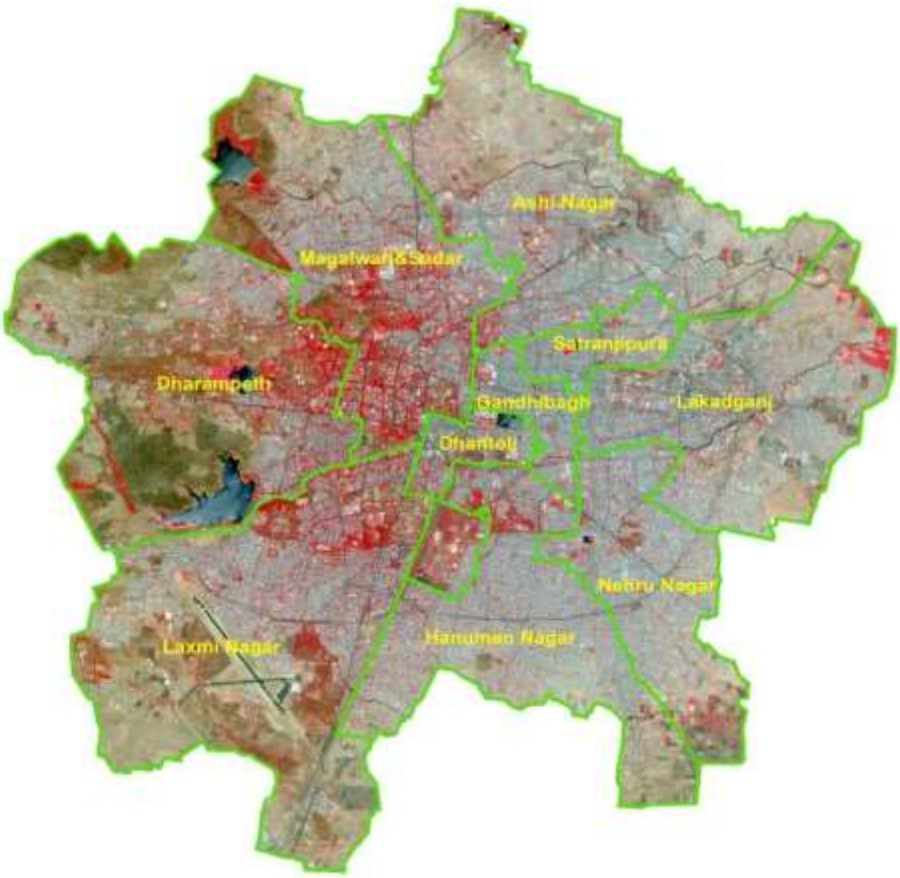

NAGPUR MUNICIPAL CORPORATION ESR (2023-2024)

ENVIRONMENT STATUS REPORT: NAGPUR CITY

CSIR- National Environmental Engineering Research Institute, Nagpur

Executive Summary
ESR 2023-24

1.1 Purpose of the ESR

- Understand the existing state of the environmental health in the city and interlink environmental issues with quality of life of the citizens
    - Pressure on the environment (e.g. discharge of industrial wastewater/ sewage, solid waste management)
    - Impact on population / ecosystem (pesticide contaminated foodstuff, drinking water quality, exposure to pests, loss of biodiversity)
- Provide information support for investment and management decisions for NMC. Be an important input into the annual budgeting and planning exercises of the NMC.
- Serve as a tool for citizens' use, serving as both an information / education resource, and as a way for tracking improvements.

The ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD) established in 1961 having a membership 38 countries, has developed key environmental indicators that can monitor the state of health of a city or target niche.

CSIR-NEERI has been entrusted by Nagpur Municipal Corporation to prepare the Environmental Status Report for the period of 2022-2027. The ESR for 2023-2024 focuses on the following environmental indicators:

- Chapter 1 : Ambient air quality
- Chapter 2 : Climate change
- Chapter 3 : Green open spaces of Nagpur city and biodiversity
- Chapter 4 : Noise environment
- Chapter 5 : Solid waste
- Chapter 6 : Water environment
- Chapter 7 : Socio-economic profile
- Chapter 8 : Recommendations

Each chapter is prepared to update the environment status and concerns using primary data collected by CSIR-NEERI and using secondary data (quoted and references provided) as well as references from literature available for drawing valuable conclusions.

Chapter 1: Ambient air quality

The chapter reports the study on ambient air quality of Nagpur in order to assess the air pollution characteristic of SO_2, NO_2, $PM_{2.5}$, PM_{10}, CO, Ozone, BTEX (Benzene, Toluene, Ethyl-benzene, Xylene) for the period April 2023-2024. This study has relied on two major sources of the data to assess the air quality in the city: (i) CPCB through CAAQMS located in four sites in Nagpur viz., Civil Lines, Ambazari, Mahal, and Ramnagar, (ii) MPCB for five locations, Civil Lines, Divisional Commissioner Office, North Ambazari Road, Sadar and Hingna in the city and at two locations, Kamptee and Wadi in the outskirts of the city. The air quality status of the city along with the major recommendations are provided to contain the air pollution in the city. CAAQMS station data indicated seasonal variation in different parameters with both PM10 and PM2.5 showing trend of lower concentration during monsoon months and higher concentrations during winter and post-monsoon. Similarly, ozone, SO_2, NO_2, concentrations were also lower than the CPCB standard while carbon monoxide, and BTEX were higher in winter and post-monsoon months. However, the average concentration of PM2.5, PM10 over the study period showed the exceedance to the prescribed standards by CPCB. Overall, analysis of air quality at manual monitoring sites showed that PM10 was the city's most concerning pollutant while, the issue of air pollution in terms of all remaining parameters during the study period were not very significant.

The study recommends control and managements policies targeting PM pollution mitigation. Maintenance of monitoring stations for providing consistent and reliable results, regular updating of gridded inventory with reference to initiation of new polluting activities, and closure of old ones, monitoring of dust emissions from roads and construction sites was recommended. The study also recommended implementing appropriate policies for reducing the pollution-induced by vehicular traffic halts, and strict action to stop open burning practises. The air-shed of the area needs to be identified to account for the emissions sources present in the area.

Chapter 2: Climate change

Climate change is one of the most complex problems faced by humanity in the 21st century. It is intricately linked with the socio-economic development of any region, making its resolution crucial for achieving the United Nations' Sustainable Development Goals. The concentration of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) has been rising due to anthropogenic activities since the advent of the industrial revolution. The impacts of climate change are long-term, as GHGs persist in the atmosphere for extended periods. Present GHG emissions will affect future generations, and even if GHG levels were to stabilize, the effects of anthropogenic forcing would continue for centuries. Furthermore, climate change is a global phenomenon; the Earth's atmosphere does not differentiate GHG emissions based on city, district, state, or country boundaries.

Nagpur, as a growing urban city, faces unique vulnerabilities. Understanding the impacts of climate change is crucial for cities like Nagpur to build resilience and ensure sustainable development. Comprehensive climate action plans are essential for mitigating risks and adapting to inevitable changes. This chapter summarizes the local climatic factors influencing Nagpur's future exposure to climate change impacts, focusing on temperature and precipitation. By implementing effective adaptation and mitigation strategies, Nagpur can enhance its resilience to climate change and ensure a sustainable future for its residents. Furthermore, local climatic factors influencing Nagpur's future exposure to climate change impacts have also been summarized. The climate data for Nagpur city for the last five decades was statistically analyzed to understand if any relationship existed between climate parameters and other variables exists. Further, temperature and rainfall-based indices were studied viz., extreme heat events, cooling degree days, heat index, precipitation concentration index, rainfall index, and their deviation from the mean (anomalies), trend and decadal changes were evaluated to understand the current impact of climate variability on the city's climate.

The study shows that, Nagpur city was at a critical juncture in its efforts to address climate change impacts and enhance its resilience. The observed trends in rising temperatures and erratic precipitation patterns underscore the need for immediate and sustained action. By implementing comprehensive climate action plans that incorporate urban greening, efficient water management, energy efficiency measures, and advanced adaptation and mitigation technologies, Nagpur can effectively combat the risks posed by climate change. The collective efforts of government, industry, and citizens will be essential in ensuring the city's sustainable and resilient future. Through proactive planning and the adoption of innovative solutions, Nagpur can serve as a model for other growing urban centers facing similar climate challenges.

Chapter 3: Green open spaces of Nagpur city and biodiversity

The chapter provides a comprehensive evaluation of Urban Green Spaces (UGS) in Nagpur city, by assessing the 3-30-300 rule for urban greenery. This rule recommends that every resident should see at least three trees from their home, have 30% tree canopy cover in their neighborhood, and live within 300 meters of a green space. The study divided the city into ten administrative zones and assessed how each zone fared against the three components of the rule. It involved surveying the citizens of Nagpur regarding the visibility, accessibility, distribution and benefits of UGS. GIS analysis was carried out to determine the tree canopy cover of each zones. The study underscores the need for Nagpur to enhance its urban greening efforts. While tree visibility and proximity to green spaces are relatively well-achieved, significant improvements are needed in tree canopy coverage. 79.61% of Nagpur residents could see three or more trees from their windows, with six out of ten city zones meeting this criterion. Only Dharampeth zone had a tree canopy cover exceeding 30%. The overall tree canopy for the city was 19.54%, which fell short of the target. Around 73.63% of residents lived within 300 meters of a green space, with three zones meeting this requirement. The results reveal that Nagpur needs to focus on scaling up its urban greenery efforts and bring new citizen-centric initiatives to increase the green cover as well as the benefits derived from them.

This study is one of the first assessments of UGS using the 3-30-300 rule in India offering a broader view of the benefits of urban greening by demonstrating how greenery may provide various ecosystem services that enhance the quality of the urban environment and human health. The specific objectives of 3-30-300 facilitate comparable studies across time, which will help in highlighting the areas which require actions and make it simpler for decision-makers to incorporate urban greening. This guideline can also significantly affect the urban planners because it is simple to follow and offers a defined framework, both of which are critical to enhancing the role of urban greening ultimately benefiting the city's environment and residents.

Chapter 4: Noise environment

Noise pollution is an increasing concern worldwide, particularly in urban areas. This chapter discusses the effect of noise pollution in Nagpur city, for which the key contributing elements include rapid population growth, traffic congestion and transportation (including road, rail, and air travel), industrial activities, construction work, and high noise emissions from social and cultural events. According to the World Health Organization (WHO), noise pollution is the third most hazardous environmental pollution problem after air and water pollution, causing severe health impacts, such as sleep disturbances, elevated stress levels, hearing loss, and a higher risk of cardiovascular diseases.

For this study, crowdsourcing approach was applied to collect noise data for Nagpur city through the CSIR-NEERI mobile app "Noise Tracker". This innovative approach harnesses the collective efforts of a large group of people, often through digital platforms, to gather information or insights providing the advantages of scalability, cost-effectiveness, and the ability to collect real-time data from diverse geographic areas, including hard-to-reach or under-represented regions. A comparative analysis of noise levels was performed across several locations in Nagpur city by evaluating noise levels in three types of areas: silent zones, residential areas, and commercial zones from 6:00 AM to

8:00 PM and 8:00 PM to 10:00 PM. Volunteers collected atleast 300 seconds data each for each location, and the average of these readings was used to assess noise pollution which was compared to the permissible limits of the Central Pollution Control Board (CPCB), Delhi.

The findings from this study emphasize the widespread nature of noise pollution in Nagpur city, with silence zones, residential areas, and commercial zones all exhibiting significant non-compliance with the CPCB noise standards. Noise levels consistently exceeded the permissible limits throughout the day and night with 100% non-compliance in silence zones of Dharampeth, Gandhibagh and Lakadganj during both the periods. The study has observed variable levels of non-compliance residential zones such as 100% non-compliance during the daytime and 81.8% non-compliance during the night in Hanuman Nagar, 66.7% & 83.3% non-compliance during day and night respectively in Nehru Nagar, 100% non-compliance during both periods in Lakadganj. Commercial zones generally showed better compliance than silence and residential zones, particularly during the day which improved further during night time.

The high levels of non-compliance across multiple zones suggest that existing noise control policies may not be effectively implemented. These results highlight the need for immediate action to curb noise pollution through stricter enforcement of regulations, better planning of urban spaces, and the adoption of noise-reduction technologies. To address this, local authorities must prioritize the development of a comprehensive noise management strategy that includes better monitoring, stricter enforcement of noise laws, and public awareness campaigns. Noise control measures, such as sound barriers, zoning regulations, and the restriction of noise-producing activities in sensitive areas, could help reduce noise levels in key areas of the city.

Chapter 5: Solid waste

In this chapter, the issues related to solid waste management in Nagpur city are discussed with recommendation for its effective management. Greater waste production on account of expansion of such urban centers has led to complications of managing this growing waste in an efficient and sustainable manner. Solid Waste in Nagpur City includes household waste from residential areas, hotels, restaurants, lawns, etc., as well as construction and demolition materials, sanitation residue, and waste from streets, hospitals, slaughterhouses, market areas, etc. primarily from the residential and commercial complexes. The trend in solid waste generation has shown an increasing trend from 2019 to 2023, after which it showed stabilization during 2023-2024 and categorization of this w3aste indicated that the predominant fraction comprised organic or biodegradable waste (~63%) followed by notable quantities of textiles, plastics, sanitary waste, paper and cardboard, and general rejects.

The inadequacies in waste management system with reference to collection, insufficient processing, and disposal facilities results in open garbage dumping. Recognizing these challenges, NMC has appointed AG Enviro and BVG India for daily door-to-door garbage collection from zones 1 to 5 and zones 6 to 10 respectively, which is transported to Bhandewadi dumping yard for disposal. Efforts by NMC for sustainable disposal of the collected waste in 2023-2024 include composting plant and vermicomposting facility, biomethanation plant for biodegradable waste, biomining of legacy waste, biomedical waste treatment, E-waste (involvement of MPCB authorized dismantler-Suritex Ltd.). The study also highlighted the ole of informal sector comprising of waste-pickers in material recovery and source segregation resulting in reduced volume of waste reaching the dumpsites. Building on the commendable steps taken by NMC in improving solid waste management in Nagpur city, the study recommended following initiatives for greater effectiveness and long-term sustainability- enhanced source segregation, community participation, modernize collection infrastructure, strengthen monitoring systems, promote decentralized composting, digital waste management tools etc.

Chapter 6: Water environment

The chapter on water environment discusses the current status of surface water bodies (rivers and lakes) and groundwater with reference to its water quality. The chapter presents the analysis of water samples from three rivers (Nag, Pilli, and Pora) and ten lakes (Sonegaon, Futala, Gorewada, Ambazari, Binaki, Naik, Sakkardara, Pandharabodi, Gandhisagar Lake and Police Line Takli) in addition to twelve ground water source (dugwells and borewells). The samples have been characterized for their physico-chemical composition and bacterial load of coliforms along with the aquatic biological parameters (phytoplanktons and zooplanktons). The chapter highlights the role of lakes on storage of water that helps to maintain ground water table. The study found substantial decline in concentration of major parameters in water samples from all lakes viz., total alkalinity- 57-62% lower, total hardness- 23% lower, sulphates & nitrates- 70-75% lower, lower nutrients such as COD, phosphate-P, sodium, and potassium. The reduction in these parameters could be attributed to difference in the sampling time period for this report (2023-2024) which was performed during the monsoon before the festive season in comparison to previous year (2022-2023) which was performed at the end of monsoon and after the festive season. Also, majority of the lakes were having complete restriction on entry as boundary walls were being constructed for prohibiting anthropogenic activities inside the lake premises. Similarly, decrease in pollution was seen for COD, and nutrient load over that of the previous year, though increase in their concentration was noted as the rivers flowed through the city which suggested that the water from three rivers Nag, Pilli and Pora was unsuitable for drinking, outdoor bathing, irrigation. The study recommended the discouraging of anthropogenic activities on the banks of rivers and lakes such as disposal of garbage- old and torn cloths, eatables, worship material used in festivals etc., preventing defecation, from contaminating the water bodies. Additionally, dumping of waste by local vendors of fruits-vegetables, meat and other products, wandering of stray animals in the river or disposal of dead animals along the river bank, flow of drains carrying untreated and uncategorized waste from the city's commercial and industrial areas needed to be prevented. Variations were noted in different parameters analyzed for 12 groundwater samples with reference to the permissible limits in BIS standards viz., TDS (all below limit), total alkalinity (all except one above limit), Mg (all below limit), total hardness (all except two above limit), Pb (all except three below limit), while remaining parameters were within desirable limits of BIS 10500:2012. The overall quality of groundwater samples was observed to be good in terms of physio-chemical characteristics but was found to be contaminated with coliforms and requires disinfection before consumption. Since the hydrogeological analysis of Nagpur city indicated a lot of variation in groundwater level a long-term monitoring was recommended for establishing the groundwater level trend and accordingly implementing the rain water harvesting programme.

Chapter 7: Socio-economic profile

The chapter on socio-economic profile describes the issues affecting Nagpur city, specifically with respect to rising population and urbanization, such as profile of notified and non-notified slums, and initiatives for their improvement through schemes focussing on providing new dwelling units to slum dwellers, in addition to development of basic infrastructure in existing slum settlements like water supply, roads, street lighting, drainage, sewer line etc. It further describes the pillars which support the economy of Nagpur such as trade and commerce, transportation, education, and the human development index.

Chapter 8: Recommendations

In this chapter, the overall recommendations related to the different environmental aspects discussed in the various chapters, are highlighted.

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Chapter 1

Ambient Air Quality

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Ambient Air Quality

1.0 Introduction

A study on ambient air quality of Nagpur is carried out to assess the status of the air environment. The study to assess the air pollution characteristics of the city can be carried out through monitoring the air quality using various methods such as; manual monitoring through air quality samplers, continuous ambient air quality monitoring (CAAQMS) and sensor-based monitoring. Recently drone-based monitoring in vertical direction has also been initiated. Each approach may have a different outcome in terms of pollution levels over time and space. This study has relied on two major sources of the data to assess the air quality in the city: Air Quality Status through 1) manual monitoring and 2) through continuous ambient air quality monitoring system. The air quality status of the city along with the major Recommendations are provided to contain the air pollution in the city.

1.1 Methodology

Ambient air quality status is analyzed by using the secondary data obtained from Central and State Pollution Control Board. CAAQMS are located in four sites in Nagpur. The CPCB web site displays data for Civil Lines, Ambazari, Mahal and Ramnagar, which is analyzed and presented. MPCB provides the data on ambient air quality of SO_2, NO_2 and PM10 at five locations, Civil Lines, Divisional Commissioner Office, North Ambazari Road, Sadar and Hingna in the city and at two locations, Kamptee and Wadi in the outskirts of the city. The data is temporally irregular and provides 104 measurements in a year. This data is also analyzed and presented. Manual air quality monitoring can be possible at a limited number of locations, therefore monitored values cannot be used to identify hot spot. Vertical profile of air quality parameters is determined using drone, however, this is only an additional information on air quality that is beneficial to the residents of high-rise buildings. There is no management plan, which needs information on vertical profile of air quality. CPCB through its PRANA portal (https://prana.cpcb.gov.in/#/air-quality-data) provides the information on air quality in various cities under the National Clean Air Programme. The AQI repository and air quality data can be obtained via the Automatic Monitoring Data. It links the user to the website of CPCB (https://airquality.cpcb.gov.in/ccr/#/caaqm-dashboard-all/caaqm-landing), which has CAAQMS data.

1.2 Ambient Air Quality (AAQ) Status

To assess the ambient air quality (AAQ) of Nagpur city, the State Air Quality Monitoring Programme (SAMP) run by Maharashtra Pollution Control Board (MPCB) and the National Air Quality Monitoring Programme (NAMP) run by the Central Pollution Control Board (CPCB) are the two air quality monitoring networks that provide the ambient air quality data. MPCB conducts ambient air quality monitoring at five locations, namely at Civil Lines, Divisional Commissioner Office, Sadar, Hingna and North Ambazari Road, across the city and two locations in the outskirts of the city, namely in Kamptee and Wadi. All the locations have manual monitoring setup. The manual monitoring is carried out for three pollutants namely particulate matter (PM10), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) at each of the manual stations. The frequency of monitoring is 24 hours and twice a week. CPCB provides the hourly frequency data at CAAQMS for the pollutants namely PM10, SO_2, NO_2, PM2.5, ground-level ozone (O_3), nitric oxide (NO), carbon mono-oxide (CO), ammonia (NH_3), benzene, toluene, ethyl-benzene, xylene (also called as BTEX) along with the meteorological parameters such as temperature, wind speed, wind direction and relative humidity. In addition to the CAAQMS at Civil lines, three stations at Ramnagar, Mahal and Ambazari in Nagpur are recently added in the monitoring network of CAAQMS. This data can be obtained from CPCB which provides it in the public domain through its website (www.cpcb.nic.in). The ambient air quality data from April 2023 to March 2024 were extracted from MPCB and CPCB websites to carry out ambient air quality assessment.

1.2.1 AAQ Data Analysis: Manual Stations (MPCB Data)

Air quality assessment is carried out for SO_2, NO_2 and PM10 concentrations at MPCB-operated stations under SAMP. CPCB guideline values for all the air pollutants are given in **Table 1.1**. The SO_2, NO_2 and PM10 concentrations during April 2023-March 2024 are plotted in **Figure 1.1a-c**. The 24h guideline value is shown in the graph for comparison purpose. It can be seen that SO_2 and NO2 are well below the regulatory limit of 80 µg/m3. NO2 concentration is observed to be near to the threshold of 80 µg/m3 at few instances during December and January. PM10 concentration has frequently exceeded its regulatory limit of 100 µg/m3 at many instances at all the locations during winter. The % exceedance rate for PM10 concentration is observed to be 67.5%, 5.9% and 17.6% at Civil Lines and 77.8%, 29.2% and 91.1% at Divisional Commissioner Office in Winter, Summer and Post-monsoon, respectively. At other locations, % exceedance rate is observed to be 15-92.3% for all the seasons.

Ambient air quality at two locations in the outskirts of the city are plotted in **Figure 1.1d-f**. As can be seen, SO_2 and NO_2 concentrations are well below the CPCB standard of 80 µg/m3 at two locations, namely, Wadi and Kamptee, located in the outskirts of the city. NO_2 concentration exceeded the CPCB standard at two instances.at Kamptee. PM10 exceeds the CPCB threshold of 100 µg/m3 at many occasions at the two locations.

Spatial analysis during April 2023-March 2024 is carried out to assess the relative concentration of PM10 at various locations. The two locations in the outskirts of the city are also included in the plot for comparison purpose. **Figure 1.2** suggests that SO2 concentration is higher at Divisional Commissioner Office followed by Sadar, NO2 concentration is higher at Hingna Road and Sadar followed by North Ambazari Road, whereas PM10 concentration is higher at Hingna Road followed by North Ambazari Road. PM10 at Wadi is less than the other locations and the annual average value is close to the threshold of 60 µg/m3. At the other locations, however, PM10 exceeds the CPCB threshold.

Further to evaluate the change in air quality, PM10 observed during 2017-2023 at the manual monitoring stations operated by MPCB is plotted in **Figure 1.3**. Since PM10 is a significant pollutant in the city, only that is taken into account. The raw data collected during January-December is used to calculate the city average and standard deviation. **Figure 1.3** suggests that air quality in terms of PM10 has witnessed increase from 2017 till 2019 before a subsequent decline till 2021. Nonetheless, PM10 exceeds the 60 µg/m3 annual average CPCB guideline value in every year.

Table 1.1: National Ambient Air Quality Standards (NAAQS, 2009)

No.	Pollutants	Time Weighted Average	Concentration in Ambient Air	
			Industrial, Residential, Rural and other Areas	**Ecologically Sensitive Area**
1.	Sulphur Dioxide (SO_2), µg/m^3	Annual *	50	20
		24 hours	80	80
2.	Nitrogen Dioxide (NO_2), µg/m^3	Annual *	40	30
		24 hours	80	80
3.	Particulate Matter, (PM_{10}), µg/m^3	Annual *	60	60
		24 hours	100	100
4.	Particulate Matter, ($PM_{2.5}$), µg/m^3	Annual *	40	40
		24 Hours	60	60
5.	Ozone (O_3), µg/m^3	8 hours	100	100
		1 hour	180	180
6.	Lead (Pb), µg/m^3	Annual *	0.50	0.50
		24 hours	1.0	1.0
7.	Carbon Monoxide (CO)	8 hours	02	02

	mg/m^3	1 hour	04	04
8.	Ammonia (NH_3), $\mu g/m^3$	Annual *	100	100
		24 hours	400	400
9.	Benzene (C6H6), $\mu g/m^3$	Annual *	5	5
			1	1
10.	Benzo (α) Pyrene ng/m^3	Annual *	01	01
11.	Arsenic (As), ng/m^3	Annual *	06	06
12.	Nickel (Ni), ng/m^3	Annual *	20	20

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.
four stations;

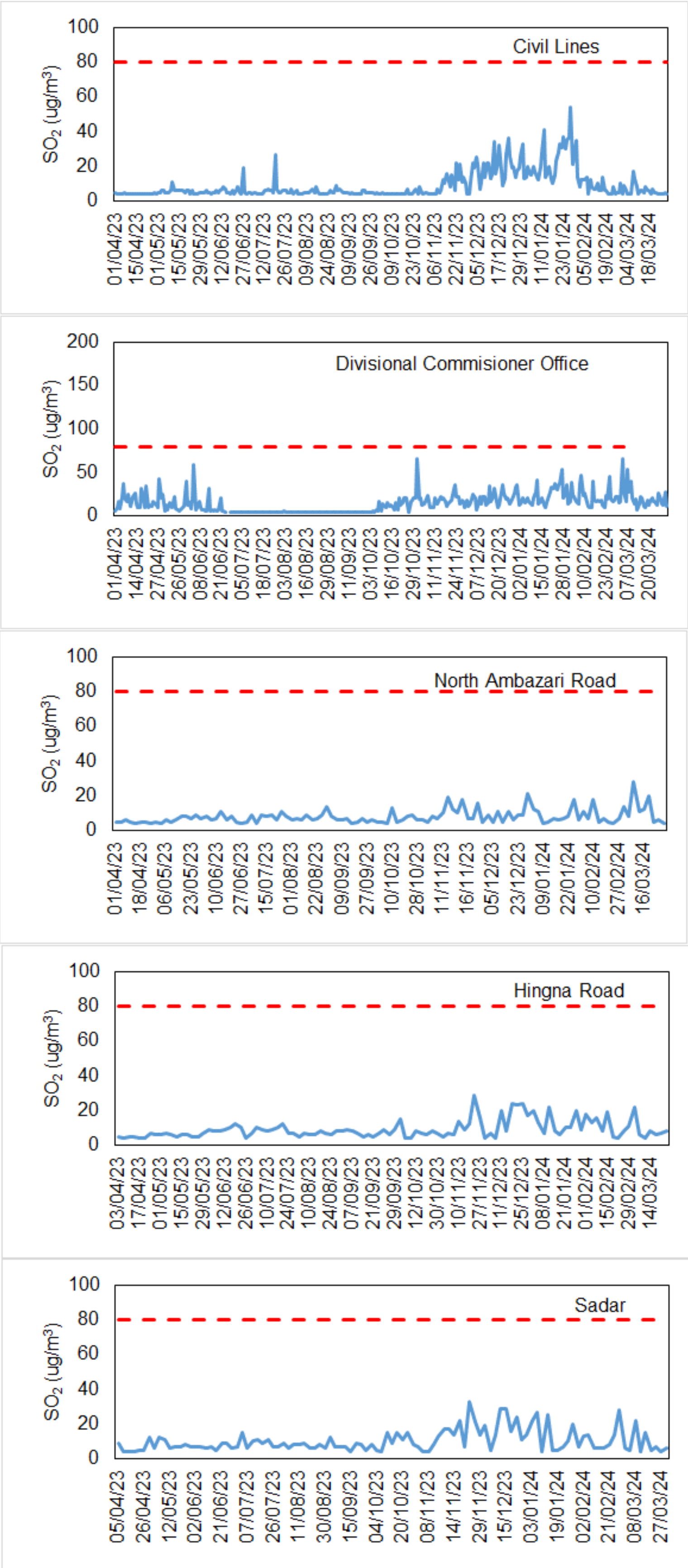

Figure 1.1a: SO_2 concentration at various locations in Nagpur (Source: MPCB). The dashed red line depicts the CPCB guideline value

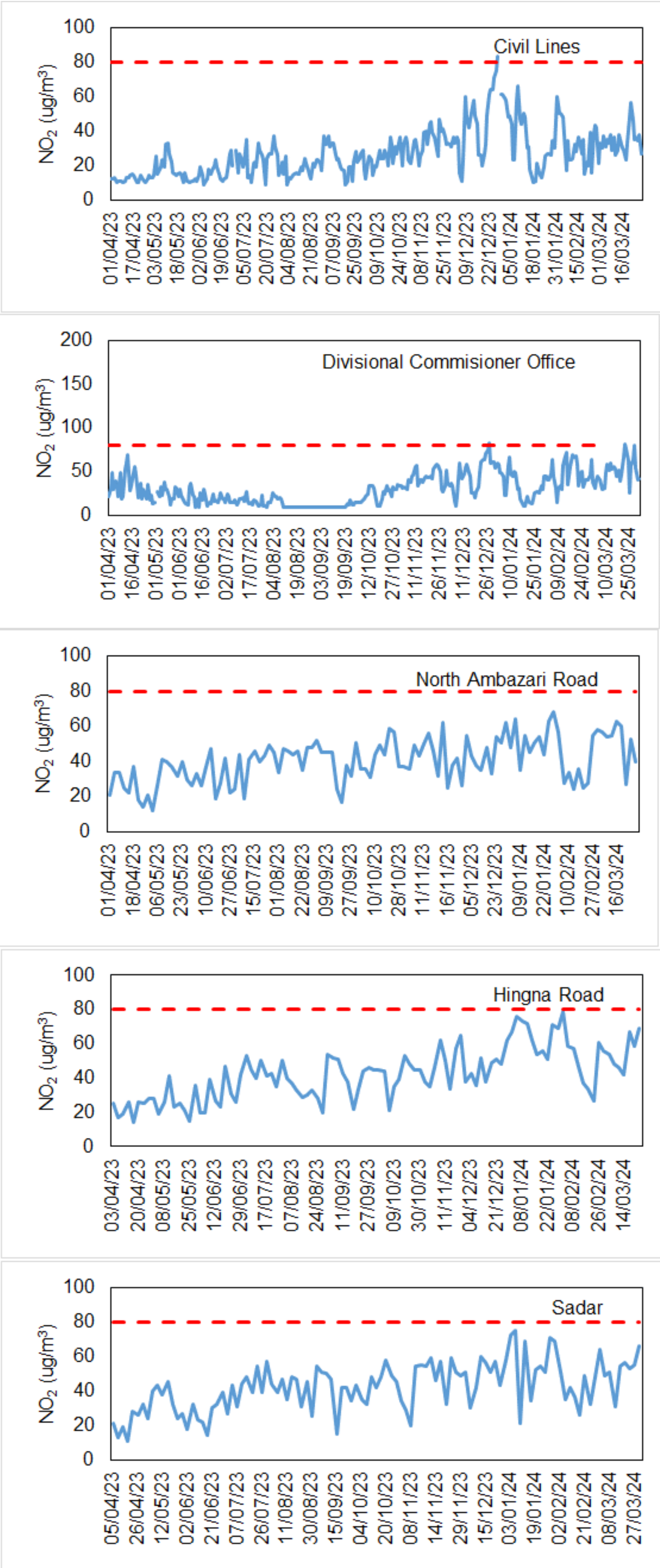

Figure 1.1b: NO_2 concentration at various locations in Nagpur (Source: MPCB). The dashed red line depicts the CPCB guideline value

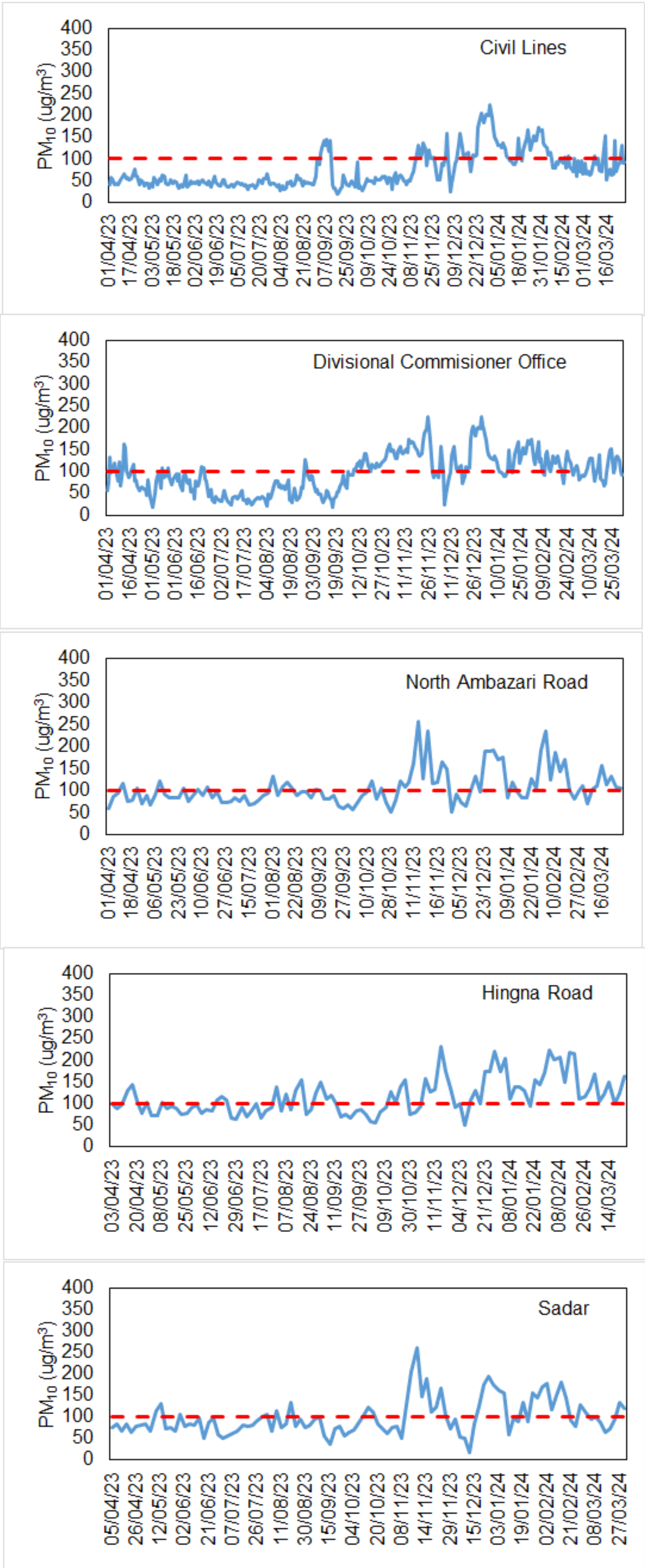

Figure 1.1c: PM10 concentration at various locations in Nagpur (Source: MPCB). The dashed red line depicts the CPCB guideline value

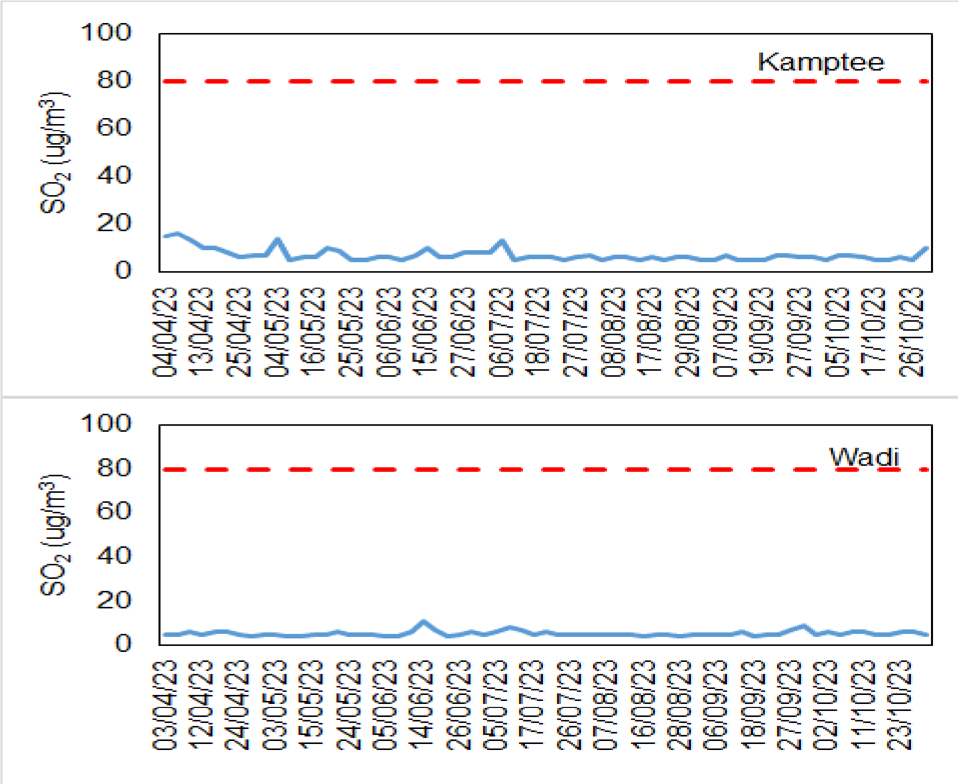

Figure 1.1d: SO_2 concentration in the outskirts of Nagpur (Source: MPCB)
The dashed red line depicts the CPCB guideline value

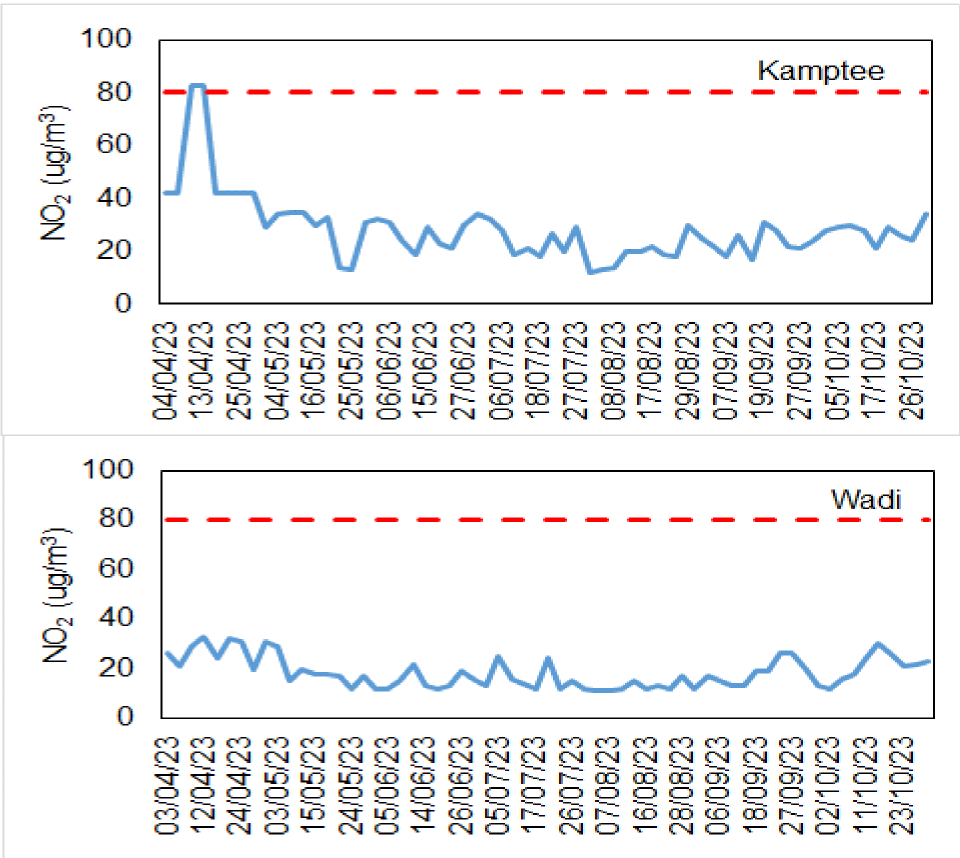

Figure 1.1e: NO_2 concentration in the outskirts of Nagpur (Source: MPCB).
The dashed red line depicts the CPCB guideline value

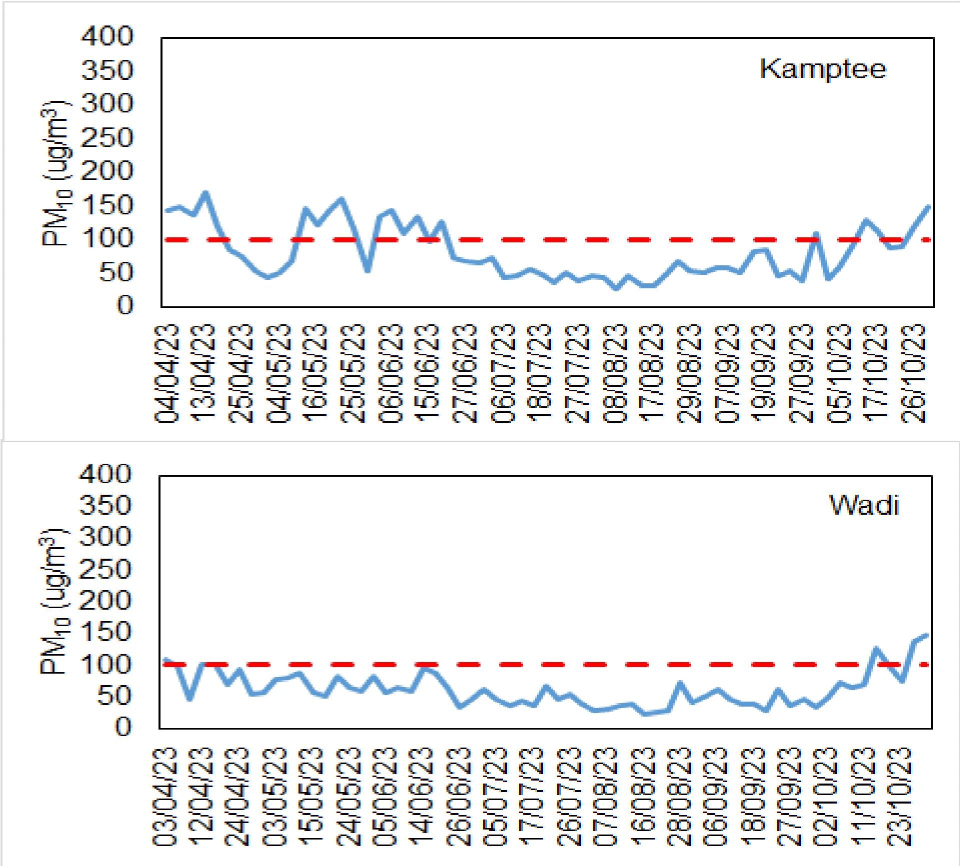

Figure 1.1f: PM$_{10}$ concentration in the outskirts of Nagpur (Source: MPCB). The dashed red line depicts the CPCB guideline value

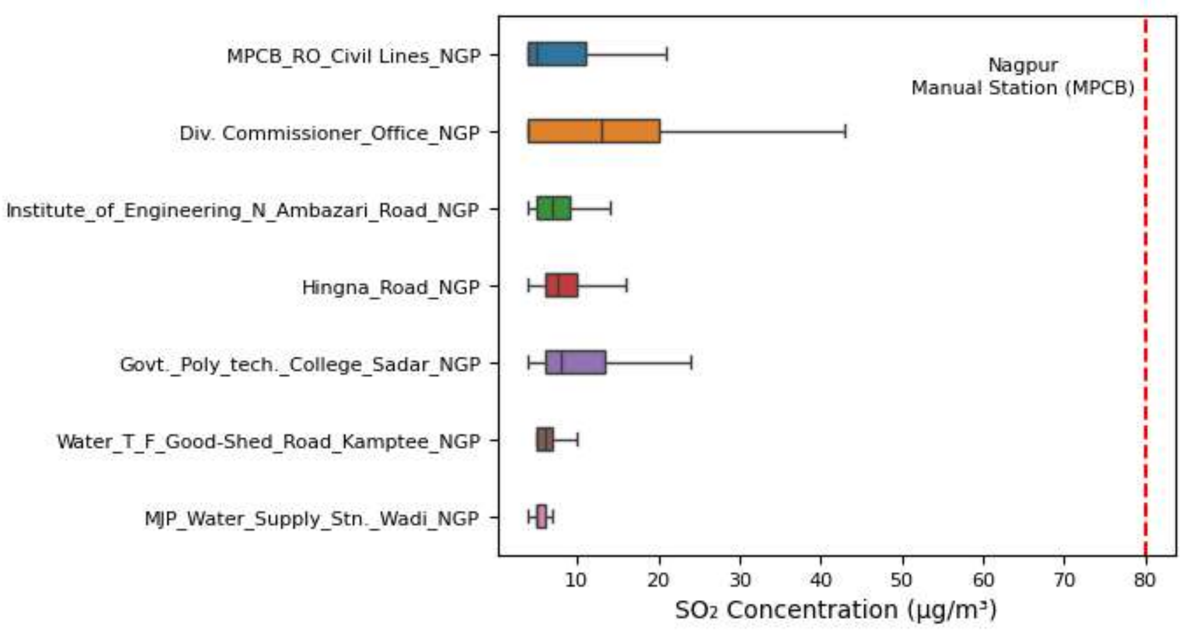

Figure 1.2 (a): Spatial analysis of SO$_2$ during April 2023 – March 2024 (Source: MPCB)

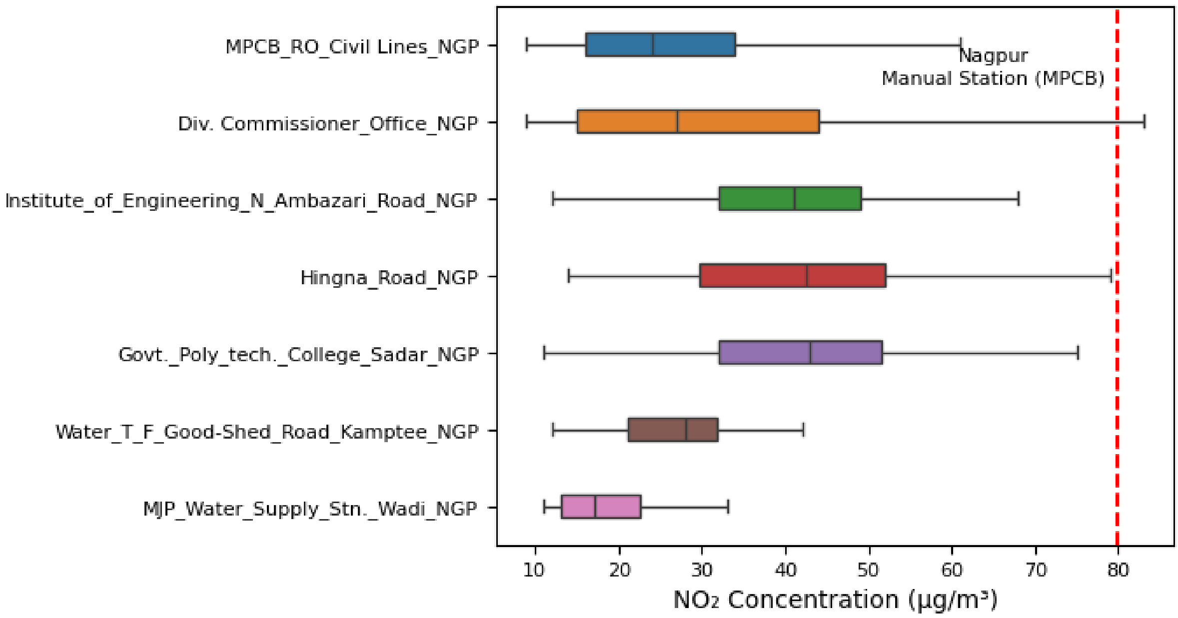

Figure 1.2 (b): Spatial analysis of NO_2 during April 2023 – March 2024 (Source: MPCB)

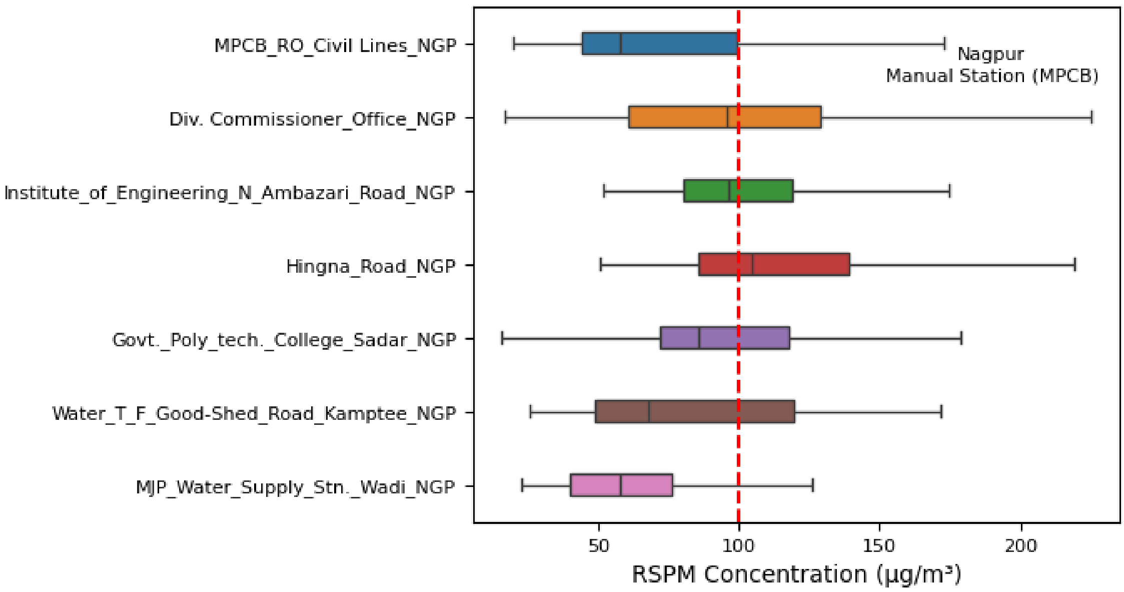

Figure 1.2 (c): Spatial analysis of PM_{10} during April 2023 – March 2024 (Source: MPCB)

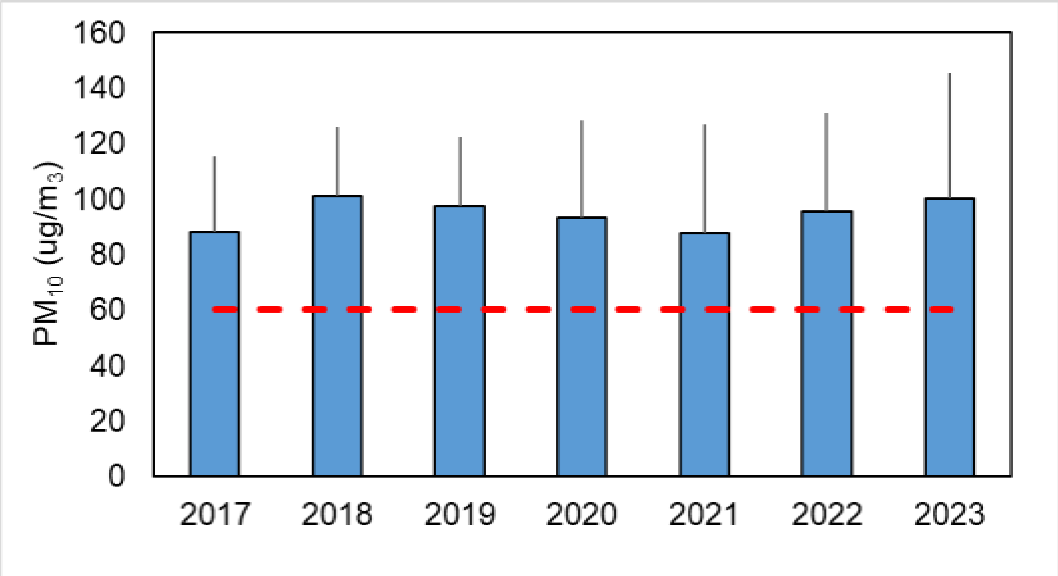

Figure 1.3: Time series analysis of PM_{10} concentration during 2017 – 2023 (Source: MPCB)

1.2.2 Air Quality Index

Based on the MPCB data, air quality index (AQI) is calculated as devised by CPCB. The various categories of AQI are given as below:

Table 1.2: Various categories of air quality index as devised by CPCB

AQI	Quality classification	Remarks	Colour code
0-50	Minimal Impact	Good	
51-100	Minor breathing discomfort to sensitive people	Satisfactory	
101-200	Breathing discomfort to the people with lung, heart disease, children and older adults	Moderate	
201-300	Breathing discomfort to people on prolonged exposure	Poor	
301-400	Respiratory illness to the people on prolonged exposure	Very Poor	
>401	Respiratory effects even on healthy people	Severe	

(Source: http://app.cpcbccr.com/ccr_docs/About_AQI.pdf)

The variation of AQI computed using PM_{10}, SO_2 and NO_2 over different manual monitoring stations is given in **Figure 1.4**. It can be seen that AQI is satisfactory at Civil Lines and in Moderate category at all the other locations.

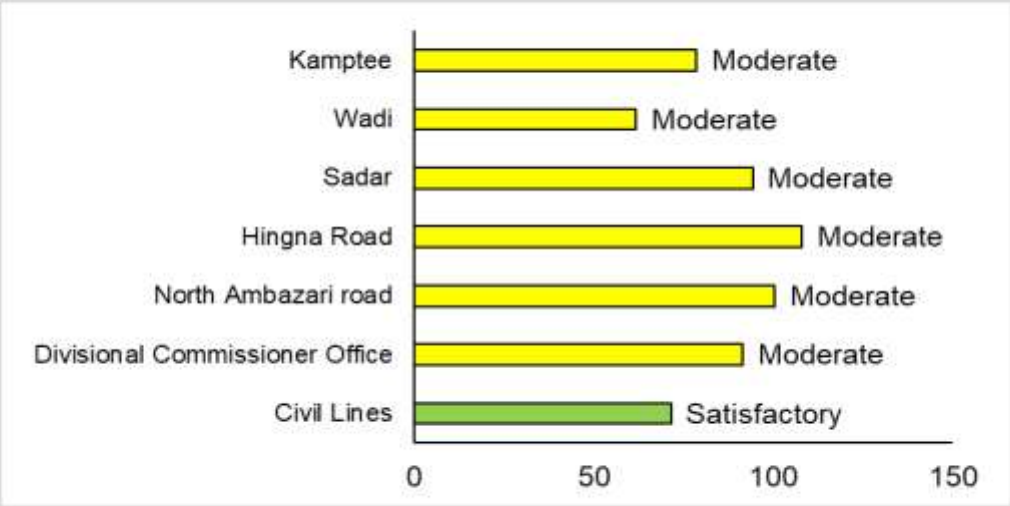

Figure 1.4: AQI observed at various locations (Source: MPCB)

1.2.3 AAQ Data Analysis: CAAQMS Station (CPCB Data)

Ambient air quality at CAAQMS station, available through CPCB, is analyzed for the data during April 2023-March 2024. CPCB provides continuous AAQ data since 2017 for Civil lines. Recently, CPCB has initiated CAAQMS monitoring at three more stations, namely, Ambazari, Ram Nagar and Mahal. The AAQ data is analyzed for four stations. The air pollutants such as SO_2, NO_2, PM2.5, PM10, CO, Ozone, BTEX (Benzene, Toluene, Ethyl-benzene, Xylene) are monitored at four stations along with the meteorological parameters. The status of AAQ in terms of PM2.5, PM10, NO_2, CO, Ozone and BTEX compounds is given in **Figure 1.5a-d** in terms of monthly plot during April 2023-March 2024.

As can be seen, there are lot of missing values at newly added monitoring stations. In all, PM10 concentration is lower during monsoon months and higher during winter and post-monsoon (**Figure 1.5a-d**), which is as anticipated. Monthly average NO_2 and Ozone concentrations are observed to be lower than the CPCB standard of 80 and 180 µg/m3, respectively (**Figure 1.5a-d**). NO_2 concentration is observed to be highest in winter and post-monsoon months. The characteristics cycle of ozone with high concentration associated with the period of high temperature and solar insolation, however could not be seen due to missing data in summer months at most of the locations. SO_2 concentration is substantially lower than the CPCB standard (**Figure 1.5a-d**). CO concentration (**Figure. 1.5a-d**) is observed to be highest in winter. The monthly variations in BTEX (Figure. 1.5a-d) shows that BTEX compounds are higher in winter and Post-monsoon months. The average concentration over the study period (2023-2024) is given in **Table 1.3**, which shows the exceedance of PM2.5 and PM10, to the prescribed standards by CPCB.

Table 1.3: Average air pollutant concentrations at CAAQMS (Source: CPCB)

Parameter	Unit	Civil Lines	Ambazari	Ramnagar	Mahal
PM2.5	$\mu g/m^3$	50.9	51.1	47.0	52.6
PM10	$\mu g/m^3$	96.0	95.6	101.1	114.2
NO_2	$\mu g/m^3$	32.8	28.1	21.5	22.2
SO_2	$\mu g/m^3$	13.2	17.9	15.9	32.2
CO	mg/m^3	0.9	0.7	0.6	1.3
Ozone	$\mu g/m^3$	26.8	38.1	28.5	35.6
Benzene	$\mu g/m^3$	5.2	4.6	2.0	5.0
Toluene	$\mu g/m^3$	13.2	26.5	9.9	24.5
Ethyl-Benzene	$\mu g/m^3$	3.4	6.0	2.1	3.7
Xylene	$\mu g/m^3$	8.5	11.3	5.0	13.8

Hourly variations in criteria pollutants depicted in **Figure 1.6** show that PM10 and PM2.5 are higher during night hours and start declining in the mid-night from 1 AM until morning 7 AM and again increase afterwards until 11 AM. The decreasing trend is seen again in the aftrenoon hours which continues until 4-5 PM and an increase is observed afterwards until midnight. The peaks and troughs cycle shows that evening and late night hours are critical from a particulate pollution point of view. The diurnal variation in SO2 is unimodal with a peak oscillatory cycle from 10 AM - 6 PM. NO2, however does not show a significant activity cycle, however increase is observed after evening hours i.e. 6 PM which continued until 8-9 PM. In Nagpur, in addition to the office goers, a major chunk of population is traders, who return back home during late evening hours causing relatively high concentration. 2-wheelers and cars are mostly used by these traders, which emit gaseous pollutants and particulate matter in ambient air.

1.2.4 Comparison of CPCB and MPCB Ambient Air quality Data at Common Monitoring Locations

As can be seen, two of the locations of manual monitoring stations of MPCB, namely Civil Lines and Ambazari Road, are coinciding with the CAAQMS locations. The annual average data at these two stations are compared to assess the variations across the type of the monitoring techniques. The results in terms of SO_2, NO_2 and PM10 for the two locations are given in **Figure 1.7**. It can be seen that SO_2 and NO_2 are well below the respective CPCB guideline value for both, CAAQMS and manual station. PM10 on the other hand, is greater than the CPCB threshold for both, CAAQMS and manual monitoring station. There is a minor variation in the concentration reported by both the CAAQMS and manual monitoring station.

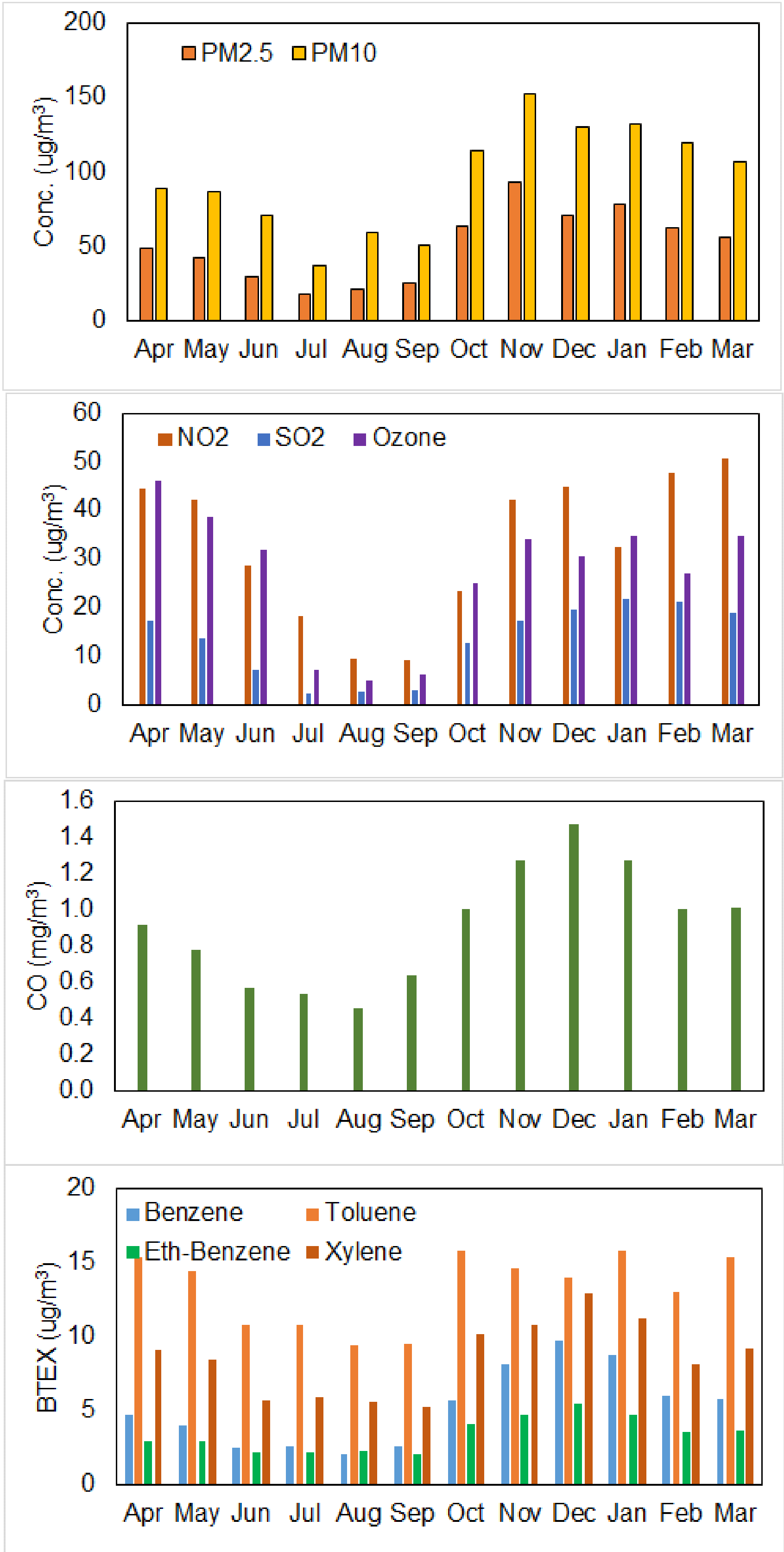

Figure 1.5a: AAQ during April 2023 – March 2024 at Civil Lines (Source: CPCB)

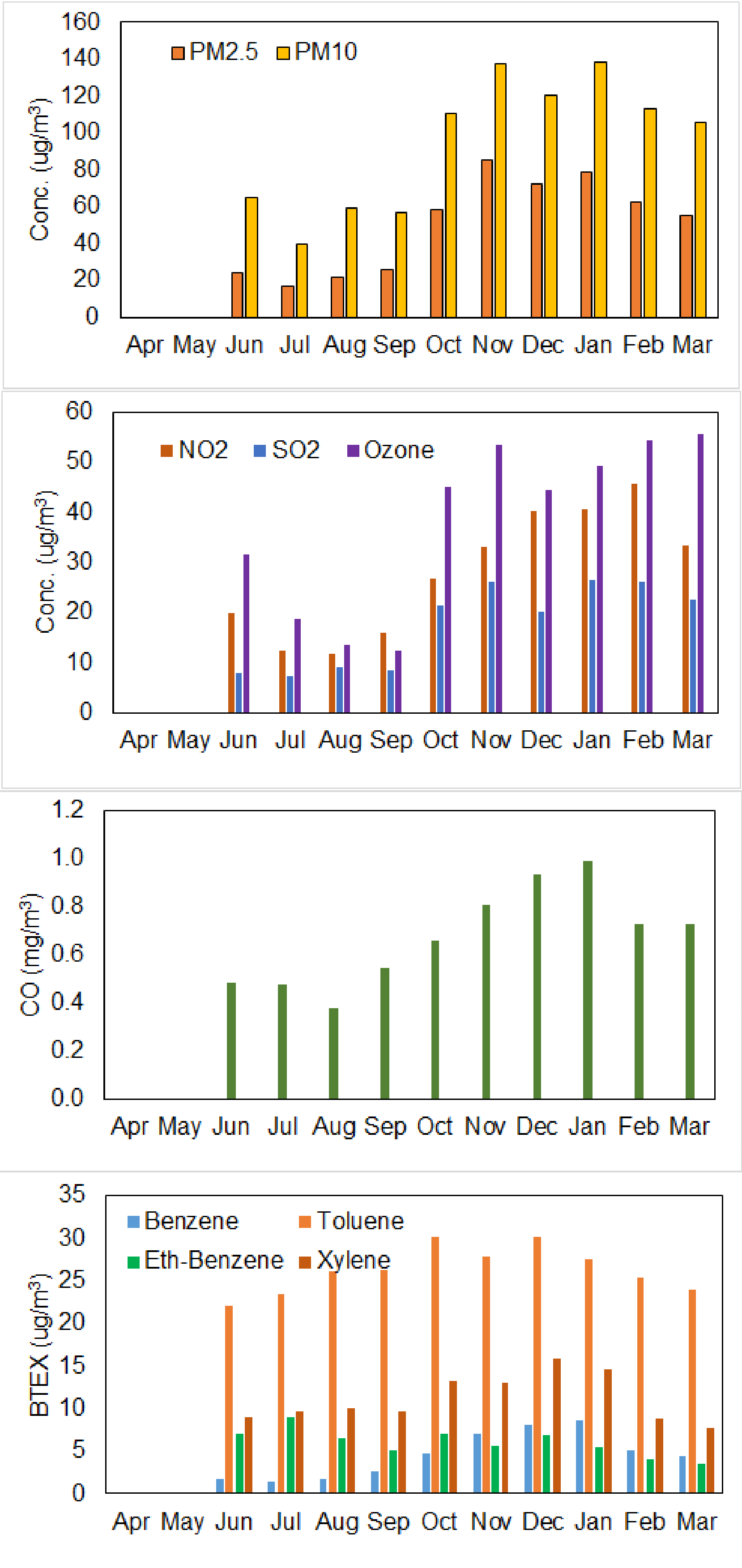

Figure 1.5b: AAQ during April 2023 – March 2024 at Ambazari (Source: CPCB)

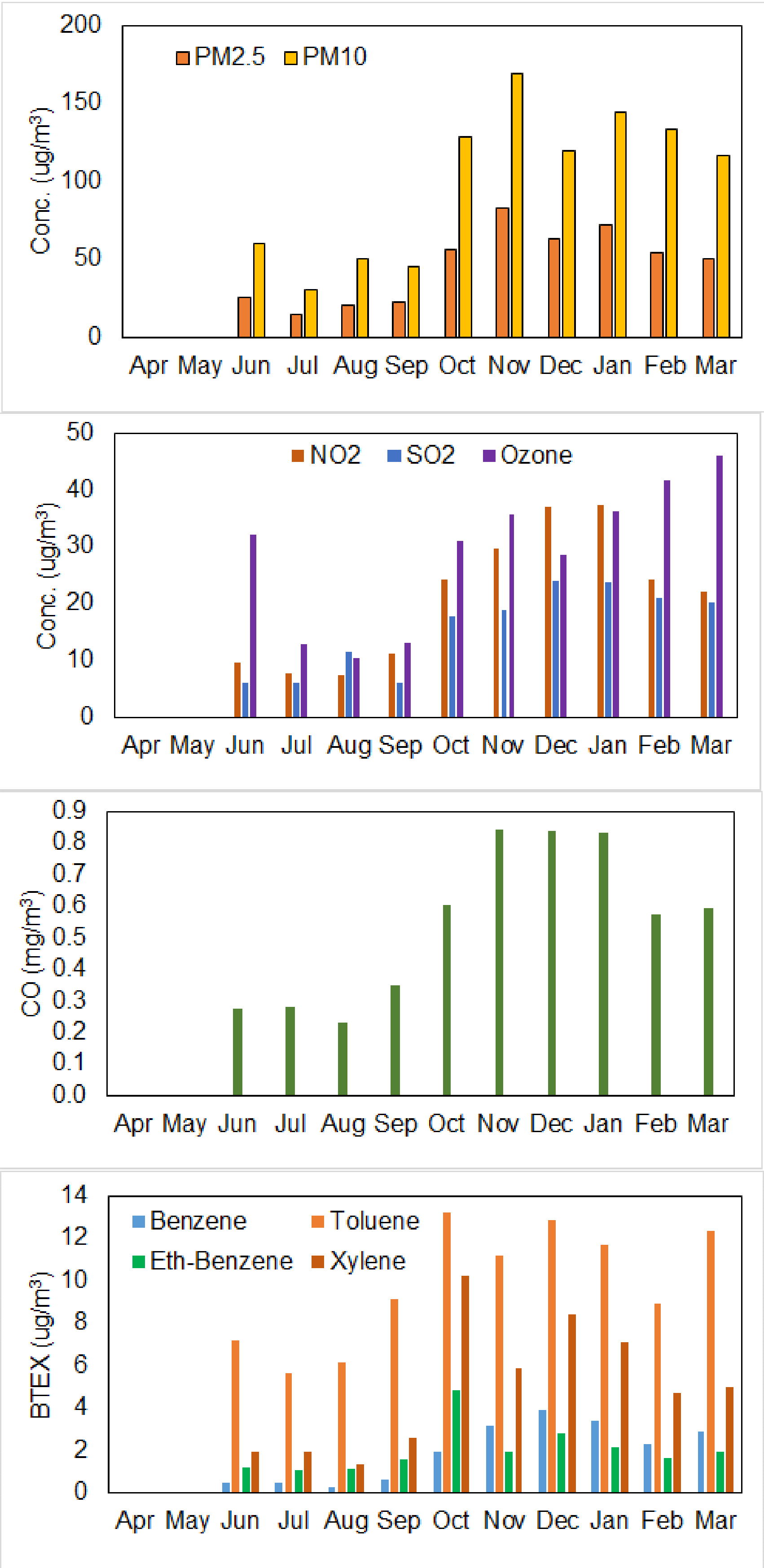

Figure 1.5c: AAQ during April 2023 – March 2024 at Ramnagar (Source: CPCB)

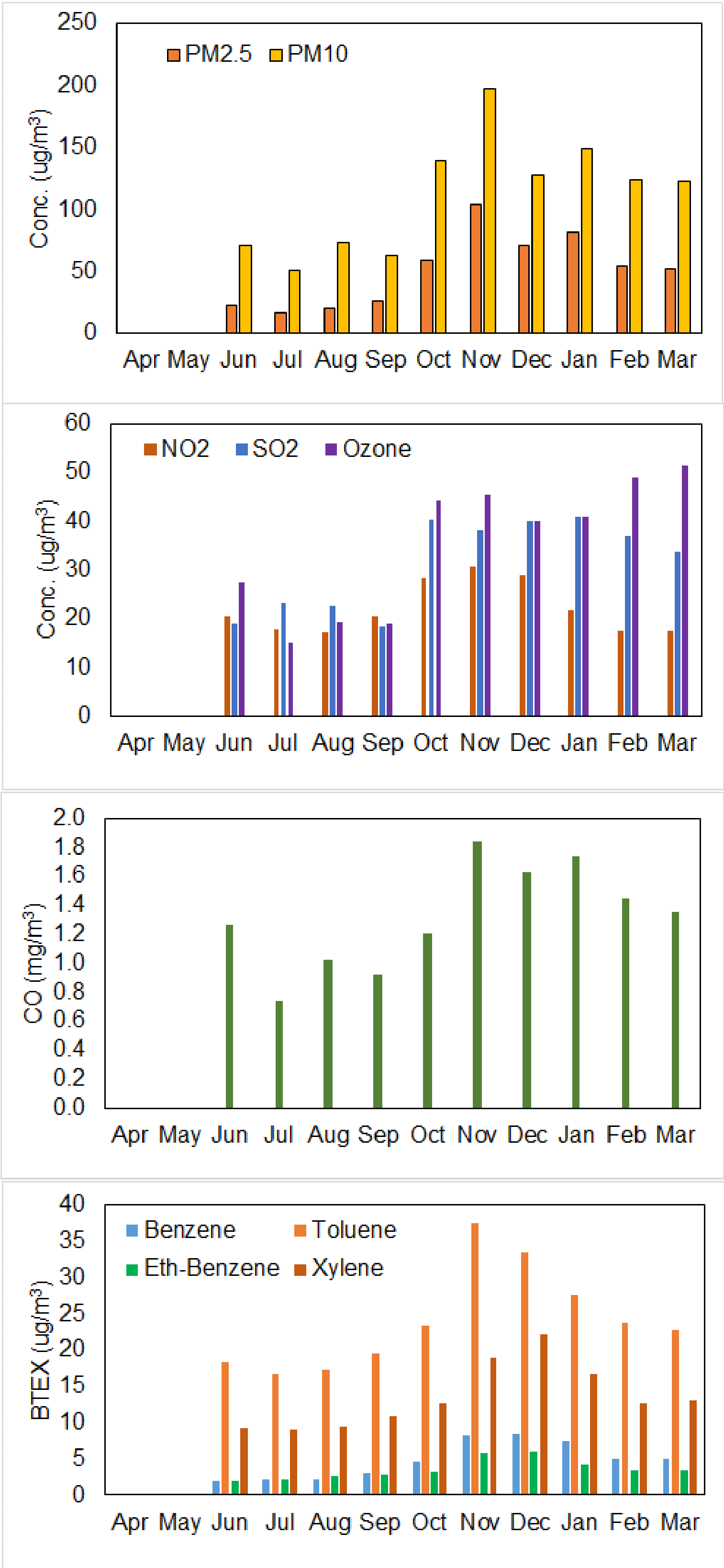

Figure 1.5d: AAQ during April 2023 – March 2024 at Mahal (Source: CPCB)

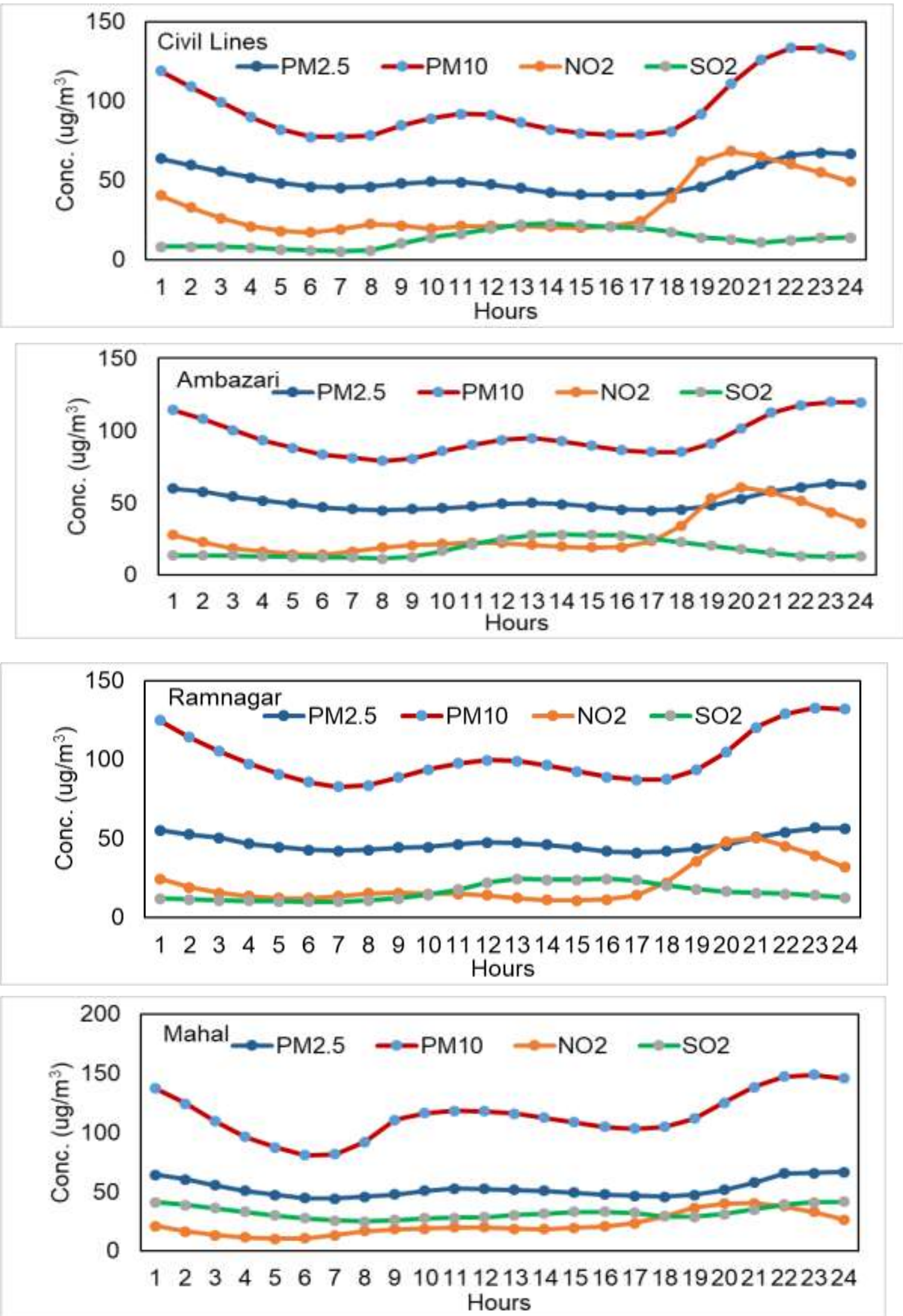

Figure 1.6: Hourly variations in criteria pollutants (Source: CPCB)

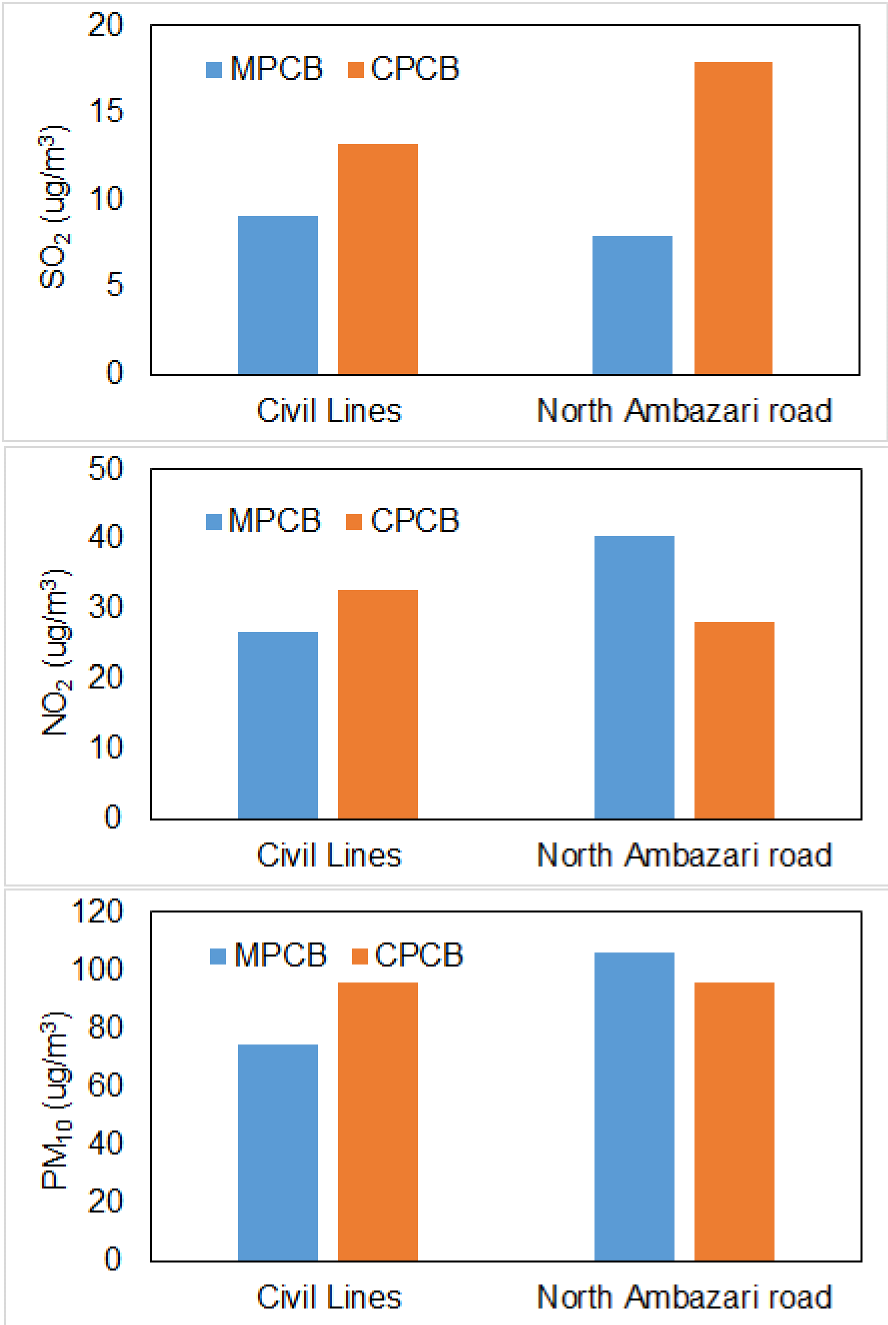

Figure 1.7: Comparison of CPCB and MPCB ambient air quality data at two common monitoring locations

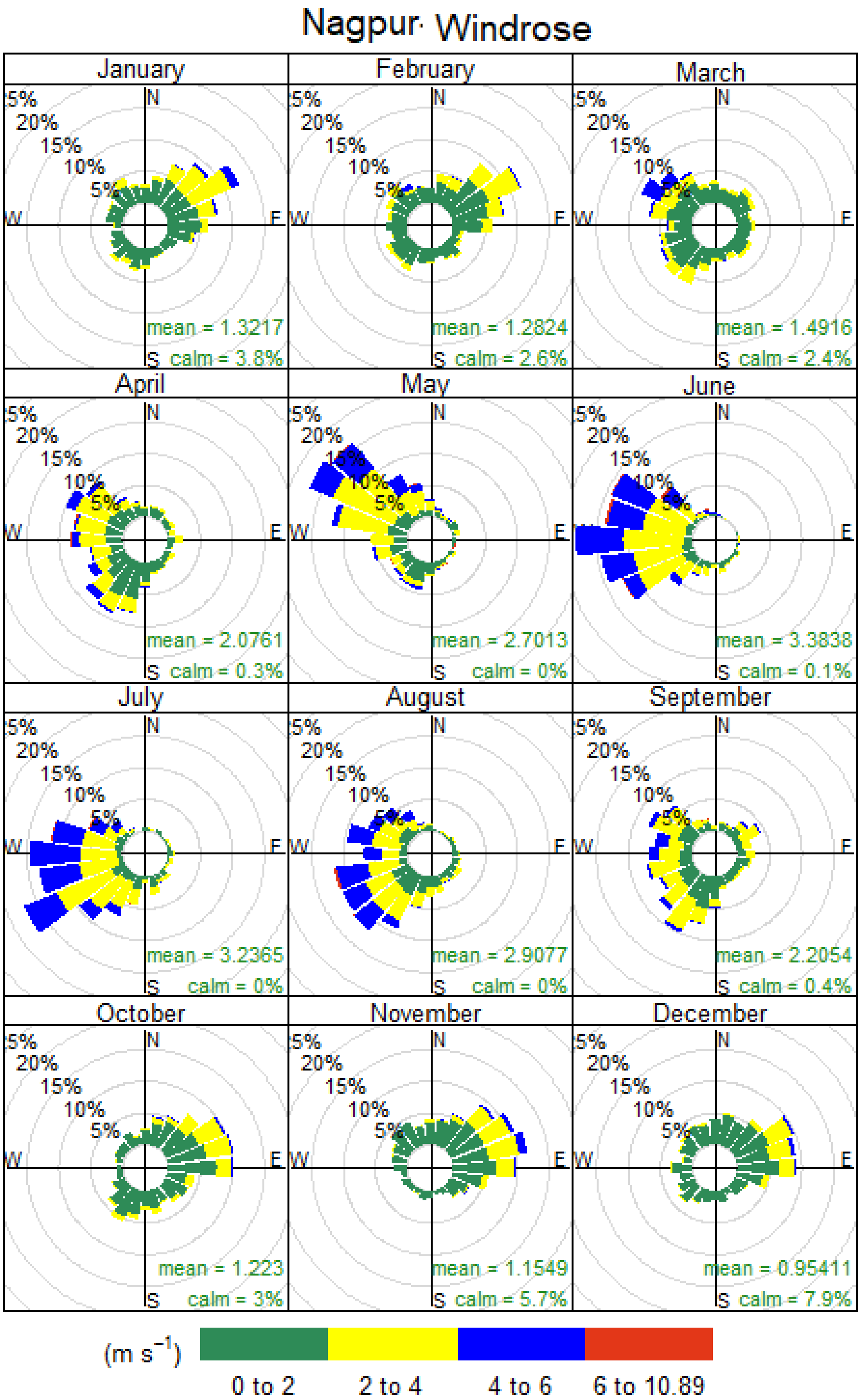

Figure 1.8: Windrose diagram from Meteorological Data (Source: CPCB)

1.2.5 Meteorology

Air pollutant's dispersion in the atmosphere is governed by meteorological parameters like wind speed and wind direction, temperature, and relative humidity. The wind speed and wind direction as gathered at CAAQMS at Civil Lines are used for plotting the windrose diagram. **Figure 1.8** depicts the monthly wind rose diagram for Nagpur. It can be seen that the predominant wind direction during winter (November - January) is from north-east direction. During summer (April – June), the predominant wind direction is north-west-south. During post-monsoon (September), wind speed is very low, however it follows the monsoon wind direction i.e., south-west-north.

1.3 Observations and Inferences

The analysis of air quality at manual monitoring sites shows that PM10 is the city's most concerning pollutant. According to a spatial analysis conducted in 2023–2024, PM10 levels are highest near Hingna, followed by North Ambazari Road. PM10 at Wadi in the outskirts of the city is less than the other locations and the annual average value is close to the threshold of 60 µg/m3. At the other locations, however, PM10 exceeds the CPCB threshold. The trend analysis of annual average PM10 suggested its exceedance to the annual average CPCB guideline value of 60 µg/m3 in every year. The assessment of the air quality at the Continuous Ambient Air Quality Monitoring Station revealed that all the parameters, with the exception of PM2.5, PM10, are below the CPCB level. Overall, the issue of air pollution in terms of all the parameters except PM pollution in the city during the study period is not very significant.

1.4 Recommendations

Based on the AAQ status of the city, the following specific recommendations to control air pollution in the city can be prioritized.

1. It is observed that particulate matter, specifically PM is a pollutant of concern, the control and management policies need to be oriented towards mitigate PM pollution in the city.
2. Ambient air quality monitoring stations operated by MPCB and CPCB under SAMP and NAMP programmes have been increased with respect to the number of stations. There is a need to maintain them properly to provide consistent and reliable data. A transparent auditing practice is required for these stations.
3. Previous ESR of Nagpur (ESR, 2022-23) showed the Gridded emission inventory of Nagpur city. This can be updated on yearly bases if activities are varying over the period of time. The information on the ongoing polluting activities need to be updated regularly in a pre-defined format. This includes, updating of number of new construction activity, closing of completed construction activity, number of dead bodies in crematoria, new hotels, restaurants etc. For arriving at Nagpur specific emission factors, sampling of road dust is necessary considering the

city road’s transition from unpaved to paved, potentially lowering the emission burden from road dust re-suspension.

4. As mentioned in previous ESR (2022-23), one of the major issues in the city that needs attention, is construction debris. Dust emissions from tall building construction are one of the major challenges that must be addressed. Residual construction material left outside the construction site, on the roads, is a nuisance and a health risk. It is recommended that no such material be stored outside to reduce the amount of road dust re-suspension. With appropriate safety precautions, the material can be stored within the plot area. Regardless of the size of the site or plot, it is possible to prevent the exposure to particulate pollution from residential construction operations by firmly encircling the area with green netting up to the top of the constructed area, or other sheets/tarpaulin to prevent pollution from dispersing. NMC will issue a SOP for building construction with the above measures.
5. The city's road network is changing from flexible to stiff pavement, so it is necessary to assess the silt load from the various routes. This will display the real emission load resulting from the re-suspension of road dust. It is suggested that CSIR-NEERI will carry out study for silt load of Nagpur roads and estimate the road dust re-suspension.
6. Traffic congestion due to parking of cars on both sides of the road in residential neighbourhoods has become a big menace in the city. Many areas are witnessing the narrowing down of the roads due to car parking on the space near the houses. The residents themselves get exposed to the micro-pollutants released due to vehicle halts. Appropriate policies need to be implemented to reduce the pollution-induced because of the vehicular traffic halts due to on-street parking.
7. Open burning occurs in local and residential areas even though it is prohibited. Residents must observe appropriate guidance on solid waste management. In numerous locations, especially during the morning, at some places authorized workers and /or sanitary personnel assigned to tidy internal lanes and streets sweep the streets, create a pile of trash and leaves, which they then publicly burn. Open burning is not a good practise from environment point of view and NMC should take strict action to stop such practises.
8. The solid waste department of NMC should issue a SOP for the respective zones mentioning the day and time for collection of garden waste. This will reduce the burning of garden waste in respective zones.
9. It is important to understand the air pollution contribution from the nearby areas and also the regional contribution. The air-shed of the area needs to be identified to account for the emissions sources present in the area.

ESR (2023-24)

Chapter 2
Climate Change

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Climate Change: Impacts, Adaptation and Mitigation

2.0 Introduction

Climate change is one of the most complex problems faced by humanity in the 21st century. It is intricately linked with the socio-economic development of any region, making its resolution crucial for achieving the United Nations' Sustainable Development Goals. The concentration of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) has been rising due to anthropogenic activities since the advent of the industrial revolution. The consumption of fossil fuels and changes in land use are major contributors to these emissions, mainly CO_2. Atmospheric CO_2 levels are currently higher than they have been for at least the last 700,000 years, and the average surface temperature is projected to rise by over 1.5°C by 2050 [1].

Most changes observed over the last fifty years are due to GHG emissions from human activities [2]. The impacts of climate change are long-term, as GHGs persist in the atmosphere for extended periods. Present GHG emissions will affect future generations, and even if GHG levels were to stabilize, the effects of anthropogenic forcing would continue for centuries. This long-term nature of climate change impacts makes it a unique and difficult policy challenge. Furthermore, climate change is a global phenomenon; the Earth's atmosphere does not differentiate GHG emissions based on city, district, state, or country boundaries. Key global impacts include:

- **Rising Temperatures:** Global average temperatures have increased, leading to more frequent and intense heatwaves that affect human health, agriculture, and ecosystems.
- **Sea Level Rise:** Melting glaciers and ice caps, along with the thermal expansion of seawater, contribute to rising sea levels, threatening coastal communities and ecosystems.
- **Changes in Precipitation Patterns:** Altered precipitation patterns result in more intense and unpredictable rainfall, leading to flooding in some regions and droughts in others.
- **Extreme Weather Events:** The frequency and intensity of extreme weather events, such as hurricanes, typhoons, and cyclones, have increased, causing significant damage to infrastructure and economies.
- **Biodiversity Loss:** Changes in temperature and precipitation disrupt ecosystems, leading to habitat loss and threatening species with extinction.

India, with its diverse geography and large population, is highly vulnerable to the impacts of climate change. Several critical areas of concern have been identified:

- **Temperature Rise:** India has experienced significant increases in average temperatures, leading to more frequent and severe heatwaves, posing severe risks to public health, particularly in densely populated urban areas.

- **Monsoon Variability:** The Indian Monsoon, crucial for agriculture, has become increasingly erratic. Monsoon pattern changes lead to droughts and floods, impacting food security and water resources.
- **Glacial Retreat:** The Himalayan glaciers, a vital source of freshwater for millions, are retreating rapidly, threatening water supply for drinking and irrigation.
- **Sea Level Rise:** Coastal regions, including major cities like Mumbai, Chennai, and Kolkata, face the threat of inundation due to rising sea levels, which impact livelihoods and infrastructure and lead to displacement.
- **Agricultural Productivity:** Climate change affects crop yields due to altered growing seasons, increased pests, and extreme weather events, threatening food security.

Modern urban cities house more than half of the world's population; by 2050, over 70% will live in cities [3]. Cities have a special relationship with the climate system, presenting unique challenges and opportunities for knowledge generation [4]. Potential impacts of climate change on urban areas include:

- **Sea Level Rise:** Affects coastal cities.
- **Extreme Events on Health:** Health-related issues increase due to extreme weather events.
- **Energy Use:** Alters energy demand and consumption patterns.
- **Water Resources:** Impacts water availability and management.
- **Infrastructure:** Affects built-up infrastructure.

Nagpur, as a growing urban city, faces unique vulnerabilities. Understanding the impacts of climate change is crucial for cities like Nagpur to build resilience and ensure sustainable development. Comprehensive climate action plans are essential for mitigating risks and adapting to inevitable changes. This report summarizes the local climatic factors influencing Nagpur's future exposure to climate change impacts, focusing on temperature and precipitation. By implementing effective adaptation and mitigation strategies, Nagpur can enhance its resilience to climate change and ensure a sustainable future for its residents.

2.1 Risk factors evaluated in this section

This section summarizes the local climatic factors influencing Nagpur's future exposure to climate change impacts. The following climate indicators were considered the most relevant to Nagpur and, therefore, investigated in the report: 1). Temperature and 2) Precipitation. The climate data for Nagpur city for the last five decades has been statistically analyzed to understand if any relationship between climate parameters and other variables exists. Further, temperature and rainfall-based indices are studied. Their deviation from the mean (anomalies), trend and decadal changes were evaluated to understand the current impact of climate variability on the city's climate. Since climate change will not affect every sector in the same manner or with the same magnitude to lower community risk, the local governments have a responsibility to ensure that critical community services are adequately prepared to face the impact of climate change [5]**.** This section of the report provides the first step in understanding if climate change affects the Nagpur region, and if yes, then to what degree. It offers future steps and recommendations to understand which sectors in the city are the worst affected and need further investigation.

2.2 Description of the study area

Nagpur City, situated in central India, experiences a tropical savannah climate characterized by distinct wet and dry seasons. The climate is influenced by its central location on the Deccan Plateau, with the Vidarbha region of which Nagpur is a part, being subject to monsoonal and continental climatic influences. Nagpur falls within the Vidarbha region and is classified into different agro-climatic zones. The area exhibits variations in climate and soil types, contributing to a diverse agricultural landscape. The agro-climatic conditions are crucial in shaping land use patterns and vegetation in and around Nagpur.

Nagpur experiences significant temperature variations throughout the year. Winters (November to February) are characterized by cooler temperatures, with minimums ranging from around 7°C to 12°C. Summers (March to June) are hot, with maximum temperatures often exceeding 40°C, and the annual average temperature in Nagpur typically ranges from approximately 25°C to 28°C. Nagpur City witnesses a monsoonal rainfall pattern. The Southwest Monsoon, from June to September, brings most of the city's annual rainfall. The average yearly rainfall is around 1,100 mm, contributing to the city's water resources and shaping local vegetation patterns. The natural vegetation in and around Nagpur comprises a mix of deciduous and dry deciduous forests. The presence of teak and bamboo reflects the region's ecological diversity. Urbanization has led to changes in land use and a reduction in natural vegetation cover. Nagpur's soil composition is diverse, with a prevalence of red and black soils. Red soils are well-drained and suitable for agriculture, while black soils are rich in nutrients, making them conducive to various crops. The soil types influence land use patterns, agricultural practices, and water retention capacities.

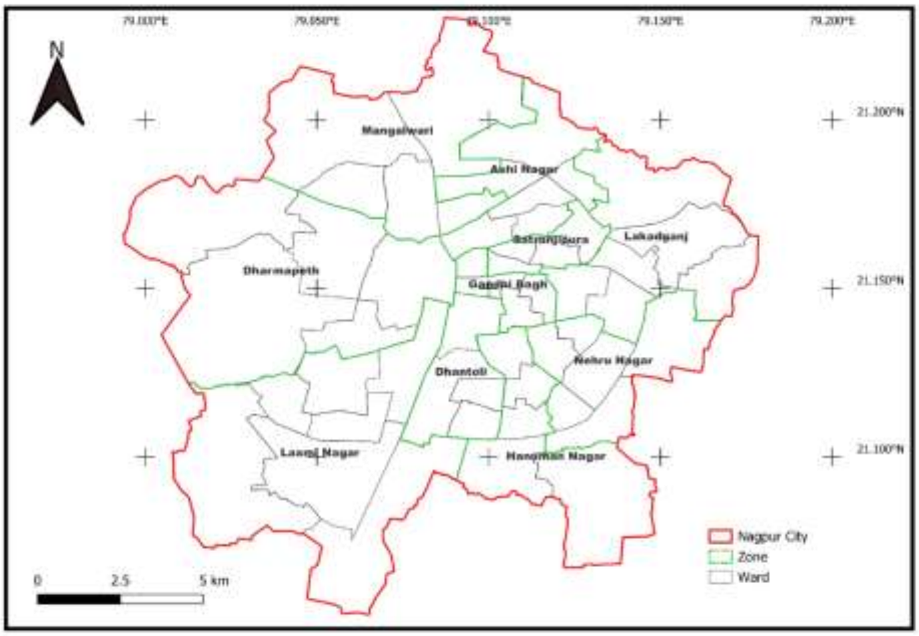

Figure 2.1: Map of the study area (City of Nagpur)

2.3 Methodology

Meteorological data (temperature, rainfall and relative humidity) has been sourced from two sources 1) Regional meteorological Centre (RMC), Nagpur, a subsidiary unit of Indian Meteorological Department (IMD), Pune and 2) OGIMET (www.ogimet.com), a free source weather information service which was extracted using the climate R-statistics package (https://github.com/bczernecki/climate). All data cleaning, wrangling and analysis are performed using R-statistics and Microsoft Excel. Various methods have been used to estimate rainfall and temperature-based indices, which will be explained in the next section.

a) Extreme heat events (EHE)

Extreme heat events have been calculated based on the Hoosier Resilience Index (HRI) developed by the Environmental Resilience Institute, Indiana University, USA [5]**.** HRI defines extreme heat events with days with highs 32 ºC or higher and nights with lows 20 ºC or greater. However, for this case, the highs of 34 ºC or higher are considered due to the weather scenario in Nagpur. Extreme heat events are divided into 1) High heat days (HHD), 2) High heat nights (HHN) and 3) High heat days and nights (HHDN). The sum of HHD, HHN and HHDN is taken as the total number of EHE. **Table 2.1** shows the formulae for calculating HHD, HHN, HHDN and EHE.

Table 2.1: Formulae used for the calculation of extreme heat events based on the Hoosier Resilience Index

Sl no	Type of Extreme Heat event	Calculation formula
1	High heat days	Number of days, on average per year, where daily max temperature (Tmax) is 34°C or greater and daily min temperature is less than 20°C.
2	High heat nights	The number of days, on average per year, where daily max temperature (Tmax) is less than 34°C and daily min temperature is 20°C or greater.
3	High heat days and nights	Number of days, on average per year, where the daily max temperature (Tmax) is 34°C or greater and daily min temperature is 20°C or greater.
4	Extreme heat events	Sum of High heat days, High heat nights and High heat days and nights

b) Cooling degree days (CDD)

Degree-days are versatile climatic indicators used in building design and operation that estimate energy consumption and carbon emissions due to space heating and cooling [6]. Degree days are estimated as the summation of temperature differences between the ambient or outdoor air temperature and a reference temperature known as the base or balance point temperature. Cooling degree-days (CDD) and heating degree-days (HDD) are determined by using the base temperature and outdoor temperature data, which can be used for forecasting the energy consumption for heating and cooling requirements of residential or commercial buildings[7] In this study; cooling degree days is estimated as majority of the energy consumption is used for space cooling. We are using the calculation method suggested by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). In this method, degree days are the difference between the daily mean temperature (T_d) and the base temperature (T_b). Cooling degree is calculated using **Eqn 4.1**.

$$CDD_d = (T_d - T_b)^+ \text{ (Eqn 4.1)}$$

Where T_d = (Tmax + T_{min}) ÷2 and T_b is taken as 18 ºC suggested in literature for Indian Conditions [7–9].

c) Heat Index (HI)

Various climate-based indices have been developed to quantify the exposure to heat. The method adopted in this study is the heat index developed by the National Weather Service, National Oceanic and Atmospheric Administration (NOAA), USA, adopted by IMD, Pune [10]. This index maps the impact of temperature and humidity as an indicator of thermal discomfort. This index is based on the work carried out by Lans P. Rothfusz in 1990 [11]. The equation is as follows:

$$HI = -42.379 + 2.04901523 * T + 10.14333127 * RH - .22475541 * T * RH - .00683783 * T * T - .05481717 * RH * RH + .00122874 * T * T * RH + .00085282 * T * RH * RH - .00000199 * T * T * RH * RH$$

(Eqn 4.2)

Where T is the temperature in ºF, RH is the relative humidity in %, and HI is also in ºF. If the RH < 13% and the temperature ranges between 80 & 112 ºF, the following adjustment (**Eqn 4.3**) has to be subtracted from Eqn 4.2. On the other hand, if the RH > 85 and the temperature is between 80 & 87 ºF, the following adjustment (**Eqn 4.4**) is added to **Eqn 4.2**. If temperature and humidity conditions warrant a heat index value below about 80 ºF, then equation 4.2 cannot be used, and a simpler formula (**Eqn 4.5**) is used.

$$ADJUSTMENT_1 = [(13 - RH)/4] * SQRT\{[17 - ABS(T - 95.)]/17\}$$ **(Eqn 4.3)**

$$ADJUSTMENT_2 = [(RH - 85)/10] * [(87 - T)/5]$$ **(Eqn 4.4)**

$$HI = 0.5 * \{T + 61.0 + [(T - 68.0) * 1.2] + (RH * 0.094)\}$$ **(Eqn 4.5)**

Equation 4.5 is first used to estimate the overall heat index for simplicity. For all the values whose HI is above 80 ºF or greater, equation 4.2 and any adjustment (Eqn 4.3 and 4.4) can be used. Finally, the temperature is converted from ºF to ºC. IMD has come out with colour-coded HI, in line with the Air quality index, to alert people on the exposure level **(Table 2.2).**

Table 2.2: Color-coded Heat Index for India [10]

Sl no.	Color Code	Heat Index Range (ºC)
1	GREEN	Less than 35
2	YELLOW	Between 36 and 45
3	ORANGE	Between 46 and 55
4	RED	Above 55

d) Precipitation Concentration Index (PCI)

Planning for water resources and managing natural resources depend on estimating annual and seasonal precipitation variability, a crucial component of the precipitation concentration index (PCI), a potent indicator of temporal precipitation distribution. First introduced by [12], PCI is used to characterize the uniformity of total rainfall in both annual (**Eqn 4.6**) and seasonal scale (**Eqn 4.7**) and is a helpful indicator for rainfall concentration, droughts or floods risk prediction and rainfall erosivity [13,14].

$$PCI_{annual} = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} p_i)^2} \times 100 \text{ (Eqn 4.6)}$$

$$PCI_{seasonal} = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} p_i)^2} \times 25 \text{ (Eqn 4.7)}$$

Where p_i is the monthly precipitation in month *i* and is calculated for Nagpur and each year for 1970-2024. In addition, the PCI was calculated on a seasonal scale for winter, summer, Monsoon and post-soon according to Equation 4.7. The PCI maps provide a compelling visual representation of the spatial variability of monthly precipitation over a studied region. As described by Oliver (1980)[12] and Zamani et al. (2018) [15], PCI or SPCI values below 10 denote a uniform monthly rainfall distribution throughout the year (low precipitation concentration); values ranging from 11 to 15 indicate a moderate concentration of precipitation; values between 16 and 20 represent an irregular distribution; and values above 20 represent a strong irregularity (high precipitation concentration) in precipitation distribution.

e) Rainfall Index (RI)

Further, rainfall is classified into different indices based on the intensity defined by the Indian Meteorological Department, Pune [16]. Based on the rainfall intensity, rainfall is classified into 1) Rain day (RD), 2) Light rain day (LRD), 3) Moderate rain day (MRD), 4) Rather heavy rain day (RHRD), 4) Heavy rain day (HRD), 5) Very heavy rain day (VHRD) and 6) Extreme rain day (ERD) is listed in **Table 2.3.**

Table 2.3: Classification of Rain Day based on rain intensity

Sl no.	Classification	Rainfall intensity (mm)
1	Rain day	R > 2.5
2	Light rain day	2.5 =< R=< 7.5
3	Moderate rain day	7.6 =< R=< 35.5
4	Rather heavy rain day	35.6 =< R=< 64.4
5	Heavy rain day	64.5 =< R=< 124.4
6	Very heavy rain day	124.5 =< R=< 244.4
7	Extreme rain day	R>=244.5

2.4 Observation and Inferences

a. Variation in Temperature and its Indices for 1970-2024

i. Temperature

2.4.1 Maximum Temperature

With the current global ambient temperature at 1.17ºC [17], it is critical to understand the change in the temperature pattern, especially maximum and minimum, as it is essential to quantify and study the impact of climate change on human thermal comfort level, especially in urban areas. So, **Figure**

2.2 describes Nagpur's overall trend of annual mean maximum temperature and the deviation from the mean (anomalies) between 1970-2024. From the illustration, it can be seen that there is a positive trend for maximum temperature (R^2 = 0.16 and m = + 0.0149). To understand this trend, we have calculated the deviation of maximum temperature for years from the 1970-2024 mean, which shows that post-2000, 75% of the years show a positive deviation from the overall mean. This tells us that the positive trend is driven by the increase in the mean maximum temperature after 2000.

Since Nagpur has distinct seasons, it is essential to analyze the trend of various climate variables and indices. The analysis of the trend of mean maximum temperature for summer (**Figure 2.3**) shows a very negligible trend for the mean maximum temperature for the summer season. (R^2 = 0.0078 and m = + 0.006). The analysis of the deviation from the mean also shows no discernible pattern.

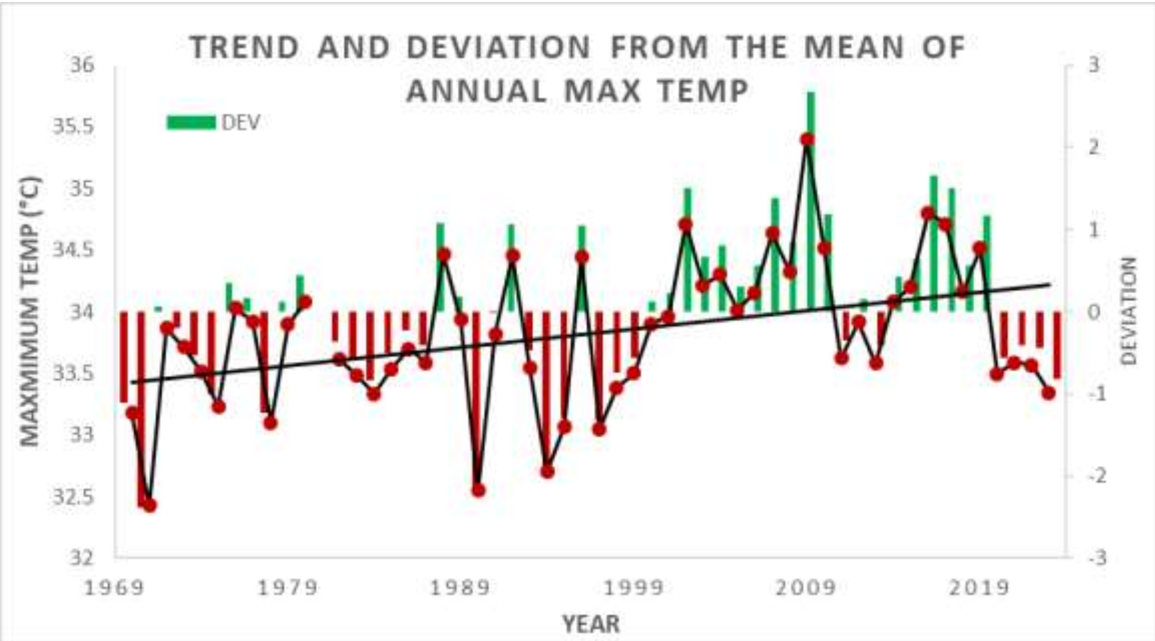

Figure 2.2: Trend and deviation from mean of average annual maximum temperature (1970-2024)

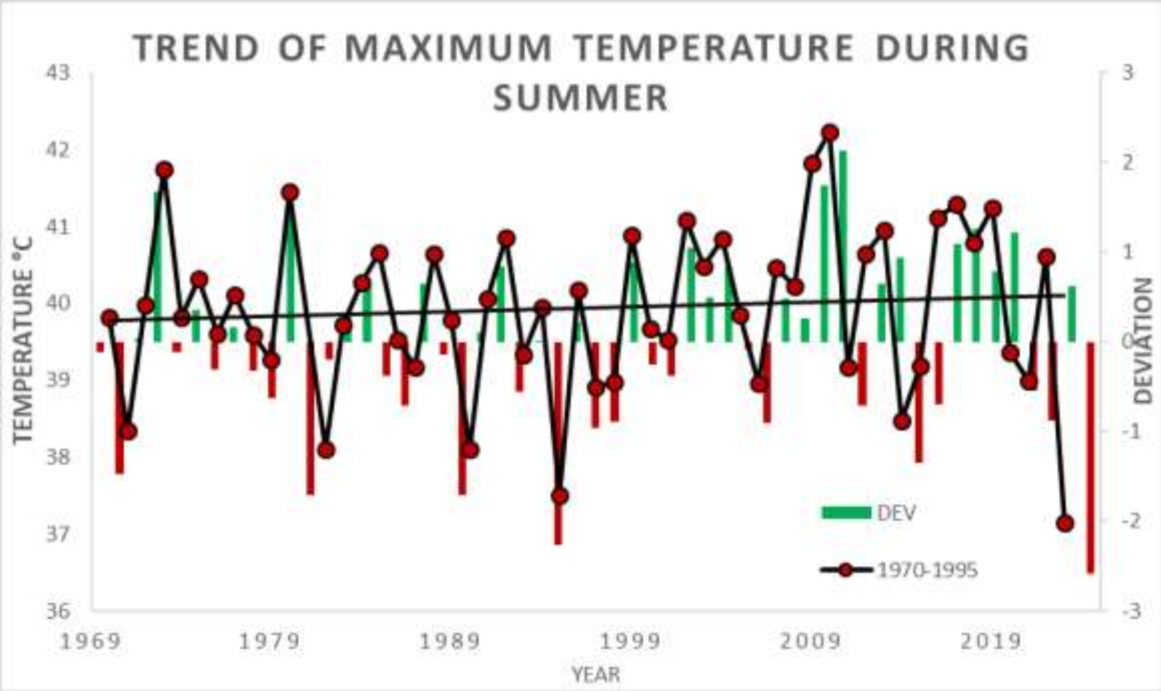

Figure 2.3: Trend and deviation from mean of average maximum temperature for summer (1970-2024)

Analysis of the mean maximum temperature for the monsoon season (**Figure 2.4**) shows a slightly positive trend (R^2 = 0.07 and m = + 0.0147). This slight positive trend is driven by the increase in the mean maximum temperature post-2010, which can be seen in the rise of positive deviation from the mean where 9 out of 10 years show a positive deviation from the mean.

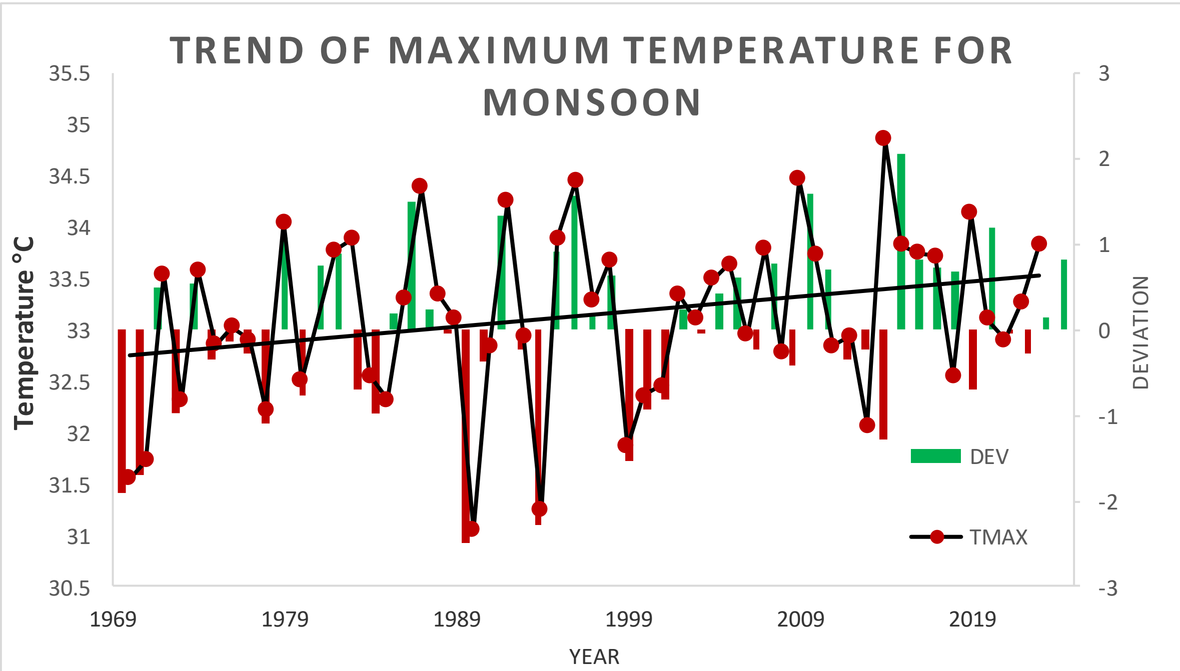

Figure 2.4: Trend and deviation from mean of average maximum temperature for monsoon (1970-2024)

Similarly, **Figure 2.5** illustrates a positive trend for the post-monsoon season for the mean maximum temperature (R^2 = 0.152 and m = + 0.027). To understand this trend, we have calculated the deviation of maximum temperature for a year from the 1970-2024 mean. In this case, the positive trend is driven by positive deviation post-2000, where 87.5% of the year shows a positive deviation.

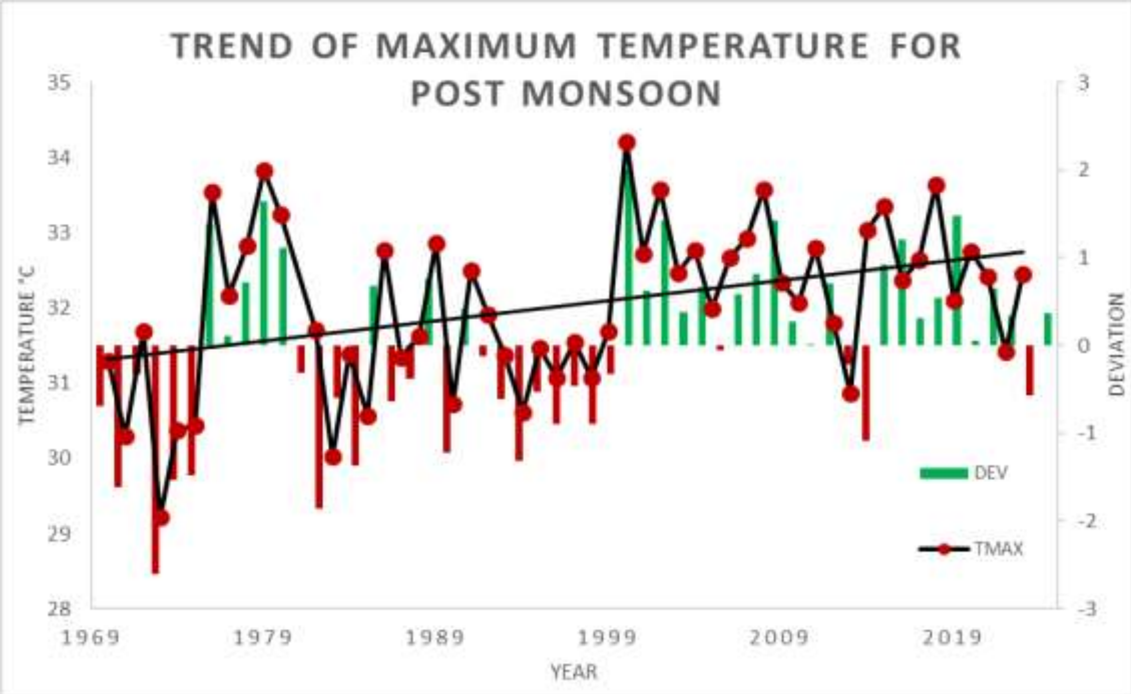

Fig 2.5: Trend and deviation from mean of average maximum temperature for post monsoon (1970-2024)

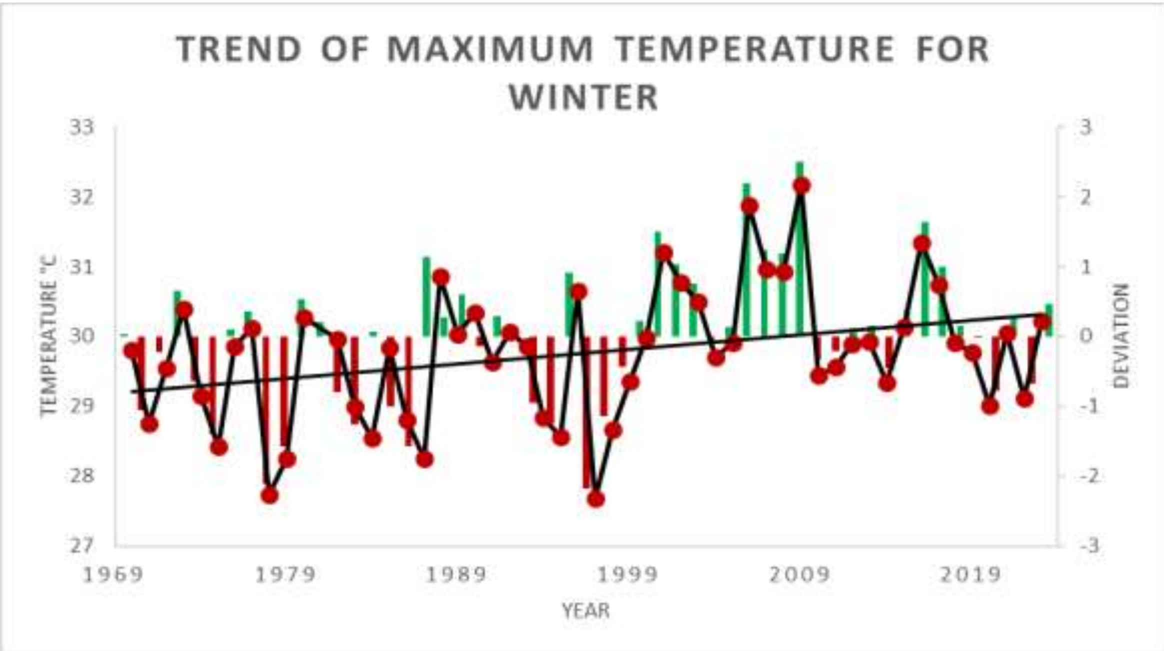

Figure 2.6: Trend and deviation from mean of average maximum temperature for winter (1970-2024)

Figure 2.6 shows the trend of mean maximum temperature for the winter season. The analysis indicates a slight positive trend (R^2 = 0.112 and m = + 0.02), which can be explained by the increase in mean maximum temperature post-2000. The investigation of deviation from the mean shows that 70 % of the years 2000 have a positive deviation.

The study of the mean maximum temperature for Nagpur shows a positive trend (increase). This increase is driven by the rise in the mean maximum temperature in both post-monsoon and winter seasons. This increase in maximum temperature in winter can adversely impact human health and crop productivity (Rabi crops). Warmer temperatures can increase the risk of disease outbreaks of ground-level ozone, leading to worsening air quality. Further, warmer winters can increase the chances of droughts, wildfires and changes in the growing seasons.

2.4.2 Minimum Temperature

Changes in the minimum temperature also have a massive impact on thermal comfort. Any increase can lead to heat wave-like scenarios during colder seasons. It can also impact the growth and productivity of rabi crops. Therefore, this study looks into the annual and seasonal changes in the minimum temperature of Nagpur city. **Figure 2.7** illustrates the trend of annual mean minimum temperature. From the figure, we can see that the study period of 1970 – 2024 is divided into two blocks: 1970-1996 and 1997-2024. The study shows that the trend for the 1970-1996 period is positive (R^2 = 0.157 and m = + 0.02). However, the trend changes to negative for the 1997-2024 period (R^2 = 0.123 and m = - 0.02). We see that post-1997, 54% of the years are lower than the mean minimum temperature (as shown by the AVERAGE line in **Figure 2.7**).

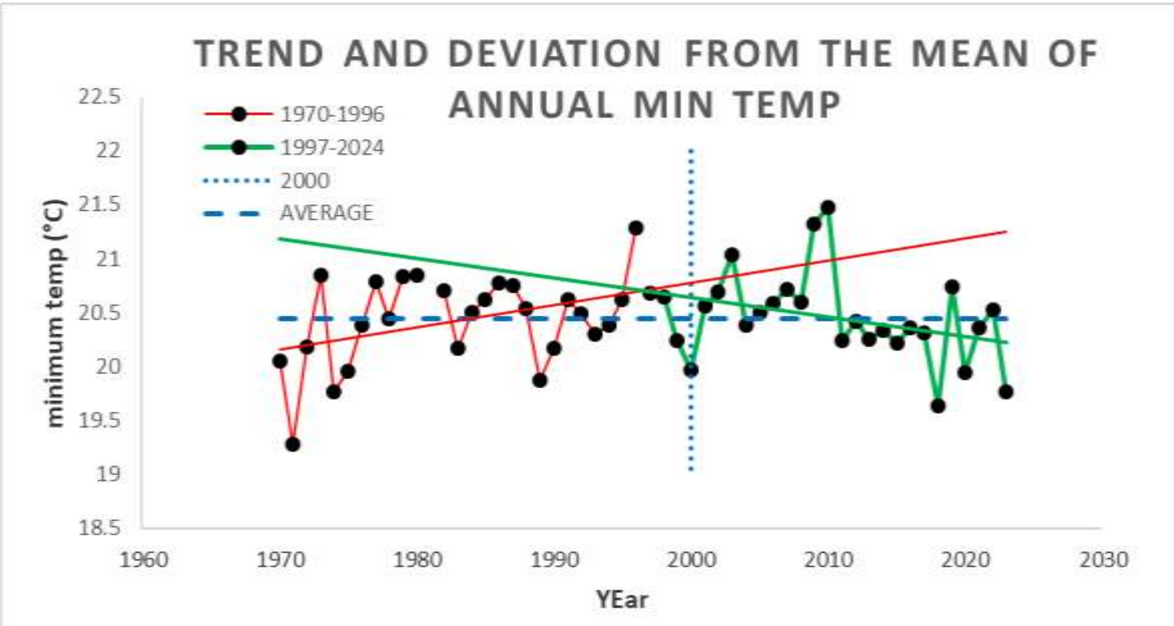

Figure 2.7: Trend and average annual minimum temperature (1970-2024)

In **Figure 2.8**, the trend of average minimum temperature for the summer season is depicted. The figure indicates a slightly positive trend for 1970-1996 (R^2 = 0.01 and m = + 0.01). However, a negative trend can be seen if the 1997-2024 period is studied (R^2 = 0.05 and m = - 0.05). It can be seen that post-1997, 58% of the years have their minimum temperature equal to or less than the mean (as shown by the AVERAGE line in **Figure 5.8**).

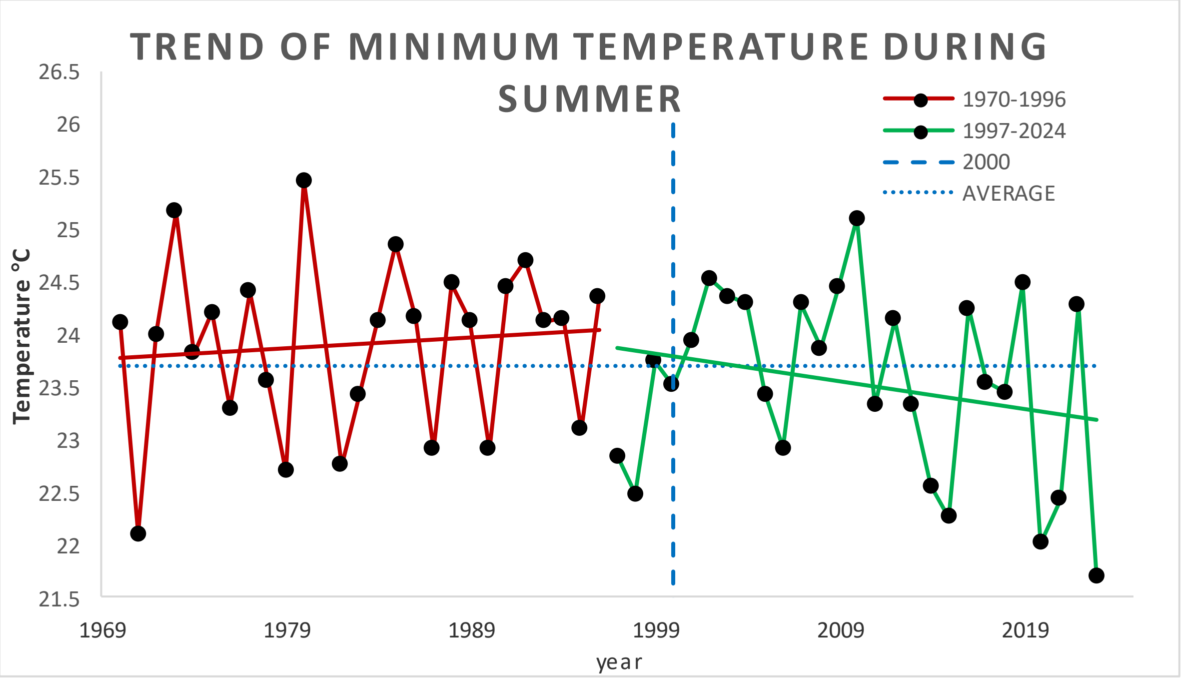

Figure 2.8: Trend of average minimum temperature for summer (1970-2024)

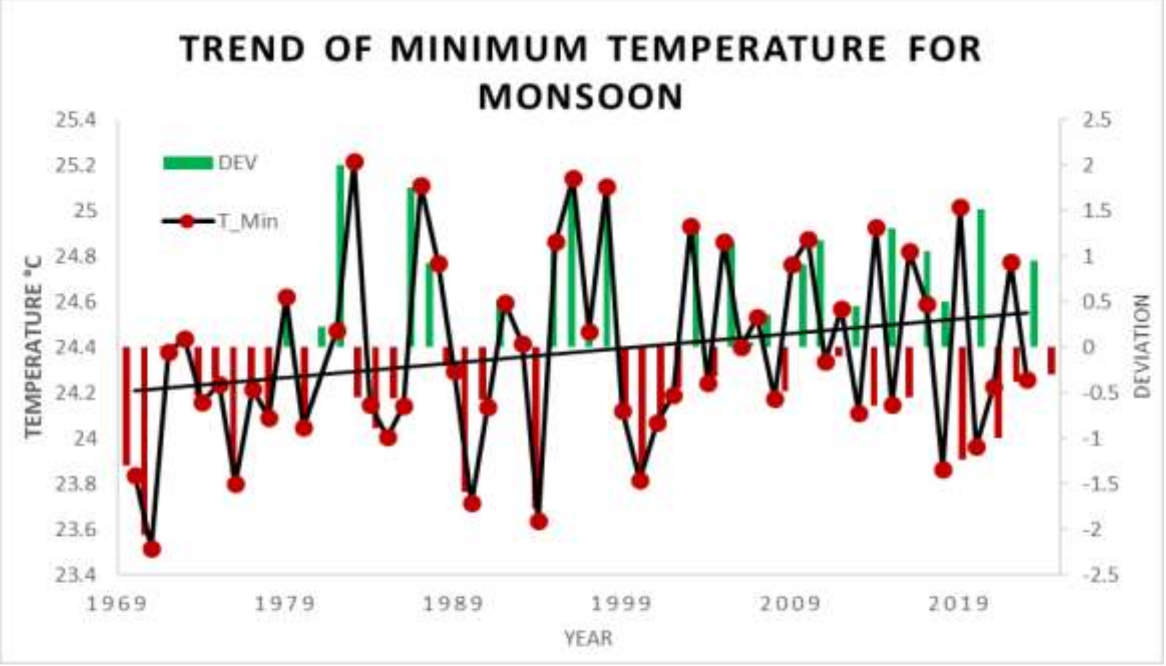

Figure 2.9: Trend and deviation from the mean of average minimum temperature for monsoon (1970-2024)

As seen in **Figure 2.9**, for monsoons, the average minimum temperature is on a slight rise (R2 = 0.06 and m = + 0.006); however, this increase is not very substantial. Further, the deviation from the mean also shows no pattern changes. A similar pattern can be observed for the average minimum temperature for the post-monsoon, where the time series analysis detects no trend, as seen in **Figure 2.10**.

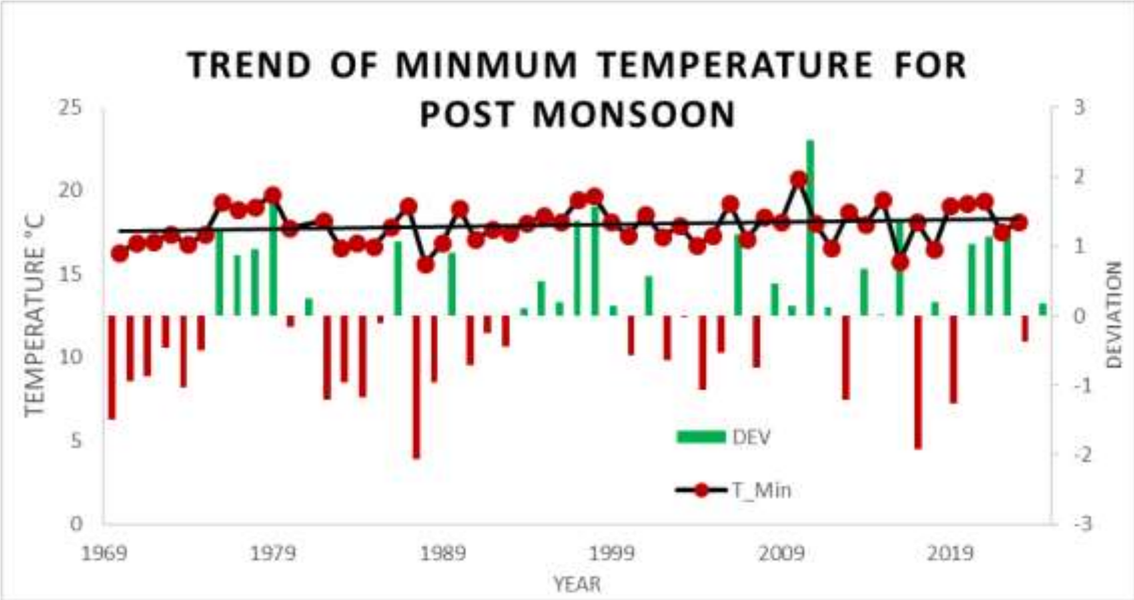

Figure 2.10: Trend and deviation from the mean of average minimum temperature for post monsoon (1970-2024)

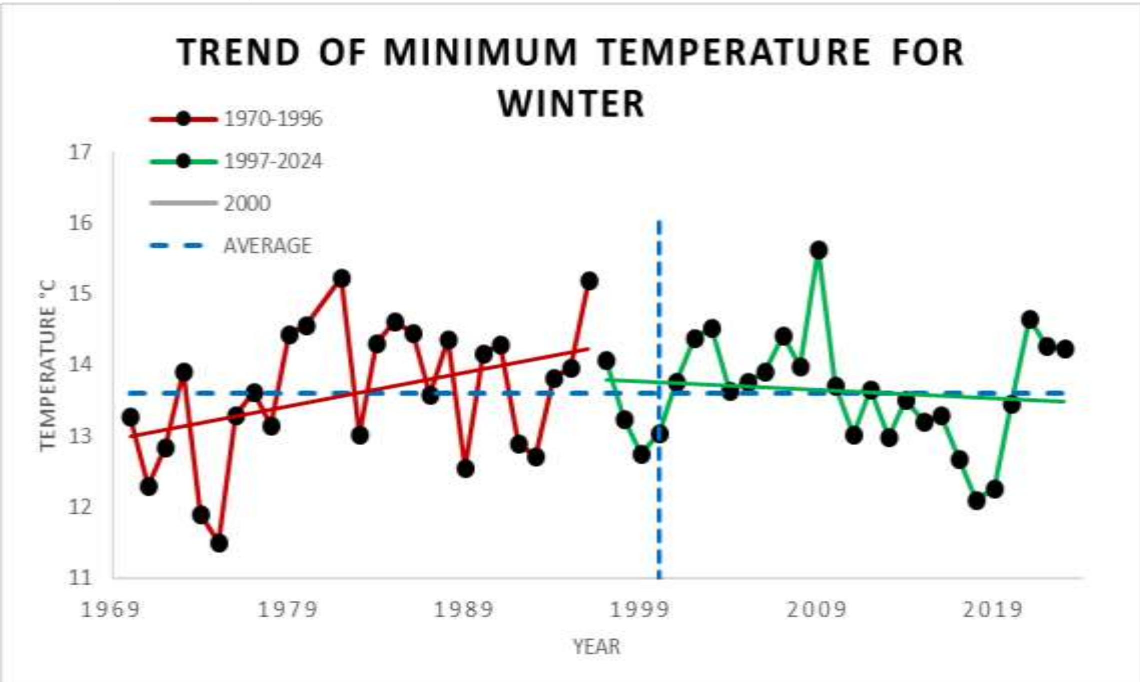

Figure 2.11: Trend of average minimum temperature for winter (1970-2024)

Figure 2.11 shows that the average minimum temperature for winter changed from positive to slightly negative between 1970-1996 and 1997-2024. For 1970-1996, the trend was positive (R2 = 0.16 and m = + 0.04) and slightly negative from 1997-2024 (R^2 = 0.01 and m = - 0.01). This change could be driven by the significant years (67%) with a minimum temperature lower than the mean (1970-2024) post-1996.

ii. Temperature Indices

a. Extreme Heat Events (EHE)

Extreme heat can be considered as one of the deadliest weather hazards for Nagpur, and with the frequency and intensity of extreme temperature events likely to occur 2.8 times (present 1ºC) and 4.1 times (1.5 ºC scenario) in comparison to the 1850-1900 period [18], it critical to understand the occurrence of extreme heat events in Nagpur that can help in future planning for the city. Though IMD reports on the heat wave scenarios, this report takes an alternate angle. Here, the extreme heat event index considers the impact of high heat during the day and the night, which is essential to understanding human thermal comfort. This index takes into account the aspect of urban heat islands.

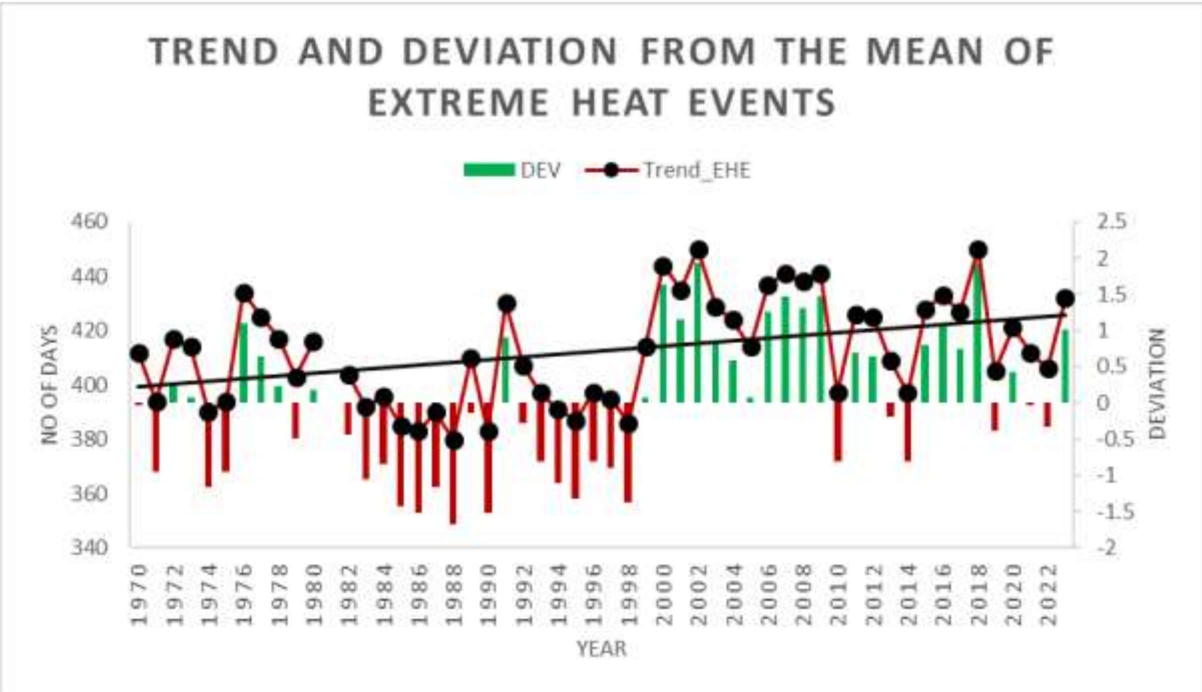

Figure 2.12: Trend and deviation from the mean of annual extreme heat events (1970-2024)

Figure 2.12 shows that the annual extreme heat events (EHEs) trend is rising in Nagpur city. The trend analysis shows a positive trend (R^2 = 0.16 and m = + 0.49). This change could be due to the high number of years with large annual EHEs post-2000, as seen in the figure. We can notice a high positive deviation from the mean post-2000, with 75% of the years showing a positive deviation from the mean. This indicates that, like the global scenario, EHEs have risen in Nagpur in the last two decades. Further, we also must understand the seasonal impact of EHEs on Nagpur, and the section below investigates the season-wise trend of EHEs.

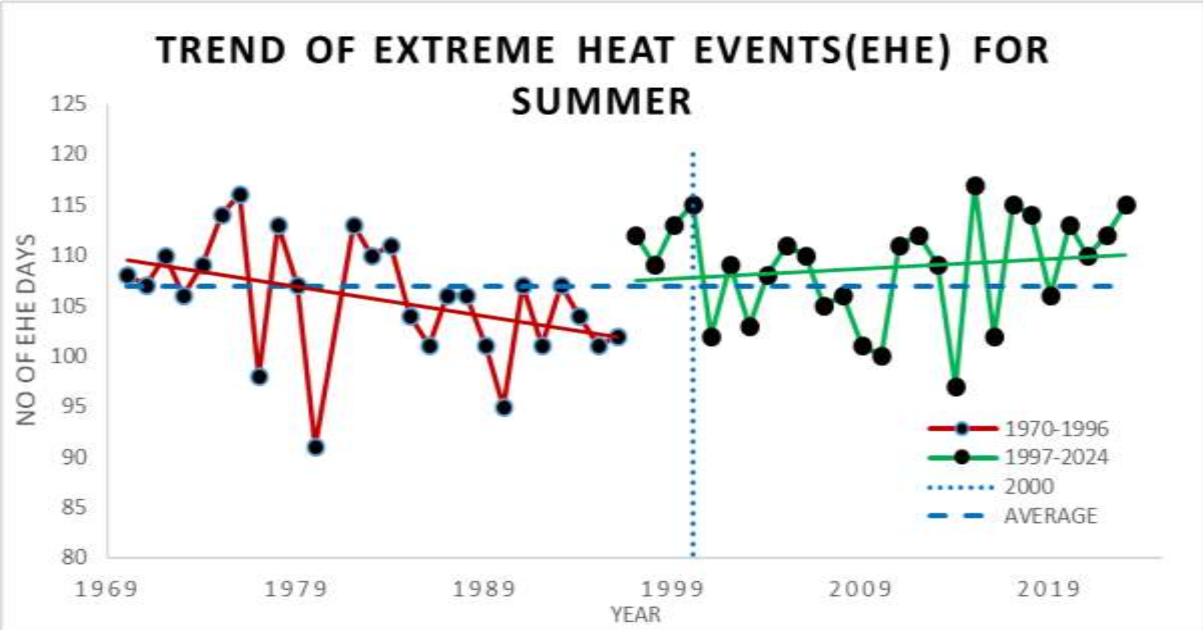

Figure 2.13: Trend of extreme heat events for summer (1970-2024)

Figure 2.13 shows that the trend of EHE for the summer season has changed from negative to slightly positive between 1970-1996 and 1997-2024. For the period between 1970-1996, the trend for EHE-Summer is negative (R^2 = 0.16 and m = - 0.29); for 1997-2024, the trend is slightly positive (R^2 = 0.02 and m = +0.09). This change can be driven by the higher no. of years (62.5%) having equal or higher EHE than the mean. A similar exercise conducted during the monsoon season yielded no trend for extreme heat events in 1970-2024.

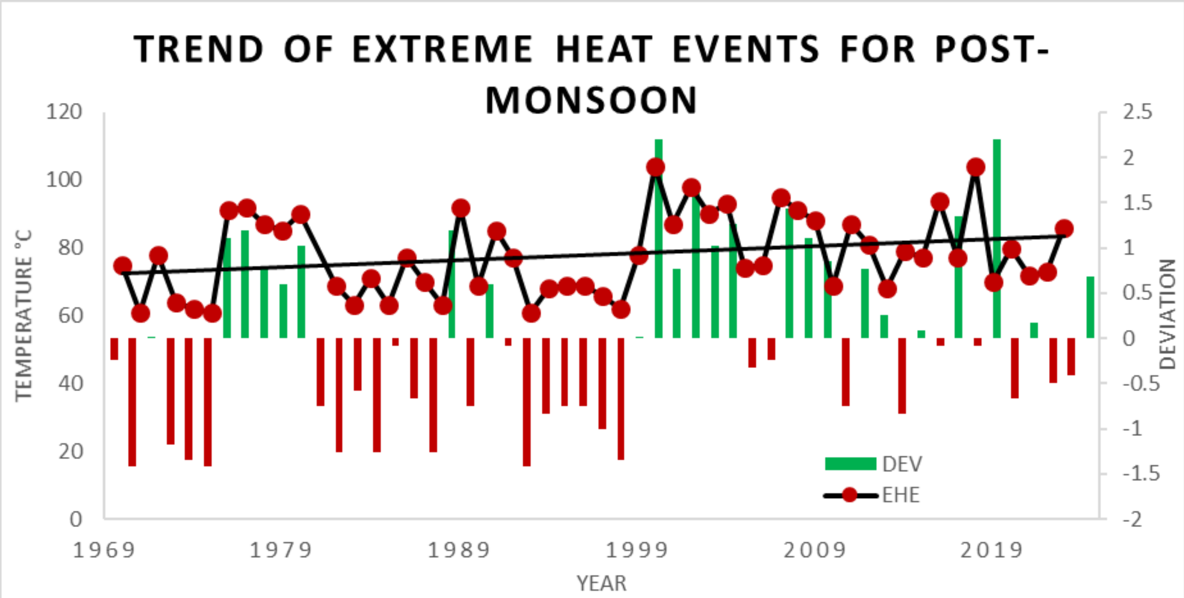

Figure 2.14: Trend and deviation from the mean of extreme heat events for post monsoon (1970-2024)

For the post-monsoon season, **Figure 2.14** indicates a slight positive trend for extreme heat events (R^2 = 0.07 and m = +0.21). However, when we evaluate the deviation of EHE data from the overall mean, we see that post-2000, 62.5% of the year has a positive deviation from the mean, which could drive the overall annual positive trend.

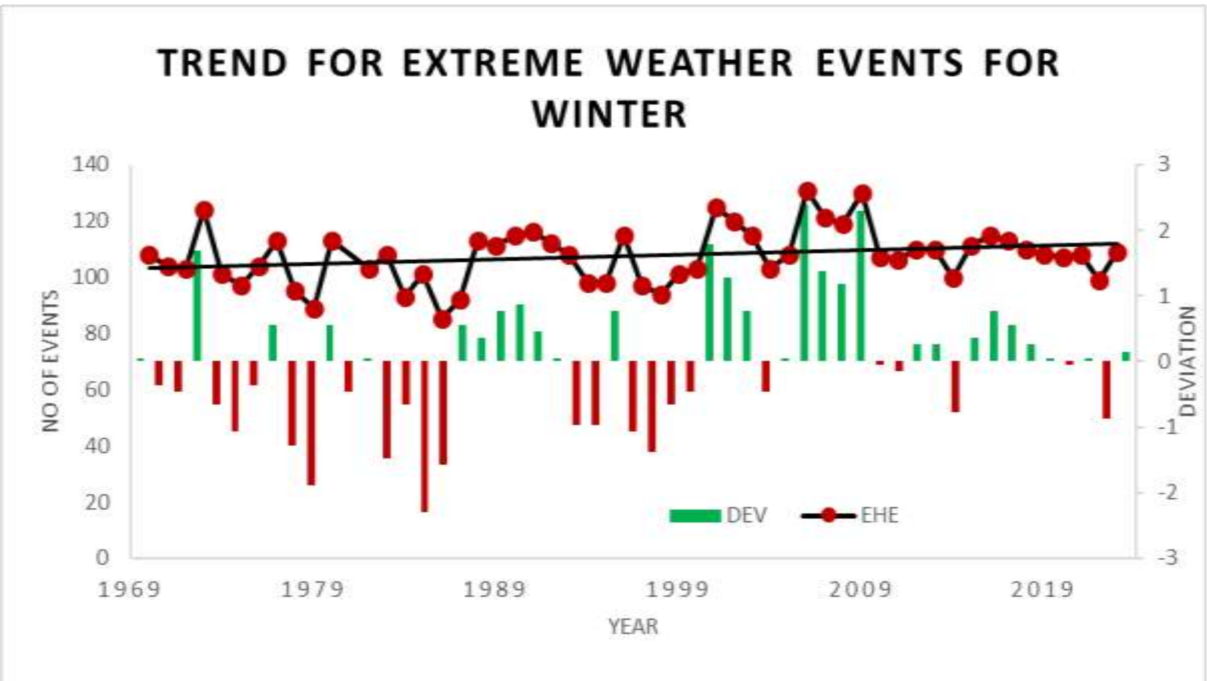

Figure 2.15: Trend and deviation from the mean of extreme heat events for winter (1970-2024)

For the winter season, **Figure 2.15** indicates a slightly positive trend for extreme heat events (R^2 = 0.07 and m = +0.168). However, when we evaluate the deviation of EHE data from the overall mean, we see that post-2000, 70.8% of the year has a positive deviation from the mean, which could drive the overall positive trend.

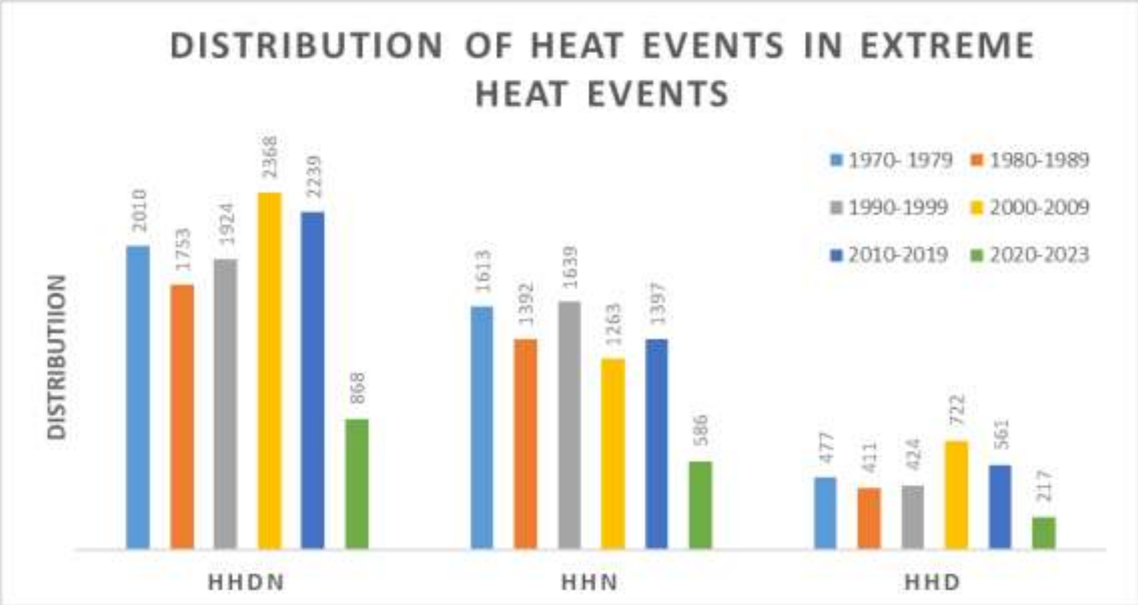

Figure 2.16: Distribution of sub-heat indices in extreme heat events index

From **Figure 2.16**, we can conclude that when comparing all three sub-heat indices, 1) High heat days (HHD), 2) High heat nights (HHN) and 3) High heat days and nights (HHDN), Nagpur has many days and nights (2239 days for 2010-2019) above the temperature threshold applied for the EHE index. It also indicates the presence of a decadal increase in the no. of HHDN. The alarming situation is that the number of HHDNs per year for 2020-23 is 290, much higher than 224 days/year (2010-2019) and 237 days/year (2000-2009). **Figure 2.17** shows the decadal change in the number of sub-heat indices compared to the base decade of 1970-1979. It can be observed that both HHDN and HHD are rising for Nagpur. So, if the current situation continues, 2020-2029 will be very challenging in managing human thermal comfort and energy consumption (discussed in the next section).

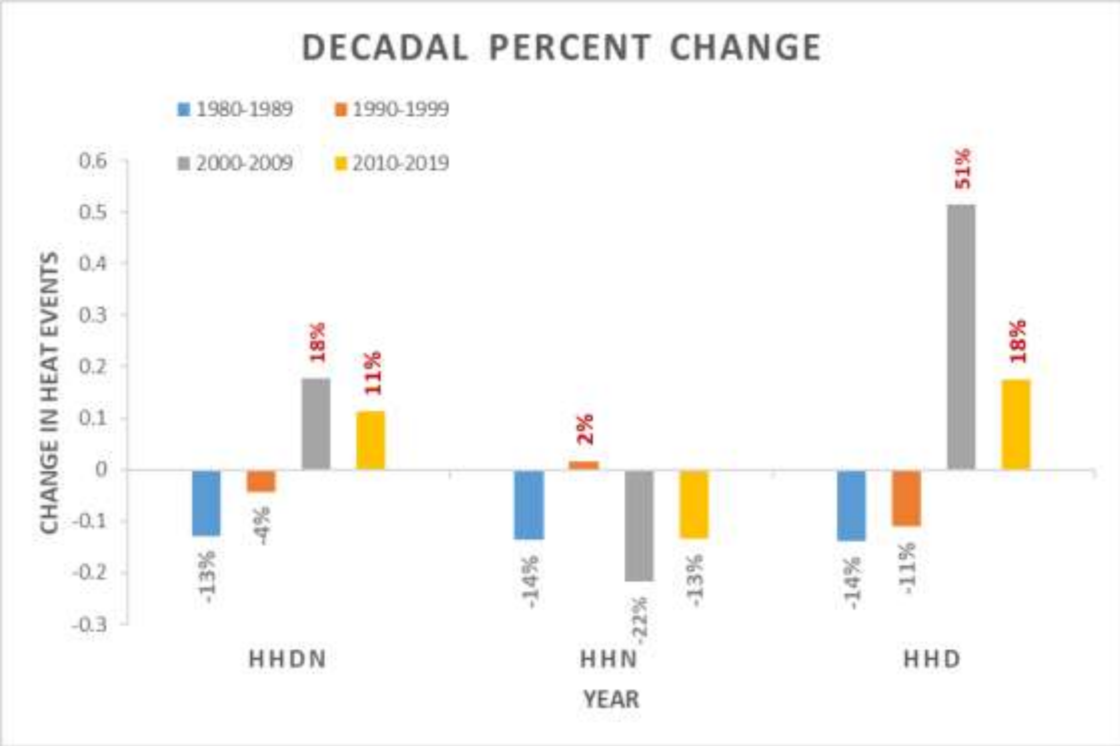

Figure 2.17: Decadal percent change in sub-heat indices in comparison to base decade (1970-1979)

b. Cooling Degree Days (CDD)

As described in the methods section, cooling degree days inform us about the energy required for space cooling in any building. The increase in the number of CDDs reflects an increase in the amount of energy needed to cool any building and a consequent increase in the release of greenhouse gases. It is reported that 80% of overall energy consumption occurs during buildings' operation (heating & cooling) [7]. **Figure 2.18** shows a positive trend for cooling degree days for Nagpur city for 1970-2024 (R^2 = 0.22 and m = + 4.4). Further, the data highlights the increase in positive deviation of CDD values from the mean post-2000, with 71% of the year showing a positive deviation.

The investigation of seasonal CDD reveals no trend for the summer season, as seen in **Figure 2.19**. However, we can observe a positive trend for the remaining seasons.

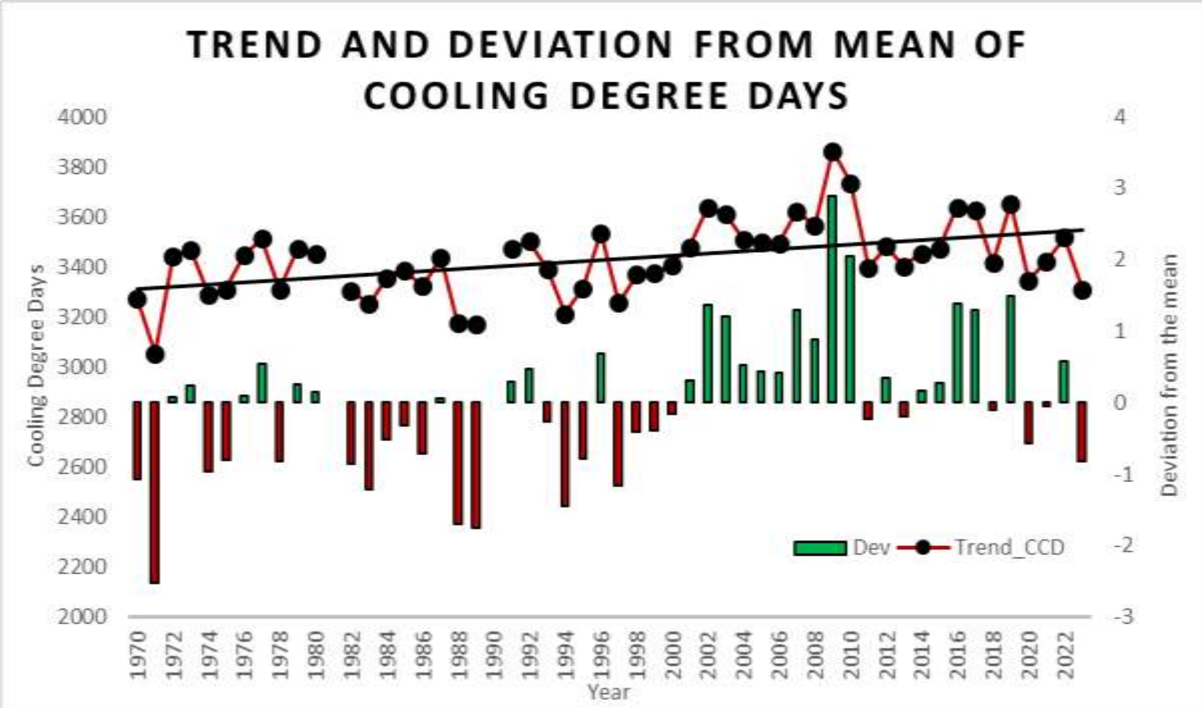

Figure 2.18: Trend and deviation from the mean of annual cooling degree days (1970-2024)

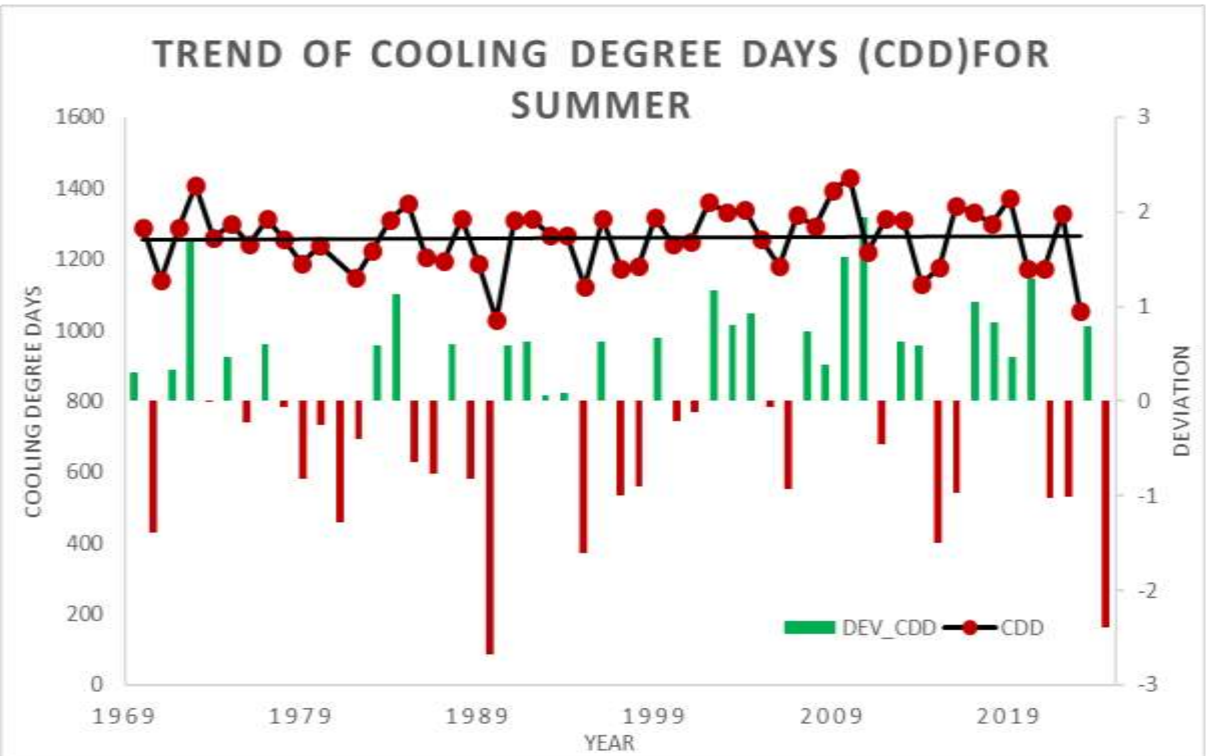

Figure 2.19: Trend and deviation from the mean of cooling degree days for summer (1970-2024)

For the monsoon season (**Figure 2.20**), we see a positive trend in the cooling degree days (R^2 = 0.135 and m = +2.0). The analysis highlights a large positive deviation from the normal post-2000, with 75% of the years showing a positive deviation.

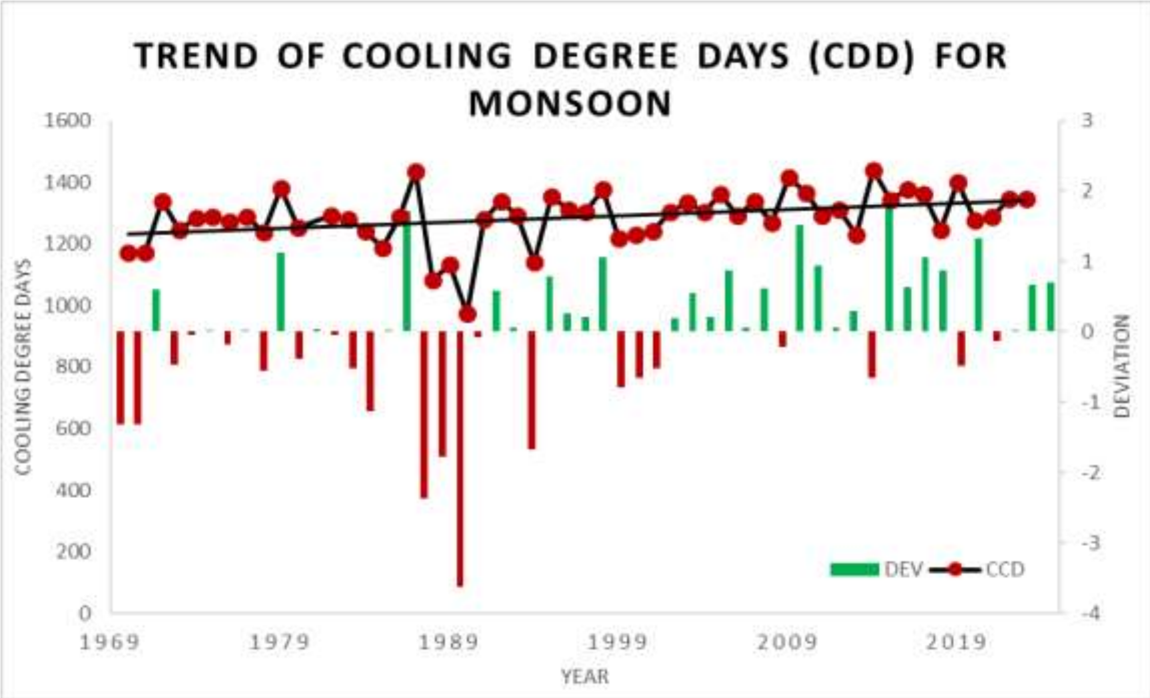

Figure 2.20: Trend and deviation from the mean of cooling degree days for monsoon (1970-2024)

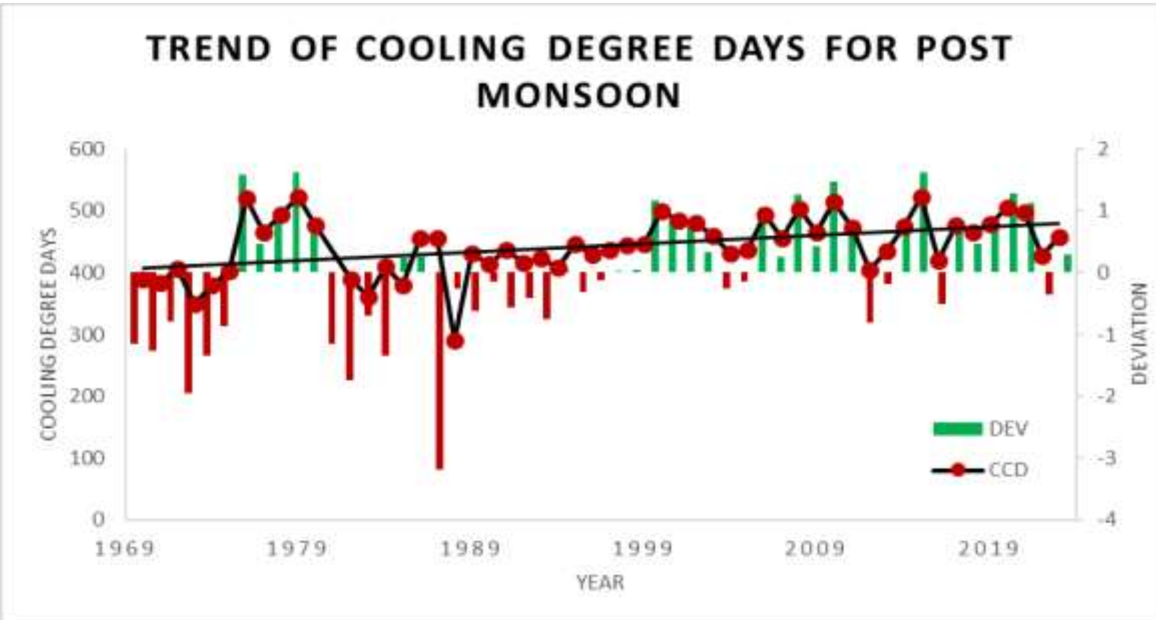

Figure 2.21: Trend and deviation from the mean of cooling degree days for post monsoon (1970-2024)

A similar pattern for the post-monsoon season (**Figure 2.21**) with a positive trend for cooling degrees (R^2 = 0.19 and m = +1.34) can be seen. Further, this trend is driven by the positive deviation from the mean post-2000, with 75% of the years showing a positive deviation.

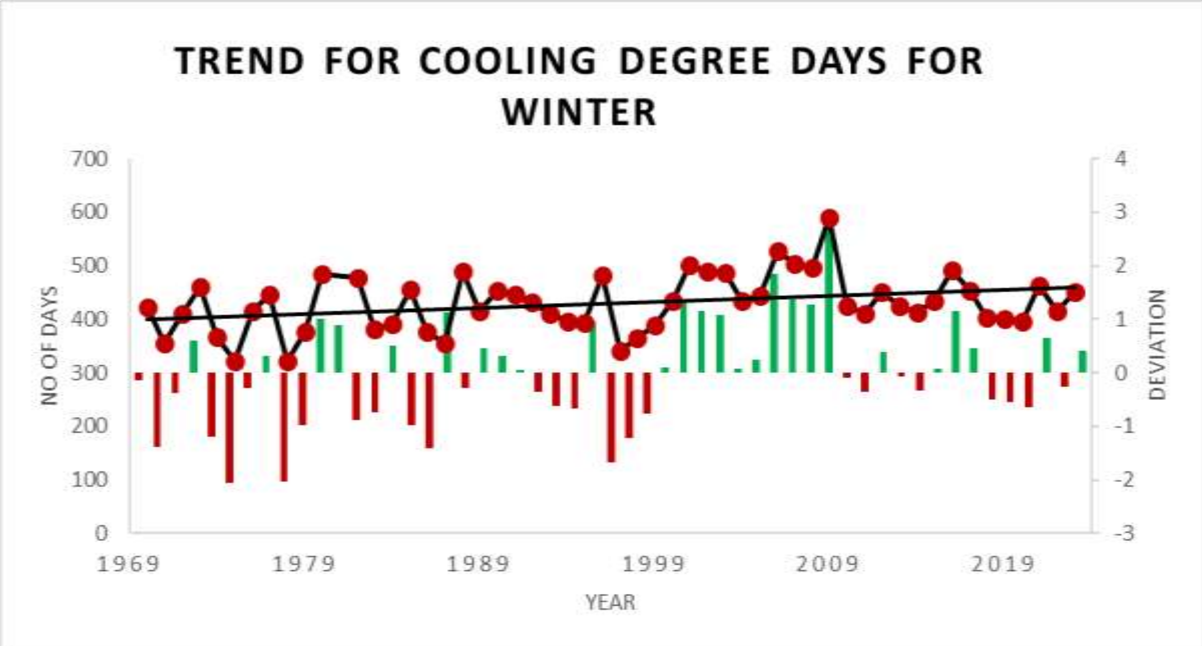

Figure 2.22: Trend and deviation from the mean of cooling degree days for winter (1970-2024)

Figure 2.22 illustrates the positive trend for the cooling degree days for the winter season ($R^2 = 0.1$ and m = +1.12). Further, this trend is driven by the positive deviation from the mean post-2000, with 67% of the years showing a positive deviation.

c. Diurnal Temperature Range (DTR)

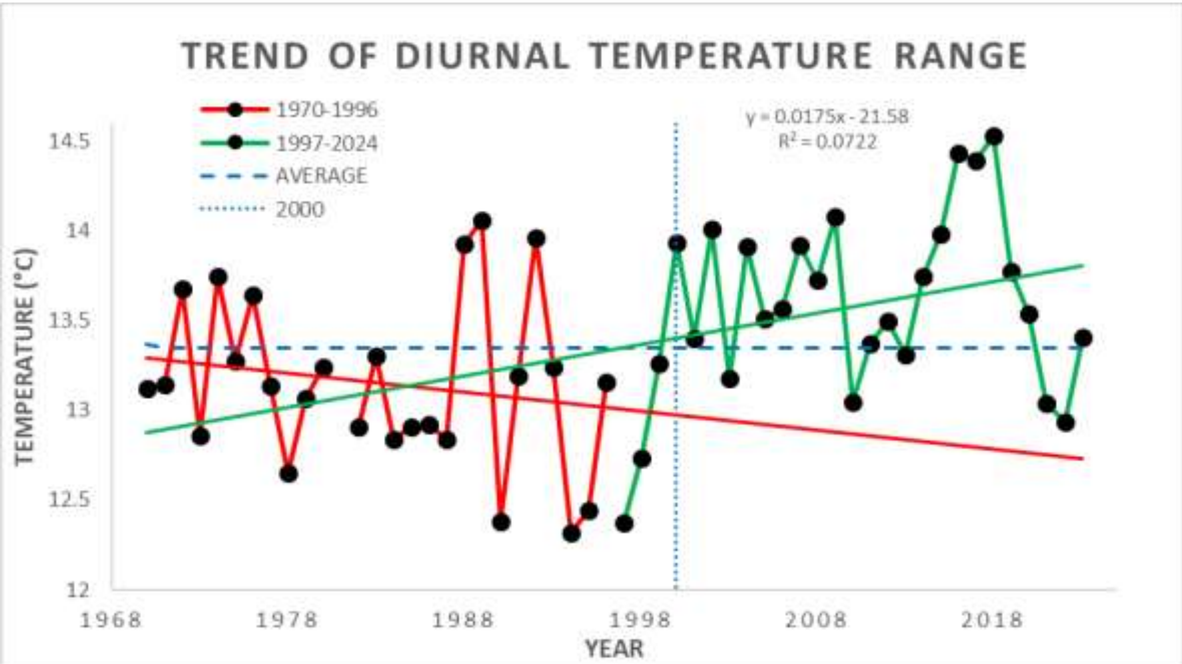

Figure 2.23: Trend of annual diurnal temperature range (1970-2024)

Diurnal temperature range (DTR), or temperature lag, is important in understanding the radioactive forcing effects and is a critical parameter affecting crop production and species performance [19]. DTR plays an essential role at an urban level as it impacts different sectors, like human health and energy consumption [20], and studies have shown that DTR is highly sensitive to urbanization[21]. Any changes (both +ve or –ve) in DTR can have significant implications, such as weather variability or exposure to heat waves (especially at night time), impacting both humans, flora, and fauna.

Figure 2.23 shows a change in the trend of DTR between 1970-1996 and 1997-2024. For the first period (1970-1996), we observe a negative trend (R^2 = 0.03 and m = -0.01), and for the second period (1997-2024), we observe a positive trend (R^2 = 0.07 and m = +0.02). This change is driven by the above-average values of DTR post-2000 (79% of the year).

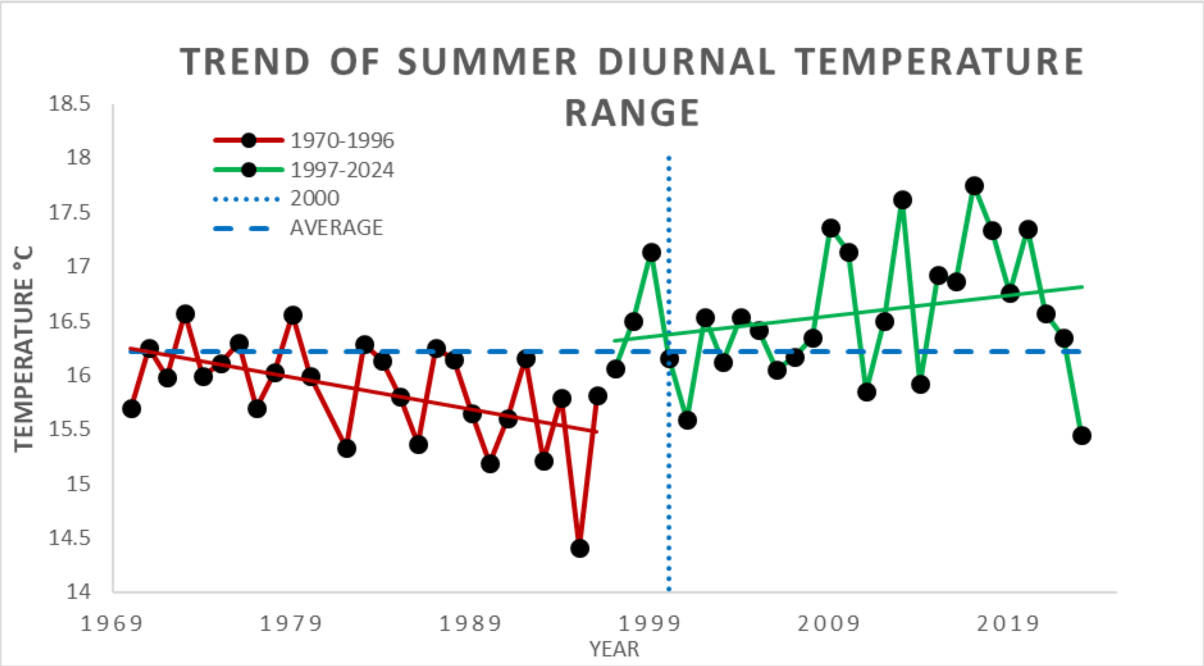

Figure 2.24: Trend of diurnal temperature range for summer (1970-2024)

The seasonal trend analysis of DTR was performed for all four seasons: 1) Summer, 2) Winter, 3) Monsoon and 4) Post Monsoon. The study showed no noticeable changes in the DTR trend in Monsoon, post-monsoon and winter. For the summer season, the analysis highlighted a shift in the trend between two 36-year periods. **Figure 2.24** illustrates a negative trend for the 1970-1996 period (R^2 = 0.25 and m = -0.02), whereas a positive trend was seen for the 1997-2024 period (R^2 = 0.06 and m = +0.02). This change can be attributed to above-average values of DTR post-2000 (67% of years).

d. Heat Index (HI)

When humans are exposed to extreme heat (heat stress and stroke), it is important to assess the role played by relative humidity. As the evaporative cooling of sweat controls heat exposure, heat stress or stroke is also influenced by ambient air temperature and relative humidity, as higher relative humidity reduces evaporative cooling and increases heat exposure [22]. The method proposed by the NOAA and adopted by IMD is the most widely used to estimate the heat index (including humidity), and this study has assessed the trend of Nagpur's heat index.

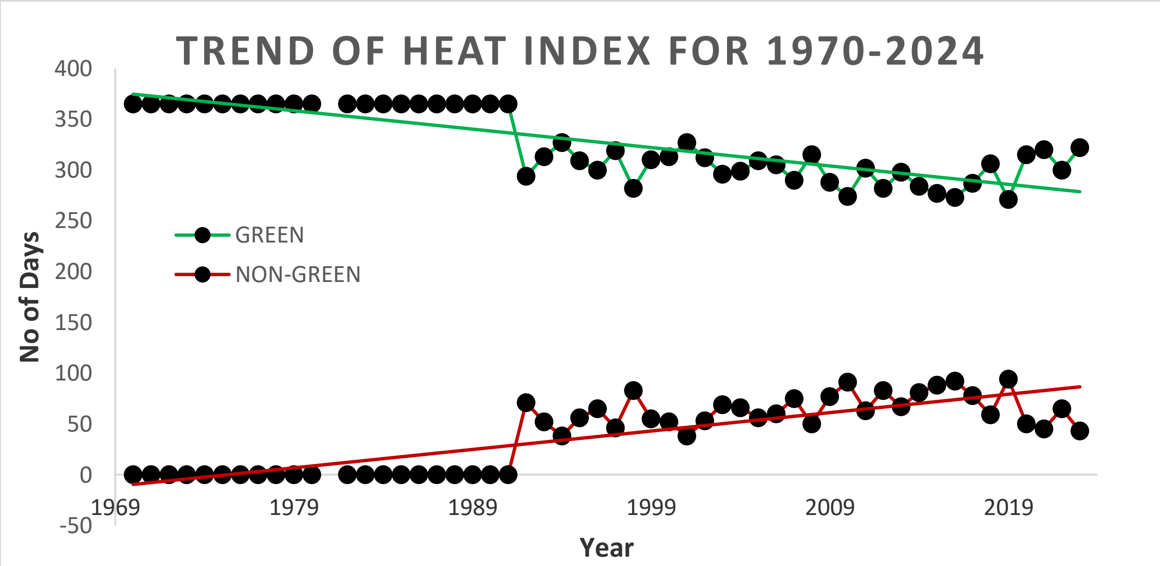

Figure 2.25: Trend of annual green and non-green heat index for Nagpur (1970-2024)

As discussed in **Table 2.2**, the estimated heat index is color-coded into 1) Green, 2) Yellow, 3) Orange and 4) Red. **Figure 2.25** shows the annual trend of days where the heat index falls into the Green and Non-Green categories. The figure shows that the green days show a negative trend (R^2 = 0.69 and m = -1.81), and the non-green days show a positive trend (R^2 = 0.7 and m = +1.8).

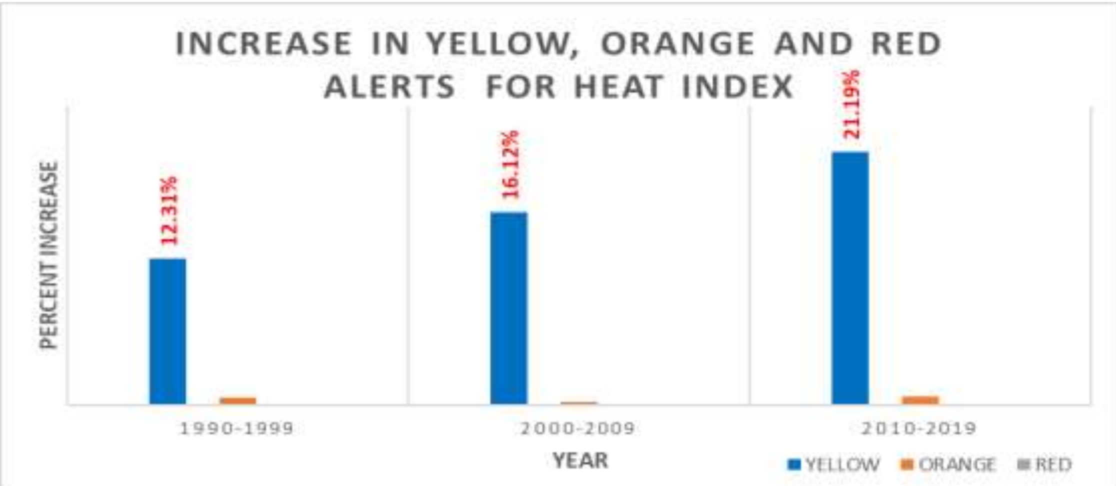

Figure 2.26: Percent increase in yellow, orange and red alert for Nagpur (1970-2024)

Figure 2.26 indicates that post-1990, there has been a considerable increase in the non-green alerts for Nagpur. As seen in the figure, yellow alerts have increased by 12.31%, 16.12% and 21.19% for 1990-99, 2000-09 and 2010-19, respectively, in comparison to the base decade of 1970-79.

Seasonal analysis shows that non-green alerts are rising for summer and Monsoon for Nagpur. **Figure 2.27** shows the summer trend of days where the heat index falls into the Green and Non-Green categories. The figure shows that the green days show a negative trend (R^2 = 0.696 and m = -0.79), and the non-green days show a positive trend (R^2 = 0.7 and m = +0.79). Similarly, **Figure 2.28** shows that, for Monsoon, the green days show a negative trend (R^2 = 0.58 and m = -0.97) and the non-green days show a positive trend (R^2 = 0.61 and m = +0.99).

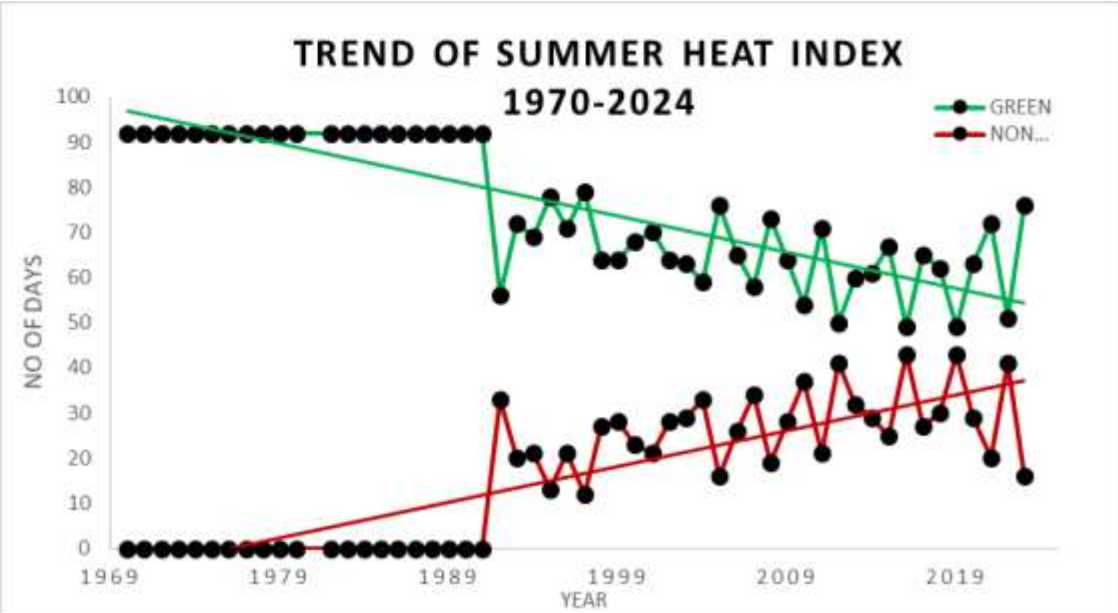

Figure 2.27: Trend of green and non-green heat index for summer (1970-2024)

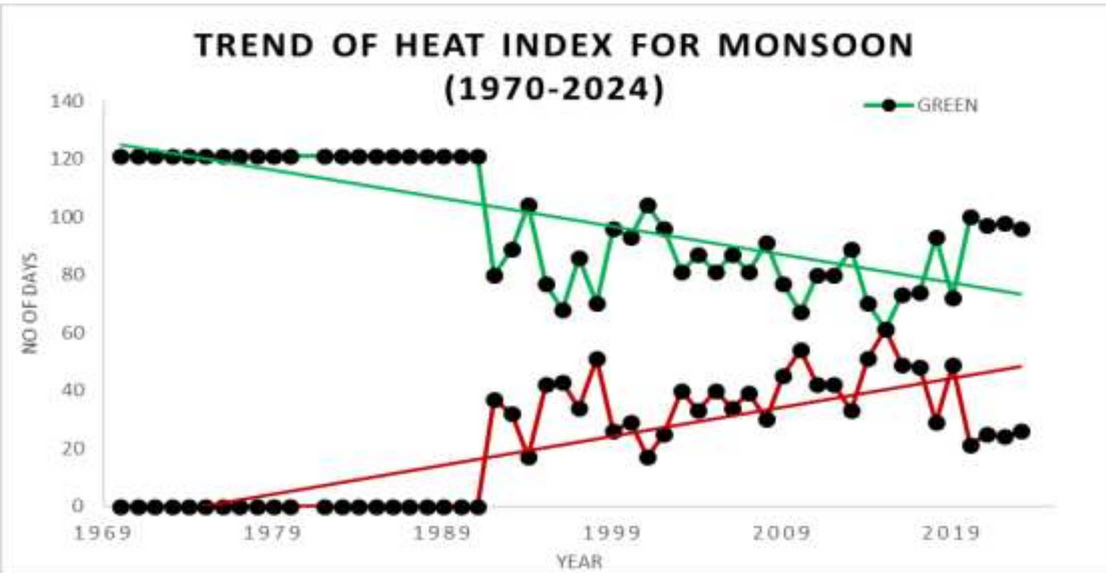

Figure 2.28: Trend of green and non-green heat index for monsoon (1970-2024)

b. Variation in Rainfall and its Indices for 1970-2024

i. Rainfall

Precipitation is one of the most critical variables in the study of climate. The change in frequency and intensity of rainfall is often studied to understand the extent and magnitude of climate change. This is especially true for India, as its agro-based economy depends on the southwest Monsoon. Therefore, it is important to examine and understand the Spatial-temporal dynamics of this variable to provide credible input to policymakers. Agriculture is the mainstay of India's economy and employs 71% of the citizens [23]. Also, India is one of the world's most vulnerable to flooding and drought-prone countries [24]. Therefore, it is crucial to understand the changes in the precipitation pattern over Nagpur to understand the impact of climate change.

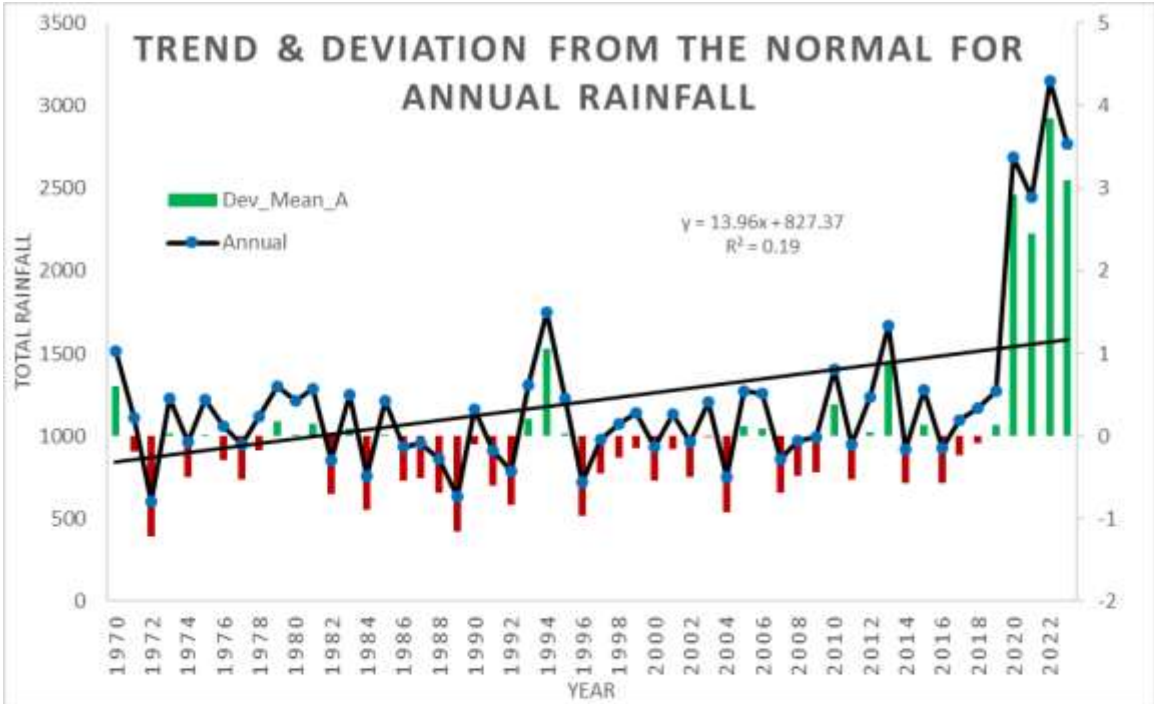

Figure 2.29: Trend and deviation from the normal of annual rainfall (1970-2024)

Figure 2.29 indicates an increase in the total annual rainfall in Nagpur city. This increase may be driven by high rainfall for the years 2020-23 with a positive trend (R^2 = 0.2 and m = +13.96). This pseudo-positive trend may be driven by a heavy deviation in rainfall from the normal in the last 2-3 years. It is important to analysis the seasonal trend of rainfall in Nagpur. Similar to the temperature variable, the time period is divided into two blocks (1970-96 and 1997-24) to understand if there has been any change in the rainfall trend in Nagpur.

The trend of summer season over Nagpur is illustrated in the **Figure 2.30**. In the figure, it can be observed that that for both time periods, a varying degree of positive trends is present. For the period between 1970-1996, a positive trend of R^2 = 0.05 and m = +0.9 and between 1997-2024, a positive trend of R^2 = 0.08 and m = +1.9) is present. Only 42% of the year post-2000 show a positive mean deviation.

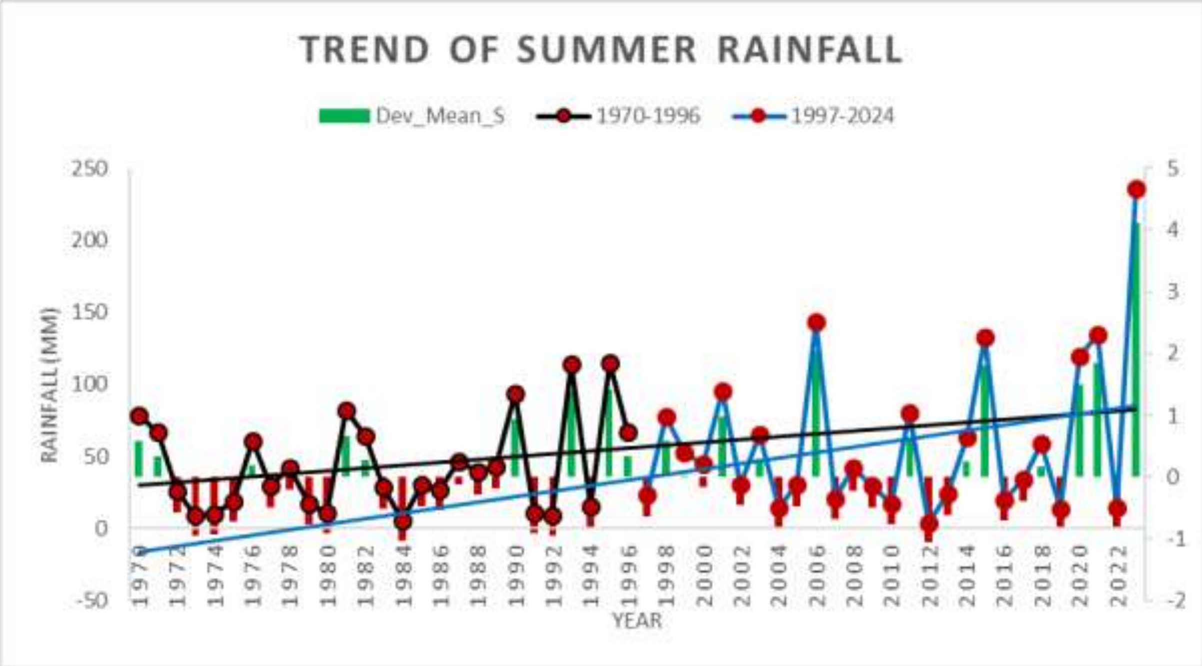

Figure 2.30: Trend and deviation from the normal of total rainfall in summer (1970-2024)

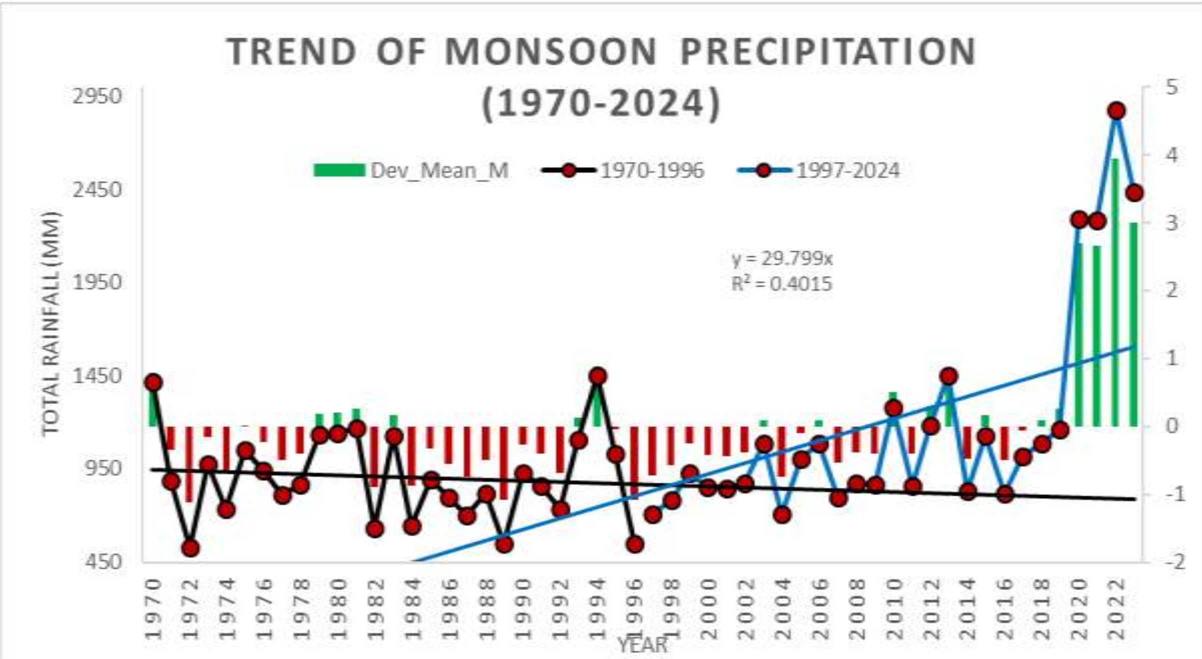

Figure 2.31: Trend and deviation from the normal of total rainfall in monsoon (1970-2024)

For the monsoon season (**Figure 2.31**), the trend analysis shows a change in the pattern for two time periods being considered, with the trend changing from slight negative (R^2 = 0.01 and m = -

2.9) during 1970-1996 to positive trend (R^2 = 0.4 and m = +29.96) during 1997-2024. This change could be due deviation from the normal post 2020.

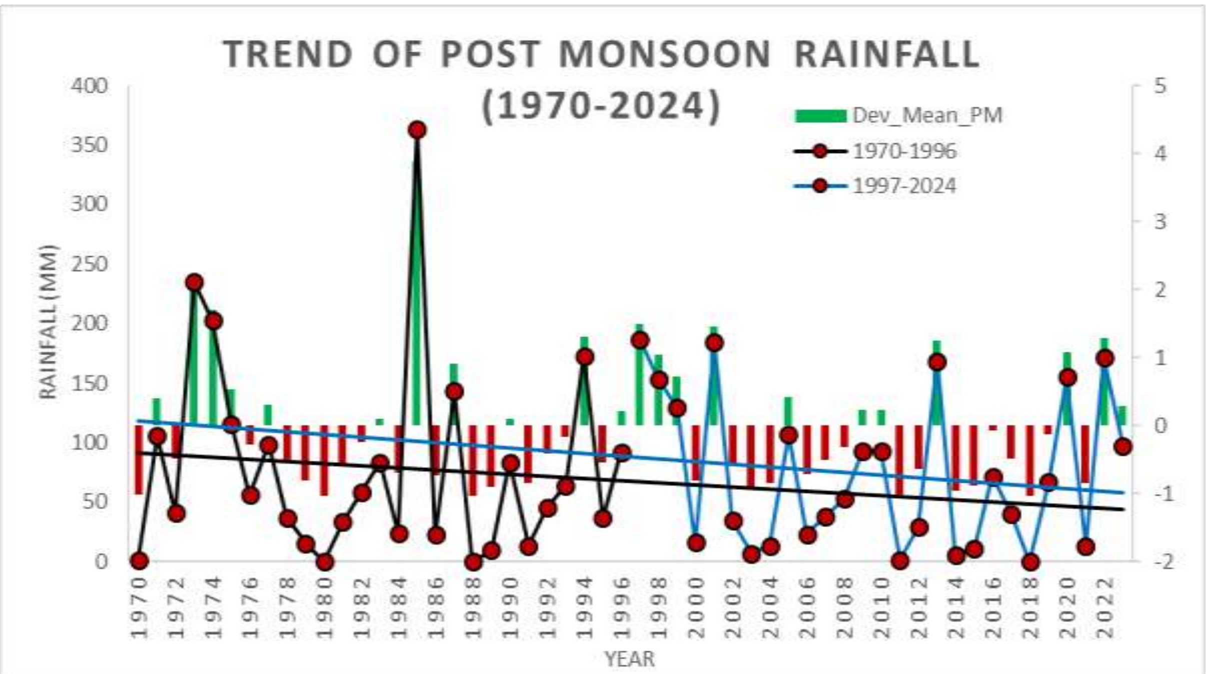

Figure 2.32: Trend and deviation from the normal of total rainfall in post monsoon (1970-2024)

The trend analysis shows a decrease for the post-monsoon season (**Figure 2.32**) for the two time periods considered. The figure shows a slight negative trend for 1970-1996(R^2 = 0.01 and m = -0.8) and 1997-2024 (R^2 = 0.02 and m = -1.14).

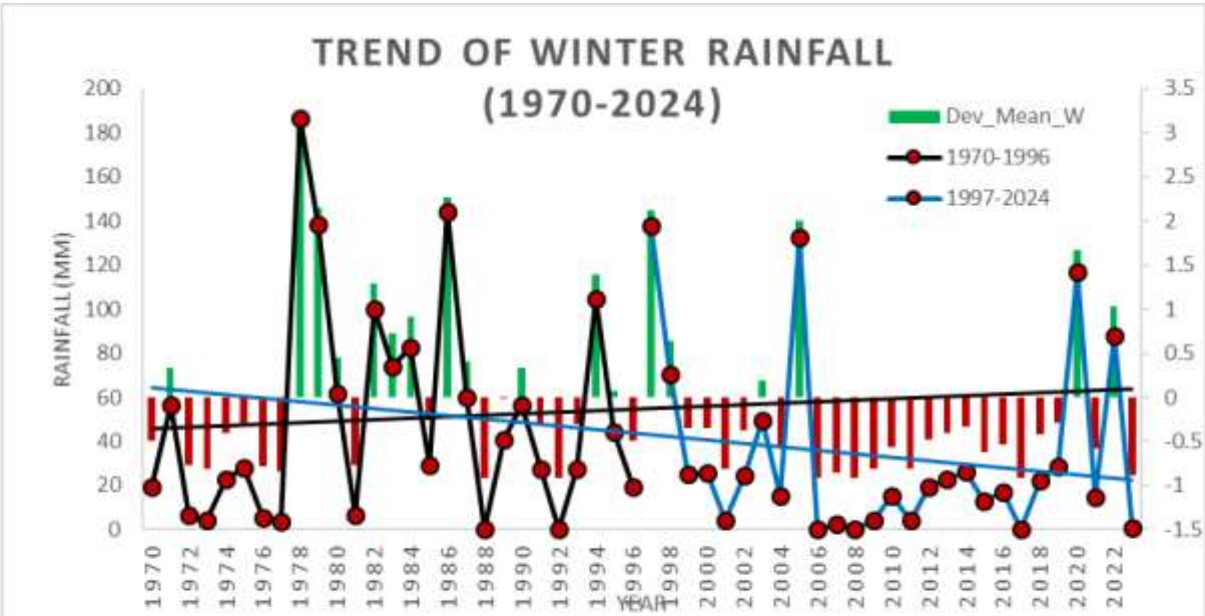

Figure 2.33: Trend and deviation from the normal of total rainfall in post monsoon (1970-2024)

For the winter season (**Figure 2.33**), the trend analysis shows a change in the pattern for two time periods being considered, with the trend changing from slight positive (R^2 = 0.003 and m = +0.3) during 1970-1996 to negative trend (R^2 = 0.02 and m = -0.7) during 1997-2024.

ii. Rainfall Indices

a. Precipitation Concentration Index (PCI)

PCI is a handy indicator of rainfall concentration, droughts or flood risk prediction, and rainfall erosivity, which was calculated on the annual and monthly scale. PCI or SPCI values below 10 denote a uniform monthly rainfall distribution throughout the year (low precipitation concentration); values ranging from 11 to 15 indicate a moderate concentration of precipitation; values between 16 and 20 represent an irregular distribution; and values above 20 represent a strong irregularity (high precipitation concentration) in precipitation distribution.

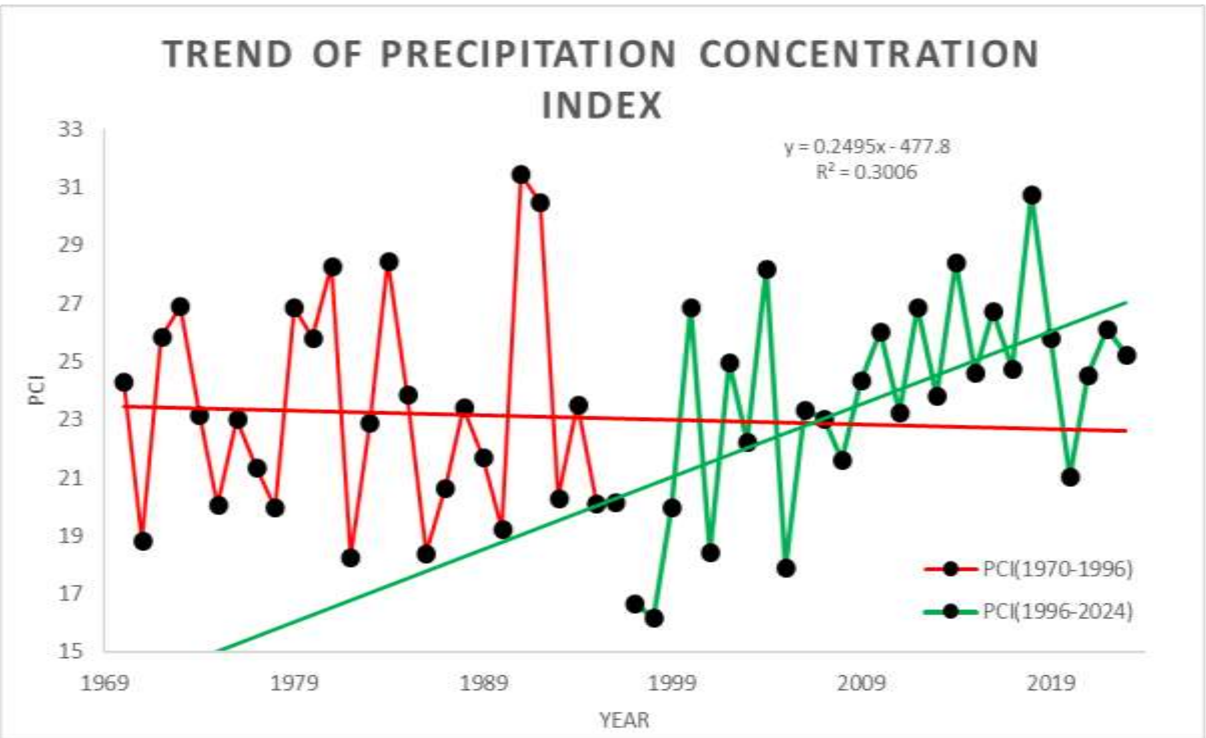

Figure 2.34: Trend of precipitation concentration index (1970-2024)

Figure 2.34 shows that Nagpur's precipitation concentration index (PCI) for 1970-2024 is above 15. This indicates that Nagpur's rainfall is irregular (16-20). If the trend of PCI is investigated, then the figure indicates a slight negative trend (R^2 = 0.001 and m = -0.02) for the period of 1970-1996 and a positive trend (R^2 = 0.3 and m = +0.24) for the period 1997-2024. Post 2000, a large number of years have a PCI above 20, indicating a high irregularity in precipitation distribution.

b. Rain day (RD) and others

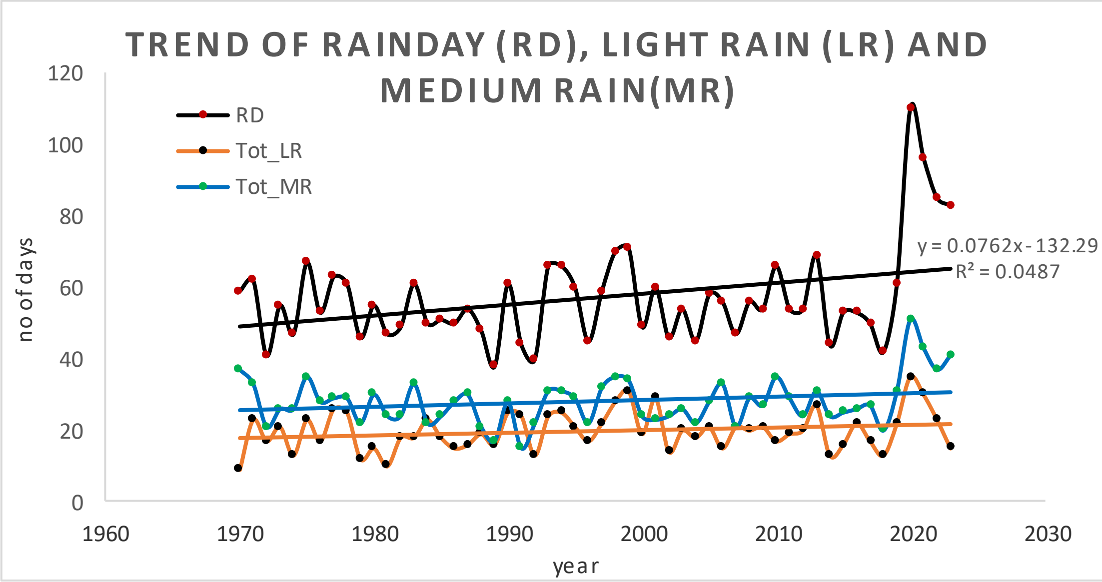

Figure 2.35: Trend of rainfall indices RD, LRD and MRD (1970-2024)

The trend analysis of rainfall indices, as discussed in section 4.e, shows a positive trend for rain day (RD), light rain day (LRD) and medium rain day (MRD). The other rainfall indices, namely, rather heavy rain days, heavy rain days, very heavy rain days, and extreme rain days, don't show any trend due to a lack of data. **Figure 2.35**, show a positive trend for RD (R^2 = 0.124 and m = +0.3), LRD (R^2 = 0.05 and m = +0.07) and MRD (R^2 = 0.06 and m = +0.1).

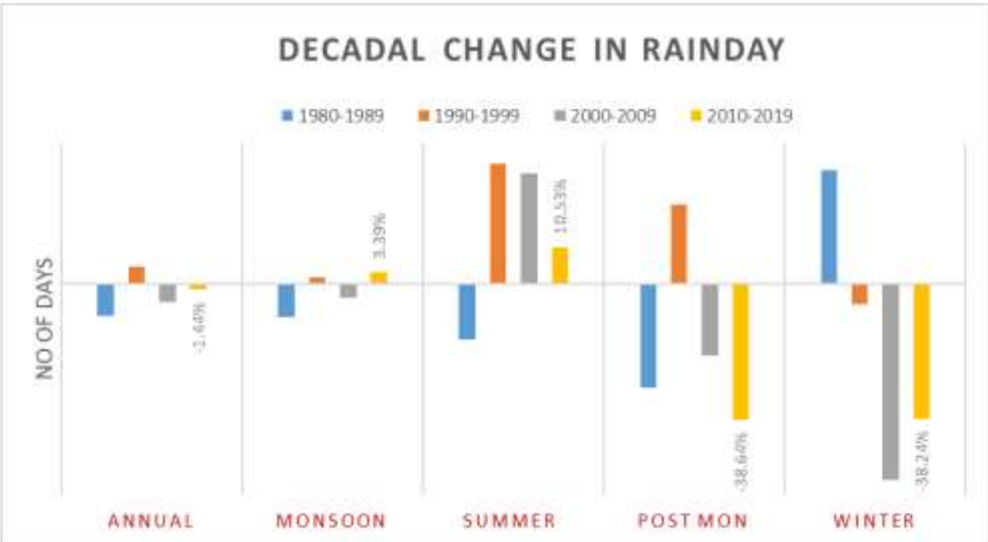

Figure 2.36: Decadal change in number of rain days for both annual and seasonal periods in comparison to 1970-79 decade

A comparative study of the decadal change in rain days to the baseline decade of 1970-1979 is depicted in **Figure 2.36**. The figure illustrates a slight increase in the monsoon rain days for 2010-19. However, we see a drastic decrease in rain days for the remaining seasons. For summer, even though the 2010-19 decade shows a 10.5% increase compared to the baseline decade, rain days in summer for the 2010-19 decade have reduced compared to the 1990-99 and 2000-09 decade. The number of rain days for 2010-19 has reduced by 38.6% and 38.2% for post-monsoon and winter, respectively. Overall, Nagpur's number of rain days has reduced by 1.44% for 2010-19.

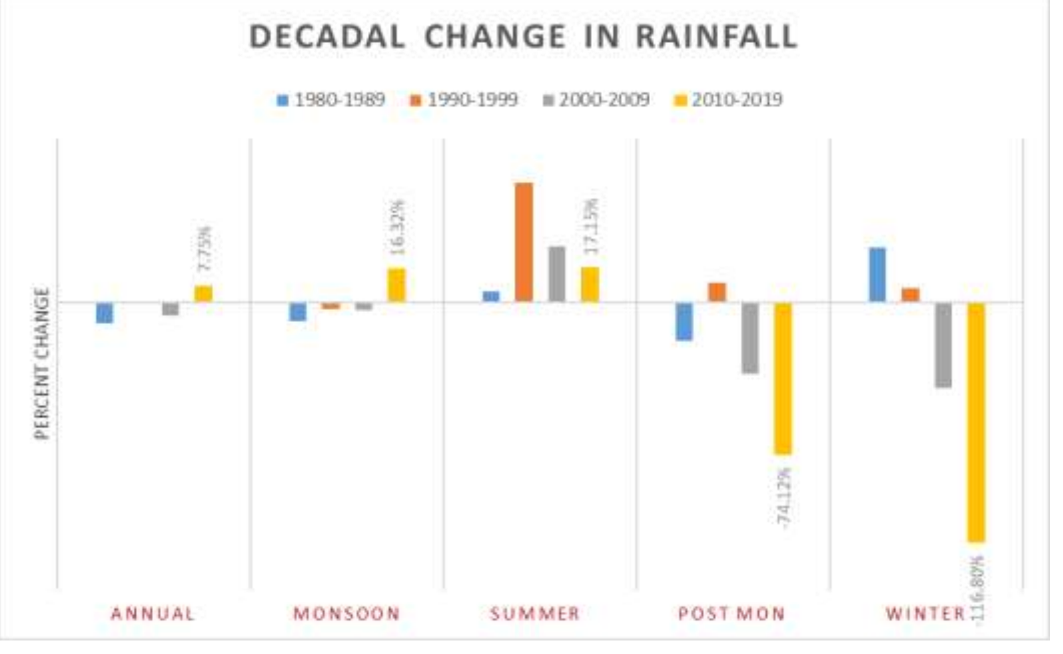

Figure 2.37: Decadal change in total rainfall for both annual and seasonal periods in comparison to 1970-79 decade

A comparative study of the decadal change in rainfall to the baseline decade of 1970-1979 is depicted in **Figure 2.37**. The figure illustrates increased monsoon and summer rainfall for 2010-19. However, we see a drastic decrease in rain days for the remaining seasons. The 2010-19 decade shows a 17.15% (summer) and 16.32% (Monsoon) increase compared to the baseline decade. The rainfall for 2010-19 has reduced by 74.12% and 118.80% for post-monsoon and winter, respectively. However, interestingly, overall annual rainfall increased by 7.75% from 2010 to 19 compared to the baseline.

2.5 Inferences

The environmental status of Nagpur city reveals a complex interplay of climatic factors that have significant implications for its sustainability and livability. The detailed study on climate change impacts, adaptation, and mitigation in Nagpur underscores the urgency of addressing these issues through comprehensive planning and technological interventions. This section integrates critical findings from the report, highlighting areas of concern, explaining the reasons behind observed trends and patterns, and proposing robust mitigation and adaptation strategies. Nagpur, situated on the Deccan Plateau, experiences a tropical savannah climate characterized by distinct wet and dry seasons. The city's climatic conditions are influenced by both monsoonal and continental factors, leading to significant variations in temperature, precipitation and its indices.

Temperature (min and max) shows no significant trend for annual and seasonal time series. However, there has been a change in the trend of temperature-based indices. We see an increase in extreme heat events with 75% of years post-2000, showing a positive deviation from the normal/mean. Seasonal analysis indicates the change in the trend of EHE in the summer season, with the negative trend for the 1970-1996 period changing to a positive trend for the 1997-2024 period. If we investigate the sub-components of the EHE index, it can be observed that Nagpur has a large number of days where both day and night time temperatures (min and max) are above the human thermal comfort levels. A significant conclusion that can be drawn is the number of HHDN per year, which has increased from 61% in 2000-2009 to 65% in 2010-2029. Further, the decadal analysis shows that compared to the base decade of 1970-79, both HHDN and HHD have increased by 11% and 18%, respectively, for 2010-2019.

In a city like Nagpur, the cooling of building spaces is a big challenge, and a lot of energy is consumed to maintain the cooling of residential and commercial buildings. Cooling degree days quantifies the amount of energy required for space cooling. For Nagpur, a positive trend can be observed, with 71% of the years after 2000 showing a positive deviation from the normal. This increase in cooling-degree days may be driven by warmer days and nights during Monsoon and post-monsoon season, corroborated by the increase in HHDN for Nagpur. Diurnal temperature range (DTR) also impacts various sectors, like health, energy, etc., at the urban level. Any changes (both +ve or –ve) in DTR can have significant implications, such as weather variability or exposure to heat waves (especially at night time), impacting both humans, flora, and fauna. The temporal analysis of DTR shows that at an annual scale, DTR has changed from a negative (1970-1996) to a positive (1997-2024) trend. This means that there is a significant difference between the daily maximum and minimum. This trend is especially true for the summer season in Nagpur city.

One of the most important indices for understanding climate variability's impact is the change in the Heat Index (proposed by NOAA), which includes the impact of temperature and humidity. The temporal data analysis shows a significant increasing trend for the non-green alerts (i.e. heat index above 35 ºC as per table 4.2), which is a worrying development. A decadal per cent change analysis was also done to see the change in the number of non-green (yellow, orange, red) in comparison to the base decade of 1970-1979. We see a 21.19 per cent increase in non-green alerts in the 2010-2019 decade. The seasonal analysis shows an increase in the positive trend of non-index alerts in both summer and monsoon seasons. This could be due to increased temperature levels in the summer and both temperature and humidity in the monsoon season.

For rainfall, the temporal trend analysis shows an uptick in rainfall in Nagpur. However, this uptick could be explained by the above-normal rainfall between 2020-23, when almost 11000 mm occurred over four years. Between 1970 and 2019, the average decadal rainfall amounts to 10000 mm; however, this average rainfall has already happened in 4 years for the 2020-29 decade. This massive increase in rainfall could be a sign heralding the changes in rainfall patterns in Nagpur. The seasonal analysis shows that this massive jump in rainfall has occurred during the monsoon season, with post-monsoon and winter showing a decreasing trend. The decadal change in rainfall shows an increase in monsoon rainfall by 16% and a drastic decrease in both post-monsoon and winter by 74% and 116%, respectively. The analysis of rainfall indices also supports the rainfall intensity and frequency change. The Precipitation concentration index (PCI) shows a drastic change in the trend for rainfall variability. The PCI for Nagpur has been above 15-16 (irregular distribution). However, post-2000, the PCI has shifted to a high/strong irregularity. This shows that post-2000, the intensity and frequency of rainfall have shifted for Nagpur. If we evaluate another rainfall index, i.e. rain day, we see a decrease in the number of rain days for all seasons for the 2010-19 decade. This bolsters the point that the intensity of rainfall has increased; however, the frequency has shifted from irregular to highly irregular. This change can lead to heavy rainfall spells of very short duration that could stress city infrastructure and services in the future.

2.6 Recommendations

The study suggests that Nagpur is steadily heading towards a warmer and irregular rainfall climate. To mitigate this, it is critical to identify areas of concern and take both adaptive and mitigative actions. From the report, we can identify four major areas of concern.

1. **Rising temperature:** The increasing average temperatures and more frequent heatwaves pose significant risks to public health, particularly for vulnerable populations such as the elderly and children. The demand for cooling energy also substantially burdens the city's energy infrastructure.

2. **Water resource management:** Erratic rainfall patterns and prolonged dry spells threaten the sustainability of water resources. The fluctuation in water availability affects both urban water supply and agricultural productivity, leading to potential conflicts over water use.
3. **Public health impacts:** Higher temperatures and extreme weather events contribute to various health issues, including heat-related illnesses, respiratory problems, and vector-borne diseases. The urban poor, who often lack adequate housing and healthcare access, are particularly at risk.
4. **Infrastructure Vulnerability:** The city's infrastructure, including roads, buildings, and power lines, is increasingly vulnerable to extreme weather events. Heavy rains can cause flooding and waterlogging, while heatwaves can damage roads and strain power grids.

The present study on the climate variability of Nagpur city for over 50 years (1970-2019) indicates that climate-related changes are happening in the town, and its impacts are being felt in terms of extreme weather events, energy consumption, and food/water security issues. This section will delineate some action points that can be taken to understand further the impact of climate change on various city-wide sectors and provide specific recommendations.

Actions	**Areas of Actions**	**Details**
Mitigation	Urban Greening	• Expanding green spaces, including parks, urban forests, and green roofs, can help mitigate the urban heat island effect. Trees and vegetation provide shade, improve air quality, and reduce surface temperatures.
	Water Conservation	• Implementing rainwater harvesting systems and promoting water-efficient practices are crucial for sustainable water management. Urban water bodies should be maintained and restored to enhance groundwater recharge and provide cooling effects.
	Energy Efficiency	• Promoting energy-efficient buildings and appliances can reduce energy consumption and lower greenhouse gas emissions. Incentives for using renewable energy sources, such as solar panels and wind turbines, should be provided to encourage their adoption. • Developing smart grid technologies can improve energy distribution efficiency and

		facilitate the integration of renewable energy sources.
	Use of Renewable Energy	• Encouraging renewable energy sources like solar panels and wind turbines can reduce dependence on fossil fuels and lower greenhouse gas emissions. • Promoting the adoption of electric vehicles can reduce vehicular emissions and improve urban air quality. Infrastructure for EV charging stations should be developed to support this transition. • Centralized energy systems — with large power plants and infrastructure connected over long distances — are more vulnerable to climate change. So decentralized energy systems, policy for block or neighbourhood level solar energy plants for energy generation and supply
Adaptation	Use of Green Urban Infrastructure	• Greening mass transit systems like heat-proofing buses and greening stops • Green roofs are specially engineered roofing systems designed to have plants and vegetation growing on their surface. With green roofing, rainwater flow is slowed, and the roof absorbs some of it. This then decreases stormwater runoff and pollution into drainage systems as the vegetated surfaces provide a degree of rainwater retention, attenuation and treatment. • Using reflective materials for roofs and walls can reduce heat absorption and lower indoor temperatures, improving comfort and reducing energy demand for cooling.
	Stormwater Management	• Use of advanced drainage systems like bioswales. Implementing advanced urban drainage systems can help manage stormwater and prevent flooding during heavy rains. These systems should be designed to accommodate future changes in rainfall patterns. • Porous surfacing like pavements. The non-porous surface creates bottlenecks, leading to flooding. Using permeable surfaces like

		porous asphalt, pervious concrete, porous turf, and open-jointed blocks can help manage stormwater and indirectly recharge groundwater.
	New scale of development	• New Urbanism: Building/Street/Block, Neighborhood and Town/City • Building and street design can respond to climate change, e.g., raising foundations or designing to accommodate flooding. On the block scale, pocket neighbourhoods may use social connection as a form of resilience • Neighbourhood-wise programmes for climate change adaptation with the involvement of the local populace

2.7 Conclusion

Nagpur city is at a critical juncture in its efforts to address climate change impacts and enhance its resilience. The observed trends in rising temperatures and erratic precipitation patterns underscore the need for immediate and sustained action. By implementing comprehensive climate action plans that incorporate urban greening, efficient water management, energy efficiency measures, and advanced adaptation and mitigation technologies, Nagpur can effectively combat the risks posed by climate change. The collective efforts of government, industry, and citizens will be essential in ensuring the city's sustainable and resilient future. Through proactive planning and the adoption of innovative solutions, Nagpur can serve as a model for other growing urban centres facing similar climate challenges.

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ESR (2023-24)

Chapter 3

Green Open Spaces and Biodiversity

CSIR-NEERI

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Evaluating the visibility, accessibility and distribution of urban green space in the context of Nagpur city

Summary

The study provides a comprehensive evaluation of Urban Green Spaces (UGS) in Nagpur city, by assessing the 3-30-300 rule for urban greenery. This rule recommends that every resident should see at least three trees from their home, have 30% tree canopy cover in their neighborhood, and live within 300 meters of a green space. We divided the city into ten administrative zones and assessed how each zone fared against the three components of the rule. The study was conducted by surveying the citizens of Nagpur regarding the visibility, accessibility, distribution and benefits of UGS. GIS analysis was carried out to determine the tree canopy cover of each zones. The study underscores the need for Nagpur to enhance its urban greening efforts. While tree visibility and proximity to green spaces are relatively well-achieved, significant improvements are needed in tree canopy coverage. 79.61% of Nagpur residents can see three or more trees from their windows, with six out of ten city zones meeting this criterion. Only Dharampeth zone has a tree canopy cover exceeding 30%. The overall tree canopy for the city is 19.54%, which falls short of the target. Around 73.63% of residents live within 300 meters of a green space, with three zones meeting this requirement. Implementing the 3-30-300 rule can guide urban planning and help increase green cover, ultimately benefiting the city's environment and residents.

3.0 Introduction

Over half of the world's population today dwells in cities, and with urbanization accelerating, almost 70% of the world's population is expected to live in cities by 2050 (United Nations, 2023). Urban green space includes natural or manmade green surfaces and green infrastructure like gardens, parks, street trees, green walls, and roofs etc. (Semeraro et al., 2021). Urban green spaces, serve as the "lungs of the city" and "carbon stock" reservoirs (Lahoti et al., 2020). Urban green spaces play a crucial role in advancing Sustainable Development Goals (SDGs). They enhance the sustainability of cities and urban communities (SDG 11), supply food and clean water (SDGs 2 and 6), boost incomes and job opportunities (SDG 1), support outdoor recreation and improve air quality (SDG 3), generate renewable energy and aid in climate change mitigation and adaptation (SDGs 7 and 13), enhance soil quality, support biodiversity (SDG 15), and promote a green economy (SDG 8). The availability of green space varies greatly between cities and is not uniformly distributed within cities (Nieuwenhuijsen et al., 2022). Numerous regulating ecosystem services are offered by urban green spaces, including the moderation of environmental extremes, water flow management, runoff reduction, and urban temperature regulation (Graça et al., 2022).

The presence of urban green spaces in Nagpur has markedly decreased over the years, primarily due to a pronounced surge in urban development and construction activities (Shukla et al., 2024). Despite the abundance of parks within the city, a notable decline in ecological connectivity and corridor linkages has also been a common observation. The city's urban landscape has undergone a significant change as a result of the significant loss and degradation of its natural vegetation, which was once known for its abundance of greenery (Dhyani et al., 2018). This is clearly outlined in (**Figure 3.1),** which highlights an increasing trend in built-up areas along with a simultaneous decline in green spaces over two decades. The per capita UGS that Nagpur residents have access to is just 3.65 m^2 (Lahoti et al., 2024), which is much less than the WHO guidelines (9 m^2) and national URDPFI guidelines (10-12 m^2) (Thomas et al., 2024). There is a disparity in the distribution of the blue-green spaces in the city (S. Lahoti et al., 2019; S. A. Lahoti et al., 2024; Shukla et al., 2024) **(Figure 3.2**). The common blue-green infrastructure in the city of Nagpur consists of urban forests, public gardens, lakes, campus green spaces, wastelands (Zudpi forests), playgrounds etc. (Dhyani et al., 2021)

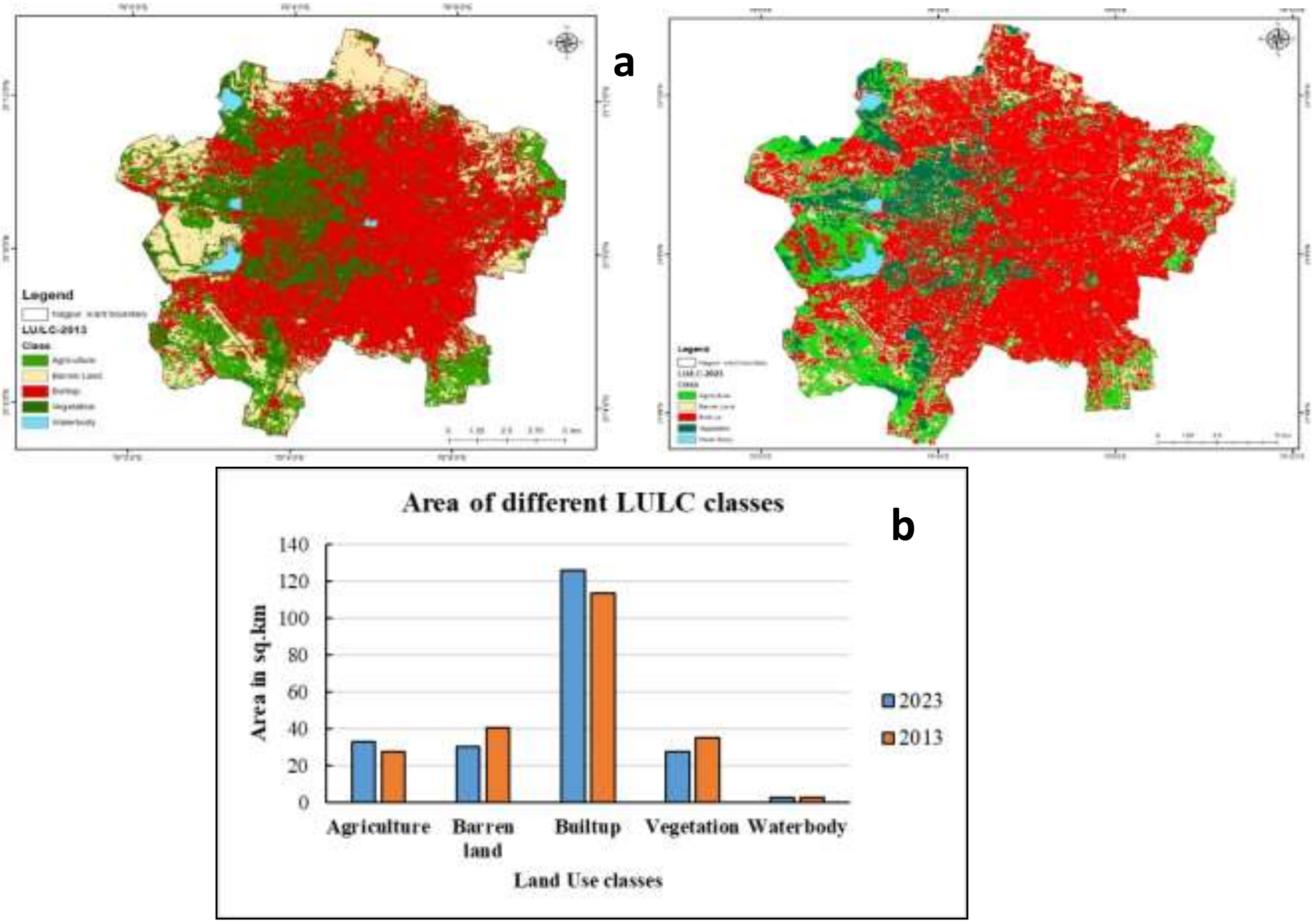

Figure 3.1: a) LULC map of Nagpur city (2013 & 2023) and b) Area of different LULC classes for the years 2023 and 2013 (sq.km)

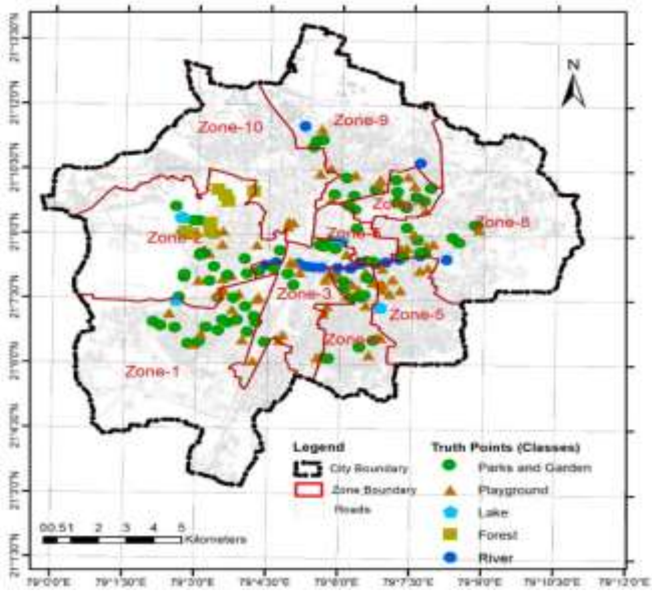

Figure 3.2: Blue-green spaces in Nagpur city (Source: Lahoti et al., 2019)

A new guideline known as the 3-30-300 green space rule was introduced by Cecil Konijnendijk, which includes recommendations related to visible vegetation, amount of greenery and distance to nearby green spaces (Nieuwenhuijsen et al., 2022). According to this rule, every individual should be able to view at least three trees (of a decent size) from their residence, each neighborhood should have at least 30 % tree canopy cover and the nearest green space should be within 300m from their residence (Konijnendijk, 2023)(**Figure 3.3**).

Even though there have been numerous studies related to the distribution of green spaces, an evaluation combining the accessibility, canopy cover and visibility of trees and greenspaces is relatively new (Nieuwenhuijsen et al., 2022). Three aspects of nature, or vegetation, are covered in 3–30–300: access to green space for outdoor recreation, residential green space, and visual green space (Browning et al., 2024). This study investigates the 3-30-300 rule in the context of Nagpur city, partly through questionnaires with city residents and through GIS analysis.

Figure 3.3: The 3-30-300 rule for urban forestry [Source: UNECE (2022)]

3.1 Methodology

The survey was conducted in Ten zones of Nagpur city: Laxmi Nagar, Dharampeth, Gandhibagh, Sataranjipura, Lakadganj, Aasi Nagar, Hanuman Nagar, Dhantoli, Nehru Nagar, and Mangalvari. These zones were selected to represent a diverse cross-section of the city's infrastructure, land use, population density. The survey was prepared using the Google forms to understand the accessibility, distribution and benefits of urban green spaces (**Plate 3.1**). The city has a large network of parks, like Ambazari Garden, Telangkhedi Garden and Maharajbah zoo as well as smaller neighborhood parks. The survey was carried out from April-August 2024 at multiple places in each zone. The survey was conducted through stratified random sampling, ensuring a diverse demographic information across different age groups, genders, and socio-economic backgrounds. The sample comprised residents from a variety of housing types, including apartments, single-family homes, and bungalows.

Plate 3.1: Participatory survey conducted by CSIR-NEERI in different locations of Nagpur city

Survey respondents were selected to avoid bias and only adult participants (18+ years) were considered. We ensured that only one respondent was interviewed from the same street to avoid similarity in their response. The survey was composed of 25 questions, in which the first 7 questions were to understand their backgrounds, age, and income. The other remaining questions focused on understanding the visibility, tree details, canopy cover, accessibility, usage and types of UGS as well as the benefits derived from them. The 3-30-300 rule does not specify any details regarding the type, age or size of the trees and about the type and state of the urban green spaces. This information was collected from the respondents during the survey.

We used residential surrounding greenness as a substitute for tree canopy cover. Soil-Adjusted Vegetation Index (SAVI) was considered over the Normalized Difference Vegetation Index (NDVI) to minimize the soil brightness in spectral influence and it is considered more suitable for semi-arid areas (Almutairi et al., 2013; Vani & Mandla, 2017).

Plate 3.2: Field Observation at different wards of zone. a) Dikshabhoomi, b) Abhyankar Nagar, c) Hansapuri, d) Shubhash Nagar, e) Shankar Nagar, f) Mominpura, g) Madhav Nagar, h) Hilltop

3.2 Results and Discussion

3.2.1 Overview of respondents

The initial section of the survey constituted questions related to the participant's age, location, sex, educational qualifications, and occupation. A total of 402 respondents were questioned including

58.5 % of males and 41.5 % of females from different zones of Nagpur city. Respondents were segregated into five age groups. The most number of respondents were in the age group of 18-30. The largest number of respondents 53.5 % were 18-30 years of age followed by 51-60 years (13.9%), 41-50 years (12.2%), > 60 years (10.2%) and the least number of respondents belonged to the age group of 31-40 (9.7 %). 41% of respondents were graduates followed by 35.6% postgraduates, 8% educated till high school, 6% had doctorate degrees whereas rest of 9.4 % had other miscellaneous educational backgrounds viz. middle school, diploma etc. 53.2 % respondents were employed, 5.2% were unemployed, 22.4% students, 10.7% were doing business, 8.5% were retired. The number of respondents from each zone was not equally distributed, most of the respondents were residing in Lakshmi Nagar and Dharampeth and the number of respondents from Satranjipura and Lakdgani were less (**Figure 3.4**). To understand accessibility to UGS we asked the respondents questions related to the type of UGS, distance travelled, frequency of visits and other questions to better understand the demand gap scenario in Nagpur city.

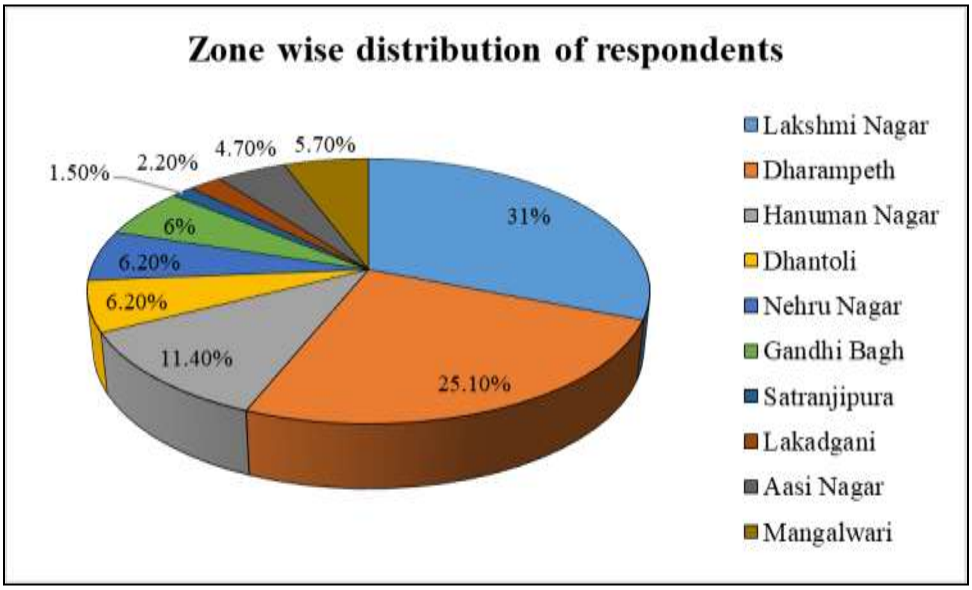

Figure 3.4: Zone wise distribution of respondents

3.2.2 Green space variables

3.2.2.1 Type of Urban Green Space

The major types of UGS seen in the neighborhood according to the respondents were playgrounds, public gardens, parks, sports fields, green campuses and avenue plantations in motorable roads (**Figure 3.5**). Around 9 respondents mentioned that there was not enough space in their neighborhood for any UGS. 35 respondents revealed that wetlands like rivers, lakes, and ponds were closer to them.

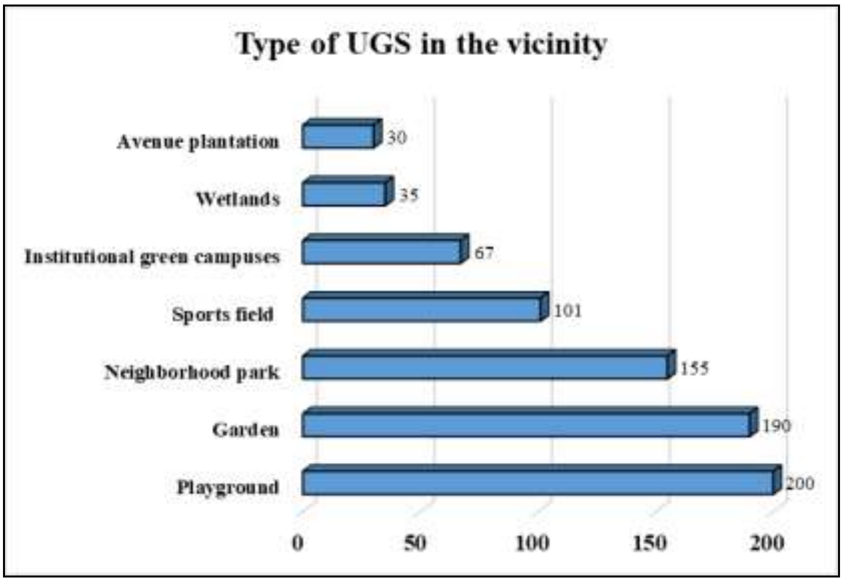

Figure 3.5: The type of UGS present near the vicinity according to the respondents

1. Street trees

2. Vertical vegetation

3. Playground

4. Garden

5. Wetland

6. Park

7. Urban orchard

Plate 3.3: Different Urban Green Spaces observed during the study in Nagpur City

3.2.2.2 Trees from every home

Approximately 76.86% of respondents informed that there were able to see more than three trees outside their window. Around 8.50% of respondents revealed that there were 3 trees which could be viewed from their residence. Around 14.7% reported that there were less than 3 trees outside their residence (**Figure 3.6**). This shows that 65.36% of the respondents have sufficient visibility of greenery outside their windows.

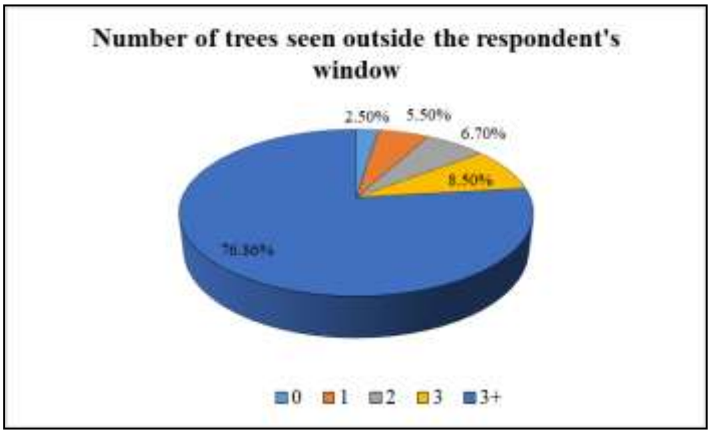

Figure 3.6: Number of trees seen outside the respondent's window

3.2.2.3 30% tree canopy cover in every zone

The SAVI was calculated to understand the tree canopy cover of the ten zones of Nagpur city. The analysis revealed that there is a huge disparity in the tree canopy cover among the ten zones. Only Dharampeth had canopy cover over thirty percentages at 37.59%. Comparatively Dhanoli (24.35%), Lakshminagar (24.15%) and Mangalwari (22.94%) had significant tree canopy cover. zones like Satranjpura (4.25%), Nehru Nagar (5.33%), Hanuman Nagar (6.73%), Gandhi Bagh (7.07%) and Lakadganj (8.81%) had tree cover of less than ten per cent of their total land area (**Figure 3.7**). These zones were found to be highly urbanized with very less vegetation covers.

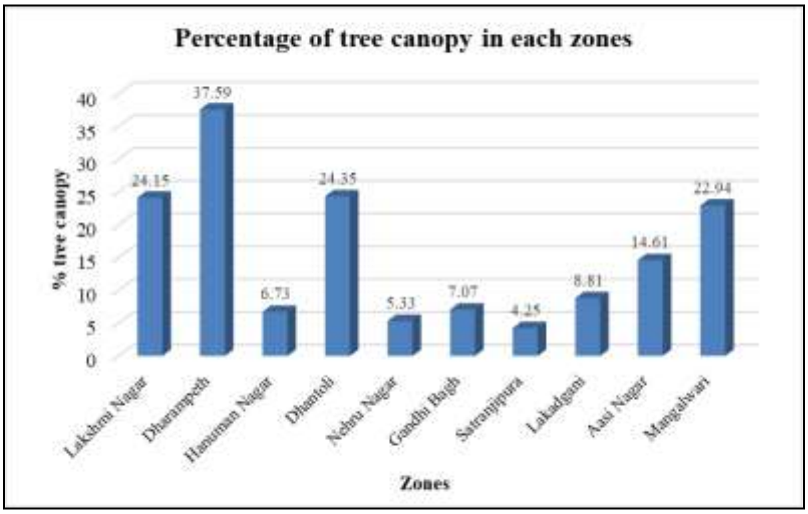

Figure 3.7: The percentage of tree canopy cover present in the ten administrative zones of Nagpur

3.2.2.4 300 m from the nearest park or green space

When enquired about the distance to the nearest UGS from their residence, the respondents reported that 26.40% of them had to travel more than 300 meters to the nearest UGS. While 33.30 % of the respondents reported that the nearest green space was within 100 meters. 28.40% of the respondents had UGS between a distance of 101-200m and it was between 201-300 meters for 11.70% of the respondents (**Figure 3.8**).

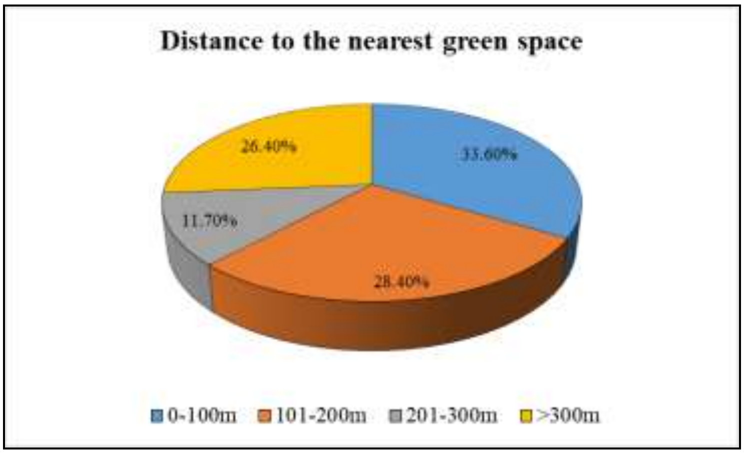

Figure 3.8: The percentage of respondents according to distance from their residence to the nearest UGS

3.2.2.5. Frequency of visits to UGS

It was reported that there is a huge interest among the respondents to avail the benefits from UGS. Almost 43.80% of respondents visited the green spaces daily, followed by 16.2 % of respondents who visited once or twice a week based on time and accessibility. The nearness of green space increases the frequency of visits. Around 16.7 % visited at least in a month whereas, there were still 7% who did not have enough time to enjoy or did not have any park or garden or lake close to their residence to avail this benefit (**Figure 3.9**).

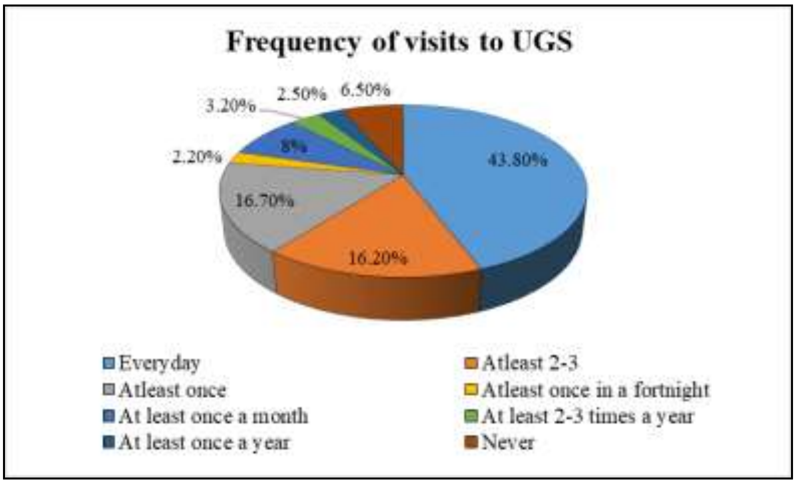

Figure 3.9: The frequency of visits to UGS among the respondents

3.2.2.6 Demand supply gap in the availability of sufficient green space

There was a divide in people's responses from different zones of the city. Almost 62.4% of respondents agreed to having sufficient greenery in their wards/vicinity whereas, 37.6 % of respondents were not satisfied and had mixed responses (neutral or dissatisfied) towards the question (**Figure 3.10**). We considered a neutral response (24.90%) as an insufficient understanding of urban green requirements.

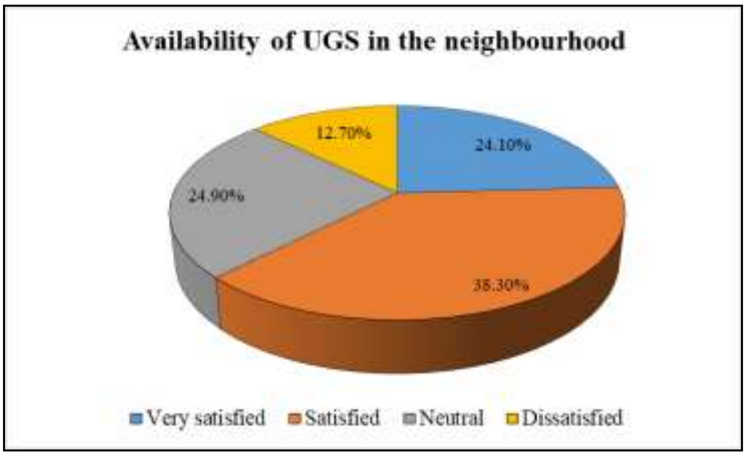

Figure 3.10: The perception of UGS availability in Nagpur city among the respondents

3.2.2.7 Activities in UGS

According to the survey it was reported that most of the visitors perform some kind of exercise (211 respondents) or relax and enjoy the scenery after visiting UGS (238 respondents). While socializing, playing sports, and bringing the kids to play were the prominent reasons why people visited the UGS in the city (**Figure 3.11**).

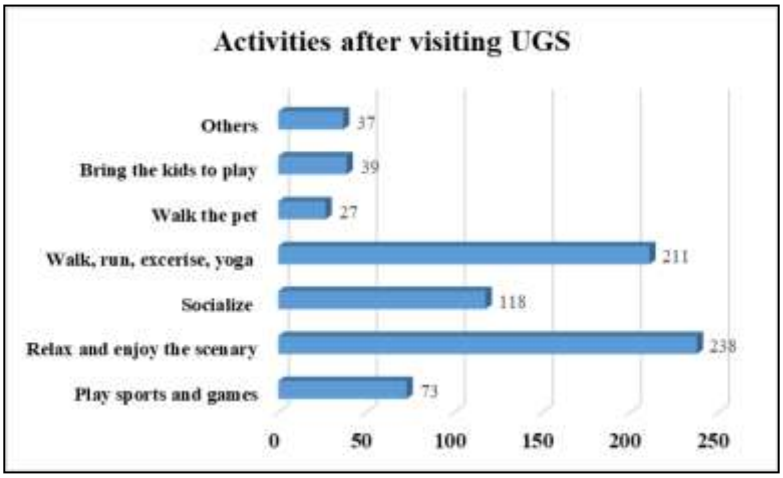

Figure 3.11: The activities carried out by the respondents after visiting UGS

3.3 3-30-300 assessment for Nagpur and its zones

Each zone differed in the extent to which it performed the three parts of the 3-30-300 rule. The ≥3 tree visibility part was achieved (>75%) by six out of the total ten zones. More than three-quarters (79.61%) of all buildings in Nagpur city were able to view three or more trees from their windows. The 30% tree canopy cover part seemed to be the most difficult to accomplish and it was only satisfied by the Dharampeth zone. Five zones of the city had tree cover less than 10% which is a cause of concern. The overall canopy cover of the city was found to be 19.54 per cent of the total land area. Hence the city does not fulfill the criterion of 30- component. The 300-meter components were accomplished only by three zones (Mangalwari, Lakshmi Nagar, Hanuman Nagar) and the total percentage of respondents having a UGS less than 300 meters was found to be 73.63%. Only the Dharampeth zone achieved all the components of the 3-30-300 rule, while Mangalwari, Lakshmi Nagar and Hanuman Nagar achieved two components *i.e.*, 3- and 300- components (**Figure 3.12**). Zones like Aasi Nagar, Gandhi Bagh, Dhantoli and Nehru Nagar failed to meet any one of the three components. These four zones are located in the north, central and southeastern parts of the city. It is necessary to note that ≥3 tree visibility part was achieved by all respondents from zones like Satranjipura, Lakadgani and Hanuman Nagar even though the tree canopy cover for these zones was less than ten per cent, this could be attributed to the smaller number of respondents from these zones. Hence a more comprehensive survey involving more respondents needs to be conducted in certain zones to get a more accurate outcome.

Table 3.1: **The scoring of Nagpur city according to the 3-30-300 rule**

Zones	≥3 Trees visible according to respondents (%)	Tree canopy cover	< 300m from green space (%)
Lakshmi Nagar	**83.2**	24.15	**81.6**
Dharampeth	**79.2**	**37.59**	74.2
Hanuman Nagar	**76.1***	6.73	**76.1***
Dhantoli	32	24.35	56
Nehru Nagar	9	5.33	72
Gandhi Bagh	45.8	7.07	45.8
Satranjipura	**100***	4.25	60
Lakadgani	**100***	8.81	66
Aasi Nagar	68.42	14.61	73.68
Mangalwari	**90.9**	22.94	**81.8**
Nagpur city	**79.61**	**19.54**	**73.63**

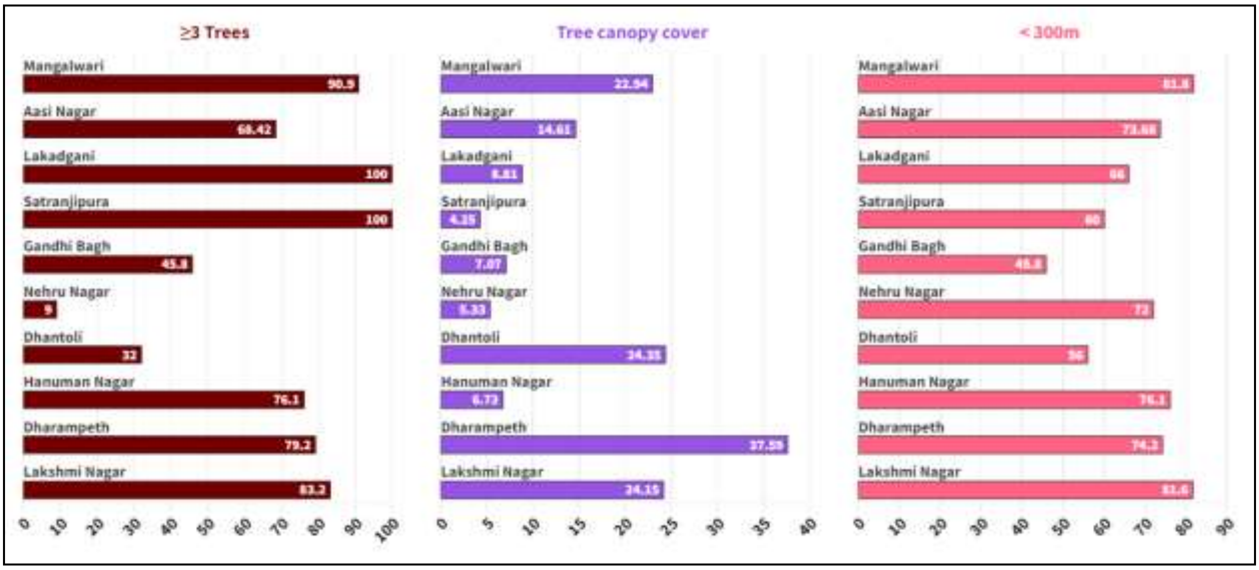

Figure 3.12: The scoring of Nagpur city according to the 3-30-300 rule

3.4 Recommendations

There have been studies related to the assessment of the new 3-30-300 rule, which assessed whether the urban areas meet the rule or not (Browning et al., 2024; Croeser et al., 2024; Li et al., 2024; Ling, 2022; Nieuwenhuijsen et al., 2022). However, no study has attempted to quantify or apply the necessary modifications to comply with the requirement.

- Understanding 3-30-300 context in cities can help urban planners to understand the key disparities across different zones of the city that could lead to demand-supply gap. Hence, it is important that NMC understands the concerns to identify green gaps that can be suitably filled by plantation cum restoration activities.
- Garden Department of NMC should also focus on increasing tree diversity by ensuring plantation native species that can adapt to local climate change and also considering the climate uncertainty are more climate proof for future.
- Improvement of green space amenities by understanding the spatio-temporal spread of UGS in the city to improve visitation among the people.
- Improve accessibility: Create new green spaces in South Nagpur to ensure that all residents have a UGS within 300 meters of their homes.
- Improving maintenance: NMC should dedicate resources to regularly maintain the existing parks and green spaces, making them more usable and visitor-friendly.
- Policy reform: Incorporating the 3-30-300 rule into the urban planning policies can ensure that future developments prioritize green space.

- Community engagement: Foster community involvement in collaboration with NMC in managing and preserving local green spaces through awareness programs and collaborative projects by active involvement of schools, colleges, government and private organisations.
- NMC needs to take action to review and improve avenue plantations along with regular maintenance in different zones and wards of Nagpur which lack sufficient green spaces and accordingly specific budget allocation has to be made.
- New high-rise buildings should compulsorily ensure greening initiatives along with rooftop and vertical greening to improve sustainability.

3.5 Conclusion

This study is one of the first assessments of UGS using the 3-30-300 rule in India. The rule's comprehensiveness offers a broader view of the benefits of urban greening. It demonstrates how greenery may provide various ecosystem services that enhance the quality of the urban environment and human health. The specific objectives of 3-30-300 facilitate comparable studies across time, which will help in highlighting the areas which require actions and make it simpler for decision-makers to incorporate urban greening. This guideline can also significantly affect the urban planners because it is simple to follow and offers a defined framework, both of which are critical to enhancing the role of urban greening. Among the three components, the 30% tree canopy component was found to be the most difficult to achieve. The overall tree canopy cover for the city was found to be 19% much less than the target. While the scores of ≥3 trees and 300 meters' parts were comparatively better. The results reveal that Nagpur needs to focus on scaling up its urban greenery efforts and bring new citizen-centric initiatives to increase the green cover as well as the benefits derived from them.

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Chapter 4:
Noise Environment

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Noise Environment

4.0 Introduction

Noise pollution is an increasing concern worldwide, particularly in urban areas. It mainly arises from transportation (including road, rail, and air travel), industrial activities, construction work, and urbanization. According to the World Health Organization (WHO), noise pollution can have severe health impacts, such as sleep disturbances, elevated stress levels, hearing loss, and a higher risk of cardiovascular diseases.

In developed countries, rising noise levels are largely due to increasing vehicle traffic, aircraft noise, and industrial activities. Many urban residents are exposed to chronic noise levels that exceed safe limits. In India, noise pollution is a significant environmental issue, especially in metropolitan cities like Delhi, Mumbai, Kolkata, and Bengaluru. Factors such as rapid urbanization, a growing population, and increased vehicular traffic have led to higher noise levels. The use of loudspeakers during religious and social events, construction activities, and inadequate traffic management further contribute to the noise burden. Many cities in India surpass permissible noise standards, especially during festivals or peak traffic hours. Research shows that urban centers like Mumbai, Kolhapur, Pune, and Nagpur have experienced noise pollution levels that exceed established regulatory limits in Maharashtra. Key contributing elements include rapid population growth, traffic congestion, and high noise emissions from social and cultural events.

In India, the permissible noise limit during the daytime in residential areas is typically around 55 dB. However, in urban centers, levels often exceed 70-80 dB, posing health risks. Noise pollution has emerged as a leading cause of discomfort, resulting in health issues such as anxiety, hearing problems, hypertension, and a reduced quality of life. While the government has implemented noise regulations, enforcement remains a challenge.

4.1 Crowd-sourced Technique of data collection

The conventional method for measuring acoustic pollution involves using professional sound level meters, which are expensive, large, highly accurate and sensitive. These measurements are typically taken at limited locations and then analyzed using various statistical methods to create acoustic pollution maps for specific areas, offering a detailed spatial representation. Crowd-sensing techniques have recently emerged as a possible alternative by encouraging collaborative monitoring of densely populated areas.

A crowdsourced data collection is an innovative approach that harnesses the collective efforts of a large group of people, often through digital platforms, to gather information or insights. Instead of relying on a small group of experts or a single agency, crowdsourcing taps into the knowledge and participation of a broad audience, typically ordinary citizens or volunteers. This technique is widely used in fields like environmental monitoring, traffic management, and citizen science. For example, apps Google Maps rely on crowdsourced data to provide real-time traffic updates, while environmental monitoring apps collect data on air quality or noise pollution from users in various locations. The primary advantages of this method include scalability, cost-effectiveness, and the ability to collect real-time data from diverse geographic areas, including hard-to-reach or under-represented regions. Consequently, crowdsourcing remains a powerful tool for large-scale data collection, offering a more dynamic and inclusive alternative to traditional methods.

Smartphone technology has made measuring sound levels much easier. Over 50 sound level meter applications (apps) are available worldwide for Android and iPhone devices. These applications could give rapid, effortless, convenient, and low-cost sound level measurement options. Additionally, the rapid adoption of mobile phones, combined with the growing number of sensors these devices are outfitted with (for example, high-quality cameras, microphones, and accelerometers), significantly simplifies the widespread implementation of crowdsourcing solutions, lowering the hardware needs as well as expenses to the bare minimum.

Understanding and reducing the risks associated with noise exposure is essential for preventing noise-induced hearing loss. The use of sound measurement apps can help increase awareness about noise levels in both work and leisure environments, enabling individuals to make informed choices regarding the potential impact of noise on their hearing and overall health.

In this context, the present project employed a crowdsourcing approach to collect noise data through the CSIR-NEERI mobile app "Noise Tracker," which involved college students living at various locations throughout Nagpur city.

4.2 CSIR-NEERI Mobile Application "Noise Tracker"

NOISE TRACKER APP

To track noise around you

Noise pollution has become a serious concern worldwide, and the noise scenario, particularly in cities in India, is at alarming levels. Several studies conducted in various parts of the country reported noise levels surpassing the Central Pollution Control Board (CPCB), New Delhi set limits. Noise pollution is the lead cause of various health-related issues such as hearing impairment, hypertension, cardiovascular problems, annoyance, and sleeps disturbance.

In this context, noise experts from CSIR - National Environmental Engineering Research Institute (NEERI), Nagpur has developed a unique Noise Application (App) "Noise Tracker" to measure the real-time noise level using android smartphones. "Noise Tracker" is a handy, essential gadget, highly reliable App and supports pre-calibrated measurements.

CSIR NEERI Nagpur had launched a "Noise Tracker" app in September 2019 on the occasion of CSIR foundation dayandsince the launching it has profoundly impacted nationally and internationally. Within a short period of launching, it has almost 20,000 plus downloads. It is regularly downloaded in India and other countries such as the United States, Canada, Italy, Spain, Germany, Indonesia, China, etc.

APP LOGO

App Downloads

19k+

Data Received

16.415k+

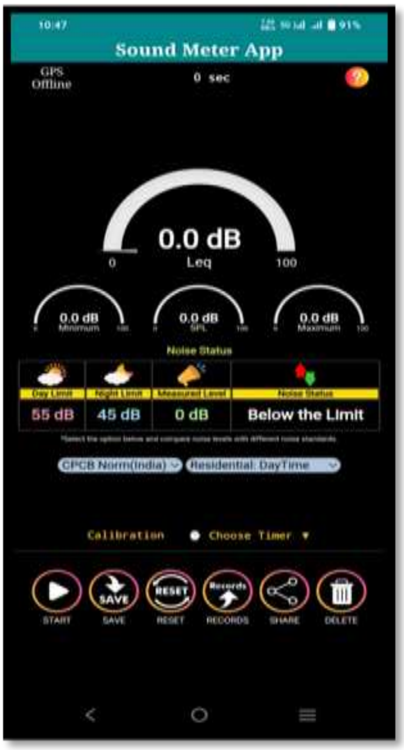
Data Received Rate

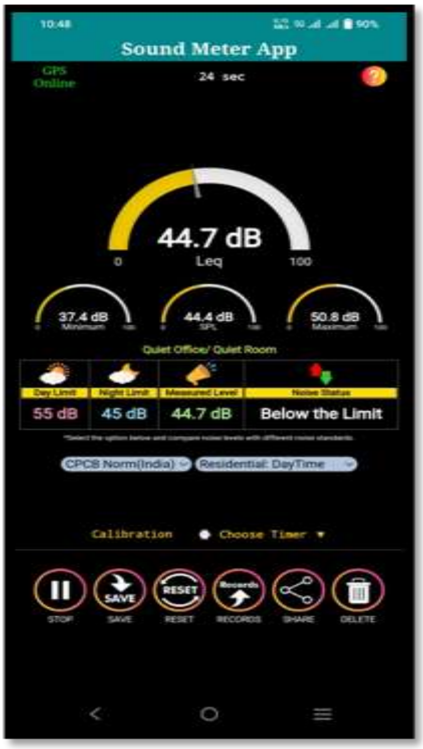
6-15/day

*From India & other countries

FEATURES

- Measure Equivalent continuous sound level (LAeq),
- Display SPL, Leq, Average, Minimum and Maximum decibel values
- Indicates decibel by digital gauge meter.
- Quick response on sound level changes.
- Compare the recorded noise level with popular international reference standards.
- Display Elapsed time of decibel
- Create the geo-tagged map for the saved history data
- Very efficient saved record data management
- Data storage in the phone.
- Performance best fits with calibrated SPL meter
- Handy custom Calibration for high precision and accuracy
- One can share the saved and recorded data across multiple platforms such as Gmail, WhatsApp, etc.





4.3 Noise Monitoring Methodology

Data collection is one of the most critical aspects of noise assessment. Therefore, this study conducted noise monitoring in accordance with national and international standard regulations. A comparative analysis of noise levels was performed across several locations in Nagpur city. The research focused on evaluating noise levels in three types of areas: silent zones, residential areas, and commercial zones. Monitoring was carried out from 6:00 AM to 8:00 PM and 8:00 PM to 10:00 PM, using the mobile application "Noise Tracker."

Data was gathered based on land use patterns through crowdsourcing. Four reputed colleges in Nagpur city expressed their willingness to enroll students as volunteers for data collection using the "Noise Tracker" app. Before monitoring began, volunteers received personal demonstrations on how to use the application for noise monitoring, data collection, and sharing. Additionally, tutorial videos and written guidelines were provided, along with instructions on necessary precautions to take during the data monitoring process.

Volunteers were required to collect three readings of at least 300 seconds each for each location, and the average of these readings was used to assess noise pollution. They shared their monitored data via text message. Finally, the collected data was compared to the permissible limits of the Central Pollution Control Board (CPCB), Delhi (**Table 4.1**).

Table 4.1: The Noise Pollution (Regulation and Control) Rules 2010

Sr. No.	Activity	Noise Levels, Leq (dBA)	
		Day time	Night Time
1.	Industrial	75	70
2.	Commercial	65	55
3.	Residential	55	45
4.	Silence Zone	50	40

4.4 NMC Zone Wise Compliance & Non-Compliance Status of Silence, Residential & Commercial Zones in Nagpur City

The data from the noise pollution monitoring conducted in various zones of Nagpur city reveals significant non-compliance with the noise standards set by the Central Pollution Control Board (CPCB). The noise monitoring was conducted across three zones, Silence, Residential and Commercial Zones, at two distinct time intervals: 06 AM to 08 PM and 08 PM to 10 PM. **Figure 4.1** illustrates the zone-wise compliance and non-compliance status of noise levels in percentage for silence, residential and commercial places. **Table 4.2** summarizes the overall percentage of compliance and non-compliance for each zone. The NMC Zone-wise Noise Level of each location for Silence, Residential, & Commercial Areas is outlined in **Table 4.3**.

4.4.1 Silence Zone

In the designated silence zones, noise levels consistently exceeded the permissible limits throughout the day and night. In Dharampeth, the silence zone recorded 100% non-compliance during the daytime (06 AM to 08 PM) and nighttime (08 PM to 10 PM). The study has observed similar patterns of non-compliance in other silence zones like Gandhibagh (100% non-compliance during both periods) and Lakadganj (100% non-compliance during both periods). The observed data highlights that noise pollution is a pervasive issue even in areas where noise levels are legally required to be minimal.

4.4.2 Residential Zones:

The residential areas displayed varying levels of noise compliance. Some zones adhered relatively better to noise standards during the daytime but experienced significant violations at night. For instance, the Hanuman Nagar area shows 100% non-compliance during the daytime and 81.8% non-compliance during the night, indicating a higher level of noise pollution during evening hours. Nehru Nagar reported 33.3% compliance, 66.7% non-compliance during the day, and 16.7% compliance and 83.3% non-compliance during the night. On the other hand, in Mangalwari, compliance during the daytime was around 28.1%, with 71.8% non-compliance, and the night-time noise exceeded permissible limits as well (31.2% compliance and 68.8% non-compliance). At the same time, the Lakadganj zone shows 100% violation of allowable limits during the day and at night.

4.4.3 Commercial Zone

Commercial zones typically experience higher noise levels due to factors such as increased vehicular traffic, construction activities, and the presence of businesses that often operate without sufficient noise mitigation measures. Commercial zones generally show better compliance than silence and residential zones, particularly during the day. However, Dharampeth, Laxmi Nagar, Ashi Nagar, Satranjipura, Mangalwari and Hanuman Nagar show high compliance during the night (100%, 80%, 75%, 65.7% and 63.7 respectively), indicating some level of improvement in night-time noise management. Dhantoli is the only area that shows 100% non-compliance during both day and night time.

4.4.4 Overall Non-Compliance:

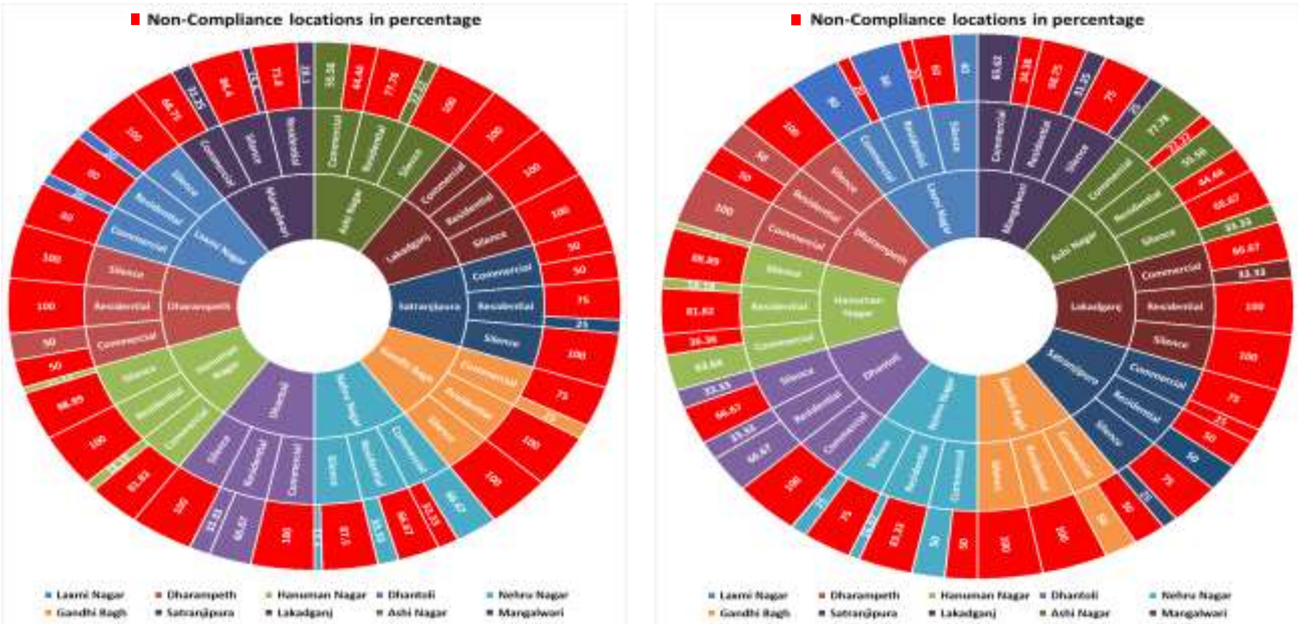
The overall non-compliance rate was high across all zones, particularly in the silence and commercial zones. The total non-compliance percentage varied across zones, with areas like

Lakadganj (94.4% non-compliance), Gandhi bagh (87.5% non-compliance), and Dhantoli (83.3% non-compliance) showing some of the highest levels of noise violations. These areas clearly exceed the acceptable noise limits set by the CPCB, suggesting an urgent need for better noise management and stricter enforcement of noise control laws.

Table No. 4.2: NMC Zone Wise Compliance & Non-Compliance Status of Silence, Residential & Commercial Zones in Nagpur City

Sr. No.	NMC ZONES	Monitoring Locations	NOISE ZONES	CPCB Compliance & Non-Compliance status in Percentage (%)				Overall Non-Compliance in percentage (%)
				(06 AM to 8PM)		(8PM to 10PM)		
				Compliance	Non-compliance	Compliance	Non-compliance	
1	**LAXMI NAGAR**	15	SILENCE	0	100	40	60	60
			RESIDENTIAL	20	80	80	20	
			COMMERCIAL	20	80	80	20	
2	**DHARAMPETH**	12	SILENCE	0	100	0	100	66.6
			RESIDENTIAL	0	100	50	50	
			COMMERCIAL	50	50	100	0	
3	**HANUMAN NAGAR**	31	SILENCE	11.1	88.9	11.1	88.9	79
			RESIDENTIAL	0	100	18.2	81.8	
			COMMERCIAL	18.18	81.82	63.7	36.3	
4	**DHANTOLI**	09	SILENCE	0	100	33.3	66.7	83.3
			RESIDENTIAL	33.3	66.7	33.3	66.7	
			COMMERCIAL	0	100	0	100	
5	**NEHRU NAGAR**	20	SILENCE	12.5	87.5	25	75	67.5
			RESIDENTIAL	33.3	66.7	16.7	83.3	
			COMMERCIAL	66.7	33.3	50	50	
6	**GANDHIBAGH**	12	SILENCE	0	100	0	100	87.5
			RESIDENTI	0	100	0	100	

			AL					
			COMMERCIAL	25	75	50	50	
7	**SATRANJIPURA**	12	SILENCE	0	100	25	75	62.5
			RESIDENTIAL	25	75	50	50	
			COMMERCIAL	50	50	75	25	
8	**LAKADGANJ**	09	SILENCE	0	100	0	100	94.4
			RESIDENTIAL	0	100	0	100	
			COMMERCIAL	0	100	33.3	66.7	
9	**ASHINAGAR**	27	SILENCE	0	100	33.3	66.7	59.2
			RESIDENTIAL	22.2	77.8	55.6	44.4	
			COMMERCIAL	55.6	44.4	77.8	22.2	
10	**MANGALWARI**	96	SILENCE	15.6	84.4	25	75	67.1
			RESIDENTIAL	28.1	71.8	31.2	68.8	
			COMMERCIAL	31.25	68.75	65.7	34.3	



a. Day time (6am to

b. Night time (8pm to

Figure 4.1 (a & b): NMC Zone Wise Compliance & Non-Compliance Status

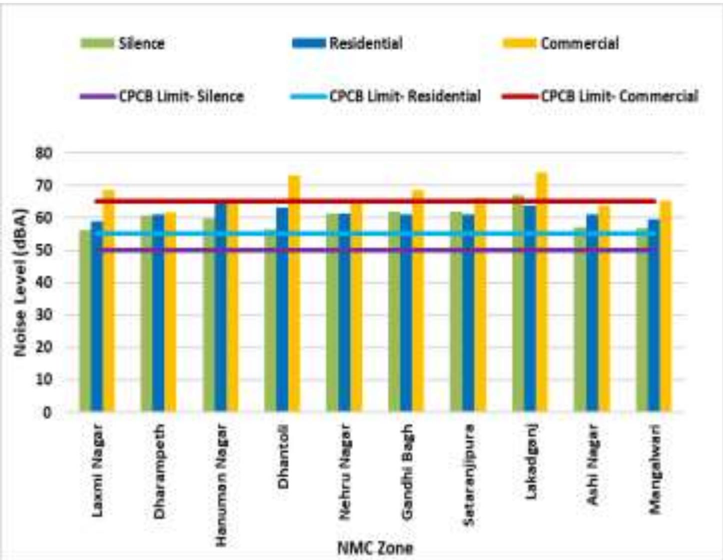
4.5 Analysis of Silence, Residential and Commercial places in each NMC Nagpur Zones

The average noise levels in silence, residential and commercial places in each zone, are depicted in **Figure 4.2**. The noise levels measured across various NMC zones during both daytime and nighttime periods reveal significant deviations from the CPCB permissible limits, especially in Silence Zones and Residential Zones. In the Silence Zones, all NMC zones except Dhantoli (which barely meets the limit at night) exceed the permissible 50 dB noise limit during the day, with areas like Lakadganj (67 dB), Gandhi Bagh (61.9 dB) and Sataranjipura showing the highest values. Nighttime noise levels in Silence Zones remain high, with Gandhi Bagh (60.6 dB), followed by Hanuman Nagar (58.2 dB), Satranjipura (57.7dB), and Lakadganj (57.6 dB) showing the highest noise level.

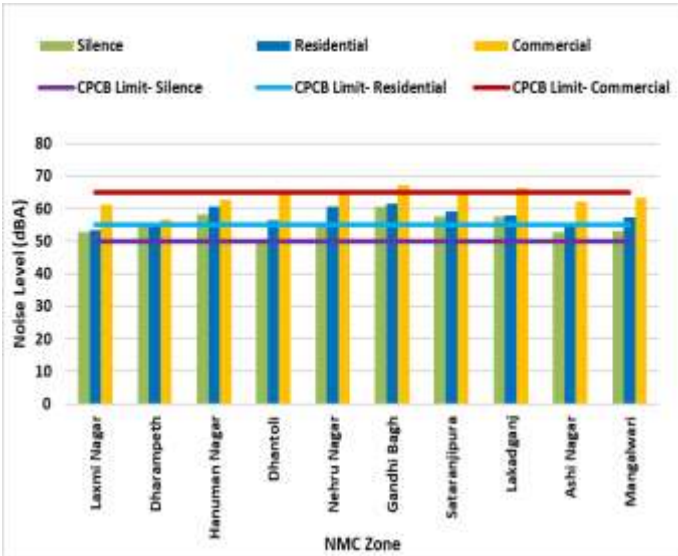
Similarly, in the Residential areas, all NMC zones surpass the 55dB limit during the day, including Hanuman Nagar (65.6 dB), Lakadganj (63.9 dB), and Dhantoli (63.3 dB), showing the highest noise level. At night, noise levels in residential zones generally remain elevated, with

Lakadganj and Nehru Nagar recording values close to or above the limit (57.8 dB and 60.6 dB, respectively). Commercial Zones are closer to the permissible 65 dB limit but still exceed it during the day in zones such as Dhantoli (73.2 dB) and Lakadganj (73.9 dB). At night, commercial zones in most areas are compliant or only slightly exceed the limit, with Lakadganj

(66.4 dB) being one of the highest. Overall, these results highlight widespread non-compliance with the noise standards, particularly in Silence and Residential Zones, indicating a need for better enforcement and mitigation measures to control noise pollution in these areas.



a. Day time (6am to 8pm)



b. Night time (8pm to 10pm)

Figure 4.2(a & b): Average noise levels status in the ten NMC Nagpur Zones

The study's results clearly show that noise pollution is a significant issue in Nagpur, with a high level of non-compliance with CPCB standards across various zones. The findings suggest several critical factors contributing to noise pollution:

4.5.1 Ineffectiveness of Silence Zone Regulations

The complete non-compliance in silence zones (such as Laxmi Nagar, Dharampeth, Dhantoli, Gandhi Bagh, Satranjipura, Lakadganj, and Ashi Nagar) highlights that the enforcement of noise regulations in these areas is inadequate. Silence zones are intended to provide relief from noise pollution, but the findings indicate that noise levels in these areas are often much higher than permissible limits. This could be due to factors such as unauthorized use of loudspeakers, construction work, and traffic congestion, all of which contribute to excessive noise. The local authorities need to step up enforcement and ensure stricter control over noise in these sensitive areas.

4.5.1.1 Day vs. Night Compliance

One of the most striking patterns observed in this study is the discrepancy between daytime and nighttime compliance. Many zones, mainly residential and silence zones, exhibit significantly higher non-compliance at night. This suggests that while noise levels may be somewhat controlled during the day (when businesses and traffic activity are more regulated), they escalate at night when noise from businesses, entertainment venues, and traffic becomes more intrusive. This is a critical concern, as nighttime noise is more likely to disrupt sleep and negatively impact health.

4.5.1.2 Impacts on Public Health

The pervasive nature of noise pollution in both residential and commercial zones has serious implications for public health. Chronic exposure to excessive noise can lead to a variety of health problems, including hearing loss, stress, hypertension, sleep disturbances, and cardiovascular diseases. The high levels of non-compliance observed in Lakadganj, Gandhi bagh and Dhantoli with total non-compliance rates exceeding 80%, raise concerns about the long-term health effects on the residents of these areas.

4.6 Conclusion

The findings from this study emphasize the widespread nature of noise pollution in Nagpur city, with silence zones, residential areas, and commercial zones all exhibiting significant non-compliance with the CPCB noise standards. These results highlight the need for immediate action to curb noise pollution through stricter enforcement of regulations, better planning of urban spaces, and the adoption of noise-reduction technologies. Addressing the issue of noise pollution is critical not only to improve the quality of life for residents but also to safeguard public health and well-being in the long term.

4.6 Recommendations

The high levels of non-compliance across multiple zones suggest that existing noise control policies may not be effectively implemented. To address this,

1. Local authorities must prioritize the development of a comprehensive noise management strategy
2. Strategies such as better monitoring, stricter enforcement of noise laws, and public awareness campaigns should be employed to curb the noise pollution.
3. Noise control measures, such as sound barriers, zoning regulations, and the restriction of noise-producing activities in sensitive areas, could help reduce noise levels in key areas of the city.

Table 4.3: NMC Zone-wise Noise Level of Silence, Residential & Commercial Areas

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
1	LAXMI NAGAR	CIIMs Hospital	SILENCE	51.6	46.7	50
		Sanjeevani Hospital Laxmi Nagar		58.6	54.2	
		School of Scholars Pratap Nagar		59.6	55.4	
		Shree Datta Mandir Trimurti Nagar		51.3	48.7	
		G T Padole Hospital Gayatri Nagar		60.3	58.5	
		Bajaj Nagar	RESIDENTIAL	53.9	49.3	55
		Laxmi Nagar East		63.8	53.6	
		P & T Colony Pratap Nagar		62.5	62.3	
		Pathan Layout Trimurtee Nagar		56.4	49.5	
		Deendayal Nagar		57.6	52.3	
		Rokde Jwellers Laxmi Nagar Square	COMMERCIA	69.8	58.3	65
		Smart Super Store Aath Rasta Chowk		69.6	62.1	

		Naivedhyam South Indian Hotel Pratap Nagar		70.7	68.5	
		Checkers Restaurant IT Park		62.5	55.4	
		Shree Radhe Mangalam Deendayal Nagar		70.4	61.5	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
2	DHARAMPETH	Allen IntituteDharampeth	SILENCE	58.6	54.8	50
		All India Institute of local Government Gokulpeth		63.3	58.5	
		Shivaji Nagar Park Dharampeth		57.0	51.3	
		JyotibaFule library Gokulpeth		63.3	55.2	
		Buddha Vihar Marg Dharampeth	RESIDENTIAL	63.1	58.6	55
		Gokulpeth		59.3	54.6	
		Tilak Nagar Gokulpeth		62.1	55.8	
		Valmiki Nagar Gokulpeth		59.3	51.2	
		Bank of Baroda WHC Road Dharampeth	COMMERCIA L	67.2	57.6	65
		Gokulpeth Chowk		52.6	48.6	
		Gokul VrundavanDharampeth		73.9	64.6	
		Londe Jewellers Bazar rdGokulpeth		52.6	56.4	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
3	HANUMAN NAGAR	St. Paul School CBSE Shyam Nagar Hudkeshwarrd	SILENCE	44.05	43.6	50
		Sai Baba Mandir Ghate layout Chandrakiran Nagar		60.8	68.7	
		Pushpachakra Hospital		73.1	62.3	
		ESI Hospital Krida Square		55.4	60.1	
		Poddar International School Besa		70.3	66.5	
		Vikas Public School Janki Nagar Uday Nagar Square		50.8	53.6	
		St. Vincent School Tapasya Chowk		65.8	61.3	
		Bhole Baba Temple Manewada		62.9	56.5	
		Snehaanchanl Palliative Care CenterRambagh		56.7	51.2	
		Chandrakiran Nagar	RESIDENTIAL	64.0	61.9	55
		Ganeshdham		58.5	53.7	
		Rakesh Layout Beltarodi		60.1	61.5	
		Janki Nagar Manewada Road		59.5	54.4	
		VinkarVasahat Omkar Nagar		71.9	63.5	
		Sanmarga Nagar Hudkeshwarrd		79.3	60.2	
		Somwaripeth		65.8	66.6	
		Gorle Layout Mahakali Nagar		61.9	58.6	
		Sant Kesar Mata Nagar Manewada		60.1	57.8	
		Shivshakti Layout HudkeshwarrdManewada		67.5	62.4	
		Rambagh		76.7	64.6	
		Maitri katta Café PiplaPhata Bus stop	COMMERCIAL	67.1	57.6	65
		Dubey Nagar Bust Stop Hudkeshwarrd		66.0	69.3	
		Mhalgi Nagar Square		64.3	68.9	
		Reshim Bagh Square		67.6	56.1	
		Apollo Pharmacy Hudkeshwarrd		80.7	61.3	

		Budhwar Bajar Raghuji Nagar		65.4	65.3	
		Jai Mahakali Chowk Manewada		72.6	60.5	
		Union Bank of India Dubey Nagar Hudkeshwarrd		72.6	61.3	
		Hudkeshwar Police Station		63.6	57.8	
		Saubhagya Nagar Manewada Besa Goghulird		73.1	72.9	
		Medical Square Rambagh Road		70.6	60.3	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
4	DHANTOLI	Mount Carmel Girls High School	SILENCE	59.6	53.6	50
		Neuron Hospital Dhantoli		52.6	44.6	
		Hanuman Mandir Prashant Nagar Ajani		57.3	51.6	
		Government Girls Hostel Rahate Colony	RESIDENTIAL	76.1	62.9	55
		Prashant Nagar NIT Layout Ajani		63.6	58.4	
		Chhoti dhantoli		50.2	47.5	
		Haldiram Ajni metro station	COMMERCIAL	73.8	65.3	65
		Yashwant Stadium Dhantoli		71..4	65.8	
		Rahate Colony Metro Station		72.5	65.9	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
5	NEHRU NAGAR	Rajendra Nagar	SILENCE	65.5	65.3	50
		Nagdwar swami mandir Kharbi		47.9	37.8	
		Navyug School, Shri Mahalaxmi Nagar New Narsala		54.4	38.7	
		Jyoti UchhaPrathmikShalanRamna Maruti Gadge baba nagar		66.9	70.1	
		SB City College Raghuji Nagar		55.8	55.9	
		KDK College Nandanvan		67.3	62.5	
		SB City College Raghuji Nagar		65.6	55.3	
		City Binzani College Raghuji Nagar		66.1	53.6	
		Near Hanuman Mandir Nandanwan	RESIDENTIAL	61.2	63.6	55
		Laxmi Narayan Colony Sai Baba Nagar Kharbi		53.3	59.7	
		Sanmarg Nagar New Narsalard		54.2	45.5	
		Ramna Maruti Gadge baba nagar		67.4	64.4	
		Om Nagar Sakkardhara		63.3	59.3	
		Rajendra Nagar Nandanvan		68.5	71	
		Near KDK College Nandanvan	COMMERCIAL	62.6	64.6	65
		Kharbi Chowk		63.0	53.1	
		New Narsalard Shri Mahalaxmi Nagar Snamarg Nagar		57.1	59.3	
		Ramna Maruti Auto Stand		70.6	72.8	
		Sakkardhara Bus Stop		71.6	65.8	
		Nandanvan Square		63.1	70.2	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
6	LAKADGANJ	Bhawani Hospital Pardi	SILENCE	63.5	59.3	50
		A.D.N Hospital Bhawani Nagar Pardi		75.3	61.4	
		Maa Durga Bhavani Mata Mandir Netaji Nagar Pardi		62.1	52.1	
		Gangabagh Pardi	RESIDENTIAL	62.4	55.5	55
		Bhawani Nagar Pardi		72.4	62.5	
		Netaji Nagar Pardi		57.0	55.3	
		Pardi Square Bhandara road	COMMERCIAL	70.3	67.6	65
		Bank of India Wardhaman Nagar		77.1	63.8	
		Power House Subhan Nagar Pardi		74.3	67.9	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
7	GANDHI BAGH	Hanuman Mandir Ram wadi Mahal	SILENCE	62.7	65.1	50
		NMC Ganjipeth Urdu High School		64.6	67.5	
		Ganeshpeth		53.0	51.3	
		Hanuman Mandir Ayachit rd Mahal		67.4	58.6	
		RamwadiGaneshpeth colony	RESIDENTIAL	62.7	58	55
		GanjipethBhaldarpura Gandhi Bagh		62.8	71.2	
		Bazariya		56.3	58.4	
		Ratan Colony Mahal		62.6	58.5	

		Shukravari	COMMERCIAL	64.1	59.2	65
		Ram Cooler Square Mahal		71.4	77	
		Medical Market Gandhi Bagh		68.7	72.7	
		Zenda Chowk Mahal		70.0	60.3	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
8	SATRANJIPURA	City Hospital Mominpura	SILENCE	61.5	69.8	50
		Navshakti Durga Mata mandir HansapuriItwari		64.7	44.6	
		Siddharth Vidyalaya Binaki		57.5	56.6	
		Sujata Nagar Buddha Vihar		64.0	59.7	
		Mominpura	RESIDENTIAL	68.1	62.3	55
		Saoji Gali TandapethItwari		67.3	70.5	
		Kolba Swami Nagar Binaki		50.3	51.6	
		Itwari station road Binaki		58.7	52.3	
		CA Road	COMMERCIAL	63.4	61.4	65
		Central Bank Of India MaskasathrdItwari		71.0	73.2	
		Kanji House Chowk Binaki		59.7	59.6	
		Vaishali Nagar Square		70.4	62.3	

Sr. No.	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
9	A S HI	Bodhisatva Library Indira Nagar Jaripatka	SIL EN	52.1	50.2	50

		Dhanoli Buddha Vihar Vishwas Nagar		56.3	51.0	
		Trisharan Buddha Vihar Nari		57.5	53.2	
		Hanuman Mandir Sanyal Nagar Bank Colony		55.6	49.2	
		Janta Maternity Hospital Jaripatka		58.1	49.4	
		Mahatma Gandhi High school Jaripatka		59.3	55.0	
		Shivgiri Hanuman Mandir Shambhu Nagar koradird		66.4	66.7	
		Gurunanak High School Bezonbagh		50.8	48.4	
		Hanuman Mandir Mahaveer Nagar Jaripatka		58.6	50.9	
		St. Martin Nagar Jaripatka	**RESIDENTIAL**	61.5	57.3	55
		Triratna Nagar Jaripatka		66.8	61	
		Vishwas Nagar		67.2	60.5	
		Sanyal Nagar Bank Colony		60.3	52.2	
		New Thaware Colony Jaripatka		52.8	52.1	
		Garden Layout Jaripatka		59.3	55	
		Bhatt Nagar Shakti Vihar Shambhu Nagar Nara Rd		57.1	51.5	
		Mecosabagh Christian Colony		69.1	55.4	
		Mahavir Nagar Jaripatka		54.9	45.3	
		Jaripatkapolic station	**COMMERCIAL**	65.3	59.1	65
		Near Jaripatka police station Nari		68.5	62.0	
		Barakholi Chowk		67.6	68.1	
		Gujjar Celebration Lawn Angulimal Nagar		58.6	55.3	
		Sidhu Society Chowk Jaripatka		64.8	64.0	
		Barakholi Chowk Jaripatka		59.3	62.5	
		Shivgiri Bus Stop Nara Road		65.9	66.7	
		Kadbi Chowk Metro Station		60.0	61.6	
		Ahok Bar Chowdhary Chowk		64.6	58.3	

Sr. No .	NMC Zone	Location	Noise Zone	Leq (6:00 AM To 8:00 PM)	Leq (8:00 PM To 10:00 Pm)	CPCB Permissible Limit (dBA)
10	**MANGALWARI**	Hanuman Temple, Ayyapa Nagar	**SILENCE**	46.4	54.1	50
		Elsiesnest School, ZingabaiTakli		49.1	61.8	
		VIMS Hospital		64.7	65.1	
		ShreenagharMankapur Ring road		57.8	56.4	
		MGM School(Mankapur Ring road Lumbini Nagar)		46.2	54.1	
		Jafar Nagar New Mankapur		52.5	54.8	
		Mohan Nagar Temple		65.5	65.3	
		Dande hospital, Gokulpeth		55.8	49.4	
		SKLN Multispeciality dental clinic		58.3	50.7	
		Alexis Hospital Mankapur		64.9	61.3	
		Bhartiya Krushi VidyalayaZingabaiTakli		53.6	49.3	
		Adarsh Primary School Borgaon, Gorewada Road		60.2	53.7	
		Tailor line Shiv Mandir		59.6	53.5	
		SFS College Seminary Hills		52.8	41.5	
		Dhamma Nagar Buddha Vihar Gittikhadan		57.8	51.4	
		JaiBai Choudhari School Sadar		59.1	50.3	
		Saint Vincent Palloti School New Mankapur		53.0	50.8	
		Rahul Buddha Vihar Gautam Nagar Gaddi Godam		54.9	55.2	
		Ideal Academy of Science Friends Colony		58.6	53.5	
		SFS College Seminary Hills		65.4	49.6	
		Hanuman temple KatolrdChhaoni Sadar		52.1	55.0	
		Tirpude Institute of Management Education Sadar		62	55	
		Sri Balaji & Shri Karthikeya Temple Seminary Hills		63.9	56.8	
		SFS College Seminary Hills		63.5	48.2	
		Sandipani School Saroj Nagar		65.7	58.3	
		Roger Stronstad High School Gorewada		59.2	52.4	

		Durga Mata Mandir Gaddigodam Mohan Nagar		61.7	50.1	
		Japanese Garden Seminary Hills		49.4	48.6	
		National Fire Engineering College Police line Takli		52.6	50.6	
		Shir GruhalaxmiAmbabai Temple Manav Sena Nagar		50.6	45.3	
		Jwala Mata Mandir Jafar Nagar Police line Takli		47.0	51.6	
		Hiltop Durga Mandir Manav Seva Nagar Seminary Hills		58.4	49.8	
		Ayyapa Nagar	**RESIDENTIAL**	58.7	64.2	55
		Ujjwal Nagar ZingabaiTakli		51.3	64.7	
		Bunk Women's Hostel Sadar		69.2	75.4	
		Near Shiv Mandir Zingabaitakli		57.7	61.2	
		Ayyapa Nagar		58.5	64.2	
		Lokhanday Layout Lumbini Nagar New Mankapur		53.8	61.2	
		Mohan Nagar		58.2	63.6	
		Valmiki Nagar Gokulpeth		65.3	59.4	
		Surendragarh Seminary Hills		47.8	46.8	
		Kirad Layout New Mankaupr		61.3	58.2	
		Geeta Nagar ZingabaiTakli		59.7	53.6	
		Surendragarh Manav Seva Nagar Gittikhadan		66.3	56.4	
		Chaman Gali, Chhawani		67.7	61	
		Virndavan Colony		49.3	46	
		Panchasheel Nagar Gittikhadan		67.8	61.1	
		Nai Basti Chhaoni Sadar		61.5	58.7	
		Suraj Nagar KatolrdGorewada		62.9	68.1	
		Chandra Vihar Mohan Nagar		60.1	65.4	
		Barde Layout Friends Colony KT Nagar		66.5	65.7	
		Raj Nagar Katol Road		67.2	60.4	
		Raj Nagar Katol Rd Sadar		59.8	57.7	
		Buddha Nagar ZingabaiTakli		55.6	47.5	
		CPWD Colony Seminary Hill		49.5	44.4	
		Raj Nagar		67.9	55.4	

		Vayusena Nagar		71.1	59.2	
		Swami Madhav Nagar Gorewada		58.2	55.4	
		Chandra Vihar Mohan Nagar		53.6	56.5	
		Mount Rd Sadar		56.9	52.3	
		Raj Nagar Katorlrd		52.4	48.5	
		Surendra Nagar Manav Sena Nagar		50.6	44.2	
		Jafar Nagar Police line takli		54.8	50.3	
		Manav Seva Nagar Seminary Hills		60.9	51.6	
		Smart Super Bazar Mankapur Road	**COMMERCIAL**	67.7	74.0	65
		Govind Lawn Prakash Nagar		65.3	69.0	
		Lenskart Shop Sadar		65.3	64.8	
		Mankapur Chowk		69.5	63.9	
		SBI ATM Adarsh Colony Mankapurrd		67.4	73.9	
		Jafar Nagar New Mankapur		60.8	63.8	
		Mohan Nagar Bazar		62.5	64.6	
		One Fitness Gym Gokulpeth		69.6	65.8	
		MECL Gittikhadan		62.0	59.4	
		Mankapur Square		65.8	60.5	
		Zingabai Talki road		70.1	68	
		Dominos KT Nagar		65.3	64.2	
		Metro Hospital Chhaoni Sadar		67.4	62.6	
		Haldiram Sadar		67.8	60.5	
		Nirmal Ganga Complex Gittikhadan		65.6	65.3	
		Bhagwan Traders New Colony Sadar		63.8	62.2	
		Raj Celebration Mankapur road		68.6	68.1	
		Nirmal Furniture Gaddi Godam		54.1	66.3	
		Unnati Gym fitness Center KT Nagar		67.4	63.9	
		Old Katol Naka Square		71.7	72.6	
		Poonam Chamber Mall Sadar		61.1	59.9	
		Shre Gganesh super market koradird		74.4	65.1	
		Regional Passport Office Seminary Hills		65.2	58.3	
		Orange Green Celebration Bal Bhavan Sadar		67.1	61.2	

		Dabha Veg Market Mankapur Ring Road		84.3	65.6	
		ASR Celebration Lawn Tower line Gorewada		67.6	59.6	
		Gaddigodam Square		72.5	58.1	
		VCA Civil Lines		57.5	55.7	
		Awasthi Chowk Borgaon Road		54.5	53.6	
		Managalwari Bazar Complex Sadar		59.9	63.4	
		Chopde Lawn Jafar Nagar Police line Takli		66.9	58.4	
		Shreenath Farsan MG Nagar rd Manav Seva Nagar Seminary Hills		45.3	51.2	

ESR (2023-24)

Chapter 5
Solid Waste

CSIR-NEERI

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Municipal Solid Waste

5.0 Introduction

Solid waste encompasses a broad array of discarded or unwanted materials resulting from human activity across residential, commercial, and industrial sectors. It includes everyday items such as food scraps, packaging, and used household goods. Solid waste is generally categorized into several types, including municipal solid waste (MSW)—commonly referred to as city or household waste—as well as construction and demolition (C&D) waste, electronic waste (e-waste), biomedical waste, and hazardous waste. Among these, MSW is of particular concern due to its ubiquity and the challenges associated with its management, especially as it comprises commonly used disposable items like food packaging, containers, and consumer goods.

The physical and chemical properties of waste vary widely depending on its source and composition. Improper management of solid waste can cause significant environmental degradation, contaminate air, water, and soil, and pose serious health risks. Moreover, remediation of contaminated sites is often far more resource-intensive than preventive waste management. The composition of MSW is highly variable, influenced by geographic location, seasonal shifts, and local consumption habits. Typical components include organic matter (e.g., food waste), packaging materials, and market refuse, with sources ranging from households and institutions to businesses and industries.

It is important to distinguish MSW from other waste streams such as industrial, agricultural, biomedical, radioactive waste, and sewage sludge, which require specialized handling and are not managed through conventional municipal systems. Managing MSW is especially challenging in rapidly urbanizing regions, where increasing population densities and expanding urban footprints place mounting pressure on already strained waste management infrastructure. These challenges highlight the urgent need for integrated and adaptive waste management strategies to ensure environmental sustainability and protect public health.

In rapidly urbanizing regions, particularly in developing countries, the challenge of establishing adequate waste management infrastructure intensifies with increasing population density. Urban expansion not only amplifies the volume of waste generated but also complicates its efficient and sustainable management. Inadequate or poorly managed waste systems can lead to severe environmental consequences, including contamination of water resources, air pollution, and land degradation, which collectively pose significant public health hazards (Kalantarifard and Yang, 2011).

To address these issues effectively, it is imperative that municipal authorities and policymakers prioritize investments in the modernization and scaling of waste management systems. These systems must evolve to accommodate changing waste generation patterns, increasing quantities, and the heterogeneous nature of waste streams.

A foundational requirement for effective waste management is the availability of accurate, current data on waste generation rates and composition. A thorough understanding of municipal solid waste characteristics enables planners and waste management professionals to devise targeted strategies for segregation, recycling, treatment, and disposal. Such data-driven approaches are essential for enhancing the efficiency of waste management systems and mitigating the associated environmental and health impacts (Gidarakos et al., 2006; Gomez et al., 2008).

5.1 Nagpur - City profile and population distribution

Nagpur, often referred to as the "winter capital" of Maharashtra, is a prominent urban centre located in Central India. The city profile in terms of population distribution, demographic structure as per 2011 census was reported in earlier report (ESR report 2022-2023). This population growth of Nagpur city has led to a corresponding increase in municipal solid waste (MSW) generation, consistent with trends observed in other expanding urban areas. This rapid urbanization underscores the growing need for robust and scalable waste management infrastructure.

Administratively, Nagpur is divided into 10 zones and 38 municipal wards, each with specific waste management challenges and service requirements. This zonal structure facilitates decentralized governance and aims to enhance the operational efficiency of waste collection, segregation, and disposal. **Table 5.1** outlines the details of the municipal zones, while **Figure 5.1** provides a visual representation to aid comprehension.

Table 5.1: List of different zones in Nagpur city

Zone	Name of Zonal Office
Zone 1	Laxminagar
Zone 2	Dharampeth
Zone 3	Hanuman nagar
Zone 4	Dhantoli
Zone 5	Nehru Nagar
Zone 6	Gandhibagh
Zone 7	Satranjipura
Zone 8	Lakadganj
Zone 9	Ashi Nagar
Zone 10	Mangalwari

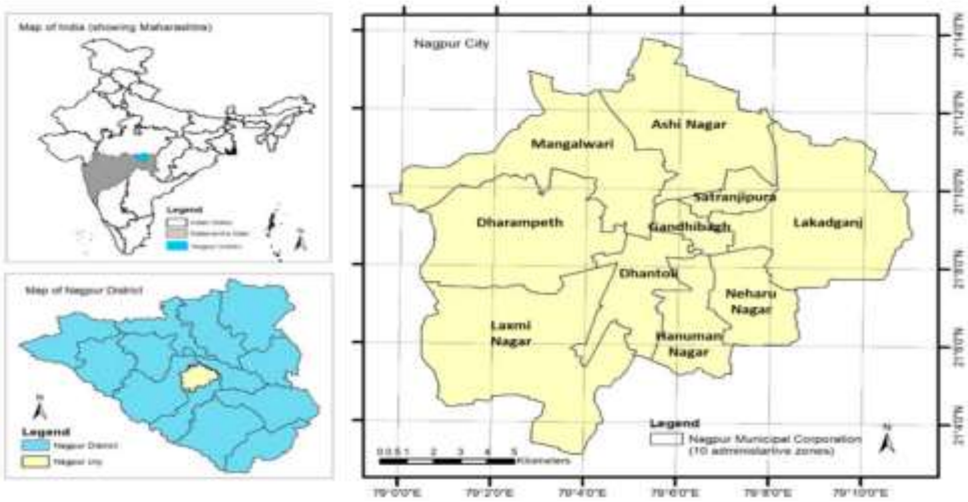

Figure 5.1: Nagpur city map (Zone-wise)

5.2 Socio-economic groups in Nagpur

Within the ten administrative zones of Nagpur, the population is socio-economically stratified. Based on household income levels, the city is demarcated such that only one zone is predominantly occupied by the low-income group (LIG), while the high-income group (HIG) spans across three zones. The remaining six zones are primarily inhabited by the medium-income group (MIG). This distribution is summarized in **Table 5.2**.

Table 5.2: Socio-economic groups in Nagpur (Source: ESR report, 2019-2020)

Socio-economic Group	Zone Names
LIG	Satranjipura
HIG	Lakshmi Nagar Dharampeth Dhantoli
MIG	Hanuman Nagar Nehru Nagar Gandhi Bagh Lakadganj Mangalwari Ashi Nagar

5.3 Current status of solid waste in Nagpur city

The composition of solid waste in Nagpur City is diverse, originating from a variety of sources. It includes household waste generated in residential areas, as well as refuse from hotels, restaurants, gardens, and lawns. Additionally, the waste stream encompasses construction and demolition (C &

D) debris, sanitation residues, street sweepings, biomedical waste from hospitals, organic waste from slaughterhouses, and refuse from markets and commercial establishments. Among these, residential and commercial complexes constitute the primary sources of municipal solid waste in the city.

5.3.1 Municipal solid waste

As urbanization intensifies and population density increases, cities face growing pressure to meet the evolving demands of their residents. In the case of Nagpur, the Bhandewadi dumping site study conducted by CSIR-NEERI reveals that the city generated approximately 1312.38 (TPD) of heterogeneous municipal solid waste (MSW) in 2023-2024, derived from both residential and commercial zones. A considerable proportion of this waste is biodegradable, alongside significant volumes of construction and demolition debris. The average per capita waste generation in Nagpur is estimated at 0.396 kg/person/day.

One of the major concerns is the widespread open dumping of waste, driven by inadequate collection services and a lack of sufficient infrastructure for waste processing and scientific disposal. The current municipal solid waste management (SWM) system in Nagpur remains underdeveloped and inefficient in coping with the increasing waste burden. Socio-economic stratification also plays a critical role in influencing waste generation patterns. Waste quantities and types vary significantly across different income groups due to varying consumption habits, lifestyle standards, and access to waste management services. High-income groups, for instance, tend to produce greater volumes of waste, often including packaging materials and e-waste, whereas low-income groups may contribute more organic and biodegradable waste. Hence, understanding these demographic dynamics is essential for designing inclusive and efficient SWM strategies.

NMC acknowledges the urgency of addressing SWM challenges, particularly those related to the escalating volume of waste, variability in waste composition, and inadequate processing and disposal methods. SWM in the city comprises four main components:

- Waste generation at the source
- Waste collection (primary and secondary)
- Transportation
- Final disposal

Currently, NMC has implemented a two-tiered collection system in all ten municipal zones. In the primary stage, waste is collected directly from households through door-to-door services and transported to intermediate transfer stations. The secondary stage involves transporting this waste from transfer stations to the designated dumpsite at Bhandewadi. To streamline waste collection, NMC has engaged two private agencies—AG Enviro Infra Project Pvt. Ltd. and BVG India Ltd. AG Enviro is responsible for managing zones 1 to 5 (Laxmi Nagar, Dharampeth, Hanuman Nagar, Dhantoli, and Nehru Nagar), while BVG India oversees zones 6 to 10 (Gandhi Bagh, Satranjipura, Lakadganj, Ashi Nagar, and Mangalwari). All collected waste is ultimately transported to the Bhandewadi dumping yard for disposal. Furthermore, annual MSW generation has shown a rising trend over recent years, as depicted in **Figure 5.2**, underscoring the need for enhanced waste management planning and execution.

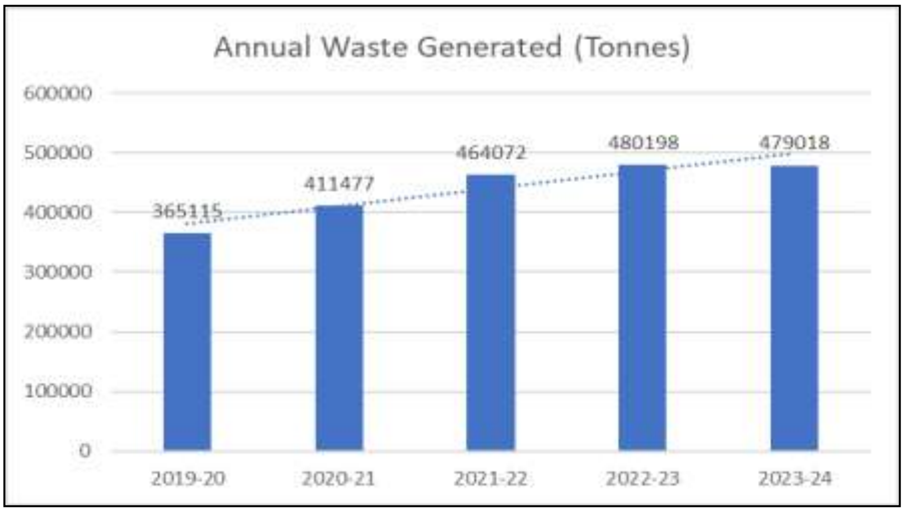

Figure 5.2: Trend in solid waste generation in Nagpur city in last five years

5.3.2 Waste categorization

A comprehensive waste categorization study was conducted by the CSIR-NEERI team at the Bhandewadi dumpsite in Nagpur. The analysis revealed that the predominant fraction of bulk MSW comprised organic or biodegradable waste, including raw vegetable residues, horticultural waste, and cooked food waste. In addition to the organic fraction, notable quantities of textiles, plastics, sanitary waste, paper and cardboard, and general rejects were identified. Glass, metals, and C&D debris were also present in smaller proportions, representing the minor fractions of the total waste stream. **Plate 5.1** showcases the various fractions separated during the waste segregation exercise. **Figure 5.3** offers a graphical summary of the overall waste composition for the entire city. The study further emphasizes that waste generation and composition vary significantly across the ten municipal zones of Nagpur. These variations are influenced by factors such as population density, socio-economic profile, and the presence of commercial hubs, market areas, and educational institutions within each zone. Particularly, the biodegradable waste fraction—comprising raw vegetables, kitchen leftovers, and cooked food—was observed to range between 57% to 74% of the total MSW generated across different zones of the city. These findings highlight the need for zone-specific waste management strategies and underscore the importance of targeted interventions for organic waste processing in Nagpur.


Biodegradable waste


Cooked Food Waste


Textile Waste


Plastic Waste


Paper and Cardboard Waste


Sanitary Waste

Plate 5.1: Major fractions/components obtained during segregation

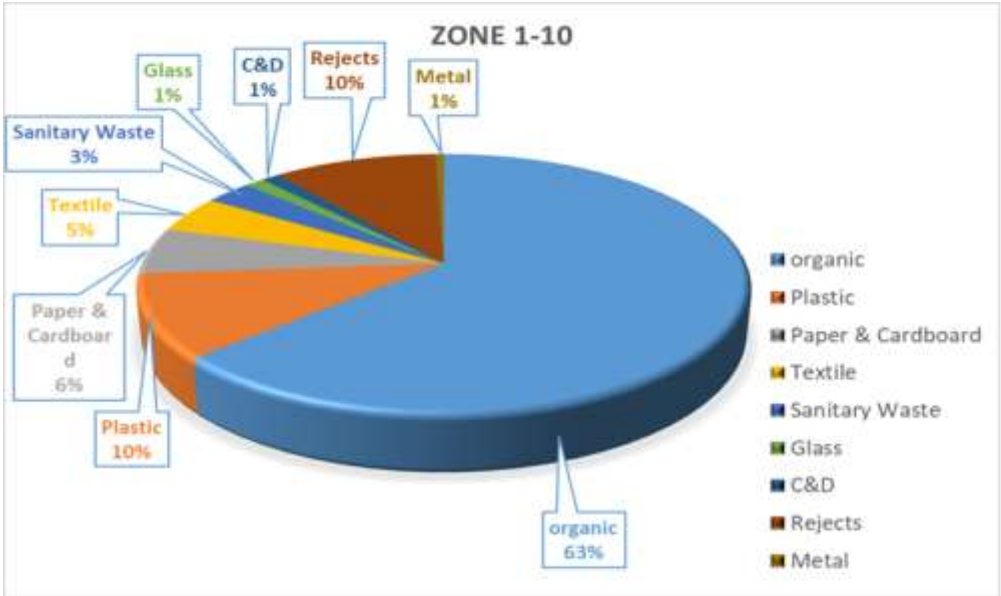

Figure 5.3: Categorization of MSW for Nagpur city

5.3.3 MSW collection and segregation

The collection of MSW plays a crucial role in safeguarding public health, maintaining environmental quality, and promoting overall community well-being. Efficient MSW collection ensures the proper disposal or recycling of waste materials, thereby minimizing adverse impacts on both human health and the surrounding ecosystem.

In alignment with the objectives of the Swachh Bharat Mission, NMC has implemented a door-to-door waste collection system across all 10 municipal zones of the city. The NMC has outsourced this service to two contracted agencies—AG Enviro Infra Pvt. Ltd. and BVG India Ltd. AG Enviro is responsible for Zones 1 to 5 (including Laxmi Nagar, Dharampeth, Hanuman Nagar, Dhantoli, and Nehru Nagar), while BVG India manages Zones 6 to 10 (Gandhibagh, Satranjipura, Lakadganj, Ashi Nagar, and Mangalwari). Waste is collected in a segregated manner, with designated compartments for wet and dry waste in each collection vehicle. Despite this arrangement, observations indicate the presence of mixed waste in both waste streams, which disrupts the efficiency of downstream processing systems. This underscores the need for enhanced source segregation practices and robust public engagement strategies to reduce cross-contamination. In the year 2023–2024, the total MSW collected in Nagpur was recorded at 4,79,018.7 tonnes. Of this, 47,165.06 tonnes constituted dry waste, and 2,32,463.75 tonnes comprised wet waste. In addition, 19,506.88 tonnes of street-swept waste were collected separately as sweeping waste.

Currently, the city lacks officially designated transfer stations—intermediary points where waste is transferred from smaller primary collection vehicles to larger secondary transport vehicles (e.g., compactors). However, informal or unauthorized transfer activities are suspected, and it is recommended that NMC identify, regulate, or formalize these facilities to ensure compliance and streamline the collection process. The city's waste collection system operates in two stages:

- Primary Collection: Involves the use of refuse collection trucks to collect waste directly from households and establishments.
- Secondary Collection: Utilizes specialized hydraulic vehicles such as refuse compactors and tippers with enclosed bodies for safe transport to the Bhandewadi landfill.

The NMC operates a total 538 door-to-door collection vehicles with- 444 primary vehicles and 94 secondary vehicles. NMC owns six mechanized street sweeping vehicles while one mechanical road sweeper is utilized on rental basis.

NMC continues to explore technological enhancements for waste segregation and emphasizes the importance of public awareness campaigns. Community participation remains central to the success of solid waste management initiatives, as it helps improve source segregation and fosters a culture of environmental responsibility.

5.3.4 Processing and disposal of MSW

The processing and disposal of municipal solid waste (MSW) play a critical role in protecting public health, reducing environmental pollution, and advancing sustainable resource management. Effective waste processing facilitates the recovery of recyclable materials, thereby conserving natural resources and reducing the dependency on landfill space. Additionally, safe and sustainable disposal methods, such as waste-to-energy (WtE) and composting, help mitigate ecological impacts and promote circular economy principles. Prioritizing scientifically sound and integrated waste management strategies is essential for developing healthier, more resilient urban ecosystems.

In Nagpur, the primary disposal site for municipal solid waste is the Bhandewadi dumpsite, located approximately 10 kilometers from the city center in the eastern suburbs. Operational since 1969, the site spans an area of 54 acres and continues to serve as the city's central landfill. To reduce the volume of waste being directly landfilled, NMC has implemented processing interventions at the Bhandewadi facility. These include:

- Composting of biodegradable waste, which accounted for the treatment of approximately 200 tonnes per day (TPD) in the year 2023–2024, yielding a total of 20 TPD of compost. This compost is subsequently used for horticultural and agricultural applications.
- Vermicomposting, with an operational capacity ranging between 5–10 TPD, complements composting efforts, especially for organic waste fractions from residential and market sources.

Despite these measures, further technological and infrastructural enhancements are required to optimize the processing of biodegradable waste, particularly considering the substantial volumes generated in urban markets and residential zones.

In a progressive move toward sustainable waste valorization, NMC has partnered with SusBDe, a Netherlands-based waste-to-energy company, through a formal Memorandum of Understanding (MoU). As part of this collaboration, a pilot-scale biomethanation plant with a capacity of 100 TPD is being operated at Bhandewadi. The plant aims to convert organic waste into biogas, thereby reducing landfill burden while generating renewable energy. Performance evaluations of the pilot plant are currently ongoing, with the long-term objective of scaling up operations under an integrated waste management framework.

By incorporating such decentralized and technologically advanced solutions, Nagpur is gradually transitioning toward a more efficient and environmentally responsible waste management system.

5.3.5 Legacy waste status at Bhandewadi dumping yard

Legacy waste refers to accumulated or historical waste that was generated in the past and remains untreated, unmanaged, or improperly managed for an extended period. This term typically applies to waste materials that were disposed of before the implementation of modern waste management practices or regulations. Legacy waste may include various types of solid waste, such as household trash, industrial by-products, and C & D debris, which can pose environmental and public health risks if not properly addressed.

NMC has taken a major initiative to deal with this legacy waste. The operation of biomining was started in 2019 lead by Zigma Global Environ Solutions Pvt Ltd, reclaiming around 54 acres of area by 2023. An additional 8 acres of land was reclaimed in 2023-2024, biomining 3000 TPD waste. A significant portion of the waste is being utilized to produce refuse-derived fuel (RDF), supplied to cement factories. Additionally, the process also yields soil that can be provided to farmers.

5.3.6 Bio-medical waste (BMW) and its management

Nagpur has established a structured and systematic approach for the management and disposal of Biomedical Waste (BMW). The city's BMW collection network covers 2,675 registered biomedical institutions, including hospitals, clinics, and diagnostic laboratories.

In the year 2023–2024, approximately 4.67 TPD of biomedical waste were collected from these facilities. The collected waste is transported to the Bhandewadi BMW Treatment Facility, where it undergoes incineration—a controlled thermal treatment process that ensures the safe disposal of hazardous biomedical materials, thereby minimizing health and environmental risks.

The current system reflects Nagpur's commitment to adhering to the Biomedical Waste Management Rules, 2016, by ensuring the safe segregation, collection, transport, and treatment of biomedical waste in compliance with public health and environmental safety standards.

5.3.7 Electronic waste management in Nagpur city

The issue of electronic waste (E-waste), which often gets integrated with MSW, presents a significant and multifaceted challenge for urban waste management in Nagpur. Currently, E-waste management is predominantly handled by the informal sector, with no formal system in place under the jurisdiction of the NMC. The absence of designated agencies or a structured collection mechanism has resulted in unregulated and inefficient handling of E-waste.

In the absence of a robust policy framework and adequate planning, a substantial portion of E-waste becomes mixed with regular household waste during collection. This leads to its unscientific disposal, often at dumping sites, thereby posing serious risks to public health and the environment due to the hazardous components present in electronic devices. Given the growing volume of E-waste and its associated risks, there is an urgent need for the strict enforcement of the E-waste Management Rules, 2016, and the establishment of a dedicated and formalized E-waste collection and processing system in Nagpur. This should include public-private partnerships, designated collection centers, and awareness campaigns to promote responsible E-waste disposal practices. However, a notable positive step has been the involvement of Suritex Ltd.—a dismantler authorized by the Maharashtra Pollution Control Board (MPCB)—along with select NGOs that conduct periodic E-waste collection drives and awareness campaigns. These initiatives, though limited in scale, represent a crucial starting point toward promoting responsible E-waste handling and building public consciousness around the issue.

5.3.8 Construction & demolition (C&D) waste

As Nagpur continues to expand, its infrastructure undergoes daily growth, underscoring the critical need for effective management practices to accommodate this development sustainably. With the city's increasing infrastructure demands, meticulous planning and oversight becomes imperative to ensure optimal utilization of resources and minimize potential challenges associated with rapid urbanization. So NMC has initiated the separate collection and disposal of Construction and Demolition (C&D) waste. C & D waste can have significant environmental impacts, including habitat destruction, soil erosion, and air and water pollution. Improper disposal of materials such as concrete, wood, metals, and chemicals can contribute to the contamination of soil and water bodies, while demolition activities can disrupt ecosystems and wildlife habitats. Additionally, the large volume of waste generated from construction and demolition activities can exacerbate landfill capacity issues.

NMC has implemented the Brown line specifically for the collection and transportation of C & D waste. In the year of 2023-2024 in between 100-150 TPD C&D waste was processed and recycled at the Bhandewadi C&D waste processing plant.

5.4 Bhandewadi Dumping Site

Initially, the disposal of MSW in Nagpur occurred across multiple scattered locations throughout the city. However, since 1969, the Bhandewadi dumpsite has served as the centralized waste disposal site, located approximately 10 kilometers from the city center (**Plate 5.2**). The geographical coordinates of the site are 21º08’26.1” N latitude and 79º07’13.8” E longitude, with an elevation of 314.79 meters above Mean Sea Level (MSL). The Bhandewadi landfill receives waste generated from residential, commercial, institutional, and market sources across the city. NMC owns a total of 184.22 hectares of land in this area. Out of this, approximately 21.57 hectares are specifically allocated for MSW disposal, while an additional 19.64 hectares are used for supporting facilities such as composting units and weighbridge installations.

The layout of the Bhandewadi dumpsite is presented in **Figure 5.6** (Source: NMC), providing a spatial representation of the designated zones for waste disposal and ancillary infrastructure.

Plate 5.2: Bhandewadi dumping site

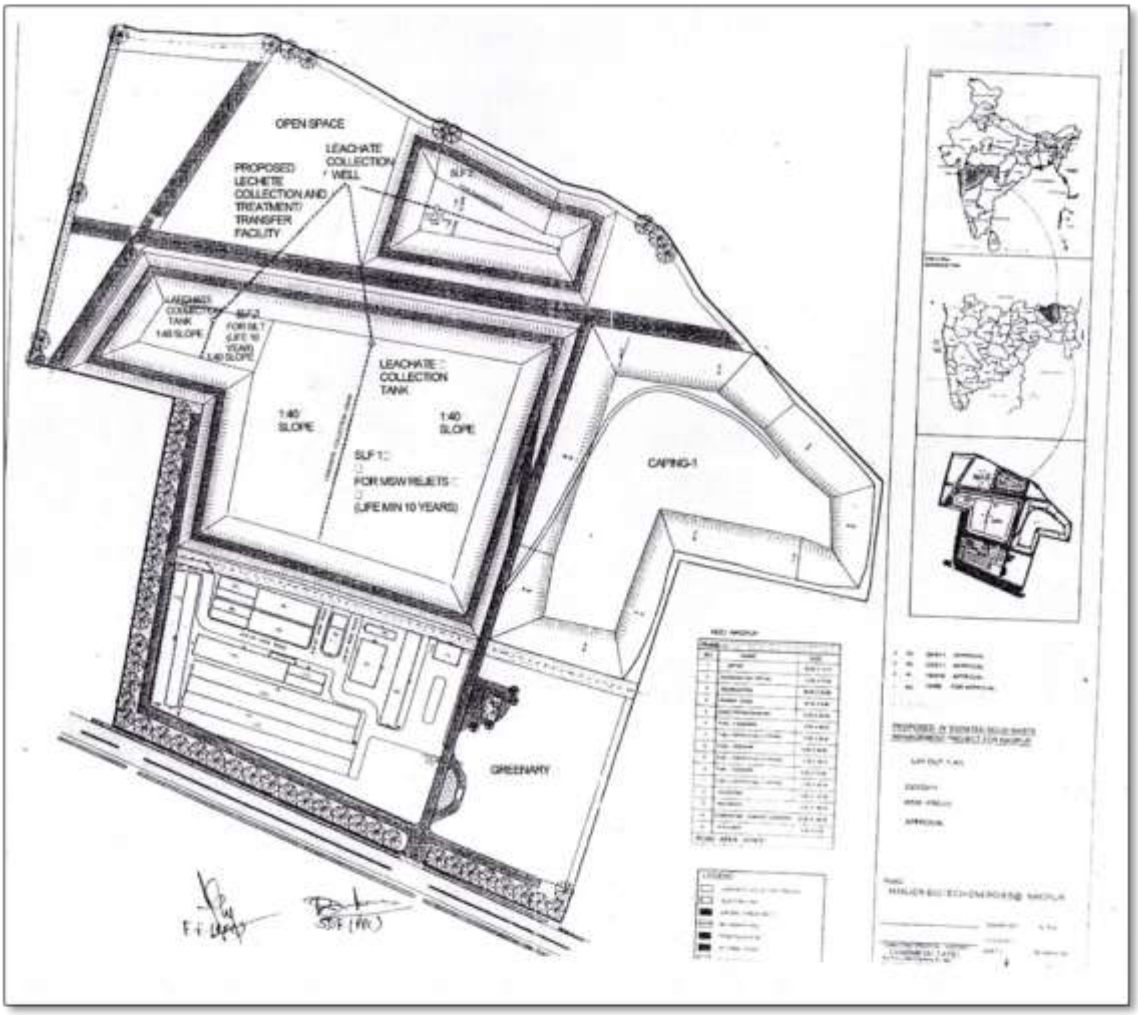

Figure 5.4: Bhandewadi layout map (Source: NMC)

5.5 Role of informal sectors in waste management

In India, the informal sector has historically played a critical role in waste management systems. The informal sector is typically defined by its labor-intensive, small-scale, unregistered nature, often involving low-technology methods in the provision of goods and services. There is growing recognition of the need to formally integrate this sector into the broader municipal waste management framework (Kumar et al., 2017). Waste pickers, who number in the hundreds to thousands across urban areas like Nagpur, are integral stakeholders in this ecosystem. They collect waste from households, commercial zones, and industrial sites, extracting valuable recyclable materials from bins, streets, drainage channels, trucks, and dumpsites. This practice of material recovery not only reduces the volume of waste reaching landfills but also aligns with sustainable waste management principles, as the economic potential of waste is best realized through effective source segregation (Agbefe et al., 2019). Despite the health risks and social vulnerabilities, waste pickers depend on waste collection for their livelihoods. Their contributions have become increasingly important, particularly in the recovery of metal, plastic, and other recyclables, which are redirected into the recycling and reuse stream.

Recent efforts in Nagpur and other cities have seen the introduction of processing technologies such as composting and the production of Refuse-Derived Fuel (RDF), often supported by private sector operators. These advancements have been facilitated through Public-Private Partnership (PPP) models, enabling a more structured and scalable approach to urban waste management. Notably, the informal sector's active participation in the waste value chain has grown significantly under these initiatives, underscoring its importance in the transition toward an integrated and sustainable waste management system.

5.6 Recommendations: Sustainable solid waste management

NMC has undertaken commendable steps in improving solid waste management (SWM) across the city, including door-to-door collection, zone-wise allocation of collection agencies, and efforts to promote waste segregation and composting. Building on this strong foundation, the following recommendations aim to reinforce and scale up these initiatives for greater effectiveness and long-term sustainability:

5. **Enhance source segregation and community participation**: NMC has already rolled out waste segregation at the household level, yet mixed waste continues to reach collection points. These efforts need reinforcement, especially in zones with high instances of non-segregation. Continued public education campaigns, with active involvement of schools, RWAs, and self-help groups, should be promoted to build a culture of civic responsibility and environmental stewardship.
6. **Modernize collection infrastructure and vehicles:** The replacement of outdated waste collection vehicles with fuel-efficient, GPS-enabled compactors has improved efficiency. Expanding this system to all wards and introducing more collection points and trolleys in congested neighbourhoods will ensure better coverage. Establishing well-equipped transfer stations will streamline the waste movement and reduce the load on landfill sites.
7. **Strengthen segregated collection and monitoring systems:** To ensure the effectiveness of door-to-door waste collection, training programs for sanitation workers should be continued and scaled. Introducing a monitoring and feedback system—including incentives for compliant households and penalties for non-segregation—can further improve compliance.
8. **Promote decentralized and community composting:** While NMC has initiated composting for bulk generators, enforcement of Solid Waste Management Rules, 2016 needs to be strengthened.

Composting at source should be made mandatory for all generators producing over 100 kg/day of waste. Compost should be promoted for use in public gardens, green belts, and urban farming initiatives.

9 **Expand plastic and metal recycling:** Plastic and metal recycling must be prioritized by forming structured partnerships with registered recyclers. Decentralized sorting hubs should be introduced in commercial areas to collect and segregate high-value recyclables. Promotion of Extended Producer Responsibility (EPR) and incentives for recycled product use should be actively pursued to drive a circular economy.

10 **Institutionalize E-waste management:** Currently, E-waste collection in Nagpur is largely informal. While Suritex Ltd. and select NGOs conduct periodic E-waste collection drives and awareness campaigns, a formal system under NMC is urgently needed. Establishment of authorized collection centers, public-private partnerships, and citywide awareness initiatives must be prioritized in line with the E-Waste Management Rules, 2016 to prevent unscientific disposal and safeguard public health.

11 **Establish data-driven recycling monitoring:** NMC should maintain a centralized digital registry of recycling units and conduct regular audits to track performance, compliance, and material flow. A robust data monitoring system will improve transparency and help in policy refinement.

12 **Adopt smart and digital waste management Tools:** NMC has already introduced technology into its waste management practices. Expanding this to include IoT-based smart bins, route optimization for collection vehicles, and real-time dashboards will help monitor progress and identify bottlenecks quickly. Integrating waste tracking features in the MyNagpur app will further enhance responsiveness and citizen engagement.

13 **Strengthen public grievance redressal systems:** The MyNagpur app should be enhanced to include features such as waste pickup alerts, reporting missed collections, and tracking complaint resolution. Communication campaigns through WhatsApp and community radio can ensure better outreach, especially among senior citizens and lower-income groups.

14 **Foster research, innovation, and capacity building:** Collaboration with research institutions, academic bodies, and start-ups can foster innovation in composting, bio-methanation, waste-to-energy (WTE), and landfill mining. Supporting pilot-scale demonstrations and facilitating knowledge-sharing platforms can accelerate the adoption of sustainable solutions.

Implementing a combination of these strategies can significantly improve Nagpur's MSW management system. A holistic, integrated approach, involving active participation from the community, municipal bodies, private sector, and academic institutions, is essential to ensure long-term environmental and public health benefits.

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ESR (2023-24)

Chapter 6
WATER ENVIRONMENT

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Water Environment

6.0 Introduction

Nagpur is third-largest city of Maharashtra, which is situated near the geographic center of the quadrilateral. The plateaus of the Satpura range surround Nagpur; the hills are forested in the west, while the hills of Ramtek cover the northeast. Kanhan and Pench rivers are in the center, Wardha in the west and the Wainganga in the east. Wardha and Wainganga rivers later merge as tributaries into the Godavari River. These rivers divide the city into three parts. The Pench-Kanhan river system includes the Nag river. The Pilli river runs through the district, merging with the Nag River near Pawangaon before joining the Kanhan River in Wainganga. Pora is the third river of the city, which flows towards the southeast part of the city. The three rivers meet at the outskirts of Nagpur. They then flow into Gosikhurd Dam in Maharashtra, with a capacity of 1,146 million cubic meters.

The chapter on water environment discusses the current status of surface water bodies (rivers and lakes) and groundwater with reference to its water quality. The chapter presents the analysis of water samples from three rivers (Nag, Pilli, and Pora) and ten lakes (Sonegaon Lake, Futala Lake, Gorewada Lake, Ambazari Lake, Binaki Lake, Naik Lake, Sakkardara Lake, Pandharabodi Lake, Gandhisagar Lake and Police Line Takli Lake) in addition to twelve ground water sources (dugwells and borewells). The samples have been characterized for their physico-chemical composition and bacterial load of coliforms along with the aquatic biological parameters (phytoplanktons and zooplanktons).

6.1 Methodology

Data related to following was obtained from secondary sources as given below;

- Water supply systems and point of use water quality- provided by Nagpur Municipal Corporation (NMC)
- Sewage Management and Sewage Treatment Plant- provided by NMC

Analysis of different physio-chemical and bacteriological parameters for surface waters from sampled rivers, lakes, and groundwater was performed as per Standard Methods (APHA, 2017). **Table 6.1** shows the different methods used for characterization of water samples;

Table 6.1: Standard methods used for physico-chemical, bacteriological, benthic analysis of surface and ground water (APHA, 2017)

Sr. No.	Parameter	Standard Method used / Number
1.	Chemical Oxygen Demand (COD)	Closed reflux method / 5220
3.	Dissolved Oxygen (DO)	Electrochemical (diaphragm electrode method) / 4500-O
4.	Total Kjeldahl Nitrogen (TKN)	Titrimetric with preliminary Distillation/Digestion / 4500-N
5.	Phosphate as P	Stannous chloride method / 4500-P D
6.	pH	Potentiometric method (pH meter) / 4500-H^+B
7.	Total Dissolved Solids (mg/L)	Gravimetric method / 2540-C
8.	Turbidity (NTU)	Nephelometric method / 2130-B
9.	Total Alkalinity as $CaCO_3$ (mg/L)	Titrimetric method / 2320-B
10.	Chloride as Cl^- (mg/L)	Argentometric method / 4500-Cl^--B
11.	Sodium	Flame photometric method / 3500 Na B
12.	Potassium	Flame photometric method / 3500 K B
13.	Fluoride	Electrode method / 4500 F C
14.	Total hardness	Titrimetric method / 2340 C
15.	Calcium	EDTA Titrimetric method / 3500 Ca B
16.	Magnesium	EDTA Titrimetric method / 3500 Mg B
17.	Nitrate	UV Spectrophotometric method / 4500 NO_3 B
19.	Bacteriological analysis (total and fecal coliforms)	Membrane filteration technique / 9222
20.	Benthic (Phyto- and zooplanktons)	Microscopy / 10200
21.	(i) Well locations & (ii) Ground water level	(i) By GPS (ii) Automatic water level indicator (Model-EPP-10/6) manufactured by M/s ENCARDIO-RITE ELECTRONICS PVT LTD)
22.	Heavy metals in ground water	ICP-OES (Model: iCAP 6300 DUO, Make: Thermo Fischer)

6.2 Observation and Inferences

6.2.1 Water supply system and point of use water quality

As per information provided by NMC, the city has five water treatment plants (WTPs) with an existing water supply system of a total capacity of 786 MLD, i.e.,

Pench I WTP of 136 MLD;

Pench II WTP of 175 MLD;

Pench III WTP of 120 MLD;

Pench-IV WTP of 115 MLD and

Kanhan WTP of 240 MLD

The maximum water is received to city is from Pench Dam. The water is supplied to the city from 73 operating command areas (CAs) consisting of GSR/ESR/MBR, through pipelines connecting the ten water distribution zones. The Gross Water Demand of the city in the year 2023-24 was of 706 MLD as reported by NMC. Of the 706 MLD water supplied to the city, 41.91% loss of water occurred during the transport and distribution of raw water from source to consumer. This water which was lost during transportation and remained unbilled was the non-revenue water (NRW), while the total volume of water which reached the consumers and was billed for the period Apr-2023-Mar 2024 was 410 MLD (pure water supply of 257.642 MCM) (NMC Month-wise statement of water supplied and billed- **Table 6.2**). There is a need for NMC to make efforts for reducing the NRW by plugging the leakages in transport pipelines, and increase the billed water.

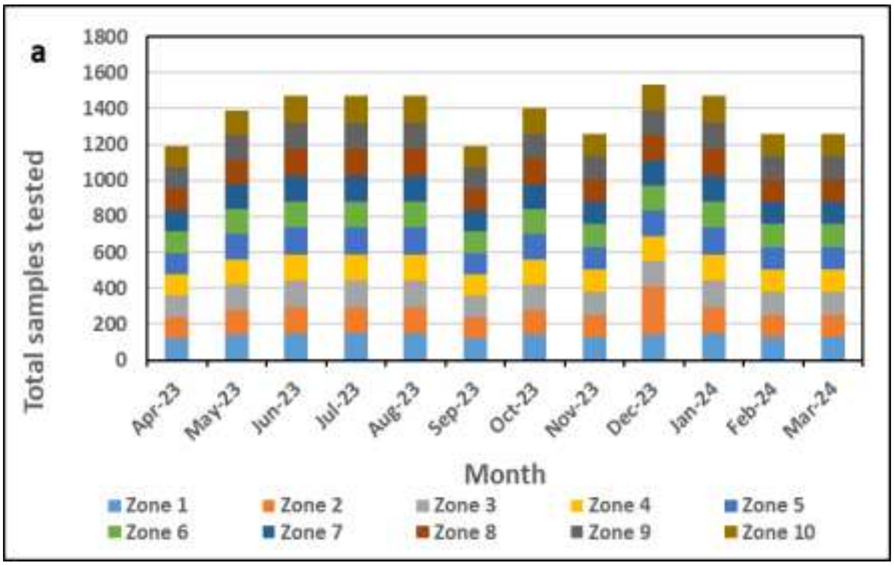
Table 6.2: Month-wise statement of water supplied and billed by NMC in 2023-2024

Month	**Pure water supply in MM^3**
Apr-23	21.245
May-23	22.366
Jun-23	21.697
Jul-23	21.803
Aug-23	21.962
Sep-23	21.071
Oct-23	22.265
Nov-23	20.850
Dec-23	21.281
Jan-24	21.452
Feb-24	19.856
Mar-24	21.794
Total	257.642 MCM
Volume billed	410 MLD

The 24x7 water supply program initiated by Nagpur Municipal Corporation (NMC) to address the city's unequal water supply was sanctioned for 704 km under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) (ESR report, 2020-2021). 377.84 km pipeline was to be laid under the Atal Mission for Rejuvenation and Urban Transformation-1 (AMRUT 1.0) scheme while remaining (287 kms) will be covered under the AMRUT 2.0 scheme. As informed by NMC, the tenders for first phase were invited and so far, the physical progress upto March 2024 shows that work for laying of 377.5 kms pipeline had been completed under the AMRUT 1.0 scheme. Under AMRUT 2.0, out of 287 Km proposed pipeline, 256 Km pipeline has been laid and the status of work is in progress. The newly laid pipeline has resulted in reduction of number of tankers employed by NMC for supply of water to different parts of the city, from 346 in 2016 to 78 in 2024. Despite the progress of this scheme, certain areas under 36 CAs were still considered as dark zones since the water supply was found to be less than 2 h per day.

There was a need for early initiation of the 2nd phase of laying of remaining pipeline for reduction in the number of tankers for supplying water to the different areas of Nagpur city, and effective implementation of the 24x7 water supply program (NESL-NMC, 2023).

As reported by NMC, the water quality was tested by the Regional Public Health Laboratory, Nagpur every month to ensure bacteriologically safe and potable water at the point of use and the results are presented in **Figure 6.1.** It can be observed that out of 16364 point of use samples analyzed, 16050 (98.08%) samples were found to be fit and 314 (1.91%) samples were found to be unfit for drinking as per bacteriological testing performed throughout the year (April 2023-Mar-2024).



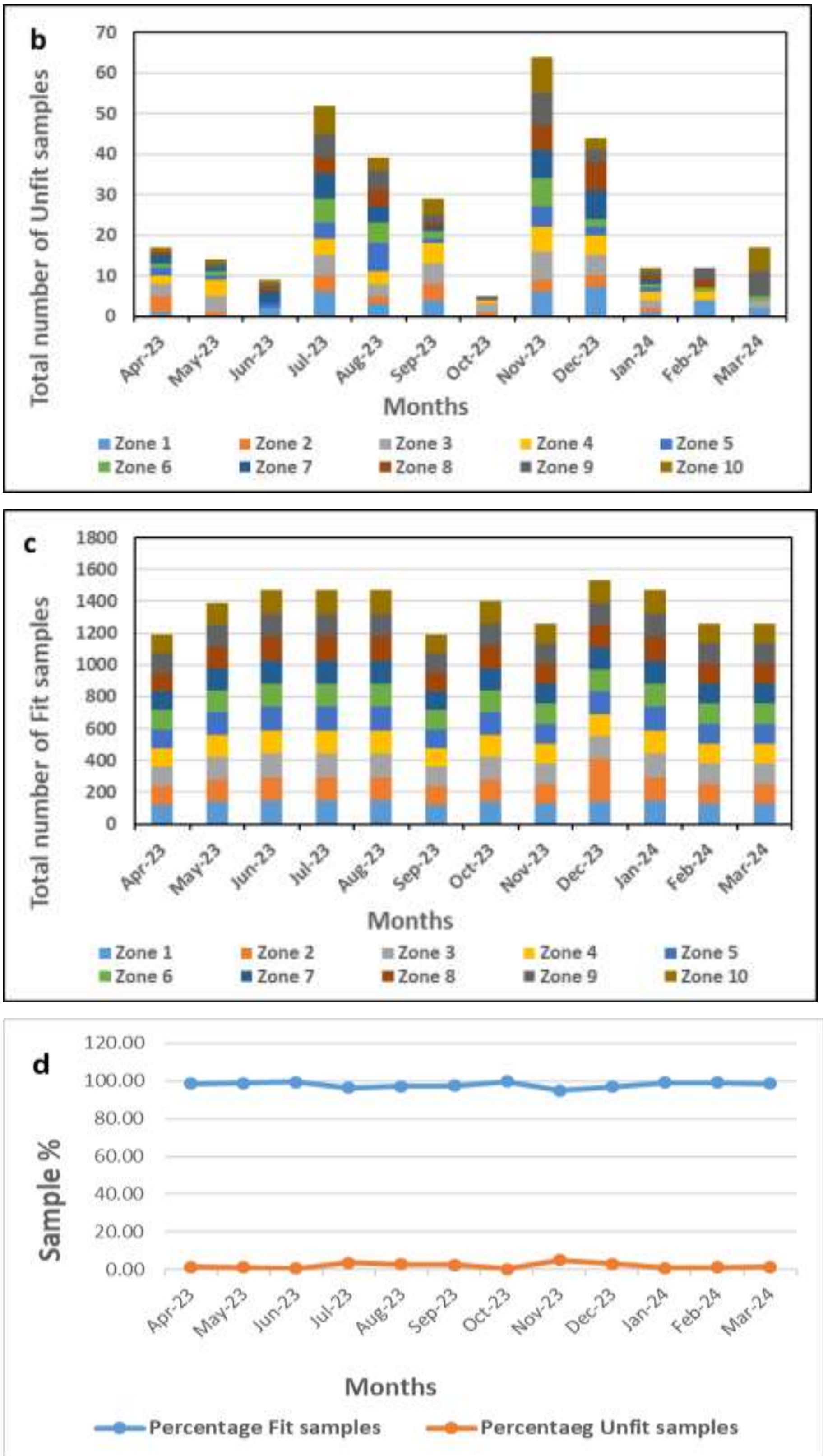


Figure 6.1: Zone-wise monthly bacteriological analysis of water (a) Total samples tested (b) Number of fit samples (c) Number of unfit samples (d) Percentage of fit and unfit samples (Source: NMC)

6.2.2 Sewage Management and Sewage Treatment Plant

Of the 706 MLD of freshwater supplied every day, about 73% (520 MLD) is converted to sewage, of which 77.5% (403.5 MLD sewage) is treated at 12 STP's operated by NMC across different locations of city **(Figure 6.2** and **Table 6.3)**. There was a need for treating sewage and reusing it to bridge the gap of sewage generation and treatment. NMC should assess the actual quantity of sewage generated daily, since the present scenario does not consider the water losses during supply and the supply of water from alternate sources. As informed by NMC, the additional sewage treatment capacities being develop under the JICA scheme (92 MLD), and AMRUT 2.0 scheme (35 + 10 MLD) are likely to bridge the gap between the sewage generation and treatment.

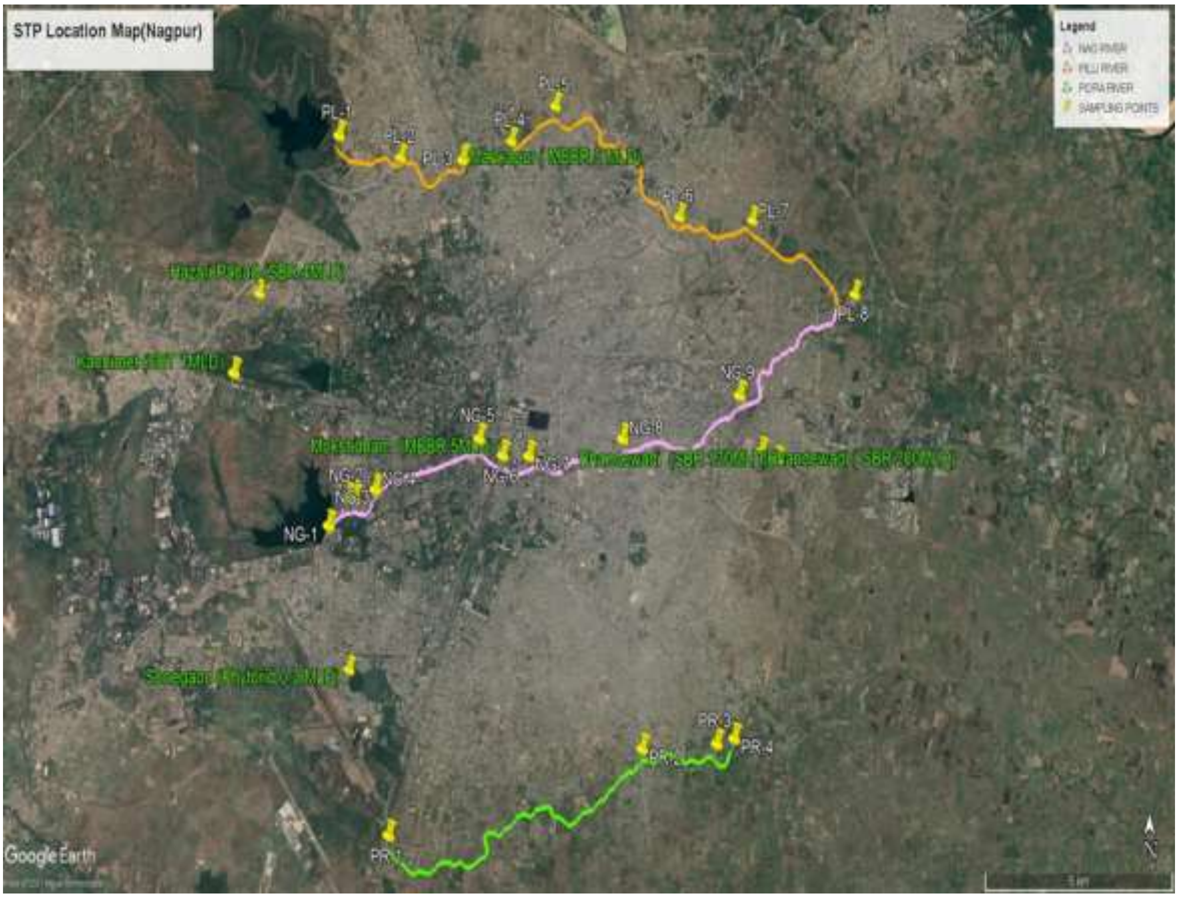


Figure 6.2: Sampling location of river along with Sewage Treatment Plant (STPs) of the city

Table 6.3: Details of sewage treatment plants run by NMC

Location of STP	Coordinates of STP (Latitude and Longitude)	STP Commissioned in (year)	Status (Operational/Non-Operational /Under Constructio	STP Installed Capacity (MLD)	Actual utilization of installed capacity (MLD)	Technology (UASB/ASP /OP/SBR/MBR/FAB etc.)	Consent Status
Bhandewadi, Nagpur	21.1378096: 79.1590347	2016	Operational	130	130	SBR	Consent to operate received by MPCB Mumbai for all 12 STPs on 15.12.2022, valid upto 30.04.2027
Bhandewadi, Nagpur	21.1381883: 79.155832	2018	Operational	200	200	SBR	
Mokshdham, Nagpur	21.137628: 79.088943	2017	Operational	5	5	MBBR	
Mankapur, Nagpur	21.190320: 79.079131	2017	Operational	5	5	MBBR	
Somalwada-1	21.086964: 79.074979	2021	Operational	20	20	SBR	
Hazaripahad	21.166345: 79.026774	2019	Operational	4	4	SBR	
Dabha	21.171881: 79.011537	2018	Operational	5	5	SBR	
Sonegaon	21.099773: 79.049576	2019	Operational	0.3	0.3	Phytorid Technology	
Kachimet	21.15095: 79.020094	2018	Operational	1	1	Soil Bio Technology	
Somalwada-2	21.088322: 79.07091	2022	Operational	20	20	SBR	
Itabhatti	21.172177: 79.121171	2022	Operational	10	10	SBR	
Ambazari	21.129474: 79.018274	2021	Operational	3.2	3.2	Phytorid Technology	
Narsala	21.087: 79.192	WIP	Trial run	20	20	SBR	

6.2.3 Surface water quality: Lakes

6.2.3.1 Lake Water Quality: Physico-Chemical

The city of Nagpur has 11 lakes. The site-specific scenarios in and around the few lakes are evident from **Plate 6.1 & Table 6.4**. The present study explored the water quality of ten significant lakes: Sonegaon Lake, Futala Lake, Gorewada Lake, Ambazari Lake, Binaki Lake, Naik Lake, Sakkardara Lake, Pandharabodi Lake, Gandhisagar Lake and Police Line Takli Lake. As reported in previous report (ESR report 2022-2023), sampling had not been done from three lakes viz., Gandhisagar, Police Line Takli, and Lendi due ongoing development work. As informed by NMC, of the different lakes, the development work was completed at following lakes viz; Gandhisagar, Sakkardara, Sonegaon, Naik (all four lakes-1st phase work completed); and Police Line Takli, Binaki (both lakes-work completed) hence sampling was possible for preparing this report. However, sampling was not performed in the Lendi lake due to presence of highly grown vegetation, and low level of water, and because the development work was not completed on account of opposition from residents to removal of encroachment. Further, as informed by NMC, Gandhisagar, Sakkardara, Sonegaon lakes were under 2nd phase of development and beautification, including desilting and desludging, walking track, rainwater drain, edge wall, retaining wall, toilet block, sewage treatment plant, colour fountains, foot bridge, parking, landscaping, electrification under various schemes. Since desilting and desludging was completed which could lead to increase in water storage capacity of the lakes.

On the banks of these lakes, slum settlements use the lake water for washing, bathing and other domestic activities. Nagpur Municipal Corporation (NMC) has always been proactive to protect these lakes from being polluted due to local activities. To generate lake water quality scenario in the city, a total of 12 sampling locations were selected for examination depending on accessibility and size of lakes viz.: 2 from Sonegaon Lake, 1 from Futala Lake, 1 from Gorewada Lake, 2 from Ambazari Lake, 1 from Binaki Lake, 1 from Naik Lake, 1 from Sakkardara Lake, 1 from Pandharabodi Lake, 1 from Gandhisagar Lake and 1 from Police Line Takli Lake. **Table 6.4** gives the details of sampling locations of the lakes under study along with observations of anthropogenic activities around the lake.

The water quality of Sonegaon, Futala, Gorewada, Ambazari, Binaki, Naik, Sakkardara Pandharabodi, Gandhisagar Lake and Police Line Takli lakes pertaining to physico-chemical parameters and COD are presented in **Tables 6.5 & 6.6**. The pH range of 6.96 - 8.82 was noted in Sonegaon, Futala, Gorewada, Ambazari, Binaki, Naik, Sakkardara, Pandharabodi, Gandhisagar and Policeline Takli lake water bodies. Total Alkalinity (Carbonates) was found in the range of 102.8-290.0 mg/L which corresponded to a 57-62% decline in total alkalinity from that in previous year (ESR report 2022-2023). Total Hardness was found to be in the range of 74.73-154.03 mg/L which was a decline by 23% from previous year (ESR report 2022-2023). Sulphates and Nitrates in the lakes were found in the range of 37-143 mg/L and 0.43-1.24 mg/L, which were 70-75% lower than the previous year data (ESR report 2022-2023). The sulphate concentration was under the permissible limit of the BIS drinking water standards 10500:2012. The concentrations of Sodium decreased marginally and was in the range of 13.9-88.6 mg/L and that of Potassium were observed to be 1.25-11.15 mg/L, that are 3.5-5-fold lower than the previous year data. Sodium and Potassium levels were found to be slightly elevated in water samples collected from Gorewada lake, over last year (ESR report 2022-23). The COD concentration was found in the range of <100 mg/L in all lakes while the nutrient load in terms of Phosphate-P was in the range of 0.44-6.28 mg/L which were lower in all the lakes compared to the previous year. In spite of overall lower nutrient load in all the lakes, which could support the growth of weeds such as *Eichhornia* (water hyacinth), extensive growth of these floating plants was seen especially in Ambazari lake. Airboat "Jaldost" developed by CSIR-National Aerospace Laboratories (CSIR-NAL) and handed over to NMC, has been operating for clearing the weeds (water hyacinth) and garbage from Ambazari Lake. From the topography of lakes, it was seen that Naik lake is located downstream of Lendi lake. Due to this topography, there were chances of transfer of contaminants from Lendi lake to Naik lake along the direction of flow of aquifer.

6.2.3.2 Lake Water Quality: Bacteriological

Microbial quality of Sonegaon, Futala, Gorewada, Ambazari, Binaki, Naik, Sakkardara Pandharabodi, Gandhisagar, Police Line Takli, lakes, under study was investigated and the water samples were analyzed for bacterial indicator organisms viz; Total Coliforms (TC) and Fecal Coliforms (FC) using Membrane Filter Technique culture-based method. Samples were collected and analyzed as per Standard Methods for the Examination of Water and Wastewater (APHA, 2017). Water samples were filtered through membrane filtration assembly in which membrane was placed on specific media plates for detecting and enumerating coliforms. For enumerating thermotolerant coliforms, media plates were incubated at 44.5℃ + 0.2℃ for 24 hours. To meet the desired minimum colony count, dilutions of samples were done.

Analysis results showed that Total Coliforms (TC) were found to be in the range of 1×10^4 (10000 CFU/100mL) to 14×10^4 (140000 CFU/100mL) and Thermotolerant Faecal Coliforms (FC) were found in the range of 1×10^4 (10000 CFU/100mL) to 10×10^4 (100000 CFU/100mL), which were slightly lower than the previous year report respectively, in all the ten lakes. Samples collected from Binaki Lake (BK) and Naik Lake (NK) showed highest number of TC (BK-140000 CFU/100mL; NK- 140000 CFU/100mL) and FC (BK-60000 CFU/100mL; NK- 100000 CFU/100mL). Samples from Sonegaon, Futala, Gorewada, Ambazari, Sakkardara and Pandharabodi lakes also showed significant numbers of total coliforms (TC) and thermotolerant coliforms (fecal coliforms-FC) as is evident from **Table 6.7.**

No anthropogenic activity was observed during sampling duration as most of the lakes had the restrictions for the public entry while boundary wall and other constructions work were under progress. However, stray animals like pigs were observed to be loitering in the vicinity of the lake. Animal feaces were observed near the lakeside, which may be the main and direct source of fecal contamination. Alongside, animals like goats, stray dogs, pigs and aquatic birds were observed which may be the main cause of fecal coliform contamination (**Table 6.4**).

Plate 6.1: Prominent lakes of Nagpur, (a) Ambazari (b) Police line Takli (c) Gandhi Sagar (d) Binaki Lake (e) Gorewada Lake (f) Futala

Table 6.4: Sampling location details of lakes of Nagpur city

Sr. No	Sample Code	Sources	Latitude	Longitude	Other Observations
1	SG-1	Lake	21°05'54.0"N	79°03'01.0"E	Plastics, Papers
2	SG-2	Lake	21°05'58.8"N	79°03'15.7"E	Plastics, Papers
3	FL	Lake	21˚09′06″N	79˚02′37″E	*Eichhornia*
4	GD	Lake	21˚11′37.79″N	79˚02′27.84″E	Plastics, weed vegetation at the bank
5	AZ-1	Lake	21°07'31.9"N	79°02'34.8"E	*Eichhornia*, Greenish water
6	AZ-2	Lake	21°07'39.8"N	79°02'28.3"E	Greenish water, surrounded areas clean
7	BK	Lake	21°10'09.2"N	79°07'17.7"E	Garbage, construction material weed growth on bank
8	NK	Lake	21°09'45.0"N	79°06'47.8"E	*Eichhornia*
9	SD	Lake	21°07'15.8"N	79°06'54.1"E	Floating weeds
10	PD	Lake	21°08'33.3"N	79°03'03.0"E	Plastics, weeds growth surrounding lakes
11	GS	Lake	21° 8'48.47"N	79° 5'56.35"E	Clear water
12	PLT	Lake	21°10'29.26"N	79° 4'13.29"E	Semi submerged vegetation, greenish water

***Note- SG - Sonegaon Lake; FL-Futala Lake ; GD- Gorewada Lake; AZ - Ambazari Lake; BK- Binaki Lake; NK- Naik Lake;SD - Sakkardara Lake; PD- Pandharabodi Lake, GS- Gandhisagar Lake, PLT- Police Line Takli Lake**

Table 6.5: Water quality of lakes of Nagpur city: Physico-chemical parameters

Sr. No	Sample Code	pH	EC	TDS	Total Alkalinity	Total Hardness	Calicum as Ca^{2+}	Magnesium as Mg^{++}	Sodium (Na^{+})	Potassium (K^{+})	Fluoride	Chloride	Sulphate SO_4^{2-}	Nitrate as N
Units		-	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
BIS 10500:2012 (Acceptable/ Permissible limit)		6.5-8.5	-	500-2000	200-600	200-600	75-200	30-100	-	-	1.0-1.5	250-1000	200-400	45
1	SG	8.44	402	282	102.8	83.88	31	7.29	15.25	2.05	0.31	37.49	63	0.43
2	FL	7.65	461	327	217.5	108.28	39	9.72	13.9	2.25	0.25	39.99	37	0.50
3	GD	8.27	304	216	160	74.73	29	6.08	88.5	1.25	0.26	27.49	47.5	1.24
4	AZ	8.82	507	360	221.25	93.03	40	6.38	21.75	2.55	0.28	48.73	55	0.73
5	BK	8.69	538	382	228.75	93.03	47	4.25	35.8	11.15	0.23	44.99	89	0.49
6	NK	6.96	846	603	290	154.03	61	12.15	54.1	10.1	0.21	59.98	143	0.55
7	SD	7.9	810	515	226.25	83.88	35	6.08	58	2.5	0.31	53.73	76.5	0.71
8	PD	7.81	601	426	201.25	108.28	43	8.51	25.65	3.15	0.19	89.97	62.5	0.44
9	GS	7.83	834	591	237.5	96.08	25	11.54	88.6	10.25	0.44	86.22	122	0.71
10	PLT	8.23	493	351	200	96.08	33	9.11	22.55	1.35	0.42	43.74	89.5	0.48

***Note- SG - Sonegaon Lake; FL-Futala Lake ; GD- Gorewada Lake; AZ - Ambazari Lake; BK- Binaki Lake; NK- Naik Lake;SD - Sakkardara Lake; PD- Pandharabodi Lake, GS- Gandhisagar Lake, PLT- Police Line Takli Lake**

Table 6.6: Water quality of lakes of Nagpur city: Organic and nutrient parameters

Sr No.	Sample CODE	DO (mg/L)	COD (mg/l)	TKN as N (mg/l)	Phosphate as P (mg/l)
1	**SG**	6.9	32.86	5.6	0.66
2	**FL**	5.39	22.86	1.75	0.44
3	**GD**	7.13	79.52	5.95	0.64
4	**AZ**	4.9	51.43	2.8	0.53
5	**BK**	1.28	34.76	17.1	4.86
6	**NK**	4.87	63.81	13.3	1.77
7	**SD**	6.31	33.33	5.25	0.62
8	**PD**	6.53	43.81	3.85	6.28
9	**GS**	7.03	81.42	9.8	3.65
10	**PLT**	7.65	71.90	3.5	2.25

Table 6.7: Water quality of lakes of Nagpur city: Bacteriological parameters

Sr. No	Sample code	Total Coliform (TC) (CFU/100ml)	Thermotolerant Faecal Coliform (FC) (CFU/100ml)
1	**SG**	20000	20000
2	**FL**	10000	20000
3	**GD**	40000	10000
4	**AZ**	40000	20000
5	**BK**	140000	60000
6	**NK**	140000	100000
7	**SD**	10000	20000
8	**PD**	80000	10000
9	**GS**	60000	40000
10	**PLT**	10000	10000

***Note- SG - Sonegaon Lake; FL-Futala Lake ; GD- Gorewada Lake; AZ - Ambazari Lake; BK- Binaki Lake; NK- Naik Lake;SD - Sakkardara Lake; PD- Pandharabodi Lake, GS- Gandhisagar Lake, PLT- Police Line Takli Lake**

6.2.3.3 Lake Water Quality: Benthic environment

The study of biological parameters is essential for identifying various factors that contaminate or pollute aquatic environments. Biological assessments serve as a valuable method for evaluating the ecological health of aquatic ecosystems, as biological communities reflect the combined effects of water chemistry on the environment. These assessments involve measuring the presence and abundance of microorganisms, invertebrates, fish, and other organisms within aquatic habitats. Factors such as water quality, habitat structure, and human activities influence these parameters. Monitoring biological indicators in aquatic systems is crucial for understanding ecosystem health and developing effective management strategies. Aquatic biological parameters, like zooplankton and phytoplankton, are crucial indicators of water quality and the overall health of aquatic ecosystems.

6.2.3.3.1 Sampling Sites

The eleven lakes of Nagpur were selected for aquatic biological parameters. These are Sonegaon, Gorewada, Police line Takli, Sakkardara, Binaki Mangalwari, Ambazari, Futala, Gandhisagar, Pandharabodi, Naik, and Lendi lake.

Among the 11 lakes surveyed, Lendi Talao was in a eutrophic state, with extensive algal blooms covering the entire surface, it was muddy site with less water condition, preventing the collection of water samples. However, multiple samples were successfully gathered from the remaining lakes for the analysis of phytoplankton and zooplankton. The sampling and analysis were done as per standard methods.

6.2.3.3.2 Observation

6.2.3.3.2.1 Phytoplankton

The name is derived from the Greek terms (photo), which means "plant," and (plankton), which means "wanderer" or "drifter. Phytoplanktons are microscopic photosynthetic organisms that form the base of aquatic food webs. These tiny plants, including algae and bacteria, inhabit the upper layers of lakes and oceans. Phytoplankton is essential to aquatic ecosystems in numerous ways such as they produce organic matter through photosynthesis, providing energy for the entire ecosystem. As a byproduct, they release oxygen into the water, supporting aquatic life. Phytoplankton also serves as a primary food source for zooplankton, initiating a complex food chain. Additionally, they play a vital role in nutrient cycling, absorbing nutrients and releasing them back into the water upon decomposition. Furthermore, phytoplankton contributes to global carbon sequestration by absorbing carbon dioxide from the atmosphere. As primary producers, phytoplanktons forms the base of marine and freshwater food webs and are essential for regulating the global carbon cycle. Excess nutrients in aquatic environments can cause phytoplankton to overgrow, leading to harmful algal blooms. These blooms can produce toxins that are dangerous to fish, shellfish, wildlife, birds, and even humans. When there are too many nutrients available, phytoplankton can overgrow and generate dangerous algal blooms such as *Microcystis*, *Anabaena*. Certain phytoplankton species, such as diatoms, cyanobacteria, and dinoflagellates, can serve as effective bioindicators in aquatic ecosystems. Their sensitivity to environmental changes allows assessing ecosystem health by monitoring their presence, abundance, and diversity.

A comprehensive study was conducted to assess the phytoplankton composition in water samples collected from various lakes in Nagpur, India. The lakes included in the analysis were Sonegaon, Gorewada, Gandhisagar Lake, Sakkardara, Binaki Mangalwari, Ambazari, Futala, Pandharabodi, Naik Talao, and Police Line Takli. The findings, detailed in **Table 6.8** and **Plate 6.2**, revealed a rich diversity of algal and diatom species across these water bodies.

During field visits, it was observed that the condition of the lakes varied significantly. Among the lakes studied, Futala, Sonegaon, Gorewada, Gandhisagar Lake, and Pandharabodi were found to be in relatively good condition, with fresher and clearer water quality compared to the others. These lakes exhibited healthier ecological conditions, with balanced phytoplankton communities indicating better water quality.

In contrast, Naik Talao was in a severely degraded state, displaying clear signs of eutrophication. The lake was overrun by algal blooms and dense growths of hydrophytic vegetation, indicating poor water quality and nutrient overload. Binaki Mangalwari also showed similar conditions, though slightly less severe than Naik Talao.

Additionally, Ambazari Lake exhibited weed growth in certain parts, signalling localized issues with water quality and nutrient imbalances. While not as critical as Naik Talao, this observation suggests that even relatively better-preserved lakes are showing signs of ecological stress.

The **Table 6.8** outlines phytoplankton composition and diversity across various water bodies, measured through samples taken from different locations. The phytoplankton community is categorized into Chlorophyceae (green algae), Bacillariophyceae (diatoms), Cyanophyceae (blue-green algae), and Euglenophyceae (euglenoids), with the Shannon-Weiner Diversity Index (SWDI- **Table 6.9**) calculated for each sample. This index (**Table 6.10**) provides insight into the biodiversity and ecological health of each water body. Under careful analysis, the observations of each lake are as follows:

a) Sonegaon Lake

Sonegaon Lake was dominated by Chlorophyceae, which comprised 55.55% of the total phytoplankton population. Bacillariophyceae and Cyanophyceae constituted 11.11% and 22.22%, respectively. This relatively balanced composition across the three phyla resulted in an SWDI of 2.26, indicating moderate diversity. Prominent genera in this lake included

Chlorella, Spirulina, Chlamydomonas, and Microcystis, representing the healthy coexistence of both green and blue-green algae.

b) Futala Lake

Futala Lake was dominated by Chlorophyceae, which comprised 64.28% of the phytoplankton community, while Cyanophyceae accounted for 21.42%. Bacillariophyceae and Euglenophyceae were relatively less abundant, each contributing 7.14% to the population. The SWDI at this lake was 2.57, reflecting higher phytoplankton diversity. Noteworthy genera included Scenedesmus, Spirogyra, Pandorina, and Oscillatoria, indicating a well-oxygenated environment conducive to the growth of green algae.

c) Gorewada Lake

Gorewada Lake exhibited a more even distribution among the three major algal groups, with Chlorophyceae and Cyanophyceae each contributing 36.36%, while Bacillariophyceae made up 18.18%. Euglenophyceae were also present, comprising 9.09% of the total phytoplankton community. The SWDI of 2.37 indicated moderate biodiversity. Common genera included Desmodesmus, Chlorella, Oscillatoria, and Euglena, highlighting the presence of both green and blue-green algae, along with Euglenoids.

d) Ambazari Lake

Ambazari Lake was heavily dominated by Chlorophyceae, which made up 71.42% of the total composition. Bacillariophyceae and Cyanophyceae each contributed 14.28%, with no Euglenophyceae detected. The SWDI at this lake was 2.11, indicating a lower diversity despite the high dominance of chlorophytes. Genera such as Chlorella, Ankistrodesmus, and Crucigenia reflected the prevalence of green algae.

e) Gandhi Sagar Lake

Gandhi Sagar Talao exhibited a balanced composition of phytoplankton, with Chlorophyceae comprising 44.44%, Cyanophyceae 33.33%, and Bacillariophyceae 11.11%. Euglenophyceae also contributed 11.11% to the total population. The SWDI was 2.17, indicating moderate diversity. Notable genera such as Synechococcus, Scenedesmus, and Spirulina emphasized the coexistence of both green and blue-green algae, along with Euglenoids, reflecting a moderately diverse ecosystem.

f) Pandharabodi Lake

Pandharabodi Lake recorded a nearly equal distribution between Chlorophyceae and Cyanophyceae, each making up 37.5%. Bacillariophyceae contributed 12.5%, while Euglenophyceae were also present, contributing 12.5%. The SWDI was 2.14, indicating moderate diversity. Genera such as Chlorella, Ankistrodesmus, and Merismopedia suggested a mix of green and blue-green algae.

g) Sakkardara Lake

Sakkardara Lake's phytoplankton community was dominated by Chlorophyceae and Cyanophyceae, each making up 33.33% of the population, while Bacillariophyceae and Euglenophyceae contributed 16.66% each. The SWDI was relatively low at 1.47, indicating limited diversity. The presence of Spirulina, Synechococcus, and Microcystis pointed toward a dominance of blue-green algae, reflecting a lower algal diversity.

h) Binaki Mangalwari Lake

Binaki Mangalwari Lake was dominated by Cyanophyceae, which accounted for 50% of the total phytoplankton population, while Chlorophyceae and Bacillariophyceae each contributed 25%. No Euglenophyceae were observed. The SWDI was 1.43, indicating low diversity. Noteworthy genera included Pandorina, Nostoc, and Microcystis, suggesting a high concentration of blue-green algae.

i) Police Line Takli Lake

Police Line Takli Lake exhibited an even distribution of phytoplankton, with Chlorophyceae and Cyanophyceae each making up 40% of the population, while Bacillariophyceae contributed 20%. The SWDI was relatively low at 1.54, indicating limited diversity, with Chlorella, Scenedesmus, Anabaena, and Microcystis being the most prevalent genera.

j) Naik Lake

Naik lake was dominated by Chlorophyceae, which made up 60% of the phytoplankton population, while Bacillariophyceae and Cyanophyceae each contributed 20%. No Euglenophyceae were present, and the SWDI was the lowest at 1.39, indicating low diversity. The presence of *Tetraedron* and *Microcystis* suggested a lake with a significant concentration of green and blue-green algae but lower overall diversity.

Table 6.8: Phytoplanktons observed from lakes of Nagpur

Sr. No	Lake	Phylum	Genus
1	**Sonegaon Lake**	Chlorophyceae	*Chlorella*
			Spirullina
			Chlamydomonas
			Akinstrodesmus
			Tetraedron
		Cyanophyceae	*Synechococcus*
			Microcystis
		Bacillariophyceae	*Centric Diatom*
			Leptocylindrus
			Navicula
			Gomphonema
2	**Futala Lake**	Chlorophyceae	*Chlorella*
			Spirullina
			Chlamydomonas
			Tetraedron ovalis
			Scenedesmus
			Desmodesmus
			Pandorina
			Akinstrodesmus
			Spirogyra
		Cyanophyceae	*Merismopedia*
			Oscillatoria
		Bacillariophyceae	*Diacentric diatom*
			Navicula
			Leptocylindrus
			Nitschia
3	**Gorewada Lake**	Chlorophyceae	*Desmodesmus*
			Chlorella
			Tetraedron
			Spirogyra
		Cyanophyceae	*Oscillatoria*
			Microcystis
			Spirulina
		Bacillariophyceae	*Nitzschia*
			Navicula
			Gomphonema
		Euglenophyceae	*Euglena*
4	**Ambazari Lake**	Chlorophyceae	*Chlorella*
			Akinstrodesmus

			Chlamydomonas
			Desmodesmus
			Crucigenia
		Cyanophyceae	*Microcystis*
		Bacillariophyceae	*Navicula*
			Leptocylindrus
			Nitzschia
5	**Gandhi Sagar Lake**	Chlorophyceae	*Chlorella*
			Synechococcus
			Akinstrodesmus
			Chlorophyceae
		Cyanophyceae	*Microcystis*
			Spirulina
			Scenedesmus
		Bacillariophyceae	*Nitzschia*
			Navicula
6	**Pandharabodi Lake**	Cholrophyceae	*Chlorella*
			Akinstrodesmus
			Crucigenia
			Spirullina
		Cyanophyceae	*Merismopedia*
			Synechococcus
			Microcystis
		Bacillariophyceae	*Navicula*
			Gomphonema
			Leptocylindrus
7	**Sakkardara Lake**	Chlorophyceae	*Chlorella*
			Spirulina
		Cyanophyceae	*Synechococcus*
			Mycrocystis
		Bacillariophyceae	*Navicula*
			Leptocylindrus
8	**Binaki Mangalwari Lake**	Chlorophyceae	*Pandorina*
		Cyanophyceae	*Nostoc*
			Anabaena
			Microcystis
		Bacillariophyceae	*Navicula*
9	**Police Line Takli Lake**	Chlorophyceae	*Chlorella*
			Scenedesmus
		Cyanophyceae	*Microsystis*
			Anabaena

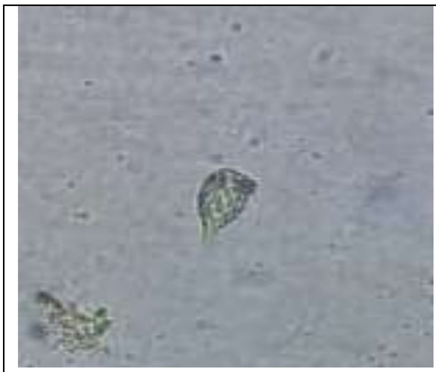
		Bacillariophyceae	*Nitzschia*
10	**Naik Lake**	Chlorophyceae	*Chlorella*
			Tetraedron
		Cyanophyceae	*Microcystis*
		Bacillariophyceae	*Navicula*
			Diacentric diatom

Table No. 6.9: Pollution level based on a Shannon Wiener Diversity Index (SWDI)

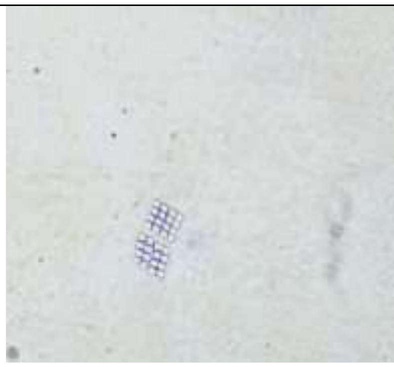
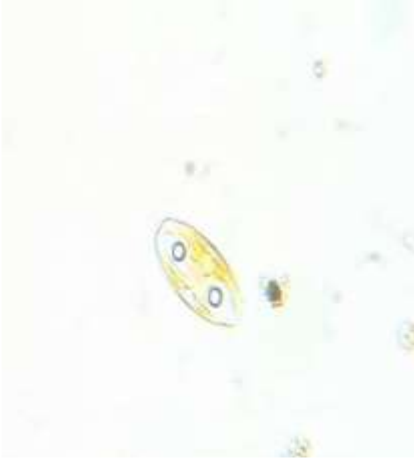
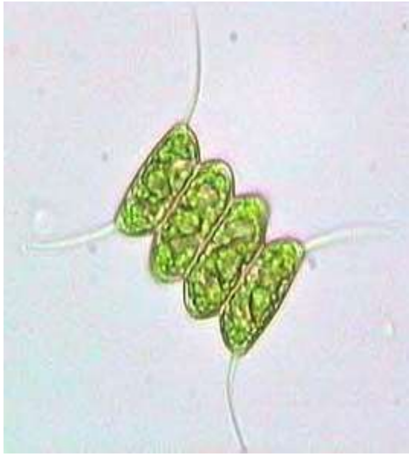
Diversity Level	Shannon Wiener Index	Pollution
High	3.0-4.5	Slight
Moderate	2.0-3.0	Light
Less	1.0-2.0	Moderate
Very Less	0.0-1.0	Heavy Pollution

Table No. 6.10: Biological parameter: Phytoplanktons

Sr. No	Lakes	Phytopla-nktons/Lit	Percentage Composition of Algal Groups				
			Chloro-phyceae	Bacillari-ophyceae	Cyano-phyceae	Euglen-ophyceae	SWDI
1	Sonegaon	44285	55.55	11.11	22.22	-	2.26
2	Futala	47142	64.28	7.14	21.42	7.14	2.57
3	Gorewada	47142	36.36	18.18	36.36	9.09	2.37
4	Ambazari	48571	71.42	14.28	14.28	-	2.11
5	GandhiSagar	55714	44.44	11.11	33.33	11.11	2.17
6	Pandharabodi	50000	37.5	12.5	37.5	12.5	2.14
7	Sakkardara	54285	33.33	16.66	33.33	16.66	1.47
8	Binaki Mangalwari	64285	25	25	50	-	1.43
9	Police Line Takli	60000	40	20	40	-	1.54
10	Naik	65714	60	20	20	-	1.39

		
Euglena	***Spirulina***	***Tetraedron caudatum***
		
Leptocylindrus	***Centric Diatom***	***Spirogyra***
		
Chlamydomonas	***Crucigenia***	***Microcystis***
		
Nitzschia	***Nostoc***	***Chlorella***

A

		
Gomphonema	***Ankistrodesmus***	***Merismopedia***
		
Amphora ovalis	***Oscillatoria***	***Scenedesmus***
		
Tetraedron	***Navicula***	***Synechococcus***

B

Plate 6.2: Phytoplanktons observed from lakes of Nagpur (A and B)

6.2.3.3.2.2 Zooplankton

Zooplankton, derived from the Greek words *zoon* (meaning "animal") and *plankton* (meaning "wanderer" or "drifter"), are heterotrophic plankton that range from microscopic organisms to larger creatures like jellyfish. Found in both marine and freshwater systems, zooplankton are drifting organisms that play an ecologically significant role in aquatic ecosystems. They are a crucial part of the food web, serving as an intermediary between primary producers—such as planktonic algae—and higher trophic levels, including invertebrate predators and fish. As key ecological indicators, zooplanktons are highly sensitive to changes in aquatic environments. Shifts in their species composition, abundance, and size distribution can provide early warning signals of environmental disturbances such as pollution, nutrient imbalances, and climate change. Because they occupy a critical position in the food chain, any fluctuations in their population dynamics can ripple through the entire ecosystem, affecting water quality, nutrient cycling, and biodiversity. Zooplankton monitoring can thus offer valuable insights into the health and stability of aquatic ecosystems, making them vital for ecological assessments and environmental management.

A comprehensive zooplankton analysis was conducted across ten lakes in Nagpur: Ambazari, Futala, Gorewada, Sonegaon, Binaki Mangalwari, Naik Talao, Sakkardara, Pandharabodi, Police Line Takli, and Gandhisagar. The study revealed a diverse range of zooplankton species, categorized into four major groups: Cladocera, Copepoda, Rotifera, and Protozoa, as shown in **Table 6.11** and **Plate 6.3**. Each of these groups plays a vital role in the aquatic ecosystem, serving as a primary food source for higher trophic levels and contributing to water quality and nutrient cycling. The SWDI of Zooplanktons is given in **Table 6.12**. Under careful analysis, the observations of each lake are as follows:

a) Sonegaon Lake

Sonegaon Lake exhibited a moderate level of zooplankton diversity, with an SWDI (Shannon-Weiner Diversity Index) of 1.89. The zooplankton population was dominated by Branchionus quadridentus from the Rotifera group, making up 42.8% of the total zooplankton community. This was followed by Copepoda, represented mainly by Cyclops (28.5%), and Cladocera, which included Daphnia (14.2%). The presence of Protozoa, specifically Paramecium and Thuricola, accounted for another 28.5% of the population, contributing to the lake's overall ecological balance. The moderate zooplankton diversity observed in Sonegaon reflects relatively stable ecological conditions, although improvements in water quality could enhance biodiversity further.

b) Futala Lake

Futala Lake exhibited the highest zooplankton diversity among the lakes studied, with an SWDI of 2.04. Rotifers, particularly Branchionus diversicornis, Branchionus quadridentus, Branchionus calyciflorus, and Monostyla, were the most abundant, comprising 50% of the zooplankton population. Copepoda, represented by Cyclops and Mysis, accounted for 25%, while Cladocera (Daphnia) and Protozoa (Paramecium) each contributed 12.5%. This balanced distribution of zooplankton groups indicates good water quality and healthy ecological conditions in Futala Lake.

c) Gorewada Lake

Gorewada Lake showed a similar zooplankton diversity to Sonegaon, with the SWDI of 1.89. The lake's zooplankton community was composed primarily of Branchionus quadridentus (42.8%) from the Rotifera group. Copepoda (Cyclops and Nauplius) made up 28.5%, while Cladocera, represented by Daphnia (14.2%), and Protozoa, specifically Paramecium, each contributed 14.2%. The presence of Keratella cochlearis also added to the lake's biodiversity. Overall, the moderately diverse zooplankton community suggests that Gorewada is in a stable, healthy condition.

d) Ambazari Lake

Ambazari Lake exhibited an SWDI of 1.70, reflecting a moderate zooplankton diversity. The zooplankton population was dominated by rotifers, particularly Branchionus quadridentus (50%), followed by an even distribution among Cladocera (Daphnia), Copepoda (Cyclops), and Protozoa (Paramecium), each contributing 16.66%. This indicates that while the lake is in reasonable ecological health, there are localized signs of nutrient imbalance, as evidenced by weed growth observed in some parts of the lake.

e) Gandhisagar Lake

Gandhisagar Lake exhibited moderate zooplankton diversity, with an SWDI of 1.73. The Rotifera group, particularly Branchionus quadridentus and Pulchritia *(Bdelloid rotifer)* dominated the community, contributing 42.8% of the population. Cladocera (Daphnia) and Copepoda (Cyclops and Nauplius) each made up 14.2%, while Protozoa (Paramecium) also contributed to the diversity. The lake's relatively balanced zooplankton composition reflects moderate ecological health.

f) Pandharabodi Lake

Pandharabodi Lake exhibited an SWDI of 1.56, indicating moderate zooplankton diversity. The Rotifera group, represented by Branchionus quadridentus and Pulchritia *(Bdelloid rotifer)* made up 40% of the population. Copepoda (Cyclops and Nauplius) accounted for another 40%, while Protozoa (Paramecium) contributed 20%. The relatively balanced distribution of zooplankton groups suggests that Pandharabodi Lake is in stable ecological condition, though there may be localized nutrient imbalances.

g) Sakkardara Lake

Sakkardara Lake exhibited a moderately low zooplankton diversity, with an SWDI of 1.48. The zooplankton community was dominated by Cladocera (40%) and Copepoda (60%), with no presence of rotifers or protozoa. The most notable species included Daphnia, Leptodora kindtii, Cyclops, Nauplius, and Mysis. While the presence of diverse Copepoda species indicates moderate ecological health, the lack of rotifers and protozoa points to potential issues with water quality.

h) Binaki Mangalwari Lake

Binaki Mangalwari Lake displayed a much lower zooplankton diversity, with an SWDI of 1.05. The zooplankton community was evenly split between Cladocera (Acroperus harpae), Copepoda (Cyclops), and Protozoa (Paramecium), each contributing 33.3%. The absence of rotifers in this lake suggests a highly compromised ecological state, likely due to poor water quality and eutrophic conditions. Additionally, the lake emitted a foul odor, reinforcing the indication of poor water health.

i) Police Line Takli Lake

Police Line Takli Lake displayed a low zooplankton diversity with an SWDI of 1.28. The lake's zooplankton population was heavily dominated by rotifers, specifically Branchionus quadridentus, Asplachna priodonata, and Pulchritia *(Bdelloid rotifer)* which together made up 75% of the community. Protozoa (Paramecium) accounted for the remaining 25%. The absence of Cladocera and Copepoda indicates ecological stress and poor water quality.

j) Naik Lake

Naik Talao was in the most degraded state among the studied lakes, with the lowest SWDI of 0.69. The zooplankton population was equally divided between Rotifera (*Branchionus quadridentus*) and Copepoda (*Cyclops*), each contributing 50% of the total zooplankton. The absence of Cladocera and Protozoa indicates a severely imbalanced ecosystem, driven by eutrophication and overgrowth of hydrophytic vegetation. Naik Talao is in critical need of ecological restoration.

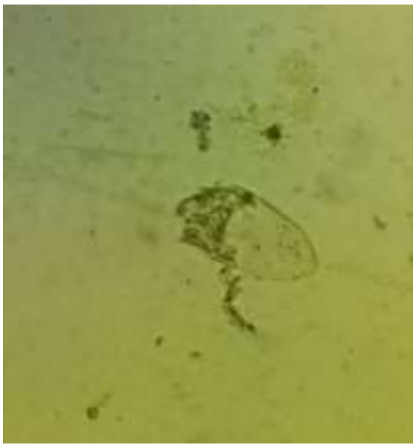
Table 6.11: Zooplanktons observed from lakes of Nagpur

S. No	Lake	Phylum/Class	Genus/Species
1	**Sonegaon**	Cladocera	*Daphnia*
		Copepoda	*Cyclops*
		Rotifera	*Asplancha priodonata*
			Branchionus quadridentus
			Monostyla
		Protozoa	*Paramecium*
			Thuricola
2	**Futala**	Cladocera	*Daphnia*
		Copepoda	*Cyclops*
			Mysis
		Protozoa	*Paramecium*
		Rotifera	*Branchionus diversicornis*
			Branchionus quadridentus
			Branchionus calyciflorus
			Monostyla
3	**Gorewada**	Cladocera	*Daphnia*
		Copepoda	*Cyclops*
			Nauplius
		Protozoa	*Paramecium*
		Rotifera	*Branchionus quadridentus*
			Monostyla
			Keratella cochlearis
4	**Ambazari**	Cladocera	*Daphnia*
		Copepoda	*Cyclops*
		Rotifera	*Branchionus quadridentus*
			Branchionus diversicornis
			Monostyla
		Protozoa	*Paramecium*
5	**Gandhisagar**	Copepoda	*Cyclops*
			Nauplius
		Rotifera	*Branchionus quadridentus*
			Pulchritia (Bdelloid rotifer)
			Monostyla
		Cladocera	*Daphnia*
		Protozoa	*Paramecium*
6	**Pandharabodi**	Copepoda	*Nauplius*
			Cyclops
		Protozoa	*Paramecium*
		Rotifera	*Branchionus quadridentus*

			Pulchritia (Bdelloid rotifer)
7	**Sakkardara**	Copepoda	*Cyclops*
			Nauplius
			Mysis
		Cladocera	*Daphnia*
			Leptodora kindtii
8	**Binaki Mangalwari**	Copepoda	*Cyclops*
		Cladocera	*Acroperus harpae*
		Protozoa	*Paramecium*
9	**Police line**	Rotifera	*Branchionus quadridentus*
			Asplachna priodonata
			Pulchritia (Bdelloid rotifer)
		Protozoa	*Paramecium*
10	**Naik**	Rotifera	*Branchionus quadridentus*
		Copepoda	*Cyclops*

Table 6.12: Biological parameter: Zooplankton

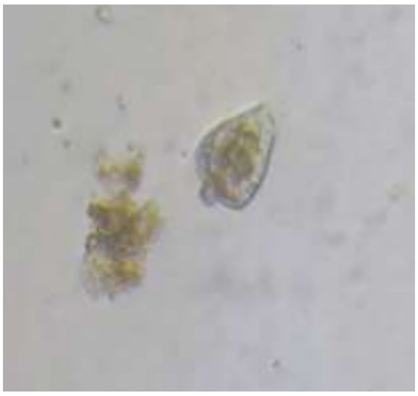
Sr. No.	Samples	Zooplankton No/m^3	Percentage Composition of Zooplankton groups				SWDI
			Clado-cera	Cope-poda	Proto-zoa	Roti-fera	
1.	Sonegaon	10000	14.2	28.5	28.5	42.8	1.89
2.	Futala	11428.57	12.5	25	12.5	50	2.04
3.	Gorewada	10000	14.2	28.5	14.2	42.8	1.89
4.	Ambazari	8571.42	16.66	16.67	16.66	50	1.70
5.	Gandhisagar	10000	14.2	28.5	14.2	42.8	1.73
6.	Pandharabodi	7142.8	-	40	20	40	1.56
7.	Sakkardara	7142.8	40	60	-	-	1.48
8.	Binaki Mangalwari	4285.7	33.3	33.3	33.3	-	1.05
9.	Police line	5714.28	-	-	25	75	1.28
10.	Naik	2857.1	-	50	-	50	0.69



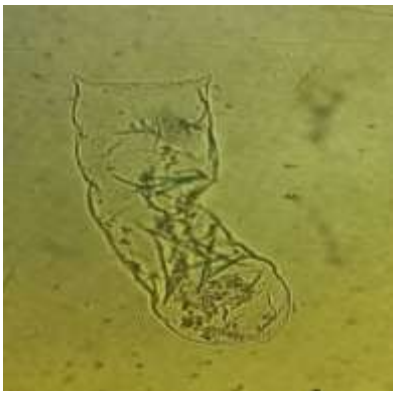
Asplancha

Acroperus harpae

Cyclops



Monostyla



Thuricola

Bdelloides

Nauplius

Daphnia

Paramecium

Plate 6.3: Zooplanktons observed from lakes of Nagpur

6.2.3.3.3 Results and Conclusion

Based on the results of the Shannon-Weiner Diversity Index (SWDI) for both phytoplankton and zooplankton, the trophic levels of the lakes were ranked as follows:

Naik Talao > Binaki Mangalwari > Police Line Takli > Sakkardara > Pandharabodi > Gandhisagar Lake > Ambazari > Sonegaon > Gorewada > Futala

This ranking highlights a gradient of ecological health and water quality across the lakes studied.

6.2.3.3.4 Key Observations

- **Futala Lake, Gorewada Lake, and Sonegaon Lake** demonstrated significantly lower pollution levels, with relatively clear water and balanced plankton communities. These lakes exhibited mesotrophic conditions, indicating moderate nutrient levels and good water quality. They are among the healthiest lakes, with diverse plankton communities supporting stable aquatic ecosystems. Their higher SWDI values suggest a balanced environment capable of sustaining a variety of aquatic life.
- **Naik Lake, Binaki Mangalwari Lake, and Sakkardara Lake** showed clear signs of eutrophication, with dense algal blooms and low zooplankton diversity. These lakes had the lowest SWDI values, reflecting high nutrient levels, poor water quality, and degraded ecosystems. The eutrophic conditions in these lakes are likely the result of nutrient overloads from anthropogenic sources, such as untreated wastewater discharge, agricultural runoff, and improper waste disposal. The excessive nutrient input fosters algal overgrowth, leading to oxygen depletion and a decline in aquatic life diversity. The water in these lakes is foul-smelling, further indicating significant pollution.
- **Pandharabodi Lake, Gandhisagar Lake, and Ambazari Lake** displayed moderate pollution levels. These lakes showed a mix of mesotrophic to eutrophic conditions, with some signs of nutrient imbalance, such as localized weed growth or moderate algal blooms. The intermediate SWDI values suggest that these lakes are under ecological stress, but their water quality has not yet reached the severely degraded levels seen in Naik and Binaki lakes. However, if not managed properly, these lakes may continue to deteriorate.
- **Lendi Lake** was excluded from the analysis due to its poor maintenance and lack of open water, consisting only of muddy regions that prevented effective sampling. This point to the urgent need for intervention to restore the lake's ecological functions.

6.2.3.3.5 Trophic State and Water Quality

The SWDI results, combined with field observations, indicate that the lakes are at varying stages of trophic states:

- **Oligotrophic (Low Nutrient Levels):** Futala, Gorewada, Sonegaon- These lakes exhibit low nutrient levels and better water quality, indicating a healthy balance of plankton communities with minimal signs of pollution.
- **Mesotrophic (Moderate Nutrient Levels):** Gandhisagar, Ambazari, Pandharabodi- These lakes show moderate pollution, with some nutrient enrichment that has started to affect water quality but has not yet led to severe ecological damage.
- **Eutrophic (High Nutrient Levels):** Naik, Binaki, Sakkardara- These lakes are characterized by high nutrient levels, dense algal blooms, and poor water quality, resulting in low biodiversity and disrupted ecosystems.

6.2.4 Surface water quality: Rivers

There are three rivers flowing through the city i.e., Nag, Pilli and Pora. The name of the city has been named after the Nag River. The Nag River, which is part of the Kanhan-Pench river system, flows through the city for 17 km, following the natural slope of the landform to merge with the Kanhan River. Pilli River flows towards the east and meets Nag river near Pawangaon, which ultimately merges into Kanhan River. The stretch of Pilli River is 18 km within the city limit. Pora river, which originates from southwest part of the city near Hingna flows towards south-east of the city.

Three rivers of the city were monitored at 23 sampling locations (**Plate 6.4**.), for the water quality analysis as mentioned in **Table 6.13 and Figure 6.3.** Out of 23 sites, 10 were of Nag River while 8 and 5 were selected for the analysis of Pilli and Pora River, respectively. The primary data of the analysis is presented in **Table 6.14-6.16.**

The initial point of Nag river has a COD of 30.95 mg/L while later it increases upto 50.95 mg/L along the length. As the river flows through the city, the pollution load goes on increasing, leading to an increase in most of the parameters such as, Phosphate-P from 1.51 to 8.16 mg/L. The COD and Phosphate-P levels were however were lower by 72-80 % and 27% respectively than that observed in the previous year (ESR report 2022-2023).

Some sampling sites show the existence of waste dumped from local vendor shops of fruits, vegetables, meat and other products. In contrast, others show animals wandering in the river or dead animals floating along the river's bank.

The COD of Pilli river water as shown in **Table 6.16,** ranges from 7.62 mg/L to 19.05 mg/L which is substantially lower by 84-90 % than previous year readings while, the Phosphate-P levels showed marginal change over those reported earlier (ESR report 2022-2023), which increased from 2.74 to 6.06 mg/L, indicating its pollution over the length of the river as it reaches the confluence point near Kanhan river.

The Pora River flows at the city's outskirts near the industrial areas. The polluted nature of Pora river was evident from organic load as COD, and Phosphate-P range between 8.57-56.67 mg/L, and 4.26-4.98 mg/L respectively, though these values were lower by 67-90 % and 35% than previous year (ESR report 2022-2023).

Total Coliforms (TC), Thermotolerant Faecal coliforms (FC) were detected in all three rivers (Nag, Pilli, Pora) shown in **Table 6.15,** which were above the desirable level (500 CFU/100 ml) indicating the occurrence of pollution from sewage source and contamination from fecal matter.

Table 6.13: Sampling locations of surface water

Sampling Points	**Sample Details / location details**	**Latitude**	**Longitude**
NAG RIVER			
Nag-1	Initial sampling point (Ambazari lake)	21°7’30.0’’N	79°2’39.6” E
Nag-2	Flow point-2 (NIT swimming pool)	21°7’47.4’’N	79°2’57.3” E
Nag-3	Flow point-3 (VNIT Campus)	21°7’47.5’’N	79°3’3.2” E
Nag-4	NIT cover point near shape up Gym	21°7’53.2’’ N	79°3’22.9” E
Nag-5	Drain mix behind Yashwant stadium (Sitabuldi bridge)	21°8’25.5’’ N	79°4’58.3” E
Nag-6	Drain mix at Mokshdham (Near NMC STP)	21°8’14.76’’N	79°5’19.88” E
Nag-7	Ashirwad talkies, great Nag road, Baidhyanath square Rambagh)	21°8’14.4’’N	79°5’44.0” E
Nag-8	Jagnade chowk, Ganeshnagar, Azamshan layout	21°8’25.3’’N	79°7’10.3” E
Nag-9	Centre point school Wardhmannagar	21°8’52.9’’N	79°8’57.9” E
Nag-10	Nag River end point	21° 9'57.57"N	79°10'48.42"E
PILLI RIVER			
Pilli-1	Initial sampling point (Gorewada)	21°11’38.5’’N	79°2’49.0” E
Pilli-2	1st and 2nd drain mix (St. Mary school, 1/F Jafarnagar)	21°11’25.2’’N	79°3’46.1” E

Pilli-3	Suflam seed company (behind Mahindra Showroom, Koradi)	21°11’23.56’’N	79°4’42.76” E
Pilli-4	Nara Kabristan Nara Road (Bridge)	21°11’35.57’’N	79°5’28.11” E
Pilli-5	Pilli river Nari bridge -2	21°11’58.0’’N	79°6’8.7” E
Pilli-6	Bhilgaon road near Rizwan motor	21°10’47.35’’N	79°8’2.90” E
Pilli-7	Kalamnagao police chowki	21°10’45.3’’N	79°9’10.1” E
Pilli-8	Blossom School (Pawangao) (Mixing of Nag and Pilli)	21°9’58.1’’N	79°10’44.4” E
PORA RIVER			
Pora-1	-	21° 4'12.79"N	79° 3'34.68"E
Pora-2	-	21° 5'7.95"N	79° 7'28.32"E
Pora-3	-	21° 5'11.08"N	79° 8'36.91"E
Pora-4	-	21° 5'14.50"N	79° 8'53.06"E
Pora-5	Pora river end point	21° 5'28.18"N	79° 9'42.94"E

Table 6.14: Water quality of rivers of Nagpur city: Physico-chemical parameters

Sr No	Sample details	pH	EC	TDS	Alkalinity as $CaCO_3$	Total Hardness $CaCO_3$	Calcium as Ca^{2+}	Magnesium as Mg^{++}	Sodium (Na^+)	Potassium (K^+)	Fluoride	Chloride (Cl^-)	Sulphate as SO_4^{2-}	Nitrate as N
Units			µS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
BIS 10500:2012 (Acceptable/ Permissible limit)		6.5-8.5	-	500-2000	200-600	200-600	75-200	30-100			1.0-1.5	250-1000	200-400	45
1	**Nag-1**	7.14	0.465	232	221.25	93.03	39	6.68	23.7	2.75	0.28	59.98	52.5	0.15
2	**Nag-2**	7.59	0.464	232	218.75	103.7	37	9.42	23.8	3.35	0.29	63.73	47.5	0.20
3	**Nag-3**	7.9	0.468	234	223.75	99.13	41	7.29	23.9	3.35	0.27	66.23	50.5	0.25
4	**Nag-4**	7.78	0.499	250	220	100.65	39	8.2	25.2	3.2	0.28	58.73	55	0.24
5	**Nag-5**	7.63	0.603	302	278.75	123.53	51	9.11	34.8	4.05	0.35	63.73	58.5	0.06
6	**Nag-6**	7.73	0.613	306	301.25	123.53	51	9.11	37.65	4.35	0.34	63.73	60	0.02
7	**Nag-7**	7.75	0.620	310	291.25	120.48	55	7.29	38.1	4.4	0.36	58.73	57	0.01
8	**Nag-8**	7.83	0.631	316	298.75	126.58	51	9.72	41.8	4.45	0.36	43.74	64.5	ND
9	**Nag-9**	7.83	0.700	350	331.25	123.53	55	7.9	58.05	7.85	0.36	57.48	69	0.01
10	**Nag-10**	8.04	0.808	404	345	120.48	49	9.11	61.95	7.6	0.4	64.98	73.5	0.01

11	**Pilli-1**	8.15	0.493	247	311.25	123.53	47	10.33	14.7	1.65	0.42	46.24	21	0.10
12	**Pilli-2**	8.21	0.671	336	312.5	132.68	46	12.45	38.85	4.6	0.36	51.23	67	0.27
13	**Pilli-3**	8.16	0.730	365	336.25	135.73	55	10.33	46.8	5.35	0.4	63.73	53	0.14
14	**Pilli-4**	8.16	0.735	368	316.25	129.63	56	8.81	51.95	5.3	0.43	64.98	56	0.25
15	**Pilli-5**	8.21	0.744	372	340	129.63	57	8.51	55	5.65	0.44	53.73	55.5	0.17
16	**Pilli-6**	8.19	0.780	390	342.5	140.3	57	10.63	54.85	6.35	0.42	68.73	61.5	0.48
17	**Pilli-7**	8.03	0.784	394	387.5	123.53	55	7.9	61.35	7.65	0.41	66.23	25	0.19
18	**Pilli-8**	8.15	0.776	388	316.25	129.63	53	9.72	58.65	8.05	0.41	63.73	63.5	0.30
19	**Pora-1**	8.46	0.807	404	383.75	166.23	61	14.58	40.5	3.25	0.46	66.23	34.5	1.48
20	**Pora-2**	8.36	0.762	381	392.5	125.05	53	8.81	61.8	5.75	0.47	63.73	59.5	0.17
21	**Pora-3**	8.3	0.766	383	382.5	129.63	61	7.29	62.05	6.15	0.48	69.98	78	0.13
22	**Pora-4**	8.29	0.854	427	402.5	126.58	59	7.29	75.65	7.85	0.51	86.22	88	0.38
23	**Pora-5**	8.35	0.799	398	392.5	122	58	6.68	74.25	7.65	0.49	82.47	84	0.31

Table 6.15: Water quality of rivers of Nagpur city: Bacteriological parameters

Sr. No.	Sample Code	Total Coliforms (TC) (CFU/100ml)	Thermotolerant Faecal Coliforms (FC) (CFU/100ml)
1	Nag-1	600000	280000
2	Nag-2	440000	280000
3	Nag-3	540000	300000
4	Nag-4	280000	100000
5	Nag-5	220000	120000
6	Nag-6	140000	80000
7	Nag-7	300000	200000
8	Nag-8	180000	100000
9	Nag-9	140000	80000
10	Nag-10	220000	100000
11	Pilli-1	320000	220000
12	Pilli-2	320000	150000
13	Pilli-3	340000	120000
14	Pilli-4	420000	180000
15	Pilli-5	100000	140000
16	Pilli-6	140000	300000
17	Pilli-7	80000	60000
18	Pilli-8	40000	40000
19	Pora-1	240000	10000
20	Pora-2	460000	10000
21	Pora-3	240000	120000
22	Pora-4	560000	320000
23	Pora-5	280000	200000

Table 6.16: Water quality of rivers of Nagpur city: Organic and nutrient parameters

Sr No.	Sample details	DO (mg/L)	COD (mg/L)	TKN as N (mg/L)	Phosphate as P (mg/L)
1	Nag-1	3.67	ND	12.9	1.51
2	Nag-2	3.63	30.95	14	1.55
3	Nag-3	3.88	18.57	7.7	3.49
4	Nag-4	3.81	4.76	8.75	6.47
5	Nag-5	1.90	50.95	10.8	8.16
6	Nag-6	1.2	46.66	5.95	4.22
7	Nag-7	1.02	36.19	5.95	6.03
8	Nag-8	1.10	40.95	12.9	4.4
9	Nag-9	1.2	36.66	10.1	5.13
10	Nag-10	0.48	40.48	8.75	4.74
11	Pilli-1	4.20	19.05	5.6	2.74
12	Pilli-2	2.87	10.95	15.4	4.65
13	Pilli-3	1.16	11.43	12.9	5.65
14	Pilli-4	0.92	11.43	7.7	3.89
15	Pilli-5	0.74	7.62	6.65	4.87
16	Pilli-6	0.95	14.76	14.7	4.85
17	Pilli-7	0.78	7.62	8.75	6.06
18	Pilli-8	1.18	7.62	6.3	6.04
19	Pora-1	4.8	14.29	9.1	4.26
20	Pora-2	2.21	ND	5.6	4.36
21	Pora-3	0.74	8.57	12.2	4.98
22	Pora-4	0.63	25.71	7.35	4.69
23	Pora-5	0.81	56.67	9.8	4.29

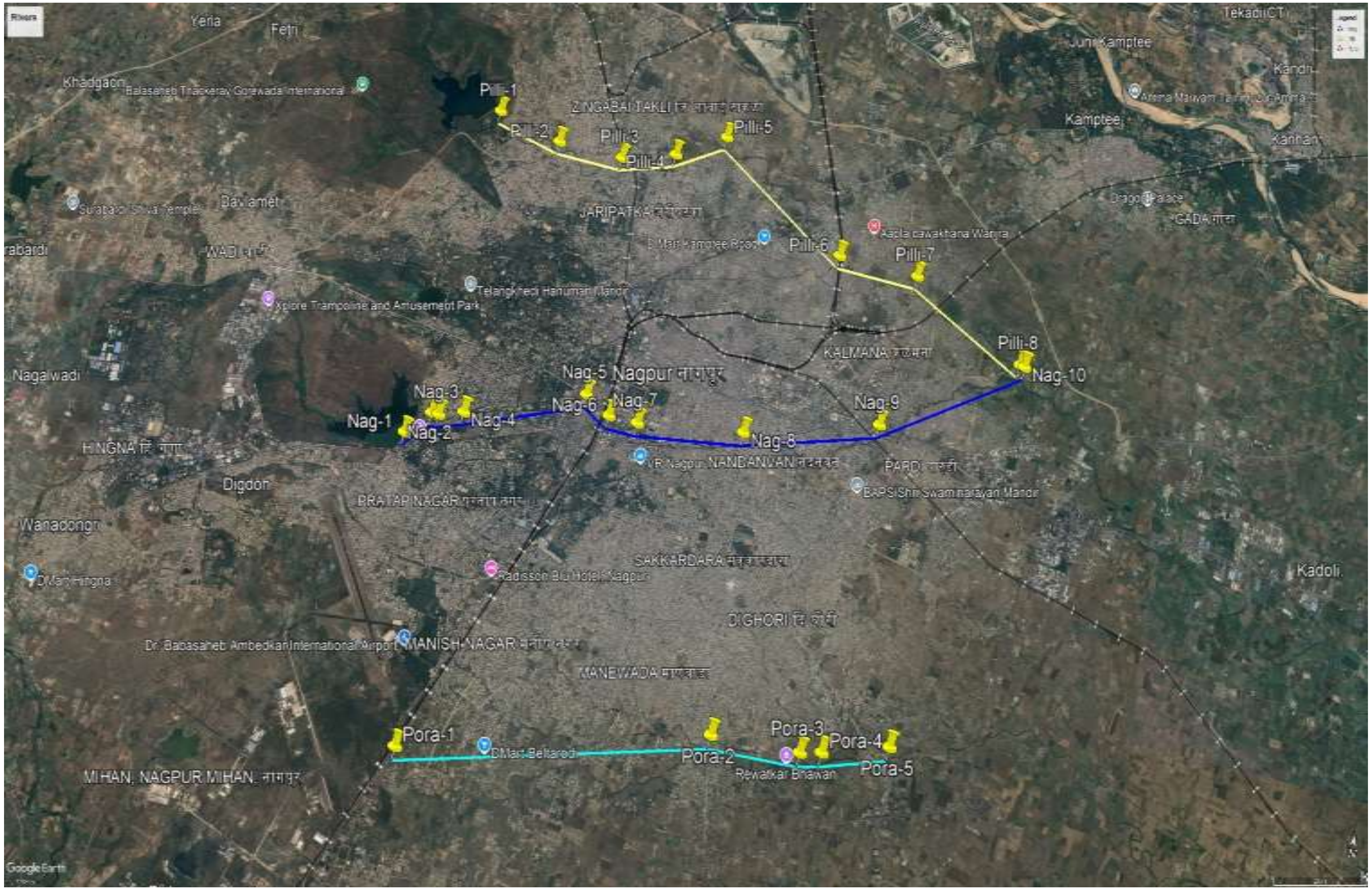


Figure 6.3: Geographical location of sampling sites of all the rivers

Plate 6.4: Sampling sites of the rivers: Nag, Pilli and Pora

6.2.5 Inferences

Analysis performed for the year 2023-2024 includes physico-chemical parameters, bacteriological parameters, organic & nutrient parameters. The results revealed that most of the parameters/readings were lower from the previous year results. The possible reasons for decline in the data may be attributed to difference in the sampling time period during the two years. The sampling for the previous year (2022-2023) was performed at the end of October month after monsoon and after the festive season. The sampling for the current report (2023-2024) was performed during the monsoon before the festive season. Also, majority of the lakes were having complete restriction on entry as boundary walls were being constructed for prohibiting anthropogenic activities inside the lake premises.

6.2.6 Hydrogeological study for the Environmental Status Report of Nagpur

6.2.6.1 Introduction

Nagpur district is one of the nine districts of Vidarbha Region of Maharashtra State. It is situated on the eastern part of the State abutting Chindwada district of Madhya Pradesh in north. It is bounded by Wardha and Amravati districts in the west, Bhandara district in the east and Chandrapur district in the south. It lies between north latitudes 20°35’ and 21°44’ and east longitudes 78°15’ and 79°40’ and falls in Survey on India toposheets 55K, O and P. The district has a geographical area of 9892 sq. km, covering an area of about 100 km^2, is situated at an altitude of over 290 m above the mean sea level. The Nagpur Municipal Corporation has jurisdiction over an area bounded by Latitude 21°03'10"N to 21°13'50"N and longitude 78°59'31"E to 79°10'44"E.

Table 6.17: Groundwater sampling sources locations in Nagpur city

S.N.	Sample Code	Source	Latitude	Longitude	Location Details
1.	NGW-1	DW	21°05'41"N	79°01'34"E	**Owner:** Chandu Dawre (LHS to highway Nagpur to Wardha Shivangaon)
2.	NGW-2	BW	21°04'00"N	79°03'33"E	**Owner:** Bedram Sunak (LHS to drainage line)
3.	NGW-3	DW	21°05'47"N	79°07'30"E	**Owner:** Saurabh Peth (Jaimaa Bhavani Dairy, Tajeshwar Nagar)
4.	NGW-4	DW	21°07'50"N	79°08'21"E	Shitla Mata Mandir, Vidya Nagar
5.	NGW-5	DW	21°06'37"N	79°06'16"E	**Owner:** Anirao shende (Plot No. 39/40 Ladika Layout)
6.	NGW-6	DW	21°07'18"N	79°04'22"E	CSIR - NEERI, Near Gate No. 1
7.	NGW-7	DW	21°10'45"N	79°02'29"E	**Owner:** Rutuj Choudhary (Plot No. 80, Narmada Colony)
8.	NGW-8	DW	21°12'03"N	79°04'51"E	**Owner:** Murlidhar Ghungure (Plot no 163, OM Nagar)
9.	NGW-9	DW	21°09'52"N	79°10'.02"E	**Owner:** Kashi Nath (Bharatwada area)
10.	NGW-10	DW	21°10'06"N	79°06'22"E	**Owner:** Raju Fulzele (Pet unlimited shop Balabhaupeth Kamal Talkies Road)
11.	NGW-11	DW	21°07'58"	79°06'43"E	**Owner:** Durga Diware (Plot N-99B, Reshimbagh)
12.	NGW-12	DW	21°09'18"	79°03'33"E	**Owner:** Krishi Paryatak, Kadimbagh

Note: NGW: Nagpur Groundwater Sample Code; BW: Bore Well & DW: Dug Well

6.2.6.2 Study Area

6.2.6.2.1 Geology

The regional geology of Nagpur is mostly characterized by geological formations Precambrian crystalline metamorphic rocks consisting of a Sausar series, Permo-Carboniferous consisting of Talchir series, Lower Gondwana sediments (Barakar series, Kamthi series), Upper Cretaceous have Lameta sediments and Cretaceous–Palaeogene Deccan trap basaltic lava flows separated by intertrappean beds along with recent alluvium of the Nag and Pilli rivers. The study area mainly comprises of rocks, namely Basalt, Sandstone, Shales, Quartzite, Marble, Clay & Gneiss.

6.2.6.2.2 Lithology

The study area (**Figure 6.4**) is characterized by Sandstone in small patches on the northern side of the boundary, while Gneiss/Migmatie rocks are found in the northeast part. Granites, Gnieiss, and Maigmatites are found in the eastern part of Nagpur. Limestones are found in patches on the central and southern sides of Nagpur.

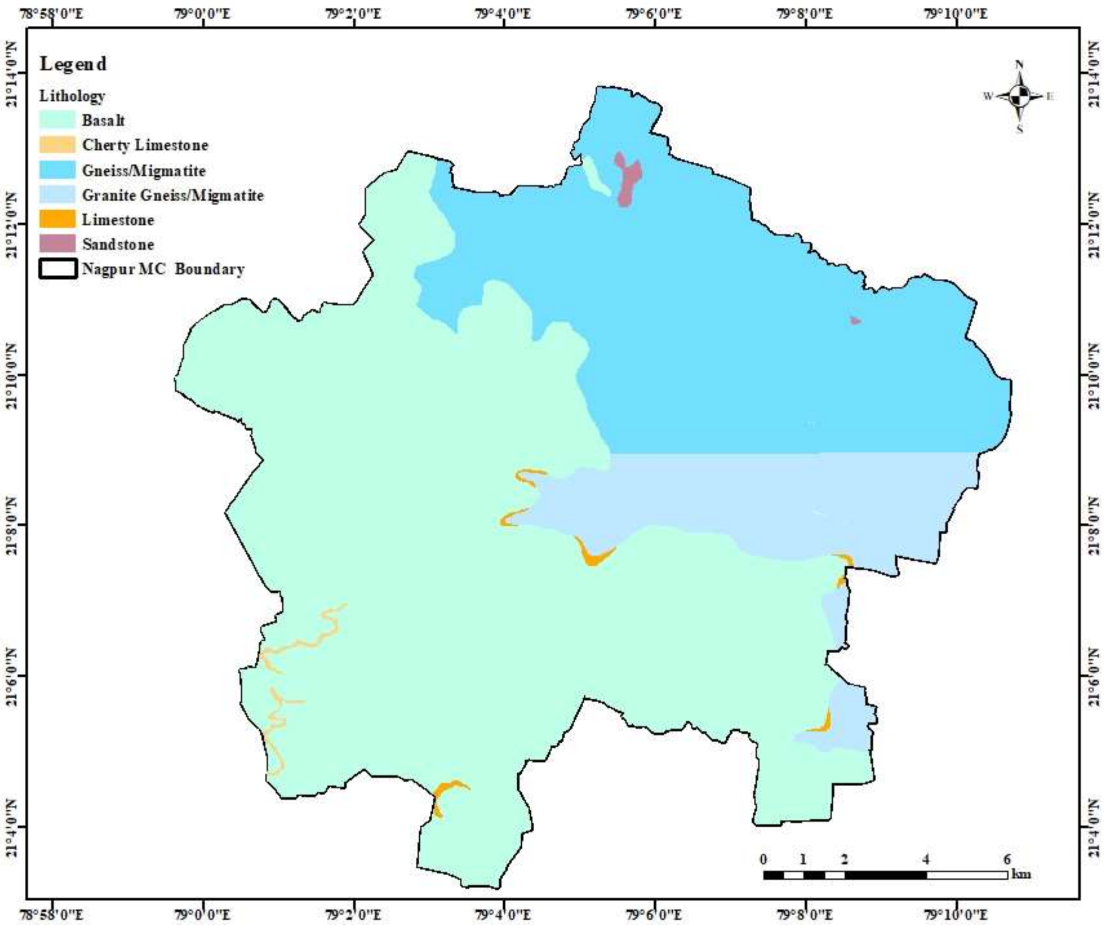


Figure 6.4: Lithological map of study area (Source: bhukosh.gsi.gov.in)

6.2.6.2.3 Topography

The study area has an elevation between 280m and 373m (**Figure 6.5**), and the overall slope is from west to east.

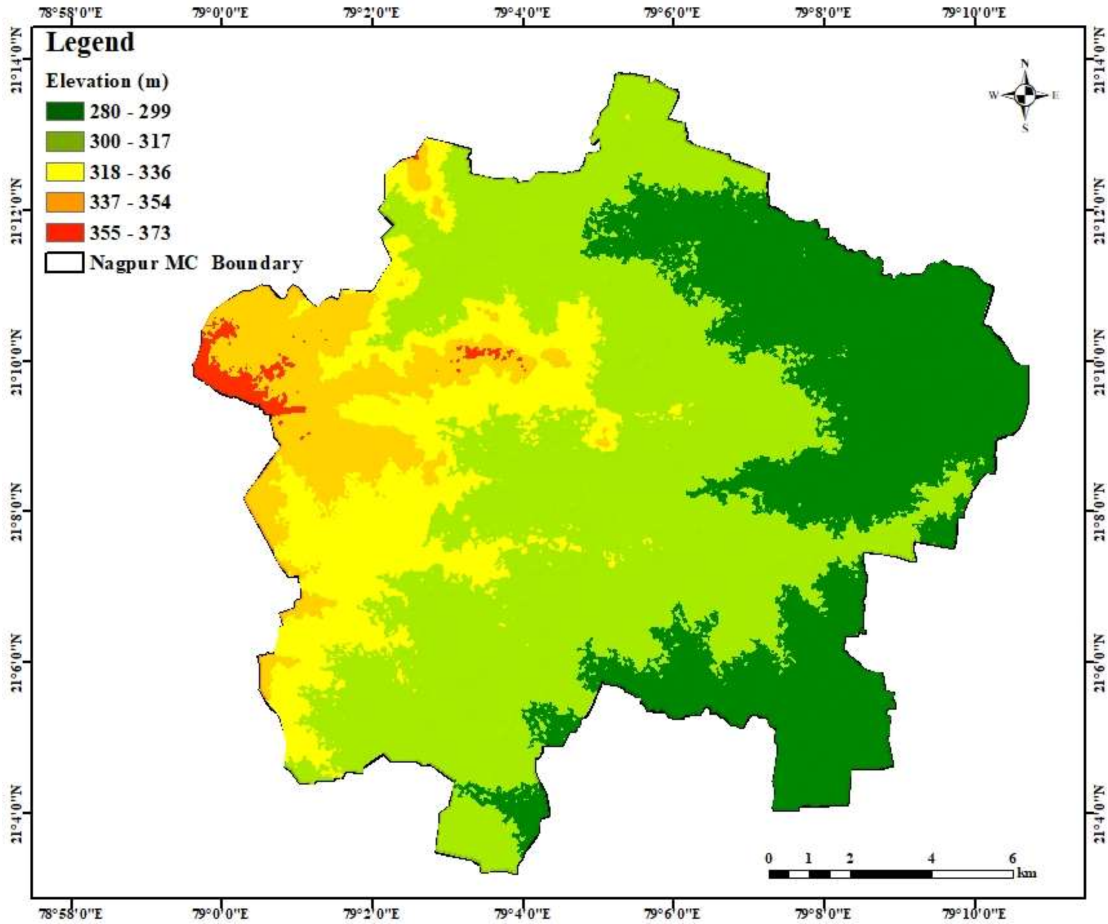


Figure 6.5: Topography map of study area

6.2.6.2.4 Hydrogeology

In the study area, the Archeans and the Deccan trap basalts are the two consolidated formations, which form the aquifer. More than half of the city area, especially the western and the southern parts, is covered by the Deccan traps (4300 km^2) formed during cretaceous period. The Groundwater stage development is 31.19% which comes under safe category. The low stage development is on account of the city getting piped water supply for the drinking requirements and only groundwater in individual houses and housing societies are non-potable purpose. The total dug wells (43 Nos.) and piezometers (18 Nos.) are monitored in Nagpur district (CGWB, 2013).

6.2.6.2.5 Drainage

The drainage pattern (**Figure 6.6**) is controlled by the Nag and Pilli rivers. The Nag River originates in the Lava hills near Wadi. The confluence point of the Nag and Pilli Rivers is near Pawangaon. The drainage pattern is dendritic in nature.

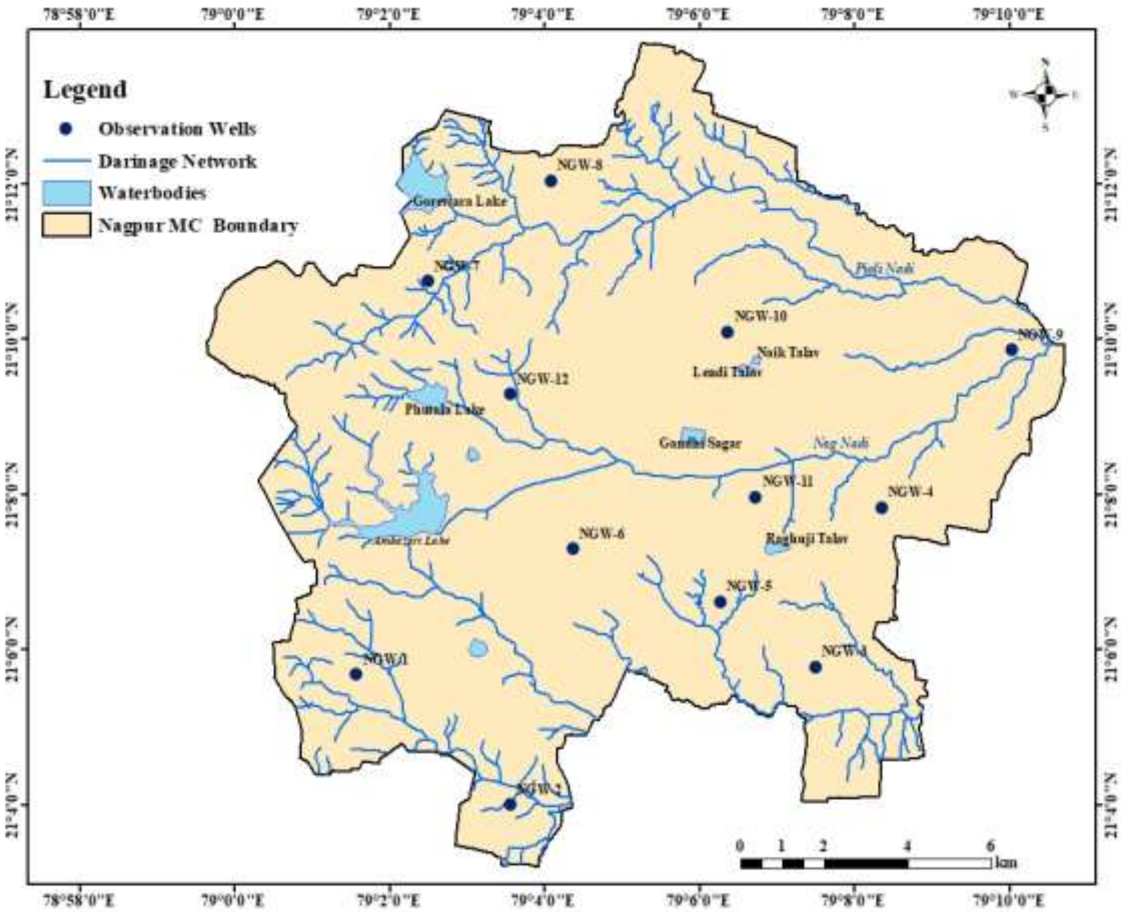


Figure 6.6: Drainage map of study area

6.2.6.3 Methodology for data collection

6.2.6.3.1 Groundwater level measurement

A network of observation wells has been set up **(Figure 6.7)** for monitoring groundwater level and groundwater quality (Major cations, anions, heavy metals & microbiological analysis). The wells are used for domestic purpose. The observation well locations were marked by GPS (Garmin Make). The groundwater level **(Plate 6.5)** was obtained by using automatic water level indicator (Model-EPP-10/6) manufactured by M/s ENCARDIO- RITE ELECTRONICS PVT. LTD.).

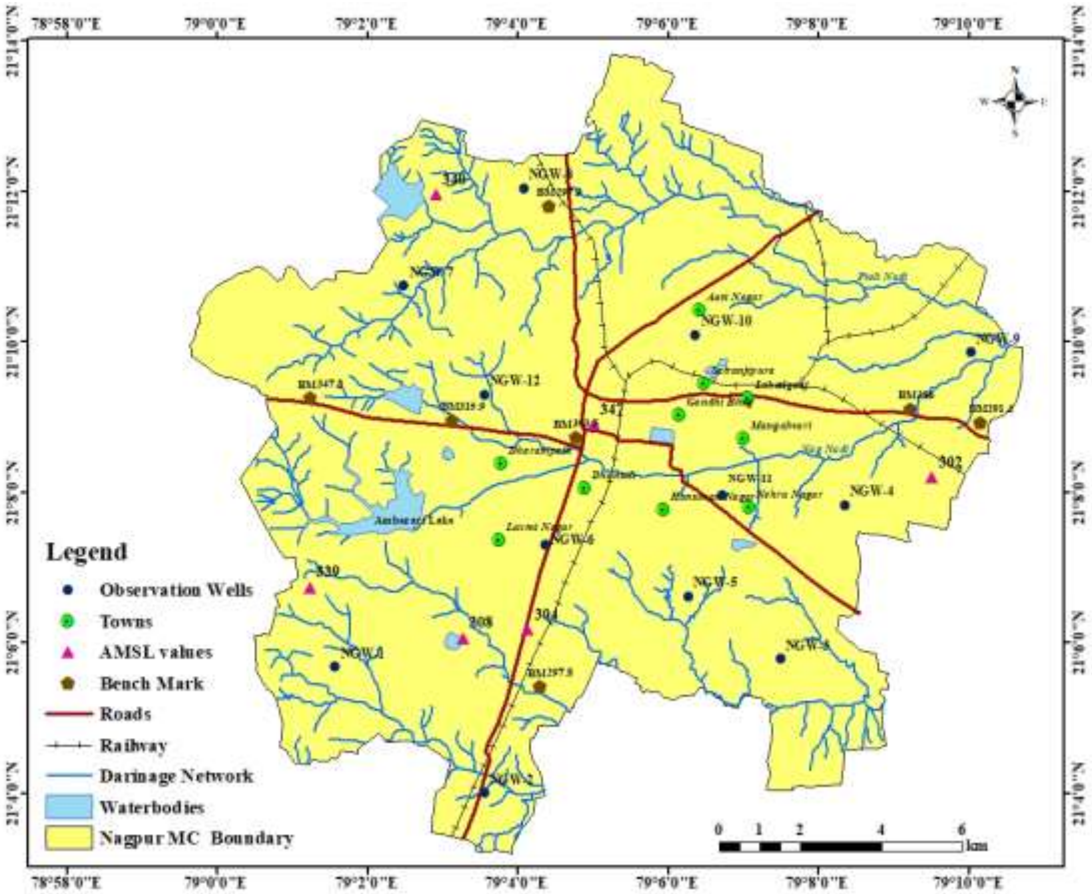


Figure 6.7: Observation well network in study area

Plate 6.5: Measurement of groundwater level using automatic water level indicators

6.2.6.3.2 Groundwater sampling & analysis

Total 12 groundwater samples (**Table-6.17**) were collected from the observation well network in the study area. The groundwater sources consisted of Dug well (11 Nos.) and Bore well (1 No). For physicochemical parameters and heavy metal analysis, the samples were collected in pre-cleaned 1000 mL and 100 mL polyethylene bottles, respectively. Concentrated HNO_3 was added to the heavy metal samples for preservation. The physicochemical parameters were analyzed by following the standard protocol (APHA, 2017). The heavy metal analysis was done by ICP-OES (Model: iCAP 6300 DUO, Make: Thermo Fischer).

6.2.6.3 Observations and Inference

6.2.6.3.1. Groundwater Level

The groundwater levels **(Table 6.18)** from the observation well network in the study area have been measured, and the groundwater level (below ground level) varied between 2.12m (NGW-3) to 12.20m (NGW-1) during the pre-monsoon season of 2024 (ESR report 2022-2023) and varied from 2m (NGW-3) to 8.80m (NGW-8) during post-monsoon of 2024. The average fluctuation range is from 0 to 3.6m. The groundwater level (above mean sea level) contours **(Figure 6.8)** indicate that the groundwater flow direction follows the topography and the flow direction is from west to east direction.

Table 6.18: Groundwater level (m) in the study area – ESR report (NMC)

Sr. No	Sample code	Source	Groundwater Level (BGL-m)		
			Pre-Monsoon May'24	Post-Monsoon Dec'24	Average Fluctuation (m)
1	NGW-1	DW	12.20	8.60	3.6
2	NGW-2	BW	7.25	5.5	1.75
3	NGW-3	DW	2.12	2	0.12
4	NGW-4	DW	6.42	6.42	0
5	NGW-5	DW	6.19	5.67	0.52
6	NGW-6	DW	5.83	3	2.83
7	NGW-7	DW	2.65	2.62	0.03
8	NGW-8	DW	10.83	8.80	2.01
9	NGW-9	DW	6.19	5.43	0.76
10	NGW-10	DW	4.36	4	0.36
11	NGW-11	DW	6.15	5.20	0.95
12	NGW-12	DW	6.48	4.96	1.52

Note: NGW: Sample code; BW: Bore well & DW: Dug well

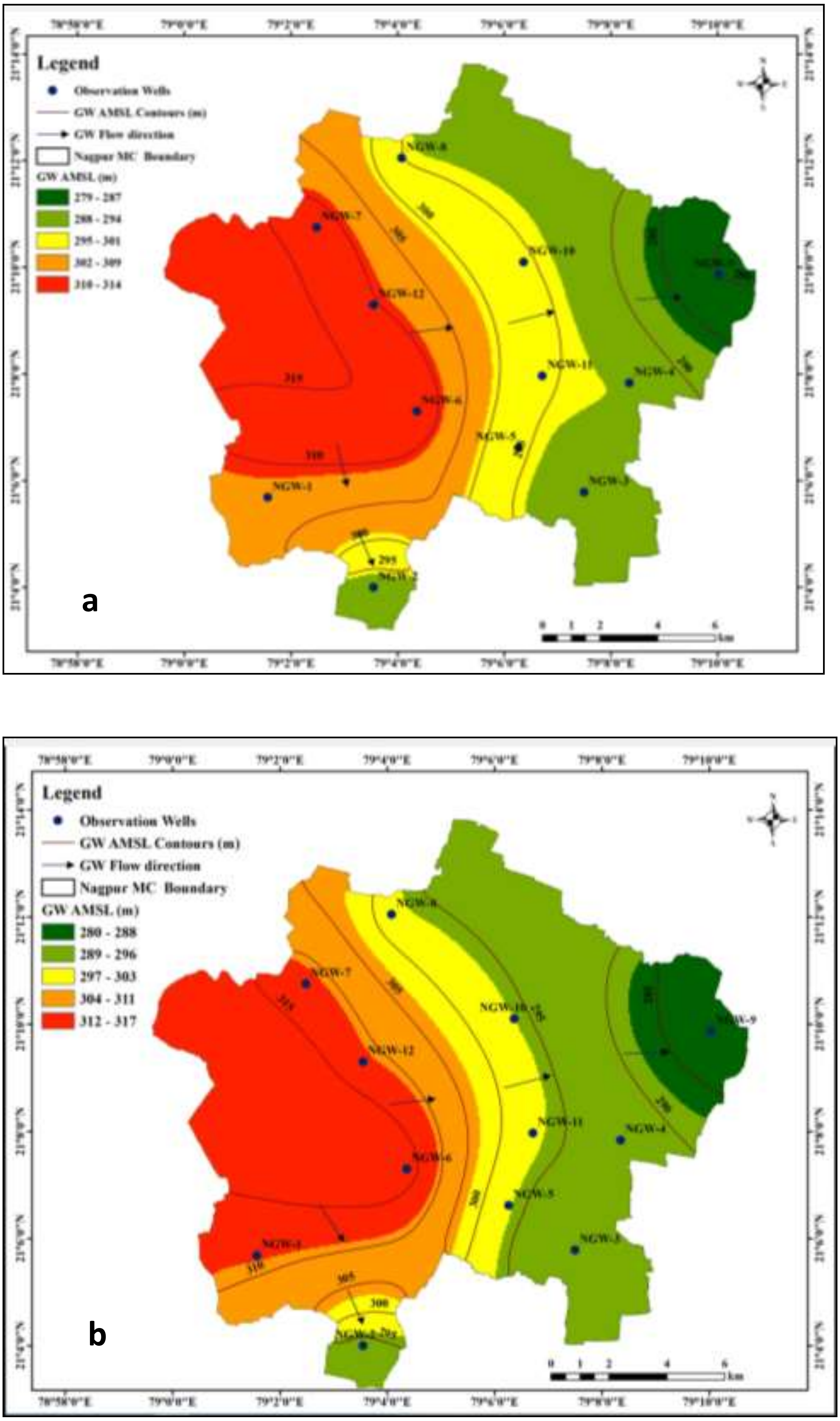


Figure 6.8: Groundwater level (AMSL) contour plot of the study area (a) May 2024 (b) Dec 2024

6.2.6.3.2. Groundwater quality

The groundwater samples were collected from 12 locations post-monsoon in December 2024. Location details are given in **Table 6.17**. The groundwater samples were analyzed for physico-chemical parameters, metals and bacteriological parameters and the results are presented in **Tables 6.19, 6.20 & 6.21 .** All the 12 Nos. groundwater collected samples were observed to be clear and did not have any objectionable odour. The pH of groundwater samples ranged from 7.15 to 7.86, and these values were within the desirable range of 6.5 to 8.5 prescribed by the BIS 10500:2012.

All 12 Nos. samples were found to have dissolved solids (TDS) well below the permissible limit of 2000 mg/L as per BIS standards. All 12 Nos. samples were observed to have total alkalinity above the desirable concentrations of 200 mg/L except NGW (180 mg/L) . Magnesium exceeded marginally in eight samples above desirable concentrations, however, it was well below the permissible limit of 100 mg/L. Phosphates were found to range between 0.05 and 0.30 mg/L. Ten of the groundwater samples were found to have total hardness exceeding the desirable value of 200 mg/L. Other parameters were found to be within the desirable limits of BIS 10500:2012.

Significant contamination was not observed in groundwater sources when compared with drinking water standards BIS 10500:2012. Lead (Pb) concentration was found in the range of 0.09-0.014 mg/L in three samples i.e. NGW1, NGW7, NGW12 that were above desirable limits. All the parameters are shown in **Tables 6.19 & 6.20.**

6.2.6.4.3 Groundwater quality: Bacteriological

Bacteriological analysis of groundwater samples indicated that the 12 samples had a significant load of Total Coliforms (TC), and Thermotolerant Faecal Coliforms (FC) ranging from 46 to 164 CFU/100 mL and 10 to 80 CFU/100 mL, respectively **(Table 6.21)**. The overall quality of groundwater samples was observed to be good in terms of physio-chemical characteristics but was found to be contaminated with coliforms and requires disinfection before consumption.

Table 6.19: Water quality of groundwater samples of Nagpur city: Physico-chemical characteristics

Sample	pH	EC	TDS	Sodium	Potassium	Hardness	Calcium	Magnesium	Alkalinity	Chloride	Nitrate	Phosphate	Fluoride	Sulphate
unit		**µS/cm**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
NGW1	7.15	798	479	29.1	0.7	332	67.2	39.36	284	25.99	36.8	0.10	0.59	40.8
NGW2	7.34	784	471	57.2	1	324	52.8	46.08	284	43.99	15.3	0.05	0.58	26.7
NGW3	7.86	775	465	29.1	1	348	56	49.92	244	59.98	30.5	0.05	1	48.7
NGW4	7.24	1467	880	122.2	2.8	440	78.4	58.56	344	179.94	5.0	0.06	1.3	58.7
NGW5	7.56	496	298	58.7	1.3	180	28.8	25.92	180	27.99	6.1	0.20	0.58	28.1
NGW6	7.4	1346	807	133.4	1.8	404	38.4	73.92	468	115.96	2.4	0.08	1.3	47.6
NGW7	7.73	835	501	36.5	0.5	352	38.4	61.44	288	57.98	13.2	0.10	1.1	46.8
NGW8	7.44	1254	752	212	3	224	43.2	27.84	456	81.97	7.3	0.24	1.2	70.7
NGW9	7.26	1870	1122	152	2.2	620	92.8	93.12	352	275.91	37.4	0.23	0.78	157.2
NGW10	7.6	1685	1011	256	5.4	296	38.4	48	392	153.95	31.5	0.30	0.81	253.9
NGW11	7.6	713	428	87.1	0.7	172	25.6	25.92	236	55.98	11.8	0.16	1.4	30.7
NGW12	7.2	834	500	23.9	19	292	99.2	10.56	288	67.98	8.3	0.28	0.21	48.8

Table 6.20: Water quality of groundwater samples of Nagpur city: Metals

Sr. No	Sample code	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BIS Limit (ppm)		**0.03-0.20**	**0.01**	**0.003**	**0.05**	**0.05-1.5**	**0.3**	**0.10-0.30**	**0.02**	**0.01**	**5.0-15**
ICP-OES detection limit		**0.0001**	**0.007**	**0.0001**	**0.01**	**0.0004**	**0.0003**	**0.0001**	**0.005**	**0.009**	**0.001**
1	NGW1	0.032	BDL	0	BDL	0	0.036	0.010	0.016	**0.014**	0.042
2	NGW2	0.057	BDL	0	0	0	0.138	0.018	0.010	0.010	0.009
3	NGW3	0.020	BDL	0	BDL	BDL	0.026	0.003	0.010	0.010	BDL
4	NGW4	0.028	0	0	BDL	0	0.035	0.257	BDL	0.006	0.006
5	NGW5	0.033	BDL	0	0.001	BDL	0.018	0.006	0.006	0.005	0.007
6	NGW6	0.133	BDL	0	BDL	0.001	0.203	0.104	0.017	0.011	0.036
7	NGW7	0.041	BDL	0	0	0.001	0.036	0.022	0.017	**0.014**	0.115
8	NGW8	0.070	BDL	0	BDL	0.002	0.091	0.010	0.011	0.007	0.551
9	NGW9	0.029	0	0	BDL	BDL	0.039	0.027	BDL	0.005	0.015
10	NGW10	0.049	0.001	0	BDL	0.001	0.049	0.010	0.006	0.006	0.147
11	NGW11	0.024	BDL	0	BDL	BDL	0.010	0.001	BDL	0.004	0.002
12	NGW12	0.023	BDL	0	BDL	BDL	BDL	0.008	0.017	**0.016**	BDL

Note- NGW- Nagpur Groundwater.

Table 6.21: Water quality of groundwater samples of Nagpur city: Bacteriological parameters

Serial No.	Sample Code	Total Coliform (CFU/100mL)	Thermotolerant Coliform (CFU/100 mL)
1	NGW-1	56	14
2	NGW-2	128	80
3	NGW-3	76	46
4	NGW-4	88	24
5	NGW-5	154	58
6	NGW-6	82	18
7	NGW-7	112	28
8	NGW-8	164	54
9	NGW-9	136	68
10	NGW-10	88	22
11	NGW-11	90	30
12	NGW-12	46	10

6.2.7 Recommendations

1. The dumping of garbage around lakes i.e., Sonegaon, Binaki, and Pandharbodi was a sign of human activity and loitering of stray animals and animal faecal matter near the lakeside may be the main and direct source of fecal contamination.
2. Though the physico-chemical analysis of lake water samples indicated an overall reduction in COD, BOD, and other nutrient (nitrogen and phosporous) concentrations as compared to previous year, this may be sufficient to support the growth of floating aquatic plants and weeds. The lakes showing signs of eutrophication, particularly Naik, Binaki, and Police Line Takli, require immediate attention. Strategies such as nutrient reduction, algal control, and oxygenation measures (e.g., aeration systems) should be implemented to restore ecological balance. In lakes like Ambazari, where localized weed growth was observed, periodic cleaning and the removal of excess vegetation are necessary to prevent further nutrient accumulation and degradation.

3. Strict monitoring and regulation of wastewater discharge and runoff into the lakes are critical. Implementing sewage treatment facilities and minimizing inflow of pollutants can help reduce nutrient input.
4. Strategies of desilting, desludging, boundary/retaining/edge wall, etc applied by NMC for rejuvenation and development of Gandhisagar, Lendi, and Police line Takli lakes, also need to be adopted for remaining lakes. Anthropogenic activities can be curtailed by building of boundary walls and appointing security guard for restricting the public entry near the banks of the lakes.
5. To improve the ecological health of these lakes and mitigate pollution levels, continuous monitoring of water quality and biodiversity in all lakes is crucial for detecting early signs of pollution or eutrophication. Implementing a long-term ecological management plan will help prevent future deterioration.
6. The public must be educated on the importance of these lakes, often referred to as the city's "blue lungs," for cooling the urban heat island projects will be vital in protecting these water bodies from further pollution.
7. Though the COD and nutrient levels were lower in samples from all the three rivers Nag, Pilli and Pora over the previous year, river water was found to be unsuitable for drinking, outdoor bathing, irrigation due to increase in COD, and phosphate-P load and the presence of fecal coliforms, as the rivers flowed through the city.
8. There is a need for reducing/preventing activities which are responsible for increased pollution load in the rivers, such as; dumping of waste by local vendors of fruits-vegetables, meat and other products, wandering of stray animals in the river or disposal of dead animals along the river bank.

   The flow of drains carrying untreated and uncategorized sewage/waste from the city's commercial and industrial areas may be directly channelized to STPs to prevent their entry into the river thereby reducing the pollution from anthropogenic sources and the bacterial contamination. The river pollution abatement plan being carried out by NMC under the AMRUT-II scheme should be aggressively implemented for rejuvenating the rivers.
9. The groundwater level (below ground level) in the study area shows a lot of variation in the range of 2 m BGL (NGW -3) to 8.80 m BGL (NGW -8). In the post-monsoon (December

2024) season, the groundwater level was very shallow at following locations namely, NGW-3 (2 m BGL), NGW-7 (2.62 m BGL), and NGW-6 (3 m BGL).

10. The rainwater harvesting structures can be implemented at suitable locations where the groundwater levels.
    a) in the range of 3 to 6 m BGL and a declining trend of 0.10 to 0.20 m/year.
    b) deeper than 9.00 m BGL and declining trend in excess of 0.40 m/year or
    c) deeper than 12.00 m BGL, but with a long term rising trend of 0.2 to 0.4 m/year.
    d) in the range of 5.0 to 10.0 m with declining trends during the report period.
11. Normally, areas having deeper water levels and declining water level trends are given higher priority identification of area feasible for artificial recharge. Areas having shallow water levels / rising water level trends are not considered for inclusion in artificial recharge plan (CGWB, 2007).
12. NMC can implement roof top rain water harvesting recharge structures in public parks and play grounds where the pre-monsoon water level is more than 3 m.

6.3 References

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ESR (2023-24)

Chapter 7

Socio-Economic Profile

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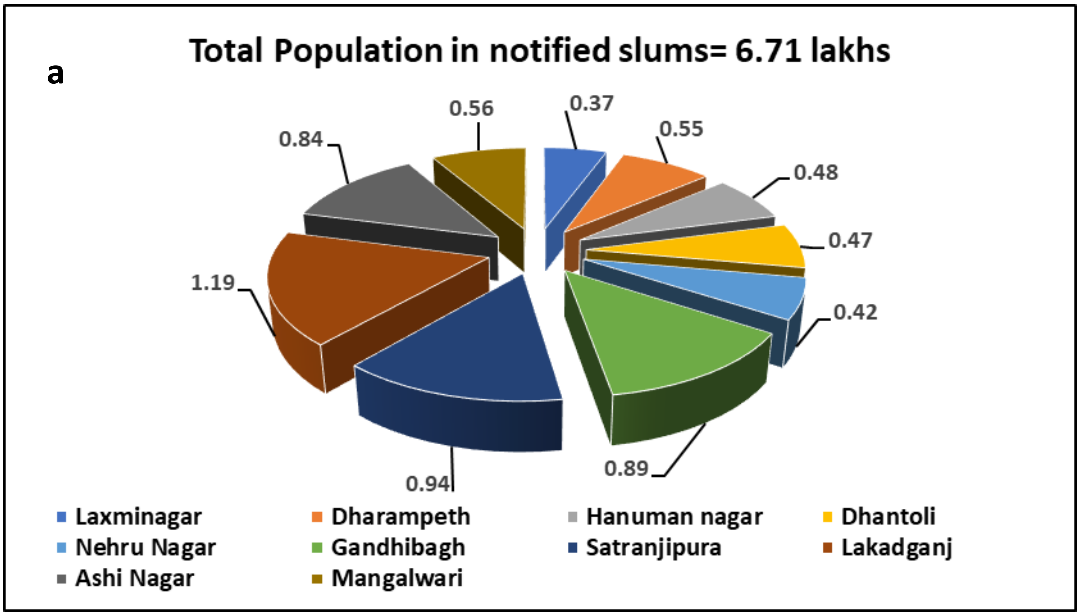
Socio-Economic Profile

7.0 Slums areas growth, legalization and rehabilitation

7.1 Profile of Slums

The early development of slums in Nagpur has taken place in proximity to the place of work and open land or low-lying unused areas which increased from 45 in the year 1971 to 439 in the year 2012 (ESR report 2022-2023). The development plan of Nagpur in 1971 for the first time identified 45 slum pockets. Currently there are a total of 429 slums in Nagpur city of which, 301 are notified slums (slum has legal status) while and 128 are non-notified slums (slums do not have any legal or administrative status) according to NMC. Centre for Sustainable Development (CFSD) has conducted detailed mapping of slums in Nagpur to support the Patta Watap program through different exercises such as plane table surveys, geospatial data integration, and community participation. The NMC has commenced a drive to identify plots, occupants, and issues of ownership to slum dwellers on lands owned by the state government. The slum population has grown to 6.71 lakhs in the notified slum areas while it is 1.36 Lakh in the non-notified slum areas (**Figure 7.1).**



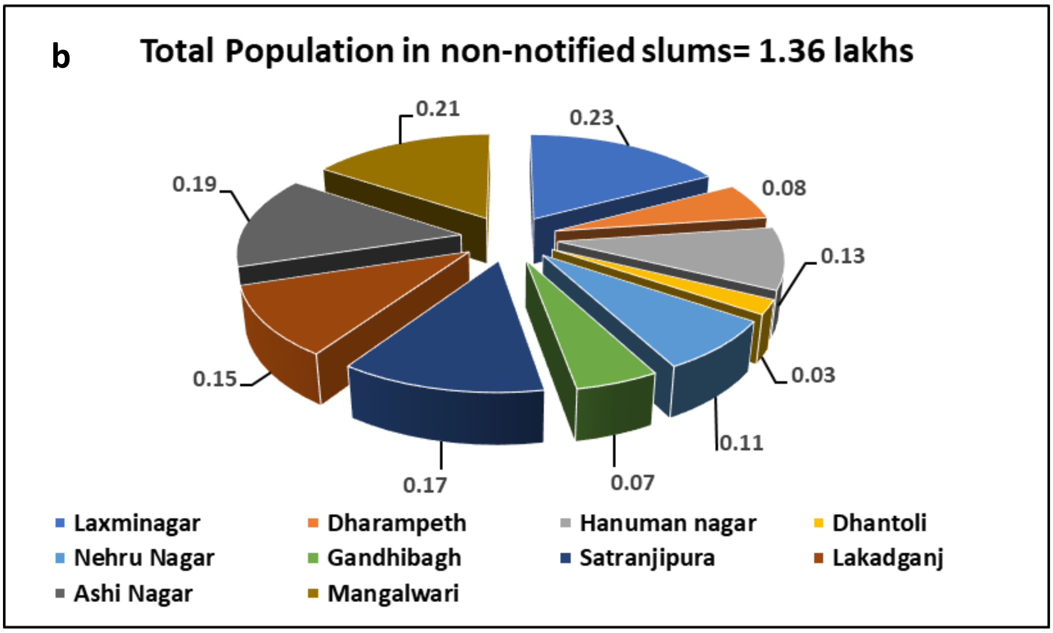


Fig 7.1: Total population in (a) Notified and (b) Non-notified slums in Nagpur city (Source: NMC)

7.1.1 Initiatives for slum improvement and rehabilitation

Three main types of settlements in Nagpur in terms of settlement development processes, land tenure and settlement characteristics include organic settlements, unauthorized housing layouts, and squatters (zopadpattis). Lakadganj zone has the highest number of notified slums (48 slums) followed by 44 in Ashi Nagar zone, 36 in Satranjipura zone, 31 in Mangalwarai zone, while it varied between 17-25 in the remaining zones. Comparative number of non-notified slums were highest at 29, 23, 20 in Ashi Nagar, Mangalwari, and Laxmi Nagar zones respectively with lower number (between 5 to13) of non-notified slums in the remaining zones.

As reported by NMC, there are around 1.41 lakh dwelling units (DUs) in slums, out of which around 1.17 structures are in notified slums while 0.24 lakh structures are in non-notified slums. Out of 429 slums, around 17.5% are on private land, while 17.5% are located on the government owned land. Other 66% of the slums are located on the land belonging to authorities like NMC, NIT, Revenue Department, University, airport/cargo hub/civil aviation, Indian Railways and on land having mix ownership.

Several initiatives have been undertaken by NMC from time to time for improving the conditions of the slums in Nagpur city viz., Slum Improvement Programme (1972-1994), Basic Services for Urban Poor (2006-Ongoing), Rajiv Awas Yojana (2007), Ramai Awas Yojana (2008-Ongoing), Slum Rehabilitation Scheme (2006-Ongoing), and Pradhan Mantri Awas Yojana (2015-Ongoing). All these schemes have focussed on providing new dwelling units (DUs) to slum dwellers, in addition to development of basic infrastructure in existing slum settlements like water supply, roads, street lighting, drainage, sewer line etc. (ESR report, 2022-2023).

7.2 Population and Demography Analysis

Demography analysis of a city includes of influential factors such as size, structure and distribution of the population, birth rate, death rate, aging, and migration. This helps in studying the previous and existing demographic status of the Nagpur city. Population forecasting till the year 2035 was worked out in the section. Nagpur, the third largest city in Maharashtra, and the largest city in Central India covering an area of 227.29 sq. km is also being developed as a Smart City under the Government of India (GoI) Smart City Program (https://smartnet.niua.org/sites/default/files/resources/ Nagpur_SCP.pdf). The decadal nation-wide census last conducted by Union Government of India in 2011, could not be conducted in 2021 due to Covid. Though the population of Nagpur city in the year 2023 was estimated at 3.316 million (ESR report, 2022-2023), the actual population was 3.046 million, which increased by 1.94% to 3.106 million in the year 2024 (https://www.macrotrends.net/global-metrics/cities/21347/nagpur/population). The population growth of the city for the period 1912-2035 is depicted in the **Figure 7.2.**

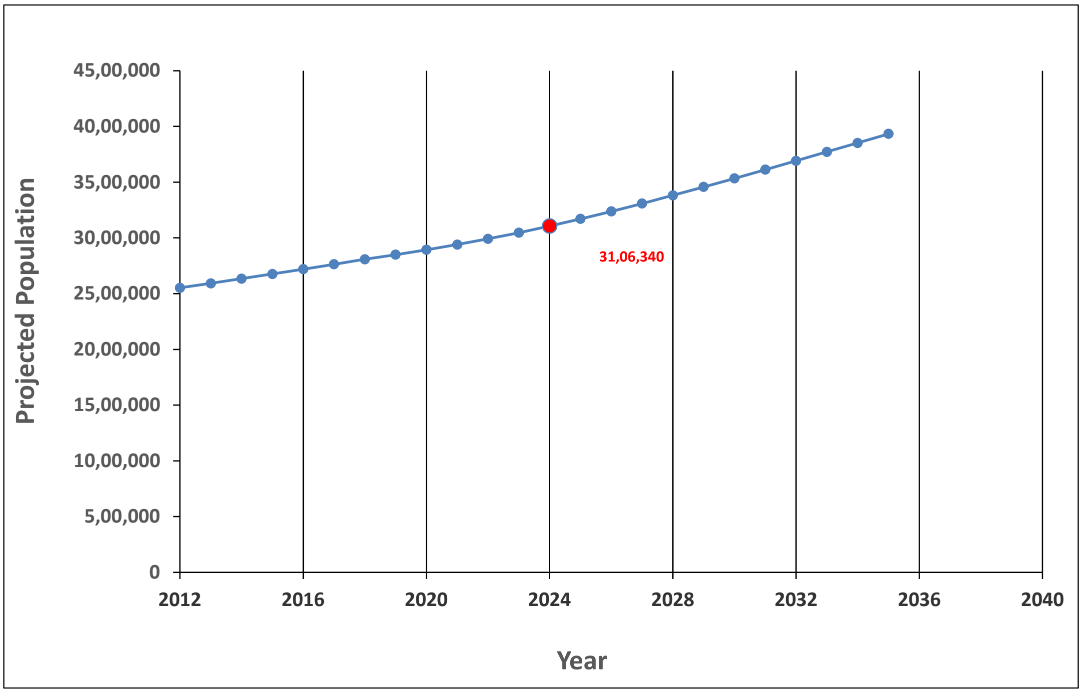


Figure 7.2: Projected population (2012 - 2035) for Nagpur city (Source: https://www.macrotrends.net/global-metrics/cities/21347/nagpur/population)

7.3 Pillars of Nagpur economy

7.3.1 Trade and commerce: Startups and new businesses

Nagpur as a hub of new startups, has made a remarkable improvement of 138 in Global Ecosystem Index ranking to 552nd global rank and 23rd in India in the year 2024 over that of last year (https://www.startupblink.com/startup-ecosystem/nagpur-in**)**. Few of the top 38 startups under diverse areas include Healthtechs (e.g. YourPhysio, ErlySign,), Software-Datas & Hardware-IoTs (e.g. Provscale, COJAG, AOTOM Technology, NONSTOP, Wings Lifestyle), Ecommerce & Retails (e.g. Frikly).

7.3.2 Transportation

Commuting to work places and other locations within Nagpur city is facilitated by multiple modes of transport metro rail system, public buses, private cabs, auto rickshaw, etc. Aapli Bus service operated by NMC for city transport in Nagpur, has seen an increase in annual passengers to 1.16 lakhs, generating an average daily revenue of Rs. 19.50 lakhs and an estimated to annual revenue of Rs. 93.17 crores from ticket sales. Its recent focus has been moving towards innovation and sustainability through introduction of more electric air-conditioned buses (250 electric buses from state and 150 from central government) (https://nagpurupdates.com/nagpur-municipal-corporations-vision-for-2024-25-aapli-bus-sustainability-and-beyond/). 372 buses were being operated by Aapli Bus over 100 routes which includes 169 electric buses while rest are diesel powered (https://timesofindia.indiatimes.com/city/nagpur/aapli-bus-fleet-surpasses-pre-covid-ridership-reaches-150-lakh-passengers/articleshow/113678270.cms). Nagpur city had a road network comprising of 1531.49 km of tar roads and 793.71 km were converted to cement roads by 2024 under the first three phases of road concretization. Further stretches of roads between 9 and 24 meters in width are earmarked for concretization in the fourth phase (https://www.nbmcw.com/news/roads-highways/nagpur-municipal-corporation-expands-road-concretisation-projects.html). A unique four-layer transport system which included (from bottom to top) an existing road with a railway bridge over it, followed by a flyover and elevated metro railway track at the top-most-level was inaugurated in Nagpur city in 2024 (https://timesofindia.indiatimes.com/city/nagpur/asias-longest-double-decker-flyover-inaugurated-in-nagpur/articleshow/113972502.cms).

As the nucleus of the country, major highways of the country also pass across the city, connecting major metropolitans such as Mumbai, Delhi, Bhopal, Hyderabad, Indore, and

Raipur. Key initiatives and projects under commuting facilities are discussed in the flowing sections.

7.3.2.1 Nagpur Metro

Nagpur metro which is the greenest one has covered a distance of 40 km with 36 stations, 2 depots and a fleet of 69 metro cars, in the Phase-I while the Phase-II of the rail project with project cost of Rs. 6708 crore consisting of 32 stations covering a 43.8 nm distance is progressing with the Stage-I of this phase to be completed in June 2025. During the year 2023-2024, the average number of passengers travelling daily was around 69769 (https://www.metrorailnagpur.com/Nagpur-Metro-Phase-2; https://mahades.maharashtra.gov.in/ESM1920/chapter/English/esm2324_e.pdf)

7.3.2.2 Railway connectivity

Nagpur city enjoys railway connectivity being a main a junction of Howrah-Mumbai and New Delhi–Chennai main lines. Its redevelopment along with Ajni station to international standards which was started in 2022 for developing modern amenities for passengers and will have green buildings with solar energy, water conservation, and rainwater harvesting. Of the estimated cost of Rs. 589.22 crore and Rs. 359.82 crore respectively, Nagpur railway station has achieved 35% physical progress and Rs. 101.48 crore financial progress while, Ajni railway station has achieved 40% physical progress and Rs. 59.36 crore financial progress (https://thelivenagpur.com/2024/10/25/major-redevelopment-of-nagpur-and-ajni-railway-stations-underway/).

7.3.2.3 Hindu Hruday Samrat Balasaheb Thackeray Maharashtra Samruddhi Mahamarg

Maharashtra Samruddhi Mahamarg is an eight-lane expressway (701 km long and 120 m wide) connecting Nagpur to Mumbai and passing through 10 districts, 26 talukas, 392 villages. Phase-I of the was inaugurated by honourable Prime Minister in December 2022 while Phase-II was inaugurated by Maharashtra Chief Minister and Deputy Chief Minister in May 2023. It is on final stage of completion with 98% physical progress, and final 76 km stretch set to become operational shortly (https://www.constructionworld.in/transport-infrastructure/highways-and-roads-infrastructure/maharashtras-samruddhi-mahamarg-to-complete-by-september-2024/60660; https://housing.com/news/samruddhi-mahamarg-to-be-completely-operational-from-nov-2024/). Nagpur to Bharveer (about 600 km) stretch of the Maharashtra Samruddhi Mahamarg has been opened to traffic (https://mahades.maharashtra.gov.in/ESM1920/chapter/English/esm2324_e.pdf)

7.3.2.4 Air connectivity

The development of Dr. Babasaheb Ambedkar International Airport, Nagpur as aviation hub in the Vidarbha region, is being carried out with an aim for elevating its capacity for annually handling 30 million passengers. The first phase will focus on creating modern passenger terminal capable of handling 4 million travelers annually along with state-of-the-art cargo facility capable of handling 20,000 metric tons, a new Air Traffic Control tower, comprehensive airside infrastructure upgrades. Nagpur airport has handled an estimated number of 25 lakh passengers on domestic routes and 0.65 lakh passengers on international routesin2023 (https://mahades.maharashtra.gov.in/ESM1920/chapter/English/esm2324_e.pdf).

7.3 Educational Institutes

Nagpur is an educational hub of Central India and comes right after Mumbai and Pune with national level institutions like Government Medical College, Indra Gandhi Government Medical College, Visvesvaraya National Institute of Technology, AIIMS, IIM, IIIT and NLU in addition to prestigious private universities like Symbiosis International University. Additionally, Nagpur also has numerous engineering colleges and other private and government aided colleges offering courses in academic and professional course affiliated with Nagpur University which complement the MIHAN project, BPOs, businesses in the city by providing skilled human resource.

7.4 Key indicators

7.4.1 Human development index (HDI)

HDI, measures the quality of life of the citizens on basis of their life expectancy, education, and per capita income. Developed by economist Mahbub ul Haq, it relates development of a state in terms of the ability of its citizens to “be” and “do” desired things in life. As mentioned in Economic Survey of Maharashtra 2022-23 and cited in earlier report (ESR report, 2022-2023), Nagpur ranked fourth among cities of Maharashtra having >20 lakh population with an HDI of 0.786, after Thane (0.800 HDI), Pune (0.814 HDI) and Mumbai (0.841 HDI). This was based on the census of 2011 and the same has been published in Economic Survey of Maharashtra 2023-24, by the Directorate of Economics and Statistics, Government of Maharashtra (https://mahades.maharashtra.gov.in/ESM1920/chapter/English/esm2324_e.pdf).

7.4.2 New business registrations

In India 95% of the business establishments come under small and medium enterprise sector which serve as the backbone of the country's economy. To identify, regularize, and promote micro, small, and medium enterprises, the GoI has launched Udyog Adhaar. The registrations of Udyog Aadhar done in region directly indicate the state of trade and commerce of that region. In Maharashtra, Nagpur stood fifth in the enrolment for medium industries (857 registrations), fourth in the enrolment for small industries (7602 registrations), and sixth in the enrolment for micro industries (390851 registrations) till January 2024. This has generated employment to nearly 9.35 lakh population (https://mahades.maharashtra.gov.in/ESM1920/chapter/English/esm2324_e.pdf).

7.4.3 Gross value added (GVA)

GVA is used to check how much value is added (or loss) from a particular region, district, or state. GVA gives a clear outlook of the region's economy as it adds up the subsidies induced by the government and subtracts the taxes imposed on the tax payers. Sector wise percent share of GVA of Nagpur revenue division and GDP is presented in the **Figure 7.3** for the period from 2011 to 2023.

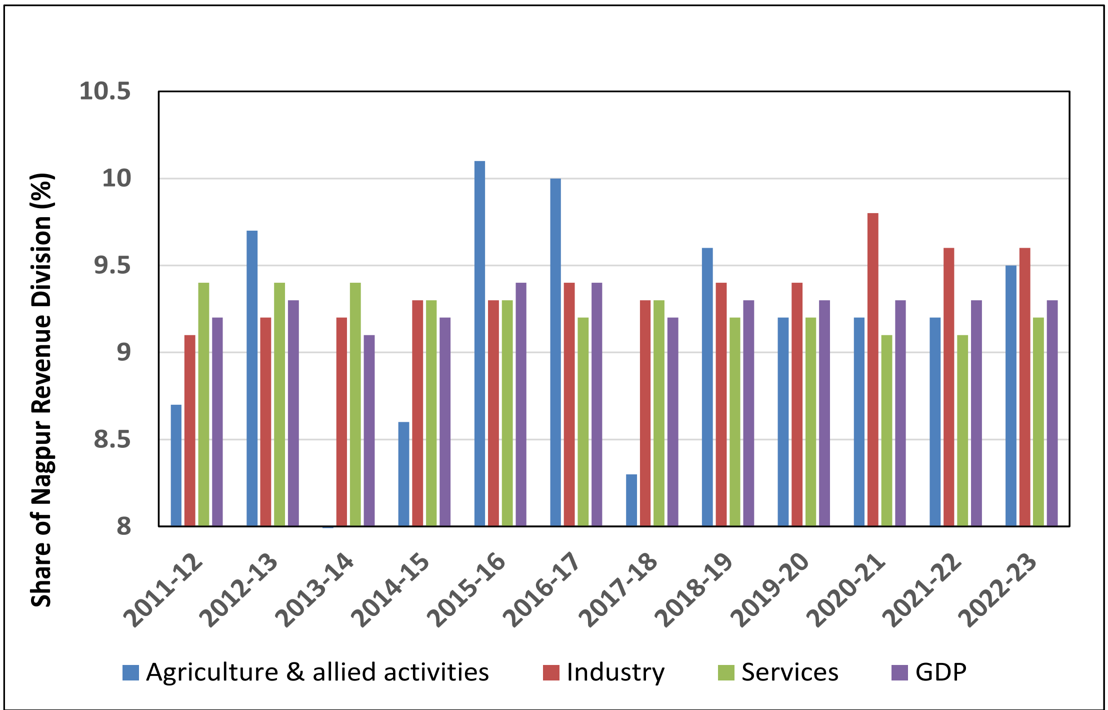


Figure 7.3: Sector-wise percent share of GVA in GSVA of Nagpur revenue division (2011-2023) (Source: https://mahades.maharashtra.gov.in/files/report/DDP_2022-23_002.pdf)

7.5 Summary & Conclusions

Being located exactly at the geographical center of the country, Nagpur offers an exclusive coverage and command over pan India. This unique characteristic of Nagpur was utilized since the independence. The first instance of taking advantage of the geographical location of Nagpur was observed when India Post exchanged mails from the major metropolis at the Nagpur through airplanes and then flown back to respective city with respective mails. The most recent effort made the government, in this direction is introducing the Multi Modal international cargo hub and industrial center named as MIHAN.

MIHAN is set to boost development of Nagpur region and will attract international companies and investors to invest in the project. The economy of Nagpur was revitalized by the inception of MIHAN with big players like Boeing, Infosys, TCS, Mahindra etc setting up their firms and offices. This has created employment opportunity to the youth of Nagpur. Nagpur always has national level educational institutions but the job opportunities always remains insignificant leading to migration of highly skilled youth to other cities. MIHAN provides a relevant option for employment to the youth within Nagpur.

The upgradation of Nagpur railway station in the lines of international standards and conversion of Ajni railway station into terminus has been initiated. Samruddhi Mahamarg will strengthen the connectivity of Nagpur with Mumbai, the economic capital of the country. Also, entry of premier national level institutes such as AIIMS, IIM, IIIT, NLU, and NIPER adds up the educational profile of the city.

Nagpur is a home for successful start-ups under diverse areas such as Healthtechs (e.g. YourPhysio, ErlySign,), Edtechs (e.g. Techquadra Soft, MenuLao, Lockene), Software-Datas & Hardware-IoTs (e.g. COJAG, AOTOM Technology, SMM growth, Tsecond Generation), Ecommerce & Retails (e.g. Sthenic Technologies, Logrow Technologies). The development of Nagpur is planned well but the government must anticipate the demand and need of the growing Nagpur city with appropriate planning, policy and implementation well in advance.

7.6 References

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Chapter 8
Recommendations

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8.0 Recommendations

8.1 Chapter 1: Ambient Air Quality

Based on the AAQ status of the city, the following specific recommendations to control air pollution in the city can be prioritized.

1. It is observed that particulate matter, specifically PM is a pollutant of concern, the control and management policies need to be oriented towards mitigate PM pollution in the city.
2. Ambient air quality monitoring stations operated by MPCB and CPCB under SAMP and NAMP programmes have been increased with respect to the number of stations. There is a need to maintain them properly to provide consistent and reliable data. A transparent auditing practice is required for these stations.
3. Previous ESR of Nagpur (ESR, 2022-23) showed the Gridded emission inventory of Nagpur city. This can be updated on yearly bases if activities are varying over the period of time. The information on the ongoing polluting activities need to be updated regularly in a pre-defined format. This includes, updating of number of new construction activity, closing of completed construction activity, number of dead bodies in crematoria, new hotels, restaurants etc. For arriving at Nagpur specific emission factors, sampling of road dust is necessary considering the city road's transition from unpaved to paved, potentially lowering the emission burden from road dust re-suspension.
4. As mentioned in previous ESR (2022-23), one of the major issues in the city that needs attention, is construction debris. Dust emissions from tall building construction are one of the major challenges that must be addressed. Residual construction material left outside the construction site, on the roads, is a nuisance and a health risk. It is recommended that no such material be stored outside to reduce the amount of road dust re-suspension. With appropriate safety precautions, the material can be stored within the plot area. Regardless of the size of the site or plot, it is possible to prevent the exposure to particulate pollution from residential construction operations by firmly encircling the area with green netting up to the top of the constructed area, or other sheets/tarpaulin to prevent pollution from dispersing. NMC will issue a SOP for building construction with the above measures.
5. The city's road network is changing from flexible to stiff pavement, so it is necessary to assess the silt load from the various routes. This will display the real emission load resulting

from the re-suspension of road dust. It is suggested that CSIR-NEERI will carry out study for silt load of Nagpur roads and estimate the road dust re-suspension.

6. Traffic congestion due to parking of cars on both sides of the road in residential neighbourhoods has become a big menace in the city. Many areas are witnessing the narrowing down of the roads due to car parking on the space near the houses. The residents themselves get exposed to the micro-pollutants released due to vehicle halts. Appropriate policies need to be implemented to reduce the pollution-induced because of the vehicular traffic halts due to on-street parking.
7. Open burning occurs in local and residential areas even though it is prohibited. Residents must observe appropriate guidance on solid waste management. In numerous locations, especially during the morning, at some places authorized workers and /or sanitary personnel assigned to tidy internal lanes and streets sweep the streets, create a pile of trash and leaves, which they then publicly burn. Open burning is not a good practise from environment point of view and NMC should take strict action to stop such practises.
8. The solid waste department of NMC should issue a SOP for the respective zones mentioning the day and time for collection of garden waste. This will reduce the burning of garden waste in respective zones.
9. It is important to understand the air pollution contribution from the nearby areas and also the regional contribution. The air-shed of the area needs to be identified to account for the emissions sources present in the area.

8.2 Chapter 2: Climate Change

The study suggests that Nagpur is steadily heading towards a warmer and irregular rainfall climate. To mitigate this, it is critical to identify areas of concern and take both adaptive and mitigative actions. From the report, we can identify four major areas of concern.

1. **Rising temperature:** The increasing average temperatures and more frequent heatwaves pose significant risks to public health, particularly for vulnerable populations such as the elderly and children. The demand for cooling energy also substantially burdens the city's energy infrastructure.

2. **Water resource management:** Erratic rainfall patterns and prolonged dry spells threaten the sustainability of water resources. The fluctuation in water availability affects both urban water supply and agricultural productivity, leading to potential conflicts over water use.
3. **Public health impacts:** Higher temperatures and extreme weather events contribute to various health issues, including heat-related illnesses, respiratory problems, and vector-borne diseases. The urban poor, who often lack adequate housing and healthcare access, are particularly at risk.
4. **Infrastructure Vulnerability:** The city's infrastructure, including roads, buildings, and power lines, is increasingly vulnerable to extreme weather events. Heavy rains can cause flooding and waterlogging, while heatwaves can damage roads and strain power grids.

The present study on the climate variability of Nagpur city for over 50 years (1970-2019) indicates that climate-related changes are happening in the town, and its impacts are being felt in terms of extreme weather events, energy consumption, and food/water security issues. This section will delineate some action points that can be taken to understand further the impact of climate change on various city-wide sectors and provide specific recommendations.

Actions	Areas of Actions	Details
Mitigation	Urban Greening	• Expanding green spaces, including parks, urban forests, and green roofs, can help mitigate the urban heat island effect. Trees and vegetation provide shade, improve air quality, and reduce surface temperatures.
	Water Conservation	• Implementing rainwater harvesting systems and promoting water-efficient practices are crucial for sustainable water management. Urban water bodies should be maintained and restored to enhance groundwater recharge and provide cooling effects.
	Energy Efficiency	• Promoting energy-efficient buildings and appliances can reduce energy consumption and lower greenhouse gas emissions. Incentives for using renewable energy sources, such as solar panels and wind turbines, should be

		provided to encourage their adoption. • Developing smart grid technologies can improve energy distribution efficiency and facilitate the integration of renewable energy sources.
	Use of Renewable Energy	• Encouraging renewable energy sources like solar panels and wind turbines can reduce dependence on fossil fuels and lower greenhouse gas emissions. • Promoting the adoption of electric vehicles can reduce vehicular emissions and improve urban air quality. Infrastructure for EV charging stations should be developed to support this transition. • Centralized energy systems — with large power plants and infrastructure connected over long distances — are more vulnerable to climate change. So decentralized energy systems, policy for block or neighbourhood level solar energy plants for energy generation and supply
Adaptation	Use of Green Urban Infrastructure	• Greening mass transit systems like heat-proofing buses and greening stops • Green roofs are specially engineered roofing systems designed to have plants and vegetation growing on their surface. With green roofing, rainwater flow is slowed, and the roof absorbs some of it. This then decreases stormwater runoff and pollution into drainage systems as the vegetated surfaces provide a degree of rainwater retention, attenuation and treatment. • Using reflective materials for roofs and walls can reduce heat absorption and lower indoor temperatures, improving comfort and reducing energy demand for cooling.
	Stormwater Management	• Use of advanced drainage systems like bioswales. Implementing advanced urban drainage systems can help manage stormwater and prevent flooding during heavy rains.

		These systems should be designed to accommodate future changes in rainfall patterns. • Porous surfacing like pavements. The non-porous surface creates bottlenecks, leading to flooding. Using permeable surfaces like porous asphalt, pervious concrete, porous turf, and open-jointed blocks can help manage stormwater and indirectly recharge groundwater.
	New scale of development	• New Urbanism: Building/Street/Block, Neighborhood and Town/City • Building and street design can respond to climate change, e.g., raising foundations or designing to accommodate flooding. On the block scale, pocket neighbourhoods may use social connection as a form of resilience • Neighbourhood-wise programmes for climate change adaptation with the involvement of the local populace

8.3 Chapter 3: Green Open Spaces and Biodiversity

There have been studies related to the assessment of the new 3-30-300 rule, which assessed whether the urban areas meet the rule or not (Browning et al., 2024; Croeser et al., 2024; Li et al., 2024; Ling, 2022; Nieuwenhuijsen et al., 2022). However, no study has attempted to quantify or apply the necessary modifications to comply with the requirement.

1. Understanding 3-30-300 context in cities can help urban planners to understand the key disparities across different zones of the city that could lead to demand-supply gap. Hence, it is important that NMC understands the concerns to identify green gaps that can be suitably filled by plantation cum restoration activities.
2. Garden Department of NMC should also focus on increasing tree diversity by ensuring plantation native species that can adapt to local climate change and also considering the climate uncertainty are more climate proof for future.
3. Improvement of green space amenities by understanding the spatio-temporal spread of UGS in the city to improve visitation among the people.

4. Improve accessibility: Create new green spaces in South Nagpur to ensure that all residents have a UGS within 300 meters of their homes.
5. Improving maintenance: NMC should dedicate resources to regularly maintain the existing parks and green spaces, making them more usable and visitor-friendly.
6. Policy reform: Incorporating the 3-30-300 rule into the urban planning policies can ensure that future developments prioritize green space.
7. Community engagement: Foster community involvement in collaboration with NMC in managing and preserving local green spaces through awareness programs and collaborative projects by active involvement of schools, colleges, government and private organisations.
8. NMC needs to takeaction to review and improve avenue plantations along with regular maintenance in different zones and wards of Nagpur which lack sufficient green spaces and accordingly specific budget allocation has to be made.
9. New high-rise buildings should compulsorily ensure greening initiatives along with rooftop and vertical greening to improve sustainability.

8.4 Chapter 4: Noise Environment

The high levels of non-compliance across multiple zones suggest that existing noise control policies may not be effectively implemented. To address this,

1. Local authorities must prioritize the development of a comprehensive noise management strategy
2. Strategies such as better monitoring, stricter enforcement of noise laws, and public awareness campaigns should be employed to curb the noise pollution.
3. Noise control measures, such as sound barriers, zoning regulations, and the restriction of noise-producing activities in sensitive areas, could help reduce noise levels in key areas of the city.

8.5 Chapter 5: Solid Waste

NMC has undertaken commendable steps in improving solid waste management (SWM) across the city, including door-to-door collection, zone-wise allocation of collection agencies, and efforts to promote waste segregation and composting. Building on this strong foundation, the following recommendations aim to reinforce and scale up these initiatives for greater effectiveness and long-term sustainability:

1. **Enhance source segregation and community participation**: NMC has already rolled out waste segregation at the household level, yet mixed waste continues to reach collection points. These efforts need reinforcement, especially in zones with high instances of non-segregation. Continued public education campaigns, with active involvement of schools, RWAs, and self-help groups, should be promoted to build a culture of civic responsibility and environmental stewardship.
2. **Modernize collection infrastructure and vehicles:** The replacement of outdated waste collection vehicles with fuel-efficient, GPS-enabled compactors has improved efficiency. Expanding this system to all wards and introducing more collection points and trolleys in congested neighbourhoods will ensure better coverage. Establishing well-equipped transfer stations will streamline the waste movement and reduce the load on landfill sites.
3. **Strengthen segregated collection and monitoring systems:** To ensure the effectiveness of door-to-door waste collection, training programs for sanitation workers should be continued and scaled. Introducing a monitoring and feedback system—including incentives for compliant households and penalties for non-segregation—can further improve compliance.
4. **Promote decentralized and community composting:** While NMC has initiated composting for bulk generators, enforcement of Solid Waste Management Rules, 2016 needs to be strengthened. Composting at source should be made mandatory for all generators producing over 100 kg/day of waste. Compost should be promoted for use in public gardens, green belts, and urban farming initiatives.
5. **Expand plastic and metal recycling:** Plastic and metal recycling must be prioritized by forming structured partnerships with registered recyclers. Decentralized sorting hubs should be introduced in commercial areas to collect and segregate high-value recyclables. Promotion of Extended Producer Responsibility (EPR) and incentives for recycled product use should be actively pursued to drive a circular economy.
6. **Institutionalize E-waste management:** Currently, E-waste collection in Nagpur is largely informal. While Suritex Ltd. and select NGOs conduct periodic E-waste collection drives and awareness campaigns, a formal system under NMC is urgently needed. Establishment of authorized collection centers, public-private partnerships, and citywide awareness initiatives

must be prioritized in line with the E-Waste Management Rules, 2016 to prevent unscientific disposal and safeguard public health.

7. **Establish data-driven recycling monitoring:** NMC should maintain a centralized digital registry of recycling units and conduct regular audits to track performance, compliance, and material flow. A robust data monitoring system will improve transparency and help in policy refinement.
8. **Adopt smart and digital waste management Tools:** NMC has already introduced technology into its waste management practices. Expanding this to include IoT-based smart bins, route optimization for collection vehicles, and real-time dashboards will help monitor progress and identify bottlenecks quickly. Integrating waste tracking features in the MyNagpur app will further enhance responsiveness and citizen engagement.
9. **Strengthen public grievance redressal systems:** The MyNagpur app should be enhanced to include features such as waste pickup alerts, reporting missed collections, and tracking complaint resolution. Communication campaigns through WhatsApp and community radio can ensure better outreach, especially among senior citizens and lower-income groups.
10. **Foster research, innovation, and capacity building:** Collaboration with research institutions, academic bodies, and start-ups can foster innovation in composting, bio-methanation, waste-to-energy (WTE), and landfill mining. Supporting pilot-scale demonstrations and facilitating knowledge-sharing platforms can accelerate the adoption of sustainable solutions.

Implementing a combination of these strategies can significantly improve Nagpur's MSW management system. A holistic, integrated approach, involving active participation from the community, municipal bodies, private sector, and academic institutions, is essential to ensure long-term environmental and public health benefits.

8.6 Chapter 6: Water Environment

1. The dumping of garbage around lakes i.e., Sonegaon, Binaki, and Pandharbodi was a sign of human activity and loitering of stray animals and animal faecal matter near the lakeside may be the main and direct source of fecal contamination.
2. Though the physico-chemical analysis of lake water samples indicated an overall reduction in COD, BOD, and other nutrient (nitrogen and phosporous) concentrations as compared to

2022-2023, this may be sufficient to support the growth of floating aquatic plants and weeds. The lakes showing signs of eutrophication, particularly Naik, Binaki, and Police Line Takli, require immediate attention. Strategies such as nutrient reduction, algal control, and oxygenation measures (e.g., aeration systems) should be implemented to restore ecological balance. In lakes like Ambazari, where localized weed growth was observed, periodic cleaning and the removal of excess vegetation are necessary to prevent further nutrient accumulation and degradation.

3. Strict monitoring and regulation of wastewater discharge and runoff into the lakes are critical. Implementing sewage treatment facilities and minimizing inflow of pollutants can help reduce nutrient input.
4. Strategies of desilting, desludging, boundary/retaining/edge wall, etc applied by NMC for rejuvenation and development of Gandhisagar, Lendi, and Police line Takli lakes, also need to be adopted for remaining lakes. Anthropogenic activities can be curtailed by building of boundary walls and appointing security guard for restricting the public entry near the banks of the lakes.
5. To improve the ecological health of these lakes and mitigate pollution levels continuous monitoring of water quality and biodiversity in all lakes is crucial for detecting early signs of pollution or eutrophication. Implementing a long-term ecological management plan will help prevent future deterioration.
6. The public must be educated on the importance of these lakes, often referred to as the city’s "blue lungs," for cooling the urban heat island projects will be vital in protecting these water bodies from further pollution.
7. Though the COD and nutrient levels were lower in samples from all the three rivers Nag, Pilli and Pora over the previous year, river water was found to be unsuitable for drinking, outdoor bathing, irrigation due to increase in COD, and phosphate-P load and the presence of fecal coliforms, as the rivers flowed through the city.
8. There is a need for reducing/preventing activities which are responsible for increased pollution load in the rivers, such as; dumping of waste by local vendors of fruits-vegetables, meat and other products, wandering of stray animals in the river or disposal of dead animals along the river bank.

The flow of drains carrying untreated and uncategorized sewage/waste from the city's commercial and industrial areas may be directly channelized to STPs to prevent their entry into the river thereby reducing the pollution from anthropogenic sources and the bacterial contamination. The river pollution abatement plan being carried out by NMC under the AMRUT-II scheme should be aggressively implemented for rejuvenating the rivers.

9. The groundwater level (below ground level) in the study area shows a lot of variation in the range of 2 m BGL (NGW -3) to 8.80 m BGL (NGW -8). In the post-monsoon (December 2024) season, the groundwater level was very shallow at following locations namely, NGW-3 (2 m BGL), NGW-7 (2.62 m BGL), and NGW-6 (3 m BGL).
10. The rainwater harvesting structures can be implemented at suitable locations where the groundwater levels.

a) in the range of 3 to 6 m BGL and a declining trend of 0.10 to 0.20 m/year.

b) deeper than 9.00 m BGL and declining trend in excess of 0.40 m/year or

c) deeper than 12.00 m BGL, but with a long term rising trend of 0.2 to 0.4 m/year.

d) in the range of 5.0 to 10.0 m with declining trends during the report period.

11. Normally, areas having deeper water levels and declining water level trends are given higher priority identification of area feasible for artificial recharge. Areas having shallow water levels / rising water level trends are not considered for inclusion in artificial recharge plan (CGWB, 2007).
12. NMC can implement roof top rain water harvesting recharge structures in public parks and play grounds where the pre-monsoon water level is more than 3 m.