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"Assessing the Impact of Government Policies and Smart City Initiatives on Sustainable Infrastructure and Air Quality Improvement" – A Case Study of Udaipur, Rajasthan

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Abstract

Udaipur, the "lake city" faces intensified environmental challenges, mainly air pollution and infrastructure stress. The main economy of Udaipur is driven by tourism and faces increasing pressure from vehicular emissions, construction activities, tourism and mining-related pollutants. This study assesses the impact of government policies like **Smart Cities Mission , National Clean Air Programme**, **Atal Mission for Rejuvenation and Urban Transformation** and **Swachh Bharat Mission** initiatives on sustainable infrastructure development and air quality improvement in Udaipur using **monthly averaged data of Air Quality Index (AQI), PM_{10}, NO_2, and SO_2** concentrations, obtained from three monitoring stations- Amba Mata, Town Hall and Regional Office of Rajasthan State Pollution Control Board (RSPCB), from year 2018 to 2024. This analysis mainly considering patterns and trends in AQI as a proxy parameter for the impact of infrastructure and environmental management. Results show a moderate improvement in average AQI between 2018 to 2024 with a partial deterioration in which PM_{10} is the main barrier for achieving good air quality. The seasonal pattern shows monsoon months having relatively better air quality than the winter months. The COVID-19 lockdown acted as a "natural experiment," proving that traffic and industry are major contributors. The results also show a distinct downward trend in SO_2 and NO_2 concentrations, local traffic control cannot be the only reason for the persistent decline in NO_2 after 2020. It strongly aligns with the adoption of BS-VI fuel and vehicles, which reduce nitrogen oxide emissions by up to 70% in diesel cars. SO_2 levels in Udaipur have remained well within safe limits. Post-2020, levels dropped and stabilized between 6 $\mu g/m^3$ and 8 $\mu g/m^3$.

Keywords: AQI, AMRUT, COVID-19, Environmental Management, NCAP, Smart City, Udaipur.

1. Introduction

The "Smart City" paradigm has transitioned from a technocratic vision to one rooted in sustainable urban development. Trindade et al. (2017) [*1] argue that genuine smart cities must integrate Information and Communication Technology (ICT) not just for efficiency but to actively mitigate environmental externalities. Rapid growth of urban population and tourism in India has intensified challenges related to environmental sustainability, Air quality degradation and public health. In India, the Smart Cities Mission

(SCM) exemplifies this shift; the Ministry of Housing and Urban Affairs [MoHUA] (2021) [*2] reports significant progress in project execution across 100 cities, while Thamilmani et al. (2025) [*3] note that disparities in environmental resilience remain a challenge. Jawaid and Khan (2020) [*4] further contend that while the SCM provides a platform for improvement, its success depends on moving beyond technology to address fundamental ecological health.

Policy frameworks at multiple levels drive these outcomes. Kashyap (2022) [*5] highlights Rajasthan's success in urban transformation through missions like AMRUT, while the Confederation of Indian Industry [CII] (2022) [*6] outlines the state's "Climate Action Charter" for low-carbon transitions. However, early critiques by Singh et al. (2020) [*7] pointed to a lack of robust environmental indicators in initial SCM guidelines. To address this, tools like the *Smart City Environmental Sustainability Index* (Shruti et al., 2021) [*8] have been developed to evaluate urban centres more rigorously.

Udaipur a heritage rich city also known as "Venice of the east" faces adverse effect of unplanned urbanisation, tourism and increasing air pollution so it is a big challenge of development of sustainable urban infrastructure which is essential due to Udaipur's ecological sensitivity, which is typified by lakes, hills, and heritage zones. By acknowledging these difficulties, the Indian government and government of Rajasthan designed and implemented policy frameworks to integrate sustainability, tech driven governance which includes the National Clean Air Programme (NCAP), Smart Cities Mission (SCM), Swachh Bharat Mission (SBM) and AMRUT, all these programs emphasise sustainable infrastructure, Air pollution reduction and the integration of smart technologies for urban management. These initiatives aim to balance economic development with environmental protection, ensuring healthier living conditions for urban populations.

Air quality of Udaipur city remains a challenge for both state and national government. Data of air quality from 2018 to 2024 shows high AQI values which fall within "unhealthy for sensitive groups" range. At some extent AQI was improved but the major region for this high AQI value is PM10 concentrations which is due to uncontrolled construction and mining activities. Concentrations of nitrogen dioxide (NO_2) shows a sharp decline after 2020 which indicate adoption of BS-VI have major impact on nitrogen dioxide (NO_2) emission. Concentrations of sulphur dioxide (SO_2) also shown a marked decline since 2020, which indicate combined effect of stricter emission regulations, improved mining technics, and temporary reductions in industrial activity due to COVID-19 pandemic. These findings that government policies on sustainable development have achieved partial success which led to decrease of emission of Nitrogen and Sulphur Oxide gases but having comparative lower impact on PM10 concentrations.

The Smart City initiatives in Udaipur have prioritized sustainable infrastructure development through investments in renewable energy, waste management, intelligent transport systems, and digital monitoring platforms. These measures are designed to reduce emissions and enhance urban resilience. Yet, the effectiveness of these interventions in delivering long-term air quality improvements requires systematic evaluation. In Udaipur, modernization efforts centre on infrastructure and mobility. Tak et al. (2019) [*9] identify critical deficits such as high vehicular growth and inadequate pedestrian paths, proposing "Smart Roads" as a solution. ICLEI South Asia (2017) [*10] provides technical support for these low-carbon urban mobility plans. Prasad and Purohit (2017) [*11] maintain that addressing Udaipur's unique challenges—such as lake contamination and inner-city congestion—is essential for sustainable development.

Air quality remains a primary metric of success. Gurjar et al. (2016) [*12] highlight that rapid urbanization in Indian megacities has led to alarming pollution trends with local-to-global implications, necessitating urgent cross-sectoral interventions. Technological solutions, such as the Big Data governance framework (Kaginalkar et al., 2022) [*13] and the IoT framework proposed by Kumar et al. (2024) [*14], now allow for real-time monitoring. The impact of human activity was vividly demonstrated during the pandemic; Sharma et al. (2020) [*15] recorded substantial drops in NO_2 (66%) and PM10 (42%) during Udaipur's lockdowns, underscoring the potential for air quality recovery through targeted policy and emission controls (De Vela, 2025) [*16].

By analysing pollutant trends from 2018 to 2024, this study assesses the impact of government policies and smart city initiatives on Udaipur's air quality, providing insights into the strengths and limitations of current approaches. This research contributes to the discourse on sustainable urban development by offering empirical evidence from a mid-sized Indian city navigating the complexities of modernization and heritage conservation. This study assesses whether these regulations and Smart City initiatives have resulted in quantifiable gains in Udaipur's infrastructure sustainability and air quality.

2. Study Area: Udaipur City

Udaipur is located in southern Rajasthan and is a major tourism centre. **Three different locations in Udaipur city- Amba Mata, Town Hall and Regional office of RSPCB in Transport Nagar are taken for data collection.** Data was collected through Rajasthan State Pollution Control Board Station's records. The city experiences increasing vehicular density, seasonal tourism influx, and construction activities, contributing to air pollution. Climatic conditions, including dust storms and winter inversions, further exacerbate air quality challenges.

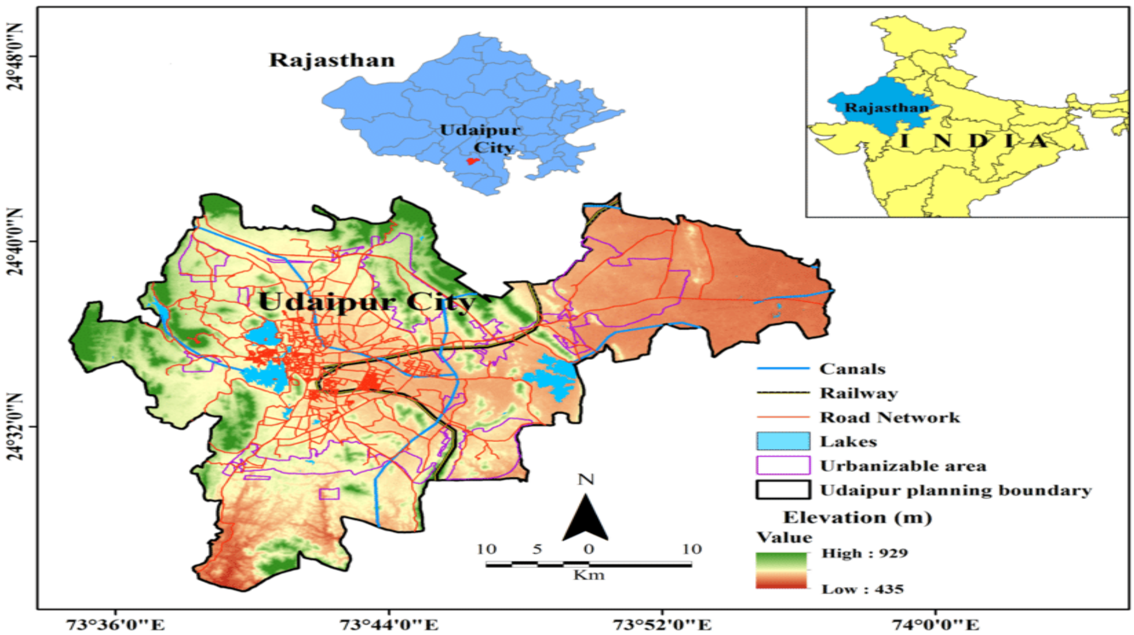

Figure 1. Study area – location map of Udaipur city. [*17]

3. Methodology

3.1 Research Design

A mixed-methods approach was adopted:

- Quantitative analysis of AQI data (2018–2024)

- Policy analysis of national, state, and city-level initiatives
- Secondary literature review

3.2 Data Source

Monthly data of Air Quality Index (AQI), PM_{10}, NO_2, and SO_2 for Udaipur from **2018 to 2024**, of Rajasthan State Pollution Control Board (RSPCB) continuous air quality monitoring records, were used to calculate monthlies and annual averages. Policies data was collected through various government websites, reports and Local newspapers.

3.3 Treatment of COVID-19 (2020)

The year **2020 is treated as an exogenous shock** due to pandemic-related lockdowns. AQI improvements during this year are not attributed to policy interventions but analysed as a temporary deviation.

4. Government Policies for Smart City Initiatives

4.1 Smart Cities Mission (2015)

Government of India launched The **Smart Cities Mission** on 25 **June, 2015** for sustainable urban development and improved infrastructure, efficient services and batter life quality for citizens. For these 100 cities across all over India are selected and Area Based Development (ABD) models are used for each city. Udaipur was selected in this project in 2015-16 to transform the city into smart city. For this **Udaipur Smart City Ltd. (USCL)** was establish to plan, monitor and implement smart city mission. Main focus of this mission to make infrastructure **economically, environmentally, and socially** sustainable and to conserve heritage versatility of city. Total 106 projects worth 806 Cr. INR was completed[*18]**.**

Key Smart City Projects in Udaipur

a. Area-Based Development (ABD) — Walled City had Integrated infrastructure upgrade with a Project Cost: 600 Cr. INR covering ~828 acres, improving roads, utilities, water supply, power, and sewage systems for ~20 % of city population[*18].

b. Mobility and Transport Enhancements—with a project Cost – INR 126 Cr. Construction of 6 Dedicated Parking and Puzzle parking,100 bus shelters[*18], large scale development of smart roads, 14.5 km of dedicated cycle tracks, 400 public bicycles sharing systems and junction improvement to reduce congestion to promote batter mobility[*19].

c. Water and Sewerage Infrastructure— A Water treatment plant with 23.47MLD capacity (Project Cost – INR 24 Cr) was built for clean water supply in Walled city. Three Sewage Treatment Plants (Project Cost – INR 80 Cr) with capacity 25,10,5 MLD were constructed and upgraded[*18].

d. Solid Waste Management—construction of 20 TPD Bio methanation plant, 30 TPD Wet Waste Processing Plant, 2 MRF Plant under which solid waste is recycled, 50TPD Construction & Demolition Waste Plant take place with a Project Cost – INR 49.5 Cr[*18].

e. Smart Governance and Citizen Services—with a Project Cost – INR 46.00 CR The Abhay Command & Control Centre was established to monitors city services, including traffic and emergency responses[*18]. With a Project Cost – INR 22 LAKHS Udaipur Smart City App developed to improves access to city services such as parking, bus stops, emergency numbers, and public utilities[*18].

f. Heritage Conservation— With a Project Cost – INR 40 Cr. 10 historical gates, 944 buildings, 8 Ghats, 6 km long heritage fort wall around the walled city were restored[*18].

g. Renewable Energy Initiatives—With a Project Cost – INR 3.00 CR Solar power installations (~500 kW) to reduce pollution and lower electricity costs—part of a broader push for environmentally sustainable infrastructure[*18].

Major Achievements

- Udaipur's Smart City projects have seen *high completion rates*—over **106 out of 118 projects completed**[*20].
- Udaipur now holds the 7th position in 2025, marking a notable jump of 2 ranks among the ongoing efforts in the development of 100 cities across the country[*21].
- Udaipur won the HUDCO Design award 2020-21 under the heritage conservation category[*18].
- Udaipur Smart City is the winner of the Smart Cities Award Contest (ISAC) 2022 Zonal Smart City Award (North Zone) [*18].
- ranked among the top 11 cities in India under "Steet 4 People" challenge[*22]
- Fund of INR 134 Cr. Allocated for Udaipur under smart city phase 2 [*23]

4.2 National Clean Air Programme (2019)

By the Ministry of Environment, Forest and Climate Change in 2019 The National Clean Air Programme (NCAP) launched. The main objective of this programme to reduce ambient particulate pollution (PM_{10} and $PM_{2.5}$) by 20–30 % by 2024 compared with the 2017-18. It is based on targeted interventions, monitoring improvements, and city-specific action plans for designated *non-attainment cities*. Udaipur is also classified as one such **non-attainment city** under NCAP due to its bad air quality and excess of air pollution then National Ambient Air Quality Standards (NAAQS), particularly for particulate matter, and is required to implement a structured Clean Air Action Plan[*24,25].

a. NCAP Classification and Monitoring in Udaipur– Due to vehicle emission, construction and mining activities and environmental factors like dry climatic conditions and dust resuspension average PM_{10} levels are above the 100 µg/m³ which exceed NCAP annual standard. One continuous Ambient Air Quality Monitoring Station (CAAQMS) and three manual monitoring sites at Amba Mata, Regional Office, and Town Hall set up the Rajasthan State Pollution Control Board's (RSPCB) dedicated air quality network for NCAP compliance [*25]**.**

b. City Action Plan and Sectoral Focus–The NCAP City Action Plan for Udaipur includes efforts in multiple crucial domains, such as public awareness, road and transport decongestion, and vehicle emission control. To lessen exposure to traffic, the plan suggests, for instance, random emissions testing, encouraging the use of e-rickshaws and electric vehicle parking laws, and road widening projects[*26]. NCAP report shows concentration of SO_2 and NO_2 are remain within safe limits but PM10 exceeds standards due to dust and dry climatic conditions[*25].

c. Funding and Implementation Data–According to available data, Udaipur received **₹28.39 crore** under the NCAP (15th Air Quality Performance Grant) for pollution control efforts, of which approximately **₹16.84 crore (≈59.3 %)** had been utilized as of November 30, 2025—the lowest utilization among Rajasthan's five non-attainment cities. This indicates constraints in executing planned interventions relative to allocated funding[*27].

d. Air Quality Management Assessment — Survey Ranking Under **Swachh Vayu Survekshan 2024-**25, conducted as part of NCAP performance evaluation, Udaipur ranked **15th** in the country and 3rd in state among cities with populations between 300,000 and 1 million based on efforts and actions to manage air quality, rather than absolute air quality metrics. This reflects relative progress in implementing NCAP action items[*28].

e. Source Apportionment and Emissions Data—Independent assessments by the **Centre for Science and Environment (CSE)** and RSPCB identify **fugitive emissions from mineral grinding and stone crushing industries** and **road dust** as major contributors to particulate pollution in Udaipur. These findings emphasize the need for stronger NCAP interventions on local emission sources beyond regulatory monitoring alone[*29].

4.3 Swachh Bharat Mission

In 2014 Prime minister of India launched **Swachh Bharat Mission (SBM)**. Which played a significant role in improving urban environmental conditions in Udaipur by strengthening sanitation infrastructure, solid waste management, and public hygiene. In the **Swachh Survekshan 2025**, Udaipur Nagar Nigam achieved a **national rank of 15th** among cities with populations between 3–10 lakh, and **3rd rank within Rajasthan**[*30].

Recent Progress in SBM in Udaipur-

Indicator	Recent Status
National Cleanliness Rank	13th (2024–25)[*30]
Door-to-Door Waste Collection	96 %[*31]
Source Segregation	82 %[*31]
Scientific Waste Processing	88 %[*31]
ODF Water+ Certification	Achieved[*30]

In combination with Smart City initiatives and NCAP action plans, SBM has supported Udaipur's transition toward a cleaner and more sustainable urban environment by addressing pollution sources beyond conventional industrial and vehicular emissions.

4.4 AMRUT

The **Atal Mission for Rejuvenation and Urban Transformation (AMRUT)**, launched by the Ministry of Housing and Urban Affairs in **June 2015**, targets enhancement of core urban services—water supply, sewerage, stormwater drainage, and green infrastructure—in Indian cities with populations over 100,000. Unlike sectoral regulatory programmes aimed primarily at emissions (like NCAP), AMRUT focuses on **underlying urban infrastructure** that shapes environmental quality and human well-being. In Udaipur, AMRUT has catalysed substantial infrastructure upgrades, with measurable outcomes relevant to ambient environmental conditions.

Sector	Baseline (2015)	Latest Status (2024–25)	Source
Water Supply Coverage	~42 %	~78 %	MoHUA/AMRUT Dashboard
Sewerage Network Coverage	~28 %	~65–70 %	RUDSICO/AMRUT SAAP
Sewage Treatment Capacity	~N/A	40–50 MLD	RUDSICO/AMRUT Reports
Stormwater Drains Built	Minimal	~13 km	AMRUT Progress Reports
Urban Green Area (Developed)	Baseline level	~55 ha	AMRUT Dashboard & Udaipur MC

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Influence on Seasonal PM_{10}	Frequent high peaks	Moderated peaks	RSPCB Air Quality Records

5. Results and Analysis
5.1 Annual Trends (2018–2024)
5.1.1 Air Quality Index (AQI)

Figure-2 AQI Trends of three stations

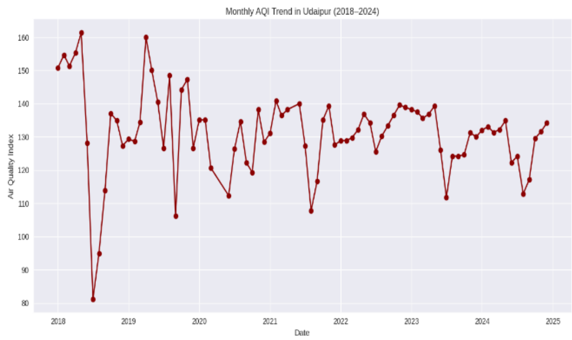


Figure-3 monthly average AQI Trends

As in figure -2 Regional Office station AQI was extremely high in 2018 (200–250), but steadily declined to ~140 by 2024.Townhall AQI fluctuated but stabilized around 130–135 in recent yearsand Ambamata station AQI remained lower overall, ~120–130 in recent years.The decline in AQI at the most polluted site (Regional Office) suggests that interventions — such as stricter vehicular emission norms, road infrastructure upgrades, and dust control measures under Smart City projects — have had a measurable impact.

The monthly average data of all stations in Figure-3 shows that 2018–2019 has poor air quality, AQI ~130–160 then in 2020–2021 Slight dip during lockdown, but still unhealthy (>120) and then in 2022–2024 Stabilized around 125–135, showing modest improvement.

5.1.2. Particulate Matter (PM10)

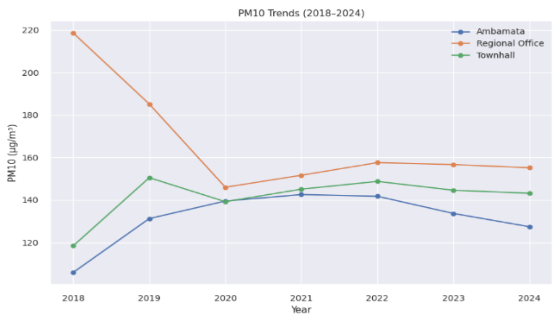


Figure-4 PM10 trends of three stations

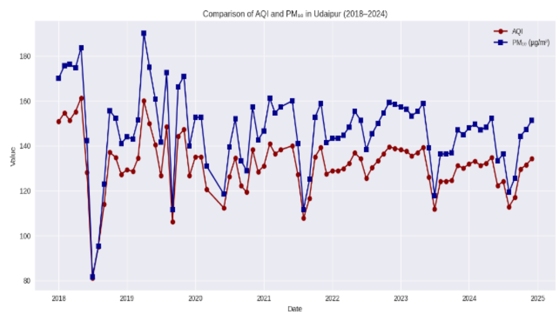
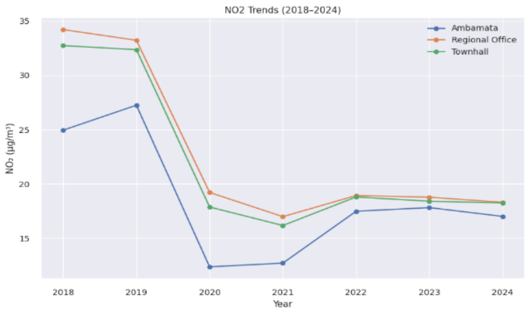


Figure-5 monthly average AQI,PM10 Trends

PM10 of Regional Office dropped from ~300 in 2018 to ~160 in 2024 shown in Figure-4 and for Townhall PM10 reduced from ~165 in 2018 to ~145 in 2024. PM10 of Amba Mata stayed relatively lower (~110–130). Thus nearly 46% reduction of PM10 At Regional office and 12% at townhall so PM10 reduction is the clearest success story. Likely linked to: Road paving and mechanized sweeping (reducing dust resuspension), Green cover expansion and lakefront development projects, Restrictions on construction dust under Smart City guidelines.

The monthly average data of all stations indicate PM10 concentration's in 2018–2019: Very high, often >150 µg/m³, with seasonal peaks in spring/autumn then in 2020–2021 Slight reduction, but still elevated (>130 µg/m³)then there is Gradual decline in 2022–2024 and stabilizing around 130–150 µg/m³.Trend shows improvement is slower compared to gases; PM10 remains the most persistent pollutant. Also, Figure-5 shows AQI mirrors PM10 trends, meaning particulates are the dominant driver of poor air quality.

5.1.3. Nitrogen Dioxide (NO_2)



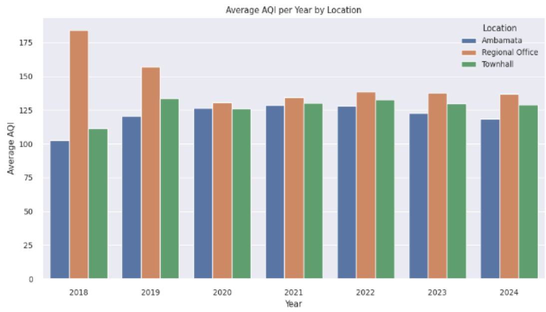
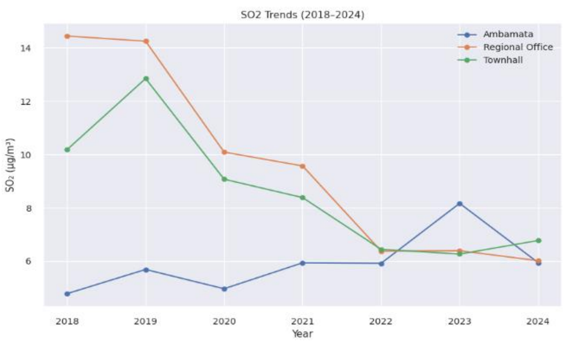


Figure-6 NO_2 Trends of three stations Figure-7 monthly average AQI Trends of three stations

Figure-6 shows concentration of NO_2 at Amba Mata Declined sharply after 2019 (from ~30 to ~17–18). Regional Office also shows Similar decline, now ~18–19 and Townhall shows Same pattern, now ~18–19. All three sites show **falling NO_2 levels**, likely due to reduced traffic or cleaner fuel use.

Figure-7 monthly average data of all stations indicate 2018–2019 High levels of NO_2 peaking above 40 µg/m³ in early 2019. There is Sharp decline in 2020–2021, especially during lockdown months (March–August 2020 shows missing/very low values). NO_2 concentration in 2022–2024 Stabilized around 16–19 µg/m³, much lower than pre-2020.So trend shows Clear long-term reduction, likely due to BS-VI rollout and manage traffic/industrial activity post-2020.

5.1.4. Sulphur Dioxide (SO_2)



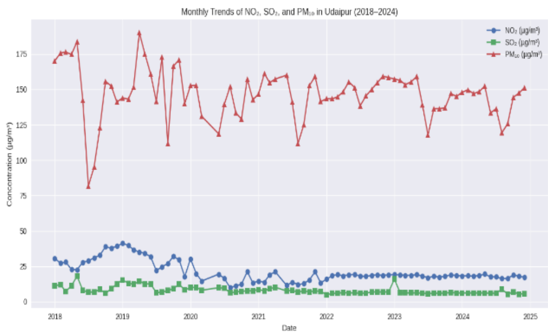
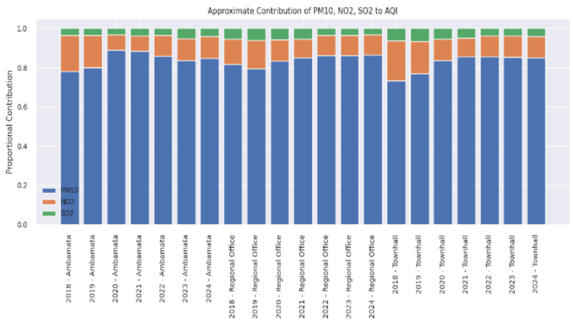


Figure-8 SO_2 Trends of three stations Figure-9 monthly average NO_2 ,SO_2 ,AQI Trends

Figure-8 shows Concentration of SO_2 at Amba Mata station was mostly stable around 5–6, except a strange spike in Jan 2023 (34). At Regional Office concentration of SO_2 Higher in 2018–2019 (10–20), but now

~6–7. Similarly, at Townhall Concentration of SO_2 is now ~6–7. This shows SO_2 concentration has stabilized at low levels, except anomalies.
The monthly average data of all stations indicate concentration of SO_2 in 2018–2019 is at Moderate levels (7–18 µg/m³), with spikes in winter months, then in 2020–2021 decline, with values mostly between 7–10 µg/m³.2022–2024 shows significant improvement, consistently ~6 µg/m³, except a spike in Jan 2023 (~16 µg/m³) as shown in Figure-9.These Trend indicate Strong downward trajectory, showing effective control of industrial emissions.

5.1.5. Overall Trend



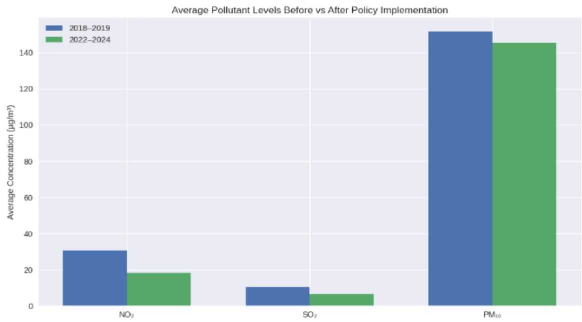


Figure-10 NO_2, SO_2 and PM10Trends of three stations Figure-11 NO_2 ,SO_2 ,AQI Trends 2018-19 vs 2022-24

As in Figure-10 Regional Office is the most polluted site (highest AQI and PM10) and Amba Mata is relatively cleaner, especially in particulate matter. Townhall sits in between.NO_2 and SO_2 have declined and stabilized across all sites, showing some improvement in gaseous pollution. Particulate matter (PM10) remains the main driver of poor AQI in Udaipur.
Lockdown Effect (2020): Both NO_2 and SO_2 dropped sharply, confirming reduced traffic/industrial activity. Sustained Improvement: Post-2021, gaseous pollutants (NO_2, SO_2) remain low, suggesting structural changes in emissions.PM10 Challenge: Despite improvements, particulate matter remains stubbornly high, keeping AQI in the “Unhealthy for Sensitive Groups” range. Seasonality: Winter months (Nov–Jan) consistently show higher pollutant levels, likely due to heating, crop burning, and stagnant atmospheric conditions.
As in Figure-11 2018–2019: AQI decline reflects early policy and infrastructure interventions. 2020: Sharp AQI improvement due to COVID-19 lockdowns (temporary). 2021: AQI rebound with resumption of economic activities.2022–2024: Moderate stabilization, indicating incremental policy-driven improvement. Seasonal analysis shows persistent winter pollution peaks, highlighting meteorological and regional influences. The lockdown acted as a “natural experiment,” proving that traffic and industry are major contributors.

6. Discussion

After controlling for COVID-19 effects, the analysis indicates that **Smart City initiatives have contributed to gradual air quality improvement**, particularly through traffic management, waste reforms, and monitoring infrastructure. However, the magnitude of improvement remains moderate.
Challenges include:
- Rising tourism-related vehicular emissions
- Weak enforcement of emission standards

• Regional pollution transport and dust
• Limited citizen participation

These findings align with national-level assessments that technology alone cannot ensure environmental sustainability without governance reforms.

7. Policy Implications

a) Strengthen enforcement of vehicular emission norms.
b) Expand electric and non-motorized mobility.
c) Integrate tourism management with air quality planning.
d) Enhance citizen engagement and awareness.
e) Promote regional coordination under NCAP.

8. Conclusion

This study empirically assesses the collective efficacy of four concurrent national policy frameworks — SCM, NCAP, AMRUT, and SBM — on ambient air quality in Udaipur, Rajasthan (2018–2024), using monthly-averaged AQI, PM10, NO_2, and SO_2 data across three RSPCB monitoring stations. Results reveal a **pollutant-specific, asymmetric pattern of improvement**.

Gaseous pollutants exhibited a clear and sustained downward trajectory. NO_2 declined from peaks exceeding 40 µg/m³ (2019) to 16–19 µg/m³ by 2022–2024, attributable predominantly to mandatory BS-VI vehicular emission norms. SO_2 similarly stabilised at 6–8 µg/m³ post-2020, consistently within NAAQS limits. The COVID-19 lockdown functioned as a natural experiment, confirming the causal role of vehicular and industrial activity in gaseous pollutant loading and validating the durability of fuel-regulation-driven gains.

In contrast, **PM10 remains the dominant unresolved stressor**. Despite a ~46% reduction at the most polluted site, mean concentrations across all stations continue to exceed the NAAQS annual standard of 100 µg/m³, sustaining AQI in the "Unhealthy for Sensitive Groups" range. Fugitive emissions from mineral grinding, construction activity, and road dust resuspension — compounded by arid climatic conditions — constitute persistent sources inadequately addressed by current interventions.

The study concludes that multi-programme policy architectures yield measurable but asymmetric environmental outcomes — effective for gaseous pollutants, insufficient for particulate compliance. A critical institutional gap in NCAP fund utilisation (~59.3%) further underscores systemic implementation constraints. Future policy phases must prioritise PM10-specific source controls, real-time source apportionment, and integrated governance to consolidate the incremental gains documented herein.

9. Limitations and Future Scope

a) Absence of data of pollutant concentration such as Ozone, Carbon Monoxide etc.
b) Limited availability of ward-level AQI data
c) Absence of use of various meteorological Data and their correlation with AQI Parameters
d) Data collections through only 3 Sites which may Not completely represent of entire city.
e) Future research may employ health impact assessments of AQI.
f) Further Study can be done on net inbound tourism and air quality.

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