DOI: https://doi.org/10.59983/s2024020401
AgroEnvironmental Sustainability, 2024, 2(4), 151-158

RESEARCH

Impact of Metro Construction Activities on Air Quality: A Case Study of Delhi Region in North India

Mukesh Ruhela [1,*], Faheem Ahamad [2,*], Sweta Bhardwaj [1] and Gajendra Singh [1]

[1] Department of Environmental Engineering, Faculty of Engineering and Technology (FET), Swami Vivekanand Subharti University Meerut 250005, India
[2] Limnology and Ecological Modelling Laboratory, Department of Zoology and Environmental Sciences, Gurukul Kangri (Deemed to be University), Haridwar 249404, India
[*] Author(s) responsible for correspondence; Email(s): mruhela@gmail.com (M. R.) and faheem.ahamad170390@gmail.com (F. A.)

ARTICLE HISTORY
Received: 24 August 2024
Revised: 20 October 2024
Accepted: 10 November 2024
Published: 17 December 2024

KEYWORDS
air quality
air quality index
construction activities
megacity

EDITOR
Jogendra Singh

eISSN 2583-942X

Abstract

The current study investigated the concerns about the possible effects of metro infrastructure's fast growth on the environment, particularly air quality. This study investigates how the building of metro lines in Delhi, India, affects the quality of the air at the selected locations in south and west parts of union territory of Delhi. Different air pollutants, including particulate matter (PM_{10}, $PM_{2.5}$), gaseous pollutants like nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), were monitored. Air Quality Index (AQI) was also applied to the obtained data to convert the intricate data into single digits. The findings revealed that the values of PM_{10} and $PM_{2.5}$ were beyond the National Ambient Air Quality Standards (NAAQS) threshold at the proximity of metro work zones due to construction activity. Moreover, higher NO_2 concentrations were noted because of construction machinery operations and vehicle emissions. The study emphasizes the necessity of efficient mitigation solutions, such as green barriers, emission control plans, and dust suppression tactics, to reduce the negative environmental effects of metro development on Delhi's air quality. The results of this study can help urban planners and politicians to create sustainable development plans for transportation infrastructure that protect the environment and public health.

Citation: Ruhela, M., Ahamad, F., Bhardwaj, S., & Singh, G. (2024). Impact of Metro Construction Activities on Air Quality: A Case Study of Delhi Region in North India. *AgroEnvironmental Sustainability*, 2(4), 151-158. https://doi.org/10.59983/s2024020401

Statement of Sustainability: Delhi is the capital and the most populous state (union territory) of India. Besides, the health concern, the air quality of Delhi is also a matter of concern due to tourist places. A lot of studies are available in literature depicting the picture of air quality but very few of them focused on the air quality of areas under ongoing construction activities. Along with different anthropogenic factors, meteorological factors are also responsible for the deterioration of air quality in and around Delhi. Therefore, there is a need for continuous assessment of air quality in Delhi with a special emphasis on those areas where multiple anthropogenic factors are working together.

1. Introduction

The Earth is a special planet with an endless supply of water to support all living forms; its atmosphere provides clean air to maintain the life cycle and has a built-in ozone layer to shield life from UV radiation (Bhutiani et al., 2022; Ruhela et al., 2022a). Its green carpet recycles exhaled carbon dioxide into oxygen, which is necessary for life to exist. Pure air is a fascinating blend of various gases, vapors, and tiny particles (Ahamad et al., 2022). Numerous waste products, especially air pollutants, are produced because of the energy-related activities, discoveries, and uses that have led to urbanization, the green revolution, industrialization, communication, transportation, and pleasant living (Xu et al., 2020; Khajeamiri et al., 2021; Meo et al., 2024). According to Cohen et al. (2017), air pollution is a significant global health concern that has a bigger influence on poor and underdeveloped nations. It also significantly increases the burden of disease and premature death worldwide (Hama et al., 2020). In addition to having a negative impact on health, air pollutants are crucial in regulating regional and global atmospheric chemistry processes. Ultra-fine particulate matter at ground level ($PM_{2.5}$) is a global environmental issue that affects many large cities.

The quality of the air is being negatively impacted by several man-made local emission sources, including suspended dust, biofuel, industrial, and fossil fuel pollutants (Seinfeld and Pandis, 2016; Wang et al., 2018). Since they occur in all major biomes (Kendrova et al., 2016), wildfires and the deliberate burning of biomass are an essential component of Earth's system and are the primary cause of global declines in air quality (Chen et al., 2018; Saxena and Shekhawat, 2017; Soni et al., 2018; Ruhela et al., 2022a; 2022b). In India, air pollution is continuously increasing due to population explosion, industrial areas expansion, increasing number of vehicles on the roads, lack of policies regarding the use and dismantling of old vehicles, and approximately neutral behavior of pollution control bodies towards the controlling strategies (Wang et al., 2020a; 2020b). The continuously increasing air pollution is responsible for six lakh premature deaths annually (Ghude et al., 2016; Hama et al., 2020; WHO, 2024).

Megacity Delhi is one of the most populous cities in the world (Kumar et al., 2015). Delhi is surrounded by several industrial hubs like Gurugram, Manesar, Faridabad, Ghaziabad, and Noida. The climate of the city is semi-arid which also added several factors to the climate of the city. Besides this, stubble burning in winter also affects the air quality of the city very badly. The ongoing construction activities also work as a catalyst for the continuous degrading air quality of the city. The average loss in life expectancy in Delhi is just double the average life expectancy of the rest of the Indian cities (Ghude et al., 2016). Therefore, the present study was taken to assess the air quality of megacity Delhi at the selected sites using the air quality index (AQI). The sites were selected along the metro line construction to accurately establish the relationship between the construction activities and the air quality of the city.

2. Material and Methods

2.1. Study Area

The current study was conducted at the selected sites (Table 1 and Figure 1) in South and West Delhi. The sites were selected along the metro line construction from Chhatarpur station to IGNOU station. Mundka casting yard was also selected as a control site as it is far away from construction activities and other vehicular activities.

Table 1. Selected sites for air quality assessment in Delhi in Northern India.

Sampling Site	Code	Geo-coordinates	Distance
Chhatarpur Station	SS-01	Lat-28.683959, Long-73.03062	0 KM
Chhatarpur Mandir Station	SS-02	Lat-28.501543, Long-77.182695	1.2 KM
Kishangarh Station	SS-03	Lat-28.516195, Long-77.162858	3.1 KM
Casting yard - Masoodpur	SS-04	Lat-28.526607, Long-77.154585	4.3 KM
Neb Sarai Station	SS-05	Lat-28.510325, Long-77.201908	7.0 KM
IGNOU Station	SS-06	Lat-28.501656, Long-77.19748	6.0 KM
Casting Yard Mundka	SS-07	Lat-28.689777, Long-77.027864	38.0 KM

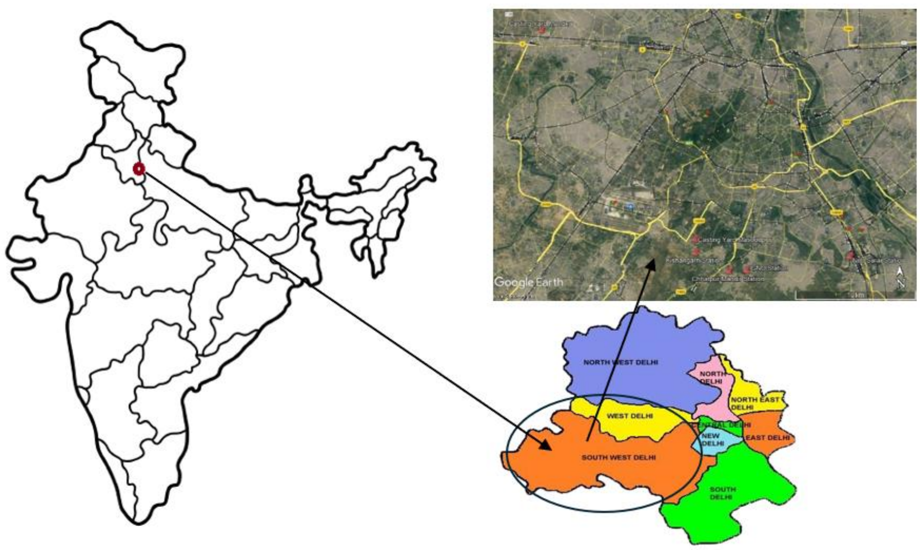

Figure 1. Showing the study area and sampling sites.

2.2. Preparation

Glass fiber filter papers for quantifying the value of PM_{10} were marked for each sampling site and then dried in the oven and then the initial weight was taken using the weighing balance. Similarly, Teflon filter papers for quantifying the value of $PM_{2.5}$ were oven-dried and weighed.

2.3. Sampling and Analysis

Sampling was performed monthly at the selected location of Delhi (Table 1), especially near metro line construction. High volume dust sampler (RDS) was used to monitor the value of PM_{10}, SO_2, and NOx, while the microprocessor-based $PM_{2.5}$ sampler to monitor the value of $PM_{2.5}$ in air. A distinct plastic zip bag was used to contain the particulate matter samples ($PM_{2.5}$ and PM_{10}) that were collected. The gas samples were put into ice cube vials and sealed in PVC bottles.

2.4. Air Quality Index (AQI)

The obtained data on the air quality of different selected sites was processed for the calculation of the air quality index (AQI) using the below-given formula:

$$\text{Air Quality Index (AQI)} = \frac{1}{4} \times \left\{ \left(\frac{\text{PM10}}{\text{PM10(s)}}\right) + \left(\frac{\text{PM2.5}}{\text{PM2.5(s)}}\right) + \left(\frac{\text{SO2}}{\text{SO2(s)}}\right) + \left(\frac{\text{NO2}}{\text{NO2(s)}}\right) \right\} \times 100$$

Where the value with (s) in bracket is the standard value recommended by NAAQ while the rest of the value are obtained value during the study period.

2.5. Statistical Analysis

The raw data obtained after monitoring and analysis was processed using the M.S. Office Excel (2010) to calculate the average value, standard deviation, and AQI of different sites.

3. Results and Discussion

The results of air quality obtained during the study period are shown in Figures 1-4.

3.1. Results of Particulate Matter Pollutants

Formation of particulate matter takes place due to the reactions between the oxides of sulfur, and nitrogen, non-methane volatile organic compounds, and ammonia. Particulate matter consists of both inanimate and animate materials. Breathing air with a high concentration of particulate matter is harmful to the health of human beings as it damages the respiratory system (Sharma et al., 2018). Particulate matter consists of particles having a diameter equal to or less than 10 microns (PM_{10}), and particles having a diameter equal to or less than 2.5 microns ($PM_{2.5}$). The sum of both these particles is known as respirable suspended particulate matter (RSPM). The larger particles having a diameter of more than 10 microns are known as non-respirable suspended particulate matter (NRSPM). The smaller the diameter of the particles, the health threat due to deep penetration in the respiratory system (Bhutiani et al., 2021). In terms of site-by-site comparison, the lowest PM_{10} values were recorded at SS-01 (115.7 μg/m^3±36.0) while the highest (131.50 μg/m^3±48.7) at SS-06, and the average value was recorded 110.50 μg/m^3±29.20. PM_{10} levels were found to be higher than the NAAQ threshold (100 μg/m^3) at all the selected locations.

In comparison to coarser particles (PM_{10}), the tiny particles ($PM_{2.5}$) are more harmful to the health of living beings as they penetrate deeper into the breathing system and affect the secondary and terminal bronchial area passage and more fine particles (<1μm) penetrates bronchioles and alveolar section. Therefore, the assessment and predictions of different sizes of fine particulate matter are a matter of serious concern (Xu et al., 2020). In a site-by-site analysis, SS-06 had the lowest $PM_{2.5}$ values (66.1 μg/m^3±15.0) while SS-02 had the highest value (81.60 μg/m^3±29.1) and 69.10 μg/m^3±17.09 was the average. Pope III et al. (2015) noted a somewhat comparable outcome. The NAAQ level, which is 60μg/m^3, was exceeded by $PM_{2.5}$ readings at every location. Cusworth et al. (2020) reported the burning of agricultural residues responsible for high pollution levels in Delhi. A similar opinion was also given by Talukdar et al. (2021). Hama et al. (2020) reviewed the four years of air quality data of Delhi and other nearby areas and observed a very high value of PM. The authors declare that high particulate matter in Delhi may be due to biomass burning, ongoing construction activities, a high number of vehicles on the roads which result in fossil fuel burning and dust emissions (Saxena et al., 2017; Hama et al., 2020). The dust emissions from excavation, earthmoving, and material transportation operations were the reason for the noticeably increased PM levels during the building phases.

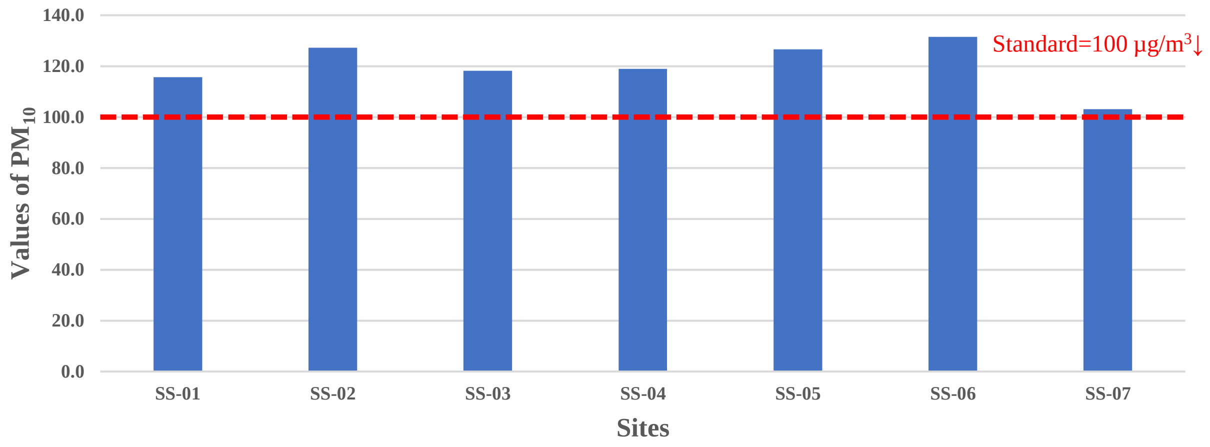

Figure 1. Variation in the values of PM_{10} at all the selected sites.

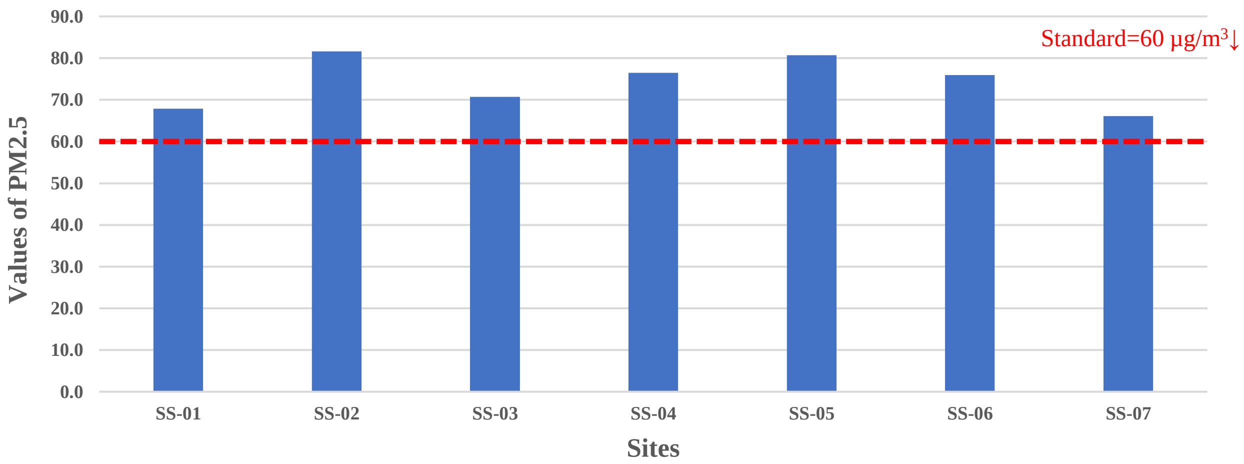

Figure 2. Variation in the values of $PM_{2.5}$ at all the selected sites.

3.2. Results of Gaseous Pollutants

Nitric oxide (NO) and nitrogen dioxide (NO_2) are the common names for oxides of nitrogen, which are produced by both natural and anthropogenic sources, including lightning and soil microbiological processes, thermal power plants, burning of fossil fuels, and transportation (WHO, 2003; Hajat et al., 2013; Cohen et al., 2018). An example of an anthropogenic source is the combustion of fossil fuels. Numerous research projects on NO_2 emissions have found that they have a major impact on Earth's tropospheric chemical processes (USEPA, 2008; Choo et al., 2020). Comparing sites, the lowest NO_2 values (15.30 μg/m^3±5.50) were found at SS-03, the highest value (18.30 μg/m^3±7.3) was found at SS-05, and the average value was found to be 16.6μg/m^3±1.03.

These findings make it evident that the transportation and industrial sectors are the main sources of nitrogen emissions, with residential areas having a less significant role. Wintertime had the highest levels because of the reduced NO_2 conversion and temperature inversion. Saxena and Shekhawat (2017) found a roughly identical result. The values of NO_2 obtained at all the sites were below the NAAQ threshold (80 μg/m^3). When comparing sites, the lowest SO_2 values (18.0 μg/m^3±2.5) were discovered at SS-02, the highest value (19.4 μg/m^3±4.4) was discovered at SS-07, and the average value was determined to be 18.7 μg/m^3±0.61. Every measurement was discovered to be below the NAAQ threshold (80 μg/m^3). Several researchers concluded that the transport sector, power sector, and fossil fuel combustion in industrial and domestic sectors are the main causes of gaseous emissions in the air (Tyagi et al., 2016; Ruhela et al., 2022a; 2022b).

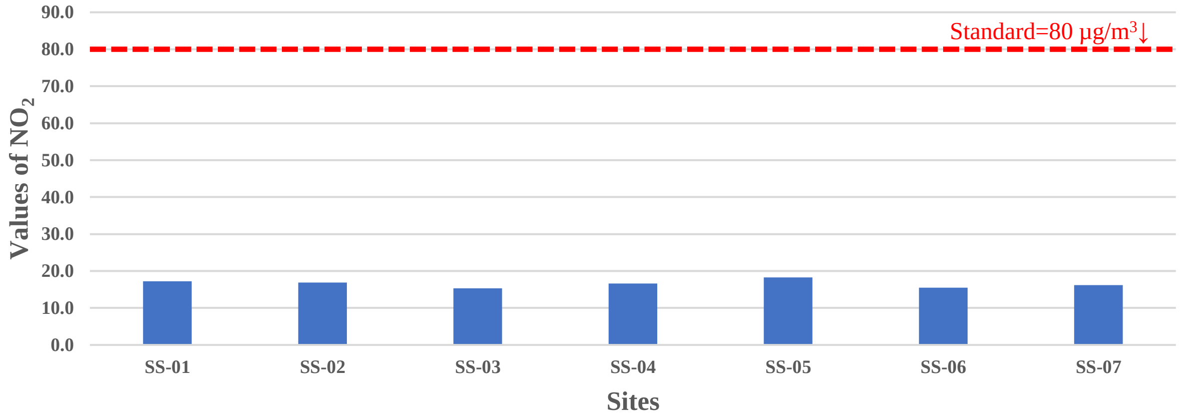

Figure 3. Variation in the values of NO_2 at all the selected sites.

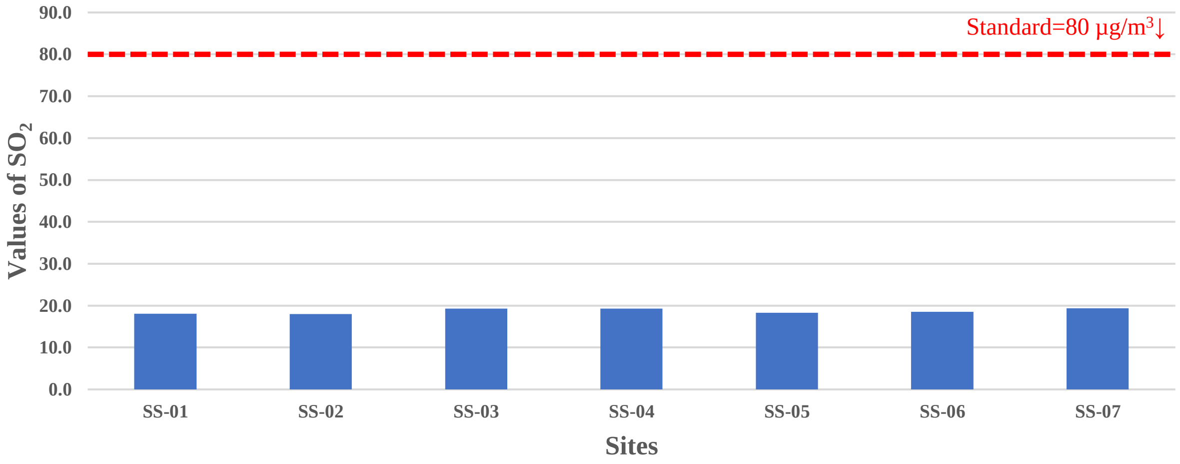

Figure 4. Variation in the values of SO_2 at all the selected sites.

3.3. Results of Air Quality Index (AQI)

The Air Quality Index (AQI) is a tool that is used by different agencies to make air quality easy to understand by the common public (Ahamad et al., 2022). The parameter that was shown to have the greatest Si value was designated as the criterion pollutant for that site. The higher the AQI number, the worse the effects will be on the health of plants and animals as well as property damage. Figure 5 illustrates the findings. According to Rao and Rao (1986), air quality is classified into five groups based on AQI values clean air (0-25), light air pollution (26-50), moderate air pollution (51-75), heavy air pollution (76-100), severe air pollution (>100). The site and parameter-specific Air Quality Index (AQI) was computed. Sub index (Si) of all the parameters of concern was determined to be 1.20, 1.24, 0.21, and 0.23 for PM_{10}, $PM_{2.5}$, NO_2, and SO_2, respectively, when results were compared parameter-by-parameter. 2.88 was determined to be the total sub-index. $PM_{2.5}$ is regarded as a criterion pollutant in Delhi among all the parameters examined based on the Si value. The parameter that is least worrying is NO_2 since it has the lowest Si value out of all the parameters that have been investigated. Based on a comparison of site-wise data, SS-02 was found to have the highest AQI value out of all the investigated sites, making it the most contaminated site, while SS-07 was found to be the least polluted. Air quality at all the selected sites during the study period falls from moderate to heavy air pollution. The air quality at the casting yard site was found to be the least polluted, showing that although construction activities are contributing to air pollution, the contribution of pollutants released from fuel burning in the transport sector is highest. Air quality of Delhi is a matter of concern for Delhi Municipal Corporation as none of the sites were found to fall within the clean air class. During the whole research period, PM_{10} and $PM_{2.5}$ values were found to be above the standard limit at every location.

Although NO_2 and SO_2 levels were determined to be under the standard limits, if all operations at the sites carry on as they did throughout the research period, NO_2 and SO_2 levels will eventually surpass the NAAQS standard limits.

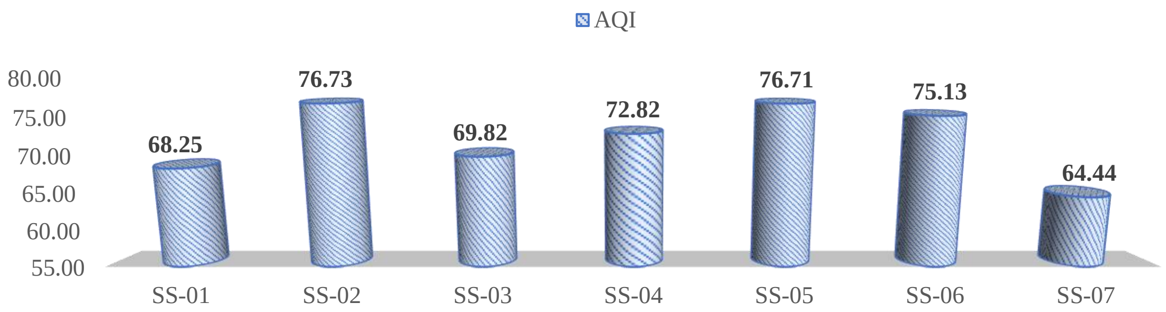

Figure 5. Showing the comparison of AQI of all the sites.

4. Conclusion

Assessment of air quality was carried out at the selected sites along the Metro line construction in Delhi starting from Chhatarpur to IGNOU station. The data obtained was processed to calculate the AQI to rank the sites according to pollution levels and to make the data more accessible to the public. Throughout the investigation, concentrations of $PM_{2.5}$ and PM_{10} were found to be higher than the recommended NAAQ levels at every location. Out of all the selected locations, SS-02 was found to be the most polluted, while SS-07 was found to be the least polluted. Because the sub-index (Si) of $PM_{2.5}$ was found to be the greatest across all locations, it was determined to be the criterion pollutant among all the metrics. The sub-index (Si) of NO_2 was determined to be the lowest of all the metrics that were examined. Based on the AQI, the overall quality of the tested region was determined to be moderate to heavily polluted.

Author Contributions: Conceptualization: Mukesh Ruhela; Data curation: Gajendra Singh; Investigation: Gajendra Singh; Methodology: Faheem Ahamad; Supervision: Mukesh Ruhela; Validation: Faheem Ahamad; Visualization: Sweta Bhardwaj; Writing – original draft preparation: Gajendra Singh, Faheem Ahamad; Writing – review & editing: Mukesh Ruhela, Faheem Ahamad. All authors have read and agreed to the published version of the manuscript.

Funding: This study did not receive project funding or external financial support.

Acknowledgment: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Institutional/Ethical Approval: Not applicable.

Data Availability/Sharing: The authors confirm that the data supporting the findings of this study are available within the article (and/or) its supplementary materials.

Supplementary Information Availability: Not applicable.

References

Ahamad, F., Bhutiani, R., & Ruhela, M. (2022). Environmental Quality Monitoring Using Environmental Quality Indices (EQI) Geographic Information System (GIS) and Remote Sensing: A Review. *GIScience for the Sustainable Management of Water Resources*, 331-348. http://doi.org/10.1201/9781003284512-21

Bhutiani, R., Kulkarni, D. B., Khanna, D. R., Tyagi, V., & Ahamad, F. (2021). Spatial and seasonal variations in particulate matter and gaseous pollutants around integrated industrial estate (IIE), SIDCUL, Haridwar: a case study. *Environment, Development and Sustainability*, 23, 15619-15638. http://doi.org/10.1007/s10668-021-01256-9

Chen, S., Guo, C., & Huang, X. (2018). Air pollution, student health, and school absences: evidence from China. *Journal of Environmental Economics and Management,* 92, 465–497. http://doi.org/10.1016/j.jeem.2018.10.002

Choo, G. H., Seo, J., Yoon, J., Kim, D. R., & Lee, D. W. (2020). Analysis of long-term (2005–2018) trends in tropospheric NO2 percentiles over Northeast Asia. *Atmospheric Pollution Research*, 11(8), 1429-1440. http://doi.org/10.1016/j.apr.2020.05.012

Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., & Forouzanfar, M. H. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *The lancet*, 389(10082), 1907-1918. http://doi.org/10.1016/s0140-6736(17)30505-6

Cohen, G., Levy, I., Yuval, Kark, J. D., Levin, N., Witberg, G., & Gerber, Y. (2018). Chronic exposure to traffic-related air pollution and cancer incidence among 10,000 patients undergoing percutaneous coronary interventions: A historical prospective study. *European Journal of Preventive Cardiology*, 25(6), 659-670. http://doi.org/10.1177/2047487318760892

Cusworth, D. H., Mickley, L. J., Sulprizio, M. P., Liu, T., Marlier, M. E., DeFries, R. S., & Gupta, P. (2018). Quantifying the influence of agricultural fires in northwest India on urban air pollution in Delhi, India. *Environmental Research Letters*, 13(4), 044018. http://doi.org/10.1088/1748-9326/aab303

Ghude, S. D., Chate, D. M., Jena, C., Beig, G., Kumar, R., Barth, M. C., & Pithani, P. (2016). Premature mortality in India due to PM2. 5 and ozone exposure. *Geophysical Research Letters*, 43(9), 4650-4658. http://doi.org/10.1002/2016gl068949

Hajat, A., Diez-Roux, A. V., Adar, S. D., Auchincloss, A. H., Lovasi, G. S., O'Neill, M. S., & Kaufman, J. D. (2013). Air pollution and individual and neighborhood socioeconomic status: evidence from the Multi-Ethnic Study of Atherosclerosis (MESA). *Environmental health perspectives*, *121*(11-12), 1325-1333. http://doi.org/10.1289/ehp.1206337

Hama, S. M., Kumar, P., Harrison, R. M., Bloss, W. J., Khare, M., Mishra, S., & Sharma, C. (2020). Four-year assessment of ambient particulate matter and trace gases in the Delhi-NCR region of India. *Sustainable Cities and Society*, 54, 102003. http://doi.org/10.1016/j.scs.2019.102003

J. H., & Pandis, S. N. (2016). Atmospheric Chemistry and Physics: from air pollution to climate change, second ed. John Wiley & Sons.

Kendrova, L., Takac, P., Kubincova, A., Mikulakova, W., & Nechvatal, P. (2016). Effect of spa treatment and speleotherapy in the treatment of chronic obstructive pulmonary disease – a pilot study. *Clinical Social Work and Health Intervention*, 7(2), 7–15. http://doi.org/10.22359/cswhi_7_2_01

Khajeamiri, Y., Sharifi, S., Moradpour, N., & Khajeamiri, A. (2021). A review on the effect of air pollution and exposure to PM, NO2, O3, SO2, CO and heavy metals on viral respiratory infections. *Journal of Air Pollution and Health*, 5(4), 6445. http://doi.org/10.18502/japh.v5i4.6445

Kumar, P., Khare, M., Harrison, R., Bloss, W., Lewis, A., Coe, H., & Morawska, L. (2015). New directions: air pollution challenges for developing megacities like Delhi. *Atmospheric Environment*, 122, 657-661. http://doi.org/10.1016/j.atmosenv.2015.10.032

Meo, S. A., Salih, M. A., Alkhalifah, J. M., Alsomali, A. H., & Almushawah, A. A. (2024). Environmental pollutants particulate matter (PM2. 5, PM10), Carbon Monoxide (CO), Nitrogen dioxide (NO2), Sulfur dioxide (SO2), and Ozone (O3) impact on lung functions. *Journal of King Saud University-Science*, 103280. http://doi.org/10.1016/j.jksus.2024.103280

Pope III, C. A., Cropper, M., Coggins, J., & Cohen, A. (2015). Health benefits of air pollution abatement policy: Role of the shape of the concentration–response function. *Journal of the Air & Waste Management Association*, 65(5), 516-522. http://doi.org/10.1080/10962247.2014.993004

Rao, M. N., & Rao, H. V. N. (1986). Air pollution, TATA Mc GrawHill publishing company, New Delhi.

Ruhela, M., Maheshwari, V., Ahamad, F., & Kamboj, V. (2022a). Air quality assessment of Jaipur city Rajasthan after the COVID-19 lockdown. *Spatial Information Research*, 30(5), 597-605. http://doi.org/10.1007/s41324-022-00456-3

Ruhela, M., Sharma, K., Bhutiani, R., Chandniha, S. K., Kumar, V., Tyagi, K., & Tyagi, I. (2022b). GIS-based impact assessment and spatial distribution of air and water pollutants in mining area. *Environmental Science and Pollution Research*, 1-15. http://doi.org/10.1007/s11356-021-18009-w

Saxena, A. and Shekhawat, S. (2017). Ambient Air Quality Classification by Grey Wolf Optimizer Based Support Vector Machine. *Journal of Environmental and Public Health*, 3131083, 12. http://doi.org/10.1155/2017/3131083

Saxena, M., Sharma, A., Sen, A., Saxena, P., Mandal, T. K., Sharma, S. K., & Sharma, C. (2017). Water soluble inorganic species of PM10 and PM2. 5 at an urban site of Delhi, India: seasonal variability and sources. *Atmospheric Research*, 184, 112-125. http://doi.org/10.1016/j.atmosres.2016.10.005

Sharma, A. K., Baliyan, P., & Kumar, P. (2018). Air pollution and public health: the challenges for Delhi, India. *Reviews on Environmental Health*, 33(1), 77-86. http://doi.org/10.1515/reveh-2017-0032

Soni, M., Payraa, S., & Verma, S. (2018). Particulate matter estimation over a semi arid region Jaipur, India using satellite AOD and meteorological parameters, *Atmospheric Pollution Research*, 3, 1-10. http://doi.org/10.1016/j.apr.2018.03.001

Talukdar, S., Tripathi, S. N., Lalchandani, V., Rupakheti, M., Bhowmik, H. S., Shukla, A. K., & Sahu, L. (2021). Air pollution in new delhi during late winter: An overview of a group of campaign studies focusing on composition and sources. *Atmosphere*, 12(11), 1432. http://dx.doi.org/10.3390/atmos12111432

Tyagi, S., Tiwari, S., Mishra, A., Hopke, P. K., Attri, S. D., Srivastava, A. K., & Bisht, D. S. (2016). Spatial variability of concentrations of gaseous pollutants across the National Capital Region of Delhi, India. *Atmospheric Pollution Research*, 7(5), 808-816. http://doi.org/10.1016/j.apr.2016.04.008

USEPA, (2008). Integrated Science Assessment for Oxides of Nitrogen-Health Criteria. U.S. Environmental Protection Agency, 2008.

Wang, C., Sun, Z., & Ye, Z. (2020a). On-road bus emission comparison for diverse locations and fuel types in real-world operation conditions. *Sustainability,* 12*,* 1798. http://doi.org/10.3390/su12051798

Wang, Y., Liu, P., Xu, C., Peng, C., & Wu, J. (2020b). A deep learning approach to real-time CO concentration prediction at signalized intersection. *Atmospheric Pollution Research*, 11(8), 1370-1378. http://doi.org/10.1016/j.apr.2020.05.007

Wang, Z., Zhong, S., Peng, Z. R., & Cai, M. (2018). Fine-scale variations in PM2. 5 and black carbon concentrations and corresponding influential factors at an urban road intersection. *Building and Environment*, 141, 215-225. http://doi.org/10.1016/j.buildenv.2018.04.042

WHO (World Health Organization), (2003). Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide, Bonn, Germany.

World Health Organization (WHO). Air Quality, Energy, and Health. Available online: https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/types-of-pollutants (accessed 12 February 2024).

Xu, X., Tong, T., Zhang, W., & Meng, L. (2020). Fine-grained prediction of PM2. 5 concentration based on multisource data and deep learning. *Atmospheric Pollution Research*, 11(10), 1728-1737. http://doi.org/10.1016/j.apr.2020.06.032