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Remote Sensing for Reducing Spatial Uncertainty in Air Pollution Measurements in Indo-Pacific Region

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Fossil fuel burning is the major cause of air pollution and climate change.[1] According to an estimate, every year 4.2 million people die of heart disease, chronic pulmonary disease and lung cancer due to poor air quality.[2] Air pollution is an important environmental issue in the Asia-Pacific region.[3-6] It is a threat for human health and ecosystems in the Indo-pacific region too[7-12] Bangladesh, India, Nepal, Indonesia, Vietnam, Myanmar, Thailand, Cambodia, Malysia, Taiwan, South Korea and Sri Lanka of Indo-Pacific region are in the list of top most polluted countries.[13]

Supply of 80% of primary energy is made through fossil fuels including coal, oil and natural gas worldwide.[14] Global coal consumption is increased from 16177 TWh to 44600 TWh from 1965 to 2021, oil consumption is increased from 18012 to 51530 and gas consumption is increased from 6303 TWh to 40239 TWh from 1965 to 2021.[15] In addition to fossil fuels, dung cakes, crop residue, fuel wood and other biomass materials are also commonly used as energy sources in South Asia. Approximately 41% of population in India still relies on biomasses for cooking emitting 340 million tones of CO_2 which is almost 13% of India's total greenhouse emissions.[16] In addition to outdoor air pollution, Indoor air pollution is also very harmful, which leads to 0.6 million premature deaths globally.

Air pollution also affects ecosystems by altering soil and water chemistry. It also threatens agricultural productivity and food security. Tropospheric ozone is responsible for crop losses of approximately 5%-20% in maize, rice, soy, and wheat. The report "Air Pollution in Asia and the Pacific: Science-based Solutions" identifies 25 policy and technological measures that could reduce carbon dioxide emissions by 20% and

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methane emissions by 45%, preventing up to a third of a degree Celsius in global warming.[3] A comprehensive air pollution scenario in Asia has been reported by Kulshrestha and Mishra.[17]

Major sources of air pollution include automobile emissions, industrial emissions, power generation, residential combustion and agricultural crop residue burning. These activities release pollutants like particulate matter ($PM_{2.5}$), nitrogen oxides (NOx), sulfur dioxide (SO_2), and volatile organic compounds (VOCs). These pollutants undergo chemical reactions in the atmosphere forming secondary pollutants such as ozone (O_3), sulphuric acid (H_2SO_4), nitric acid (HNO_3) and secondary organic aerosols (SOA). These reactions are influenced by sunlight, temperature, and the presence of other chemicals in the atmosphere. Hence, air pollution shows its variations in time and space. Also, increased population needs increased supply of materials requiring more and more production. Increased production process is also responsible for increased solid-wastes including plastic, tires, metals, and other materials. Incineration and other combustion-disposals of such wastes emit air pollutants. Tire pyrolysis emits HCl which acts as a quenching agent and thus ozone is destructed due to plastic waste burning.[18-19] Recently, control on tire pyrolysis has been reported to have increasing ozone effect resulting in ozone spikes in Delhi region.[20]

The transport and chemistry of air pollutants are influenced by seasonal changes. For instance, during winter months, temperature inversions can trap pollutants close to the ground, leading to higher concentrations of pollutants in urban areas. Due to this reason higher deposition of these pollutants is recorded in urban and industrial areas.[21-23] Studies have shown rising concern for increasing emissions of reactive N gases (NH_3 and NOx), which undergo chemical transformations in the atmosphere.[24-27] Most of the primary emissions of NOx are in the form of NO which is oxidized quickly to NO_2. Major atmospheric oxidants such as OH, O_3, NO_3, HO_2 and Cl play an important role in the gas to particle conversion of atmospheric N species.

Long Range Transport (LRT) and Trans-boundary Transport of pollution also play very important role in various atmospheric processes. Pollutants can travel long distances, crossing national borders and affecting regions far from their sources. Most air pollution sources exist over land but the pristine air of oceans is also affected significantly by these terrestrial sources. For example, pollutants from South Asia can be transported to the Bay of Bengal and Indian Ocean, impacting air quality and climate in the region. East Asian air pollution emissions significantly affect ozone concentrations in Taiwan.[28] Findings of Seven Southeast Asian Studies (7SEAS) program revealed that the Southeast Asia is one of the most challenging aerosol observing environments[29] which need further investigation about its comparison with aerosol environment in south Asia, in particular winter vs summer chemistry and transport. In a report from India, an increase of 3 % in $PM_{2.5}$ levels from 2007-2021 has been estimated over Indo-Gangetic plain by using Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations(CALIPSO).[30] Aerosol increase due to air pollution also results in weather modification including fog formation. Frequent flight disruptions during wintertime fogs are very common in the region. Also, oxides of sulphur and nitrogen can be transported from far west to the Himalayas during winter season. Deposition of these oxides is future threat to the Himalayan ecosystem.[10,31-32]

During Integrated Campaign of Atmospheric Aerosols, gases, and Radiation Budget(ICARB) of Indian Space Research Organization–Geosphere Biosphere Programme (ISRO-GBP), concentrations of major ions in PM_{10} aerosols were found to be higher over Bay of Bengal (BOB) compared to Arabian Sea (AS).[33] Sulphate levels were recorded higher than nitrate over Bay of Bengal as well over Arabian Sea. Concentrations of major ions were found to be influenced by Indian land airmasses, oceanic airmasses, Northern Arabian Sea, Middle East airmasses and African continental airmasses. During this campaign, the pH of rainwater over both BOB and AS was found to be lower than the pH reported at the Indian continental sites.

Remote sensing is a powerful tool for identifying and monitoring air pollution sources. It provides high resolution spatial and temporal data which helps in identifying pollution hotspots and understanding the dispersion patterns of pollutants. In a study, remote sensing data helped in estimating net decrease of air pollution during COVID-19 shutdown. Pathakoti and co-workers have estimated 17% decrease of mean

NO_2 levels over India compared to pre-lockdown period.[34] These workers found a decrease of 62 % in NO_2 at New Delhi against 2019 levels. Land use and land cover changes for urbanization and industrialization indirectly reflect air pollution emission source regions for which remote sensing play an important role in data capturing. In this regard, impact of historical land cover changes (1930-2013) on land surface characteristics have been analysed over the Indian subcontinent by Jose and co-workers.[35] Sharma and Kulshrestha have reported very positive correlation between MODIS AOD values and suspended particulate matter (SPM) at different urban sites in India indicating an influence of industrial and vehicular pollution in cities.[36] In their study, north Indian sites showed higher particulate concentrations than the sites of southern India indicating an effect of mineral dust contributing dust aerosols transported from Thar and Sahara deserts to north-central India. Weather conditions of North India especially raining limited to Monsoon season supports accumulation and resuspension of these dust aerosols. Due to this reason, out of top ten most polluted cities, nine were found to be located in the state of Uttar Pradesh (UP) which falls in north India, a high mineral dust aerosol zone. Contrary to North Indian sites, South Indian sites experience aerosol wash out effect due to their proximity to coastal areas and occasional rains helping in maintaining the particulate levels lower.

Satellites can monitor air quality worldwide, facilitating a possibility of networking and international cooperation in pollution control. The data obtained from remote sensing can be used to formulate effective air quality improvement strategies and policies.[37] More details about air quality and satellite data are given at NASA weblink (https://science.nasa.gov/earth/explore/air-quality/). Satellite data of AOD can be used to calculate aerosol concentrations at ground level. It has been reported that the relationship between AOD and $PM_{2.5}$ aerosols improved significantly when the researchers considered the role of vertical profile and relative humidity.[38-40] Lin and co-workers have reported a fitting approach for accurate calculation of $PM_{2.5}$ from the AOD data on regional scale where they found a good agreement between extinction coefficient and $PM_{2.5}$ concentration within the surface layer.[41] In this regard LiDAR-derived aerosol extinction profiles is of great help to get improved correlation between AOD and surface $PM_{2.5}$.[42] Aerosol optical depth partitioning in terms of mineral dust, anthropogenic pollutant and biomass burning particle fractions is also possible as attempted by Lin and co-workers using aerosol optical size distribution, spectral absorption and scattering.[43] However, there might be some discrepancies between ground data and satellite data which need to be attempted. Exercise of quantification of a particular chemical species is very challenging having a scope of development of more appropriate differentiation and quantification method. A careful comparison of ground based and satellite data and their calculations might be helpful in obtaining more accurate results. Anggraini and co-workers have developed global air quality index using remote sensing and ground based data.[44] A much more advanced remote sensing for aerosol and air pollution research is anticipated in coming two decades.[45]

Addressing air pollution on Indo-Pacific scale including the Himalayas, Bay of Bengal, Indian Ocean and Pacific Ocean is necessary but challenging due to the vast area involved. This region extending upto Taiwan is less investigated. Traditional ground-based monitoring approaches are costly and difficult to implement in large regions. Hence, there is a great need of integrating satellite observations with surface air pollution chemistry measurements and transport for a more comprehensive understanding of air pollution dynamics in Indo-Pacific region.Without further action, air pollution is set to increase due to continued economic growth and urbanization. Therefore, it is crucial for evolving effective air quality management strategies in Indo-Pacific on the following points-

- In order to understand the air pollution chemistry and transport in Indo-Pacific region, a formal initiative is needed in the region. It might be India and any one country in the Pacific as a startup campaign.
- A team of experts to be identified for carrying out a focused work.
- We need to select a few representative sites for carrying out ground-based measurements of selected air pollutants which are directly or indirectly available from the satellite.
- We need active participation of young researchers for extraction and interpretation of data using modern tools of computing such as machine learning etc.

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