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Recurring South Asian smog episodes: Call for regional cooperation and improved monitoring

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HIGHLIGHTS

- South Asia stands out globally for fine particle pollution.
- The precise nature, sources, and potential transboundary impacts of air pollutants have been understudied in South Asia.
- Imbalanced AQ monitoring capacity is an impediment to regional cooperation that is critical in addressing air pollution.
- Revitalization of the Malé Declaration would be one way to make progress.

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1. South Asia stands out globally for fine particle pollution

Air pollution has emerged as a major environmental challenge across South Asian states, affecting human health and causing severe socio-economic disruption. The region accounts for around 32% of global mortality associated with exposure to the exceedingly high levels of poor ambient air quality (Lelieveld et al., 2020). Moreover, the average life expectancy for the region has been estimated to have been reduced by approximately five years with four South Asian countries: Bangladesh, India, Nepal and Pakistan, accounting for 60% of loss of life-years globally (Greenstone and Fan, 2020). The economic toll associated with additional impacts to health, agricultural productivity, mobility, etc. can account for reductions of Gross-Domestic Product (GDP) of several percent for the regional economies (Cheewaphongphan et al., 2017).

Geographically, these four countries share the Indo-Gangetic Plain (IGP) where population, emissions, and circulation conspire to create a shared air pollution problem that calls for regional cooperation (Khokhar et al., 2021). The thick cloud of air pollution is most prominent during the months of October to February. This period of smog/smoke activity is referred to by some as the “fifth season” due to its occurrence on a regular basis and its associated ever-increasing health impacts

Abbreviations: MODIS, Moderate Resolution Imaging Spectroradiometer; TROPOMI, Tropospheric Monitoring Instrument; AOD, Aerosol Optical Depth.

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across the region. In some of these countries, governments have started the practice of closing educational institutes and implemented road-rationing during intense smog/smoke episodes and cautioning the public to restrict outdoor activities. These steps to stave off potential adverse health impacts are expected to become more drastic as impacts increase and severely hamper socio-economic activity in the region. Whether or not these steps are effective is an open question that calls for immediate attention. The situation is complicated by a number of key structural weaknesses, such as the lack of adequate infrastructure and an uneven approach to regulation and enforcement across these countries. The resulting imbalance in air quality monitoring across the region limits dialogue and hinders effective action between countries.

Because of the lack of balanced air quality monitoring across South Asia, the precise nature, sources, and potential transboundary impacts of air pollutants have been understudied. This impedes the cooperation between countries that is critical to stem the worsening air pollution problem that is crippling the region.

2. The case for improved monitoring

Fine particle pollution (defined as the mass of particulate matter with diameters of 2.5 μm or less, $PM_{2.5}$) is of primary concern as a cause of the poor air quality across the region. Consistent information on $PM_{2.5}$ has only recently become available for selected locations across South Asia as part of the AirNow Department of State program that has placed monitors at US Embassies and Consulates (US-EPA. AirNow. Research Triangle Park and N.C. U.S. Environmental Protection Agency). Because of the similarity in the monitoring method and the shared data quality assurance programme, it is used here to demonstrate spatial and temporal trends across the IGP for two transboundary city pairs: Lahore-Delhi in the west and Kolkata-Dhaka in the east (Fig. 1). Separated by a little over 400 km in the northwestern part of the IGP, Lahore and Delhi experience similar seasonal variability and degree of poor air quality as defined by $PM_{2.5}$. For reference, the EPA guideline for daily average $PM_{2.5}$ (35 μg/m^3) is shown with a black line in Fig. 1 to emphasize the extreme pollution levels routinely encountered.

MODIS fire counts included in Fig. 1 are for the region between Lahore and Delhi, which includes the Indian provinces of Punjab and Haryana and the Pakistani province of Punjab. In both cities, $PM_{2.5}$ is at its lowest at the end of the monsoon season (August–September) before an abrupt increase occurs in mid-October. MODIS active fire counts show the initial increase in $PM_{2.5}$ each year to be associated with agricultural burning, but elevated $PM_{2.5}$ levels persist well beyond the burning period throughout the winter months. This clearly shows the need to gather information to better understand the factors controlling air pollution for this region. Without appropriate monitoring across the

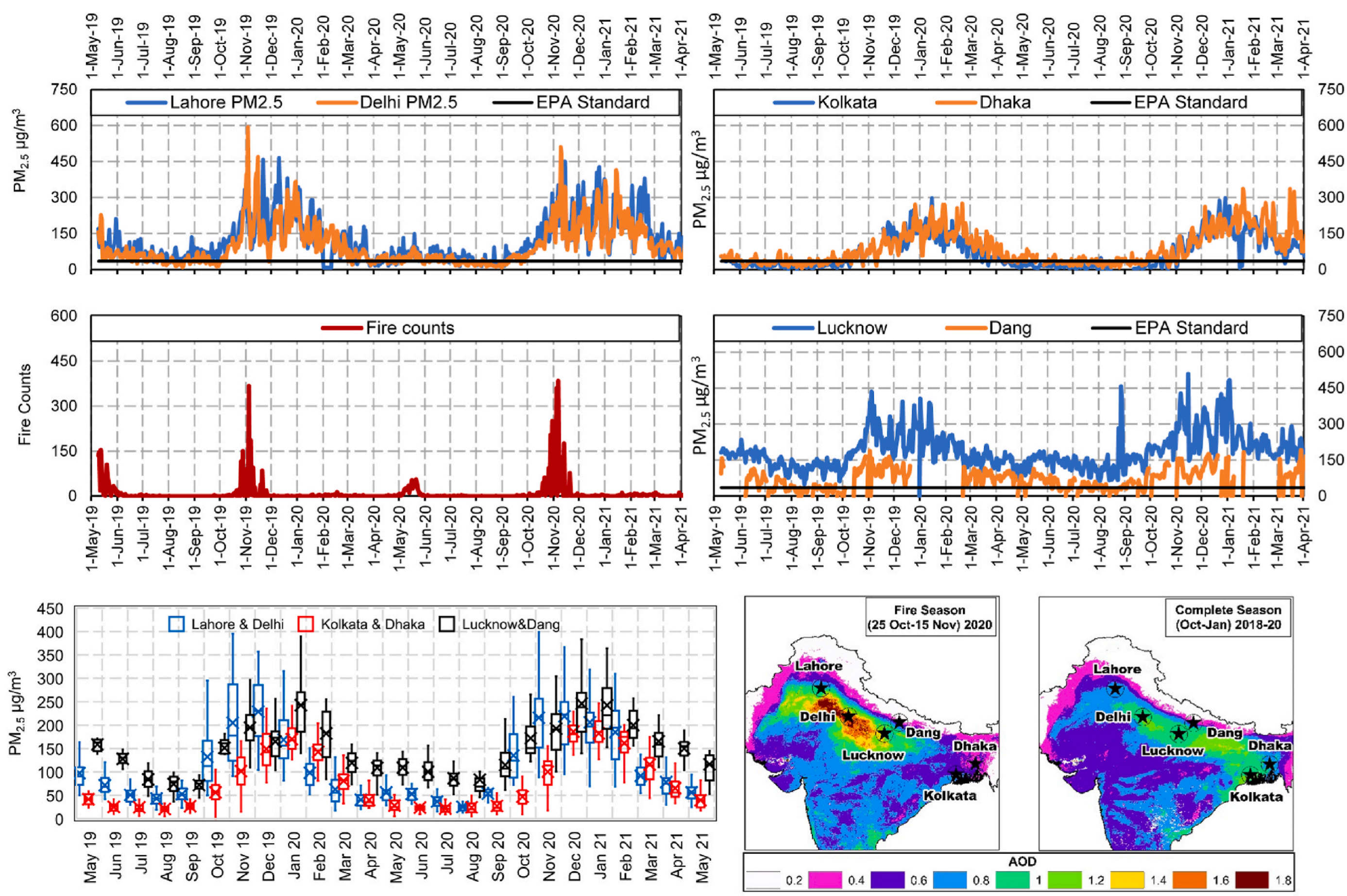

Fig. 1. Seasonality of fine particle pollution across the Indo-Gangetic Plain. Time series comparisons for city pairs are shown for Lahore and Delhi in the west (top left), Kolkata and Dhaka in the east (top right), and Lucknow and Dang in the central Indo-Gangetic Plain (middle right). US EPA standard of 35 μg/m^3 is also marked to emphasize the extreme conditions during peak pollution periods. The seasonality of MODIS fire counts (middle left) are shown for Punjab (Pakistan) and Punjab and Haryana (India) provinces between Delhi and Lahore. Monthly mean statistics for the city pairs (bottom left) are shown using box-whiskers for the median, interquartile values, and range, while average values are denoted with an " × ". Maps of average MODIS AOD (bottom right) are provided for both the 2020 fire season and the peak pollution months of October–January 2018–2020 with city locations marked. (For AOD, MODIS product MCD19A2 Version 6 data product from both Terra and Aqua retrieved by Multi-angle Implementation of Atmospheric Correction (MAIAC) AOD gridded Level 2 product, MCD14DL FIRMS V0061 NRT for fire activities produced daily at 1 km (km) pixel resolution was used here. Data set with QA flag 3 (recommended for most application) with lowest absolute uncertainties was used, see Sayer et al., 2020).

region, targeted transnational action cannot efficiently be implemented. The longer winter problem is expected to be tied more to seasonal meteorology that is conducive to pollution trapping in shallow boundary layers. Winter traditionally brings increased residential biomass burning/solid waste burning for heating due to the colder temperatures.

The cross-border comparison for Kolkata-Dhaka in the east is similarly strong, but not marked by the strong fire influence seen in the west. To add a comparison for Nepal and India, which share much of the central Indo-Gangetic Plain, data from local monitors in Lucknow (India) and Dang (Nepal) are also included in Fig. 1. The box-whisker plots shown in the bottom panel of Fig. 1 allow for a comparison of the seasonal patterns for these three city pairs. As described above, Lahore and Delhi (located in the west) experience an extended pollution season that begins with the annual burning of agricultural residues in October–November. The central cities also show evidence of pollution impacts that start during the fire season, but pollution during this early period does not stand out in magnitude. The eastern cities show a later peak in December, due to the lack of burning influence, and is driven more by lower boundary layer heights and dry winter meteorological conditions.

The quantification of levels and patterns of air pollutants and their precursors is necessary to provide a more complete understanding of their economic and societal impacts. At present, there are no official air quality monitoring stations in either Pakistan or Bangladesh. Efforts are underway to introduce low-cost sensor networks for particulate matter into these countries and across South Asia in general. Such efforts are welcome, but they do not eliminate the need for rigorous, high-quality monitoring at a fixed number of sites to anchor and evaluate to quality of information coming from such small sensor networks. Additional monitoring of gaseous pollutants is also needed. Due to recent investments by national governments and agencies, the monitoring infrastructure is currently much better in India and Nepal. India currently operates more than 370 air quality monitoring stations measuring both particulate and gaseous pollutants, although there is still need for rigorous evaluation of observations and maintenance of these sites. In Nepal, a smaller number of sites are operated to measure particulate matter with fewer than 10 of the 27 sites routinely reporting data. As a consequence of the monitoring imbalance between South Asian states, it is difficult to measure the effectiveness of the air quality conservation strategies employed by the countries as well as strongly advocating the nations to take part in enhanced regional cooperation initiatives for this transboundary issue of air pollution.

The Malé Declaration is a framework for regional cooperation in South Asia established to tackle the issue of air pollution (SACEP). Since 1998, it has correctly pointed out the need for regional cooperation and management of transboundary air pollution. Nevertheless, its objectives have not been fully realized. The ongoing poor air quality situation in South Asia calls for revitalization of this framework. Financial issues have also plagued this declaration. Cooperation among South Asian countries is challenged by economic constraints. However, each nation must decide to commit resources to tackle this problem. The most important step for South Asian countries is to develop and strengthen their monitoring and reporting infrastructure in order to offset monitoring imbalances and strengthen goodwill within and across borders. Considering the overall scenario, it appears that strengthening the Malé Declaration would be instrumental in improving regional cooperation in this area.

Satellites offer one way to both provide broad scale information on pollution as well as clearly identify the need for adequate ground monitoring. Fig. 1 also includes maps of aerosol optical depth (AOD) for both the period of burning in the west as well as the longer period of peak pollution. The MODIS sensor provides a good data basis for aerosol research in different regions with a long time series of global aerosol observation data (Sayer et al., 2020) and fire activities. MCD19A2 is the latest MODIS C6 aerosol data released by NASA, which uses the Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm (Lyapustin et al., 2018) to produce daily global aerosol products and MCD14DL FIRMS V0061 NRT for fire activities produced daily at 1 km (km) pixel resolution was used here. Data set with QA flag 3 (recommended for most application, see Sayer et al., 2020) with lowest absolute uncertainties was used. Qin et al. (2021) validated the MCD19A2 product with ground-based observations for AOD. The results indicate that both data sets are highly correlated ($R^2 > 0.8$ at more than 68% of AERONET sites). Although, the regional pollution across the Indo-Gangetic Plain is well captured, the similarity between the ground observations of $PM_{2.5}$ for the city pairs does not come through. During these polluted periods, satellite and ground-based observations can differ significantly because satellite observations are columnar observations that are insensitive to changes in boundary layer mixing and are further affected by ambient humidity effects. Thus, while satellite data still provide a critical qualitative view of the region, they are not an adequate substitute for ground-based monitoring which is essential for the quantitative assessment of the situation in South Asia. Hence, additional monitoring of multiple ground-based parameters, e.g., CO, NO_2, SO_2, and aerosol composition is needed to provide information on composition, sources and processes driving particulate pollution levels and trends.

3. Conclusions

There is a strategic and urgent need for an expansion of routine air quality monitoring networks across South Asia. US Embassy $PM_{2.5}$ monitors are a helpful start, but they do not provide details on other pollutants which are needed to understand the root causes for the region's air pollution problem. South Asian partners have several identified constraints (e.g., limited observations, technical capacity, and financial resources) but have shown a strong determination to combat pollution issues, particularly seasonal smog. Air pollution in South Asia is a multi-dimensional problem that cannot be effectively mediated without the open exchange of proper information and capacity building between all parties, and therefore presents a need to come together. Unfortunately, the yearly South Asian smog episodes are a very real representation of the limitations of the ongoing regional efforts to safeguard. Revitalization of the Malé Declaration would be one way to make progress, but this needs to be accompanied by commitments from each country to work collaboratively to improve regional monitoring across nations with their resources.

Without having consensus across South Asian countries, the current situation cannot be resolved. Fundamental infrastructure for ground-based monitoring across South Asia must be considered as a key element for regional cooperation. This would foster the growth of a stronger community of air quality scientists and decision makers across South Asia needed to address these challenges. Addressing the air pollution problem jointly for the sake of the people who inhabit this densely populated and diverse region of the world would set a good example of regional cooperation to address pressing environmental issues.

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Notes

The Authors declare no competing interests.

Data and materials availability

All data used in this article is publicly available.

US Embassy $PM_{2.5}$ data for Lahore, Delhi, Kolkata, and Dhaka was obtained from https://www.airnow.gov/international/us-embassies-and-consulates/

$PM_{2.5}$ data for Lucknow and Dang were obtained from https://aqicn.org/

The data for Lucknow was sourced from the CPCB - India Central Pollution Control Board (cpcb.nic.in) (https://aqicn.org/city/india/lucknow/central-school/)

The data for Dang was sourced from the Government of Nepal, Ministry of Population and Environment, Department of Environment Air Quality Monitoring (https://aqicn.org/city/nepal/dang/)

For MODIS AOD, the MCD19A2 V6 data product i.e. MODIS Terra and Aqua combined Multi-angle Implementation of Atmospheric Correction (MAIAC) Land Aerosol Optical Depth (AOD) gridded Level 2 product produced with a daily resolution of 1 km was used.

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The processed MODIS fire product MCD14MLfrom the MODIS collection 6.1 was used. Downloaded from FIRMS (Fire Information Management System)

https://firms.modaps.eosdis.nasa.gov/download/

DOI: 10.5067/FIRMS/MODIS/MCD14ML.

CRediT authorship contribution statement

M. Fahim Khokhar: Conceptualization, Visualization, Writing. **M. Shehzaib Anjum:** Conceptualization, Visualization, Writing. **Abdus Salam:** Writing. **Vinayak Sinha:** Writing. **Manish Naja:** Writing. **Kirpa Ram:** Writing. **Hiroshi Tanimoto:** Writing. **James H. Crawford:** Conceptualization, Visualization, Writing. **Mohammed I. Mead:** Writing. All other co-authors contributed to extensive revision and discussion that substantively contributed to the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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