Spatio-Temporal Monitoring and Assessment of Air Quality and its Impact on Public Health from Geospatial perspective over Haryana, India

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Abstract

This study aims to evaluate the air quality of the Haryana state, India by utilizing Sentinel-5P satellite data. This study aims to track, quantify, and analyze the level of air pollutants in several regions of Haryana. By integrating and analyzing diverse satellite datasets, the study provides a comprehensive understanding of air quality conditions in the region and supports informed decision-making for pollution mitigation and environmental sustainability. This also examines the public health and environmental impacts of air pollution, identifies pollution sources, reviews existing policies, and also provides recommendations for prevention of air pollution. The outcomes of this study will improve the understanding of air quality dynamics in Haryana and provide preventive measures towards sustainable environmental practices. This paper presents a detailed assessment of air quality in Haryana, India, covering the period from 2019 to 2023 using satellite datasets. This evaluates the concentrations and spatial distributions of air pollutants across Haryana. The experimental results provide significant variations in pollution levels over the four years, with higher concentrations in 2019 and 2021, and lower levels in 2020 and 2023. Moreover, spatial distribution maps illustrate pollutant patterns, emphasizing the temporal and spatial changes in pollution levels. The results also highlight the ongoing challenge of increasing pollution in certain areas of Haryana and the need for continuous monitoring to improve air quality.

1. Introduction

Climate change is primarily triggered by airborne pollutants, particularly greenhouse gases such as methane and carbon dioxide. Quantifying these emissions using Sentinel-5P satellite data can thus improve inputs for climate change detection models and mitigation efforts (Sharma et al. 2017; Chawala and Sandhu 2020). This information can aid in the formulation of specific objectives to obtain zero carbon emissions which can be considered as an essential element in preventing climate change and also to a worldwide awareness of sources of pollution (Badarinath et al. 2009; Chakrabarti et al. 2019). Therefore, air pollution is a major global concern and has adverse effects on societal well-being, environmental integrity, and human health. Air quality assessments are important to determine the pollution levels and analysing their effect on various societal components (Arunkumar and Dhanakumar 2021).

The satellite data may help in planning the cities and infrastructure of the cities can be optimized for improved air quality in highly dense areas through land use and land cover classification. This can also help to advise the strategic placement of green spaces in metropolitan areas, which act as the city's "lungs" by absorbing toxins and providing cleaner air (Jain et al. 2014; Jeet et al. 2023).

When harmful substances such as pollutants, airborne particles, and organic compounds reach the climate of the planet, they promote air pollution (Spivakovsky et al. 2000). Notwithstanding the fact that oxygen, argon, nitrogen, and tiny particles are the primary components of the environment, greenhouse gases such as carbon dioxide and methane can always influence climate change in exceptionally small quantities (Weitekamp et al. 2021). All living beings, including individuals, plants, and animals, rely on the preservation of a composition for their continued existence and health (Singh and Panigrahy 2011; Weitekamp et al. 2021). There are numerous sources of air pollution, including gaseous and particulate pollutants. Carbon dioxide, methane, and nitrogen dioxide are among the gases emitted by a variety of sources, including fuel-burning firms and transportation (Maurya et al. 2022; Manjeet et al. 2022). Nanoparticles pollution has a negative impact on air quality and contains materials like smoke and black carbon (Ravindra et al. 2019; Sha et al. 2021). Though pollution in the environment remains an issue, this study is largely concerned with pollution caused by various activities including forest fires, eruptions of volcanoes, and sand or beach erosion. Early civilizations exposed greater numbers of people to air contamination and hazards due to their usage of biomass and fossil fuels for cooking and heating purposes (Arunkumar and Dhanakumar 2021). The analysis of air pollution in Haryana, India, using Sentinel-5P satellite data yields intricate findings that simply discovering toxic substances. It allows for in-depth topographical and temporal analysis, highlighting recurring trends and patterns in contamination levels over time. To effectively execute prevention strategies, it is vital to figure out pollution locations and peak pollution hours (Singh and Panigrahy 2011; Chakrabarti et al. 2019).

Considering the geographical region's growing population and rapid growth in industries, monitoring the air quality in Haryana, India, is very important. As a result of innovations in this field, there are now more emissions emanating from manufacturing plants, automobiles, and other artificially generated emissions, raising pollution levels. Sentinel-5P satellite data provides a precise assessment of the air's cleanliness, important insights into the extent of pollution, which are necessary when designing effective mitigating initiatives (Spivakovsky et al. 2000; Singh and Panigrahy 2011; Chakrabarti et al. 2019).

Furthermore, Sentinel-5P data may possess an enormous effect on establishing policies. The data can be used by authorities to create and reinforce air quality guidelines. This may involve everything from implementing significant limits on emissions for companies and automobiles to provide subsidies for implementing more sustainable procedures and technologies. Practical metrics are more probable to support focused, effective approaches that promote benefits for the planet and the population (Jain et al. 2014; Manjeet et al. 2022).

The objective of this research is to assess the air quality of Haryana using Sentinel-5P satellite data. The satellite provides high-resolution data on numerous atmospheric contaminants, enabling the assessment of substantial air quality indicators such as nitrogen dioxide, carbon dioxide, and particulates. The region's quantitative statistics and pollution maps will be created by analysing satellite data and applying relevant models and techniques. To create specific initiatives that will reduce the adverse impacts of pollutants on people's wellness, productivity in farming, and the ecosystem, it becomes essential to understand Haryana's air quality. The findings of this study will be significant for developing efficient policies and programmes to improve the quality of air and promote sustainable development in Haryana, India.

2. Study Area

Haryana, located in northern India, is a landlocked state bordered by Punjab to the northwest, Himachal Pradesh and Uttarakhand to the north and northeast, Uttar Pradesh and Delhi to the east, and Rajasthan to the south and southwest. Positioned approximately between 27.8954° N latitude and 76.3131° E longitude (Figure 1) (Manjeet et al. 2022; Jeet et al. 2023). Haryana encompasses a variety of geographical landscapes. Chandigarh serves as its capital, while Faridabad is the largest city. The state, established in 1966, covers an area of 44,212 sq.km (1.3% area of the country) having population of over 25 million people (Singh and Panigrahy 2011). As per agroclimatic classification (Weitekamp et al. 2021), the state is divided into two zones. The eastern zone includes districts Panchkula, Ambala, Yamuna Nagar, Kurukshetra, Karnal, Kaithal, Panipat, Sonipat, Faridabad and parts of districts of Jind, Rohtak, Jhajjar and Gurgaon. It covers about 49% of the state's areas, comprising the Gurgaon, Rohtak, Central Plain, and Hill tracts. The Western zone includes the districts of Sirsa, Hisar, Bhiwani, Fatehabad, Mahendragarh, Rewari, Jind, Rohtak, Jhajjar, and Gurgaon (Jain et al. 2014; Sha et al. 2021). The state's air quality varies seasonally from reasonable to severe in different months.

Haryana features a variety of landscapes, including urban centres, fertile plains, mountains, and semiarid plateaus. Analysing Haryana's air quality using data from the Sentinel-5P satellite provides important insights into the state's environmental conditions. This satellite data has been crucial for monitoring and understanding air pollution levels in Haryana, which stem primarily from industrial activities, vehicle emissions, agricultural practices, and urban growth. The Sentinel-5P satellite, equipped with the Tropospheric Monitoring Instrument (TROPOMI), accurately measures key air pollutants such as formaldehyde (HCHO), nitrogen dioxide (NO2), ozone (O3), sulphur dioxide (SO2), carbon monoxide (CO), and aerosol absorbing index (AAI).

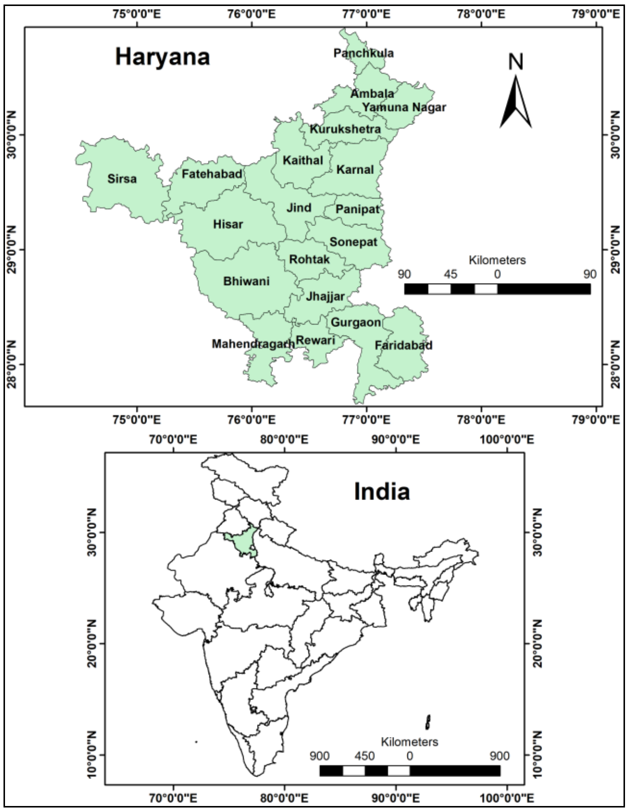

Figure 1. Study Area Map.

3. Data Used and Methodology adopted

In this comprehensive study satellite-based air quality data were used to prepare a spatio-temporal map of Haryana's air quality over the time. Data is provided by European Space agency and accessed via Google Earth Engine (GEE) platform (https://earthengine.google.com/) for computational analysis. GEE is a cloud-based platform designed to monitor and measure environmental changes on a global scale using an extensive database of Earth Observation (EO) data. By leveraging thousands of computers in Google's data centres, the platform offers parallel-computing capabilities. Additionally, GEE provides a new application programming interface (API) available in Python and JavaScript, enabling scientists to access these computational and data resources to develop or enhance their methods. A diverse range of air quality data is used and employed to conduct a thorough assessment of air quality and its impact on health in Haryana, India, using Sentinel-5P satellite data (Table 1).

Table 1. Data used in the study.

Name of the data	Spatial Resolution	Duration	Purpose	Data Source
AAI CO NO2 SO2 CH4 O3 HCHO	1113.2m	Jan 2019-Dec 2023 Jan 2019-Dec 2023	To detect atmospheric pollutants like; Aerosol Absorbi	European Space Agency

			Jan 2019-Dec 2023	ng Index, SO_2, NO_2, CH_4, HCHO, CO, and O_3	
			Jan 2019-Dec 2023		
			Feb 2019-Dec 2023		
			Jan 2019-Dec 2023		
			Jan 2019-Dec 2023		

The Sentinel-5P TROPOMI (Tropospheric Monitoring Instrument) was launched on October 13, 2017 as part of the Copernicus project. This instrument efficiently monitors concentrations of atmospheric pollutants and trace gases such as NO_2, O_3, SO_2, HCHO, CH_4, CO, and the Aerosol Absorbing Index (AAI), all of which result from human activities (Chakrabarti et al. 2019; Chawala and Sandhu 2020). Additionally, TROPOMI enhances the evaluation of aerosols and clouds. The precise air quality data obtained from the Sentinel-5P satellite are essential for evaluating air quality in Haryana. These data help understand the impact of various factors like biomass burning, road dust emissions, and industrial pollution on the region's air quality. These activities emit harmful gases and pollutants, leading to a decline in air quality. Analyzing these data is vital for understanding the extent and nature of these environmental issues in Haryana. By using Sentinel-5P satellite imagery, the study gains significant insights into the concentration and distribution of air pollutants in Haryana. The satellite data offer a comprehensive view of the sources and intensity of pollution, identifying areas with high levels of pollutants. This information is crucial for assessing the effectiveness of pollution control measures and developing targeted interventions to improve air quality.

Sentinel-5P employs the TROPOMI instrument, a multispectral sensor designed to measure atmospheric gas concentrations by recording wavelength reflectance with a spatial resolution of 0.01 arc degree. Data from Sentinel-5P were retrieved for pre-processing where yearly average data is prepared for monitoring purposes, while map generation was performed using SNAP and ArcGIS software.

4. Results and Discussion

Utilizing multiple datasets allowed for a comprehensive assessment of air quality by considering the contributions of various pollutants. This method offered valuable insights for policymakers, researchers, and stakeholders working to address air pollution and formulate strategies to improve air quality in Haryana. The integration and analysis of these diverse datasets provided a thorough understanding of the region's air quality conditions. This supported informed decision-making processes aimed at reducing pollution and promoting environmental sustainability.

4.1 CO (Carbon Monoxide) concentration over Haryana

The Carbon Monoxide Product is utilized to estimate the total column required for determining background CO levels and surface reflection. Carbon monoxide (CO) is a significant atmospheric trace gas crucial for understanding tropospheric chemistry and is a major pollutant in some urban areas. The main sources of CO include fossil fuel combustion, biomass burning, and the atmospheric oxidation of methane and other hydrocarbons.

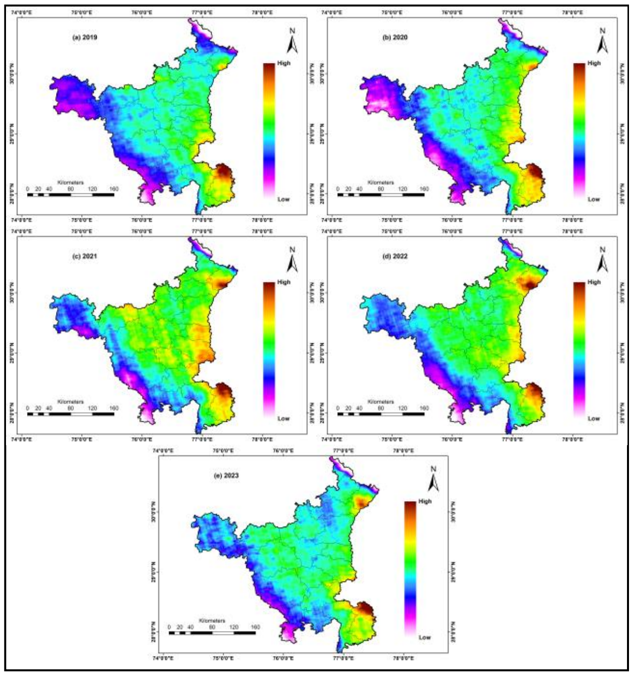

Figure 2. Yearly average of Carbon Monoxide (CO) concentration over study region during Jan 19 – Dec 23, where (a) 2019, (b) 2020, (c) 2021, (d) 2022, and (e) 2023.

Sentinel-5P provides the CO concentrations ranging from a minimum of 0.031 to a maximum reported value of 0.034 over the study region during Jan 2019 to Dec 2023 (Figure 2). The results showed that the maximum concentrations were seen over the northern region of Faridabad, eastern region of Panipat, Sonipat, Jhajjar, and southern region of Yamuna Nagar district. Figure 2 also illustrates that southern part of the state depicts lower CO concentration includes southern part of Sirsa, Hisar, Bhiwani, and Mahendragarh district.

The average value of CO concentration in the study area was found to be 0.037, 0.038, 0.038, 0.036, and 0.037 for the years 2019, 2020, 2021, 2022 and 2023, respectively. The results concluded that CO concentrations were found to be slightly lower in the year 2020 which increased by the next year in 2021. This results to put more areas of the state under moderate to higher concentration level of CO (Figure 2).

4.2 Aerosol Absorbing Index (AAI) concentration over Haryana

The Aerosol Absorbing Index Product offered by S5P TROPOMI is a qualitative indicator used to gauge the presence of aerosols with significant absorption capacity. Positive values of the Aerosol Index indicate the presence of absorbing aerosols such as dust and smoke, whereas small or negative values indicate non-absorbing aerosols and clouds.

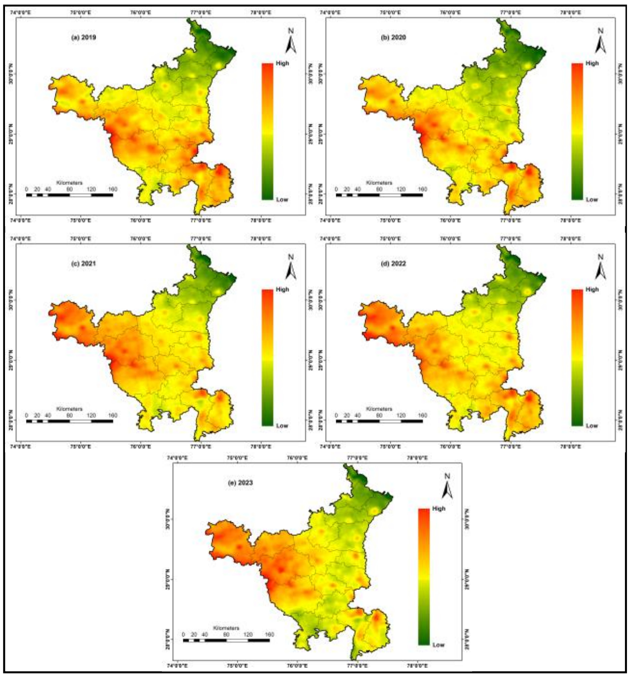

Figure 3. Yearly average of AAI (Aerosol Absorbing Index) concentration over study region during Jan 19 – Dec 23, where (a) 2019, (b) 2020, (c) 2021, (d) 2022, and (e) 2023.

AAI concentrations ranging from a minimum of -1.1 to a maximum reported value of 0.5 over the study region during Jan 2019 to Dec 2023 (Figure 3). The results showed that the maximum concentrations were seen over the western, south-eastern, and central region of Haryana during 2019-2023. The districts which were highly affected are Hisar, Bhiwani, Gurgaon, Faridabad, Fatehabad followed by Sirsa. Figure 3 also illustrates that north-eastern part of the state depicts satisfying AAI concentration includes Panchkula, Ambala, Yamuna Nagar, and Kurukshetra district.

The average value of AAI concentration in the study area was found to be -0.082, -1.014, -0.048, 0.012, and -0.032 for the years 2019, 2020, 2021, 2022 and 2023, respectively. The results revealed that AAI concentrations were found to be constantly higher in Sirsa district which makes it more prone towards AAI concentration. However, over Panchkula, Ambala, and Yamuna Nagar it is constantly at lower side (Figure 3).

4.3 Methane (CH4) concentration over Haryana

Methane (CH4) is the second-largest contributor to greenhouse gases (GHGs) from human activities after carbon dioxide (CO2), significantly impacting global warming. Approximately 75% of CH4 emissions are anthropogenic, making continuous satellite-based monitoring crucial. The TROPOMI instrument is designed to measure CH4 column concentrations with high sensitivity to surface readings, offering excellent spatiotemporal coverage and accuracy to support the inverse modelling of methane sources and sinks.

CH4 concentrations ranging from a minimum of 1808.64 to a maximum reported value of 1943.22 over the study region during Jan 2019 to Dec 2023 (Figure 4).

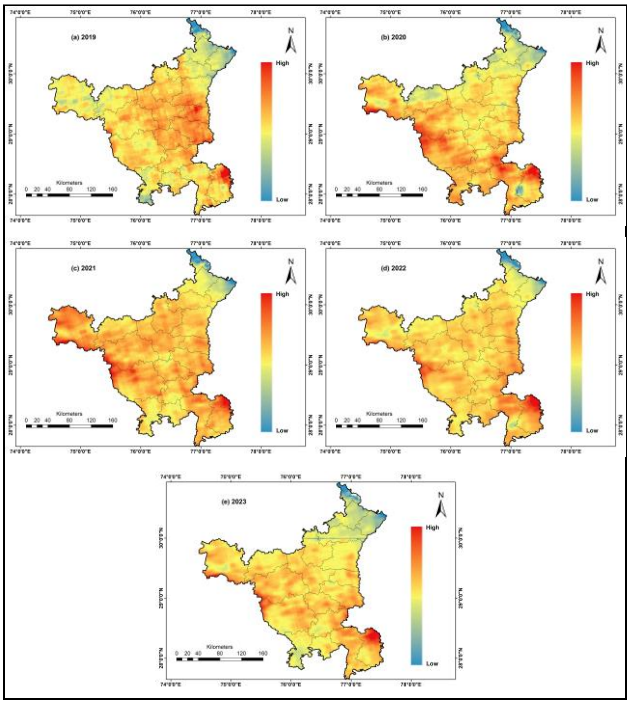

Figure 4. Yearly average of Methane (CH4) concentration over study region during Jan 19 – Dec 23, where (a) 2019, (b) 2020, (c) 2021, (d) 2022, and (e) 2023.

The results showed that the maximum concentrations were seen over western and central region of Haryana during 2019-2023. The districts over which the concentration was centred are the northern part of Faridabad, Panipat, Sonipat, and southernmost part of Hisar and Bhiwani. Figure 4 also illustrates that north-eastern part of the state depicts satisfying CH4 concentration includes Panchkula, Ambala, Yamuna Nagar, and Kurukshetra district.

The average value of AAI concentration in the study area was found to be 1888, 1902, 1906, 1906.7, and 1917 for the years 2019, 2020, 2021, 2022 and 2023, respectively. The results revealed that CH4 concentrations were found to be constantly higher over Faridabad and Gurgaon districts which makes it more prone. However, over Panchkula, Ambala, and Yamuna Nagar it is constantly at lower side (Figure 4).

4.4 Formaldehyde (HCHO) Concentration over Haryana

Formaldehyde is a notable contributor to air pollution due to its potential conversion into carbon dioxide (CO2) over prolonged periods in the atmosphere. Its emissions not only exacerbate pollution but also worsen the global warming problem, a pressing issue on a global scale. People are generally exposed to surface concentrations of HCHO, which are directly related to health risks.

HCHO concentrations ranging from a minimum of 0.000141896 to a maximum reported value of 0.000272522 over the study region during Jan 2019 to Dec 2023 (Figure 5). The results showed that the maximum concentrations were seen over eastern, south eastern and north-eastern parts of the

Haryana during 2019-2023. The districts over which higher concentration found are the eastern part of Faridabad, Gurgaon, Jhajjar, Karnal Sonipat, and Yamuna Nagar. Figure 5 also illustrates that central, western, and southern part of the state depicts satisfying HCHO concentration includes Sirsa, Fatehabad, Hisar, Bhiwani, Mahendragarh, and Rewari district.

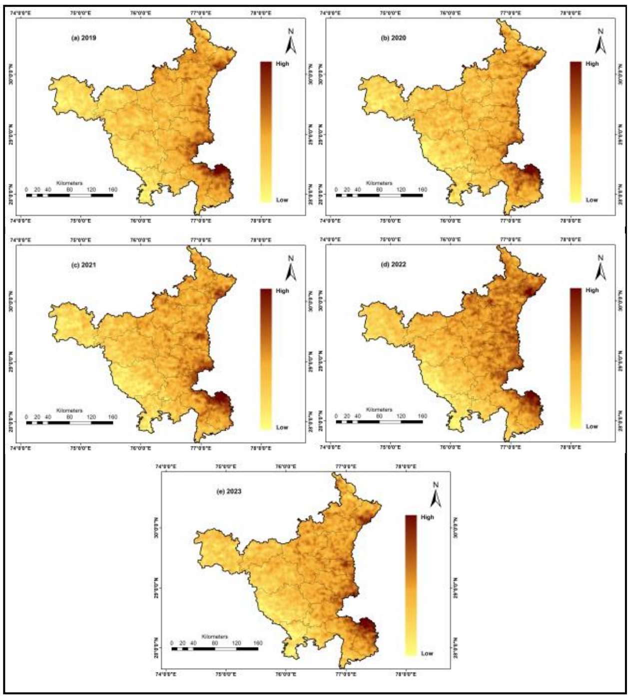

Figure 5. Yearly average of Formaldehyde (HCHO) concentration over study region during Jan 19 – Dec 23, where (a) 2019, (b) 2020, (c) 2021, (d) 2022, and (e) 2023.

The average value of HCHO concentration in the study area was found to be 0.000194773, 0.000195287, 0.000187487, 0.000188595, and 0.000192046 for the years 2019, 2020, 2021, 2022 and 2023, respectively. The results revealed that HCHO concentrations were found to be constantly higher over Faridabad and Gurgaon districts which makes it more prone. However, over Hisar, Bhiwani, and Mahendragarh it is constantly at lower side (Figure 5).

4.5 Sulfur dioxide (SO_2) Concentration over Haryana

Sulfur dioxide (SO2) is introduced into the Earth's atmosphere via both natural occurrences and human activities. It participates in chemical processes locally and globally, with its effects spanning from short-term pollution to influences on the climate. Over time, there has been a noticeable increase in sulfur dioxide (SO2) emissions in Haryana. Potential sources of these emissions encompass electroplating facilities, small smoke-emitting industrial chimneys, and notably, older vehicles, particularly those exceeding a decade in age, emerge as the primary contributors. These aged vehicles significantly elevate SO2 concentration levels.

SO2 concentrations ranging from a minimum of -8.78601e-006 to a maximum reported value of 0.000471398 over the study region during Jan 2019 to Dec 2023 (Figure 6). The results showed that the maximum concentrations were seen over eastern and north-eastern parts of the Haryana. The districts over which higher concentration were found are Panchkula, Ambala, Jhajjar, Panipat, Sonipat, and Yamuna Nagar. Figure 6 also illustrates that western, and south-western part of the state depicts satisfying SO2 concentration includes Sirsa, Fatehabad, Hisar, Bhiwani, Mahendragarh, and Rewari district.

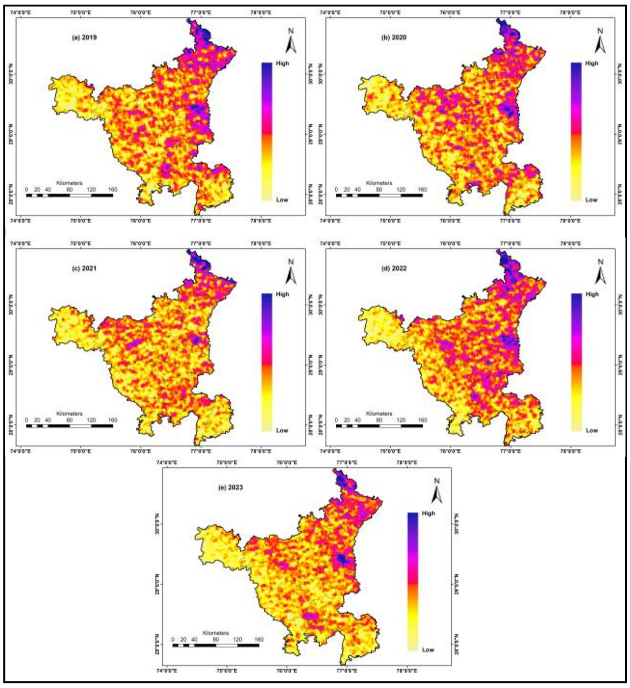

Figure 6. Yearly average of Sulfur dioxide (SO_2) concentration over study region during Jan 19 – Dec 23, where (a) 2019, (b) 2020, (c) 2021, (d) 2022, and (e) 2023.

The average value of SO2 concentration in the study area was found to be 0.000124576, 0.000150882, 0.000135666, 0.000158881, and 0.000167258 for the years 2019, 2020, 2021, 2022 and 2023, respectively. The results revealed that SO2 concentrations were found to be constantly higher over the Panchkula district which makes more prone. However, over Hisar, Bhiwani, and Mahendragarh it is constantly at lower side (Figure 6).

4.6 Nitrogen Dioxide (NO2) Concentration over Haryana

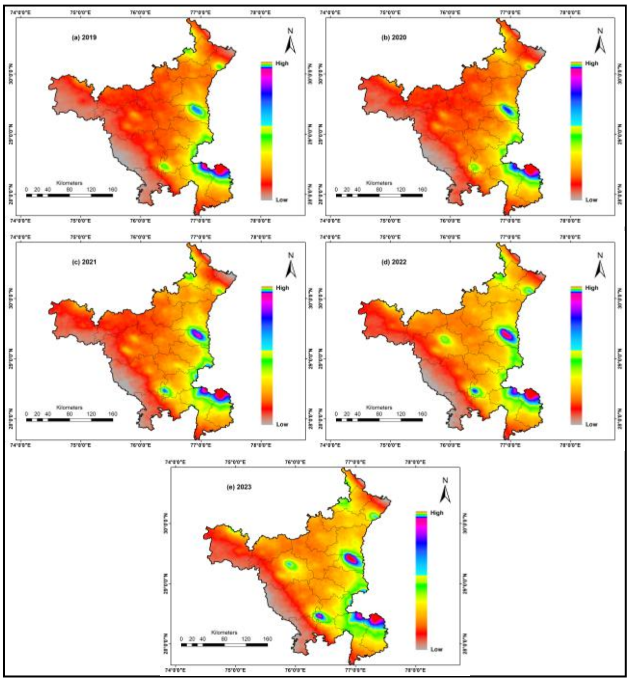

Figure 7. Yearly average of Nitrogen Dioxide (NO2) concentration over study region during Jan 19 – Dec 23, where (a) 2019, (b) 2020, (c) 2021, (d) 2022, and (e) 2023.

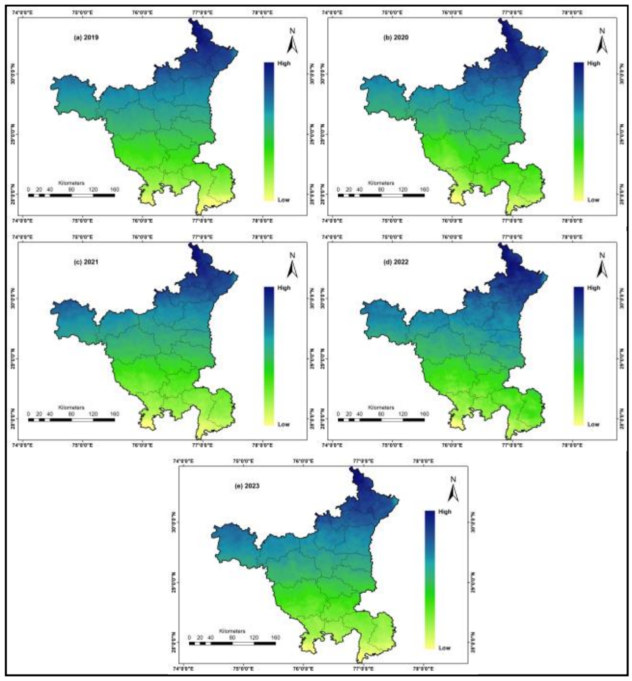

Figure 8. Yearly average of O3 concentration over study region during Jan 19 – Dec 23, where (a) 2019, (b) 2020, (c) 2021, (d) 2022, and (e) 2023.

Nitrogen oxides, which comprise nitrogen dioxide (NO2) and nitrogen oxide (NO), are important trace gases that arise from natural events as well as human activity. These gases are released into the atmosphere, where they cause problems including acid rain and smog. As trace gases found in the troposphere and stratosphere, nitrogen oxides (NO2 and NO) are significant. Their release into the atmosphere results from both natural and human-caused processes, including lightning, wildfires, and soil microbiological activity. Human-caused activities include burning biomass and fossil fuels.

NO2 concentrations ranging from a minimum of 7.05741e-005 to a maximum reported value of 0.000207354 over the study region during Jan 2019 to Dec 2023 (Figure 7). The results showed that the maximum concentrations were seen over eastern and south-eastern parts of the Haryana. The districts over which higher concentration were found are Faridabad, Gurgaon, and Panipat. Figure 7 also illustrates that western, southern, and part of northern region of the state depicts satisfying NO2 concentration.

The average value of NO2 concentration in the study area was found to be 0.000097544, 0.000091464, 0.000100216, 0.000100166, and 0.000104122 for the years 2019, 2020, 2021, 2022 and 2023, respectively. The results revealed that SO2 concentrations were found to be constantly higher over the Faridabad district which makes more prone. However, Sirsa is constantly at lower side (Figure 7).

4.7 Ozone (O3) Concentration over Haryana

When O3 (ozone) is found in the lower troposphere and closer to the ground, it is thought to be harmful to living things. When present in the stratosphere, it is thought to be harmless and helpful in protecting the biosphere from harmful solar UV radiation. HCHO is one of the key pollutants that create tropospheric O3.

O3 concentrations ranging from a minimum of 0.122384 to a maximum reported value of 0.129096 over the study region during Jan 2019 to Dec 2023 (Figure 8). The results showed that the maximum concentrations were seen over northern parts of the Haryana. The districts over which higher concentration were found are Panchkula, Ambala, Yamuna Nagar, Kurukshetra, Kaithal, and Karnal. Figure 8 also illustrates that southern and south-eastern region of the state depicts satisfying O3 concentration.

The average value of O3 concentration in the study area was found to be 0.124527808, 0.126612574, 0.126096217, 0.126270895, and 0.126172838 for the years 2019, 2020, 2021, 2022 and 2023, respectively. The results revealed that O3 concentrations were found to be constantly higher over the Panchkula, Ambala, Yamuna Nagar, and Kurukshetra districts which makes them more prone. However, Mahendragarh is constantly at lower side (Figure 8).

5. Conclusion

The study's findings offer a thorough evaluation of distribution of air pollutants over Haryana, India, between 2019 and 2023. A comprehensive assessment of the concentrations and spatial distributions of these pollutants throughout the various regions of Haryana was made possible by the use of Sentinel-SP satellite dataset which provided the distribution of NO2, SO2, O3, CH4, HCHO, CO, and AAI over the study region and emphasized the need for continuous monitoring and targeted interventions to improve air quality, particularly in identified hotspots. The results of this study highlight the constant challenge of Haryana's rising air pollution levels and the significance of taking practical steps to reduce the adverse impacts of air pollution on the ecosystem and human health.

The outcomes also made clear how external variables, such lockdown procedures, affected air quality. The COVID-19 lockdown showed a notable improvement in air quality, which highlights the possible advantages of lowering emissions and human activity. It's crucial to understand that these advancements were just temporary while long-term fixes are required to maintain clean air. It is evident that elevated atmospheric concentrations, such as those caused by automobiles and transportation, factories, and other industrial activities, raise the risk of respiratory issues in young children and the elderly.

This information is valuable for policymakers, researchers, and stakeholders involved in ad-dressing air pollution and developing strategies to improve air quality in Haryana.

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