BEYOND NORTH
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NO_2 POLLUTION AND HEALTH RISKS IN SEVEN MAJOR INDIAN CITIES

GREENPEACE
ग्रीनपीस

DECEMBER 2024

Acknowledgments

This report was made possible through the collaborative efforts of Ali Abbas, Avinash Kumar Chanchal, Selomi Garnaik, Aidan Farrow, Igor Glushkov, Coco Wu, and Jeffrey Albertson-Kwok, whose insights and dedication greatly contributed to its depth and impact.

We extend our gratitude to Anirudh from the International Council on Clean Transportation (ICCT) for providing valuable peer review, enhancing the report's rigour and quality. Anirudh Narla is a researcher for ICCT's vehicular emissions testing, electric vehicles and heavy-duty vehicles programs in India.

Testimonies Credits: Warrior Moms- Mothers for Clean Air.
Design Credits: Atreyi B, Dinesh

Published by Greenpeace India, December 2024.

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Executive Summary

Nitrogen dioxide (NO_2) is a near-invisible toxic gas that is closely linked to traffic and fuel burning, and which is common in urban areas. Compared to particulate matter, NO_2 air pollution has been seldomly considered in India's public discourse.

North India, particularly Delhi, receives high attention from authorities, media, and in public discourse due to severe air pollution concentrations. This often overshadows the fact that other cities and regions in India also face significant air pollution challenges. This report finds that, beyond Delhi and Northern India, other Indian cities are experiencing alarming NO_2 concentrations and require urgent intervention.

The Indian cities discussed in the report—Jaipur, Pune, Mumbai, Kolkata, Hyderabad, Bengaluru, and Chennai—are among the ten most populated in the country, with high urban population densities. They serve as economic hubs and contribute significantly to the Indian economy.

The research uses data from India's official air monitoring programme (CAAQM), the European Commission Joint Research Council's Emission Database for Global Atmospheric Research (EDGARv8.1[1]) and European Space Agency satellite observations, alongside analysis of scientific literature, to investigate NO_2 air pollution. The findings underscore a need for improved air quality standards, and improved air quality management to protect public health.

[1]edgar.jrc.ec.europa.eu/index.php/dataset_ap81 | Map for representational purposes only

Nationally the analysis reveals:

- **The health impacts of NO_2 in India are serious**

There were an estimated 21,000 disability-adjusted life years (DALYs) lost due to NO_2 pollution in India in 2021 (HEI, 2024a).

- **Health-based air quality standards from the World Health Organisation (WHO) are routinely breached**

During 2023, 89% of monitoring stations exceeded annual health based pollution guidelines from the World Health Organisation (72 monitors from a total of 81 monitors across the seven cities).

- **Exposure to NO_2 in India is worse than in neighbouring countries**

India has had the highest average annual population-weighted NO_2 concentration in the South Asian region since 2002. This measure of pollution is an important indicator of health risk because it combines NO_2 concentrations with the number of people exposed. India's population-weighted NO_2 concentrations worsened persistently from 1990 until the COVID-19 pandemic (HEI, 2024b). Post-pandemic exposure data are not yet available.

- **Road traffic causes NO_2 problems**

Road traffic is consistently in the top three sectors for emissions of nitrogen oxides (NO_2 and NO) in the EDGAR emissions database; it contributes a quarter of total nitrogen oxide emissions in Jaipur and Hyderabad. Comparison of air quality monitors located on busy roads and those farther from heavy traffic indicates that traffic is a serious pollution source. Latitude and longitude coordinates provided by the station operators suggest that relatively few monitors exist at roadside locations in the cities investigated, raising questions about the availability of data in places that might be India's most polluted.

- **Vehicle emission standards are not a complete solution**

Mass use of internal combustion engine vehicles gives rise to numerous environmental and social problems, from pollution to noise and congestion, for example. Vehicle emission standards only combat a subset of these, and can have unintended adverse impacts. A holistic approach, such as reducing vehicle numbers and investing in public transport, is likely to be more effective.

At the city level the analysis reveals:

There is a worsening NO_2 pollution trend for all cities at the city-wide level, according to observations from satellites. Data measured by local air quality monitoring stations reveal frequent exceedance of health based standards. They also show a complicated pattern of both worsening and improving air quality at the local level, depending on location. This is expected because ground level air quality monitors reflect local conditions which may not always follow the city-wide trend.

BENGALURU

In 2023, annual NO_2 concentrations:

- Exceeded the health based WHO guideline at all 13 air quality monitors analysed, and
- Were highest at City Railway Station monitoring station, and
- Monitoring stations that exceeded WHO health guidelines in 2023 were located near five schools.

IN 2023, DAILY NO_2 CONCENTRATIONS WERE HIGHER THAN THE WHO DAILY GUIDELINE AT THE CITY RAILWAY STATION FOR 80% OF THE YEAR.

Over the last five years:

- Trends in NO_2 concentrations from ground level monitors show no strong evidence that NO_2 air quality is improving. In fact,
- satellite observations of NO_2 in the atmosphere suggest pollution across the whole city is worsening.

CHENNAI

In 2023, annual NO_2 concentrations:

- Exceeded the health based WHO guideline at all but one air quality monitor analysed, and
- Were highest at Alandur Bus Depot monitoring station.

IN 2023, DAILY NO_2 CONCENTRATIONS WERE HIGHER THAN THE WHO DAILY GUIDELINE AT THE ALANDUR BUS DEPOT STATION FOR 86% OF THE YEAR.

Over the last five years:

- Trends in NO_2 concentrations from ground level monitors show mainly worsening trends,
- Six of eight ground level monitor have a significant worsening trend, and

- Satellite observations of NO_2 in the atmosphere suggest pollution across Chennai city as a whole is worsening.

HYDERABAD

In 2023, annual NO_2 concentrations:

- Exceeded the health based WHO guideline at nine out of 14 air quality monitors analysed, and
- Were highest at the Central University Hyderabad monitoring station, followed by monitors near the zoo, and a high school.

307 Days (84%)

IN 2023, DAILY NO_2 CONCENTRATIONS WERE HIGHER THAN THE WHO DAILY GUIDELINE AT THE CENTRAL UNIVERSITY HYDERABAD STATION FOR OVER 80% OF THE YEAR.

Over the last five years:

- Trends in NO_2 concentrations from ground level monitors show mainly worsening trends,
- Six ground level monitors have a significant worsening trend, only three of the 14 stations included in the trend analysis have a significant improving trend, yet
- Satellite observations of NO_2 in the atmosphere suggest pollution across the city as a whole is worsening.

JAIPUR

In 2023, annual NO_2 concentrations:

- Exceeded the health based WHO guideline at all six air quality monitors analysed, and
- Were highest at Adarsh Nagar monitoring station.

277 Days (75.89%)

IN 2023, DAILY NO_2 CONCENTRATIONS WERE HIGHER THAN THE WHO DAILY GUIDELINE AT THREE STATIONS FOR MORE THAN 60% OF THE YEAR, AND FOR 277 DAYS AT THE ADARSH NAGAR MONITOR.

Over the last five years:

- Trends in NO_2 concentrations from ground level and satellite monitors are generally increasing,
- Two of three ground level monitors with sufficient data have a worsening trend, and
- Satellite observations of NO_2 in the atmosphere suggest pollution across the city as a whole is worsening.

KOLKATA

In 2023, annual NO_2 concentrations:

- Exceeded the health based WHO guideline at all seven air quality monitors analysed, and
- Were highest at Bally Gunge monitoring station.

IN 2023, DAILY NO_2 CONCENTRATIONS WERE HIGHER THAN THE WHO DAILY GUIDELINE AT THE BALLY GUNGE STATION FOR 133 DAYS IN ONE YEAR.

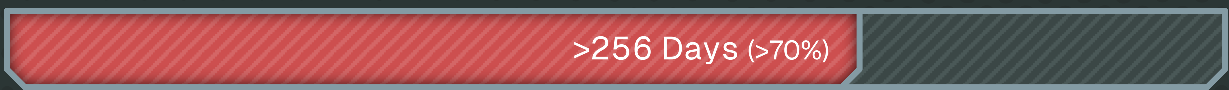
Over the last five years:

- Trends in NO_2 concentrations from ground level monitors show a mixture of improving and worsening trends,
- Only one ground level monitor has a significant worsening trend, yet
- Satellite observations of NO_2 in the atmosphere suggest pollution across the city as a whole is worsening.

MUMBAI

In 2023, annual NO_2 concentrations:

- Exceeded the health based WHO guideline at 22 out of 24 air quality monitors analysed, and
- Were highest at Mazgaon monitoring station.



IN 2023, DAILY NO_2 CONCENTRATIONS WERE HIGHER THAN THE WHO DAILY GUIDELINE AT TWO STATIONS, AND MEASURED NO_2 CONCENTRATIONS WERE HIGHER THAN THIS GUIDELINE FOR MORE THAN 70% OF THE YEAR.

Over the last five years:

- Trends in NO_2 concentrations from ground level monitors show a mixture of improving and worsening trends,
- Nine monitoring stations have a significant worsening trend, nine have a significant improving trend, yet
- Satellite observations of NO_2 in the atmosphere suggest pollution across the city as a whole is worsening.

PUNE

In 2023, annual NO_2 concentrations:

- Exceeded the health based WHO guideline at eight out of nine air quality monitors analysed, and
- Were highest at the Revenue Colony monitoring station.

312 Days (85.48%)

IN 2023, DAILY NO_2 CONCENTRATIONS WERE HIGHER THAN THE WHO DAILY GUIDELINE AT THE REVENUE COLONY STATION FOR 312 DAYS IN ONE YEAR.

Over the last five years:

- Trends in NO_2 concentrations from ground level and satellite are generally worsening,
- Only two ground level monitors have a significant improving trend, and
- Satellite observations of NO_2 in the atmosphere suggest pollution across the city as a whole is worsening.

NO_2 air pollution must be prioritised with a focus on improved public health. Greenpeace India urges the Central Pollution Control Board (CPCB) and relevant authorities to:

Update the national ambient air quality standards to follow the WHO's sequence of interim targets and health based guidelines.

Focus air quality management on improving health,

Create coordinated air-shed management strategies to address regional differences,

Improve public transport provision, and

Improve monitoring of NO2, especially in roadside locations.

Introduction

Poor air quality in India, particularly in major Indian cities, is a serious public health issue. Particulate matter air pollution is often the focus of attention, however air can be contaminated with many other pollutants, such as nitrogen dioxide (NO_2). Air quality reporting in India often focuses on Delhi, which can overshadow issues in other cities and regions.

This report investigates NO_2 levels in seven major Indian cities beyond Delhi and Northern India. These cities, which are significant metropolitan areas with dense urban populations, are Bengaluru, Chennai, Hyderabad, Jaipur, Kolkata, Mumbai, and Pune. The research asks:

Are national and World Health Organisation (WHO) air quality standards for NO_2 met in each city?

Is NO_2 air quality improving or getting worse in each city?

What are the consequences of NO_2 air pollution for health in India?

What are the most important emission sources for NO_2 in each city?

What steps can be taken to address NO_2 air pollution in India's cities?

NO_2 along with other oxides of nitrogen (NO_x) are very reactive and have serious health and environmental impacts. These gases are produced when fuels are burned. That means that vehicles and energy generation from fossil fuels are important NO_2 sources.

Air Quality Standards

In 2021 the WHO reviewed the latest scientific evidence on air quality to update its public health guidelines (WHO, 2021). The review recommended a guideline for annual average concentrations of NO_2 of 10 $\mu g/m^3$ and for 24-hour averages of 25 $\mu g/m^3$, in order to protect public health (Table 1).

India's existing legal standards for ambient air pollution concentrations, the National Ambient Air Quality Standards (NAAQS), fall woefully short of the WHO's health based recommendations. India's NAAQS were last revised in 2009 (CPCB, 2009), and have not kept pace with the significant advances in understanding of air pollution during the following one and a half decades.

Outdated standards fail to protect public health, leaving millions vulnerable to the consequences of air pollution.

Table 1. Annual average and 24-hour average NO_2 concentrations included in the NAAQS and WHO air quality guidelines.

Average Period	NAAQS	WHO Guidelines
Annual average	40 µg/m^3	10 µg/m^3
24 hour average	80 µg/m^3	25 µg/m^3

Health Effects

Overwhelming scientific evidence links NO_2 exposure to adverse health impacts. NO_2 exposure increases the risk of asthma, airway inflammation, respiratory irritation, and the worsening of existing respiratory conditions. It can impair lung development, intensify allergies, and increase susceptibility to respiratory infections. The risks extend beyond respiratory health, and are linked to adult ischemic stroke, premature mortality, and deaths from circulatory diseases, ischaemic heart disease, and lung cancer. Despite an extensive body of research (Rice et al. 2013, Nagpure et al. 2014, Hamra et al. 2015, Khreis et al. 2017, Wang et al. 2020, HEI, 2022, HEI, 2024b), authorities have yet to take sufficient action to mitigate these risks, leaving the public exposed to a preventable health crisis.

NO2 is especially relevant for child health, whose developing bodies are more susceptible to the health effects of air pollution. India is home to 472 million children under the age of 18 years, comprising 39 percent of the country's total population (NIUA, 2016). The Global Burden of Disease study estimated that NO_2 exposure was linked to 177,000 disability adjusted life years (DALYs), or healthy years of life lost for children and adolescents globally in 2021, of these more than 21,000 were in India (IHME 2024).

When mixed with other chemicals in the air, NO_2 can react to generate other pollutants like particulate matter and ozone which are both hazardous to health. Ozone exposure has increased in India in the last decade partly as a result of NO_2 pollution (HEI, 2024b).

Indian Health Research

There is a growing body of India-specific data linking NO_2 exposure to health effects (Pandey et al. 2005, Saini et al. 2008, Rajak and Chattopadhyay 2020). By the early 2000s studies had published results on the impact of traffic on air quality and health in India's cities (e.g. Mondal et al. 2000, Ghose et al. 2004, Pandey et al. 2005). Long-term exposure to air pollution from roads increases the risk of early death due to cardiovascular diseases and lung cancer (HEI 2022). It is estimated to lead to thousands of attributable deaths in Indian cities (Song et al. 2023, Table 2).

Researchers working in India have linked air pollution exposure to asthma, pneumonia, influenza and premature mortality (Jayaraman and Nidhi 2008, Nagpure et al. 2014, Mohegh et al. 2020). NO_2 has been associated with a decline in lung function in low-income adults in Mysore (Nori-Sarma et al. 2021). It has been estimated that 350,000 new cases of paediatric asthma are attributable to NO2 every year in India (Achakulwisut et al. 2019). In 2021 the Indian Academy of Pediatrics published a 'consensus statement' on the effects of air pollution on respiratory allergies. They recommended measures to reduce NO_2 emissions from vehicles, especially diesel (Reddy et al. 2021).

Table 2. NO_2 attributable deaths in selected Indian cities in 2019 (Song et al. 2023).

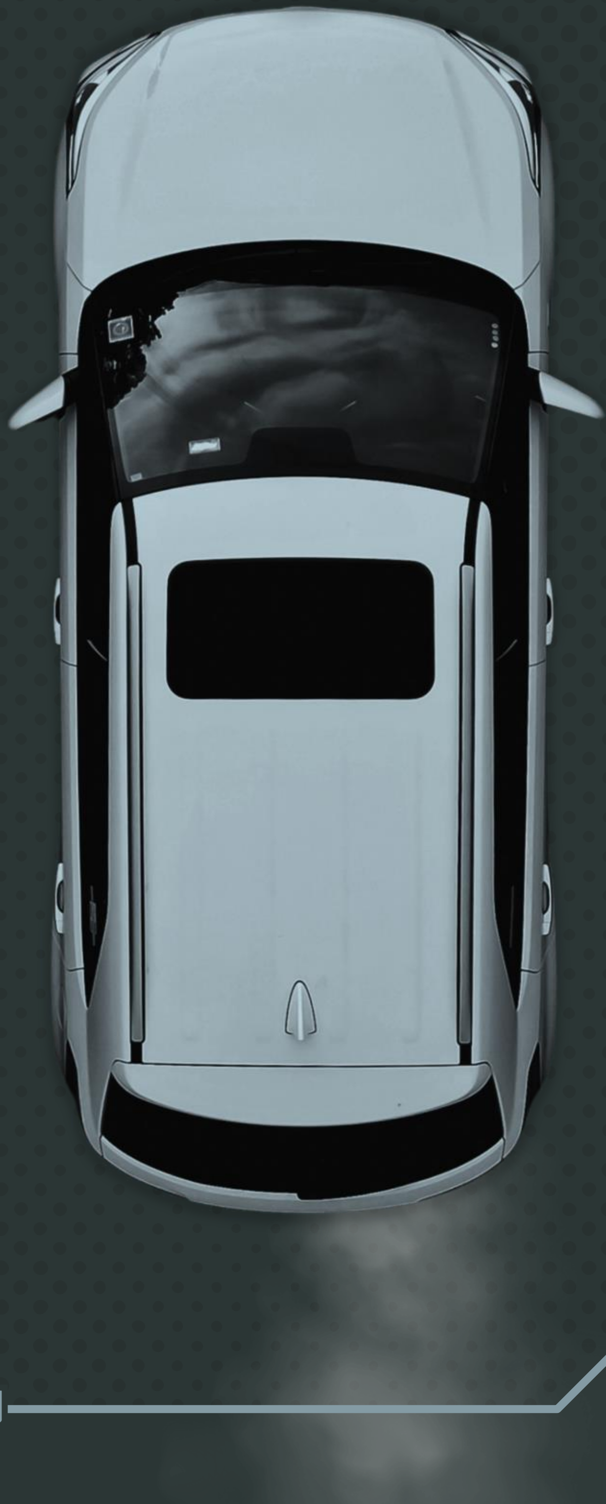
City	NO_2 (ppb)	Number of deaths attributable to NO_2 (Central Estimate*)
Mumbai	14.4	5,400
Kolkata	11.3	4,600
Bengaluru	18.4	3,800
Hyderabad	18.0	2,800
Pune	15.4	2,100
Chennai	11.0	1,900

*The values presented here are central estimates within a range of possible values that reflect uncertainty in the method as described fully in Song et al. 2023.

Assessment by the Health Effects Institute suggests that India has the highest average annual population-weighted NO_2 concentration of all nations in the South Asian region; it overtook Pakistan in 2002. This measure of pollution is an important indicator of health risk because it combines NO_2 concentrations with the number of people exposed. India's population-weighted NO_2 concentrations worsened constantly from 8.79 µg/m³ in 1990 to 13.5 µg/m³ in 2019 before the COVID-19 pandemic (HEI, 2024a).

India recorded the highest number of Disability-Adjusted Life Years (DALYs) attributable to NO_2 between 1990 and 2020 in South Asia. In 1990, NO_2-attributable DALYs were 21,000, peaking at 27,000 in 2010, before declining to 21,000 in 2021. In 2021, India had the third-highest number of DALYs attributable to NO_2 of any nation globally (IHME, 2024).

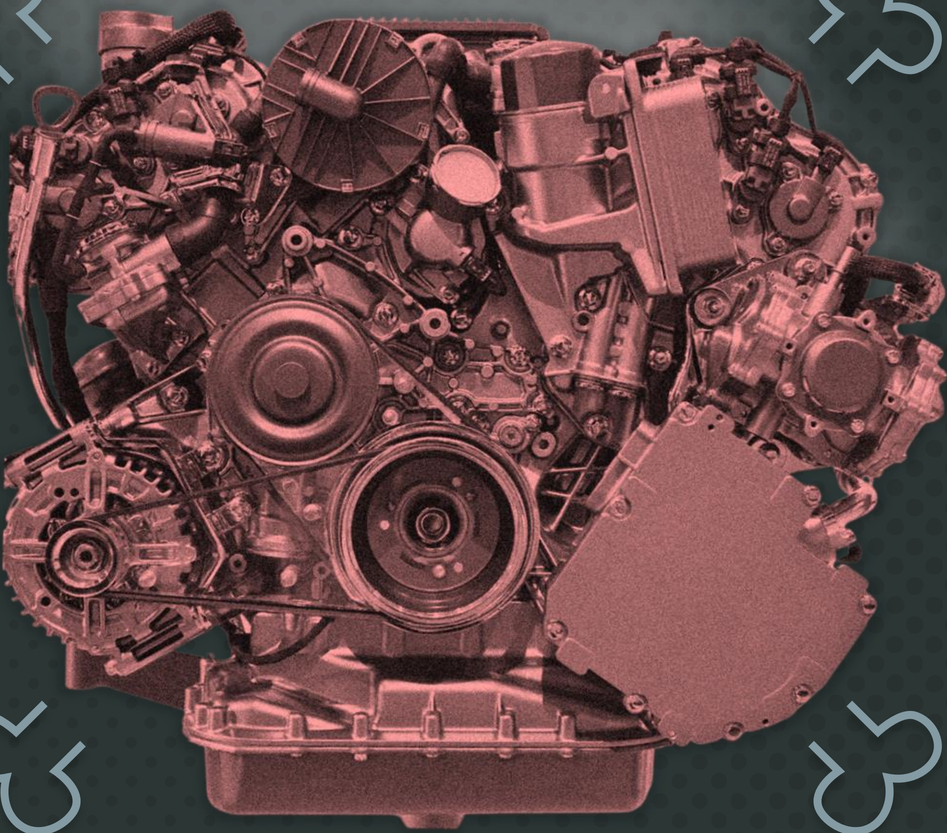
Vehicle Emissions



NO_2 air pollution is closely associated with road vehicles (Beckerman et al. 2008). Vehicle emissions are the biggest contributor to NO_2 concentrations in India's urban pollution hotspots (Mondal et al. 2000, Ghose et al. 2004, ARAI, 2010).

India's Central Pollution Control Board (CPCB) and Ministry of Road Transport and Highways (MoRTH) use emission standards to regulate NO_2 air pollution from vehicles. The Bharat Stage Emission Standards (BS) were adopted in 2000 and have been revised five times (Gajbhiye et al. 2023a). The two initial phases of BS (BS-I and BS-II) had combined HC and NO_x limits, and separate limits on tailpipe nitrogen oxides were introduced starting from the third phase, in 2025 (BS-III) (MarkLines, 2024). The next BS stage, BS-VII, is expected to align with the European Union's EURO7 regulations on tailpipe emissions but final details and the exact launch date have not yet been announced by the CPCB or MoRTH (The Times of India, 2024). The lack of clarity provided about future changes to the standards raises urgent concerns about the implementation and effectiveness of these measures.

MASS USE OF INTERNAL COMBUSTION ENGINE VEHICLES GIVES RISE TO NUMEROUS ENVIRONMENTAL AND SOCIAL PROBLEMS.



For a nation grappling with severe air quality challenges, timely and decisive action is essential to protect the public who are exposed to pollution right now.

Between 2017 and 2021 when BS-IV and BS-VI norms were implemented, national NO_x concentrations worsened by 4.9% (Gajbhiye et al. 2023b). This has been attributed to inadvertent outcomes of aftertreatment technologies used to cut the emission levels of black carbon, carbon monoxide, non-methane volatile organic compounds, sulphur dioxide, and organic carbon which led to elevated NO_x emissions (Gajbhiye et al. 2023b). This highlights the complexity of emission control. Mass use of internal combustion engine vehicles gives rise to numerous environmental and social problems. A holistic approach, such as reducing vehicle numbers, and investing in affordable, accessible, safe and environmentally friendly public transport is likely to be more effective than attempts to address one, or a subset of the issues resulting from mass use of fossil fuel vehicles.

Data and Methods

Ground level NO_2 concentrations monitored by the Continuous Ambient Air Quality Monitoring (CAAQM) are analysed in this report. Data from India's other monitoring network, the National Air Quality Monitoring Programme (NAMP) are not included because station level data for 2021 and 2022 were not available at the time of writing.

CAAQM measured concentrations of NO_2 are compared with health relevant thresholds recommended by the WHO and India's NAAQS. The contribution of traffic to NO_2 pollution is investigated by comparing concentrations at roadside and non-roadside monitoring sites. Both ground monitoring and satellite data are used to investigate long-term city level trends in NO_2 concentrations and emissions databases are analysed to characterise NO_2 sources.

Continuous Ambient Air Quality Monitoring

Hourly average observations published by the continuous ambient air quality monitoring programme (CAAQM) and aggregated and processed independently by the Center for Energy and Clean Air (CREA, 2024) are analysed. These data are processed by CREA to remove outliers using a Median Absolute Deviation (MAD) method, with the following parameters: values outside median ±15 times 70^{th} percentile of the absolute deviation. Raw CAAQM data are available from the Central Control Room for Air Quality Management website. Table 3 shows the number of CAAQM stations analysed for each city in each year.

Table 3. Number of Continuous Ambient Air Quality Monitoring (CAAQM) stations.

City	2018	2019	2020	2021	2022	2023
Bengaluru	10	10	10	10	11	13
Chennai	3	4	8	8	9	8
Hyderabad	6	6	6	6	14	14
Jaipur	3	3	3	3	3	6
Kolkata	2	7	7	7	7	7
Mumbai	1	10	20	21	20	24
Pune	1	1	6	8	8	9
Total	26	41	60	63	72	81

Inter-annual Trend Analysis

The inter-annual trend from 2019-2023 was calculated using annual means of CAAQM ground monitoring observations. The Theil-Sen linear trend method (Theil 1950, Sen 1968) was applied to monthly mean station data using the R-Openair package (version 1.8–3) (Carslaw and Ropkins 2011) to assess trend significance. The Theil-Sen analysis is advantageous because intra-annual variability is included, the method is not heavily skewed by outliers and bootstrap sampling is used to generate a 95% confidence bound. A p-value test of statistical significance is included. Significant trends, a 90% chance the trend was not random, are considered to be when $p < 0.1$ (Font and Fuller 2016). A minimum data threshold of 75% was used, data were deseasonalised, and any stations with only one year data, and stations without 2023 data, were removed.

Satellite observations of NO_2 columnar density from the TROPOMI instrument and Copernicus Sentinel-5P satellite are analysed (Copernicus Sentinel-5P 2021). The COPERNICUS/S5P/OFFL/L3 dataset for the period from 2019 to 2023 was downloaded via Google Earth Engine and converted from Sentinel 5P Level 2 (L2) using the harpconvert tool with the bin_spatial operation, and pixels with quality assurance (QA) values below 75% for the tropospheric NO_2 column number density band were removed. The data were then processed by first converting from moles to molecules/m² using Avogadro's number (6.022×10^{23}), and then calculating 2-week period averages. A cloud-masking function was applied, and the median function was utilised for temporal reduction across the image collection, as it is less affected by missing data than the mean. Finally, mean values were spatially aggregated for each designated city airshed. The script for data processing can be found here.

Health Guideline Exceedances

To assess compliance with health guidelines, we compared daily and annual averages against air quality guidelines set by the WHO (2021) and the Indian NAAQS (CPCB 2009) (Table 1). The number of exceedances of these limits was calculated at both city-wide and monitoring station levels.

Roadside monitoring station analysis

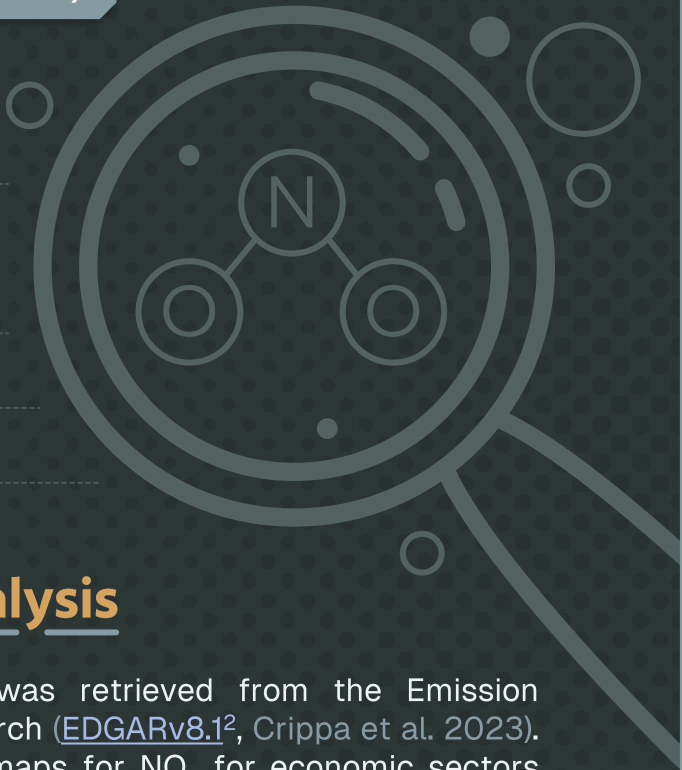
To better understand NO_2 pollution from road transport in each city, we categorised monitoring stations from the CAAQM network according to their proximity to major roads. OpenStreetMap[1] data and road classifications were used to identify the locations of monitors alongside primary and secondary roads (OpenStreetMap contributors 2015) by applying a 10 m buffer to the road network. Stations within 10 m of busy roads were classified as "roadside". Only

[1]OpenStreetMap data is open data, licensed under the Open Data Commons Open Database License (ODbL) by the OpenStreetMap Foundation (OSMF).

12 of 81 monitors were classified as roadside and only six of the seven cities had at least one roadside monitor. These were Bengaluru, Chennai, Hyderabad, Jaipur, Mumbai and Pune (Table 4). We also compare the annual average NO_2 concentrations from roadside monitors with those from non-roadside monitors.

Table 4. Number of NO_2 monitoring stations within 10 m of primary and secondary roads.

City	Number of Stations (2023)
Bengaluru	2
Chennai	2
Hyderabad	2
Jaipur	1
Kolkata	-
Mumbai	4
Pune	1



Emission Inventory Analysis

City level emission inventory data was retrieved from the Emission Database of Global Atmospheric Research (EDGARv8.1[2], Crippa et al. 2023). The database provides emission grid maps for NO_x for economic sectors expressed in ton / 0.1 degree × 0.1 degree / year. Emissions within a city airshed were summed and then divided by the total NO_x emissions from road transport within each city's boundaries. The boundaries of airsheds were defined by Urbanemissions.info (Guttikunda et al. 2023). Boundary maps are presented in Appendix 1.

City level health impact

We analysed annual global incidence data for new paediatric asthma cases attributable to NO_2 exposure (Achakulwisut et al 2019). The NO_2 attributable incidence estimate uses 2015 country-specific and age group-specific asthma incidence rates from the Institute for Health Metrics and Evaluation, gridded 250 × 250 m population counts from the Global Human Settlement population grid and 2010-2012 annual average surface NO_2 concentrations estimated using land-use regression models at a resolution of 100 × 100 m. A concentration-response function based on relative risk estimates from a multinational meta-analysis is then used to estimate the burden of asthma incidence attributable to NO_2 for children aged one to 18 years at a grid spacing of 250 × 250 m.

[2]https://edgar.jrc.ec.europa.eu/index.php/dataset_ap81.

Results Summary

Analysis of data from India's official air monitoring programmes (CAAQM), the global EDGARv8.1 emissions database, and satellite observations reveals that:

- **All seven cities face unhealthy annual NO_2 concentrations.**

Annual average concentrations in 2023 reached more than three times the health-based guidelines proposed by the WHO in Pune and Jaipur. Thus, there are significant health risks to residents. Among the seven cities, Pune, Jaipur and Kolkata had the highest concentrations of NO_2 pollution, ranked in that order (Figure 1).

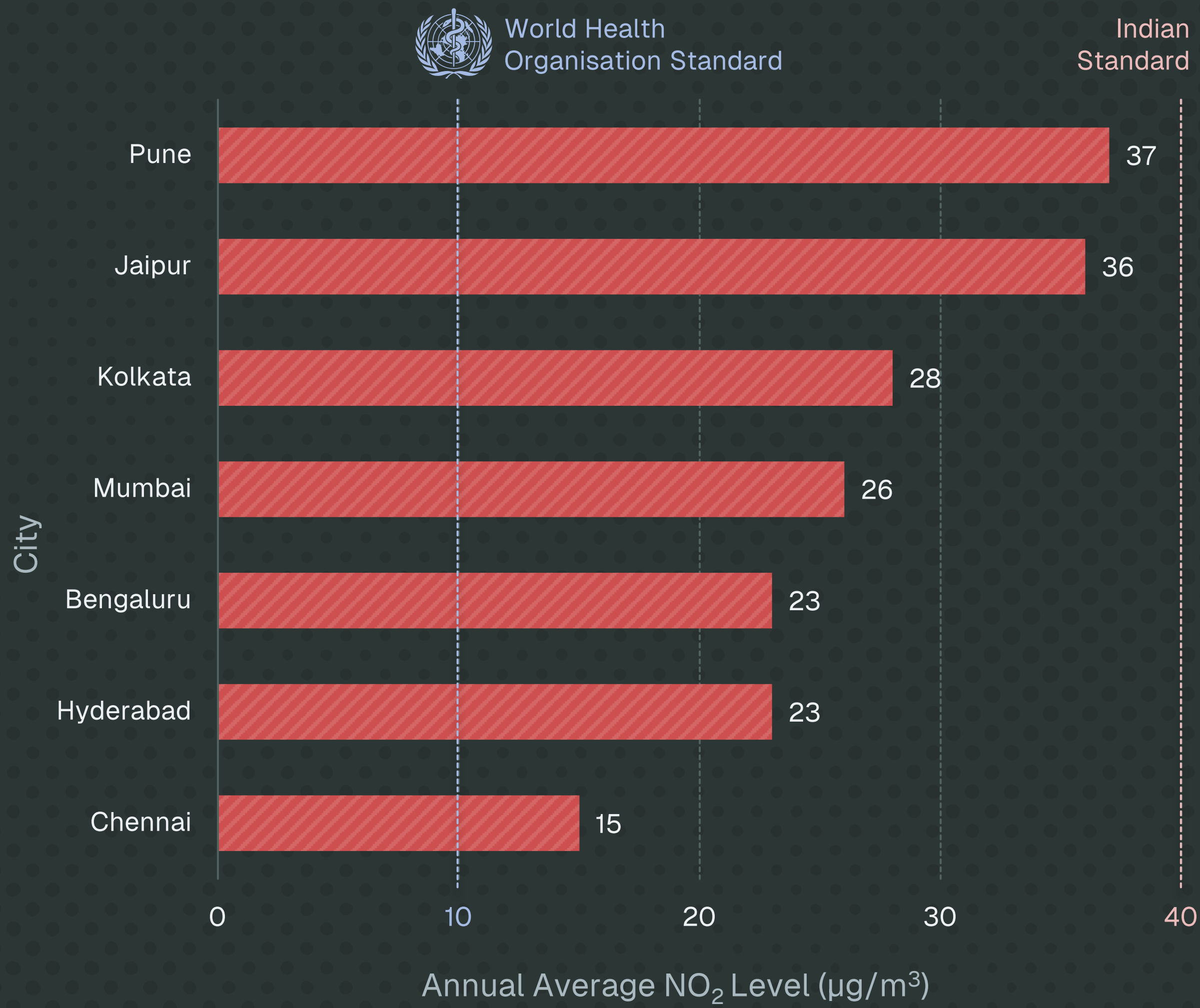


Figure 1. Annual average NO_2 concentrations for all CAAQM NO_2 monitors in each city, 2023.

- **Road transport is a major NO_x emission source in all seven cities.**

Estimated 2022 emissions in the EDGAR database show road transport contributed a quarter of total NO_x emissions in Jaipur and Hyderabad (Appendix 2. Figure A2.1).

• NO_2 pollution is widespread and persistent throughout the cities.

In 2023, 89% of monitoring stations in the seven cities (72 out of 81) breached health-based guidelines for annual concentrations of NO_2 (Figure 2). The data suggest that residents in several of the cities are continuously exposed to unhealthy concentrations of pollution. Four out of seven cities experienced concentrations exceeding the WHO daily concentration guideline for a quarter of the year. Pune and Jaipur experienced unhealthy concentrations for more than half of the observed days in the year. In Pune, guidelines were exceeded on 95% of days (Figure 3).

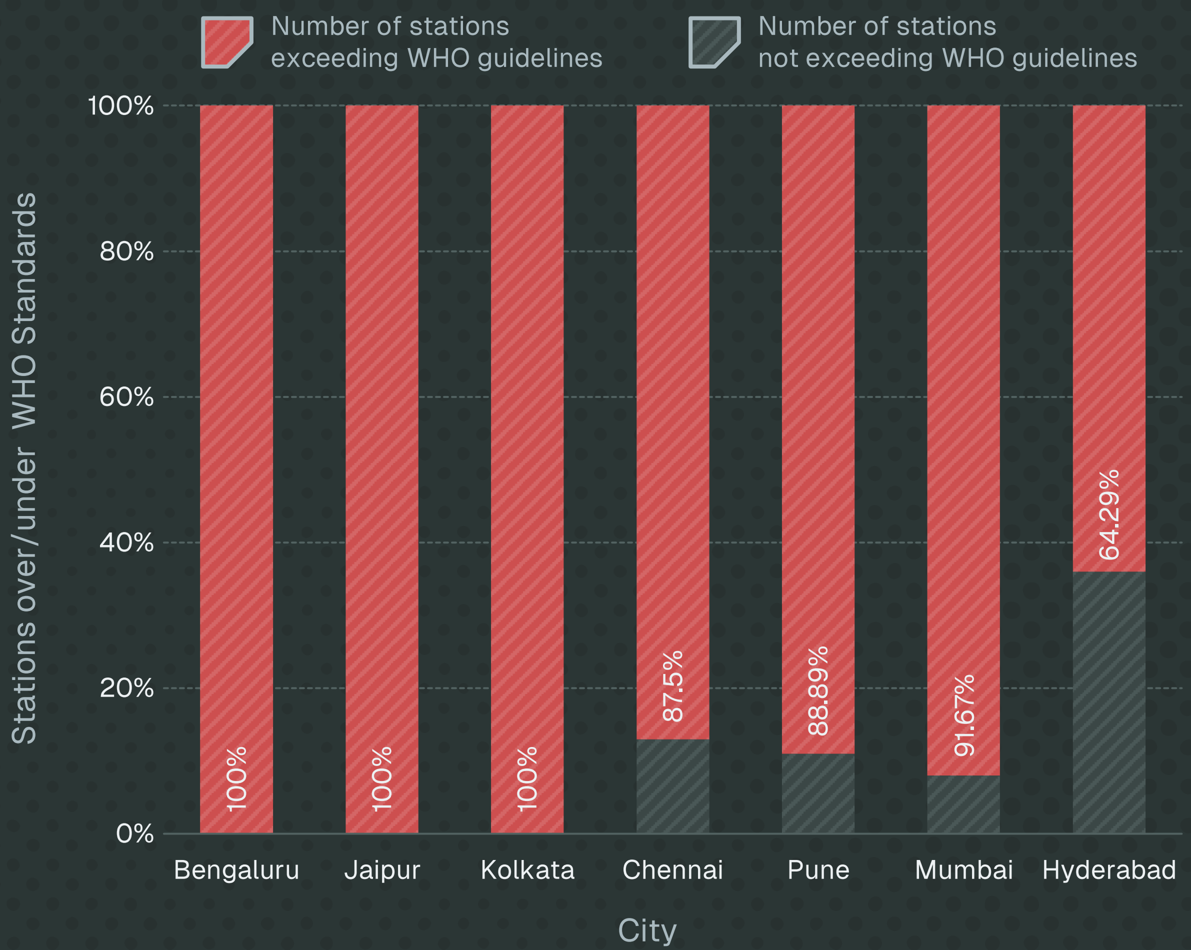


Figure 2. Percentage of stations exceeding annual average NO_2 WHO air quality guidelines.

• Monitoring of NO_2 at roadside locations is inadequate.

Despite the significant contribution of road transportation and high risk of exposure at roadside locations, there are only nine roadside monitoring stations across six cities. When comparing within each city, four out of six cities' roadside stations had higher annual average than non-roadside stations (Appendix 3. Figure A3.1). Limited roadside data availability suggests that enhancements to the monitoring network could help characterise NO_2 pollution in the worst affected areas of India's diverse urban environments. An increased number of roadside monitors in high-traffic areas, and integrating mobile air quality monitoring to make observations in the worst affected areas could ultimately inform better pollution management strategies.

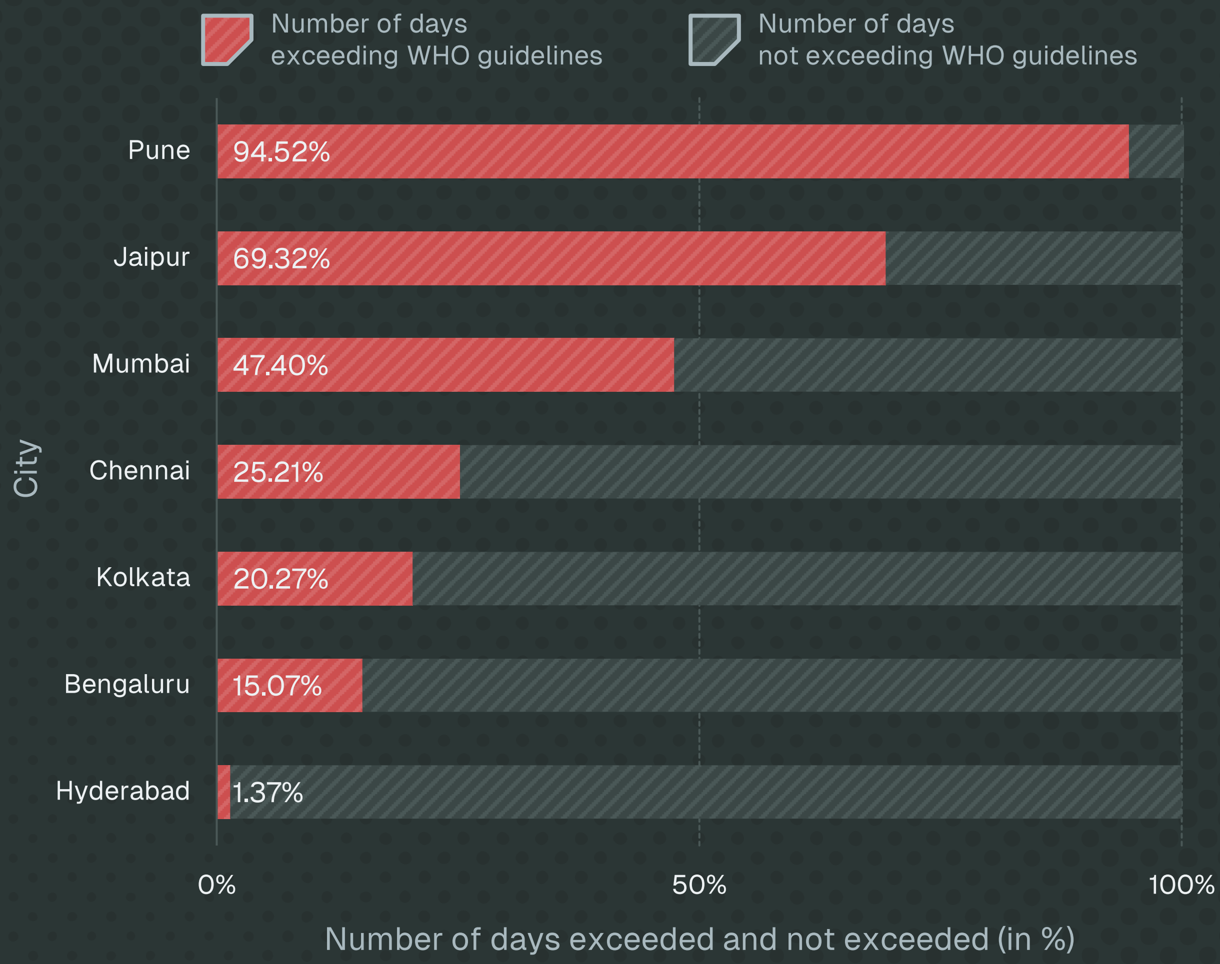


Figure 3. Percentage of days with observations that exceeded the WHO air quality guideline for daily average NO_2 in 2023.

• Trends in NO_2 concentrations are complex but there is little to no improvement overall.

Despite updated emission standards and transportation policies, annual mean NO_2 concentrations have shown little to no improvement overall. Data from 69 CAAQM ground monitoring stations had sufficient data for trend analysis. More than half of the stations (46) across the seven cities have either observed increasing concentrations or no statistically significant decrease over the past five years (Table 5). Jaipur, Mumbai and Pune are experiencing a statistically significant worsening trend in NO_2 concentrations (Appendix 3. Figure A3.2). The increasing trend means that Pune was the city with the highest annual average NO_2 pollution in 2023 (Figure 1). Road transport is the third largest source of NO_x emissions in Pune (Appendix 2. Figure A2.1).

In the years preceding the global COVID-19 pandemic, NO_2 concentrations were increasing in India. NO_2 in 99% of Indian urban areas rose by an average of 2.2% per year between 2000 and 2019 (Sicard et al. 2023), and NO_2 in the lower part of the atmosphere increased in almost every part of India between 2005 and 2019 (Singh et al. 2023). TROPOMI satellite data for the last five years suggest that all the cities are experiencing a worsening trend in annual average NO_2 column amount (Appendix 4. Figure A4.1).

Table 5. Theil-Sen NO_2 trend analysis of CAAQM stations with sufficient data for trend analysis.

City	Stations with Worsening Trends	Stations with no Significant Trends	Stations with Improving Trends	Total Number of Stations Analysed
Bengaluru	3	3	4	10
Chennai	6	2	0	8
Hyderabad	6	5	3	14
Jaipur	2	1	0	3
Kolkata	1	1	5	7
Mumbai	9	2	9	20
Pune	2	3	2	7
Total	29	17	23	69

Trends are considered significant when $p < 0.1$, whereas $p > 0.1$ indicates the absence of significant trends.

BENGALURU

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KARNATAKA

The city's 2023 annual average NO_2 concentration was nearly twice the WHO's health based guideline. That year all 13 CAAQM monitoring stations exceeded this guideline. Bengaluru is one of the most populous cities in India; the number of residents potentially exposed to unhealthy NO_2 concentrations is therefore highly concerning.

The station with the highest NO_2 annual average was City Railway Station, located in the city centre. The two monitoring stations which we classified as roadside stations, BTM Layout and Silk Board, were among the most polluted in the city (Figure 4), suggesting that traffic emissions are one of the important sources of NO_2 in Bengaluru.

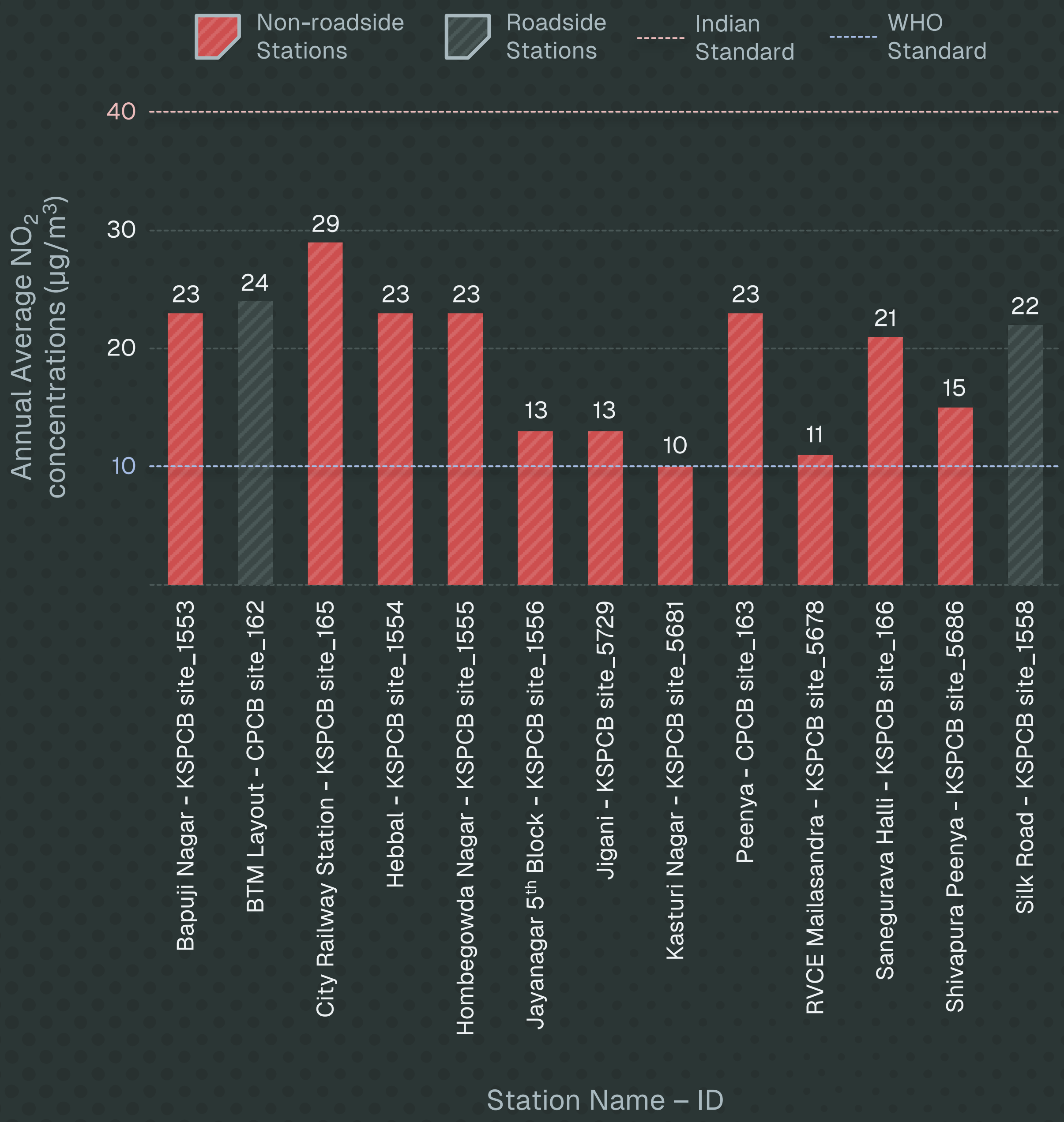


Figure 4. Annual average NO_2 concentrations for all CAAQM monitors in Bengaluru, 2023. Roadside Monitoring Stations are in grey (column values are rounded).

Daily average NO_2 concentrations also breached the relevant WHO health based air quality guideline. The City Railway Station monitor in Bengaluru (KSPCB site_165) measured NO_2 concentrations higher than this guideline over 80% of the year. One station, Bapuji Nagar (KSPCB site_1553), located at an intersection of one of the biggest arterial roads in the city, recorded 21 days exceeding the much less stringent Indian national standard (Figure 5).

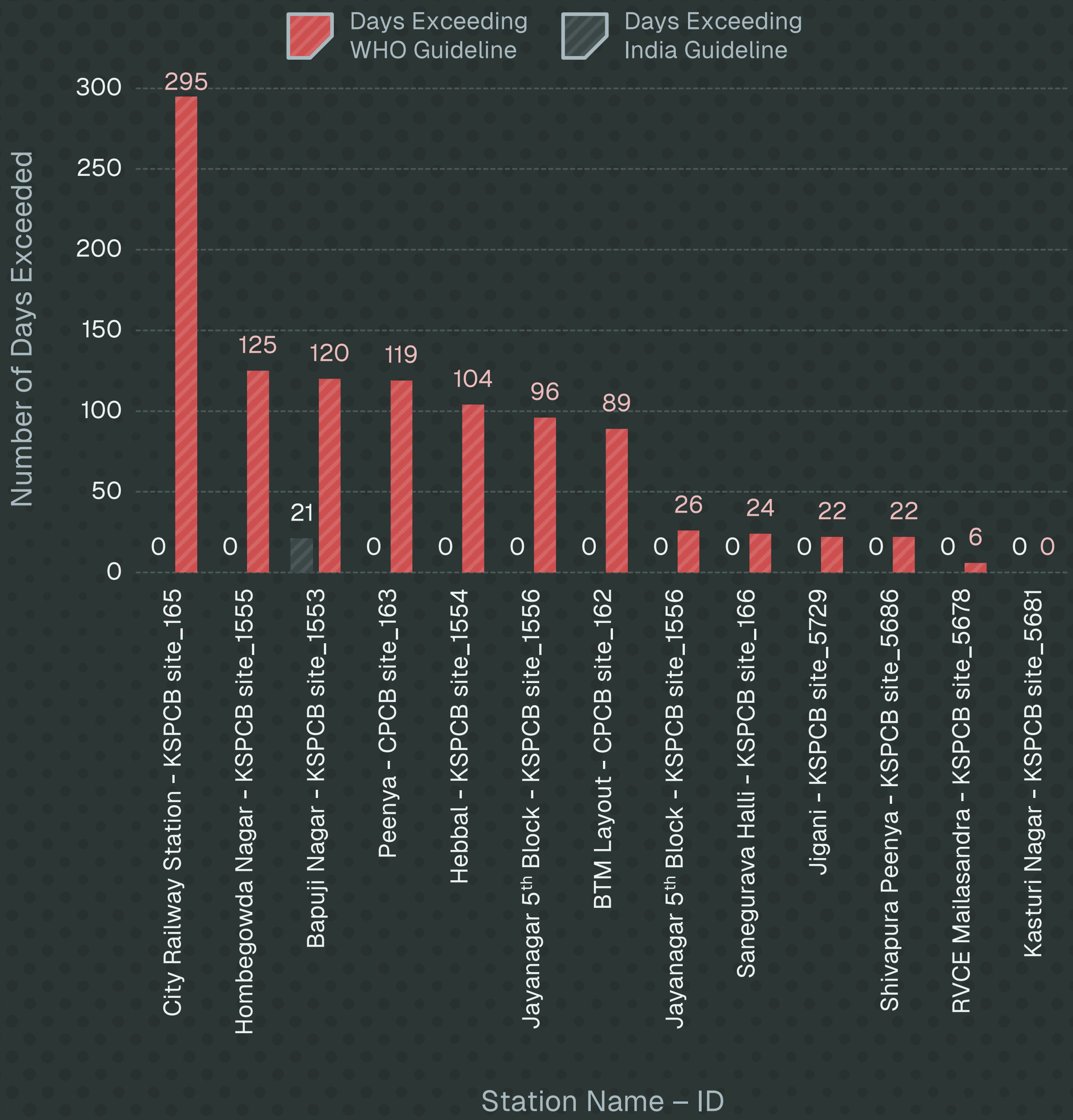


Figure 5. Number of days exceeding WHO guideline and NAAQS for daily average NO_2 concentration at CAAQM monitoring stations in Bengaluru city.

Monitoring stations that exceeded WHO health guidelines in 2023 were located within 500 m of five schools, indicating that young students are exposed to NO_2 pollution and their health may be at risk. Achakulwisut et al. (2019) estimated that 2,730 cases of paediatric asthma could be attributed to NO_2 pollution in Bengaluru in 2015.

The 5-year trend in NO_2 concentrations recorded by CAAQM monitors is complex. We found that city-average at CAAQM sites is decreasing, but only four of the 10 stations included in the trend analysis have a significant improving trend, while three stations have significant worsening trends (Table 5, Appendix 3. Figure A3.3). Individual monitoring stations are often only representative of their immediate location. As cities change and develop, some areas will likely experience worsening and others improving air quality. It is not unexpected that stations within a city can have opposing trends.

Satellite observations of NO_2 in the atmosphere over Bengaluru from 2019-2023 also suggest that NO_2 pollution across the city as a whole is increasing (Appendix 4. Figure A4.1). There is no strong evidence that NO_2 air quality is improving in the city.

Road transport is the second largest source of NO_x emissions in Bengaluru, accounting for 20% of emissions in the EDGAR emission inventory (Appendix 2. Figure A2.1).

Road transport is Bengaluru's 2nd largest source of NO_x emissions, accounting for 20% of it in the EDGAR emission inventory.

Representational Photo by Rohit Durbha (Edited)

CHENNAI

சின்னை

TAMIL NADU

The city's 2023 annual average NO_2 concentration was twice the WHO's health based guideline. That year NO_2 concentrations exceeded the guideline at all but one CAAQM monitoring station. The station with the highest NO_2 annual average, Alandur Bus Depot (CPCB site_293) is located in southern Chennai. Latitude and longitude coordinates provided by the CPCB for the monitor do not match the street address provided[3]. However both locations suggest that the monitor is positioned in an area of the city where emissions from busy roads and airports could be important. The two monitoring stations which we classified as roadside stations, Gandhi Nagar Ennore and Royapuram, also exceeded WHO guidelines (Figure 6).

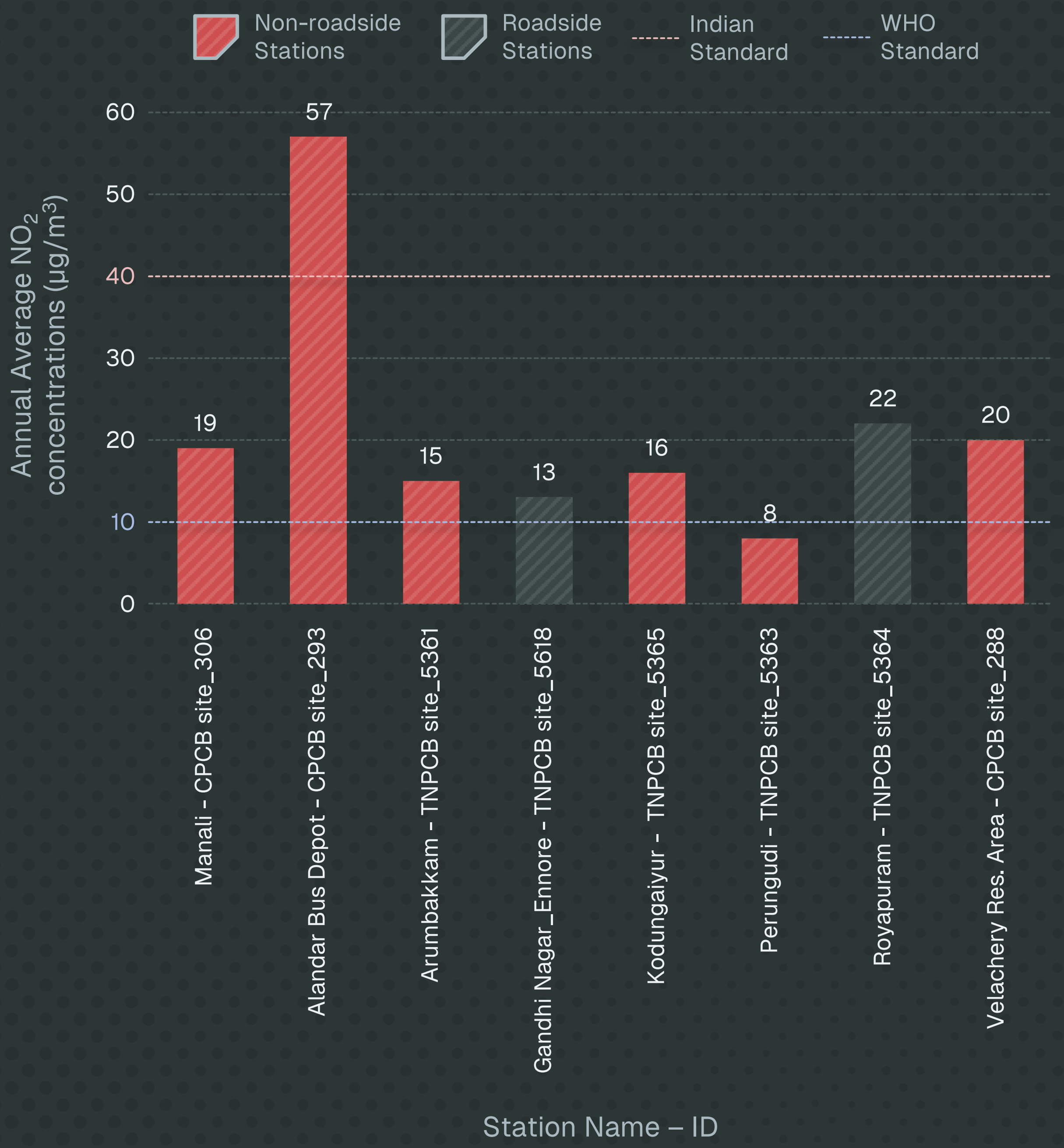


Figure 6. Annual average NO_2 concentrations for all CAAQM monitors in Chennai, 2023. Roadside monitoring stations are in grey.

[3]The CPCB was approached for clarification.

Daily average NO_2 concentrations also breached the relevant WHO health based air quality guideline. The Alandur Bus Depot monitoring station measured NO_2 concentrations higher than this guideline over 86% of the year. It also recorded 75 days exceeding the much less stringent Indian national standard (Figure 7).

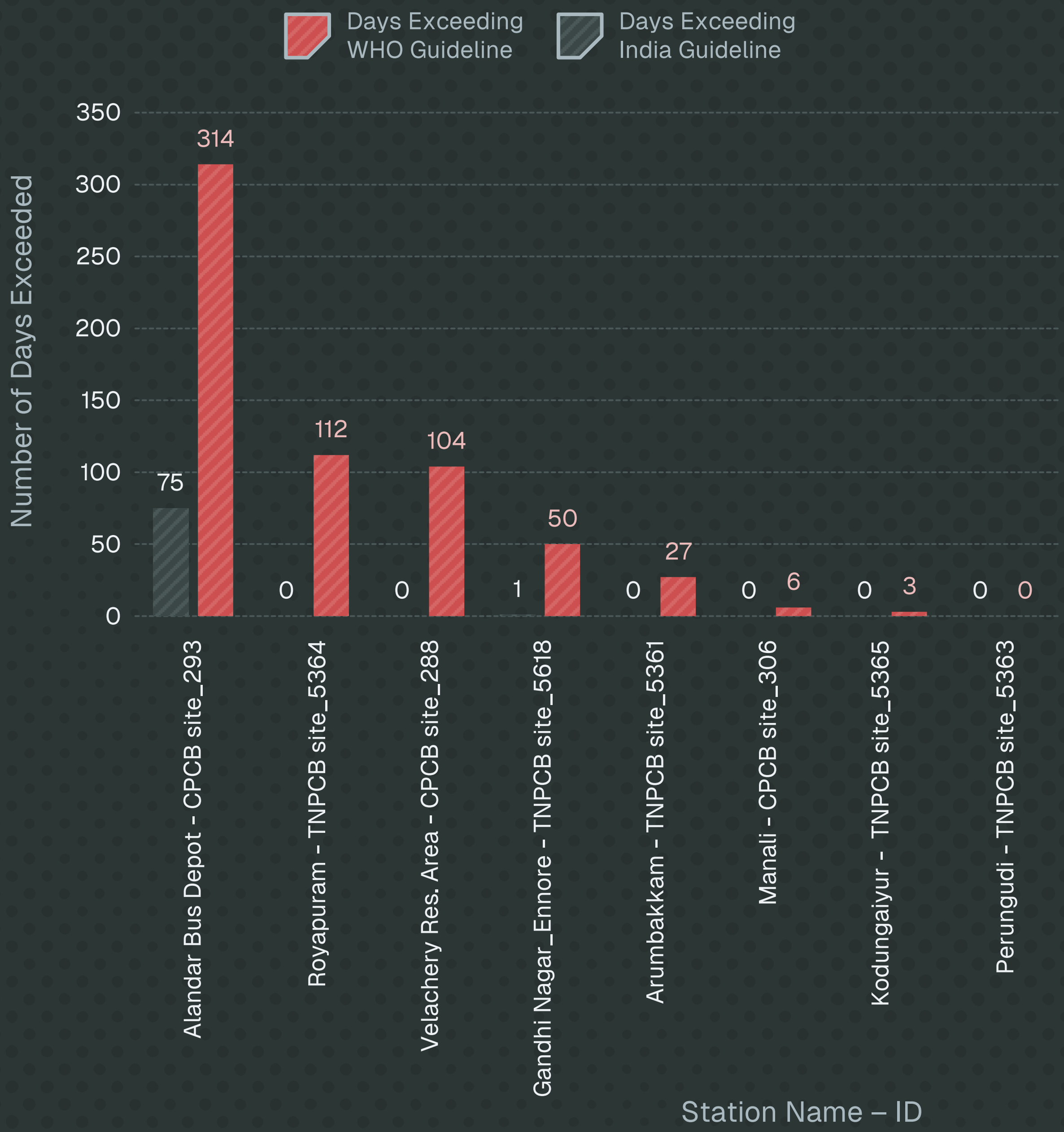


Figure 7. Number of days exceeding WHO guideline and NAAQS for daily average NO_2 concentration at CAAQM monitoring stations in Chennai city.

Ten percent of Chennai's total population (Appendix 5) consists of children under six, who are highly vulnerable to NO_2 health effects. Importantly, these effects impact all children aged 0-18. Achakulwisut et al. (2019)'s estimates state 1,420 cases of paediatric asthma in Chennai in 2015 could be attributed to NO_2 pollution.

Chennai's disparity in private and public transportation growth may contribute to NO_2 emission increases.

Representational Photo by Rajaraman Arumugam (Edited)

The 5-year trend in NO_2 concentrations recorded by CAAQM monitors is increasing. We found the city-average was increasing, where six of the eight stations included in the trend analysis had significant worsening trends (Table 5, Appendix 3. Figure A3.4). Satellite observations of NO_2 in the atmosphere over Chennai from 2019-2023 also suggest that NO_2 pollution across the city as a whole is not decreasing (Appendix 4. Figure A4.1). MoRTH data from 2010 to 2020 shows an increasing trend in the number of motor vehicles registered in Chennai (MoRTH, 2023), while in recent years the number of buses has not increased (MTC, 2024). A disparity in private and public transportation growth may contribute to NO_2 emission increases.

Road transport is the third largest source of NO_x emissions in Chennai, accounting for 9% of emissions in the EDGAR emission inventory (Appendix 2. Figure A2.1). Energy industry (70%) is the highest, and industrial emissions are second (15%).

HYDERABAD

హైదరాబాదు

TELANGANA

The city's 2023 annual average NO_2 concentration exceeded the WHO health based guideline at nine out of 14 CAAQM monitoring stations. The station with the highest NO_2 annual average was Central University Hyderabad, which even exceeded the less stringent Indian national standard (Figure 8).

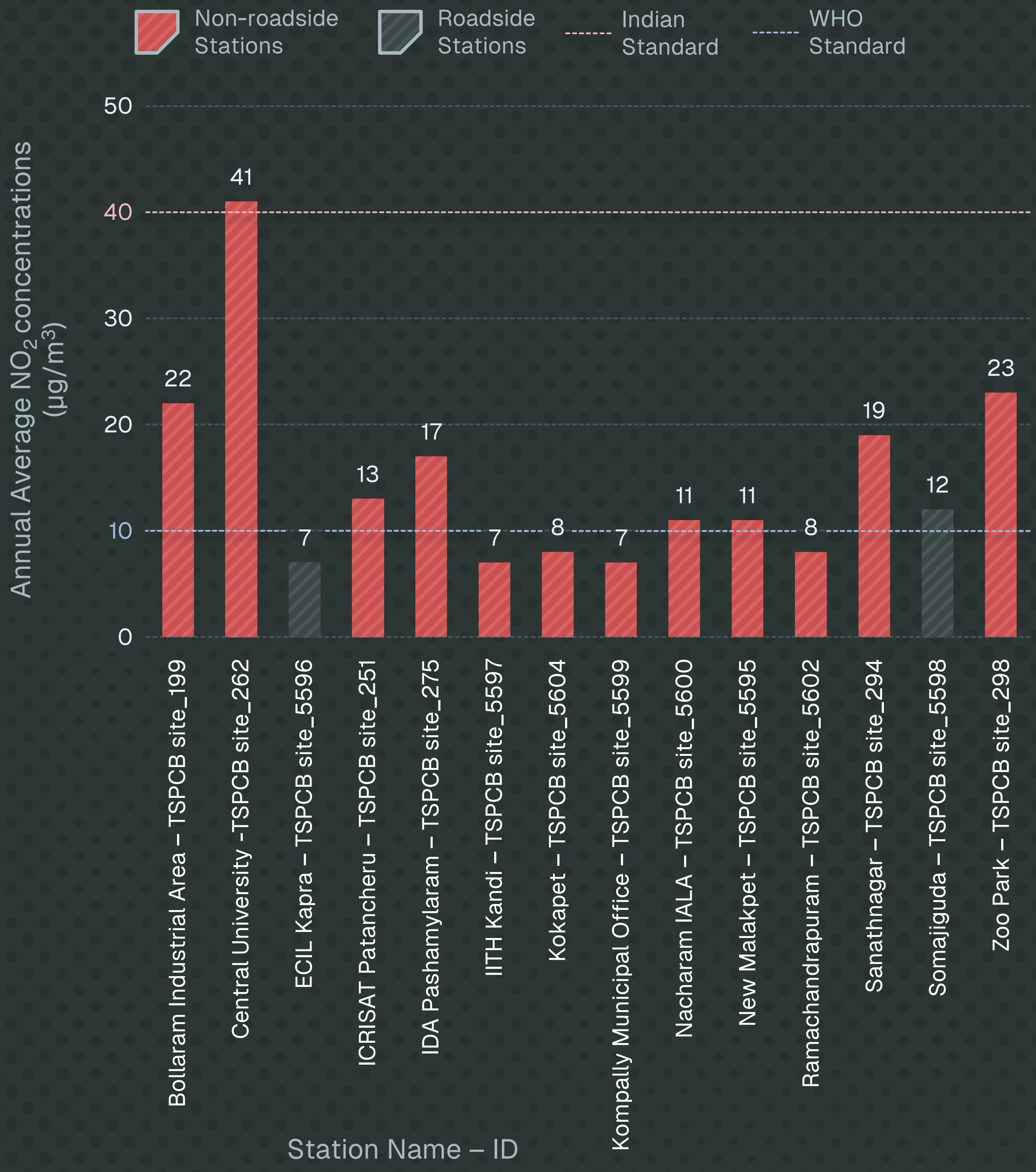


Figure 8. Annual average NO_2 concentrations for all CAAQM monitors in Hyderabad, 2023. Roadside Monitoring Stations are in grey.

Daily average NO_2 concentrations also breached the relevant WHO health based air quality guideline. The Central University Hyderabad station measured NO_2 concentrations higher than this guideline over 80% of the year. One station, IDA Pashamylaram (TSPCB site_275), recorded 16 days exceeding the much less stringent Indian national standard (Figure 9).

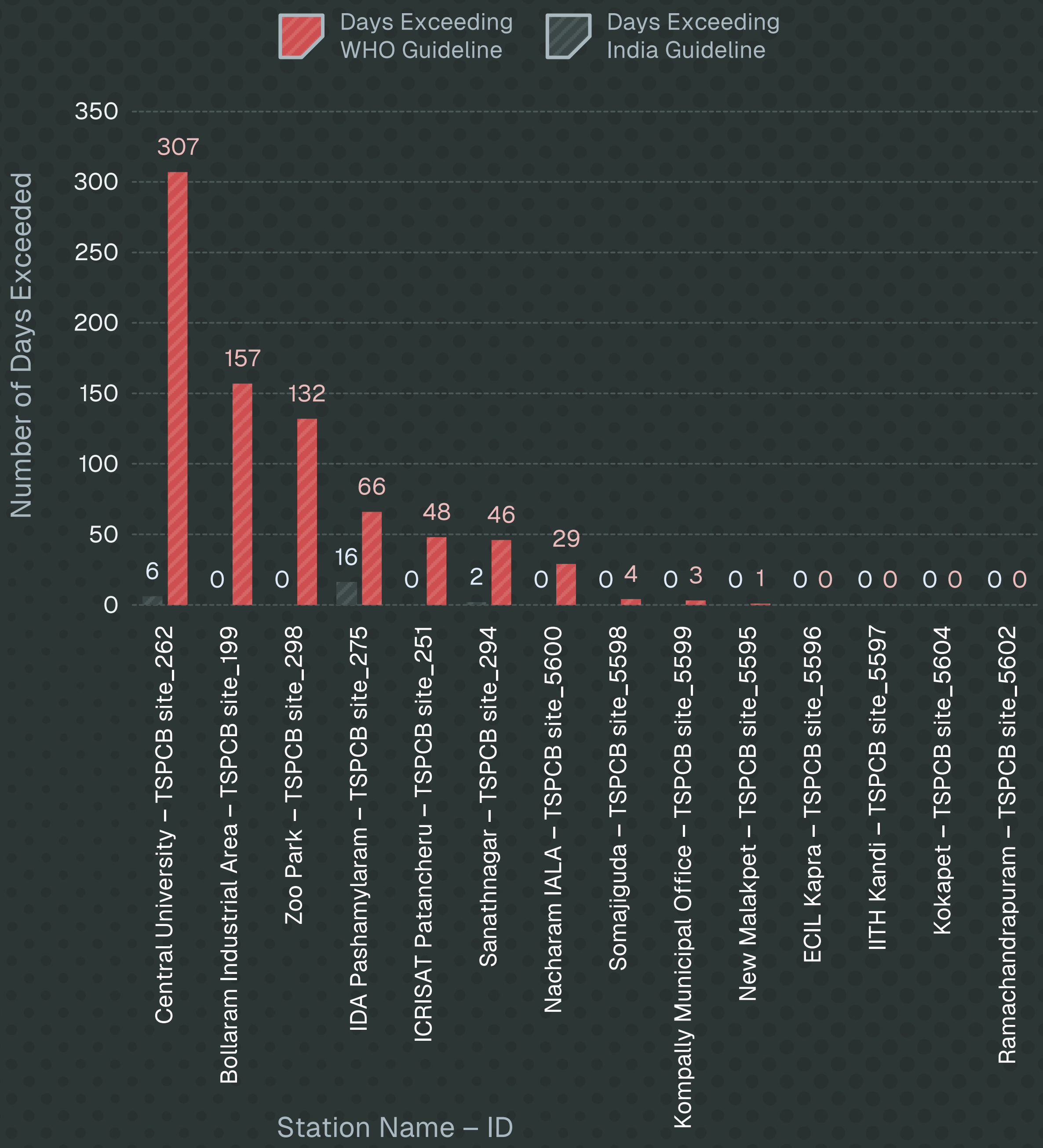


Figure 9. Number of days exceeding WHO guideline and NAAQS for daily average NO_2 concentration at CAAQM monitoring stations in Hyderabad city.

The station with the worst level is located inside the Central University Hyderabad, the second highest is near the zoo, and third highest is near a high school, which suggests students are exposed to NO_2 associated health risk. Achakulwisut et al. (2019) estimated that 2,430 cases of paediatric asthma could be attributed to NO_2 pollution in Hyderabad in 2015, signifying the risks associated with NO_2 exposure.

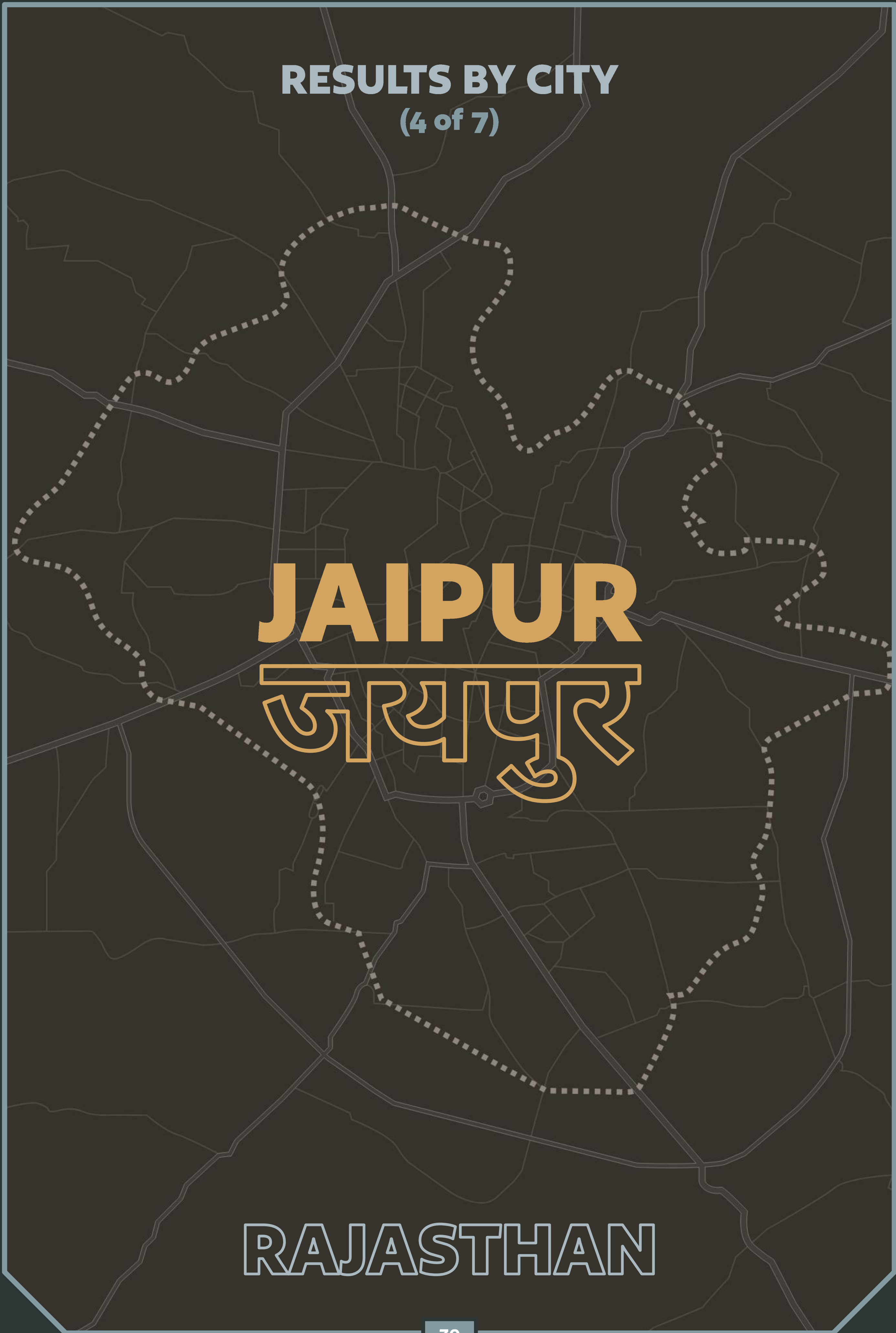
The 5-year trend in NO2 concentrations recorded by CAAQM monitors is complex. The city-average trend is decreasing overall (Appendix 3. Figure A3.2.), but six stations have significant worsening trends. Only three of the 14 stations included in the trend analysis have a significant improving trend (Table 5, Appendix 3. Figure A3.5). Satellite observations of NO_2 in the atmosphere over Hyderabad from 2019-2023 suggest that NO_2 pollution across the city as a whole is increasing (Appendix 4. Figure A4.1). Individual monitoring stations are often only representative of their immediate location, and as cities change and develop some areas will experience worsening or improving air quality. It is not unexpected that stations within a city can have opposing trends.

Road transport is the second largest source of NO_x emissions in Hyderabad, accounting for 24% of emissions in the EDGAR emission inventory (Appendix 2. Figure A2.1.).

Road transport is Hyderabad's 2nd largest source of NO_x emissions, accounting for 24% of emissions in the EDGAR emission inventory

Representational Photo by Cascoly (Edited)

RESULTS BY CITY
(4 of 7)



JAIPUR
जयपुर

RAJASTHAN

The city's 2023 annual average NO_2 concentration exceeded the WHO health based guideline at all six CAAQM monitoring stations. The station with the highest NO_2 annual average was Adarsh Nagar (RSPCB site_1393), which even breached the less stringent Indian national standard (Figure 10).

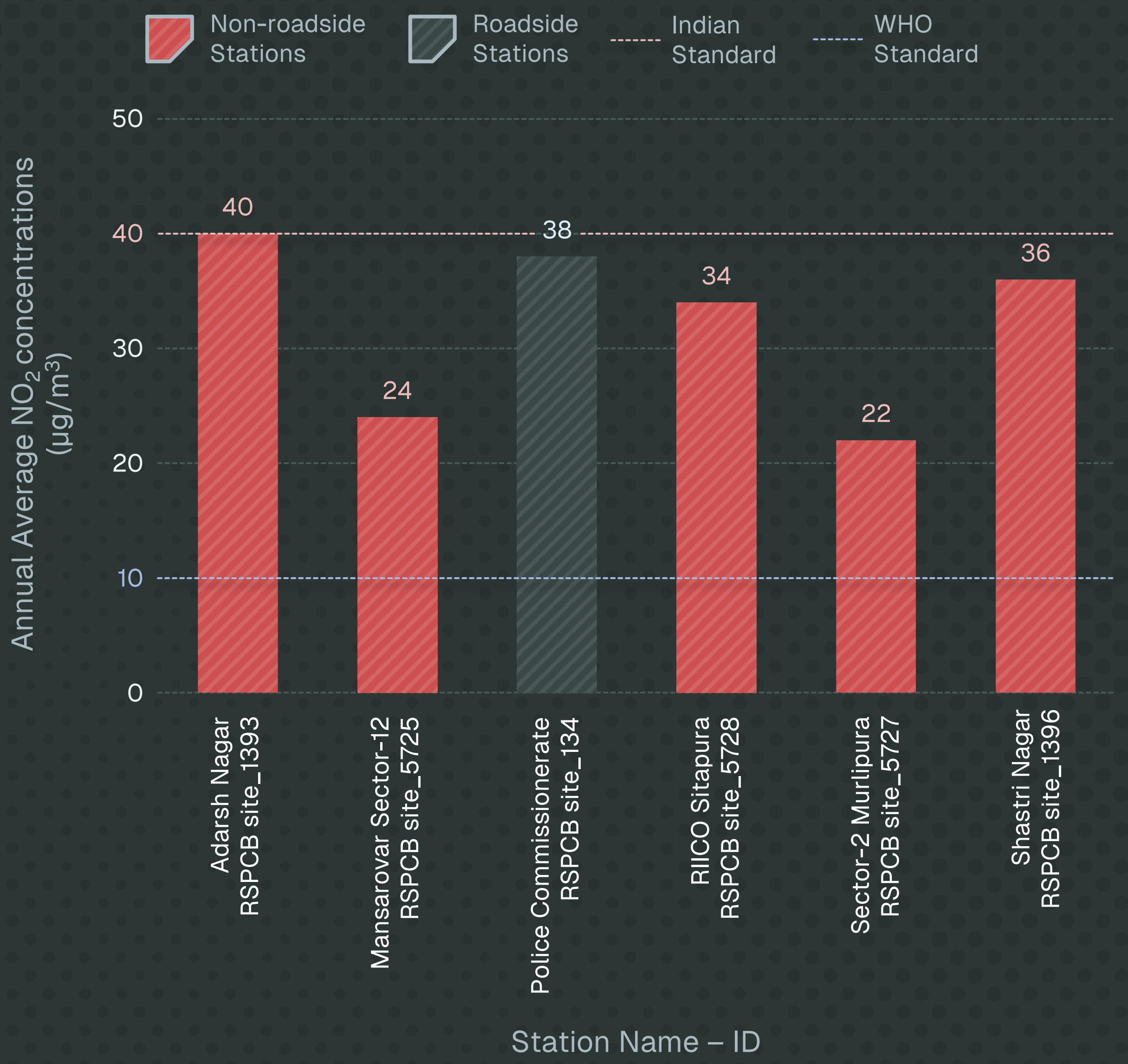


Figure 10. Annual average NO_2 concentrations for all CAAQM monitors in Jaipur, 2023. Roadside monitoring stations in grey.

Daily average NO_2 concentrations also breached the relevant WHO health based air quality guideline. Three stations (Adarsh Nagar, Police Commissionerate, Shastri Nagar) measured NO_2 concentrations higher than this guideline over 60% of the year, and Adarsh Nagar station recorded 277 days exceeding the WHO guideline. Adarsh Nagar station even recorded 20 days exceeding the much less stringent Indian national standard (Figure 11).

Continuous exposure to unhealthy concentrations of NO_2 poses serious health risks, particularly to children (0-6 years), who make up 12% of Jaipur's population. According to Achakulwisut et al. (2019), an estimated 2,430 cases of paediatric asthma in Jaipur in 2015 could be linked to NO_2 pollution.

The 5-year trend in NO_2 concentrations recorded by CAAQM monitors is increasing (Appendix 3. Figure A3.2). We found that two of the three stations with sufficient data have significant worsening trends (Table 5, Appendix 3. Figure A3.6). Satellite observations of NO_2 in the atmosphere over Jaipur from 2019-2023 also suggest that NO2 pollution across the city as a whole is increasing (Appendix 4. Figure A4.1).

Road transport is the second largest source of NO_x emissions in Jaipur, accounting for 26% of emissions in the EDGAR emission inventory (Appendix 2. Figure A2.1).

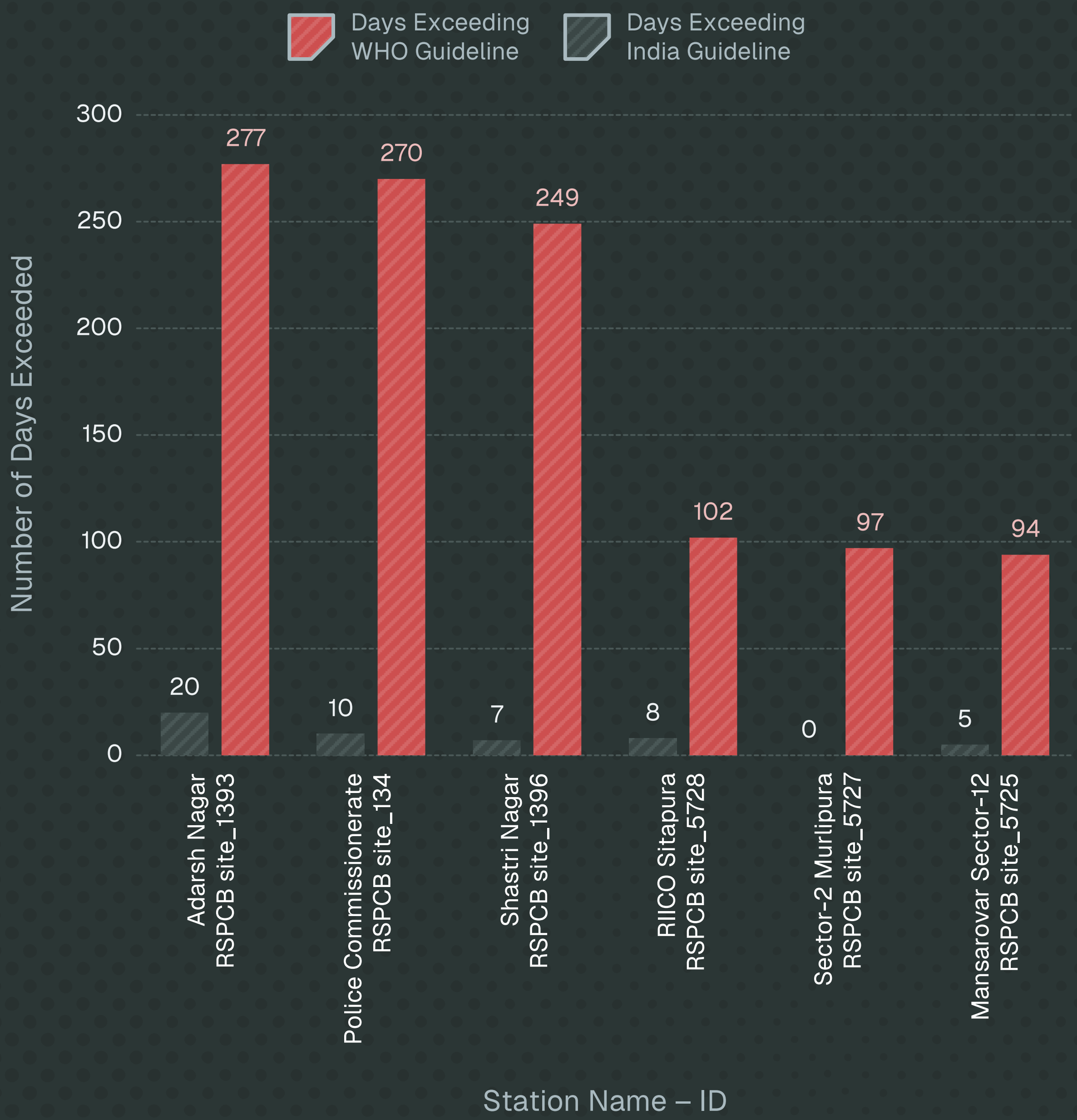


Figure 11. Number of days exceeding WHO guideline and NAAQS for daily average NO_2 concentration at CAAQM monitoring stations in Jaipur city.

RESULTS BY CITY

(5 of 7)

KOLKATA

কলকাতা

WEST BENGAL

The city's 2023 annual average NO_2 concentration exceeded the WHO health based guideline at all seven CAAQM monitoring stations. The station with the highest NO_2 annual average was Bally Gunge (WBPCB site_5238) (Figure 12). Daily average NO_2 concentrations also breached the relevant WHO health based air quality guideline. Bally Gunge measured NO_2 concentrations higher than this guideline for 133 days (Figure 13).

Continuous exposure to unhealthy concentrations of NO_2 poses serious health risks, particularly to children, who make up 13% of Kolkata's population. Achakulwisut et al. (2019) estimated that 3,210 cases of paediatric asthma could be attributed to NO_2 pollution in Kolkata in 2015.

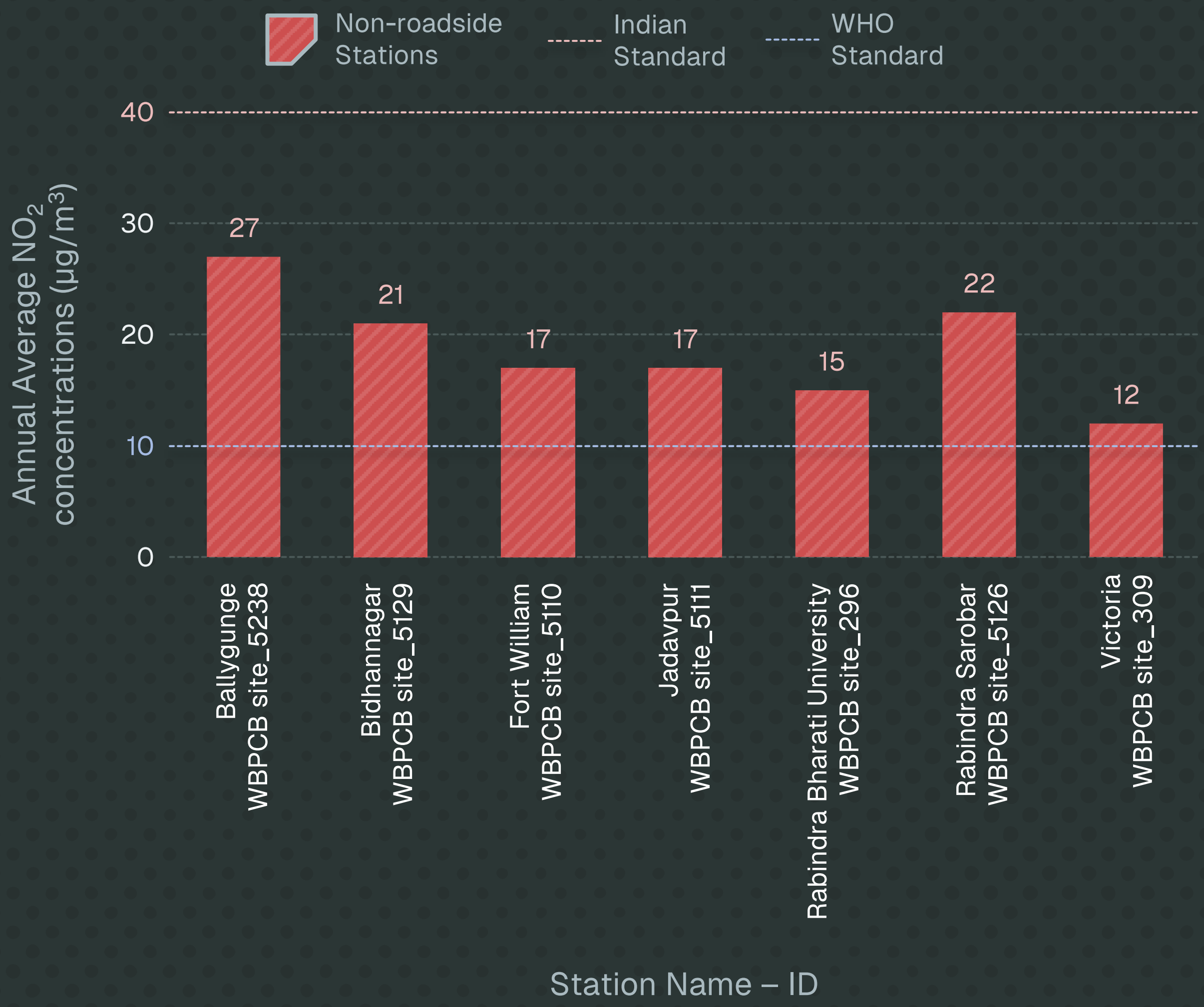


Figure 12. Annual average NO_2 concentrations for all CAAQM monitors in Kolkata, 2023.

The 5-year trend in NO_2 concentrations recorded by CAAQM and satellite monitors is complex. We found that city-average is decreasing, with five of the seven stations included in the trend analysis having a significant improving trend, and that one station has significant worsening trends (Table 5, Appendix 3. Figure A3.7). However, satellite observations of NO_2 in the atmosphere over Kolkata from 2019-2023 suggest that NO_2 pollution across the city as a whole is increasing (Appendix 4. Figure A4.1).

Road transport is the second largest source of NO_x emissions in Kolkata, accounting for 16% of emissions in the EDGAR emission inventory (Appendix 2. Figure A2.1).

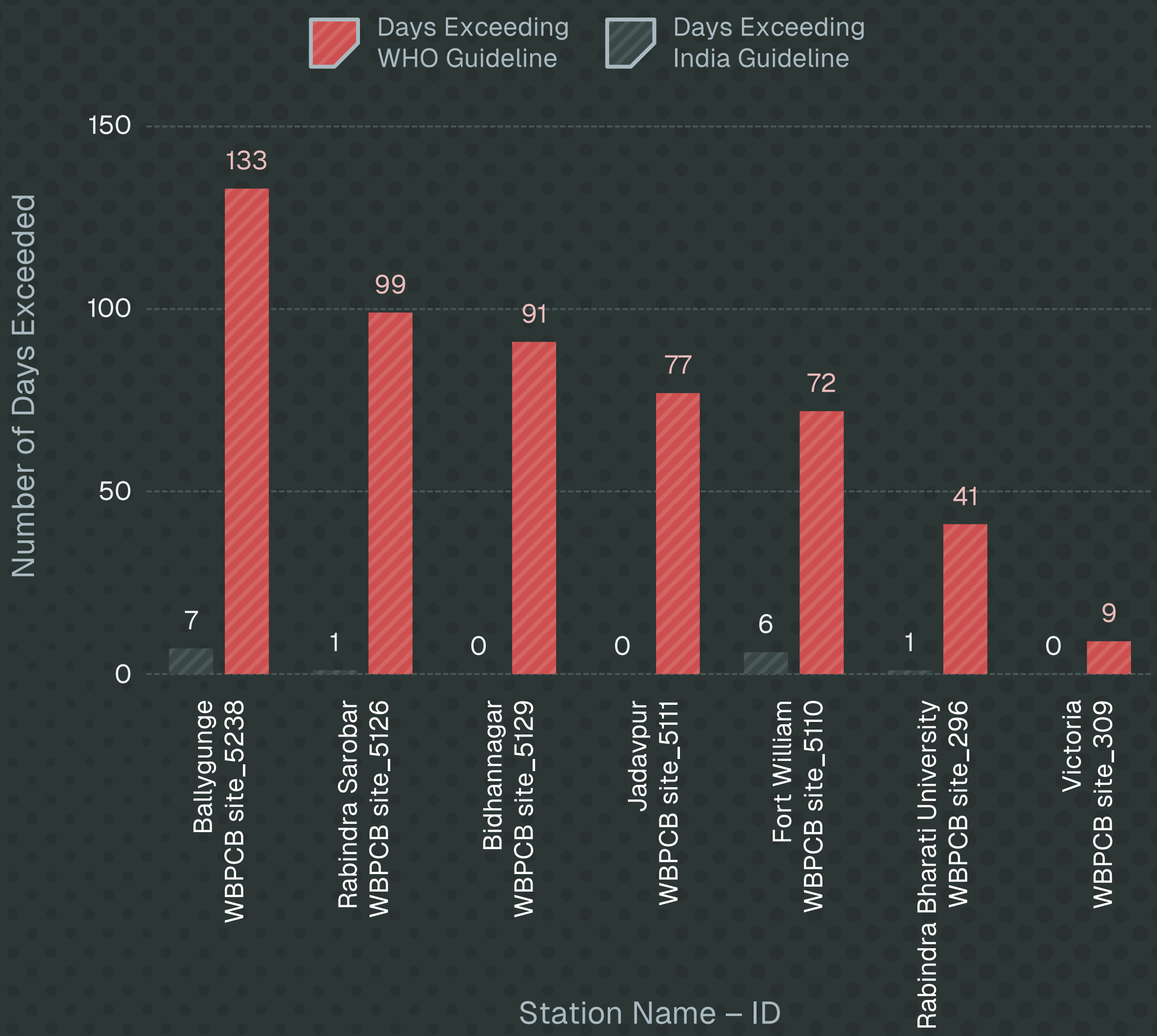
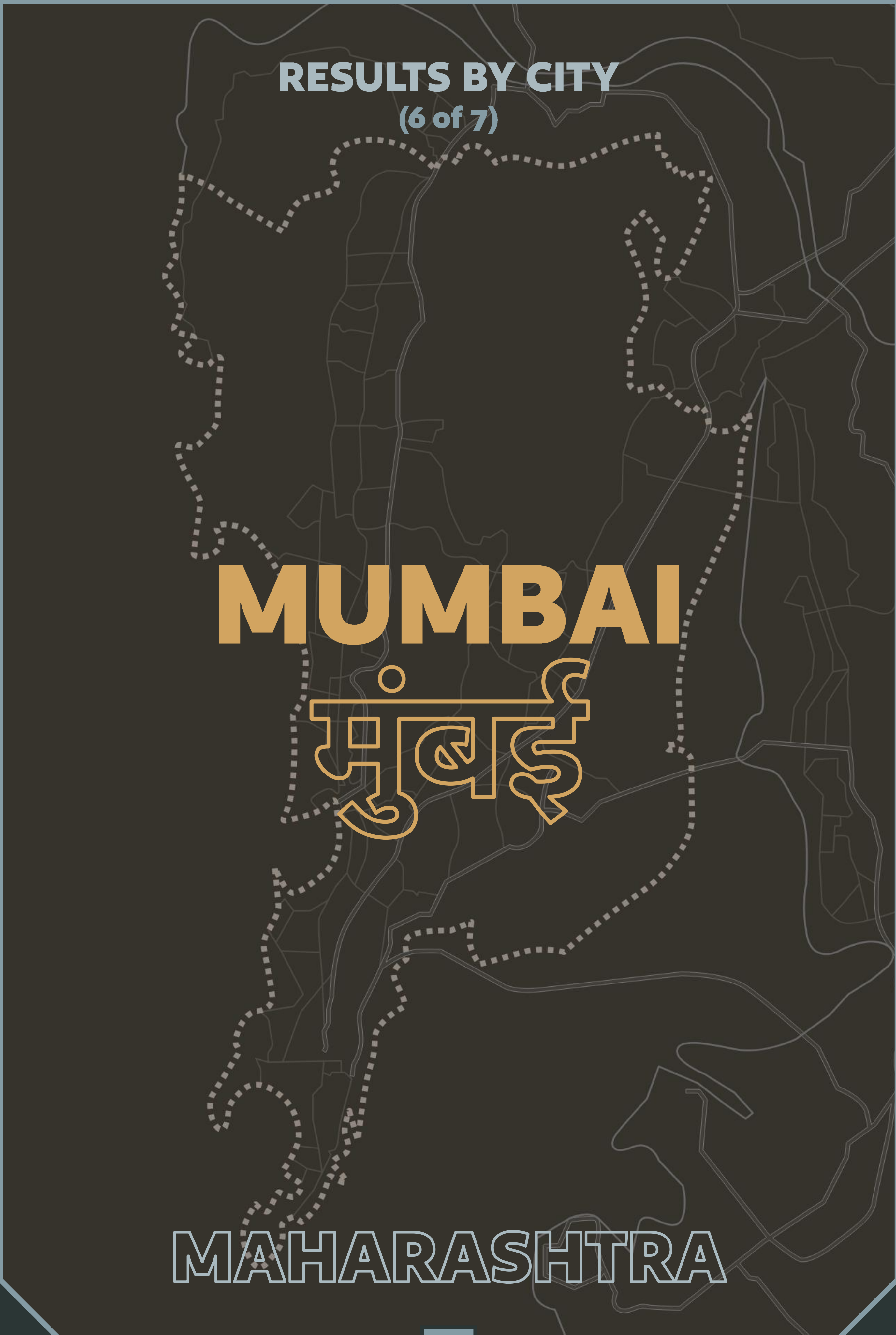


Figure 13. Number of days exceeding WHO guideline and NAAQS for daily average NO_2 concentration at CAAQM monitoring stations in Kolkata city.

> *"Amid Kolkata's chaotic traffic, families and children bear the brunt of rising pollution levels, with every breath becoming a challenge. The city's deteriorating air quality is a daily reminder of the urgent need for sustainable public transport solutions. Yet, as we face this crisis, we are witnessing the slow disappearance of Kolkata's iconic green trams, a symbol of eco-friendly transport, shut down due to neglect and lack of modernization. It's time to rethink our priorities and invest in transport systems that safeguard our health and the environment."*
>
> **ARGHYADIP HATUA, KOLKATA**

RESULTS BY CITY



MUMBAI

मुंबई

MAHARASHTRA

The city's 2023 annual average NO_2 concentration exceeded the WHO health based guideline at 22 out of 24 CAAQM monitoring stations. The station with the highest NO_2 annual average was Mazgaon (IITM site_5394) (Figure 14). The station with the second highest level, Bandra Kurla (IITM site_5392), is classified as a roadside station, located near a bus depot. Daily average NO_2 concentrations also breached the relevant WHO health based air quality guideline. Two stations (Mazgaon and Sion) measured NO_2 concentrations higher than this guideline over 70% of the year, with Mazgaon recording 267 days (Figure 15).

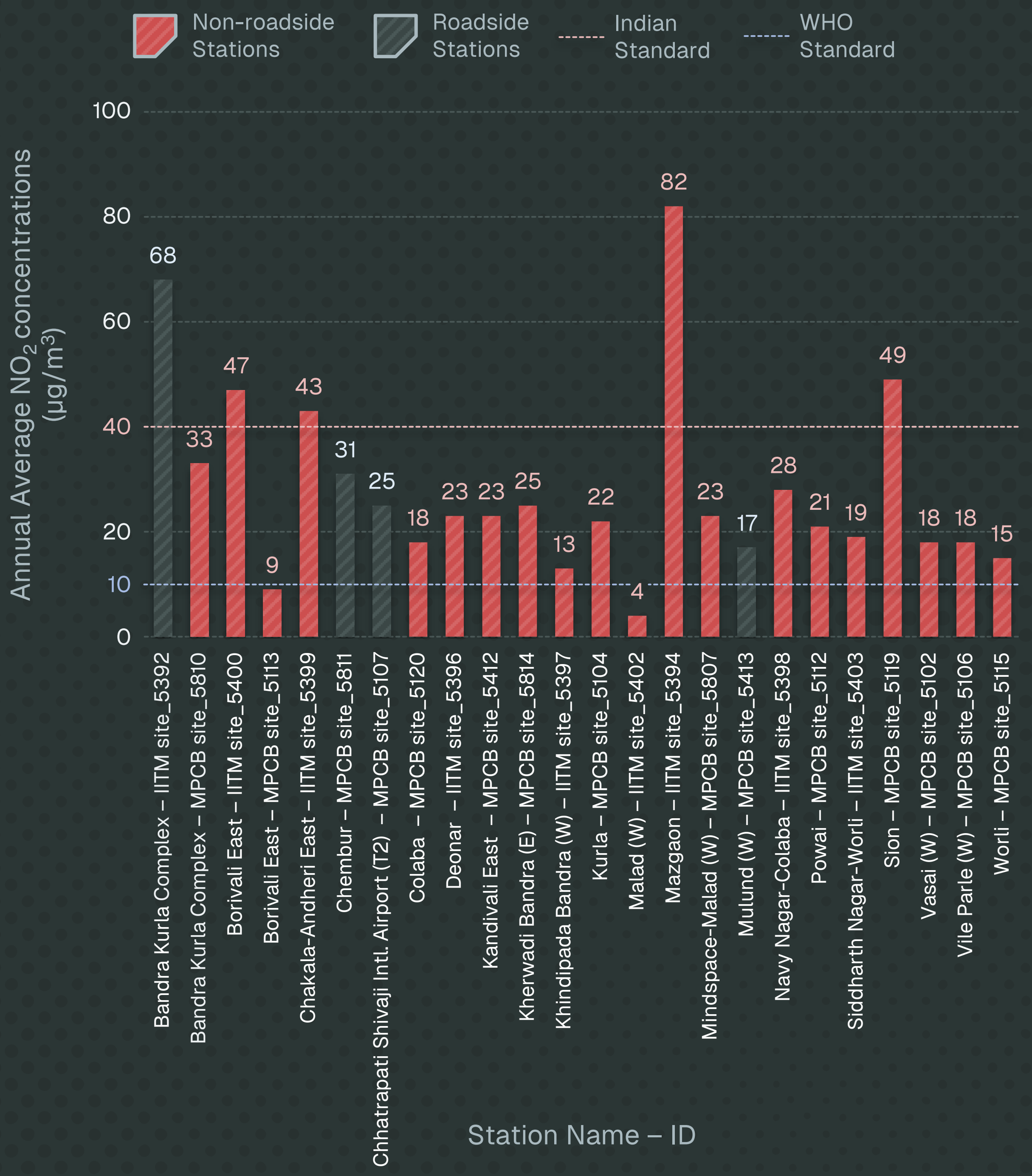
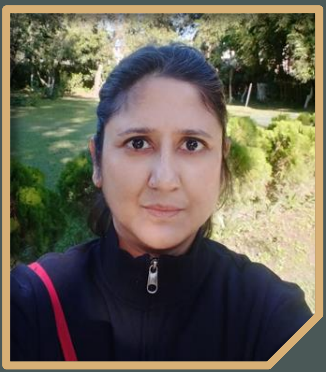


Figure 14. Annual average NO_2 concentrations for all CAAQM monitors in Mumbai, 2023. Roadside monitoring stations in grey.

Continuous exposure to unhealthy concentrations of NO_2 poses serious health risks, particularly to children, who make up 10% of the population. Achakulwisut et al. (2019) estimated that 3,970 cases of paediatric asthma could be attributed to NO_2 pollution in Mumbai in 2015.



"Having been born and brought up in Mumbai, over the years, I have seen air quality go from bad to worse. This is immediately visible as the skyline becomes invisible or visibility becomes limited on 'bad air' days especially during our winter months. In the past few years, we have been competing with Delhi's thickly polluted air and soon in the years to come we will likely win the race!

The second sign is the number of times we line up to visit out GP for medicines to help cope. Our senior citizens and kids are the worst affected; not a day goes by when they can breathe easily. If standard of living has supposedly increased in a so-called world-class city, I would say 'standard of life' has plummeted in mismanaged cities like Mumbai. If only priorities were focused on public health and welfare, then maybe the situation would have been better. Municipal and state authorities need to take off their rose-tinted glasses and see the air for what it is, grey hazy and dangerously loaded with pollutants damaging lungs and hearts of its citizens. Technology and resources are vastly available to swiftly reverse the situation but unfortunately, the will to do anything, is missing. The simplest most effective solution is given by Nature herself. If only we could humbly acknowledge it!"

SONAL ALVARES, MUMBAI

The 5-year trend in NO_2 concentrations recorded by CAAQM monitors appears to be complex. We found that the city-average trend to be increasing (Appendix 3. Figure A3.2), and while nine of the 20 stations included in the trend analysis have a significant improving trend, nine stations have significant worsening trends (Table 5, Appendix 3. Figure A3.8). Satellite observations of NO_2 in the atmosphere over Mumbai from 2019-2023 suggest that NO_2 pollution across the city as a whole is increasing (Appendix 4. Figure A4.1).

Road transport is the third largest source of NO_x emissions in Mumbai, accounting for 9% of emissions in the EDGAR emission inventory (Appendix 2. Figure A2.1).

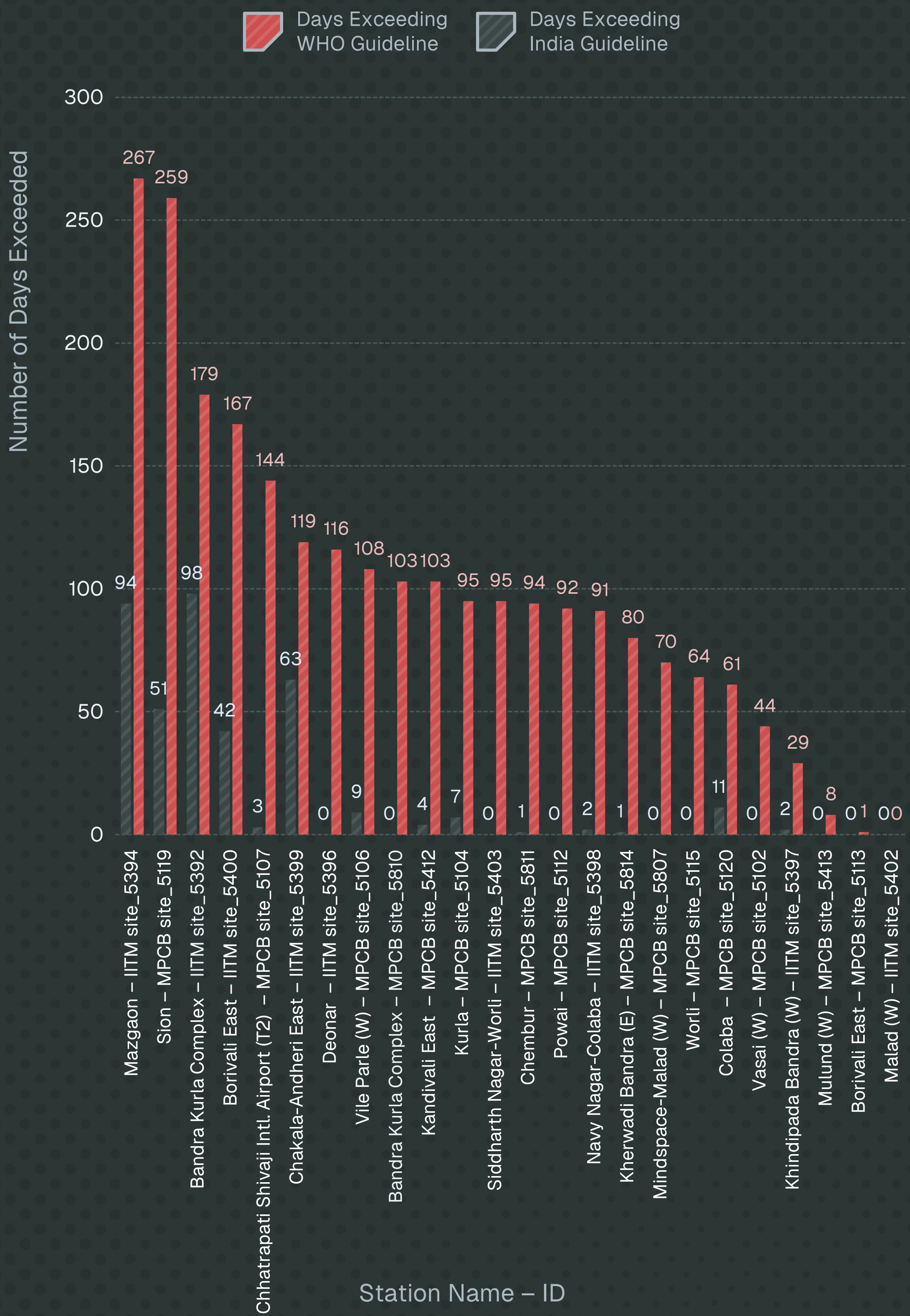


Figure 15. Number of days exceeding WHO guideline and NAAQS for daily average NO_2 concentration at CAAQM monitoring stations in Mumbai city.

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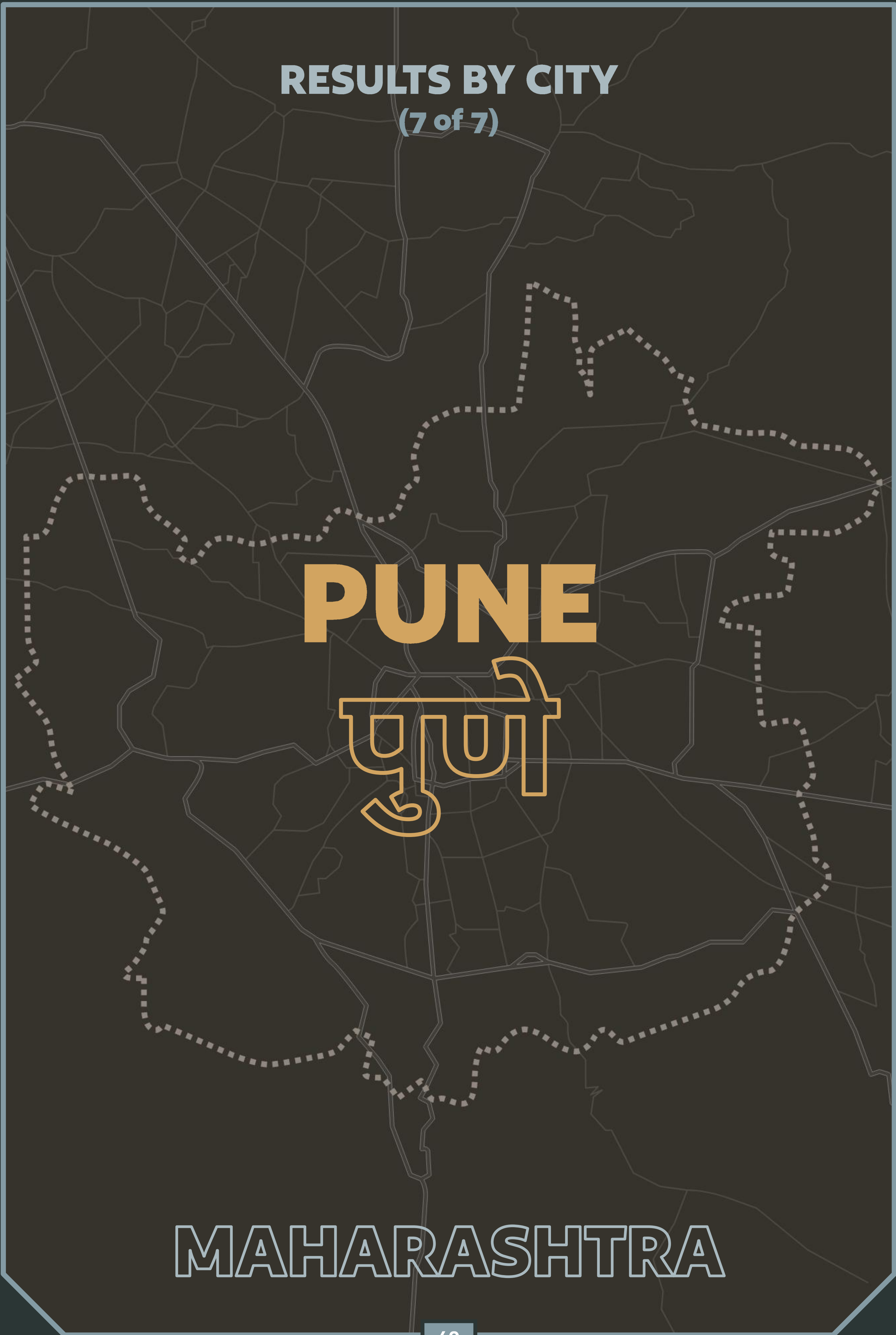

PUNE
पुणे

MAHARASHTRA

The city's 2023 annual average NO_2 concentration exceeded the WHO health based guideline at eight out of nine CAAQM monitoring stations. The station with the highest NO_2 annual average was Revenue Colony (IITM site_5409), which is also classified as a roadside station (Figure 16). Daily average NO_2 concentrations also breached the relevant WHO health based air quality guideline. Revenue Colony station measured NO_2 concentrations higher than both WHO and Indian National guideline over 80% of the year, recording over 300 days (Figure 17).

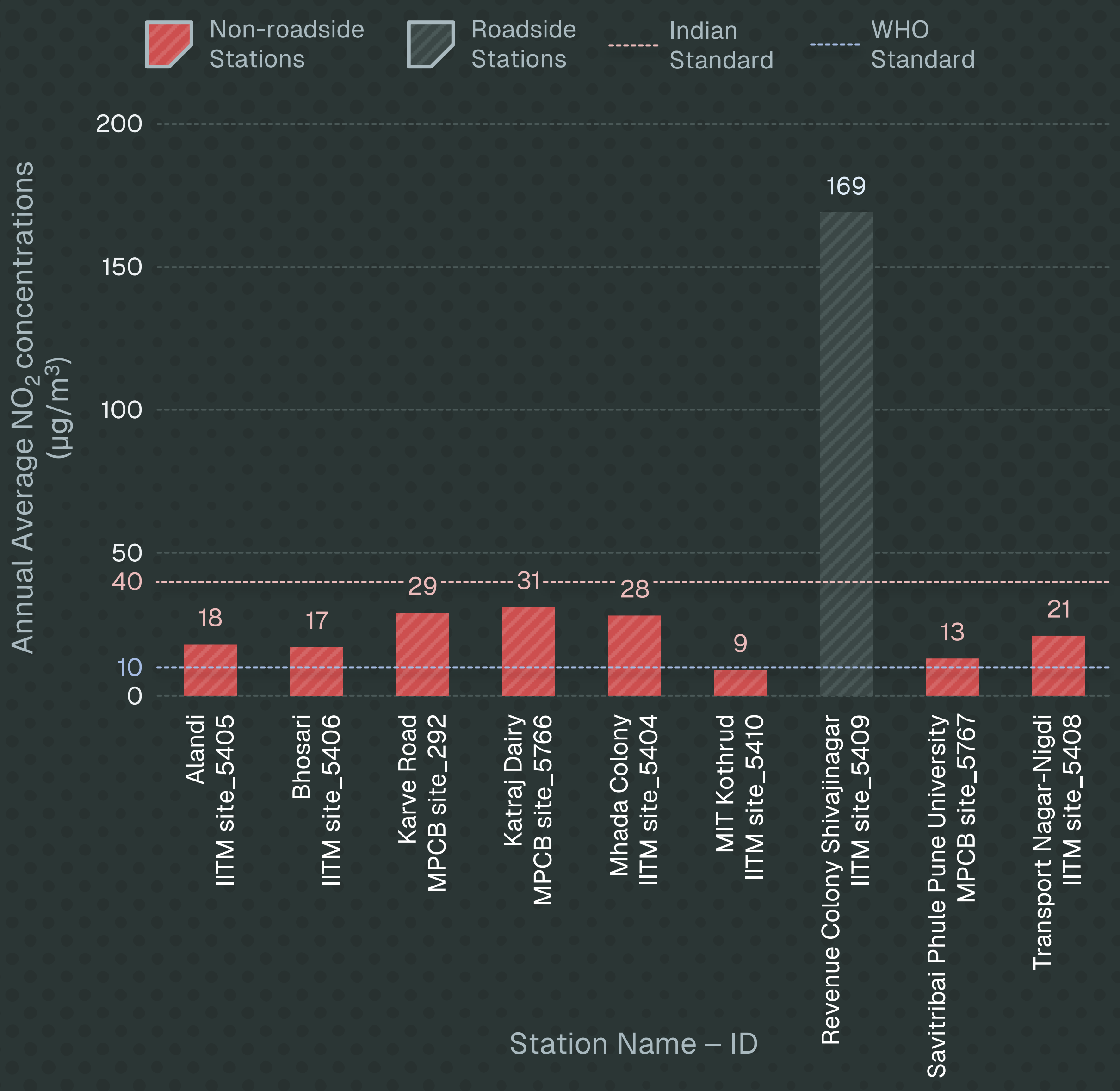

Figure 16. Annual average NO_2 concentrations for all CAAQM monitors in Pune, 2023. Roadside monitoring stations in grey.

Continuous exposure to unhealthy concentrations of NO_2 poses serious health risks, particularly to children, who make up 11% of the population. Achakulwisut et al. (2019) estimated that 1,570 cases of paediatric asthma could be attributed to NO_2 pollution in Pune in 2015.

The 5-year trend in NO_2 concentrations recorded by CAAQM monitors appears to be increasing (Appendix 3. Figure A3.2). We found that only two of the seven stations included in the trend analysis have a significant improving trend, and that two stations have significant worsening trends (Table 5, Appendix 3. Figure A3.9). Satellite observations of NO_2 in the atmosphere over Pune from 2019-2023 also suggest that NO2 pollution across the city as a whole is increasing (Appendix 4. Figure A4.1).

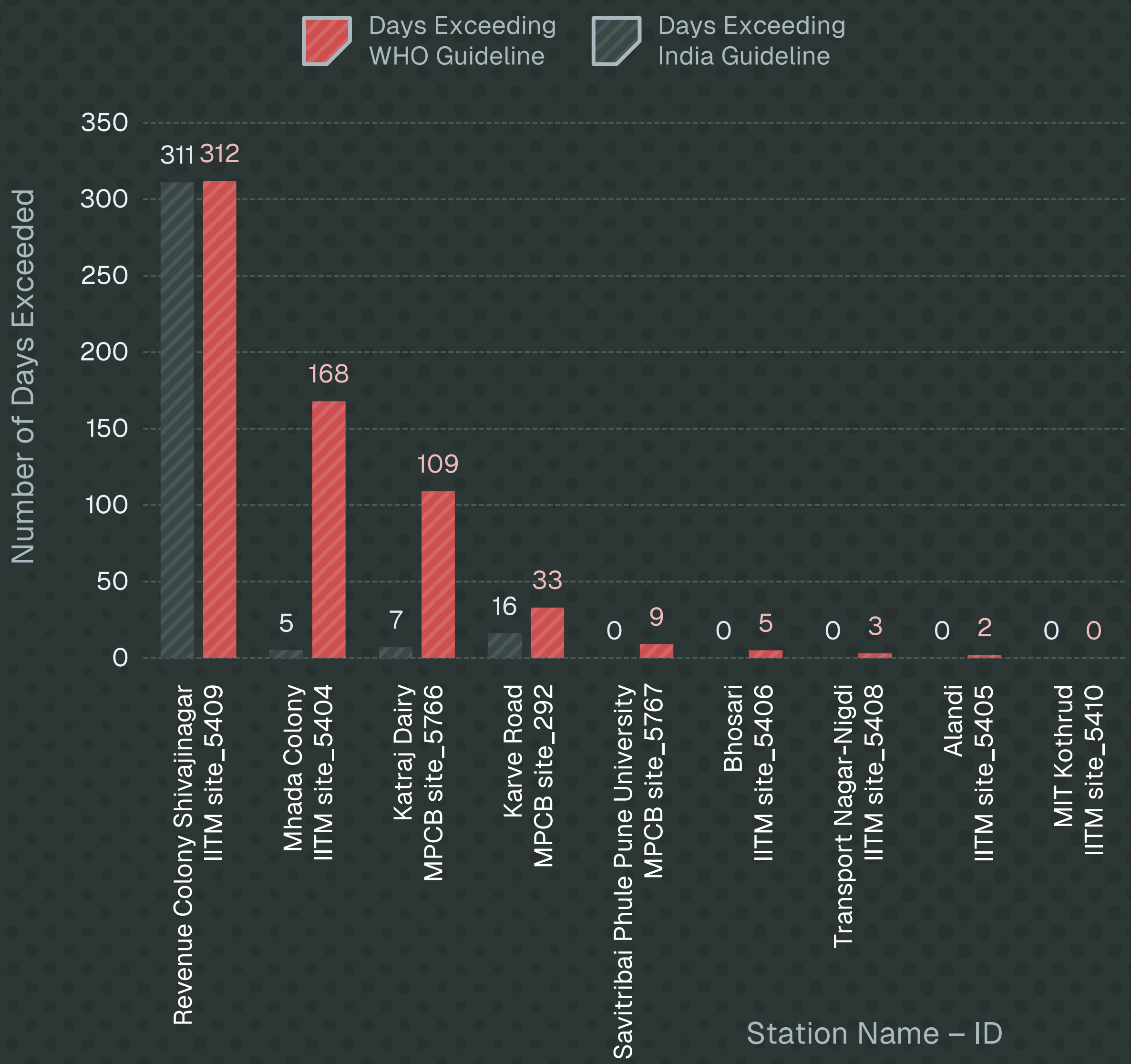

Figure 17. Number of days exceeding WHO guideline and NAAQS for daily average NO_2 concentration at CAAQM monitoring stations in Pune city.

Road transport is the third largest source of NO_x emissions in Pune, accounting for 9% of emissions in the EDGAR emission inventory (Appendix 2. Figure A2.1). The high level of road transport emissions could be linked to the low number of buses per lakh population at 26, which is significantly lower than the service level benchmark[4] of 60 set by the Ministry of Housing and

[4]According to MoHUA, Cities should have at least 60 buses per lakh population to achieve Level of service (LOS) 1.

Urban Affairs for urban transport. Pune also lags behind other Indian cities, such as Bengaluru, Delhi, Hyderabad, and Chennai (ITDP, 2022, Figure 18). This situation likely contributes to elevated NO_2 concentrations, as the increased reliance on private vehicles results in higher traffic congestion and emissions.

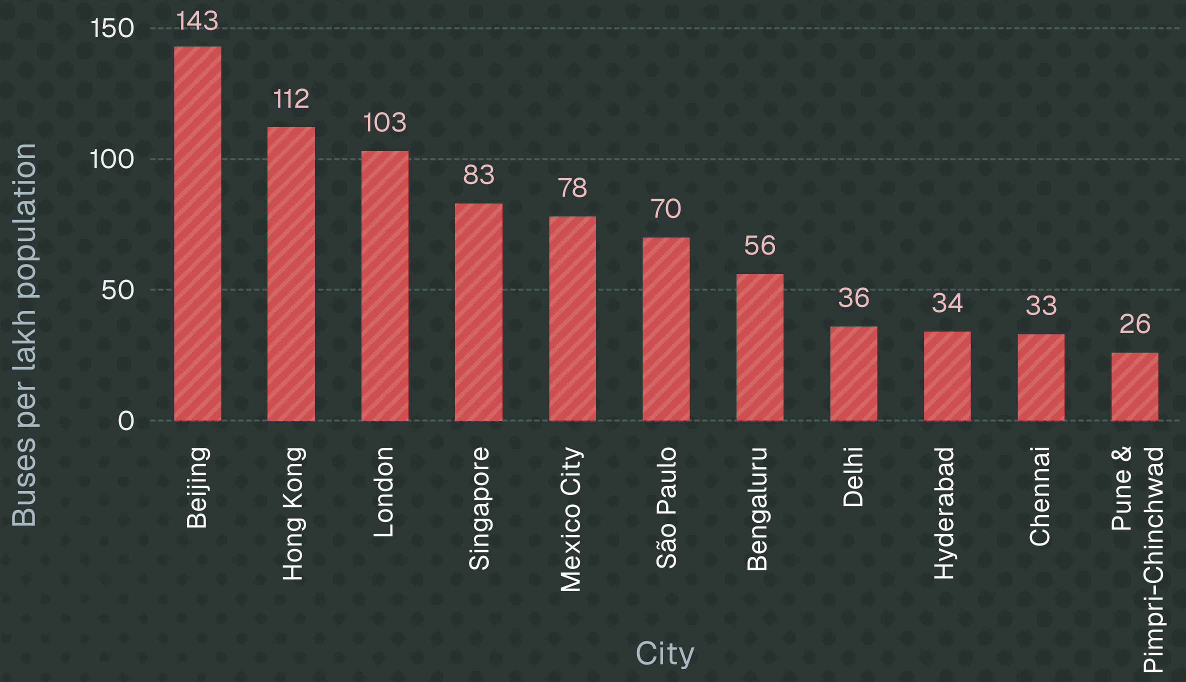

Figure 18. Buses Per Lakh Population 2021-2022 (Reproduced from ITDP, 2022).

"Pollution including NO_2 causes ill effects on health; last 27 years in my practice we have seen effects on foetus with preterm birth to congenital anomalies, severe infections in children to adults as bacteria become more resistant, cardiac problems, severe skin, eye, respiratory allergies to asthma, chronic respiratory diseases as COPD which is 2nd death causing disease in India.

Even pollution has effects as a factor in infertility, on neuropsychiatric disorders, stomach problems, hair loss and many more. We always along with medicines tell patients to do efforts to reduce NO2 in environment by effective measures."

DR. VIJAY WARAD
ALLERGY AND CLINICAL IMMUNOLOGY EXPERT
DR WARAD SAI ALLERGY ASTHMA EYE HOSPITAL PUNE

Representational Photo by Carlovenson (Edited)

"Pune city is grappling with a silent menace of air pollution. As someone who has experienced its effects first-hand, I can attest to the urgency of addressing this issue.

Nitrogen dioxide (NO_2), a toxic gas emitted primarily from vehicle exhaust permeates Pune's air. The polluted air irritates my respiratory system, exacerbating conditions like sinusitis and allergies. For me, there are tri--ggers like wheezing and shortness of breath, turning simple walks into battles for clean air. This results in frequent visits to my ENT specialist and too many medications.

Walking or riding the city streets, I wear a mask—a shield against airborne pollutants. But it's not just me; countless Punekars like me don masks daily. We navigate this everyday pollution with our lungs protesting. The mask becomes our ally, filtering out particulate matter and NO2, even as we yearn for fresher air."

VANDANA CHAUDHARY, PUNE

Conclusion and Recommendations

Poor air quality in India, particularly in major Indian cities, is a serious public health issue. This report investigated NO_2 in Bengaluru, Chennai, Hyderabad, Jaipur, Kolkata, Mumbai, and Pune. Data from India's official air monitoring programme (CAAQM), the European Commission Joint Research Council's Emission Database for Global Atmospheric Research (EDGARv8.1), and European Space Agency satellite observations reveal the extent of the problem.

It found that:

NO_2 air quality is not improving consistently in Indian cities. In many cases there is evidence of significant trends towards worse NO_2 air quality.

There are locations where NO_2 observations suggest improving air quality. Individual monitoring stations are often only representative of their immediate location, as cities change and develop some areas will experience worsening or improving air quality. It is not unexpected that stations within a city can have opposing trends. Satellite data which gives insight over wider areas suggest that NO_2 has a worsening trend over larger spatial areas.

Transport and energy are important emission sources of NO_2.

Literature reviewed during the study found evidence that investment in public transport is not matching the growth in polluting fossil fuel vehicles, while exposure to NO_2 air pollution seriously impacts public health especially for children.

Therefore Greenpeace India recommends that:

- **The Central Pollution Control Board (CPCB) must update the National Ambient Air Quality Standards to follow the World Health Organisation's (WHO) sequence of interim targets and health based guidelines.**

India must achieve the World Health Organisation's health based air quality guidelines. However, the different climates and pollution patterns of India's regions necessitate a tailored approach. Allowing for regional heterogeneity may help achieve the greatest possible health benefit in the shortest possible time. Ambitious revisions to the National Ambient Air Quality Standards are urgently needed; last revised in 2009, they are out of date. The World Health Organisation's interim targets for air quality provide a means for developing locally feasible routes toward improved air quality.

- **There must be a focus on improving health.**

Until clean air is achieved for all, millions of people will continue to live with health risks and health impacts. The existing health burden from air pollution should be addressed by:

1. Strengthening primary healthcare services' ability to diagnose and treat air pollution-related conditions.

2. Establishing and developing an easy-to-understand health advisory system, community education and timely alerts to the public during high pollution periods and offer guidance on protective measures.

3. Prioritising health interventions for at-risk groups, including children, the elderly, pregnant women, outdoor workers, and individuals with pre-existing conditions, by implementing customised programs such as school-based health screenings and educational campaigns aimed at raising awareness and offering essential support to mitigate the effects of air pollution.

- **Authorities must adopt a regional air-shed management strategy.**

A regional approach to air quality management should involve coordinated efforts across multiple cities and states within the same air shed, focusing on shared sources of pollution, cross-boundary impacts, and collaborative solutions. The management plan should map and analyse pollutant and emission hotspot areas to develop targeted action points for effective pollution control. By managing air quality collectively within defined regions, stakeholders can more effectively address the complex interplay of local and regional pollution sources, ensuring more comprehensive and impactful improvements in air quality.

- **Provision of public transport is improved.**

NO_2 is closely associated with traffic and fuel burning. Local governments should target vehicular emissions by supporting enhancing public transit, for example through schemes like those in Delhi and Bengaluru offering fare free travel for women. They should also promote renewable energy, improve waste management and urban planning, further regulate industrial emissions, and target reductions in biomass burning.

- **Investment is made in monitoring of NO_2, especially at roadside locations.**

Increased investment should be directed towards developing "hybrid" air quality monitoring networks that integrate low-cost sensors with existing systems and satellite data. Wider deployment of monitoring equipment could provide richer spatial data and help to identify locations with greatest exposure risk and the most vulnerable populations. In-depth data gathering and analysis will allow progress to be tracked and support more effective and targeted interventions.

LOCAL GOVERNMENTS SHOULD TARGET VEHICULAR EMISSIONS BY SUPPORTING ENHANCING PUBLIC TRANSIT

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TAP TO VIEW APPENDIX

Greenpeace India is an independent campaigning organization that acts to change attitudes and behaviour, to protect and conserve the environment and to promote peace.

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