ABSTRACT

The Indo-Gangetic Plain (IGP) is one of the most densely populated and agriculturally intensive regions of the world, supporting millions of livelihoods but facing severe challenges from air pollution. Aerosols, largely driven by land use changes, agricultural practices, and rapid urbanization, represent a major environmental and health concern in this region. Recognizing the critical importance of the IGP, this study investigates long-term aerosol trends, retrieval of high-resolution Aerosol Optical Depth (AOD), seasonal variability, and the application of advanced machine learning approaches to improve AOD estimation. Long-term analysis of MODIS AOD (2001–2022) highlights strong links between land use and land cover (LULC) changes, crop residue burning (CRB), and rising aerosol levels, with particularly sharp increases observed in the lower IGP due to cropland expansion and biomass burning. Conversely, the upper IGP exhibited declining AOD in recent years, consistent with reduced CRB activity. Building on this regional perspective, this study also focused on the city scale, where coarse-resolution satellite datasets are inadequate for capturing localized variability. To address this limitation, 30m resolution AOD was retrieved over Kanpur city in IGP using the radiative transfer model based SEMARA algorithm applied to Landsat-8 imagery. Validation with AERONET observations confirmed its high accuracy and comparative analysis with MODIS MAIAC AOD product revealed that SEMARA performed particularly well over built-up and barren land. To further demonstrate the utility of high-resolution retrievals for urban air quality assessment, AOD was analysed in relation to land surface temperature (LST) for urban region over Kanpur and its surrounding areas, revealing distinct seasonal patterns. During cultivation, the city exhibited higher LST and AOD than the outskirts while during harvesting, LST and AOD increased significantly in the outskirts, bringing AOD to levels similar to the city. This seasonal shift corresponded with higher urban heat island (UHI) and urban aerosol pollution intensity (UAPI) intensities over the city during cultivation and over the outskirts during harvest. While SEMARA proved effective, its reliance on prior assumptions and reference observations posed limitations for broader applications. To overcome these challenges, a Physics-Informed Convolutional Neural Network (PI-CNN) was developed for 30m AOD retrieval by embedding radiative transfer principles within a deep learning framework. Trained over Kanpur and fine-tuned to Delhi, PI-CNN reproduced spatial distributions across different land classes consistent with SEMARA and achieved strong agreement with AERONET observations, demonstrating its robustness and scalability.

Keywords: Aerosol optical depth, Urban Heat Island, Convolutional neural network