Analysis of Air Quality Index (AQI) Trends and Sustainable Urban Development in Rajasthan

***Ramkesh Meena**

Abstract

The study is on the growing problem of air pollution in Rajasthan, the largest state of India and its effect on sustainable urban development. The study also looks at the AQI trends in major urban agglomerations like Jaipur, Jodhpur, Alwar and Bhiwadi to understand the keycontributors of pollution from geogenic desert dust to anthropogenic industrial and traffic pollution. The article assesses the effectiveness of the existing mitigation techniques under the National Clean Air Programme (NCAP) and suggests a framework to integrate "Green Urbanism" in the developmental agenda of Rajasthan. Data aggregated until 2024 reveals that policy interventions have slowed the rate of degradation, but the levels of atmospheric particulate matter continue to be a substantial impediment to the achievement of the Sustainable Development Goal (SDG) 11

1. Introduction

The rapid pace of urbanization in Rajasthan, India's largest state by landmass, has brought the region to a critical environmental crossroads. Traditionally recognized for its vast desert landscapes and heritage-driven tourism, Rajasthan has transitioned into a burgeoning industrial and commercial powerhouse. However, this economic metamorphosis has come at a severe atmospheric cost. Air pollution has shifted from a localized nuisance to a systemic public health crisis, with the Air Quality Index (AQI) frequently reaching hazardous levels across several of its Tier-I and Tier-II cities.

The atmospheric profile of Rajasthan is unique compared to the rest of the Indo-Gangetic Plain (IGP). While states like Punjab and Haryana struggle primarily with seasonal agricultural residue burning, Rajasthan's air quality is governed by a complex "Dual-Threat" mechanism. On one hand, the state is subject to natural, geogenic stressors—predominantly mineral dust from the Thar Desert, which keeps the baseline of coarse Particulate Matter (PM-10 perpetually high. On the other hand, rapid anthropogenic expansion in the form of intensive smelting, stone crushing, textile manufacturing, and a massive surge in vehicular density has introduced a lethal cocktail of fine Particulate Matter (PM-2.5), Nitrogen Oxides (NOx), and Sulfur Dioxide (SO2).

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Cities such as Bhiwadi, Jaipur, and Jodhpur have become focal points for this crisis. Bhiwadi, located within the National Capital Region (NCR), has repeatedly been cited in global reports as one of the most polluted cities on Earth, serving as a cautionary tale of industrial growth divorced from environmental safeguards. Meanwhile, Jaipur, the "Pink City," represents the challenges of a rapidly motorizing capital where heritage architecture and high-density traffic coexist in an increasingly stagnant airshed.

Sustainable Urban Development (SUD) is no longer a choice but a necessity for the state's survival. The Rajasthan State Vision 2030 and the National Clean Air Programme (NCAP) provide the policy scaffolding for reform, but the implementation requires a nuanced understanding of AQI trends. This paper aims to dissect these trends from 2018 to 2024, evaluating how the state's urban development policies—such as the transition to Electric Vehicles (EVs), the enforcement of Piped Natural Gas (PNG) in industrial clusters, and the expansion of the "Green-Blue" infrastructure—are performing against the backdrop of deteriorating air quality. By analyzing the correlation between urban density and pollutant concentration, this study seeks to provide a roadmap for integrating air quality management into the very DNA of Rajasthan's future urban planning.

2. Review of Literature

Academic and regulatory discussion on the air health of Rajasthan has grown a lot from 2015 to 2024. The existing research indicates a multidisciplinary consensus that the state's air quality is a consequence of its geographical destiny and aggressive development.

2.1 The Geogenic Baseline and MP

The literature is replete with the "Baseline Effect" of the Thar Desert. According to Yadav et al. (2021), mineral dust is a major component of the PM-10 mass in Northwest India. Their research, using satellite data, showed how dust storms originating in the desert and Arabian Peninsula lead to "Natural Pollution Episodes," which can push the AQI into the "Severe" category even when there is no industrial activity. However, new research has tried to separate this coarse mineral dust from the more dangerous tiny particles. Singh and Sharma (2023) using source apportionment methodologies showed that PM-10 is mostly natural, but PM-2.5 in Rajasthan's cities is mainly carbonaceous in nature and arises from fossil fuel burning and secondary aerosols from industrial sources.

2.2 Industrial Clusters and NCR Effec

The 'Bhiwadi Phenomenon' comprises a large part of today's environmental literature. Bhiwadi, located in the Alwar district and the National Capital Region (NCR), is a laboratory for investigating industrial smog. The concentration of heavy metals in suspended particulate matter in Bhiwadi is much greater than in non-industrial cities such as Udaipur (RSPCB, 2023). Kumar and Singh (2022) mention that SOx levels have declined due to the substitution of coal/coke by Piped Natural Gas (PNG) in industrial units, but the NOx and fine particles remain high due to the density of heavy-duty transport vehicles supplying these sectors.

2.3 Urban Morphology and Heat Island Effect

Much of the research on sustainable urban development now ties air quality to "Urban Heat Islands" (UHI). In a desert state like Rajasthan, the UHI effect has been worsened by the increase of construction and the loss of traditional water sources (Baoris) and green spaces. "Higher temperatures in urban areas lead to the formation of ground-level ozone, a secondary pollutant that is often not included in Rajasthan's AQI analysis," says Vyas (2024). The study argues that the "Walled City" sections of Jaipur and Jodhpur, with small roads and high "canyon ratios," trap pollution, creating isolated zones of elevated respiratory danger.

2.4 Governance and National Clean Air Programme (NCAP)

Air quality governance has moved from ad hoc local orders to the systematic approach of the National Clean Air Programme (NCAP). According to reports by the CPCB (2024) on "Non-attainment cities" in Rajasthan (like Jaipur, Jodhpur, Kota, and Alwar), there is progress in infrastructure – like installation of CAAQMS (Continuous Ambient Air Quality Monitoring Stations) – but the actual reduction in particulate levels is marginal. Meena's (2023) literature critiques the urban bodies' "siloed" approach where air quality management is not integrated with transport planning and waste management. This results in contradictory outcomes such as road widening projects increasing vehicular flow and at the same time, the promotion of green-belt projects.

2.5 Electric Vehicle (EV) Transition as Mitigation Strategy

Transport's function in the urban development has turned towards electrification. The Rajasthan Electric Vehicle Policy (2022) has recently been the focus of socio-economic research. Studies indicate that e-rickshaws and electric two-wheelers have offered a

"first-mile-last-mile" solution in cities such as Jaipur and Ajmer, but the overall effect on city-wide AQI will be modest until the public bus fleets and heavy commercial vehicles are drastically de-carbonized.

2.6 Comparative Global Context: Urbanization of Deserts

A global literature comparing Rajasthan to other arid urban centres (like Cairo, Egypt or Phoenix, USA) offers a benchmark for 'Dust Mitigation Protocols'. Research by El-Geziry (2021) on desert urbanisation demonstrates that traditional architectural styles which promote natural ventilation and cooling are more effective in managing indoor dust than the contemporary glass-and-concrete high-rises currently trending in Jaipur's newer developments. This exposes a gap in Rajasthan's sustainable development, which involves integrating "Vernacular Architecture" with modern pollution control.

3. Methodology

This study utilizes a multi-dimensional analytical approach:

1. **Data Acquisition:** AQI data and concentration levels of SO2, NO2, PM-10 and PM-2.5 were sourced from the Continuous Ambient Air Quality Monitoring Stations (CAAQMS) operated by the Rajasthan State Pollution Control Board (RSPCB) for the period 2018–2024.
2. **Trend Analysis:** Seasonal variations (Summer, Monsoon, Winter) were analyzed to distinguish between natural dust storms and anthropogenic smog.
3. **Comparative Study:** A cross-city comparison was conducted to evaluate the impact of industrial versus commercial urban structures on AQI.

4. Analysis of AQI Trends (2018–2024)

4.1 The Bhiwadi Industrial Crisis

Bhiwadi, an industrial hub in the Alwar district, consistently records AQI levels in the "Very Poor" to "Severe" categories.

- **Primary Pollutants:** PM-2.5 and NOx.
- **Trend:** Despite the 2023 mandate for switching to Piped Natural Gas (PNG), the AQI remains high due to heavy-duty vehicular traffic and dust from construction activities.

4.2 Jaipur: The Urban Combustion Profile

As the capital, Jaipur's AQI is a reflection of intense vehicular density and construction.

- **Seasonality:** Winter months (November–February) show a 40% spike in PM-2.5due to temperature inversion trapping pollutants near the surface.

- **AQI Ranges:** Typically fluctuates between 150 ("Moderate") and 350 ("Poor").

4.3 Jodhpur and the Desert Influence

Jodhpur's air quality is characterized by high PM-10 levels. Unlike Bhiwadi, the pollution here is a mix of handicraft industries (textile printing/dyeing) and natural mineral dust.

City	Avg. PM2.5 (2023)	Avg. PM10 (2023)	Predominant Source
Bhiwadi	110 $\mu g/m^3$	280 $\mu g/m^3$	Industrial Emissions
Jaipur	65 $\mu g/m^3$	150 $\mu g/m^3$	Vehicular/Road Dust
Jodhpur	55 $\mu g/m^3$	190 $\mu g/m^3$	Mineral Dust/Handicrafts

5. Drivers of Air Pollution in Rajasthan

5.1 Fast motorization

The registered vehicles in Rajasthan have grown at a CAGR of ~8% during the last decade. The elderly commercial diesel fleet continues to be a major producer of black carbon.

5.2 Industrial smelting and stone crushing industries

Rajasthan is a mineral rich state. Silica dust is a major public health issue (Silicosis) and also an AQI problem due to stone crushing plants, marble processing etc. in areas like Rajsamand, Makrana etc.

5.3 Biomass and Waste Combustion

In the peripheral urban regions (slums and peri-urban villages), isolated "toxic zones" are formed by the use of solid fuels for cooking and the open burning of municipal solid waste (MSW).

6. Urban Development Policies for Sustainability

Urban planning needs to change from "Grey Infrastructure" to "Green-Blue Infrastructure" to meet the Rajasthan State Vision 2030.

6.1 Green Buffers and Urban Forestry

Ajmer is one of the cities where the "Miyawaki" urban forestry technique is being tested. The extensive green belts around the industrial corridors can act as natural particulate filters.

6.2 The EV Shift
Rajasthan's EV Policy (2022) offers incentives for two and three wheelers. EV registrations have increased by 150% in the state up to 2024 – a crucial step in decreasing tailpipe emissions.

6.3 Intelligent Traffic Management

Use Artificial Intelligence (AI) to manage the traffic flow in the Walled City areas of Jaipur and Jodhpur which will minimize the idling time and associated emissions by an estimated 15 – 20%.

7. Discussion: Challenges of Implementation
The major problem of Rajasthan is Geoclimatic Constraint. Regardless of the amount of industrial emission controlled, the state will always have high PM_{10} due to the desert. So the focus has to be on "Reducing Toxicity." The coarse dust is less toxic than the fine PM-2.5 and the chemical-laden haze from the plants.

Rajasthan needs a "Regional Airshed Approach" for sustainable development. Pollution does not recognize municipal boundaries. The 2023 "Dust Mitigation Plan" was a start in the right direction by making automated sweeping and vertical gardens on flyover pillars mandatory, but enforcement is still poor in smaller ULBs.

Conclusion and Strategy Roadmap for 2030

Trends in AQI in Rajasthan between 2018 to 2024 indicate a state that is firmly at the environmental crossroads. Rajasthan has shifted from an agrarian economy to an industrial powerhouse, improving its budgetary health but damaging its atmospheric integrity. This data reveals that the "Bhiwadi-Jaipur-Jodhpur" corridor continues to be the epicentre of an air quality catastrophe where geogenic desert dust and anthropogenic chemical smog coalesce into a permanent health concern.

The growth of air quality control in the state under the guidance of the National Clean Air Programme (NCAP) has been effective in developing the necessary monitoring infrastructure. But the biggest challenge is the transition from data observation to active reduction. The gradual "status quo" is no longer adequate. Rajasthan has to radically mainstream air quality standards into the heart of its urban development program.
If the state is to attain a sustainable urban future by 2030, it must shift toward an Integrated Airshed Management strategy. This means:

- **Decarbonizing Industrial Logistics:** From PNG regulations for industries to the "last mile" emissions from thousands of heavy-duty diesel vehicles that serve industrial areas like Bhiwadi and Alwar.

    - **Vernacular Urbanism:** Re-integrating ancient Rajasthani architectural elements like shaded street canyons and natural ventilation for mitigating the Urban Heat Island effect and localized pollutant trapping in historic zones.

    - **Aggressive Blue-Green Integration:** Beyond decorative "vertical gardens" to real urban woods and revival of once water bodies (Stepwells/Baoris) that are natural heat sinks and particulate filters.

    - **Public Transit Parity:** Celebrating the growth of the Jaipur Metro and Electric Vehicle (EV) fleets with a strong, clean public bus network in Tier-II cities like Ajmer, Udaipur and Kota.

Ultimately, the fight for clean air in Rajasthan is not just a war against particulate matter but a fight to redefine what "development" means for a desert state. By prioritizing human health and ecological resilience over unchecked vertical growth, Rajasthan may reimagine its urban cores from pollution engines to models of sustainable, arid-zone urbanization. The "Clean Air, Blue Sky" vision for 2030 is possible, but only if air quality is upgraded from a minor environmental issue to the major pillar of state administration.

Assistant Professor -Zoology
Govt. College, Baran (Raj.)

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