Review Article

Remote Sensing and GIS in Air Pollution Mitigation: A Bibliometric Review of Chhattisgarh, India

ABSTRACT

Remote sensing and GIS play a crucial role in the assessment and management of air pollution and air quality. Remote sensing technologies, such as satellite and aerial imaging, provide vast amounts of data on atmospheric and environmental conditions, including air quality and pollution levels. This data can then be analysed and integrated with other environmental and geographic information using GIS software. Remote sensing technologies can detect various air pollutants, including sulphur dioxide, nitrogen oxides, and particulate matter. These pollutants can have harmful effects on human health and the environment. By analysing satellite images and data, scientists can track the movement of pollutants, identify sources of pollution, and monitor the effects of air quality on surrounding areas. GIS can be used to create maps and visualizations of air pollution and air quality data. This information can be used to identify areas with high levels of pollution and help decision-makers develop targeted mitigation strategies. GIS can also be used to analyse the relationships between air pollution, demographic patterns, and land use practices. One of the main advantages of using remote sensing and GIS in air pollution and air quality management is that they provide a comprehensive and integrated view of the environment. This information can be used to make informed decisions on how to reduce emissions and improve air quality. GIS can be used to identify areas where there is a high risk of air pollution, such as urban areas or areas with heavy industrial activities. This information can then be used to develop mitigation strategies and monitor the effectiveness of these strategies over time. Remote sensing and GIS can also help monitor the effectiveness of air quality regulations and policies. By tracking the emission levels of factories and vehicles, GIS can help governments determine if regulations are being followed and if they are having the intended effect. This information can then be used to make any necessary changes to improve air quality. Remote sensing and GIS play a crucial role in the assessment and management of air pollution and air quality. By providing a comprehensive and integrated view of the environment, these technologies can help decision-makers make informed decisions on how to reduce emissions and improve air quality. In this review paper we aim to highlight the advancements in this field that has occurred in controlling air pollution in the state of Chhattisgarh, India.

Keywords: Environmental Monitoring, Pollution Detection, Remote Sensing and GIS, Air Pollution, Bibliometric Study

1. INTRODUCTION

Chhattisgarh, located in central India, has undergone rapid industrialization and urbanization, significantly impacting its air quality [1]. The state's rich mineral resources have fuelled the establishment of numerous industries, including power plants, steel manufacturing units, and cement factories. While these industries have driven economic growth, they have also led to a complex air pollution scenario [2] [3]. Studies, such as the one conducted by the Central Pollution Control Board (CPCB), highlight the presence of various air pollutants in Chhattisgarh. Particulate matter (PM 10 and PM 2.5), sulfur dioxide (SO2), nitrogen dioxide (NO2), and volatile organic compounds (VOCs) are prominent contributors. Industrial clusters in cities like Raipur, Bhilai and Korba have been identified as hotspots with elevated pollutant concentrations [4] [5]. The primary sources of air pollution in the region include the combustion of fossil fuels, industrial emissions, and vehicular traffic. The impact on public health is substantial, with reports of respiratory ailments and cardiovascular diseases among the local population. Environmental consequences, including soil and water pollution, further compound the challenges faced by Chhattisgarh [6] [5]. Regulatory measures, spearheaded by the Chhattisgarh State Pollution Control Board (CSPCB), aim to monitor and control industrial emissions. However, the situation calls for a more comprehensive approach, integrating advanced technologies for monitoring and sustainable development practices.

Air pollution in Chhattisgarh is imperative for protecting public health and ensuring environmental sustainability. Implementing effective strategies to reduce pollution levels will benefit both current and future generations by improving health outcomes and preserving the environment for years to come [6]. Air pollution in Chhattisgarh, India, is crucial for protecting public health and ensuring environmental sustainability. The state, known for its industrial growth and rapid urbanization, faces significant challenges related to air quality due to emissions from industries, vehicular traffic, and biomass burning. Poor air quality in Chhattisgarh has serious implications for public health [7] highlights the association between air pollution and various health issues, including respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD), cardiovascular diseases, and even premature death [8]. Vulnerable populations, including children, the elderly, and individuals with pre-existing health conditions, are particularly at risk. Addressing air pollution can lead to improved public health outcomes, reduced healthcare costs, and enhanced quality of life for residents. Furthermore, mitigating air pollution is essential for environmental sustainability. High levels of pollutants such as particulate matter (PM), [5]sulfur dioxide (SO2), nitrogen dioxide (NO2), and volatile organic compounds (VOCs) contribute to environmental degradation, including acid rain, smog formation, and damage to ecosystems [3]. This degradation threatens biodiversity, agricultural productivity, and the overall ecological balance. Implementing measures to reduce air pollution, such as enforcing emission standards for industries, promoting cleaner technologies, and investing in renewable energy, can help preserve natural resources and support long-term environmental sustainability [6].

Remote Sensing (RS) and Geographic Information System (GIS) play critical roles in environmental management, providing powerful tools for data collection, analysis, and decision-making. Remote sensing involves the acquisition of information about the Earth's surface using sensors mounted on satellites, aircraft, or drones, while GIS enables the capture, storage, manipulation, analysis, and presentation of spatial and geographic data [9] [10]. RS and GIS are instrumental in environmental management for several reasons. Firstly, remote sensing provides a means to gather large-scale spatial data, allowing for the monitoring of environmental parameters such as land cover, vegetation health, water quality, and pollution levels over time. This data can then be integrated into GIS platforms for analysis and visualization, enabling researchers and policymakers to identify trends, patterns, and areas of concern. Secondly, RS and GIS are invaluable for assessing and managing natural disasters and environmental hazards. Satellite imagery can be utilized to monitor phenomena like floods, wildfires, and landslides, aiding in early warning systems and emergency response planning. GIS complements this by providing spatial analysis tools to identify vulnerable areas, assess risks, and develop mitigation strategies [11] [12]. Furthermore, RS and GIS play a crucial role in environmental modeling and planning. GIS enables the integration of various layers of spatial data to create models for predicting environmental impacts, such as air and water pollution dispersion, habitat suitability, and climate change scenarios. Remote sensing data serves as inputs for these models, helping to validate their outputs and inform decision-making processes. The integration of Remote Sensing and Geographic Information Systems is essential for effective environmental management. Their combined capabilities enable the collection, analysis, and visualization of spatial data, facilitating informed decision-making and sustainable resource management [13].

This review paper evaluates and synthesizes the latest advancements in Remote Sensing (RS) and Geographic Information System (GIS) technologies tailored to address air pollution in study area Chhattisgarh (Figure 1). It explores how these techniques monitor, analyse, and mitigate air pollution levels in the region, offering insights into their effectiveness in managing environmental challenges. The paper is guided by specific research questions aimed at examining the role of RS and GIS technologies in addressing air pollution in Chhattisgarh and aims to provide a comprehensive overview of their current applications while identifying areas for future research and technological development by properly examining the need for more studies through a bibliometric appraoch. This overview emphasizes the urgency of addressing air pollution in Chhattisgarh and advocates for innovative solutions, with RS and GIS technologies offering promise in providing insights into spatial and temporal pollution patterns to inform effective policy measures for sustainable development.

2. AIR POLLUTION IN CHHATTISGARH: A HISTORICAL PERSPECTIVE

2.1 Historical Trends

Chhattisgarh, located in central India, has experienced rapid industrial growth since its formation in 2000. The state is rich in mineral resources, leading to the establishment of numerous industries, including coal-fired power plants, steel plants, and cement factories. Additionally, urban centers like Raipur, Bilaspur, and Durg have witnessed significant population growth and industrial expansion, contributing to air pollution [6]. The primary air pollutants of concern in Chhattisgarh include particulate matter (PM), sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and volatile organic compounds (VOCs). These pollutants are emitted from various sources such as industrial activities, vehicular emissions, biomass burning, and construction activities [14]. Studies conducted by the Chhattisgarh Pollution Control Board (CPCB) and other research organizations have documented the increasing trend of air pollution in the state. Data from monitoring stations indicate rising concentrations of PM2.5 and PM10, especially in urban areas with high industrial and vehicular traffic. Similarly, elevated levels of SO2 and NO2 have been observed near industrial clusters and coal-fired power plants [3] [15]. The deteriorating air quality in Chhattisgarh poses significant risks to public health and the environment. Exposure to high levels of air pollutants has been linked to respiratory diseases, cardiovascular disorders, and premature mortality. Moreover, air pollution contributes to environmental degradation, including acid rain, smog formation, and biodiversity loss [16] [17]. Recognizing the urgent need to address air pollution, the state government has implemented various policy measures and regulations. These include emission standards for industries, promotion of cleaner technologies, expansion of public transportation, and initiatives to promote renewable energy sources. However, effective implementation and enforcement of these measures remain a challenge [14]. The historical trends of air pollution in Chhattisgarh underscore the importance of concerted efforts to mitigate its adverse effects on human health and the environment (Table 1). Continued monitoring, research, and policy interventions are essential to achieve sustainable development and improve air quality in the state.

2.2 Major Pollutants

Chhattisgarh, a central Indian state with rapid industrialization and urbanization, faces significant challenges regarding air pollution. Understanding the major pollutants and their sources is crucial for effective pollution control strategies. This review aims to identify the primary pollutants and their sources in Chhattisgarh, drawing insights from existing research and data [18]. Particulate Matter (PM): Particulate matter, including PM2.5 and PM10, is a major pollutant in Chhattisgarh. Sources of PM emissions include industrial activities such as coal-fired power plants, steel manufacturing, and construction activities. Vehicular emissions and biomass burning also contribute significantly to PM levels in the state [19] [1]. Sulfur Dioxide (SO2): Sulfur dioxide emissions primarily originate from industrial sources, particularly coal combustion in power plants and metal smelting. Studies have shown elevated SO2 levels in areas surrounding industrial clusters in Chhattisgarh. A study by Kumar et al. (2013) [11] provides detailed insights into SO2 emissions from coal-fired power plants in the state [1]. Nitrogen Dioxide (NO2): Nitrogen dioxide is predominantly emitted from vehicular exhaust and industrial combustion processes. With increasing urbanization and industrial activities in Chhattisgarh, NO2 levels have risen, especially in urban centers. The study by Gupta and Singh (2019) [20] highlights the impact of vehicular emissions on NO2 concentrations in Raipur, the capital city of Chhattisgarh [21] [18]. Carbon Monoxide (CO): Carbon monoxide emissions stem from various combustion sources, including vehicles, industrial processes, and biomass burning. A study focusing on CO emissions from industries in Chhattisgarh, emphasizing the need for emission control measures to mitigate air pollution [22]. Volatile Organic Compounds (VOCs): Volatile organic compounds are emitted from industrial processes, solvent use, and vehicular exhaust [18]. Apart from this, the presence of Ozone(O3) and NH3 gas,heavy metal has also been observed in the air here [23].

2.3 Impact on Human Health and Environment

Air pollution has profound effects on human health, impacting various organ systems and contributing to a range of acute and chronic health conditions. Here are some of the primary effects of air pollution on human health [24]. Respiratory Problems: Inhalation of pollutants such as particulate matter (PM), nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3) can lead to respiratory issues such as asthma exacerbation, bronchitis, and chronic obstructive pulmonary disease (COPD). PM can penetrate deep into the lungs, causing inflammation and irritation of the respiratory tract. NO2 and SO2 can irritate the airways and exacerbate respiratory conditions, leading to wheezing, coughing, and shortness of breath [25] [24] [26]. Cardiovascular Diseases: Long-term exposure to air pollution is associated with an increased risk of cardiovascular diseases such as heart attacks, strokes, and hypertension. Air pollutants like PM, NO2, and carbon monoxide (CO) can enter the bloodstream, triggering systemic inflammation, oxidative stress, and endothelial dysfunction, which are factors contributing to cardiovascular disease development [27] [28]. Adverse Pregnancy Outcomes: Exposure to air pollution during pregnancy is linked to adverse outcomes such as low birth weight, preterm birth, and developmental abnormalities in newborns. Air pollutants can cross the placental barrier and affect fetal development, leading to long-term health consequences for the child [24]. Neurological Effects: Studies suggest that air pollution exposure is associated with cognitive impairment, neurodevelopmental disorders in children, and an increased risk of neurodegenerative diseases such as Alzheimer's and Parkinson's. Fine particulate matter (PM2.5) and certain air toxics can penetrate the blood-brain barrier, causing neuroinflammation, oxidative stress, and neuronal damage [24] [25]. Cancer: Some air pollutants, such as benzene, formaldehyde, and polycyclic aromatic hydrocarbons (PAHs), are classified as carcinogens by international agencies. Prolonged exposure to these carcinogens through air pollution increases the risk of lung cancer, bladder cancer, and other malignancies[28] [29]. Allergic Reactions: Airborne allergens, such as pollen and fungal spores, can adhere to air pollution particles, exacerbating allergic reactions and respiratory symptoms in susceptible individuals. Air pollution can also stimulate the release of pro-inflammatory mediators, worsening allergic conditions like allergic rhinitis and allergic asthma [29]. Mortality: Long-term exposure to high levels of air pollution is associated with increased mortality rates, particularly from respiratory and cardiovascular causes. Vulnerable populations such as the elderly, children, and individuals with pre-existing health conditions are at higher risk of adverse health effects from air pollution exposure [26].

Air pollution in Chhattisgarh, akin to many other industrialized regions, engenders significant environmental ramifications that impact ecosystems, biodiversity, natural resources, and overall environmental quality. The consequences of air pollution in Chhattisgarh are multifaceted, encompassing ecosystem degradation, loss of biodiversity, water and soil contamination, climate change, and damage to cultural and historical sites. Ecosystems are detrimentally affected by the deposition of pollutants such as sulfur dioxide (SO2), nitrogen oxides (NOx), and particulate matter (PM) onto soil, water bodies, and vegetation [28]. Acid rain, resulting from sulfur and nitrogen compounds deposition, can acidify soils and water bodies, adversely affecting soil fertility, aquatic organisms, and plant health. Sensitive ecosystems such as forests, wetlands, and rivers may experience disruptions in nutrient cycling, species composition, and overall ecological balance due to air pollution [30] [31]. Biodiversity loss ensues as air pollution directly harms plants, leading to reduced growth, yield losses, and mortality in sensitive species. Elevated pollutant levels can disrupt plant-pollinator interactions, affecting pollination dynamics and reproductive success in flowering plants [29]. Pollution-induced stressors may exacerbate existing threats to biodiversity, including habitat loss, fragmentation, and climate change impacts. Airborne pollutants can deposit onto soil and water surfaces, leading to contamination and degradation of these vital resources [32]. Heavy metals, like mercury, lead, and cadmium, accumulate in soil and water bodies, posing risks to human health and ecosystem integrity [5] [19]. Contaminated soils may affect agricultural productivity and food safety, particularly in regions with high pollutant deposition, such as near industrial sites and urban areas. Some air pollutants, such as black carbon and methane, significantly contribute to global warming and climate change, exacerbating weather extremes, altering precipitation patterns, and impacting agriculture and water resources [30]. Chhattisgarh's air pollution also impacts regional and global climate change through the emission of greenhouse gases and aerosols. Furthermore, air pollution accelerates the deterioration of cultural heritage sites, monuments, and historical buildings through pollutant deposition and acidic compound formation [31]. Acid rain and air pollutants corrode building materials, erode surface finishes, and degrade artistic and architectural elements, jeopardizing Chhattisgarh's cultural heritage [33].

3. REMOTE SENSING TECHNOLOGIES FOR AIR POLLUTION MONITORING

Remote sensing technologies for air pollution monitoring involve the use of sensors and imaging devices to detect and quantify pollutants in the atmosphere. These technologies can be deployed on satellites, aircraft, drones, and ground-based stations to provide comprehensive coverage and data for air quality assessment [34]. They typically measure pollutants such as ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM) [35] [36] [37]. Satellite-based remote sensing offers global coverage and the ability to monitor large-scale air pollution patterns over time. Instruments such as spectrometers and imaging sensors onboard satellites can measure the concentration and distribution of pollutants in the atmosphere [38] [39]. Aircraft-based remote sensing provides high-resolution data for localized air pollution studies. Manned or unmanned aircraft equipped with sensors can fly over specific areas to measure pollutant levels and identify pollution sources [40]. Ground-based remote sensing stations are deployed in urban areas, industrial zones, and near pollution sources to monitor air quality at the surface level. These stations use various sensors to measure pollutant concentrations and meteorological parameters [41]. Overall, remote sensing technologies play a crucial role in air pollution monitoring by providing comprehensive, real-time data for decision-making and policy development to improve air quality and public health.

3.1 Satellite-Based Remote Sensing

Satellites used for air quality monitoring are typically equipped with sensors that can detect various pollutants in the atmosphere. These satellites fall into two main categories:

Geostationary Satellites: These satellites are placed in geostationary orbit, which means they orbit the Earth at the same rate as the Earth's rotation, allowing them to continuously observe the same region. Geostationary satellites are valuable for monitoring air quality over specific areas, such as urban regions or industrial zones. They provide high temporal resolution data, allowing for near-real-time monitoring of pollution events. Examples of geostationary satellites used for air quality monitoring include the Sentinel-4 satellite in Europe and the GEMS satellite in Asia [42] [43].Polar-orbiting Satellites: These satellites orbit the Earth from pole to pole, providing global coverage with a lower revisit time compared to geostationary satellites. Polar-orbiting satellites are equipped with sensors that can measure various air quality parameters, such as aerosols, ozone, and trace gases. They are particularly useful for studying long-term trends and global patterns of air pollution. Examples of polar-orbiting satellites used for air quality monitoring include the NASA Aura satellite and the European Space Agency's Sentinel-5P satellite [40] [42].

Both geostationary and polar-orbiting satellites play important roles in monitoring air quality and providing valuable data for air quality management and research. Satellites utilized for remote sensing employ a diverse array of sensors and spectral bands to capture intricate details about the Earth's surface and atmosphere. Various sensors and spectral bands are utilized in remote sensing, each serving distinct purposes and providing unique insights into Earth's dynamics [44]. Visible and Near-Infrared (VNIR) bands, ranging from 0.4 to 1.0 micrometers, are instrumental in studying vegetation health, land cover, and ocean color [1]. Shortwave Infrared (SWIR) bands, spanning from 1.0 to 3.0 micrometers, enable the study of geological features, vegetation moisture content, and mineral identification. Thermal Infrared (TIR) bands, covering 3.0 to 14.0 micrometers, facilitate the measurement of temperature variations on the Earth's surface, aiding in the detection of urban heat islands, volcanic activity, and forest fires. Microwave sensors are pivotal in penetrating clouds and providing crucial information regarding soil moisture, sea surface temperature, and ice cover. Lidar (Light Detection and Ranging) sensors utilize laser pulses to measure distances to the Earth's surface, facilitating the creation of high-resolution topographic maps, studying vegetation structure, and monitoring atmospheric conditions. Radar (Radio Detection and Ranging) sensors utilize radio waves to detect objects on the Earth's surface, aiding in terrain mapping, monitoring sea ice, and detecting changes in land cover. Hyperspectral sensors, by capturing images in hundreds of narrow spectral bands, allow for detailed analysis of the Earth's surface composition and properties [45] [44] [1]. The synergistic use of these sensors and spectral bands provides a comprehensive view of the Earth's surface and atmosphere, empowering scientists to study a wide array of phenomena and processes.

3.2 Aerial and Ground-Based Remote Sensing

Aerial remote sensing, a method involving the capture of images and data from elevated platforms such as aircraft or drones, offers a comprehensive view of the Earth's surface and finds applications in mapping, environmental monitoring, agriculture, and disaster response. The platforms for aerial remote sensing vary from small drones to manned aircraft equipped with specialized sensors, with drones commonly used for small-scale surveys and manned aircraft for larger-scale projects requiring higher altitudes and longer endurance. Aerial sensors encompass a range of technologies including cameras (RGB, multispectral, hyperspectral), LiDAR (Light Detection and Ranging), thermal sensors, and radar, capturing data at different wavelengths and resolutions for the detection of various features and phenomena on the Earth's surface [46] [47]. Applications of aerial remote sensing include mapping and surveying for creating high-resolution maps and terrain models, environmental monitoring for tracking changes like deforestation and land use changes, and agricultural applications for monitoring crop health and optimizing farming practices. Aerial imagery is also utilized in infrastructure planning for projects like roads, railways, and pipelines, as well as in disaster response for assessing damage and planning response efforts during natural disasters [47]. The method offers advantages such as high spatial resolution, flexibility, accessibility to challenging terrain, and near-real-time monitoring capabilities, making it valuable in emergency situations or dynamic environments [42] [48]. However, it also has limitations including high cost due to specialized equipment and personnel, weather dependency affecting data quality and flight safety, limited endurance and coverage compared to satellite-based remote sensing, and regulatory restrictions especially in populated or sensitive areas [49].

Ground-based remote sensing involves data collection from sensors positioned on the Earth's surface or structures such as towers or buildings, offering detailed, localized information for various applications including weather monitoring, air quality assessment, and infrastructure monitoring [50]. Ground-based sensors encompass a variety of technologies including weather stations, air quality monitors, LiDAR, radar, and GPS receivers, collecting data on parameters such as temperature, humidity, air quality, and terrain elevation [46] [51]. These sensors play crucial roles in weather monitoring by tracking conditions like temperature, humidity, wind speed, and precipitation, as well as in air quality assessment by monitoring pollutants such as ozone, nitrogen dioxide, and particulate matter. Ground-based sensors also find utility in geological surveys for mapping terrain features and monitoring geological hazards [52]. The method offers advantages such as high precision for detailed studies or validation of remote sensing data, continuous monitoring over time for long-term environmental parameter tracking, cost-effectiveness for small-scale or localized studies, and ease of deployment for short-term or temporary monitoring campaigns [53] [54]. However, it has limitations including limited range and coverage compared to aerial or satellite-based methods, restricted accessibility to remote or inaccessible areas, interference from local sources like vegetation or buildings affecting data quality, and the need for regular maintenance and calibration [46]. Ground-based remote sensing and aerial remote sensing each have unique advantages and limitations, with the choice between them depending on the specific requirements of the study or application.

3.3 Overview of alternative RS technologies

Alternative remote sensing (RS) technologies complement traditional satellite-based methods, offering unique advantages for specific applications and providing valuable insights when used alongside satellite data. Unmanned Aerial Vehicles (UAVs), equipped with various sensors, capture high-resolution imagery and data over smaller areas with greater flexibility and lower cost compared to satellites, benefiting mapping, monitoring, and research in agriculture, forestry, environmental management, and disaster response [55](Han et al., 2006). Manned aircraft, equipped with specialized sensors, capture high-resolution imagery and data over large or inaccessible areas, supporting detailed mapping, environmental monitoring, and disaster assessment [46]. Ground-based sensors, such as weather stations, air quality monitors, and GPS receivers, provide continuous and localized data for environmental monitoring, research, validating satellite data, calibrating models, and monitoring specific areas of interest [50] [56]. Terrestrial Laser Scanning (TLS) systems, utilizing laser light, create highly detailed 3D models of the Earth's surface, facilitating terrain mapping, vegetation structure monitoring, and geological feature assessment [57] [58]. Mobile Mapping Systems (MMS) combine sensors like LiDAR, cameras, and GPS, mounted on vehicles, capturing detailed geospatial data along road networks and urban areas for infrastructure planning, navigation, and asset management [59] [60]. Underwater Remote Sensing employs sonar and acoustic sensors for mapping and monitoring underwater environments, benefiting marine resource management, habitat monitoring, and underwater archaeology [61]. Geophysical Remote Sensing techniques like ground-penetrating radar (GPR), electromagnetic induction (EMI), and magnetometry study subsurface features, archaeological sites, and soil properties, enhancing our understanding of the Earth's surface and subsurface and supporting informed decision-making in various fields [60] [62].

4. GIS APPLICATIONS IN AIR POLLUTION MITIGATION

GIS (Geographic Information System) plays a pivotal role in air pollution mitigation, mapping, and analysis through its spatial analysis tools and visualization capabilities. In air pollution management, GIS aids in pollution source identification, mapping sources like industrial facilities, traffic congestion points, and agricultural activities, enabling targeted mitigation efforts. It integrates data from air quality monitoring stations, satellite imagery, and meteorological data to create real-time air quality maps, identifying pollution hotspots and tracking changes over time. GIS assesses health impacts by mapping pollution levels against population density, prioritizing interventions and health resources. It optimizes transportation routes, reducing traffic congestion and emissions, and supports urban planning efforts by mapping land use patterns, population density, and transportation infrastructure. GIS also evaluates the effectiveness of air pollution control policies, aiding policymakers in decision-making and identifying areas needing additional measures. Overall, GIS serves as a critical tool in air pollution management, assisting policymakers, researchers, and environmental managers in mitigating air pollution and safeguarding public health [63].

GIS tools are extensively utilized for mapping air pollution due to their ability to integrate spatial data from diverse sources and perform spatial analysis. ArcGIS by Esri is widely used, offering tools for data visualization, spatial analysis, and map creation. QGIS, a free and open-source software, provides similar functionalities to ArcGIS, commonly used for mapping air pollution and spatial analysis. Google Earth Engine, a cloud-based platform, allows analyzing and visualizing geospatial data, including air pollution data, offering access to vast satellite imagery and geospatial datasets. GRASS GIS, another open-source software, provides advanced geospatial analysis capabilities for mapping air pollution and analyzing spatial patterns. ENVI, a software package designed for remote sensing analysis, processes satellite imagery and maps air pollution using remote sensing data. IDW (Inverse Distance Weighting) interpolation, a spatial analysis technique, creates air pollution concentration maps from point data collected from monitoring stations. These GIS tools and software packages offer powerful capabilities for mapping air pollution, analyzing spatial patterns, and visualizing data, essential for air quality management and research [64] [65] [66] [67] [68] [69]. Spatial analysis techniques are fundamental in air quality studies, analyzing the spatial distribution of pollutants, identifying hotspots, and assessing their impact on human health and the environment. Common techniques include interpolation, such as inverse distance weighting (IDW), kriging, and spline, to estimate pollutant concentrations at unsampled locations based on nearby monitoring stations. Buffer analysis creates buffer zones around pollution sources or sensitive areas, like schools or hospitals, to evaluate exposure extent. Spatial join combines datasets, like air quality monitoring and land use, to analyze pollutant-land use relationships. Hotspot analysis, like Getis-Ord Gi* statistic, identifies areas with significant high or low pollutant concentrations, aiding in mitigation prioritization. Spatial autocorrelation analysis examines spatial relationships between pollutant concentrations, identifying spatial patterns and clusters. Geographically Weighted Regression (GWR) considers spatial variations in pollutant-predictor relationships, assessing spatial pollutant concentration variability. Remote sensing, using satellite imagery and aerial photography, monitors air quality from space, analyzing data in GIS to map pollutant concentrations over large areas. GIS tools create 3D visualizations of air pollution data, such as pollutant plumes or dispersion patterns, enhancing understanding of pollutant spatial distribution [70] [71] [72] [73] [74] [75] [76] [77] [78]. These techniques are crucial for understanding air pollution spatial patterns, assessing its impact, and developing effective air quality management strategies.

5. INTEGRATION OF REMOTE SENSING AND GIS

The integration of remote sensing with GIS applications is crucial in air pollution mitigation, incorporating satellite and aerial data into spatial analysis and decision-making processes. Remote sensing provides data on pollutant concentrations, atmospheric conditions, and land cover, integrated into GIS platforms for analysis and visualization [79]. Monitoring air quality over large areas is possible using remote sensing data, such as satellite imagery and aerial photographs, with GIS tools used to analyze data, identify pollution hotspots, and track air quality changes [80]. Estimation of emissions from various sources, such as industrial facilities and vehicles, is facilitated by remote sensing, with GIS used to spatially distribute emissions and create inventories for air quality modeling [81]. GIS integration with remote sensing and meteorological data allows for simulating pollutant dispersion and assessing air quality impacts under different scenarios [82]. Health impact assessment utilizes remote sensing and GIS to map pollution levels against population density and health data, aiding in prioritizing mitigation efforts in high-risk areas [83]. Visualizing and analyzing pollutant spatial distribution and sources with GIS assists policymakers in developing targeted air quality management strategies and regulations [84]. GIS also plays a role in public awareness and education by creating interactive maps and visualizations about air pollution sources, impacts, and mitigation strategies [79]. Overall, the integration of remote sensing with GIS provides a powerful tool for air pollution mitigation, enhancing understanding of air quality dynamics, supporting informed decision-making, and aiding in the development of effective mitigation strategies.

The integration of GIS (Geographic Information System) and RS (Remote Sensing) in environmental monitoring is highly beneficial, allowing for the incorporation of spatial data from remote sensing sources into GIS platforms for analysis, visualization, and decision-making. Remote sensing provides valuable spatial data, such as satellite imagery, aerial photographs, and LiDAR data, which enhances the spatial resolution and coverage of GIS databases, enabling more detailed and comprehensive environmental monitoring [85] [86] . GIS can integrate remote sensing data with other spatial data sources, such as topographic maps, land use data, and hydrological data, providing a holistic view of the environment and enabling the analysis of complex spatial relationships [87]. GIS tools can perform spatial analysis on remote sensing data, such as image classification, change detection, and spatial interpolation, identifying trends, patterns, and anomalies in environmental data for better decision-making [70]. Remote sensing data can also be used to parameterize environmental models within GIS platforms, such as estimating vegetation cover for input into hydrological models to simulate water flow and quality [88]. Continuous monitoring and surveillance of environmental parameters, such as land cover changes, deforestation, and urban sprawl, can be achieved using remote sensing data, with GIS tools aiding in visualizing and analyzing the data for timely interventions and management strategies [89]. The integration of GIS and RS provides decision-makers with valuable information for environmental planning and management, with GIS platforms used to create interactive maps and decision support systems facilitating informed decision-making. Furthermore, GIS and RS technologies can be utilized to create visually compelling maps and presentations for communicating environmental issues to the public, raising awareness about the importance of environmental conservation [90]. Overall, the synergy between GIS and RS in environmental monitoring enhances our ability to understand, manage, and protect the environment by providing valuable spatial information and analysis tools.

6. CURRENT AIR QUALITY MONITORING SYSTEMS IN CHHATTISGARH

6.1 Evaluation of Existing Infrastructure

Chhattisgarh, like many other states in India, faces challenges related to air pollution, particularly in urban areas and industrial regions. The state government, along with various agencies, has implemented several air quality monitoring systems to track pollution levels and take necessary actions to mitigate the impact. The Central Pollution Control Board (CPCB) has set up monitoring stations to measure air quality parameters such as PM10, PM2.5, SO2, NO2, O3, and CO, providing real-time data for assessing air quality status [86](Kolios et al., 2017). The Chhattisgarh State Pollution Control Board has also established its network of monitoring stations in cities and industrial areas [91]. Continuous Ambient Air Quality Monitoring Stations (CAAQMS) provide real-time data on air quality parameters in key cities and industrial hubs [86]. Manual monitoring stations collect data through sampling and analysis methods, while mobile monitoring units are deployed in areas without fixed stations [87]. The air quality data collected is used to calculate the Air Quality Index (AQI), providing a standardized way to communicate air quality to the public.

In Chhattisgarh, air quality monitoring systems measure key pollutants and compare the data with national and international standards to assess pollution levels and their impact on public health. The CPCB has established National Ambient Air Quality Standards (NAAQS) for pollutants like PM10, PM2.5, SO2, NO2, O3, and CO. The air quality monitoring systems in Chhattisgarh compare the data with NAAQS to assess compliance [30] [31]. The World Health Organization (WHO) has set guidelines for air quality based on the health effects of pollution. Monitoring systems may compare data with WHO guidelines to assess health impacts [92]. Additionally, monitoring systems may compare data with international standards, such as those set by the European Union (EU) or the United States Environmental Protection Agency (EPA), to assess pollution levels and their impact on public health [93]. Compliance with these standards is crucial for ensuring clean and healthy air for the residents of Chhattisgarh.

6.2 Limitations and Gaps

Identifying the shortcomings in the existing air quality monitoring systems in Chhattisgarh is crucial for improving their effectiveness and addressing air pollution challenges. Some potential shortcomings include limited coverage, with monitoring stations concentrated in urban and industrial areas, leading to gaps in data, especially in rural and remote areas where pollution sources may also exist [94]. The lack of an adequate number of mobile monitoring units limits the ability to capture real-time data from diverse locations [56]. Additionally, there may be limitations in the accessibility and availability of monitoring data to the public and researchers, hindering public awareness and research efforts [56]. While the existing systems measure key pollutants, such as PM10, PM2.5, SO2, NO2, O3, and CO, there may be other pollutants of concern, like volatile organic compounds, that are not adequately monitored, necessitating a more comprehensive approach [95]. Furthermore, the frequency of monitoring at some stations may not be sufficient to capture short-term fluctuations in air quality, highlighting the need for increased monitoring frequency, especially during high pollution events [96]. Ensuring proper maintenance and calibration of monitoring equipment is essential for obtaining accurate and reliable data, as inadequate maintenance can compromise the effectiveness of the monitoring systems [56]. Addressing these shortcomings will require investment in infrastructure, technology, and capacity building to improve understanding and support the development of effective mitigation strategies to protect public health and the environment.

Remote sensing (RS) and Geographic Information System (GIS) technologies can significantly enhance air quality monitoring capabilities in Chhattisgarh by providing spatial data and analysis tools to understand air pollution patterns, identify sources, and assess impacts on human health and the environment. RS can identify and map sources of air pollution, such as industrial facilities and vehicular emissions, while GIS can analyze the spatial distribution of these sources and their impact on air quality [97] [98](Karan et al., 2016; Briggs et al., 1997). RS can monitor industrial emissions using thermal sensors and satellite imagery to detect hotspots and assess pollutant release, with GIS integrating this data to track industrial emissions and dispersion patterns [98]. RS data on vegetation cover can help assess its impact on air quality, guiding areas for afforestation or green cover enhancement, which GIS can analyze [99]. RS and GIS can monitor urbanization patterns, analyzing land use changes and traffic patterns to understand urban air pollution drivers [98]. RS can monitor agricultural practices like crop burning and fertilizer use, integrating with air quality data in GIS to assess their impact on air quality [100]. RS and GIS can develop air quality models predicting pollutant dispersion, aiding in mitigation strategy effectiveness assessment [56]. RS and GIS can also assess health impacts by mapping pollution levels against population density and health data, guiding interventions and resource allocation [101]. By leveraging RS and GIS, Chhattisgarh can enhance its air quality monitoring, improving data-driven decision-making and targeted pollution mitigation strategies, ultimately protecting public health.

7. METHODOLOGY

The foundations underlying the concept of "air quality" have become well-established and acknowledged, leading to an increased prevalence of terms such as "air quality" and "air pollution" in the literature on environmental studies and regional assessments [102] [103] [104]. Despite the growing frequency of the term "air quality" in numerous publications, there remains ambiguity regarding whether these studies genuinely focus on air quality assessments by integrating Remote Sensing (RS) and GIS techniques to comprehend the extent of air pollution. Conducting a bibliometric study can assist in visualizing and understanding the treatment of the term "air pollution" in literature specific to Chhattisgarh, guiding future research initiatives and informing governmental policies. Utilizing bibliometrics enables the systematic review of registered data, extracting the roles and statuses of relevant information pertinent to air pollution studies [105].

Given the circumstances, it is imperative to quantitatively understand how the terms "air quality" and "air pollution," specifically addressed through the lens of remote sensing and GIS, are discussed in recent literature with a focus on Chhattisgarh. Once this numerical comprehension is achieved, it will be possible to steer the community towards the precise objectives of air quality research, enhancing the effectiveness of studies related to this vital environmental concept. The primary goal of our study was to critically analyze the utilization of the term "air pollution" in recent literature based on research conducted in Chhattisgarh. To address key questions in each study, we meticulously reviewed scientific peer-reviewed papers published between 2013 and 2022 using Google Scholar databases. Key questions included (i) whether the study assessed air quality indicators or referenced the term, (ii) which indices of air quality were evaluated, and (iii) whether the indicators were assessed individually or collectively. Collating this data enabled us to conduct a systematic review with specific objectives: (i) analyzing the prevalence of "air quality" in Chhattisgarh, and (ii) determining the proportion of filtered studies that evaluated air quality comprehensively.

The investigation into the current use of the term "air pollution" in Chhattisgarh followed a methodical approach. Google Scholar database was utilized after the final versions of articles published in peer-reviewed journals were curated. Employing Google Scholar, which identifies subsequent papers citing a previously published article, allowed for an efficient search for potentially relevant articles on air pollution in Chhattisgarh [106] [107] [108]. Given the frequent references to this database by researchers in India and internationally, it was chosen for its comprehensive coverage. The search phrases employed were [("air pollution" OR "air quality") AND "Chhattisgarh" AND "Remote sensing and GIS"]. The entire text of all sections of the papers was considered during the search for the aforementioned terms across all fields. The review highlights the significant parameters considered for air quality assessments in Chhattisgarh, incorporating remote sensing and GIS techniques, shedding light on the importance of these technologies in addressing air pollution challenges in the region.

8. RESULTS & DISCUSSION

Air pollution in Chhattisgarh is not just a public health issue but also an environmental concern. The pollution from industrial emissions and vehicular traffic has been found to have a significant impact on the quality of water bodies in the state [2]Additionally, air pollution contributes to climate change, which has serious implications for the state's agriculture and biodiversity. The changing weather patterns and extreme weather events caused by climate change can negatively impact crop yields and food security, particularly for rural communities in Chhattisgarh [109]. To address air pollution in Chhattisgarh, various measures have been taken by the state government and other stakeholders. The National Clean Air Programme (NCAP) was launched in 2019 by the Ministry of Environment, Forest and Climate Change to address air pollution in 102 cities across India, including Raipur [110]. Under this program, a comprehensive air quality monitoring network has been established in Raipur, and measures such as shifting to cleaner fuels and promoting public transport have been initiated. In addition to the NCAP, various other initiatives have been launched by the state government to mitigate air pollution in Chhattisgarh. The Air Quality Management Plan (AQMP) for Raipur was developed in 2020, which includes measures such as strengthening enforcement of emission standards for industries and vehicles, promoting renewable energy, and implementing dust control measures in construction and mining activities [111](Dey and Chowdhury, 2022). The state government has also set up a Pollution Control Board to monitor and regulate industrial emissions in the state [112].

The quantity of scholarly articles addressing air pollution in the state of Chhattisgarh has witnessed a substantial increase, exhibiting a noteworthy upward trend over the years. However, the body of literature focusing on the mitigation of air pollution through the application of remote sensing and Geographic Information Systems (GIS) remains conspicuously limited, demonstrating marginal growth in the last decade. The observed trends in the data underscore a substantial and consistent increase in the number of scholarly publications addressing air pollution in Chhattisgarh over the decade from 2013 to 2022 (Figure 2). This escalating interest is indicative of the growing recognition of the critical environmental challenges posed by air pollution in the region. The peak in the year 2022, with 269 papers, suggests an intensified focus on this environmental concern, possibly fueled by the cumulative impacts of industrialization, urbanization, and other anthropogenic activities in the state. On the other hand, the subset of publications specifically delving into the mitigation of air pollution through the utilization of remote sensing and GIS technologies reveals a more nuanced pattern. While there is a general upward trend, as evidenced by the increasing number of papers from 2013 to 2022, there are noticeable variations in certain years. The peaks in 2018, 2019, and 2021 indicate heightened attention to employing advanced technologies for air pollution studies during these periods.

These findings prompt several reflections on the state of air pollution research in Chhattisgarh. Firstly, the significant overall increase in publications underscores a collective acknowledgment of the urgency to address air quality concerns in the region. This may be attributed to a heightened awareness of the detrimental effects of air pollution on public health, ecosystems, and overall well-being. Secondly, the fluctuations in the number of papers focusing on remote sensing and GIS technologies for air pollution studies suggest a dynamic landscape in the adoption of advanced methodologies. The peaks in certain years could be associated with specific research initiatives, technological advancements, or funding opportunities that catalyzed a surge in studies utilizing these sophisticated tools. However, it is noteworthy that despite the growing volume of literature on air pollution, the utilization of remote sensing and GIS technologies in Chhattisgarh remains comparatively low, especially when juxtaposed with the global landscape where these tools have become integral to air quality research. This disparity emphasizes the untapped potential and underutilization of advanced technologies in the region.

While the increasing number of publications on air pollution in Chhattisgarh indicates a heightened awareness and interest in the subject, there is a clear need for a more robust integration of advanced methodologies, particularly remote sensing and GIS technologies, to enhance the precision and comprehensiveness of air quality studies in the region. Future research endeavors should strive to bridge this gap by leveraging these sophisticated tools to unravel the complexities of air pollution, ultimately contributing to more effective mitigation strategies and environmental sustainability in Chhattisgarh. It is imperative to underscore the underutilization of remote sensing and GIS in the context of air pollution research in Chhattisgarh, especially when compared to global endeavors. RS and GIS are crucial tools for mitigating air pollution due to their ability to provide comprehensive spatial data and analytical capabilities. RS offers valuable data on atmospheric conditions and pollutant concentrations through satellite and aerial imaging, while GIS integrates this data with other environmental and geographical information [11]. Together, they help identify pollution sources, monitor pollutant movements, and assess impacts on air quality. GIS enables the creation of maps and visualizations, aiding in the identification of high-pollution areas and the development of targeted mitigation strategies [56]. Additionally, RS and GIS facilitate environmental modeling, providing insights into pollution dispersion and supporting decision-making processes for effective air quality management. This disparity underscores the untapped potential of these advanced technologies in the region. Encouragingly, this review highlights the need for intensified research efforts in Chhattisgarh, positioning remote sensing and GIS as central components in air pollution studies. A comprehensive exploration of these technologies is poised to provide a more holistic and effective approach to air pollution mitigation, paving the way for future studies to enhance our understanding and strategies for addressing this critical environmental concern.

9. CONCLUSION

The study elucidates the pressing need to address air quality challenges in Chhattisgarh, driven by rapid industrialization and urbanization. The region's reliance on industries, coupled with vehicular emissions, has led to heightened levels of pollutants, including particulate matter, sulfur dioxide, nitrogen dioxide, and volatile organic compounds. These pollutants not only pose significant risks to public health but also contribute to environmental degradation. While regulatory measures such as the National Clean Air Programme and the Air Quality Management Plan for some parts of the state are in place, there remains a crucial gap in leveraging advanced technologies, specifically remote sensing and GIS, to comprehensively address air pollution as a whole.

The bibliometric analysis reveals a growing awareness of air pollution issues in Chhattisgarh, as evidenced by the increasing number of scholarly articles[113]. However, the limited integration of remote sensing and GIS technologies in these studies underscores an untapped potential for these advanced methodologies. The fluctuating trends in publications focusing on these technologies suggest a need for more consistent and integrated approaches in air quality research. Moving forward, it is imperative to enhance the utilization of remote sensing and GIS technologies to enhance the precision and depth of air quality studies in Chhattisgarh. Bridging the gap between awareness and action through the systematic integration of these tools can provide valuable insights into air pollution patterns, sources, and impacts. This, in turn, will facilitate the development of more effective mitigation strategies and promote environmental sustainability in Chhattisgarh.

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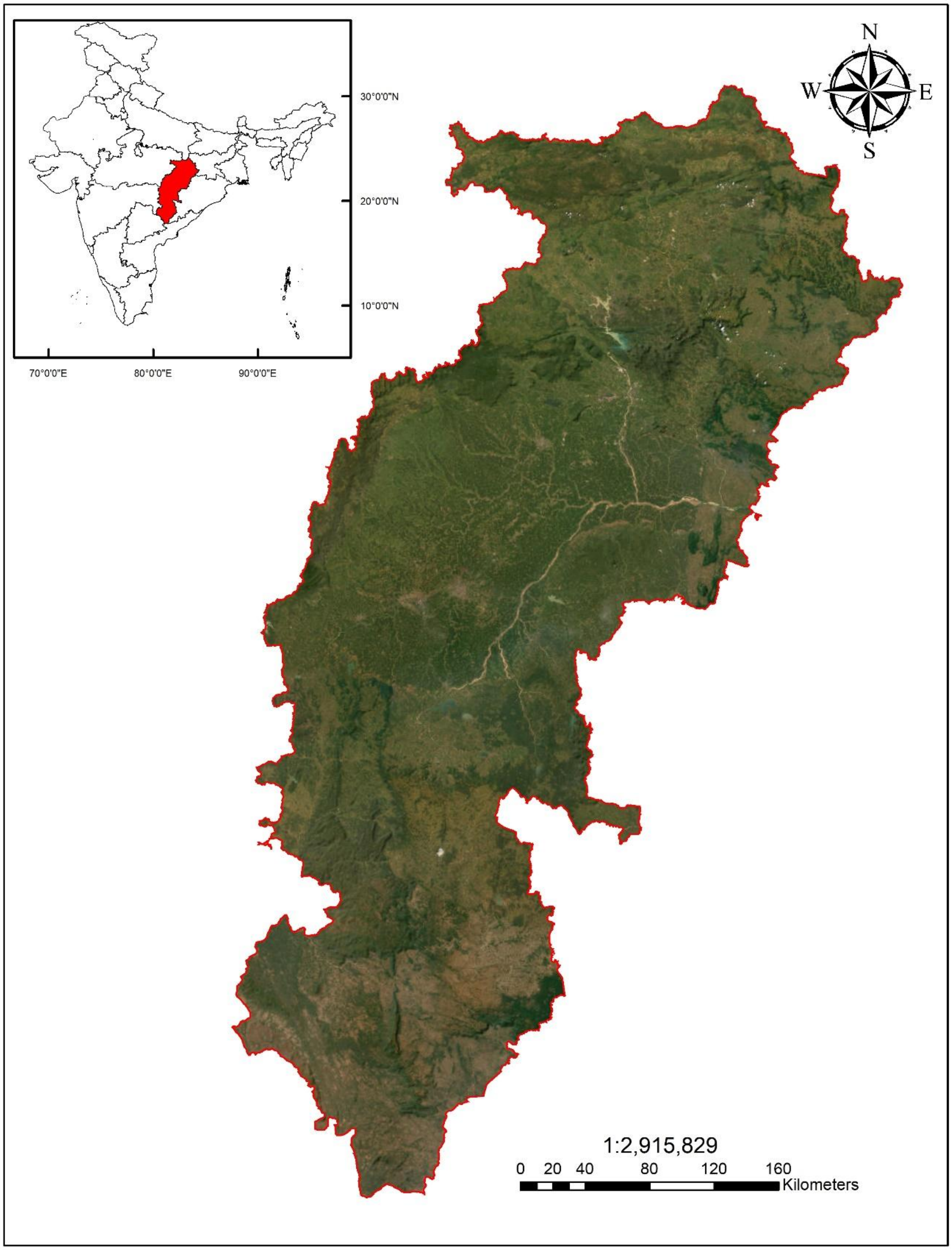

Fig. 1: Study Area of Review.

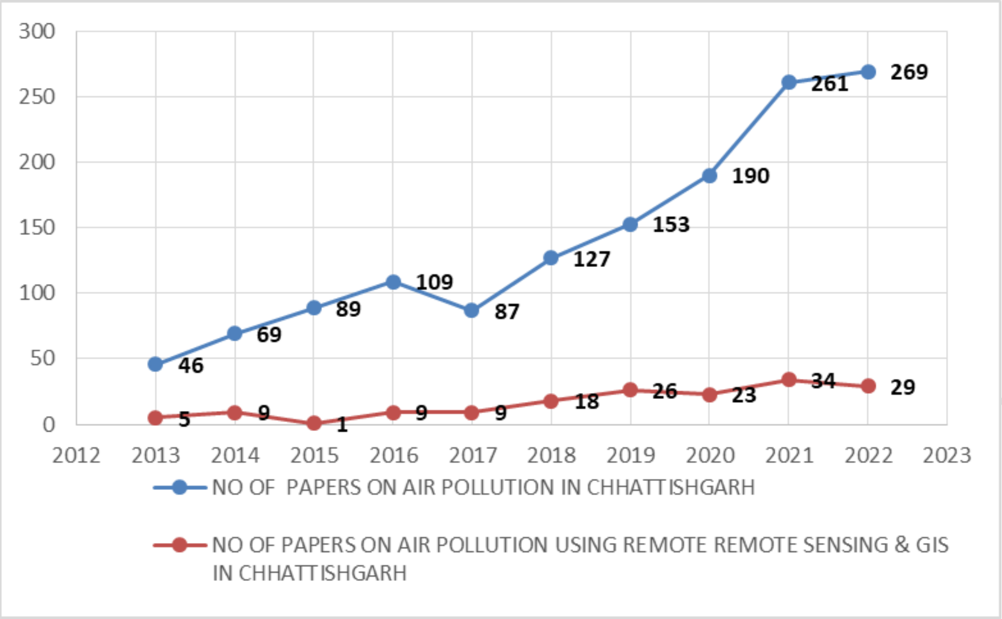

Fig. 2: Papers published on Air Pollution using and without using RS and GIS technology in Chhattisgarh.

Table 1: Some major areas studied for Air Pollution Monitoring in Chhattisgarh

Study Area	Pollutants Studied	Methodology	Reference
Raigarh District	LULC Changes	LandsatMSS,TM,ETMandIRSP6 LISS III digital data	[1]
Entire Chhattisgarh	NO2, SO2, O3 and CO	Air Quality monitoring using Sentinel-5P satellite using the application programming interface	[2]
Raipur, Durg, &Bhilai cities	PM 10, PM 2.5, CO2, NO2, SO2, and CO	Computation of Air Quality Index using CPCB data	[3]
Raipur, Bilaspur, &Raigarh cities	NO2, SO2, RSPM, SPM	AQI analysis through USEPA methodology	[4]
Raipur, Bilaspur, Durg-Bhilai, & Korba Districts	PM 10, PM 2.5, NO2, SO2, and CO	Comparative analysis of air pollutants through acquired data from CECB	[5]
Entire Chhattisgarh	Aerosols	Review Work	[6]

Rajnandgaon District	As, Cr, Cu, Mn, Zn, and Pb	Bioindicator study for heavy metal air pollution	[7]
Raipur and Korba city	AQI and Wind data	Metereological data from MSI for wind directional changes aiding air pollution increase	[8]
Bailadila mine	PM 10, PM 2.5, NO2, & SO2	Open source data	[9]
Raipur & Bilaspur city	PM 10, PM 2.5, NO2, & SO2	CECB data used for AQI computation and coparative analysis	[10]