHARTER**:** Maintain proper engine tuning, tire air pressure, and up-to-date PUC certificates on vehicles. Avoid idling and turning off engines at red lights, Dispose of waste in open spaces, and report air pollution activities using apps like 311, Green Delhi, and SAMEER.	9. promoting public awareness about vehicle maintenance's impact on air quality through campaigns and educational programs. encourages regular engine tuning, tire pressure checks, and PUC certifications. Strict regulations and fines for idling at red lights are also suggested. Responsible waste disposal is encouraged through accessible bins and clean-up drives. Real-time air quality monitoring apps are suggested for prompt action.
Stage 2	1. Mechanical/vacuum-based sweeping of roads to be carried out daily. Moreover, ensure water sprinkling along with the use of dust suppressants (at least every alternate day) on roads to arrest road dust, especially at hotspots, heavy traffic corridors, and vulnerable areas (before peak hours) and proper disposal of dust collected in designated sites/landfills.	1. Stage 2 of the Graded Response Action Plan (GRAP) can be enhanced to improve air quality in the NCR by implementing comprehensive road cleaning strategies, including mechanized road sweeping in high-traffic areas multiple times a day, and a more frequent schedule for water sprinkling and dust suppressants, especially during peak traffic hours.
	2. Regular inspection and strict enforcement of dust control measures at C&D sites.	2. Increasing inspections and imposing stricter penalties for non-compliance at construction and demolition sites.
	3. Do not allow coal/firewood including in Tandoors in Hotels, Restaurants, and open eateries. In addition, ensure hotels, restaurants, and open eateries use only electricity / clean fuel gas-based appliances.	3. Besides encouraging restaurants and hotels to switch to clean cooking fuels, conducting awareness campaigns to discourage coal and firewood use in tandoors, implementing efficient power management through improved grid infrastructure and demand-side techniques, and incentivizing industries to rely more on renewable energy sources during peak pollution periods.

	4. Ensure uninterrupted power supply to discourage the use of Generator sets. additionally, Diesel generators are prohibited except for essential services like medical facilities, elevators, railway services, metro rail stations, airports, sewage treatment plants, water pumping stations, national security activities, defence projects, and telecommunication/data services. Industrial sector-regulated use of DG Sets is permitted due to operational and technical exigencies. No restrictions on CNG, PNG, or LPG-fired generator sets are allowed.	4. Investments in reliable power infrastructure, encouraging cleaner energy sources, imposing strict penalties for unauthorized generator usage, and promoting energy-efficient practices to reduce backup generator needs.
	5. Synchronize traffic movements and deploy adequate personnel at intersections/traffic congestion points for a smooth flow of traffic.	5. Improving traffic management, investing in public transportation infrastructure, and promoting sustainable transportation.
	6. Resident Welfare Associations to provide electric heaters during winter for security staff to avoid open Bio-Mass and MSW burning.	6. Create tailored strategies for specific seasons, like promoting crop residue management during winter to minimize stubble burning, and a robust monitoring and evaluation framework is being established to track the effectiveness of these measures and adapt strategies based on real-time data and stakeholder feedback.
	CITIZEN CHARTER**:** people to use public transport, replace air filters regularly, and avoid dust-generating construction activities from October to January.	7. Creating interactive campaigns to promote public transport benefits, offering incentives for consistent use, and educating citizens on regular air filter replacements. Collaboration with construction companies to implement dust control technologies and schedule non-dust-generating activities during peak pollution months can encourage compliance.

		Regular updates on air quality metrics and their impact can foster a sense of collective responsibility and accountability, using accessible platforms like mobile apps or community newsletters.
Stage 3	1. Further intensify the frequency of mechanized/ vacuum-based sweeping of roads.	1. The Graded Response Action Plan (GRAP) for stage 3 severe air quality in the NCR needs to be improved through strict measures. These include increased road cleaning and dust control, and real-time monitoring of dust levels to ensure timely and effective response in high pollution areas.
	2. Further intensify public transport services. Introduce differential rates to encourage off-peak travel.	2. Furthermore, introduce differential rates to encourage off-peak travel and increase the frequency and capacity of public transport services to accommodate higher demand during pollution episodes.
	3. The National Capital Region (NCR) is imposing a strict ban on construction and demolition activities, except for certain projects such as railway services, metro rail services, airports, national security projects, hospitals, linear public projects, sanitation projects, and ancillary activities. These exemptions are subject to strict compliance with C&D Waste Management Rules and dust prevention/control norms. Other activities banned include earthwork, structural construction, demolition, loading and unloading of materials, raw material transfer, vehicle movement, batching plant operation, sewer line and drainage work, and road construction. Non-polluting activities like plumbing, interior decoration, electrical, and	3. Moreover, enforcing a ban on dust-generating construction and demolition activities ensuring compliance with waste management rules, and monitoring and penalizing violators to deter illegal construction activities.

	carpentry-related works are allowed for all construction projects.	
	4. Industrial operations in areas with PNG infrastructure and supply must be closed or banned for non-fuel-operated industries. For non-PNG areas, industries not using approved fuels must operate for a maximum of five days a week. Paper and pulp processing, distilleries, captive thermal power plants, paddy/rice processing units, textile/garment/address manufacturing, and other industries must remain in operation. Starting January 1, 2023, closures or bans will be enforced nationwide.	4. industries should be regulated based on fuel usage and compliance with the approved fuels list, and operating days should be staggered for non-compliant industries, gradually transitioning toward complete closure.
	5. Close brick kilns, and hot mix plants that are not operating on fuels, as in the standard list of approved fuels for NCR. Close down operations of stone crushers. / Ban / Close down mining and associated activities in the NCR.	5. In addition, implementing strict measures such as closing polluting activities like brick kilns, hot mix plants, stone crushers, and mining, and imposing strict penalties for violations and non-compliance with pollution control norms.
	6. State Governments in NCR/ GNCTD may impose restrictions on BS III petrol and BS IV diesel LMVs (4 wheelers).	6. Additionally, restrictions on older vehicles, promotion of cleaner fuels and vehicles, and incentives for cleaner commuting practices are suggested.
	CITIZEN CHARTER**:** Choose a cleaner commute by sharing rides, using public transport, walking or cycling, or working from home. Avoid using coal and wood for heating, and provide electric heaters	7. Winter-specific measures include promoting electric heaters and collaborating with resident welfare associations. Monitoring mechanisms

	for security staff during winters. Combine errands and walks to reduce trips, and consider using electric heaters for security staff.	should be strengthened through real-time monitoring and legal actions.
Stage 4	1. Close down all industries in NCR, even in areas which do not have PNG infrastructure and supply but still running on fuels, other than the fuels as per the Standard list of approved fuels for NCR. Note: Industries like milk & dairy units and those involved in the manufacturing of life-saving medical equipment/devices, drugs, and medicines shall however be exempted from the above restrictions.	1. Stage 4 of the Graded Response Action Plan (GRAP) can be enhanced to improve air quality in the NCR by regular inspections and audits are conducted to ensure industries that use non-approved fuels are shut down while providing technical and financial support for transitioning to cleaner fuels and technologies.
	2. NCR State Governments / GNCTD to decide on allowing public, municipal, and private offices to work on 50% strength and the rest to work from home.	2. Additionally, implement flexible scheduling and encourage remote work options for non-essential sectors to reduce commuting during peak pollution periods.
	3. The Central Government may make a decision on permitting work from home for the central government offices.	3. Moreover, explores strategies like online education and telecommuting for alternative learning and business continuity to minimize vehicular emissions and outdoor exposure.
	4. State Governments may consider additional emergency measures like closure of schools/ colleges/ educational institutions, closure of non-emergency commercial activities and plying of vehicles on an odd-even basis etc.	4. Besides implement targeted awareness campaigns to educate vulnerable populations about indoor air quality management and health precautions, while also offering accessible resources and support for air purification, respiratory health management, and telemedicine services during air quality crises and establishing a robust monitoring framework to track the effectiveness of GRAP Stage IV measures.

	CITIZEN CHARTER: Children, elderly, and those with respiratory, cardiovascular, cerebrovascular, or other chronic diseases to avoid outdoor activities and stay indoors, as much as possible.	5. Real-time air quality data and health indicators will be used to inform adaptive strategies and policy adjustments for sustained air quality improvement, ensuring public health and safety.

REFERENCES

Agarwal, D., Iyengar, S., & Kumar, P. (2024). PollutionMapper: Identifying Global Air Pollution Sources. *ACM Journal on Computing and Sustainable Societies*, *2*(1), 1–23. https://doi.org/10.1145/3617129

Ashutosh Deshpande, Ashish Tomar, & Akash Pagare. (2024). Quantitative analysis of air pollution levels and its health implications in Delhi-NCR: A longitudinal study. *International Journal of Science and Research Archive*, *11*(2), 759–768. https://doi.org/10.30574/ijsra.2024.11.2.0488

Aswin Giri J, & Shiva Nagendra S M. (2024). Air pollution perception for air quality management: a systematic review exploring research themes and future perspectives. *Environmental Research Letters*, *19*(5), 053002. https://doi.org/10.1088/1748-9326/ad3bd0

Batterman, S., Ganguly, R., & Harbin, P. (2015). High Resolution Spatial and Temporal Mapping of Traffic-Related Air Pollutants. *International Journal of Environmental Research and Public Health*, *12*(4), 3646–3666. https://doi.org/10.3390/ijerph120403646

Bhardawaj, A., & Bhardwaj, Raghav, & Chaudhary, & Anurag. (2022). Design and development of a model policy document for controlling air pollution in Delhi and NCR of India. *25th ETH-Conference on Combustion Generated Nanoparticles*.

Bhardawaj, Avdesh, & Chaudhary, Anurag, & Bhardwaj, & Raghav. (2022). Comparative assessment of indoor and outdoor air quality at a semi-urban site in Delhi for observing seasonal variations and potential health effects. *25th ETH-Conference on Combustion Generated Nanoparticles*.

Chaudhary, A., Prakash, C., Sharma, S. K., Mor, S., Ravindra, K., & Krishnan, P. (2023). Health risk assessment of aerosol particles (PM2.5 and PM10) during winter crop at the agricultural site of Delhi, India. *Environmental Monitoring and Assessment*, *195*(11), 1297. https://doi.org/10.1007/s10661-023-11826-1

Chowdhury, Soumi, & Pohit, Sanjib, & Singh, & Rishabh. (2023). *Health and Economic Impact of Air Pollution in Delhi HEALTH AND ECONOMIC IMPACT OF AIR POLLUTION IN DELHI NCAER Working Paper*.

Commission for Air Quality Management. (2022). *COMMISSION FOR AIR QUALITY MANAGEMENT IN NATIONAL CAPITAL REGION AND ADJOINING AREAS REVISED GRADED RESPONSE ACTION PLAN (GRAP) FOR NCR*.

Dalai, D., Jandrotia, R., Sharma, S., Kanwar, V., & Kaushal, J. (2024). Air pollution trend in Chandigarh during 2019–2022: status and influence of meteorological factors. *Environmental Monitoring and Assessment*, *196*(2), 164. https://doi.org/10.1007/s10661-024-12321-x

European Environment Agency. (2017). *Air pollution from agriculture*.

Ganguly, R., Sharma, D., Kumar, P., & Gurjar, B. R. (2021). Dispersion Modeling of Air Pollutants in a Hilly City in India. *Journal of Hazardous, Toxic, and Radioactive Waste*, *25*(2). https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000574

Ghaida, A., Firdaus, F. M., Qatrunnada, K. M., Peters, D., Cardenas, B., & Lestari, P. (2024). Spatial patterns of PM $_{2.5}$ air pollution in Jakarta: Insights from mobile monitoring. *E3S Web of Conferences*, *485*, 06002. https://doi.org/10.1051/e3sconf/202448506002

Goyal, P., Gulia, S., & Goyal, S. K. (2022). Development of strategic air quality improvement framework for urban hotspots. *Journal of Cleaner Production*, *380*, 134886. https://doi.org/10.1016/j.jclepro.2022.134886

Gulia, S., Goyal, P., & Goyal, S. K. (2024). Estimation of pollutant baseline concentration in Delhi city: An opportunity from coupled effect of rainfall scavenging and lockdown restriction. *Atmospheric Pollution Research*, *15*(5), 102097. https://doi.org/10.1016/j.apr.2024.102097

Gulia, S., Goyal, P., Prakash, M., Goyal, S. K., & Kumar, R. (2021). Policy Interventions and Their Impact on Air Quality in Delhi City — an Analysis of 17 Years of Data. *Water, Air, & Soil Pollution*, *232*(11), 465. https://doi.org/10.1007/s11270-021-05402-x

Gupta, M., Mohan, M., & Bhati, S. (2022). Assessment of Air Pollution Mitigation Measures on Secondary Pollutants PM10 and Ozone Using Chemical Transport Modelling over Megacity Delhi, India. *Urban Science*, *6*(2), 27. https://doi.org/10.3390/urbansci6020027

Guttikunda, S. K., & Gurjar, B. R. (2012). Role of meteorology in seasonality of air pollution in megacity Delhi, India. *Environmental Monitoring and Assessment*, *184*(5), 3199–3211. https://doi.org/10.1007/s10661-011-2182-8

Guttikunda, S. K., & Jawahar, P. (2014). Atmospheric emissions and pollution from the coal-fired thermal power plants in India. *Atmospheric Environment*, *92*, 449–460. https://doi.org/10.1016/j.atmosenv.2014.04.057

Jayachandran, V., & Rao, T. N. (2024). Long-term regional air pollution characteristics in and around Hyderabad, India: Effects of natural and anthropogenic sources. *Atmospheric Environment: X*, *22*, 100254. https://doi.org/10.1016/j.aeaoa.2024.100254

Jha, A. K., Jhamaria, C., Yadav, M., Singh, N. K., Singh, P. K., Jindal, M. K., Mishra, S. K., & Kumar, S. (2023). Temporal Analysis of Atmospheric Pollutant Concentrations with Specific Regard to NAAQS Compliance in an Industrial Cluster of New Delhi, India. *MAPAN*. https://doi.org/10.1007/s12647-023-00688-0

Jha, A. K., Suman, & Mishra, S. K. (2024). Critical Analysis of PM2.5 in Delhi Region to Strategize Effective Air Pollution Management Plan. *Journal of The Institution of Engineers (India): Series A*, *105*(1), 49–59. https://doi.org/10.1007/s40030-023-00777-y

Kalisa, W., Zhang, J., Igbawua, T., Henchiri, M., Mulinga, N., Nibagwire, D., & Umuhoza, M. (2023). Spatial and temporal heterogeneity of air pollution in East Africa. *Science of The Total Environment*, *886*, 163734. https://doi.org/10.1016/j.scitotenv.2023.163734

Kanawade, V. P., Srivastava, A. K., Ram, K., Asmi, E., Vakkari, V., Soni, V. K., Varaprasad, V., & Sarangi, C. (2020). What caused severe air pollution episode of November 2016 in New Delhi? *Atmospheric Environment*, *222*. https://doi.org/10.1016/j.atmosenv.2019.117125

Kaushik, N., & Das, R. M. (2023). Investigation of NOx and related secondary pollutants at Anand Vihar, one of the most polluted area of Delhi. *Urban Climate*, *52*, 101747. https://doi.org/10.1016/j.uclim.2023.101747

Kuttippurath, J., Patel, V. K., Pathak, M., & Singh, A. (2022). Improvements in SO2 pollution in India: role of technology and environmental regulations. *Environmental Science and Pollution Research*, *29*(52), 78637–78649. https://doi.org/10.1007/s11356-022-21319-2

Maknae, C. (2024). The Impacts of Air Pollution on Human Health: A Critical Literature Review. *American Journal of Natural Sciences*, *5*(1), 1–11. https://doi.org/10.47672/ajns.1731

Malhotra, Nitasha, & Sen, & Shyamoli. (2023). *SPATIO-TEMPORAL VARIATION OF AIR POLLUTION IN DELHI -A FOCUS ON RESPIRATORY DISEASES*. *8*(9).

Mark LI, & Léo MALLAT. (2018). Health impacts of air pollution. *SCOR*.

Mishra, M. S. M. K. R. K. (2023). Air quality changes in Delhi due to open waste burning : an accidental fire in Bhalswa landfill. *International Journal of Environmental Science and Technology*, *0123456789*. https://doi.org/10.1007/s13762-023-04921-w

Muhammad Usman, Sohail Amjad, & Asif Khan. (2023). Clearing the Air: Legal Strategies for Combating Smog and Pollution. *Journal of Strategic Policy and Global Affairs*, *04*(01), 15–21. https://doi.org/10.58669/jspga.v04.i01.02

Nassikas, N. J., McCormack, M. C., Ewart, G., Balmes, J. R., Bond, T. C., Brigham, E., Cromar, K., Goldstein, A. H., Hicks, A., Hopke, P. K., Meyer, B., Nazaroff, W. W., Paulin, L. M., Rice, M. B., Thurston, G. D., Turpin, B. J., Vance, M. E., Weschler, C. J., Zhang, J., & Kipen, H. M. (2024). Indoor Air Sources of Outdoor Air Pollution: Health Consequences, Policy, and Recommendations: An Official American Thoracic Society

Workshop Report. *Annals of the American Thoracic Society*, *21*(3), 365–376. https://doi.org/10.1513/AnnalsATS.202312-1067ST

Nirwan, N., Siddiqui, A., Kannemadugu, H. baba shaeb, Chauhan, P., & Singh, R. P. (2024). Determining hotspots of gaseous criteria air pollutants in Delhi airshed and its association with stubble burning. *Scientific Reports*, *14*(1), 986. https://doi.org/10.1038/s41598-023-51140-x

Pandey, A., Brauer, M., Cropper, M. L., Balakrishnan, K., Mathur, P., Dey, S., Turkgulu, B., Kumar, G. A., Khare, M., Beig, G., Gupta, T., Krishnankutty, R. P., Causey, K., Cohen, A. J., Bhargava, S., Aggarwal, A. N., Agrawal, A., Awasthi, S., Bennitt, F., … Dandona, L. (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. *The Lancet Planetary Health*, *5*(1), e25–e38. https://doi.org/10.1016/S2542-5196(20)30298-9

Quintero-Nuñez, M., & Nieblas-Ortiz, E. C. (2008). *Failures and successes in the implementation of an air quality management program in Mexicali, Baja California, Mexico*. 169–178. https://doi.org/10.2495/AIR080181

Ramakrishna.G.N., Qarya Adeeba Noor, Nazneen Mohammed Ismail, Jhanavi V R, & Amal V Thomas. (2023). A STUDY ON STATE WISE AIR POLLUTION WITH REGARD TO PARTICULATE MATTER IN INDIA. *International Journal of Research - GRANTHAALAYAH*, *11*(11). https://doi.org/10.29121/granthaalayah.v11.i11.2023.5390

Ravichandran, S., Singh, R., & Sri, R. M. M. (2021). Air pollution: A major threats to sustainable development. *International Journal of Clinical Biochemistry and Research*, *8*(3), 176–178. https://doi.org/10.18231/j.ijcbr.2021.037

Rong Ge, Yixuan Wang, Zhiyao Xu, Lu Yuan, Jiaxuan Zhu, & Yizhe Su. (2023). Effects of air environmental audit on reducing air pollutant emissions: evidence from China. *Environmental Science and Pollution Research*, *30*(51), 111596–111610. https://doi.org/10.1007/s11356-023-30124-4

Sahu, S. K., Beig, G., & Parkhi, N. S. (2011). Emissions inventory of anthropogenic PM2.5 and PM10 in Delhi during Commonwealth Games 2010. *Atmospheric Environment*, *45*(34), 6180–6190. https://doi.org/10.1016/j.atmosenv.2011.08.014

Sahu, Saroj, & Mangaraj, Poonam, & Beig, & Gufran. (2023). *Decadal Growth in Emission Load of Major Air Pollutants in Delhi*.

Sengupta, A., Govardhan, G., Debnath, S., Yadav, P., Kulkarni, S. H., Parde, A. N., Lonkar, P., Dhangar, N., Gunwani, P., Wagh, S., Nivdange, S., Jena, C., Kumar, R., & Ghude, S. D. (2022). Probing into the wintertime meteorology and particulate matter (PM2.5 and PM10) forecast over Delhi. *Atmospheric Pollution Research*, *13*(6), 101426. https://doi.org/10.1016/j.apr.2022.101426

Sharma, A., Sharma, S. K., & Mandal, T. K. (2021). Ozone sensitivity factor: NOX or NMHCs?: A case study over an urban site in Delhi, India. *Urban Climate*, *39*, 100980. https://doi.org/10.1016/j.uclim.2021.100980

Sharma, G. K., Tewani, A., & Gargava, P. (2022). Comprehensive analysis of ambient air quality during second lockdown in national capital territory of Delhi. *Journal of Hazardous Materials Advances*, *6*, 100078. https://doi.org/10.1016/j.hazadv.2022.100078

Sharma, P., Peshin, S. K., Soni, V. K., Singh, S., Beig, G., & Ghosh, C. (2022). Seasonal dynamics of particulate matter pollution and its dispersion in the city of Delhi, India. *Meteorology and Atmospheric Physics*, *134*(2), 28. https://doi.org/10.1007/s00703-021-00852-8

Sharma, S., & Mathur, S. (2020). *Analyzing the Patterns of Delhi's Air Pollution* (pp. 33–44). https://doi.org/10.1007/978-981-15-0372-6_3

Shivani, Gadi, R., Saxena, M., Sharma, S. K., & Mandal, T. K. (2019). Short-term degradation of air quality during major firework events in Delhi, India. *Meteorology and Atmospheric Physics*, *131*(4), 753–764. https://doi.org/10.1007/s00703-018-0602-9

Singh, D., Gupta, I., & Roy, A. (2023). The association of asthma and air pollution: Evidence from India. *Economics & Human Biology*, *51*, 101278. https://doi.org/10.1016/j.ehb.2023.101278

Sinha, Priyanka, & Singh, Siddhartha, & Saroj, Pooja, & Beig G., & Murthy, & Bs. (2021). *Study of surface ozone (O3) and its relationship with NO, NO2, NOx, OX and CO at five different locations in New Delhi, India from 2013 to 2019*.

Wang, P., Liu, D., Mukherjee, A., Agrawal, M., Zhang, H., Agathokleous, E., Qiao, X., Xu, X., Chen, Y., Wu, T., Zhu, M., Saikawa, E., Agrawal, S. B., & Feng, Z. (2023). Air pollution governance in China and India: Comparison and implications. *Environmental Science & Policy*, *142*, 112–120. https://doi.org/10.1016/j.envsci.2023.02.006

Wu, W. (2023). Is air pollution joint prevention and control effective in China—evidence from "Air Pollution Prevention and Control Action Plan." *Environmental Science and Pollution Research*, *30*(58), 122405–122419. https://doi.org/10.1007/s11356-023-30982-y

Yadav, V., & Ganguly, R. (2023). Assessment of Effect of Vehicular Emissions on Kanpur City Using Vulnerability Analysis. In *Challenges and Advancements in Civil Engineering* (pp. 25–31). Grinrey Publishing. https://doi.org/10.55084/grinrey/ERT/978-81-964105-0-6_3

You, Z., Hou, G., & Wang, M. (2024). Heterogeneous relations among environmental regulation, technological innovation, and environmental pollution. *Heliyon*, *10*(7), e28196. https://doi.org/10.1016/j.heliyon.2024.e28196