PhD thesis synopsis

PhD thesis title: **Air pollution dynamics in two coastal megacities of India amidst COVID-19 pandemic**

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The COVID-19 pandemic led many countries, including India, to implement nationwide lockdowns to halt the virus's spread. India implemented the first lockdown on 24 March 2020 during the first wave. Kolkata and Mumbai experienced subsequent lockdowns due to pandemic surges: Kolkata from 16 May to 30 May 2021 and from 01 January to 15 January 2022, while Mumbai's lockdowns occurred from 22 April to 1 May 2021 and from 10 January to 19 January 2022. This doctoral thesis examines the impact of COVID-19 lockdowns on air quality in Kolkata and Mumbai, two coastal megacities, using Delhi as a control. The study includes six chapters. One chapter focused on air pollution levels worldwide, and another on air pollution in China, India, and Pakistan. The remaining chapters concentrate on Kolkata, Mumbai, and Delhi. Data were collated from the Central Pollution Control Board (CPCB), Real-time Air Quality Index (AQI), IQAir, and NASA GIOVANNI. The climate datasets used in this research were sourced from Weather Underground and NASA Power. Kolkata has ten, Mumbai has fifteen, and Delhi has thirty-seven ambient air monitoring stations. India's tropical monsoon climate features distinct wet and dry seasons, with pandemic surges occurring during early pre-monsoon and winter months, which enabled me to study the effect of meteorology on air pollution levels.

Chapter 1 introduced the research topic. The doctoral thesis utilized various methods, including spatial-temporal variation maps generated with the Inverse Distance Weighting (IDW) interpolator using ESRI ArcGIS 10.5, de-weathering through the generalized additive model (GAM) with XLSTAT-R, statistical analysis via the Pearson correlation coefficient in R. Additionally, it employed cartographic techniques and statistical methods, such as point plots, box plots, and sparkline diagrams to illustrate changes in average concentration trends. Chapter 2 detailed the methodology adopted in this doctoral study.

Chapter 3 examines the impact of the COVID-19 lockdown on global atmospheric pollution levels, focusing on ambient NO_2 and Aerosol Optical Depth (AOD) data from NASA's

GIOVANNI portal. Before the lockdowns, China had the highest tropospheric pollution, followed by India, the U.S., Germany, France, and Italy, with the most polluted regions identified in eastern China, India, northern Italy, and western Germany. The study analyzed four time phases for each country: normal phases in 2019 and pre-, during, and post-lockdown phases in 2020. A significant reduction of up to -60% in pollutant levels was observed during the lockdown, with a partial rebound post-lockdown. The findings suggest that periodic short lockdowns could effectively help reduce air pollution and promote a sustainable environment.

Chapter 4 presents a seven-year analysis (2017-2023) of $PM_{2.5}$ data from 760 cities across China, India, and Pakistan, which together represent over 38% of the global population. It reveals that all cities in these countries exceed the WHO's standard limit of 5 μg/m³, with $PM_{2.5}$ levels in Pakistani and Indian cities more than double those in China. The study highlights a significant shortage of monitoring stations in Pakistan. Delhi, India, stands out as the most polluted area, with a $PM_{2.5}$ level of 97.5 μg/m³. The highest $PM_{2.5}$ concentrations were found in the Indo-Gangetic plain of India, north-central Pakistan, and central-east China. Urgent government intervention is needed to address these levels, as prolonged exposure poses risks to human health and ecological well-being. Continuous monitoring of $PM_{2.5}$ across all cities is essential for effective research and solutions.

Chapter 5 analyzed air quality in three Indian megacities—Mumbai, Kolkata, and Delhi—during the lockdown and compared it to pre-lockdown and post-lockdown periods. Seven major pollutants ($PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, CO, and O_3) were studied using data from 62 AAMSs under the CPCB. Delhi was the most polluted, followed by Kolkata and Mumbai. The lockdown (25 March to 14 April 2020) resulted in significant improvements in air quality compared to the pre-lockdown phase and the same period in 2019. Post-lockdown showed mixed results. Major pollutants reduced as follows: $PM_{2.5}$ by -47% in Mumbai, -52% in Delhi, and -49% in Kolkata; PM_{10} by -41%, -39%, and -37%, respectively; and CO by -27%, -13%, and -21%. This study highlights that short-term lockdowns can refresh air quality in these megacities.

Chapter 6 highlights the differences in air pollution levels during Diwali celebrations in 2020, amid the COVID-19 pandemic, compared to 2019. The concentrations of key pollutants—$PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, CO, and O_3—were significantly higher in 2020. $PM_{2.5}$, PM_{10}, and CO consistently exceeded permissible limits, especially in Delhi, indicating increased

firecracker usage during the pandemic. However, pre-Diwali to Diwali changes in pollutant levels showed lower pollution in Mumbai and Kolkata. Meteorological conditions likely contributed to the heightened pollution in Delhi in 2020, as pollutants lingered for nearly a week after the celebration. The study underscores the need for stricter regulations to reduce pollution from such festivities.

Chapter 7 examines Kolkata's air quality during three pandemic waves. It analyzed seven pollutants ($PM_{2.5}$, PM_{10}, CO, NH_3, NO_2, SO_2, O_3) from 10 monitoring stations. NO_2, NH_3, SO_2, and O_3 were below CPCB standards, but CO exceeded them during all waves. $PM_{2.5}$ and PM_{10} levels fluctuated. Declines of -44%, -34%, -15%, -48%, and -51% in $PM_{2.5}$, PM_{10}, NO_2, SO_2, and O_3 were observed during the second wave compared to the first. The AQI improved by -40% during this period. However, the third wave saw a rise in pollution, making it the highest among the three. Strong positive correlations were found between $PM_{2.5}$, PM_{10}, CO, and NO_2 levels. Seasonal changes affected pollutant concentrations, and specific industrial areas showed compromised air quality. Policymakers should consider short-term lockdowns to improve air quality.

Chapter 8 analyzed air pollutant dynamics in Mumbai during three COVID-19 lockdown phases with varying stringencies: very stringent, moderately stringent, and loose to moderately stringent. Data on $PM_{2.5}$, PM_{10}, CO, NH_3, SO_2, NO_2, O_3, and AQI were sourced from the CPCB. CO consistently exceeded CPCB standards, while $PM_{2.5}$ and PM_{10} were below standards during the first wave but showed mixed results later. During the second wave, pollutants increased by 56% ($PM_{2.5}$), 45% (PM_{10}), 40% (CO), and others compared to the first wave. In the third wave, increases were 89% ($PM_{2.5}$), 15% (PM_{10}), and others compared to the second wave. The findings indicate that lockdowns improved air quality, but as restrictions eased, pollutant levels rose. Lockdowns during winter were more effective in reducing air pollution than those in summer.

Chapter 9 detailed the conclusions and recommendations. To improve air quality in megacities, the following steps are essential: halting construction during high pollution days, expanding electric public transport to reduce private vehicle use, using sweepers and water sprinklers to reduce road dust, implementing the Clean Air Mumbai Initiative, i.e., enforcing monitoring and penalties for non-compliance, planting trees and creating urban green spaces, instituting

short-term lockdowns during winter to prevent PM buildup. These actions will help combat air pollution effectively.