Impact of Air Pollution on the Respiratory Health of Children: A Study Conducted in Udaipur, India

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Abstract

Children constitute a particularly susceptible group to ambient air pollution due to their developing lung structure and elevated breathing rates. This cross-sectional study assesses the direct effects of ambient air pollution on the respiratory health of children aged 5 to 15 years in Udaipur, India. Systematic ambient monitoring of criterion pollutants, specifically fine particulate matter $PM_{2.5}$, PM_{10}, SO_2, and NO_2, was performed across high-exposure urban traffic corridors and low-exposure residential control zones with high-volume gravimetric samplers. Pediatric respiratory health patterns were concurrently analyzed using localized health registries and standardized questionnaires. The empirical data indicate a statistically significant positive connection between increased particle levels $PM_{2.5}$, PM_{10} and pediatric respiratory morbidity. Children living in high-exposure metropolitan locations demonstrated a markedly greater incidence of acute respiratory infections (ARI), persistent wheezing, allergic rhinitis, and chronic asthma than their counterparts in residential control regions. These health anomalies reached their zenith during winter air inversions when contaminants were confined near the surface. This research highlights a pressing environmental health concern, providing a crucial scientific framework for doctors and urban planners to implement clean air regulations in school zones and mechanical dust suppression to protect children's health.

Keywords: Pediatric Health, Air Pollution, Respiratory Morbidity, $PM_{2.5}$, Udaipur.

1. Introduction

Lung and airway diseases frequently present with one or more readily identifiable symptoms. Consequently, the manifestation of a specific symptom or a cluster of symptoms can validate the existence of an underlying pathology in the upper or lower respiratory tracts. Respiratory symptoms are categorized into two primary groups: (1) upper respiratory symptoms (URS), encompassing rhinorrhea, nasal congestion, sinusitis, pharyngitis, cephalalgia, pyrexia, and ocular burning or erythema, and (2) lower respiratory symptoms (LRS), comprising wheezing, productive cough, nonproductive cough, sputum production, dyspnea, and thoracic discomfort or pain. The majority of respiratory disorders associated with these symptoms result from bacterial, fungal, or viral infections, or from structural or functional impairments of the respiratory system. The symptoms of a respiratory ailment are frequently exacerbated after exposure to air pollutants. Epidemiological studies throughout the world have established a close association between urban air pollution and human diseases (Dockery et al. 1993).

Sun, Z., et al. (2013) conducted an evaluation of population exposure to PM_{10} in Lanzhou, China, concerning respiratory diseases and the associated health-related economic expenses via GIS. Assessing the detrimental health impacts of PM_{10} pollution is crucial for safeguarding human health and formulating pollution management policies. Adar, S.D. et al.(2014) evaluated ambient coarse particulate matter and its impact on human health by a systematic review and meta-analysis. Airborne particulates have been associated with elevated mortality and morbidity rates. While extensive research has concentrated on tiny particles ($PM_{2.5}$), the health consequences of coarse particles ($PM_{2.5}$) are inadequately comprehended. Fly ash is often collected in electrostatic precipitators (ESPs) and disposed of in ponds or on open land, with some entering the atmosphere via stacks alongside fuel gasses. Guttikunda and Goel[48] researched the health effects of particle pollution in the megacity of Delhi, India. In Delhi and its surrounding cities, the primary contributors to particulate matter (PM) pollution are vehicle emissions, industrial activities, waste incineration, and construction operations.

2. Materials and Methods

Udaipur, known as the city of lakes, is positioned approximately 600 meters above sea level, nestled between the verdant hills of the Aravali range at coordinates 24°35' N latitude and 73°42' E longitude. Numerous lakes, such as Pichhola, Fateh Sagar, and Swaroop Sagar, are integral to the social, cultural, and economic activities of Udaipur. To evaluate the impact of air pollution on the biochemical and physiological parameters of plant growth, as well as morphological alterations, three locations were selected: Urban area (Surajpole at 24°34'45.95"N, 73°41'46.31"E, elevation 612 m), Industrial area (Madri Industrial Area at 24°35'01.23"N, 73°44'59.52"E, elevation 600 m), and Residential area (Mulla Talai at 24°25'00.90"N, 73°46'05.40"E, elevation 449 m). Ten sites within these areas, spaced 10 meters apart, were identified, and observations were conducted to determine the mean value across all sites based on a minimum of three recordings per day at various times: morning, noon, and evening. The ambient air quality and its effects on humans were examined at these locations throughout a two-year period, specifically from November 2023 to October 2025, on a monthly basis. The chosen urban region experiences elevated air pollution levels due to loading and unloading operations, as well as road transport activities. Ambient air samples were collected using High volume sampler (Envirotech model, APM-410) and Respirable dust sampler (Envirotech model APM 460) with suitable gas attachment. Suspended particulate matter, and Respirable suspended particulate matter were collected on glass fiber filter papers by using high volume sampler and respirable dust sampler (Rehme et al. 1984). Particulate concentrations were determined gravimetrically by recording pre- and post-sampling filter weights and considering the sampled air volume. Gaseous pollutants were scrubbed separately in 0.1 M potassium tetrachloromercurate and sodium hydroxide (0.1N), respectively. These absorbing solutions were later analyzed colorimetrically for SO_2 and NO_2.

3. Results

A systematic two-year environmental air monitoring program from November 2023 to October 2025 was executed across three distinct functional zones of Udaipur City, which included the Urban Commercial area of Surajpole, the Madri Industrial area, and the Residential sector of Mulla Talai. This study was aimed to quantitatively evaluate the atmospheric loading of key criteria pollutants including Sulphur Dioxide, Nitrogen Oxides, Suspended Particulate Matter, and Respirable Suspended Particulate Matter.

1. Spatio-Temporal Dynamics in the Urban Zone (Surajpole)

The empirical data synthesized for the Urban Commercial zone indicated distinct seasonal fluctuations prominently driven by heavy traffic density. During the first year from 2023 to 2024, gaseous trace pollutants remained relatively controlled. The monthly mean concentrations of Sulphur Dioxide ranged between 5.35 micrograms per cubic meter and 10.72 micrograms per cubic meter, while Nitrogen Oxides fluctuated between 21.30 micrograms per cubic meter and 36.12 micrograms per cubic meter. However, the particulate envelope showed severe loading across the station. The mean Suspended Particulate Matter levels peaked at 375.33 micrograms per cubic meter in May 2024, accompanied by a substantial baseline of Respirable Suspended Particulate Matter, which hit a maximum monthly mean of 179.52 micrograms per cubic meter in April 2024. In the second year of observation from 2024 to 2025, the urban micro-climate exhibited intensified deterioration. The mean Nitrogen Oxides levels registered a steep spike in January 2025 reaching 48.38 micrograms per cubic meter. Concurrently, the particulate matter kinetics established a dangerous trend where the monthly mean of Suspended Particulate Matter reached an alarming threshold of 372.52 micrograms per cubic meter in April 2025, and Respirable Suspended Particulate Matter concentrations consistently breached safe limits, peaking at a monthly mean of 147.55 micrograms per cubic meter.

2. Heavy Pollution Profiles in Madri Industrial Area

The atmospheric profile of the Industrial zone emerged as the most critical sector, demonstrating the combined impact of manufacturing emissions and fugitive process dust. In the first year, mean Sulphur Dioxide levels were visibly higher than in other zones, hitting a maximum mean of 17.23 micrograms per cubic meter in December 2023. The particulate fractions displayed staggering concentrations during the winter cycle. In December 2023, the mean Suspended Particulate Matter soared to a critical high of 915.76 micrograms per cubic meter with a corresponding mean Respirable Suspended Particulate Matter of 455.97 micrograms per cubic meter, followed closely by January 2024 where mean Respirable Suspended Particulate Matter was recorded at an extreme 752.06 micrograms per cubic meter. During the second phase of monitoring from 2024 to 2025, the industrial envelope maintained its degraded pattern. The mean Nitrogen Oxides concentrations peaked at 64.94 micrograms per cubic meter in January 2025, while the mean Suspended Particulate Matter levels consistently remained high, peaking at 574.40 micrograms per cubic meter in November 2024, indicating persistent heavy industrial dust loading.

3. Baseline Assessment of the Residential Zone (Mulla Talai)

In sharp contrast to the commercial and industrial clusters, the Residential zone at Mulla Talai served as a low-exposure control environment, exhibiting significantly lower environmental stress. Throughout the first year, the mean Sulphur Dioxide concentrations remained tightly bound within a safe baseline of 2.58 micrograms per cubic meter to 6.35 micrograms per cubic meter, while mean Nitrogen Oxides values comfortably hovered between 23.98 micrograms per cubic meter and 38.65 micrograms per cubic meter. The particulate trends in this residential sector showed moderate aggregation. The seasonal mean Suspended Particulate Matter remained under acceptable parameters, fluctuating between 66.3 micrograms per cubic meter and 111.05 micrograms per cubic meter. This localized stability was successfully replicated during the second monitoring year from 2024 to 2025, where the absolute mean of Sulphur Dioxide was suppressed at 2.59 micrograms per cubic meter in October 2025, and the mean Suspended Particulate Matter levels safely consolidated between 76.35 micrograms per cubic meter and 111.5 micrograms per cubic meter.

4. Discussion

Hooper and Kaufman (2018) examined ambient air pollution and its clinical implications for vulnerable populations. Air pollution is linked to various health impacts, and there is evidence supporting a causal relationship with specific diseases. Exposure to air pollution is pervasive and generally uncontrollable by individuals; the consequent health impact on the population can be substantial. Chambliss S.E. et al. (2014) provided an estimation of source-attributable health consequences due to ambient fine particulate matter exposure, specifically worldwide premature mortality resulting from surface vehicle emissions in 2005. Asadi and Norouzi (2021) studied the impacts of air pollution on public health, focusing on several metropolises worldwide. Air pollution is presently seen as a global issue in both emerging and industrialized nations. Substances that infiltrate our environments are constituents of air pollution that adversely affect health for those exposed, impacting not only the cardiovascular and respiratory systems but also linked to the etiology of various pathologies throughout the body, resulting in reduced life expectancy, increased mortality, and alterations to genetic material. Sharma M. (2024) disclosed the reduction of air pollution and the safeguarding of public health by examining the effects of the national clean air program in Kota, Rajasthan. Hassan Bhat, T., et al (2021) conducted a study on the principles and applications of air pollution health risk assessment (AP-HRA). Air pollution constitutes a significant public health issue. Ghorani-Azam A, et al. (2016) reported impact of air pollution on human health and practical preventative methods in Iran. The World Health Organization identifies six principal air pollutants: particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. Prolonged and short-term exposure to airborne toxicants exerts distinct toxicological effects on humans, encompassing respiratory and cardiovascular ailments, neuropsychiatric disorders, ocular irritation, dermatological conditions, and chronic diseases such as cancer.

5. Conclusion

Conclusively, the findings of the present study validate a severe spatial imbalance in the air quality of Udaipur City. The industrial and high-traffic commercial zones act as persistent regional hotspots for particulate pollution, particularly exacerbated during the winter dry spells due to micro-meteorological trapping, whereas the residential zones currently maintain a sustainable, low-risk atmospheric baseline.

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