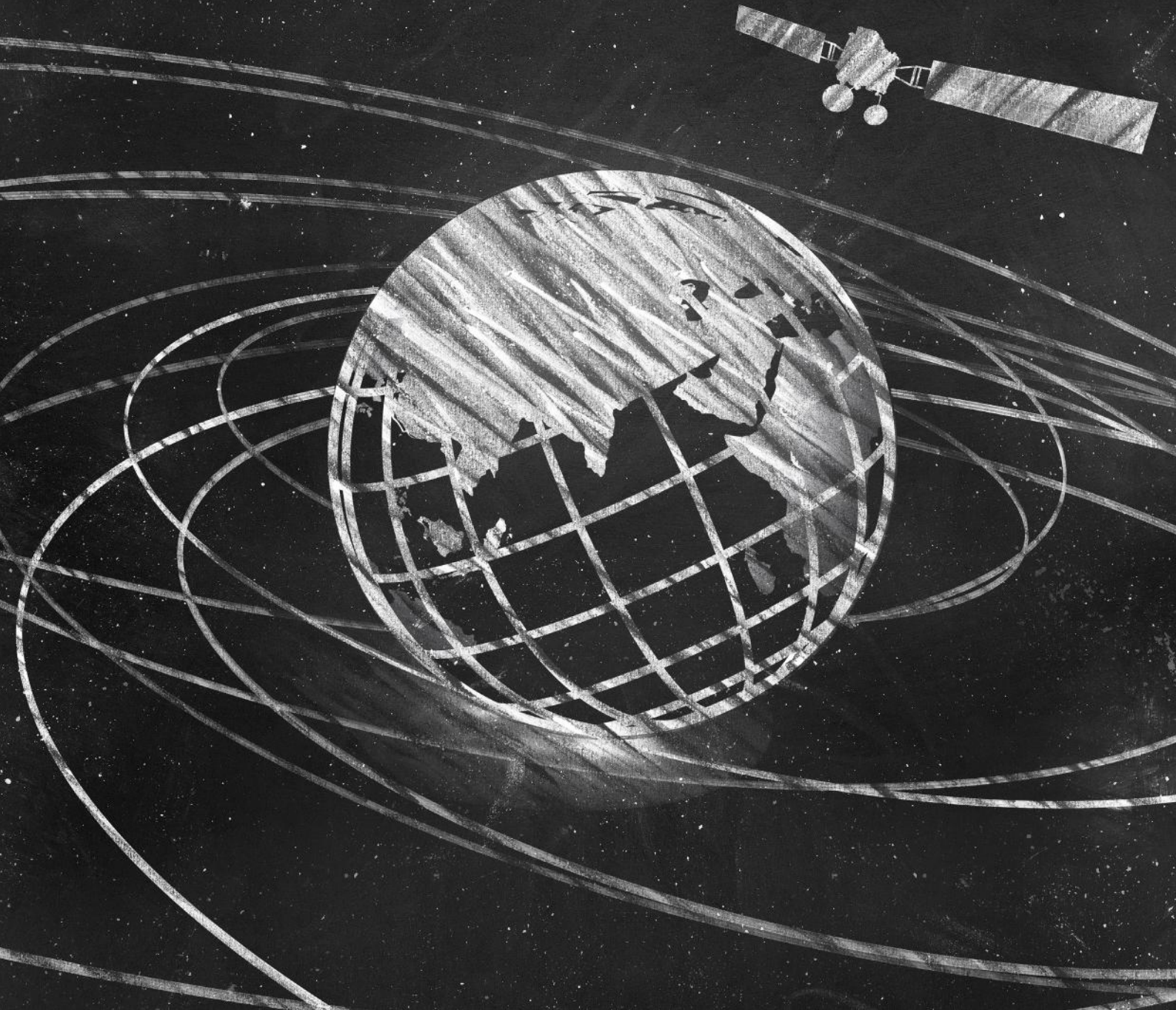# Managing India's Air Quality Through an Eye in the Sky

L. S. Kurinji and Tanushree Ganguly

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Managing India's Air Quality Through an Eye in the Sky

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About CEEW

The Council on Energy, Environment and Water (CEEW) is one of South Asia's leading not-for-profit policy research institutions. The Council uses data, integrated analysis, and strategic outreach to explain – and change – the use, reuse, and misuse of resources. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public.

In 2019, CEEW once again featured extensively across nine categories in the 2018 *Global Go To Think Tank Index Report*, including being ranked as South Asia's top think tank (15th globally) with an annual operating budget of less than USD 5 million for the sixth year in a row. CEEW has also been ranked as South Asia's top energy and resource policy think tank in these rankings. In 2016, CEEW was ranked 2nd in India, 4th outside Europe and North America, and 20th globally out of 240 think tanks as per the ICCG Climate Think Tank's standardised rankings.

In nine years of operations, The Council has engaged in over 230 research projects, published over 160 peer-reviewed books, policy reports and papers, advised governments around the world nearly 530 times, engaged with industry to encourage investments in clean technologies and improve efficiency in resource use, promoted bilateral and multilateral initiatives between governments on 80 occasions, helped state governments with water and irrigation reforms, and organised nearly 300 seminars and conferences.

The Council's major projects on energy policy include India's largest multidimensional energy access survey (ACCESS); the first independent assessment of India's solar mission; the Clean Energy Access Network (CLEAN) of hundreds of decentralised clean energy firms; the CEEW Centre for Energy Finance; India's green industrial policy; the USD 125 million India-U.S. Joint Clean Energy R&D Centers; developing the strategy for and supporting activities related to the International Solar Alliance; designing the Common Risk Mitigation Mechanism (CRMM); modelling long-term energy scenarios; energy subsidies reform; energy storage technologies; India's 2030 Renewable Energy Roadmap; energy efficiency measures for MSMEs; clean energy subsidies (for the Rio+20 Summit); Energy Horizons; clean energy innovations for rural economies; community energy; scaling up rooftop solar; and renewable energy jobs, finance and skills.

The Council's major projects on climate, environment and resource security include advising and contributing to climate negotiations in Paris (COP-21), especially on the formulating guidelines of the Paris Agreement rule-book; pathways for achieving NDCs and Mid-century Strategy for decarbonisation; assessing global climate risks; heat-health action plans for Indian cities; assessing India's adaptation gap; low-carbon rural development; environmental clearances; modelling HFC emissions; the business case for phasing down HFCs; assessing India's critical minerals; geoengineering governance; climate finance; nuclear power and low-carbon pathways; electric rail transport; monitoring air quality; the business case for energy efficiency and emissions reductions; India's first report on global governance, submitted to the National Security Adviser; foreign policy implications for resource security; India's power sector reforms; zero budget natural farming; resource nexus, and strategic industries and technologies; and the Maharashtra-Guangdong partnership on sustainability.

The Council's major projects on water governance and security include the 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; irrigation reform for Bihar; *Swachh Bharat*; supporting India's *National Water Mission*; collective action for water security; mapping India's traditional water bodies; modelling water-energy nexus; circular economy of water; participatory irrigation management in South Asia; domestic water conflicts; modelling decision making at the basin-level; rainwater harvesting; and multi-stakeholder initiatives for urban water management.

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Kurinji is a Research Analyst at CEEW. At The Council, her research revolves around air pollution studying crop residue burning using technologies like remote sensing in northern India, and addressing the regulatory challenges in the implementation of mitigation measures. She holds a bachelor's degree in Energy and Environmental Engineering from Tamil Nadu Agricultural University, Coimbatore. She is an Indian Green Building Council (IGBC) Accredited Professional.

"Much of the satellite observations on pollution over the Indian landmass comes from overseas satellites that are temporally inconsistent. As satellites enable us to get a wider view of pollution, it is time for India to consider having a geostationary satellite to keep a constant watch."

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Tanushree Ganguly is a Programme Associate at CEEW. Her work focuses on assessing the potential of alternative methods of monitoring air quality, and understanding and addressing current regulatory challenges for the effective implementation of clean air policies. She has a master's degree in Environmental Engineering from Georgia Institute of Technology and is a certified Engineer-in-training under California law.

"Fires, dust storms, aerosols – satellites see it all. The air quality management framework in India would remain incomplete without the integration of satellite-based observations."

Contents

Abbreviations

AOD	aerosol optical depth
CAAQMS	Continuous Ambient Air Quality Monitoring System
CPCB	Central Pollution Control Board
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CEEW	Council on Energy, Environment and Water
CEMS	Continuous Emission Monitoring System
CREAMS	Consortium for Research on Agroecosystem Monitoring and Modelling from Space
DPCC	Delhi Pollution Control Committee
ESA	European Space Agency
FAST	Forest Fire Alerts System
FIRMS	Fire Information for Resource Management System
FSI	Forest Survey of India
GEE	Google Earth Engine
HCHO	formaldehyde
IITM	Indian Institute of Tropical Meteorology
INSAT	Indian National Satellite System
ISRO	Indian Space Research Organisation
MoEFCC	Ministry of Environment, Forest and Climate Change
MoES	Ministry of Earth Sciences
MOPITT	Measurements Of Pollution In The Troposphere
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NCAP	National Clean Air Programme
NCTPS	North Chennai Thermal Power Station
NO_2	nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
O_3	ozone
OMI	Ozone Monitoring Instrument
PM	particulate matter
SAC	Space Applications Centre
SPCB	State Pollution Control Board
VCD	vertical column density
VIIRS	Visible Infrared Imaging Radiometer Suite
USA	United States of America
US EPA	United States Environmental Protection Agency
SO_2	sulphur dioxide

Abstract

Toxic air has emerged as a high-mortality environmental risk resulting in over 4.2 million deaths annually (WHO 2016). The indiscriminate use of dirty fuels for power generation and transportation, in combination with unscientific combustion practices, have led to dangerous levels of air pollution. Effective air quality management calls for identifying polluting sources, estimating the relative contributions of these sources, setting pollution reduction targets, designing cost-effective pollution control strategies, and constantly monitoring the implementation progress of these strategies.

The *National Clean Air Programme* (NCAP)—launched by the Ministry of Environment, Forest and Climate Change (MoEFCC) in January 2019 has stipulated a target of 20-30 per cent reduction in particulate matter (PM) concentration by 2024. The NCAP sets out an air pollution mitigation strategy for the country and acknowledges the need for extensive monitoring infrastructure which would integrate both ground-based and satellite observations. The heavy infrastructural investment required to set up Continuous Ambient Air Quality Stations (CAAQMS) will hinder the scaling up of the number of CAAQMS in the country. In the absence of adequate ground monitoring facilities, effective utilisation of satellite data would help in tracking air quality.

Applications of satellite data can be put to uses that go beyond just complementing ground monitoring. This brief examines how satellite observations are currently aiding air quality management in India and identifies possible applications of satellite data to enhance the process. Possible applications include identifying airsheds, demonstrating episodic pollution, and carrying out inspections of consistently non-compliant sources.

The brief identifies challenges associated with the utilisation of satellite data, the most important being the lack of technical capacity to accurately interpret satellite observations in order to derive insights. The lack of adequate infrastructure to store and process such large volumes of data is also a major bottleneck in scaling up the utilisation of satellite data. Also, all insights drawn from satellite observations need to be evaluated and appropriately validated with ground information to ensure that they are accurate and suitable for the purpose.

> **Possible applications of satellite monitoring include identifying airsheds, demonstrating episodic pollution, and carrying out inspections of consistently non-compliant sources.**

Finally, the brief recommends that India should envision launching its own satellite mission to monitor air quality. National space agencies must ensure that the remotely captured information is made easily accessible to the public through online platforms. The MoEFCC should design and conduct training programmes to develop and upgrade the necessary skill-set among air quality practitioners, both regulators and researchers in the country.

1. Introduction

Due to recent technological advances and their versatility, satellite observations have found several applications in environmental monitoring. Satellites provide visual evidence of every major environmental occurrence, including rapidly changing land use and land cover patterns (Alam, Bhat, and Maheen 2019), settlement patterns, the acute water crisis in Chennai (Radhakrishnan 2019), and the massive forest fires in the Amazon (Lai, Lu, and Migliozzi 2019).

Globally, atmospheric scientists have started using satellite data to derive valuable findings on air pollution. This ranges from analysing long-term trends in particulate matter (PM) concentration (Chowdhury et al. 2019) to tracking pollutant plumes from large industrial units. Particulate concentrations derived from satellite-measured aerosol optical depth (AOD) readings find application in global health studies that estimate the mortality and morbidity burden attributable to air pollution (Donkelaar et al. 2010); (Balakrishnan et al. 2018). Scientists from National Aeronautics and Space Administration (NASA) have used information collected by the Ozone Monitoring Instrument (OMI) aboard the NASA Aura satellite to develop bottom-up SO_2 emission inventories and estimate the long-term sulphur dioxide (SO_2) emission trends from large anthropogenic sources across the globe (Fioletov et al. 2015; Zheng et al. 2018).

Regulatory agencies in countries like China and the USA have also identified ways to employ satellite measurements in air quality forecasting, thereby aiding the process of air quality management and enabling accurate early warnings. The National Oceanic and Atmospheric Administration (NOAA), in partnership with the United States Environmental Protection Agency (US EPA), issues daily air quality forecast guidance. These forecasts incorporate AOD observations made by Moderate Resolution Imaging Spectroradiometers (MODIS) Aqua and Terra satellites. Indeed, since the incorporation of satellite data in 2018, the accuracy of forecasts has improved by approximately 38 per cent (Poteet 2019).

Need for satellite monitoring

Studies have shown that India's monitoring network has a density of ~0.14 monitors/million persons (one monitor for every 6.8 million people), which is well below that of other highly populated countries, as shown in Table 1.

Table 1: Density of air quality monitoring networks across different countries

Country	Air quality monitoring network density (no. of monitors/million persons)
India	0.14
China	1.2
USA	3.4
Japan	0.5
Brazil	1.8
Most European countries	2–3

Source: Brauer, Michael, Sarath K. Guttikunda, K A Nishad, Sagnik Dey, Sachchida N. Tripathi, Crystal Weagle, and Randall V. Martin. 2019. "Examination of monitoring approaches for ambient air pollution: A case study for India." Atmospheric Environment.

As of September 2019, the Central Pollution Control Board (CPCB) operates 779 manual and 200 Continuous Ambient Air Quality Monitoring Systems (CAAQMS) in India; most of these stations are located in urban areas (CPCB 2019). The National Clean Air Programme (NCAP), launched by the Indian Government in January 2019, plans to increase the coverage to 1,500 manual systems and add 150 CAAQMS by 2024 (MoEFCC 2019). However, even with this proposed increase, the number of monitoring stations would still be inadequate. More than 4,000 monitoring stations (2,800 in urban areas and 1,200 in rural areas, as per a 2011 census) are required to spatially, temporally, and statistically represent the $PM_{2.5}$ (particulate matter) pollution in urban and rural areas in India as per the thumb rule proposed by the CPCB, which computes the required number of monitoring stations on the basis of the population of an area (Brauer et al. 2019).

While manual monitoring stations under the National Ambient Monitoring Programme generate two observations per week, CAAQMS generate more instantaneous data. Given the higher frequency of data generation, installing CAAQMS would aid in the constant surveillance of air quality. However, CAAQMS require heavy capital investment, to the tune of

approximately INR 1.5 crore each (Brauer et al. 2019), and they have limited spatial coverage. The wide spatial coverage of satellite remote sensing can help to fill the data gaps that exist due to the vast geography; it would also give clear information on the spatial distribution of air pollution across the country. Satellite monitoring can also help in understanding the columnar profile of the pollutant and its possible long-range transport, which is not feasible with traditional ground monitoring.

> **The wide spatial coverage of satellite remote sensing can help to fill the data gaps that exist due to the vast geography.**

While the academic and research community in India has been using satellite measurements of atmospheric products to develop insights on India's air pollution crisis, regulatory agencies are yet to identify and tap the potential of remote sensing use for air quality management. The fact that NCAP recognises the need to augment India's air quality monitoring network with satellite monitoring is definitely a step in the right direction. However, applications of satellite data should not just be confined to using satellite-based measurements to augment the monitoring network and to aid air quality forecasting. Satellite data could be used as an effective tool to monitor episodic pollution, estimate emissions from large point sources, and understand the contribution of outside sources to local air pollution. This brief identifies these potential applications of remote sensing.

2. Atmospheric products from satellites

Satellite data can primarily be used to complement air quality monitoring and support air quality forecasting. Monitoring refers to the measurement of parameters like AOD and gaseous columnar volume densities, which are then translated into particulate concentration (Chowdhury et al. 2019) and gaseous emissions, respectively. Monitoring products can be used to estimate long-term trends in pollutant concentrations and to derive the emission inventories of major pollution sources in a region.

Air quality forecasting predicts the concentration of pollutants, which involves combining satellite-derived measurements; meteorological parameters like relative humidity, wind speed, and height of the planetary

boundary layer; external contributions from dust storms and forest and crop fires; and land use parameters into a chemical transport model. A chemical transport model uses emissions and meteorological parameters as inputs, simulates the physical processes and chemical transformations occurring in the atmosphere, and generates estimates of pollutant concentrations. Table 2 itemises the atmospheric products related to pollution monitoring from satellites that are currently active. It is worth noting that most satellite data listed as being used to draw inferences on India's air quality come from satellites that were not launched in the country.

3. Satellite application in air quality management: the Indian context

As mentioned earlier, satellite observations have found application in monitoring and measuring pollution and polluting activities across the globe. At a small scale, regulatory agencies in India have started making note of possible applications of satellite data in pollution monitoring.

Table 2: List of pollution monitoring products provided by satellites

Domain	Data product	Time period	Satellite	Space agencies	Data source
Air quality	Aerosol optical depth	2014–present	INSAT 3D	ISRO	(Mishra, Rastogi, and Chauhan 2014)
		2002–present	MODIS Aqua	NASA	(Giovanni 2019)
		2000–present	MODIS Terra	NASA	(Giovanni 2019)
	UV aerosol optical depth	2004–present	Aura OMI	NASA	(Giovanni 2019)
	UV aerosol index	2004–present	Aura OMI	NASA	(Giovanni 2019)
		2018–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
	Aerosol layer height	2006–present	CALIPSO	NASA	(NASA 2019)
		2019–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
	Aerosol profile	2006–present	CALIPSO	NASA	(NASA 2019)
	Carbon monoxide total column	2019–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
		2000–present	MOPITT	NASA	(Giovanni 2019)
	Carbon monoxide vertical profile	2000–present	MOPITT	NASA	(Giovanni 2019)
	Nitrogen dioxide total column	2018–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
		2006–present	Aura OMI	NASA	(Giovanni 2019)
	Sulphur dioxide total column	2018–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
		2006–present	Aura OMI	NASA	(Giovanni 2019)
	Formaldehyde total column	2007–present	Aura OMI	NASA	(Giovanni 2019)
	Formaldehyde total column	2018–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
	Ozone tropospheric column	2019–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
	Ozone tropospheric profile	2019–present	Sentinel 5P	ESA	(ESA Sentinel online 2019)
Open fires, such as forest fires and biomass burning	Thermal anomalies and fire	2002–present	MODIS Aqua	NASA	(Earth Data 2019)
		2000–present	MODIS Terra	NASA	(Earth Data 2019)
		2012–present	SNPP-VIIRS	NASA/ NOAA	(Earth Data 2019)

Source: Authors' compilation
Note: The list considers products only from satellites that are currently active.

Forest Fire Alerts System

Forests in India are vulnerable to forest fire outbreaks, especially during the summer. Forest fires cause great damage to biodiversity and emit a large amount of carbon monoxide, carbon dioxide, and black carbon. The Forest Survey of India (FSI), under MoEFCC, has been tracking forest fire episodes using satellite data since 2004.

The Fire Alerts System (FAST) launched by FSI tracks forest fire events on a near real-time basis using MODIS and SNPP–VIIRS satellite data, and generates timely fire alerts that are sent to the respective nodal officers (FSI 2019). These timely fire alerts help forest officials seek assistance with suppressing and mitigating forest fires; this could potentially reduce the damage caused by large forest fires. FAST has an improved feedback system to enable nodal officers to provide feedback on aspects such as the causes for fires and the extent of the area affected. Continuously tracking these fire events could offer deeper insights into the pattern, intensity, and duration of forest fires in a given area; this information can then be used to devise working plans.

Monitoring agricultural fires

Agricultural farm fires are episodic events that contribute to Indo–Gangetic air pollution. Over the past few years, satellites have been instrumental in generating images that have helped in identifying the location and count of these fires and led environmental researchers and policymakers to realise that the mitigation of air pollution in the Indo Gangetic plain calls for regional cooperation in addition to local solutions.

A statement issued by the Ministry of Agriculture and Farmers' Welfare in January 2019 stated that satellite data indicated a 11 per cent reduction in paddy residue burning events in Punjab in 2018, as compared to 2017 (Issues of Parali Burning 2019). This value comes from a crop residue monitoring exercise using MODIS and VIIRS data, undertaken by the Consortium for Research on Agroecosystem Monitoring and Modelling from Space (CREAMS), an interdisciplinary research initiative of the Indian Agricultural Research Institute, New Delhi, which is coordinated by its Division of Agricultural Physics.

Interestingly, a study by researchers at the CEEW carried out a similar assessment and found no significant reduction in the number of fires between 2017 and 2018 (Kurinji 2019). The study used information from the SNPP–

Image: iStock

Image: iStock

Figure 1: No significant reduction in the number of open fires in Punjab in 2018 as compared to 2017
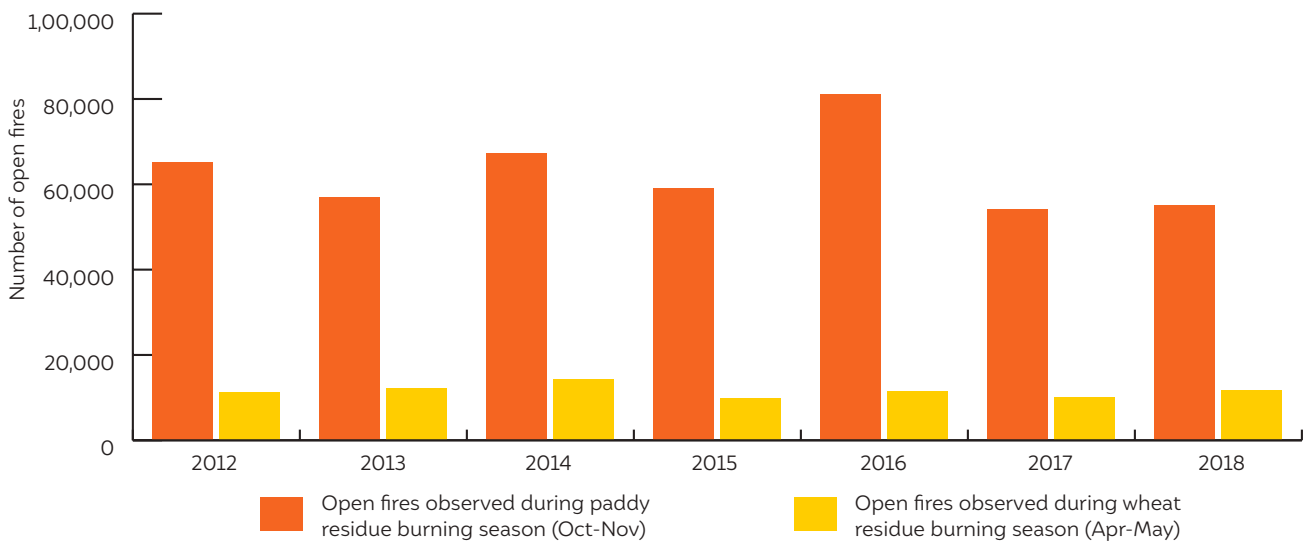
Source: L.S. Kurinji, 2019. Alternative Methods to Monitor Air Pollution: A Study of Crop Residue Burning in Punjab. New Delhi: Council on Energy, Environment and Water. Accessed September 15, 2019.

VIIRS satellite, maintained by the Fire Information for Resource Management System (FIRMS). Figure 1 illustrates the historical trends in open fires detected by VIIRS during the paddy and wheat residue burning season in Punjab between 2012 and 2018—the data are from the study.

The incongruency between the findings of the two studies could stem from difficulties in determining the right data set and a suitable methodology that accurately represents ground realities. There are multiple satellites that collect the same data—fire counts, in this case—albeit with different spatial resolutions. Despite the varying results, in the absence of remote surveillance, it would be difficult to assess the impact of policy interventions on crop residue burning; ground monitoring is limited in most parts of the country and satellites have a much wider coverage area and can provide spatially continuous data. Additionally, satellite images help in identifying regions where government-supported initiatives have succeeded and where they have failed. In other words, using these data, the government could strategise region-specific approaches and track the progress systematically and transparently.

Estimating the health burden due to air pollution

It is pertinent to study the impact of air pollution on health as India has disproportionately high mortality and disease burdens due to air pollution. To inform and initiate action at the sub-national level in India, scientists through the Global Burden of Disease India Study estimated the population's exposure to air pollution and its impact on mortality, disease burden, and life expectancy in every state in India in 2017. The $PM_{2.5}$ exposure estimates used in the study use satellite-derived aerosol optical depth and chemical transport models to compute district-level particulate concentrations (Balakrishnan et al. 2018). The study found that the annual population-weighted mean exposure to ambient $PM_{2.5}$ in India was 89.9 μg/m³ in 2017, and that 76.8 per cent of the Indian population was exposed to an annual population-weighted mean $PM_{2.5}$ greater than the National Ambient Air Quality Standards of 40 μg/m³. With limited ground monitoring, which is mostly concentrated in urban areas, determining particulate exposure concentrations at such a granular spatial resolution would have been impossible without satellite data.

4. India's proposed plan for the applications of satellites in air quality management

The NCAP intends to incorporate satellite data into both air quality monitoring and forecasting. Table 3 lists the planned action points for satellite application and the corresponding timelines.

Table 3: Planned applications of satellite data as listed under NCAP

Domain	Action point	Agencies involved	Timeline
Monitoring of crop residue burning	Coordination with ISRO for a regular availability of remote sensing monitoring data for crop residue burning by the farmers	MoEFCC, CPCB	2019
Air quality monitoring network	Capacities will be strengthened to develop indigenous satellite-based products and techniques for estimating particulate and gaseous concentration.	CPCB, state pollution control boards (SP-CBs), Space Application Centre (SAC), ISRO	2024
Air quality forecasting system	Satellite data available through the satellite network of ISRO to be integrated for monitoring and forecasting	Indian Institute of Tropical Meteorology (IITM), Pune, under MoES, CPCB	2022

Source: MoEFCC. 2019. "National Clean Air Programme." Ministry of Environment, Forest & CLimate Change, Government of India. Accessed September 15, 2019.

It is noteworthy that the plan proposes strengthening capacities to develop indigenous satellite-based products and techniques to derive useful air quality information. It also states that the required algorithms to correlate AOD values with ground-level PM concentrations over the Indian regions would be derived from an indigenous database. However, currently, the only indigenously developed satellite product available is AOD from the INSAT 3D satellite. Unlike other satellites like Sentinel 5P and MODIS that specifically monitor air quality, the INSAT 3D/3DR Imager was launched to enhance the country's capabilities in weather forecasting and disaster warning systems (PTI

2013). Therefore, this system has certain limitations when it comes to AOD estimation. Generally, the contrast between aerosols and the surface can only be well detected in the 0.412 μm band, as aerosol signals tend to be brighter than the Earth's surface at that wavelength (Chen, Howl, and Sidel 2019). But, INSAT 3D measures aerosol signals at a wavelength channels – Visible (0.55 – 0.75 μm), Thermal infrared - 1 (10.2 – 11.3 μm), and Thermal infrared - 2 (11.5 – 12.5 μm), in which case the aerosol signals may not get captured entirely.

The current indigenous AOD retrieval algorithm, which uses measurements from a wavelength of 650 nm, has an uncertainty of ±30–45 per cent (Mishra 2018). With this high degree of uncertainty present in the current AOD product , there is a higher chance of this uncertainty getting translated into the quantification of $PM_{2.5}$ and PM_{10} derived from AOD.

The NCAP also proposes exploring other satellite products for retrieving information on gaseous products. While there is at least one indigenous satellite measuring AOD, as of now, there exists no indigenously developed satellite-based products to measure gaseous pollutants such as sulphur dioxide (SO_2) and nitrogen dioxide (NO_2).

In order to overcome the aforementioned issues and achieve the NCAP objectives, India must consider launching a geostationary satellite that would specifically measure atmospheric properties. As geostationary satellites give out information every 15–30 minutes, they are better suited to study temporal variations in particulates and mesoscale atmospheric phenomena like dust transport. They can also help to keep a check on emissions from various anthropogenic sources like thermal power plants.

How could satellite data be used?

CEEW's recent review of the online pollution monitoring portals (see Table A1 in the Annexure) of SPCBs revealed that only 8 out of the 29 SPCBs and Delhi Pollution Control Committee (DPCC) in the country have made Continuous Emissions Monitoring Systems (CEMS) data publicly available as of September 2019. Directions on installation of CEMS devices in the 17 categories of highly polluting industries were first issued by the CPCB in February 2014. This was done to regulate compliance by industries with minimal inspection and to bring discipline in the industries to exercise self-monitoring and compliance. Data reported by CEMS help in tracking the quantum of emissions being released by an industrial unit and the unit's compliance with emission standards.

However, experts are highly sceptical about the use of CEMS data as there is a high possibility of data and equipment being manipulated (Aggarwal 2018).

The government can use satellite data to independently verify the credibility of measurements reported by CEMS and other on-ground audits. For example, while evaluating the impact of China's stringent SO_2 emission standards by comparing data reported by CEMS with satellite measures, experts spotted a very low correspondence between SO_2 emissions reported by the power plants and by independent satellite measures after the announcement of stringent emission standards. They then questioned the reliability of the CEMS data, which is susceptible to manipulation (Karplus, Zhang, and Almond 2018). Applications like these can help in monitoring industries' interference with CEMS data—from incomplete reporting to the manipulation of sensors. The existing legal framework does not consider data from alternate monitoring systems such as low-cost sensors and satellites as permissible evidence. But

> **Sudden variations in satellite observations, if identified during regular monitoring and found to correspond with the location of large industries or power plants, could initiate an inspection.**

sudden variations in satellite observations, if identified during regular monitoring and found to correspond with the location of large industries or power plants, could initiate an inspection.

Regional and continental air circulation patterns frequently carry pollution from one area to another. Experts have used satellite data to communicate that emissions from crop residue burning regions and industries spread in all directions and are often carried to the cities present downwind through long-range transport mechanisms, depending upon meteorological conditions, thus making them non-attainment cities (Sarkar, Singh, and Chauhan 2018). In such cases, mitigation measures focussed only on cities and not on emissions from the nearby regions may not have a considerable impact on air quality. The government can use satellite data to identify the air shed covering all the air pollution sources that influence a city's air quality and can devise regional air quality management strategies to mitigate the impact of air pollution drift.

Satellite data can also be used as evidence to demonstrate the negative impact on air quality caused by exceptional events like forest fires and dust storms, as the impact of these cannot be captured by traditional ground monitoring systems. In early October 2017, regulatory monitors in Delhi measured a sudden upsurge in pollution levels, which triggered an

Remote sensing for smarter air pollution management

Satellite Monitoring

Dissemination
Dissemination of alerts to the regional officers

User
Pollution Control Boards (PCBs), among others

Comparing and identifying disparity between data

A constant eye on various sources of air pollution

Sandstorms

Biomass burning

Industries

Ground Monitoring
Continuous Emission Monitoring System (CEMS) | Continuous Ambient Air Quality Monitoring System (CAAQMS)

Ground Inspection
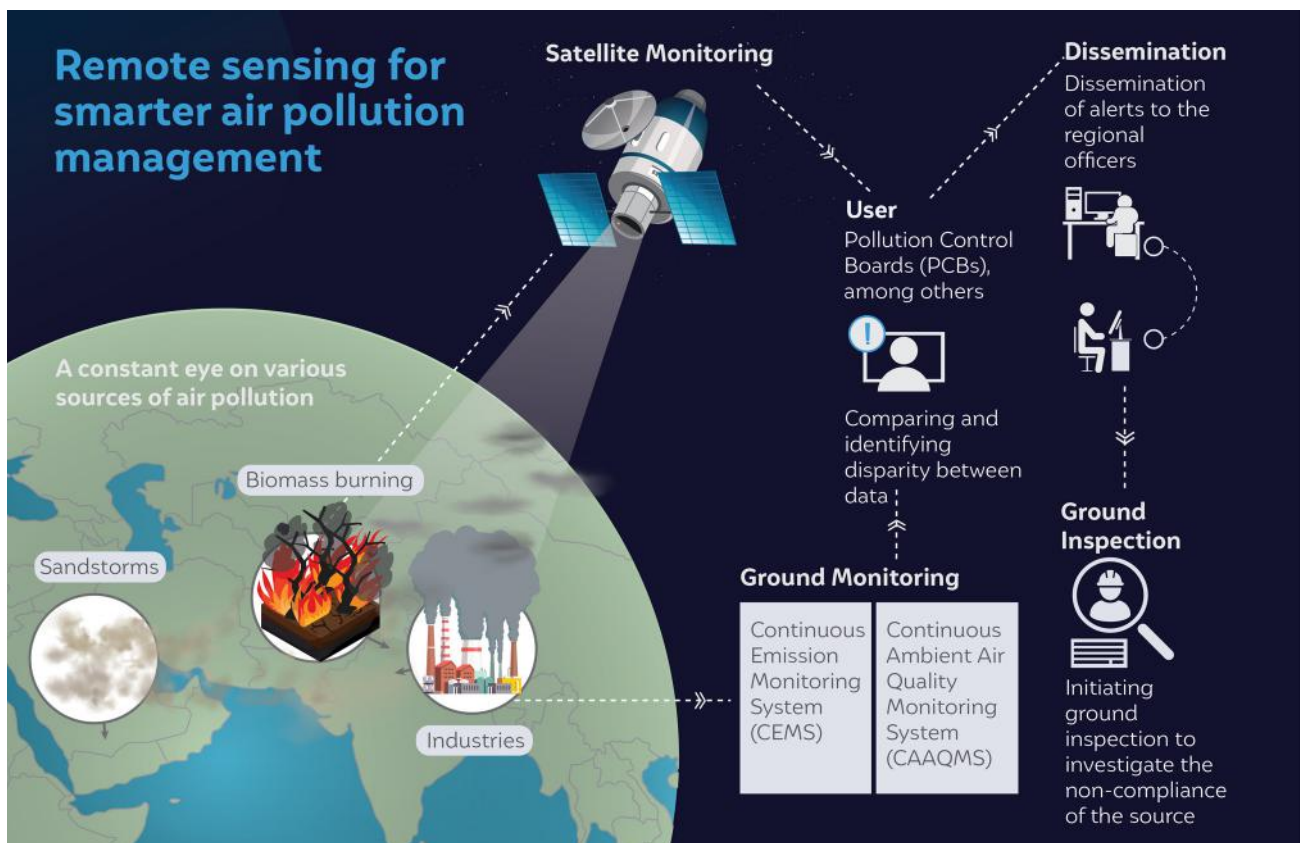Initiating ground inspection to investigate the non-compliance of the source

Image: Authors' compilation

emergency warning in Delhi. Experts then investigated the mechanisms leading to this severe event using satellite data and identified the cause as long-range transport of dust emerging from Gulf countries (Beig et al. 2019). Another study used MODIS data to explain that a major fire incident had taken place in the northern Himalayas in Uttarakhand in April 2016, which had a significant impact on air quality in neighbouring areas such as Delhi (Singh 2016). Applications like these help in understanding the impact of exceptional events on air quality, which may or may not be reasonably controlled. It can also lead to the devising of preventable actions like increasing vegetation cover to reduce the impact of dust storms (UNEP, WMO, and UNCCD 2016).

5. Primary challenges in using satellite measurements

Notwithstanding the dearth of geostationary satellites that provide near-continuous coverage of the Indian landmass, the lack of technical skills and computation capabilities needed to translate satellite observations into ground measurements of pollutants is one of the primary impediments in scaling up the application of remote sensing in air quality management. This section highlights the challenges associated with applications of satellite data.

Technical and computational capabilities

With the increase in the availability of satellite-derived atmospheric products as a result of more satellite launches, assessing the storage and computational capability to store and process the available data becomes pertinent. For instance, the Copernicus Sentinel-5P satellite launched by the European Space Agency (ESA) in October 2017 alone currently produces 1,096 Gbits of data volume per day, which is equivalent to 84,118 photos of 1.5 MB average size (ESA 2013; ESA 2015). The Sentinel-5P helps in mapping a multitude of air pollutants like NO_2, SO_2, O_3, CO, and HCHO and in identifying emission hotspots around the globe. Traditional storage and computing methods are inadequate for the quick processing of such large volumes of data from earth-orbiting satellites.

Fortunately, with tools like Google Earth Engine (GEE) and other cloud computing platforms (remote servers accessed via Internet connection) to manage and process data, handling and interpreting data from these sources is made much easier. They enable non-

Figure 2(a): Copernicus Sentinel5P SO_2 VCD data illustrates the SO_2 emission hotspots in India

0	11	23	35	48	59

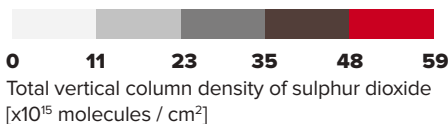Total vertical column density of sulphur dioxide [$\times 10^{15}$ molecules / cm^2]
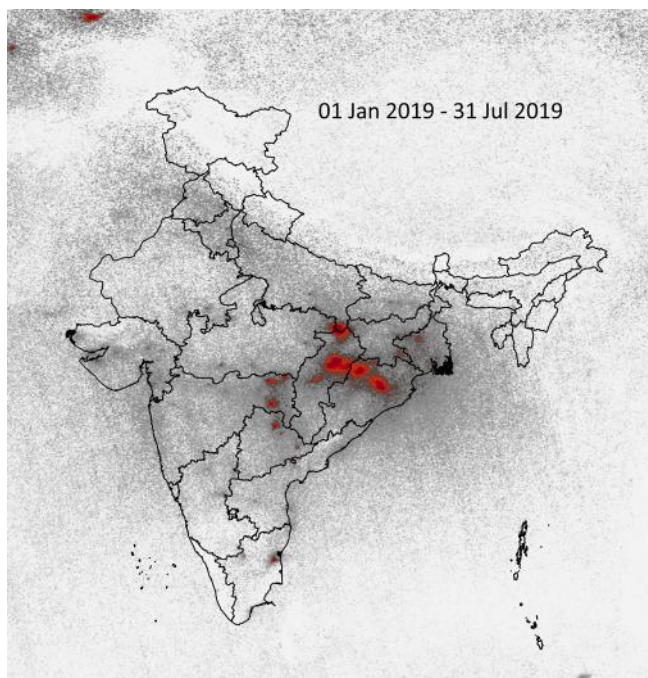
Figure 2(b): Copernicus Sentinel5P Tropospheric NO_2 VCD data illustrates the NO_2 emission hotspots in India

0	1	4	8	12	16	22

Tropospheric vertical column density of nitrogen dioxide [$\times 10^{15}$ molecules / cm^2]
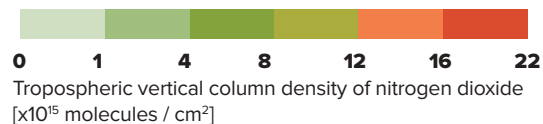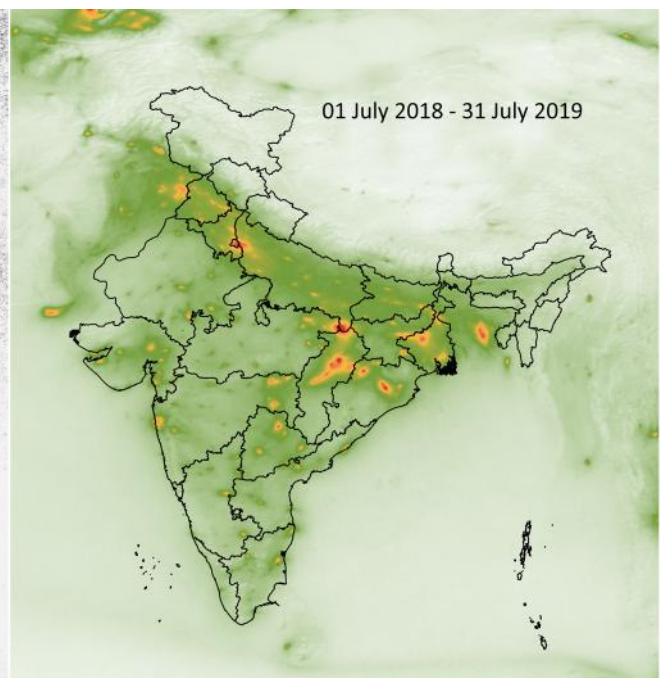
Source: Authors' analysis

traditional users and non-experts to access and make use of satellite data using intuitive scripting languages and also help visualise the results.

Using GEE, we processed and visualised SO_2 and NO_2 vertical column density (VCD) data from Copernicus Sentinel 5P over the Indian subcontinent, which are shown in Figures 2(a) and 2(b), respectively. The SO_2 and NO_2 emission hotspots in the country in most cases coincide with the location of power-generating units and vehicle-congested cities, respectively, and are clearly visible in the visualisation generated. One can then go on to attribute the high levels of these pollutants to these sources. However, this is where the use of satellite monitoring enters a murky space. While it can be helpful to point out a dominant source, it cannot differentiate it from other small sources without the help of atmospheric models.

Data interpretation and validation

The major challenge associated with using satellite measurements to draw inferences on air quality is arriving at the right method to translate the satellite data, i.e., converting AOD into ground particulate concentrations or columnar volume densities into emissions. Given the inadequacy of ground monitoring data in our country, the results obtained by the translation process will have large uncertainties.

For instance, a recently released study (Dahiya and Myllyvirta 2019) used the SO_2 source emission catalogue put out by NASA Global Sulfur Dioxide Monitoring to rank SO_2 emission hotspots across the globe. The SO_2 source emission catalogue lists the annual SO2 emission from large anthropogenic sources across the globe (NASA 2019). Some media outlets used the ranking to infer that Chennai was the most polluted Indian megacity in 2018, with 215 kilotons (kt) of SO_2 emissions (Chatterjee 2019). We reviewed the emission figures listed in NASA's SO_2 emission catalogue and found that the entire 215 kilotons of SO_2 has been attributed to the North Chennai Thermal Power station (NCTPS). Given that the catalogue reports SO_2 emissions at a unit level, it would be erroneous to attribute the emissions stemming from a plant to an entire city.

The SO_2 database uses information from the Ozone Monitoring Instrument (OMI) sensor aboard the NASA Aura satellite, which has a coarse spatial resolution of 13 * 24 km (NASA 2012). Unfortunately, the sensor does not have the sensitivity to detect small or area sources. Hence, the catalogue attributes all the emissions

observed from OMI within a defined area to the single large point source within that area.

Ideally, emissions from power plants can be measured directly at the stack level. According to Tamil Nadu Pollution Control Board's online pollution monitoring platform, the SO_2 emissions from the NCTPS are well within limits. But a compliant power plant could still be generating significantly high emissions. In order to compute emissions from the NCTPS, we have used a crude methodology that takes into account the plant's annual coal consumption and the sulphur content of coal, which has been assumed to be 0.5 per cent (Guttikunda and Jawahar 2014).

Table 4: Annual estimated and reported SO_2 emissions for NCTPS in 2018

North Chennai Thermal Power station (NCTPS)	
Generation capacity	1,830 MW*
Coal requirement for 2018–2019	8,472,000 tonnes**
Sulphur content in Indian coal	0.5 per cent
Estimated annual emission in 2018	82.6 kt
Annual emission reported in NASA OMI SO_2 catalogue	215 kt
Difference between the estimated and the reported SO_2 emission	132.4 kt

Source: Authors' analysis

* List of thermal power plants and their capacities accessed from Lok Sabha reply to unstarred question on pollution emanating from thermal power plants (Lok Sabha Unstarred Question No. 532 2018)

** Coal requirement accessed from Rajya Sabha reply to unstarred question on pollution emanating from thermal power plants (Rajya Sabha Starred Question No. 201 2019)

While NASA's OMI SO_2 catalogue puts the emission figures at 215 kt for 2018, authors' estimated emissions are significantly lower and stand at 82.6 kt (as seen in Table 4). As explained earlier, this significant difference could potentially stem from the fact that the sensor does not have the sensitivity to detect small area sources and attributes all the emissions observed within a defined area to the single large point source.

The above inconsistency in emission estimates reinforces the fact that in the absence of ground-based measurements, satellite observations remain vulnerable to erroneous interpretations. Thus, the best way to

utilise satellite data would be to integrate it with ground monitoring and chemical transport models (Brauer et al. 2019).

6. Driving policies: what is needed?

The brief provides insights on the scope of use of satellite data for air quality applications that can serve key stakeholders, policymakers, and researchers. Based on these insights, this brief has the following recommendations.

Build capacities for the potential use of satellite data on air quality

India should focus on developing computational capacities and infrastructure facilities along with trained human resources (air quality modellers and atmospheric chemists) to generate meaningful insights from the monitored geospatial data. The technical capacity needed to integrate satellite data with air quality management and support policymakers to enable an early response system and put in place suitable mitigating or precautionary measures when pollution spikes should be imparted to air quality professionals working across pollution control boards in the country. Training programmes built around utilising existing satellite datasets should also be imparted to these air quality professionals.

Satellite data-based inspection trigger mechanism

As mentioned earlier, while CEMS data and manual stack measurements can be manipulated, satellite observations cannot be tampered with. Pollution control boards generally get alerts when emissions from an industrial unit as tracked by CEMS devices exceed emission standards. If manipulated with, CEMS devices may not send these alerts. Under such circumstances, tracking satellite imagery on a regular basis could help keeping track of exceedances and help detect the possible tampering of CEMS devices.

Identification of emission hotspots to drive local area interventions

Most regions in the country, both urban and rural, are not adequately equipped with ground monitoring stations. Given the limited number of monitoring

stations, a series of satellite images over a period of time could be used to identify pollution hotspots. Both pollution hotspots and the pollutants of concern can be identified by tracking satellite observations. This could help pollution control agencies design area- and pollutant-specific interventions.

Envision launching a geostationary satellite to specifically monitor air quality

India cannot solely rely on data made available by NASA and ESA from existing earth-orbiting satellites, as they are polar-orbiting and can only provide 1–2 observations per day for a given place. Deriving more representative inferences with lesser uncertainties would need more frequent observations. India should thus envision launching its own high-resolution geostationary satellite that focuses specifically on monitoring atmospheric parameters.

Make indigenous satellite-derived products easily accessible for public use

Remotely captured information should be made easily accessible for public use through online platforms to support various applications. Making the data freely accessible promotes innovation in its application, and allows academics and research communities to utilise it to its full potential. The functioning of India's premiere (and only) space research organisation, ISRO, is supported by public financing. There is no reason why the data that these satellites gather (except for security-related matters) should not be made public.

7. Conclusion

India's ambitious target of reducing PM concentration by 20-30 per cent by 2024 calls for extensive monitoring infrastructure and an effective air pollution mitigation strategy for the country. There is a strong need for a whole range of innovative approaches that facilitate active monitoring and inspection mechanisms to identify what the pollutants are and where, why, and how they should be managed. The setting up of CAAQMS requires heavy infrastructural investment, which is a barrier to scaling up ground monitoring in the country. With frugal budgets and a tight schedule for achieving the air quality improvement target, there is a

pressing need to effectively utilise satellite data to help track air quality.

We have evaluated the potential for remote sensing in air quality management. Remote sensing can augment ground monitoring and air quality forecasting, which mirrors findings from earlier studies both at global and national levels. However, satellite observations should not be limited to just supplementing ground monitoring. They can be used to identify airsheds, demonstrate episodic pollution, and inspect consistently non-compliant sources.

These potential applications, however, come with associated challenges. The foremost being the lack of technical capacity to accurately interpret satellite observations to derive meaningful insights. There are a limited number of researchers who are able to link satellite-based observations with modelled estimates, which is important to fill gaps and to add value to satellite observations. Without this, the credibility of satellite data often lies on shaky ground. A smaller but still significant challenge lies in acquiring and processing the data that is produced by satellites. India should target the aforementioned challenges with concerted efforts involving credible international and institutional collaborations.

As Indian cities and rural areas experience high pollution for most of the year, continuous data providing useful insights and leading to focussed efforts

The Ministry of Environment, Forest and Climate Change, CPCB, and space agencies should design and conduct specialised training programmes to develop and upgrade the necessary skill sets among environmental professionals in pollution control boards.

are needed. This would support regulatory agencies and policymakers and encourage prompt responses. India cannot solely rely on data made available by overseas agencies like NASA and ESA from existing earth-orbiting satellites as they are temporally limited; it needs to have its own mechanism in place to operate independently. India should thus envision launching satellites dedicated to monitoring air quality. More importantly, the relevant space agency must ensure that the information so captured is made freely accessible to the wider public and must allow the scientific and research communities to innovate and find new use cases for the data.

While the introduction of satellite applications in air quality management is gaining momentum in India, a systematic framework integrating both scientific institutions and regulatory agencies to actively incorporate the insights derived into the mitigation measures is the need of the hour.

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Annexure

Table A1: Details on the accessibility of the online pollution monitoring portals of SPCBs as of September, 2019

State	Accessibility	Link	Comments
Andhra Pradesh	Yes	http://aprtpms.ap.gov.in/dashboard.html	Public access
Arunachal Pradesh	-	-	-
Assam	No	-	-
Bihar	No	http://bpcbcems.nic.in/login	Password protected
Chattigarh	Yes	http://enviscecb.org/Industry_list_CEMS_Stations.htm	Public access
Delhi	No	https://www.dpcc.delhigovt.nic.in/waste_to_energy_and_thermal_power_plant.html	Password protected
Goa	Yes	http://gspcb.glensserver.com/GSPCB_ONLINE/index.html	Public access
Gujarat	No	-	-
Haryana	Yes	http://www.hspcbcems.nic.in/industry-public-view?industry_id=22	Public access
Himachal Pradesh	Yes	http://hppcb.glensserver.com/public/	Couldn't access website
Jammu & Kashmir	Yes	http://jkspcb.glensweb.com/public/index.html	Public access
Jharkhand	Yes	http://jsac.jharkhand.gov.in/pollution/	Public access
Karnataka	Yes	https://kspcb.gov.in/caaqm.html	Couldn't access website
Kerala	No	https://keralapcb.glensserver.com/public/	Couldn't access website
Madhya Pradesh	Yes	https://erc.mp.gov.in/SMSOpen/emission	Hidden
Manipur	No	-	-
Meghalaya	Yes	http://megspcb.glensserver.com/public/	Public access
Mizoram	No	-	-
Nagaland	No	-	-
Odisha	No	http://ospcbrtdas.com/	Password protected
Punjab	No	http://cpcbrtdms.nic.in/#	Password protected
Rajasthan	No	http://environment.rajasthan.gov.in/content/environment/en/rajasthan-state-pollution-control-board.html#main	Tickr on home screen
Sikkim	-	-	
Tamil Nadu	Yes	http://117.232.97.121/RealTime_tnpcb_cac/index.html	Public access
Telangana	Yes	http://183.82.41.227:8080/enviroconnect/aqms	Public access
Tripura	No	-	-
Uttar Pradesh	No	-	-
Uttarakhand	No	-	-
West Bengal	Partial	https://www.wbpcb.gov.in/cmsdata.php	Limited access

Source: Authors' compilation

As of Sep 2019, the CPCB operates 200 Continuous Ambient Air Quality Monitoring Systems (CAAQMS) in India; most of these stations are located in urban areas (CPCB 2019). Installation of CAAQMS require heavy capital investment of approximately INR 1.5 crore each.

Images: CEEW/Milan Jacob