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Role of Remote Sensing and GIS in mitigating Particulate Matters that intensify Air pollution in India: A Review

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ABSTRACT
In India, air pollution is a significant environmental problem, especially in metropolitan areas where excessive particulate matter (PM) emission levels pose serious dangers to the public's health. Geographic information systems (GIS) and remote sensing (RS) have become effective tools for tracking and reducing air pollution. By highlighting the sources of PM emissions and the use of RS and GIS for monitoring and modelling particulate matter concentrations, this paper examines the relevance of the use of RS and GIS in reducing particulate matters that are boosting air pollution in India. Indian industry, transportation, mining, forest fires, and domestic sources like cooking and heating all contribute to the country's emissions of particulate matter. These sources are frequently concentrated in cities, where people are most at risk for the health effects of air pollution. Technologies like RS and GIS have been used to predict the geographical distribution of pollutants in the atmosphere, map and monitor the sources of PM emissions, and detect hotspots. For the benefit of public health experts and policymakers, these methods have also been used to estimate the exposure levels for communities living around pollution sources. These technologies may be used to pinpoint actions, such as better traffic management, altered land use, and stronger emissions limits, along with determining PM conditions in remote places, in high-risk areas for air pollution. To completely comprehend the connection between particulate matter and human health, further study is required. However, the full potential of RS and GIS in lowering PM emissions has not yet been realised. In order to provide a more thorough understanding of the effects of air pollution on public health and thereby play a crucial role in mitigating air pollution and enhancing public health in India, RS and GIS technologies must also be integrated with other data sources, such as meteorological data and health records.
Keywords: Remote Sensing, GIS, particulate matter, air pollution, human health

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INTRODUCTION

India faces a significant environmental challenge in the form of air pollution, particularly in urban areas. The emission of high levels of particulate matter (PM) poses serious health risks to the public. According to the World Health Organization [127], air pollution ranks as the fourth leading cause of premature deaths worldwide, resulting in over 7 million fatalities annually due to exposure to polluted air. In India, the impact of air pollution is severe, causing an estimated 1.2 million premature deaths each year and making it a leading cause of death in the country [46]. Particulate matter is a major contributor to air pollution and has well-documented detrimental effects on human health. To address this issue, remote sensing (RS) and geographic information systems (GIS) have emerged as effective tools for monitoring and mitigating air pollution. RS involves the collection of data from a distance, typically utilizing satellites or aircraft, while GIS is a software system that facilitates the analysis and visualization of geographical data. These tools have been applied in various ways to tackle air pollution, including the identification of pollution sources, monitoring of air quality, and modeling of pollutant distribution in the atmosphere.
Air pollution and climate change pose significant challenges to rapidly growing cities in today's world. India, which is transitioning from a predominantly rural society to an increasingly urban one, faces crucial obstacles in terms of addressing climate change and achieving sustainable development [108]. Projections suggest that by 2050, India will have 53% of its population residing in cities, with an additional 416 million

urban dwellers [114]; [115]. The expansion of cities through continuous urbanization brings about changes in land use and land cover patterns, which in turn affect regional climate by altering surface and atmospheric conditions in the boundary layer [106]; [94]; [129]. Urbanization not only contributes to anthropogenic emissions, but it also leads to increased precipitation, urban floods, rising temperatures, and more frequent heatwaves, all of which have significant adverse effects on human health [19]; [93]; [102]. These local climate changes are driven by anthropogenic sources such as greenhouse gas (GHG) emissions. Additionally, the growth of urban populations and automobile traffic exacerbates pollution emissions and the aerosol burden in the atmosphere. The combination of urbanization, population growth, and industrial activities is identified as a primary cause of increased aerosol loading in the Indian subcontinent [55]; [92]; [57]. Consequently, climate change and air pollution pose serious threats to human health and well-being in cities, and these issues are closely interconnected, as further elaborated in this paper. According to a report by the World Health Organization (WHO), more than seven million people worldwide die each year due to illnesses linked to PM 2.5 pollution [125]. As a rapidly developing country with a growing population, India faces severe air pollution, with nine out of the world's ten most polluted cities located within its borders [124]. The escalating levels of air pollution in Indian megacities over the past few decades and the resulting health implications, such as asthma and respiratory illnesses, have gained significant attention in recent years [44]; [35]; [103]; [113].

Numerous studies have explored air pollution and its health effects in various Indian cities, including Delhi [41]; [42]; [47]; [95]; [76], Chandigarh [39], Kolkata [37]; [43]; [46], Rajasthan [98], Lucknow [59]; [63], Mumbai [53]; [64], Maharashtra [64], Agra [65]; [66], Gwalior City [22], and Chennai [52]; [47] just to name a few. Research has shown that the mutagenicity and cytotoxicity of particulate matter from biodiesel-fueled engines are significantly higher than those from diesel engines, highlighting the importance of exhaust gas after-treatment. Chemical analysis of the exhaust revealed the presence of hazardous polycyclic aromatic hydrocarbons (PAHs) and trace metals in biodiesel-fueled engines, which impact the biological activity of particulate matter. Air quality monitoring plays a vital role in informed decision-making and effective air quality management. Initially, the Ringelmann scale, which measures the apparent density or opacity of smoke, was employed as a method of measurement. The Indian Standard code for the use of the Ringelmann scale and a small smoke chart were introduced on February 20, 1979 [38]. However, the Air Act of 1981 established the requirement for air quality monitoring and provided guidelines for the monitoring techniques currently employed in India under the oversight of the Central Pollution Control Board (CPCB) (Table 1).

Particulate air pollution is an intricate amalgamation of minuscule and substantial particles, bearing diverse origins and chemical compositions. Within the diameter range of 2.5 to 100 micrometers, these particles predominantly encompass dust originating from agriculture, construction, vehicular traffic, botanical pollens, and other natural sources. On the other hand, diminutive particles, measuring less than 2.5 micrometers in diameter, are frequently engendered through the combustion of fossil fuels. Notably, soot emitted from automobile exhaust stands as a representative example, often enshrouded by a medley of chemical contaminants and metallic substances. Furthermore, when sulphur oxides and nitrogen oxides coalesce within the atmosphere, they give rise to the formation of delicate sulphates and nitrate aerosols. Major contributors to the presence of fine particles along transportation corridors are coal-fired power plants, industrial fuel combustion, as well as vehicle and diesel emissions [17]. Airborne fine particles, encompassing those below 2.5 micrometers in diameter, engender hazy conditions, impede visual acuity, and exert influence on the global radiation budget. PM 2.5 particles, in particular, are regarded as perilous to human health, with respiratory ailments
and increased mortality rates being linked to the inhalation of respirable particulate matter. Epidemiological investigations have also unveiled a correlation between elevated concentrations of fine particles and adverse health consequences in human populations [82].

Table 1: Laws, Rules and Regulations enforced by the Govt. of India for controlling Air Pollution (developed from [4]; [121])

Law, Rule, or Regulation	Date (Effective/ Revised)	Briefing	Acts/Programs
Air Pollution Control Areas	1981	The state government can declare any areas as air pollution control areas in which burning any materials that can cause air pollution would be prohibited, and only prescribed fuels can be used.	The Air (Prevention and Control of Pollution) Act
Restriction on certain industrial plants	1981	The operation of industrial plants within the air pollution control areas is prohibited unless permissions are granted	The Air (Prevention and Control of Pollution) Act
Standards for air pollutants	1981	No industrial plant is permitted to discharge air pollutants above standards.	The Air (Prevention and Control of Pollution) Act
Forty-two action point	2019	Central Pollution Control Board (CPCB) issued 42 measures for mitigating air pollution sources (including vehicular emissions, fugitive emissions, solid waste burning emissions, industrial emissions) in major cities of India.	National Clean Air Program
Increasing air quality monitoring networks	2019	Past data should be analyzed to make city super networks, and the networks should be monitored. Reassessment should be done so that the monitoring network could be augmented.	National Clean Air Program
Bharat Stage IV Emission Standards	2014	This regulation establishes new evaporative emission standards for two-wheelers. Emission limits of gases CO, NOX, HC+NOX were enlisted in regulating different types of two-wheelers.	Bharat Stage IV Emission Standards

The objective of this comprehensive analysis is to delve into the momentousness of employing Remote Sensing (RS) and Geographic Information Systems (GIS) to mitigate the exacerbation of particulate matter, thereby alleviating air pollution concerns prevalent in India. This examination will concentrate on discerning the roots of particulate matter emissions within the Indian context, exploring the utility of RS and GIS in monitoring and simulating concentrations of particulate matter, and appraising the potential of these cutting-edge technologies to inform policy-making endeavors and enhance public health outcomes.

Current Air Pollution scenario of some major Indian cities

Kolkata

The measurement of diverse airborne contaminants is undertaken as an integral part of the comprehensive ambient air quality monitoring network. In order to ensure the continual surveillance of ambient air quality in prominent industrial and urban regions across the nation, the esteemed Central Pollution Control Board (CPCB) established the National Ambient Air Quality Monitoring (NAAQM) in 1984, which now bears the title of the National Air Monitoring Programme (NAMP). Subsequently, the inclusion of Haldia and Durgapur within the network occurred when the routine project for monitoring ambient air quality in West Bengal commenced in Kolkata and Howrah under the aegis of NAMP. The West Bengal Pollution Control Board (WBPCB), operating under the guidance of NAMP, dutifully conducts regular assessments of the ambient air quality in significant urban and industrial zones within the state. Amongst the multifarious contributors to air pollution in Kolkata, transportation reigns supreme as the principal source of this environmental predicament [48]; [14]. This can be attributed to a confluence of factors, including the proliferation of poorly maintained vehicles, the employment of petrol, and subpar regulatory oversight. Additionally, within the vicinity of Kolkata, three thermal power plants operate, alongside a smattering of small-scale enterprises that further impinge upon the air quality. Analysis pertaining to the various sources of air pollution in Kolkata reveals that motor vehicles assume the mantle of primary culpability (51.4%), followed by industrial activities (24.5%), and the dispersion of dust particles (21.1%).

The exacerbation of vehicular pollution in Kolkata can be attributed to the heavy influx of cars that traverse the city's limited 6% of available road space, thereby engendering congestion, reduced average vehicle speeds, and consequential emissions. Notably, the number of automobiles has witnessed an almost twofold surge, escalating from 0.73 million in 1996 to 1.20 million in 2011. Within Kolkata, the proliferation of vehicles has occurred at a rate of 4% per annum. Furthermore, the count of private automobiles has undergone a 2.5-fold increase, surging from 0.26 million in 2000 to 0.65 million in 2011. The high density of private motor vehicles stands as one of the leading culprits responsible for the plague of traffic congestion, protracted travel times, heightened pollution levels, and a surge in accidents. Notably, Kolkata boasts the lengthiest stretch of accessible surface roads. Collaborative research conducted by the esteemed Chittaranjan National Cancer Institute (CNCI), the West Bengal Department of Environment, and the venerable Central Pollution Control Board (CPCB) revealed that approximately 70% of Kolkata's denizens suffer from respiratory ailments as a direct consequence of air pollution. In the year 1995 alone, it is estimated that air pollution contributed to a staggering 10,647 premature deaths within Kolkata [36]; [101]. Studies have further indicated that children exposed to the deleterious effects of polluted air in Kolkata exhibit severe pulmonary reactions and genetic abnormalities within their vulnerable lung tissues. Due to the perils of air pollution, an astounding 47% of the city's populace grapple with lower respiratory tract symptoms, with the burden on their lungs being nearly sevenfold that of their rural counterparts [98]; [102]; [46]. Moreover, the adverse health ramifications attributable to air pollution encompass an array of afflictions, including hematological abnormalities, impaired liver function, and genetic anomalies [46].

Mumbai

The diligent monitoring and characterization of PM 2.5 levels have become an imperative, as these fine particles in the atmosphere not only induce respiratory ailments but also engender diverse deleterious impacts on the ecosystem. To devise effective strategies for mitigating the presence of fine particles, it is crucial to establish air quality criteria [11]; [61]. Mumbai, a sprawling megacity with a populace exceeding 12 million, stands as one of the world's major urban centers. Within its confines, an array of industries such as oil refineries, pharmaceutical companies, thermal power plants, fertilizer enterprises, as well as engineering, electronic, and electrical establishments, contribute to its substantial industrial, commercial, and trade foundation [80]. Notably, according to the global air pollution database compiled by the World Health Organization (WHO), Mumbai ranked as the fourth most polluted megacity from 2010 to 2016 The air quality index (AQI) of Mumbai in 2019 ranged between 300 to 400, signifying [126] an alarmingly low and hazardous level of pollution [109]. In contrast to the 1%–5% occurrence of days with extremely poor AQI in 2017–2018, the city witnessed a rise to 6% in 2019 [107]. However, amidst the challenges, there emerged a silver lining as the lockdown measures implemented in 2020 led to a significant reduction in particulate matter (PM) and a drastic decline in nitrogen and sulfur oxides. Researchers observed that this decline in pollutants during the lockdown period enhanced air quality and subsequently played a role in limiting the spread of the virus in certain areas [68]; [104].

Delhi

In a manner akin to numerous other Asian cities, the air pollution predicament in Delhi predominantly stems from vehicular activity. Astonishingly, approximately 8% of the entire nation's motor vehicle population congregates within the confines of Delhi [6]. Estimates suggest that the vehicular sources in Delhi give rise to an alarming daily emission of over 3000 metric tonnes of pollutants (MT/day) [38]. As for the residential sector, its contribution to the city's air pollution is gradually waning. Household sources now constitute a mere 8% of Delhi's air pollution, witnessing a significant decline from 21% in 1970-1971 and 18% in 1980-1981.

The utilization of coal, kerosene, and unprocessed solid biomass such as firewood, cow dung, as well as agricultural waste including hay, husk, and dried leaves, serves as the principal culprits behind pollution arising from residential sources. Within Delhi, an array of monitoring stations operate under the umbrella of the esteemed National Air Quality Monitoring Programme (NAMP). The monitoring regimen focuses on three primary pollutants, namely, sulphur dioxide (SO2), nitrogen dioxide (NO2), and particulate matter (PM 10), and these parameters are subject to regular scrutiny at all designated locations. The monitoring process is conducted twice a week, spanning a 24-hour duration (with gaseous pollutants sampled every 4 hours and particulate matter sampled every 8 hours), resulting in a total of 104 observations over the course of a year. Across Delhi's industrial, commercial, and residential areas, 18 CPCB CAAQM (continuous ambient air quality monitoring) sites serve as the ground truth data sources for the primary pollutants analyzed in the present study, namely, PM 10, PM 2.5, and CO. These facilities ensure the daily measurement of air pollutant levels on an ongoing basis. In recent times, remote sensing technology has been harnessed in various research endeavors aimed at monitoring suspended airborne particles. Within the scope of the present case study, decision-support tools were employed to aid the regional government in their quest for effective air quality control measures in Delhi [111].

Bilaspur

Bilaspur has emerged as a paramount figure in the realm of national pollution concerns. Notably, Bilaspur holds distinction as the nucleus of India's electricity generation endeavors. Similar to its neighboring city Raipur, Bilaspur has witnessed a significant transformation since the inception of the state. Moreover, akin to its counterpart in Chhattisgarh, Bilaspur hosts a multitude of iron and coal plants. The rapid development and subsequent surge in iron and steel production have engendered environmental challenges due to the vast amounts of waste generated and the ramifications of its management. It is imperative to recognize that the steel sector stands as the largest consumer of energy and natural resources, while simultaneously emitting copious amounts of air pollutants, thereby posing substantial local and global environmental problems.

In the grand tapestry of steel manufacturing, the Raipur-Durg-Bhilai (RDB) region reigns as India's preeminent hub. The RDB region encompasses numerous foundries, metal-alloy factories, steel casting and rolling operations, iron and sponge factories, cement production facilities, as well as formalin manufacturing centers. It is within this landscape that India's largest and most productive integrated steel production, the Bhilai Steel Plant, takes center stage. Meanwhile, in the northern region of Chhattisgarh lies Korba, a locale teeming with coal-fired thermal power plants, including the National Thermal Power Corporation (NTPCR) and the Chhattisgarh State Electricity Board (CSEB). Korba proudly boasts 14 thermal power plants with a cumulative capacity of 8,625 MW, contributing a noteworthy 17.26 percent to the nation's total coal production. Annually, the Korba plant generates over 1 lakh metric tons of fly ash. These power plants have an electricity generation capacity of 6090 MW, catering to the energy needs of Korba and its surrounding regions. Regrettably, this scenario has led to the city becoming a focal point of pollution. Furthermore, the transportation of coal in open trucks within Korba exacerbates the air and water pollution predicament plaguing the city. The Comprehensive Environmental Pollution Index Report by the Central Pollution Control Board (CPCB) identifies Korba as one of the most severely polluted areas in the country. To gather pertinent data on air pollutants, an exhaustive examination of the official website of the Chhattisgarh Environment Conservation Board (CECB) was conducted. The CECB, headquartered in Raipur with additional regional offices in significant cities such as Raipur, Bilaspur, Durg-Bhilai, and Korba, played a pivotal role in providing vital information. The data was categorized into two distinct time periods: pre-lockdown (December 2019 to February 2020) and during lockdown (March to May 2020). The four cities in question received data from 15 monitoring stations, including six in Raipur, and one each in Bilaspur, Durg-Bhilai, and Korba. Notably, Chhattisgarh's CECB boasts an air quality monitoring system in addition to the systems employed by other states [90].

Sources of Air Pollution in India

The imperative task of controlling air pollution holds utmost importance for municipal authorities, and the formulation of an effective program to address air quality necessitates a precise understanding of the various sources contributing to the issue. Receptor modelling, a commonly employed technique, has been utilized in numerous Indian cities to estimate the contributions of different sources to ambient PM pollution [21]; [79]. However, it is worth noting that only a limited number of studies were conducted between 2000 and 2013 in other cities that also exceeded environmental limits and WHO guidelines, while a significant majority of known studies during this period focused on the five major cities of Delhi, Mumbai, Chennai, Kolkata, and Hyderabad [123].

While road transportation is often regarded as the primary contributor to urban air pollution, it is important to recognize that there are other significant sources that demand immediate attention [21] (Figure 1). The proportion of road transportation's contribution varied across the six cities, ranging from 7% in Pune to 43% in Chennai. Chennai, being a prominent commercial port alongside Mumbai, witnesses a substantial influx of diesel-fueled heavy-duty trucks traversing the city to and from the port, thereby amplifying the impact of road transport on ambient PM pollution. Notably, the spatial representation of contributions, confined to the sampling location and a 23-kilometer radius surrounding it, poses a noteworthy limitation of the receptor modelling technique. Therefore, it becomes imperative to conduct comprehensive investigations at various sites in order to gain a holistic understanding of source contributions within a city. Moreover, detailed chemical identification of emission sources serves as a crucial component in receptor modelling investigations, both as input data and for validation purposes. Although India has produced various source profiles, there remains a need for further development and expansion of this knowledge base [79].

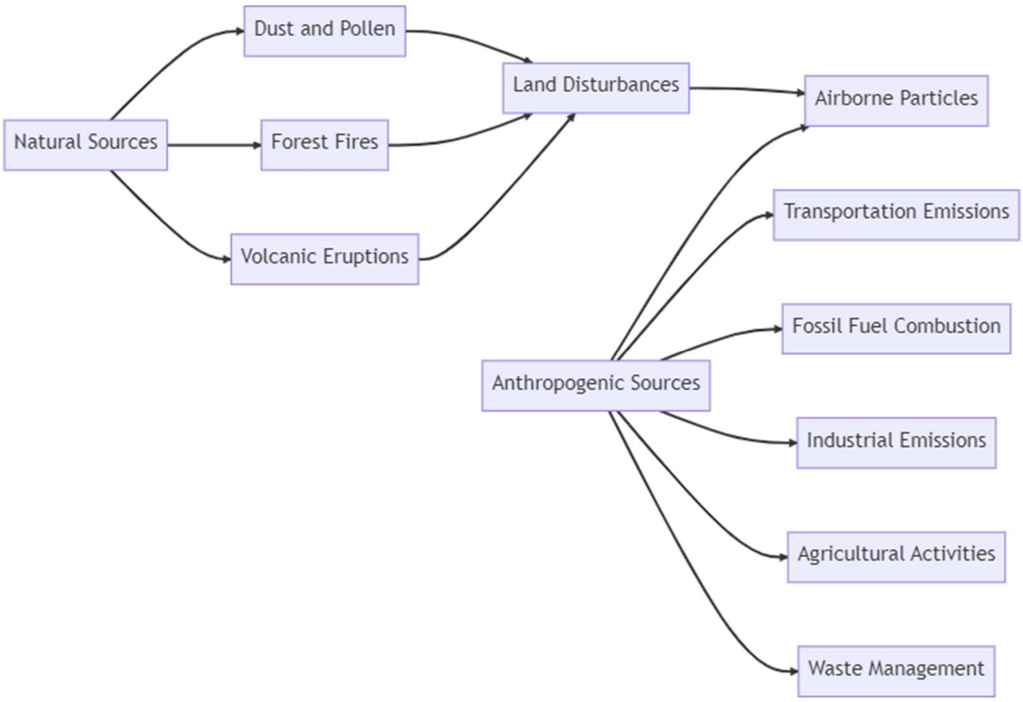

Figure 1: Sources of Air Pollution

Home consumption and indirect emissions from transportation together contributed roughly twice as much to ambient PM 2.5 concentrations as direct emissions from biomass cook stoves. Additionally, lower-income families bear a disproportionate share of the mortality risk from these indirect sources, which exacerbates the mortality risks that are already associated with their use of cook stoves that burn wood. End-of-pipe regulations that apply to the entire economy can thereby lessen pollution inequality [3]; [81]. However, clean cook stoves significantly minimise overall mortality risks and, in particular, the burden on the population with lower incomes [58]; [81].

In 2010, the average annual ambient PM 2.5 concentration in the country was about 43 gm^3, of which 23 gm^3 may be ascribed to household activities in India, either directly via the use of fuel in the home or indirectly through the manufacturing of consumer goods [74]. The remaining components are made up of contributions from non-anthropogenic and international sources, as well as economic activities carried out by institutions including governmental and non-profit Organisations, gross fixed capital creation, inventory changes, and exports. Our country's population-weighted PM 2.5 levels are somewhat lower than the choice of 2015 as a baseline which may help to explain the lowest estimate found in the reviewed papers is of 55 gm3. Across income classes, the share of direct and indirect contributions varies significantly. Industrial, motor vehicle, and anthropogenic fuel combustion, which includes residential burning of biomass for domestic reasons like cooking, all contribute to India's poor air quality. Even in rural regions, average daily PM 2.5 levels routinely surpass the 24 hour limit of 60 gm^3 and can even reach 200 gm^3 [88]. PM 2.5 is a combination of particles that are directly released as well as those created when secondary organic aerosols are generated in the atmosphere from volatile organic chemicals [96].

It is essential to emphasize that controlling air pollution encompasses not only the sources associated with road transportation, but also a diverse array of sectors, including industries, electricity generation, construction activities, road dust, open burning of waste, household use of coal, oil, and biomass, as well as marine/sea salt and agricultural activities [45]; [110]; [128]. Contrary to common perception, there exist additional sources of urban air pollution that warrant immediate attention [118]. Some sources of air pollution are illustrated in figure 2. Consequently, a comprehensive approach is imperative in addressing the multifaceted challenges posed by air pollution.

Figure2: (A) Usage of coal as fuel for burning in local shops are prevalent on large scale in most cities and villages; (B) Constructions on road by clearing trees; (C) Increase of private vehicles leading to more consumption of fuel as well as traffic problems; (D) Open dumping of wastes; (E) Conversion of green fields into barren fields for different activities; (F) Tanneries drying the skins for leather product making.

Role of Remote Sensing in Air Pollution monitoring

On-road Remote Sensing (RS)

The ever-changing nature of vehicle emissions in real-world driving scenarios has been acknowledged by various studies [23]; [48]; [14]. To enhance the accuracy of identifying high-emitters, a novel dual RS approach has been devised. When a vehicle passes an RS site, emissions of CO2, CO, HC, and NO, driving conditions such as speed and acceleration, and the vehicle's number plate (to obtain registration information) are recorded twice. The utilization of RS and GIS in air pollution monitoring encompasses diverse methodologies and takes varied forms (Figure 3, 4, and 5).

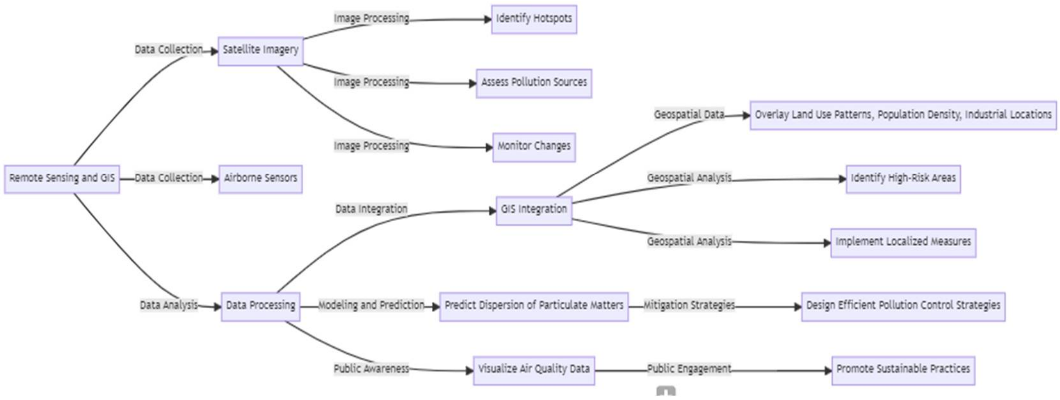

Figure 3: Uses of RS and GIS in Air Pollution management

Since 2012, the Hong Kong Environmental Protection Department (HKEPD) has been consistently measuring car emissions using on-road RS technology. Over a span of seven years, from 2012 to 2018, approximately 2.6 million gasoline and LPG vehicles were monitored as part of a continuous measurement program with license plate data linked to the measurements. A pair of emission records is considered valid if two conditions are met. First, both RS systems must measure sufficient CO2 exhaust emissions. Second, the vehicle's driving conditions while passing both RS systems must align with the conditions specified by the Hong Kong Transport Emission Testing (HKTET) cycle (i.e., speed between 7 to 90 km per hour and acceleration within 5 to 3 km per hour per second). This approach aims to mitigate excessive emissions resulting from off-cycle driving situations, thereby improving the accuracy of identifying high-emitters. Applying these criteria, a total of 1,057,913 pairs of valid emission records were collected from the complete dataset, comprising 661,003 petrol vehicles and 396,910 LPG vehicles.

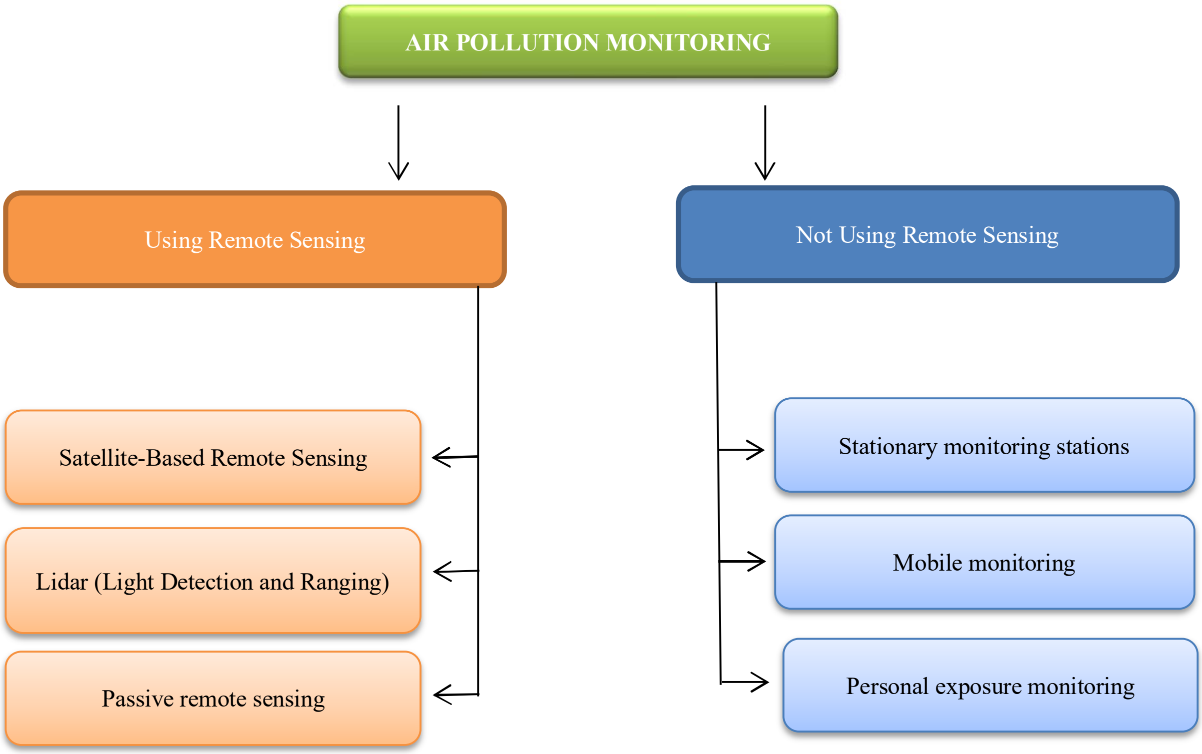

Figure 4: Air Pollution control with and without using RS and GIS techniques

Air Quality Monitoring

The HKEPD has been actively establishing an air quality monitoring network to continually assess concentrations of criteria pollutants, including CO, NOx, O3, SO2, PM 10, and PM 2.5 on an hourly basis. The network comprises three roadside and fifteen general air quality monitoring stations that respectively measure roadside and ambient air quality. Chemiluminescence-based techniques, utilizing commercial devices such as T-API 200A, T-API T200, or TECO 42i, are employed to detect NOx emissions. CO emissions are measured using non-dispersive infrared spectrometers, specifically T-API 300, T-API T300, or TECO 48C techniques [49].

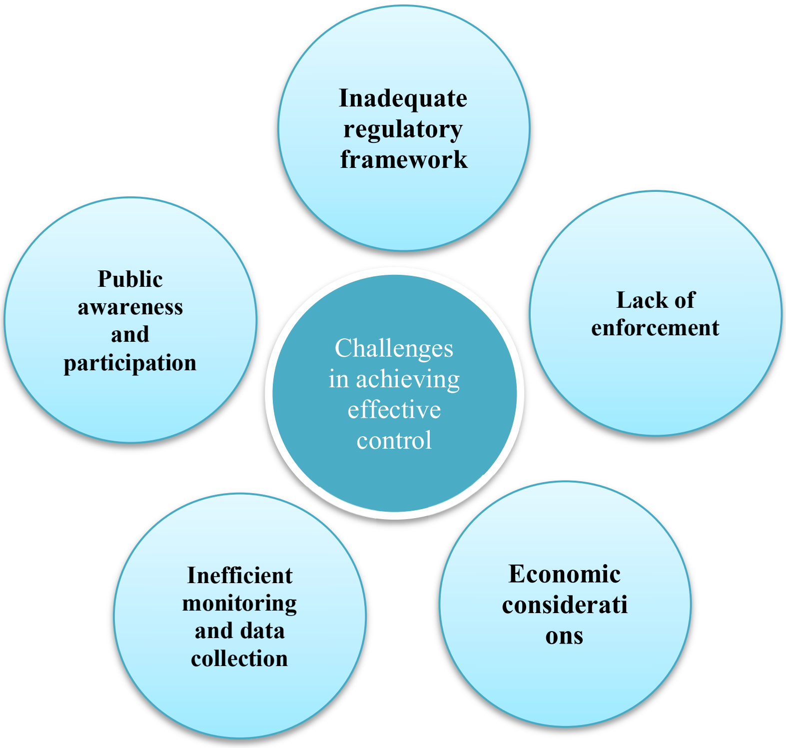

Figure 5: Ways to achieve effective control on Air Pollution [60]; [4].

PM 2.5, which refers to fine particulate matter with a diameter of less than 2.5 micrometers, has been associated with lung cancer, pulmonary inflammation, and cardiovascular mortality [5]; [83]. Comprehensive global assessments of these aerosols play a crucial role in epidemiological studies, air quality management strategies, and air quality forecasting [2]. Since the launch of NASA's Terra satellite in 1999, the Moderate Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging Spectroradiometer (MISR) instruments have provided global measurements of aerosol optical depth (AOD), which quantifies the amount of light extinction by aerosols in the atmospheric column during their overpass time at 10:30 local time (LT) [20]. Establishing temporal connections between space-based AOD observations and surface PM concentrations has garnered considerable attention [30]; [29]; [28]; [27].
RS enables the determination of relative concentration ratios of pollutants over CO2, such as CO/CO2, HC/CO2, and NO/CO2 [50]. Simultaneously, the RS system records the vehicle's speed, acceleration, and captures an image of its license plate. When a vehicle passes a measurement location, the on-road RS approach captures tailpipe emissions, speed, acceleration, and license plate information in just half a second. These data serve various purposes, including the development of emission factors [13]; [15]; [77]. The primary advantages of RS are its cost-effectiveness in testing a large number of vehicles and its ability to provide emissions data for individual vehicles and specific vehicle classes. However, compared to air quality monitoring stations, RS has limitations such as measuring only a limited number of emission species (mostly CO2, CO, HC, and NO) and providing data for a limited time period (mostly during work hours and dry weather) due to the need for constant human supervision and on-site calibration every two hours. Ambient approaches measure the mass or volume concentrations of pollutants (e.g., g/m3 or ppm) at monitoring locations near roadways or other relevant sources. Pollutant concentration data can be utilized to assess vehicle emission patterns and devise emission control strategies that require minimal or no treatment [12]; [16]; [71]; [72]; [78]; [99].

Orbits and Viewing Geometry

Satellites that collect data on trace components in the lower troposphere generally orbit near-polar, sun-synchronous, low Earth orbits. These satellites maintain an average altitude of 705 kilometers, completing one circle every 100 minutes, resulting in approximately 14 complete orbits per day. Orbital precession, caused by the non-uniformity of the Earth's gravitational field, compensates for the Earth's movement around the Sun. As a result, the satellite crosses the equator twice during each orbit, once in the southward or descending direction and once in the northward or ascending direction. Observations are made at nearly consistent local times in low and mid-latitudes, allowing for relatively high sampling frequency in these regions [50].

Vertical Sensitivity

The ability of nadir-viewing satellite instruments to detect trace gases and aerosols in the atmosphere depends on factors such as surface reflectivity or emissivity, cloud cover, viewing geometry, retrieval wavelength, and, in the case of solar backscatter, the presence of aerosols. The sensitivity of these instruments to trace gases in the middle and upper troposphere is typically near 100% [50].

Satellite-based Earth remote sensing refers to the measurement of reflected and emitted radiation from the Earth's surface using satellite platforms. These observations are crucial inputs for climate models, which analyze model output to understand short- and long-term changes and trends in the Earth's climate and environment, identify the causes of such changes, and forecast or influence future changes [14]. Ground PM 2.5 data for global estimates have been derived through geographically weighted regression (GWR) using satellite sources. Data from multiple satellites, including Misr, MODIS Dark Target, MODIS and SeaWiFS Deep Blue, and MODIS MAIAC, have been integrated with modeling based on their relative uncertainty as assessed by a terrestrial solar photometer (AERONET). The global ozone observation experiment (GOME), SCIAMACHY, and GOME-2 satellite sensors have been utilized for monitoring NO2 pollution [117]. The surface concentration of nitrogen dioxide (NO2) is calculated by employing local ratios with a global three-dimensional model (GEOS-Chem) and the distribution of tropospheric NO2 observed by the ozone monitoring instrument (OMI) aboard the satellite Aura [87].

Effect of Air Pollution on Human health

We explore potential pathways and uncover that exposure to air pollution exerts a deleterious impact on self-reported physical well-being, exacerbates respiratory ailments, and elevates the risk of sleep disturbances [84]; [67]. Accounting for the mental health implications of pollution exposure is imperative in assessing the true health costs of air pollution and formulating effective environmental policies [7]. A study on the respiratory system in Kolkata revealed that 27% of inhaled PM settled in the trachea, while 10% reached the alveolar regions [75]. Analysis of outdoor exercisers' estimated deposited dosage indicated that males had higher respiratory doses compared to females (Table 2).

Table 2: Pollutants and the respective diseases.

Pollutant	Disease	References
Particulate Matter (PM)	Acute nasopharyngitis, Long Term Cronic effect, Respiratory diseases and affection of the immune, Asthma, Pneumonia, Diabetes, Respiratory and Cardiovascular diseases.	[129]; [54]
Ozone (O3)	Functional, and immunological disorders, Affects the upper layers of the skin and the tear ducts, malondialdehyde formation in the upper skin (epidermis), effect on lungs, respiratory deaths, and cardiovascular deaths.	[122]; [112]
Carbon Monoxide (CO)	Hypoxia, Ischemia, and cardiovascular disease.	[129]
Nitrogen Oxide (NO2)	Irritant of the respiratory system, respiratory diseases, Coughing, Wheezing, dyspnea, bronchospasm, and even pulmonary edema, impair the sense of smell; affect T-lymphocytes, particularly the CD8+ cells and NK cells that produce our immune response. Eye, throat, and nose irritation.	[17]; [18]
Sulfur Dioxide (SO2)	Lung disease, respiratory irritation, bronchitis, mucus production, and bronchospasm, bronchoconstriction, skin redness, damage to the eyes, mucous membranes, and worsening of Pre-existing cardiovascular disease.	[17]; [18]
Polycyclic Aromatic Hydrocarbons(PAHs)	Lung cancer.	[1]; [97]
Volatile Organic Compounds(VOCs)	Irritation of eyes, nose, throat, and mucosal membranes.	[73]
Dioxins	Dark spots and lesions on the skin, developmental problems, impairment of the immune, endocrine and nervous systems, Reproductive infertility and cancer.	[51]
Lead	Affects the fetal nervous system, edema or swelling of the brain, loss of concentration and memory, muscle and joint pain, learning disabilities, impairment of memory, hyperactivity, and Even mental retardation.	[31]

Deposition levels were higher in the morning than in the evening during both winter and summer seasons. Additionally, PM 10 deposition predominated in the head region, while PM-1 deposition was prominent in the tracheobronchial areas, and PM 1-2.5 deposition occurred primarily in the alveolar region [40]; [86]. In Chennai, the Multiple Path Particle Dosimetry model was utilized to predict pedestrian dosage on urban sidewalks near the beach and highway roadways. The findings indicated that PM10 and PM 2.5 doses were highest in the evening on the seaside route, whereas they were lowest in the morning, with the reverse pattern observed on the motorway road. Doses of respiratory deposition were estimated for street vendors in residential areas during both winter and summer seasons. PM9-10 deposition was found to be highest in the head and tracheobronchial regions compared to other size categories. Notably, regardless of PM size or respiratory area, deposition in the alveolar region consistently exceeded that in residential vendors during the winter season [85]. Deposition doses of size-segregated PM were predicted for various age groups near a major traffic location in Chennai. The highest PM mass deposition was reported in the 8-year-old age group. Furthermore, clearance of deposited PM was observed to be greater in the tracheobronchial area compared to the alveolar region during the post-exposure period, with higher PM doses observed in the lower lobes compared to the middle and upper lobes [69]; [70]. Except for PM0.3-0.4, the dominant mass deposition fraction pattern at Kanpur was found to be head > alveolar > tracheobronchial across all seasons. The PM0.3-0.4 range exhibited an alveolar > head > tracheobronchial trend. PM5.8-7.8 contributed the most to the total deposited mass during the summer and monsoon seasons, while PM0.3-0.4 contributed the most during the winter and post-monsoon seasons [91]. During the monsoon season, the head area exhibited the highest proportion of deposition, followed by summer and winter, whereas the alveolar region displayed a seasonal pattern of winter > summer > monsoon [33]; [34].

The annual average excess number of respiratory mortality (RM) per million population is relatively modest. According to the graph, Mumbai had the highest annual average excess number of RM (121/year), followed by Chandrapur (98/year), Navi-Mumbai (84/year), Pune (78/year), Nashik (68/year), and Solapur (67/year). The excess RM was estimated by aggregating the totals of PM10, SO2, and NO2 [64]. The annual average excess number of COPD-related mortality (ENCsOMP) exhibited a different trend and was relatively low since only SO2 and NO2 were considered responsible for COPD. The top five cities with the highest ENCsOMP were Mumbai (34/year), Navi-Mumbai (21/year), Pune (20/year), Nasik (18/year), and Chandrapur (17/year). Suspended particle matter (SPM) is the primary cause of COPD, but it was not included in this study, hence the lower numbers across all cities [64].

The physiological implications of air pollution on human health are intricate and multifaceted. Animal model studies provide most of the foundational data on physiological impacts, and there is widespread consensus that cellular damage and inflammation play significant roles [116]. Air pollution affects not only the respiratory system but also the cardiovascular, hematopoietic, and central nervous systems. It poses hazards to health through various mechanisms. Particulate matter intake can lead to both acute and long-term consequences, depending on the duration of exposure. Air pollution may (1) increase the risk of underlying diseases that contribute to frailty and higher short-term mortality risk in frail individuals, (2) increase the risk of chronic diseases associated with frailty but not related to timing of death, or (3) increase the risk of short-term mortality in frail individuals without affecting the risk of chronic diseases [62]. While numerous studies have explored the health impacts of pollution globally, research in India remains limited. Most of the health and pollution studies in Delhi are cross-sectional in nature. Air pollution reduction in Delhi, including the closure of polluting firms and the use of compressed natural gas for buses were examined in a study. They conducted surveys with 1,576 households and evaluated pollution at 113 locations over a six-month period (July to December 2003). Their findings indicated that stringent control measures were associated with improved respiratory function, although the benefits varied depending on gender and socioeconomic status [32]. Recently, short-term effects of air pollution on daily mortality in two Indian cities, Delhi and Chennai, were investigated, highlighting the need for further research in this area [8]; [9]; [10]; [89]. Both studies utilized daily all-cause mortality and pollution data from 2002 to 2004 to run Poisson regression models examining the association between PM10 and daily deaths. In Delhi, each 10 g/m3 increase in PM10 concentrations was associated with a 0.15% (95% CI 0.07 to 0.23) increase in daily all-cause mortality [24]; [25]; [26].

In Kolkata, a health survey was conducted in dispensaries run by the Kolkata Municipal Corporation (KMC). Dispensaries were chosen due to their accessibility and availability of target cases. The primary objective of the survey was to determine if air pollution, as perceived by the respondents, poses a significant barrier to healthy living and to avoid misconceptions regarding a direct causal link between air pollution and health. Among the numerous dispensaries in Kolkata, two were selected for the primary survey: Behala Dispensary, where air pollution was reported as critical, and Ultadanga Dispensary, where pollution levels were higher based on RPM concentration. Due to the absence of monitoring stations falling into the moderate or low pollution categories for SO_2 and NO_2 concentrations, dispensaries in the low pollution category were not identified. While the research design aimed to include dispensaries with varying pollution levels, the selection was limited to critical and high-risk facilities [46].

Only dispensaries falling into the high pollution categories were included. Tangra Dispensary, which was not associated with any monitoring station, was chosen for the health survey. The selection of Tangra Dispensary was not based on its low pollution levels, but rather on its easy accessibility and availability of the target cases sought in the research. A total of 100 individuals were interviewed, including 28 from Ultadanga Dispensary, 43 from Tangra Dispensary, and 29 from Behala Dispensary. Only patients suffering from respiratory or waterborne infections were included in the survey, with respiratory disorders accounting for more than 85% of the respondents. The patients with respiratory disorders were identified with the assistance of medical officials and health practitioners from each of the three dispensaries. The survey was conducted in July and August 2014, employing a structured questionnaire that inquired about people's reactions to ambient air pollution, major symptoms experienced by patients with respiratory diseases, and outdoor pollution-avoidance activities practiced by respondents in their daily lives. The survey approach was purposive, with emphasis placed on clinics falling into various pollution categories due to their accessibility and availability of the target cases, and only patients with the specific disorders under investigation were included [46].

The primary route for pollutants to enter the human body is through inhalation, and the most common consequence of air pollution is respiratory system damage. Exposure to pollutants in polluted air can cause symptoms such as headaches, eye irritation, skin allergies, chest pain, respiratory problems (including asthma, shortness of breath, difficulty breathing, cough, and wheezing), and lung problems (such as chronic bronchitis, emphysema, tuberculosis, and pneumonia). The Health Status Study involved selecting 35 participants from each sample site, and personal interviews were conducted to gather background information. The criteria for participant selection were based on random selection of individuals aged 20 to 45 at the respective locations. Following the completion of the cohort health sampling, it was observed that a majority of the individuals reported experiencing headaches, eye irritation, skin allergies, chest pain, respiratory problems (including asthma, shortness of breath, cough, wheezing, difficulty breathing), and lung problems (such as bronchitis infection, pneumonia, tuberculosis, and emphysema). The link between air pollution and indicators of lung function has been well-established [100]; [120]. Long-term exposure to particle concentrations has been associated with increased mortality from lung diseases [120]. Particulate matter in the ambient air has been shown to have acute effects, including increased daily mortality and increased hospital admissions for exacerbation of respiratory illnesses [120]. However, the health consequences of suspended particulate matter in humans are influenced by particle location, concentration, and duration of exposure [56].

Conclusion

In conclusion, it is crucial that remote sensing and Geographic Information Systems (GIS) play a major role in minimising particulate matter and lowering air pollution in India. Effective techniques for pollution management and control have been made possible by the combination of various technologies, which has given useful insights into the distribution, origins, and movement of particulate matter. Our understanding of air pollution has been completely transformed by remote sensing technologies, such as satellite images and airborne sensors, which provide detailed and real-time data on particulate matter levels across wide regions. With the use of this information, pollution hotspots may be found, pollution sources can be evaluated, and variations over time can be tracked. Policymakers and academics may create focused interventions and make educated judgements with the aid of remote sensing to successfully combat air pollution.

Remote sensing data must be combined with other pertinent geographical data, like population density, land use patterns, and industrial sites. This is where GIS comes into play. GIS enables the identification of high-risk locations and vulnerable people by superimposing and analysing these data layers, easing the deployment of localised pollution control strategies. Additionally, GIS supports the modelling and forecasting of particulate matter dispersion, assisting in the creation of effective pollution control methods. Additionally, GIS and remote sensing have shown to be helpful in raising public awareness of and participation in the fight against air pollution. These technologies offer accessible platforms for individuals to visualise air quality data and comprehend the effects of pollution on their health and well-being through user-friendly interfaces and interactive maps. This increased awareness encourages individuals to adopt sustainable practices and actively participate in initiatives aimed at reducing air pollution.

Nevertheless, despite the fact that GIS and remote sensing are important instruments for reducing particulate matter and battling air pollution, their efficient application necessitates cooperation and coordination among several parties. To create effective monitoring systems, communicate data, and execute policies that are supported by evidence, governments, research institutions, businesses, and communities must collaborate. Our strategy for minimising particle matter and lowering air pollution in India has been completely transformed by the combination of remote sensing and GIS. These technologies hold the key to establishing a cleaner and healthier environment for all people by delivering accurate and current information, enabling targeted actions, and raising public awareness. A sustainable future with better air quality in India is possible with the help of proactive measures combined with ongoing improvements in remote sensing and GIS.

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