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Babarmahal, Kathmandu

Status of Air Quality in Nepal
Annual Report, 2023

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Foreword

It is my honor to present the "Status of Air Quality in Nepal: Annual Report 2023" where data generated from ten air quality monitoring stations scattered in four different provinces of Nepal from 1st January 2023, to 31st December 2023, has been analyzed. It is our diligent effort to provide valuable insights into the state of the air quality we are breathing.

The Department of Environment (DoEnv) is committed to creating a sustainable and conducive environment for all. This report is the step towards the journey of building a better environment. Though we have 27 real-time air quality monitoring stations throughout the country, this report analyzed data from only ten such stations. We hope to include all 27 stations in the upcoming annual reports.

The problem of air pollution has grown in recent years, necessitating precise and accurate data for its management and control initiatives. We believe this analysis helps policymakers and stakeholders with the information needed to make meaningful changes in air quality management and enhance livelihood.

We are grateful to Dr. Govinda Prasad Sharma, Secretary, Ministry of Forests and Environment for his inspiration to prepare this report. We are very thankful to members of the air quality data analysis committee for their constructive suggestions in preparing the report. We acknowledge the ICIMOD team and experts from different institutions for their critical comments and suggestions. Special thanks go to the report preparation team for their hard work in preparing the report and all technical and non-technical staff of DoEnv for their support in the report preparation.

DoEnv strongly believe in cooperation, coordination and collaboration with all stakeholders. So we welcome suggestions, comments and recommendations from all stakeholders to create livable environment for all.

Bhupal Baral
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31 May, 2024

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Message

Air pollution stands as a significant threat to human health globally, causing approximately 7 million premature deaths annually. In Nepal, the issue is more acute, contributing to 42,100 deaths yearly and reducing the average life expectancy of Nepali citizens by 4.1 years. Constantly, cities of Nepal are ranked among the most polluted in terms of air quality. Considering those issues, ensuring clean air is not just an aspiration but a necessity for the quality life and the sustainability of the ecosystems. To tackle the challenge of air pollution effectively, it is crucial to understand the current state of air quality. Therefore, Department of Environment has installed 27 Air Quality Monitoring Stations (AQMS) across the nation. The data gathered from these monitoring stations is utilized for the compilation of reports on air quality.

The report on "Status of Air Quality in Nepal: Annual Report 2023", was developed using real-time air quality data on particulate matter ($PM_{2.5}$, PM_{10} and TSP) obtained from AQMS from 1st January 2023 to 31st December 2023 which serves as a comprehensive examination of current state of atmospheric conditions. The present report provides the snap shot of highlights on air quality of ten different AQMS for the year 2023. It assesses the dynamics of air pollutants and changing air quality index in hourly, daily and seasonal basis. This study report's primary purpose is to add another dimension to our understanding of air pollution, and additionally serves as a repository of knowledge that can act as a catalyst for policy interventions in obtaining clean air.

This report is interdisciplinary in nature and brings together an unprecedented number of experts including academic researchers in air pollution, climate related services provider and ICIMOD engaged in related work. The valuable contributions of these individuals and organizations have been integral to the development of this report, and I extend my sincere gratitude to all those who have contributed to this endeavor.

Finally, I urge all actors, including government agencies, private sector, industrial partners, developmental projects, business community and civil society to take urgent action to halt air pollution and restore clean air. Also, we welcome your feedback on this report and also encourage you to reach out our website www.pollution.gov.np for the report.

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31 May, 2024

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We are equally grateful to the air quality data analysis committee members Dr. Ramesh Prasad Sapkota, Associate Professor, Central Department of Environment Science, Tribhuvan University; Mr. Keshab Raj Joshi, Environment Inspector, Ministry of Forests and Environment; Mr. Sangha Ratna Shakya, Meteorologist, Department of Hydrology and Meteorology; and Mr. Suresh Pokhrel, Senior Research Associate, ICIMOD, for their constructive comments and recommendations. Special support in R coding from Dr. Ramesh Prasad Sapkota and in Python and R coding from Mr. Suresh Pokhrel had simplified data downloading and analysis.

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We are thankful to everyone who directly and indirectly contributed their time and expertise to this report. Your contributions have been invaluable and are deeply appreciated.

EXECUTIVE SUMMARY

In this report “Status of Air Quality in Nepal: Annual Report 2023”, data of $PM_{2.5}$, PM_{10}, and TSP were analyzed for ten different air quality monitoring stations (AQMS) of Nepal from January 1, 2023, to December 31, 2023. These ten stations represent four out of the seven provinces of Nepal namely Koshi, Bagmati, Karnali, and Sudurpaschim. The CSV-formatted data were downloaded from central server located at the National Information Technology Centre (NITC), Singha Durbar, Kathmandu using Python, and the dataset was further analyzed using a combination of basic R programming techniques and specialized R packages such as openair and ggplot2. Hourly averages were computed from the minute-level data, ensuring a data availability threshold of 80% for each hour. This criterion meant that at least 80% of the data within an hour needed to be present to contribute to the hourly average calculation. Subsequently, daily averages were derived from these hourly averages, maintaining the same 80% data availability threshold. Similarly, the monthly averages were calculated from daily average data, but for only those months with data availability equal to or greater than 50%. The seasonal average is the mean of daily average data of that season. However, the seasonal average is calculated for only those seasons where monthly averages are available for at least 50% months in that season. HYSPLIT, Google Earth Engine, QGIS were used for satellite data analysis. Aerosol Optical Depth (AOD), CO and NO_2 analyses were conducted using these satellite data.

The Dhankuta AQMS, representing the Koshi Province has 222 days of valid measurement, with mean of daily average concentrations of $PM_{2.5}$, PM_{10}, and TSP at 32.7 µg m^{-3}, 39.9 µg m^{-3}, and 71.3 µg m^{-3}, respectively. Among the eight months with data availability (excluding September to December), February emerged as the most polluted month for both $PM_{2.5}$ and PM_{10}. Similarly, the winter season recorded the highest seasonal average for these parameters. Additionally, 86 days exceeded the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$, just 1 day exceeded that standard for TSP, and no days exceeded standard for PM_{10}.

This report analyzes data from six AQMS of Bagmati Province namely-Bhaisepati, Hetauda, Khumaltar, Pulchwok, Ratnapark, Shankhapark, and TU Kirtipur. The Bhaisepati AQMS has 317 days of valid measurement, with the mean of daily average of $PM_{2.5}$, PM_{10}, and TSP were calculated to be 38.9 µg m^{-3}, 69.9 µg m^{-3} and 173.5 µg m^{-3} respectively. Out of 11 months (except March) with data, April was found to be the most polluted month for $PM_{2.5}$ and PM_{10} and the pre-monsoon season has the highest seasonal average for these parameters. Similarly, 130 days exceeded the NAAQS for $PM_{2.5}$ while no of days exceeding that standard for PM_{10}, and TSP was 61 and 91 respectively.

The Hetauda AQMS has 321 days of valid measurement where the mean of daily average of $PM_{2.5}$, PM_{10}, and TSP were calculated to be 21.6 µg m^{-3}, 32.4 µg m^{-3}, and 65.6 µg m^{-3} respectively. Out of the 11 months with data (excluding May), December was determined to be the most polluted month for $PM_{2.5}$ and June for PM_{10} and TSP. Similarly, the winter season was the most polluted

season for $PM_{2.5}$ and PM_{10}. The number of days exceeding the NAAQS was found to be 33, 1, and 16 for $PM_{2.5}$, PM_{10}, and TSP, respectively.

The Khumaltar AQMS has 355 days of valid measurement with the mean daily average of $PM_{2.5}$ and PM_{10} was found to be 46.0 μg m^{-3} and, 88.3 μg m^{-3} respectively. April was the most polluted month and the winter season was the most polluted season for analyzed parameters. In comparison to NAAQS, 115 days for PM_{10} and 189 days for $PM_{2.5}$ have exceeded the guideline value.

The Pulchowk AQMS has 179 days of valid measurement where the mean of daily average of $PM_{2.5}$, PM_{10}, and TSP were calculated to be 23.1 μg m^{-3}, 28.1 μg m^{-3}, and 39.5 μg m^{-3}, respectively. For this station, monthly averages were determined for just six months, and seasonal averages were calculated for only two seasons (monsoon and post-monsoon). Out of these two seasons, the post-monsoon season was the most polluted for analyzed parameters. The number of days exceeding the NAAQS was found to be 32 days for $PM_{2.5}$ while none of days exceeded the NAAQS for PM_{10} and TSP.

The Ratnapark AQMS has 325 days of valid measurement where the mean daily average of $PM_{2.5}$, PM_{10}, and TSP were calculated to be 39.2 μg m^{-3}, 52.6 μg m^{-3}, and 66.4 μg m^{-3} respectively. Out of 12 months, April was found to be the most polluted month for analyzed parameters and similar a similar condition was observed during the pre-monsoon season. The number of days exceeding the NAAQS was found to be 128 for $PM_{2.5}$, 39 for PM_{10}, and 1 for TSP.

The Shankhapark AQMS has 283 days of valid measurement, with the mean daily average of $PM_{2.5}$, PM_{10}, and TSP were calculated to be 50.3 μg m^{-3}, 78.7 μg m^{-3}, and 163.6 μg m^{-3}, respectively. For this station, monthly averages were calculated for just nine months (excluding June, July, and September), and seasonal averages were determined for only three seasons (excluding the monsoon). The number of days exceeding the NAAQS was found to be 184, 32 and 58 days for $PM_{2.5}$, PM_{10}, and TSP, respectively.

The TU Kirtipur AQMS has 254 days of valid measurement where the mean of daily average of $PM_{2.5}$, PM_{10}, and TSP were calculated to be 37.0 μg m^{-3}, 63.4 μg m^{-3}, and 112.0 μg m^{-3} respectively. For this station, monthly average of nine months (except January, February and October) was determined. Out of the three seasons (except winter) for which seasonal averages were calculated, the pre-monsoon season have the highest seasonal average for analyzed parameters. The number of days exceeding the NAAQS was found to be 100, 34, and 21 days for $PM_{2.5}$, PM_{10}, and TSP, respectively.

This report analyzes data from only one station of Karnali Province- Rara AQMS. The Rara AQMS has 327 days of valid measurement, with the mean daily average of $PM_{2.5}$, PM_{10}, and TSP found to be 10.5 μg m^{-3}, 14.5 μg m^{-3}, and 23.7 μg m^{-3} respectively. Out of 12 months, April was found to be the most polluted month for analyzed parameters and pre-monsoon season was the most polluted season for analyzed parameters. The number of days exceeding the NAAQS was found to be 3 days for $PM_{2.5}$ and none of the days exceeded NAAQS for PM_{10} and TSP.

This report analyzes data from only one station of Sudurpaschim Province – Mahendranagar AQMS. This station has 203 days of valid measurement where the mean of daily average of $PM_{2.5}$, PM_{10}, and, TSP was found to be 32.2 μg m^{-3}, 44.4 μg m^{-3}, and 68.0 μg m^{-3}, respectively. Out of seven months with valid data, December was found to be the most polluted month for analyzed parameters. Among the two seasons (Monsoon and Post-Monsoon) for which seasonal averages were calculated, post-monsoon season was most polluted season for these parameters. The number of days exceeding the NAAQS was found to be 68 days for $PM_{2.5}$ and none of the days exceeded NAAQS for PM_{10} and TSP.

The annual pollution rose diagram of most of the stations shows the high level of $PM_{2.5}$ seems to be associated with wind from the southwest direction. Highly polluted months for various stations also seem to be linked with south westerly wind and monsoon months have major wind from the eastern sides. The HYSPLIT model analysis indicates that in Kathmandu Valley, during months of high PM pollution (January and April), wind direction seems to be primarily originated from the west or south direction. Satellite images and satellite based products show spatial extent of urban and regional pollution. From various satellite products, the high level of air pollution in March and April can be linked to the fire events. The high level of NO_2 is a good indicator of high economic activities. The annual mean tropospheric NO_2 level was high in some places where economic activities are relatively higher. The assessment of AOD from Aqua and Terra MODIS satellites indicates a higher concentration of $PM_{2.5}$ in the Terai region, notably in the central and eastern parts. AOD data also reveal regional levels of air pollution and allow us to assess pollution trends. Noticeable decreases in annual average AOD were observed in the Lumbini and Sudurpaschim Province between 2021 to 2023 while there was a visible increase in average AOD in the eastern part of the country between 2022 to 2023.

Air pollution arises from a multitude of sources, local to regional influences. Pollutants can travel extensively from their origins, impacting areas far from where they originated. These sources encompass a range of activities, including construction, industrial processes, forest fires, biomass burning, among others. Despite various efforts to address pollution, the compliance level for $PM_{2.5}$ remained poor in 2023.

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Acronyms and Abbreviations

$\mu g\ m^{-3}$	Microgram per cubic meter
µm	Micrometer
AOD	Aerosol optical depth
AQI	Air Quality Index
AQMS	Air Quality Monitoring Station
CO	Carbon-monoxide
CSV	Comma-separated values
DoEnv	Department of Environment
EDM	Environmental Dust Monitor
EPA	Environmental Protection Act
EPR	Environmental Protection Regulation
GoN	Government of Nepal
ICIMOD	International Centre for Integrated Mountain Development
L/min	Liter per minute
m	Meter
MAIAC	Multi-Angle Implementation of Atmospheric Correction
masl	Meter above sea level
MODIS	Moderate Resolution Imaging Spectroradiometer
NAAQS	National Ambient Air Quality Standards
NITC	National Information Technology Centre
NO_2	Nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
NO_x	Oxides of Nitrogen
O_3	Ozone
PM_1	Particulate matter having aerodynamic diameter less than 1 micron
PM_{10}	Particulate matter having aerodynamic diameter less than 10 micron
$PM_{2.5}$	Particulate matter having aerodynamic diameter less than 2.5 micron
SD	Standard Deviation
SDC	Senior Divisional Chemist
SO_2	Sulphur dioxide
TSP	Total Suspended Particulate
TU	Tribhuvan University
VIIRS	Visible Infrared Imaging Radiometer Suite
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The constitution of Nepal has ensured rights to live in clean and healthy environment as the fundamental right of every citizen. To implement this basic right, Government of Nepal has legislated Environment Protection Act (EPA) in 2019 and Environment Protection Regulation (EPR) in 2020, which focus on development that balance environment. National Environment Policy 2019 and 15^{th} Periodic development plan (2019-2023) also highlight urgent need to reduction pollution from various sectors. Additionally, Government of Nepal has endorsed National Ambient Air Quality Standards (NAAQS), 2012 to ensure better air for all. Department of Environment (DoEnv) under Ministry of Forests and Environment is a leading government agency to monitor the status of air quality based on NAAQS 2012 in Nepal.

Air pollution locally is a global problem as it knows no physical boundaries. According to World Health Organization (WHO), seven million people die prematurely every year globally due to air pollution. $PM_{2.5}$ is associated with a 3.7% rise in mortality per 10 μg m^{-3} rise in $PM_{2.5}$ (7 days' geometric lag effect); CO is associated with a 0.15-0.7% rise in mortality per 10 μg m^{-3} rise in CO level (same day effect)(Karki et al., 2015). Particulate matter emitted after biomass burning is very toxic to human health (Suriyawong et al., 2023). Not only does air pollution harm people's health, but it also has an impact on their wellbeing as well as financial security (Maharjan et al., 2022).

Air quality dependent to various natural as well as anthropogenic factors (Ren & Matsumoto, 2020). Quality of ambient air is influenced by the spatial as well as temporal variance of emissions and the dynamics of dispersion of pollutants. Hence measurement of air we breath is necessary as the quality of air keeps on changing. Real time air quality monitoring of ambient air pollution helps to assess concentration of pollutants on the basis of available standards and guidelines. Air quality measurement it the keystone of air quality management. By 2022, Department of Environment under Ministry of Forests and Environment has established 27 real time air quality monitoring stations (AQMS) throughout seven Provinces of Nepal.

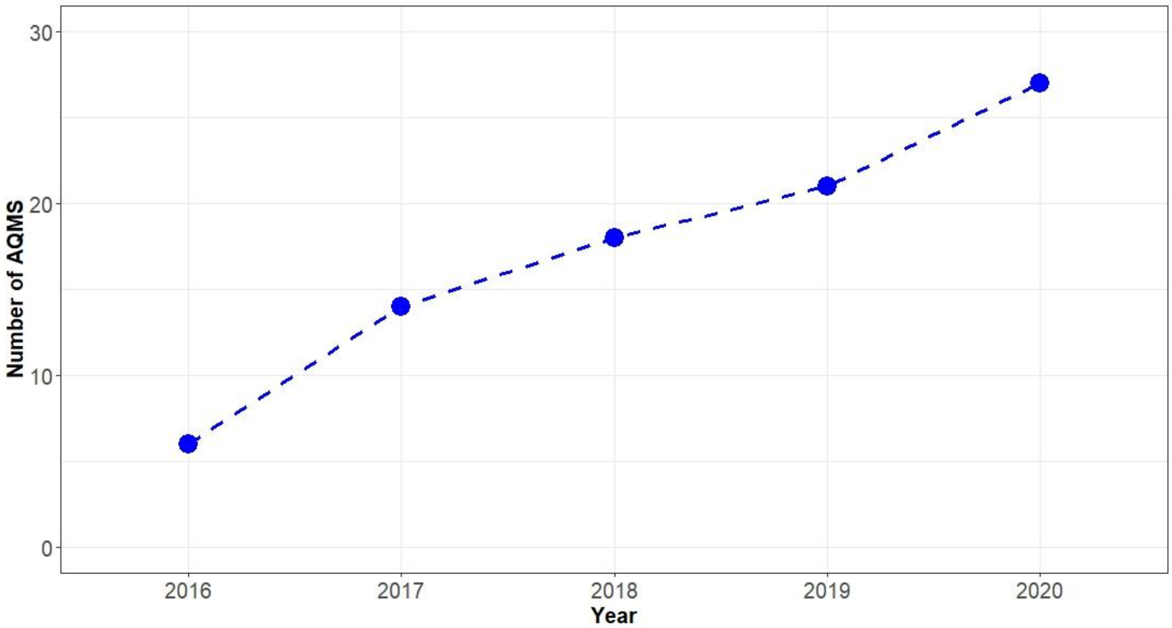


Figure 1: Establishment of real time AQMS with years

The progressive increase in these AQMS since its first establishment is shown in Figure 1. The installed AQMS represents air quality of both urban as well as pastoral environments. All 27 stations (Figure 2) measure PM_1, $PM_{2.5}$, PM_{10} and TSP. AQMS at Ratnapark, Dhulikhel, and Lumbini measure CO, SO_2, NOx, and O_3, and AQMS at Sauraha and Pulchowk measure O_3 in addition to particulate matter.

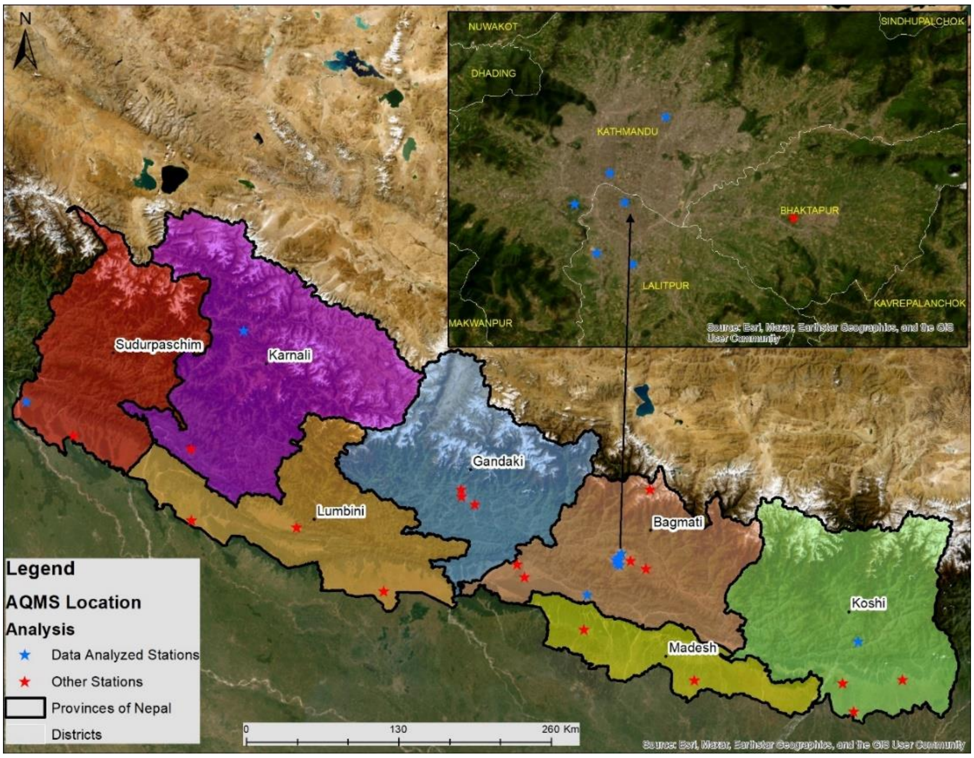


Figure 2: Distribution of AQMS in Nepal

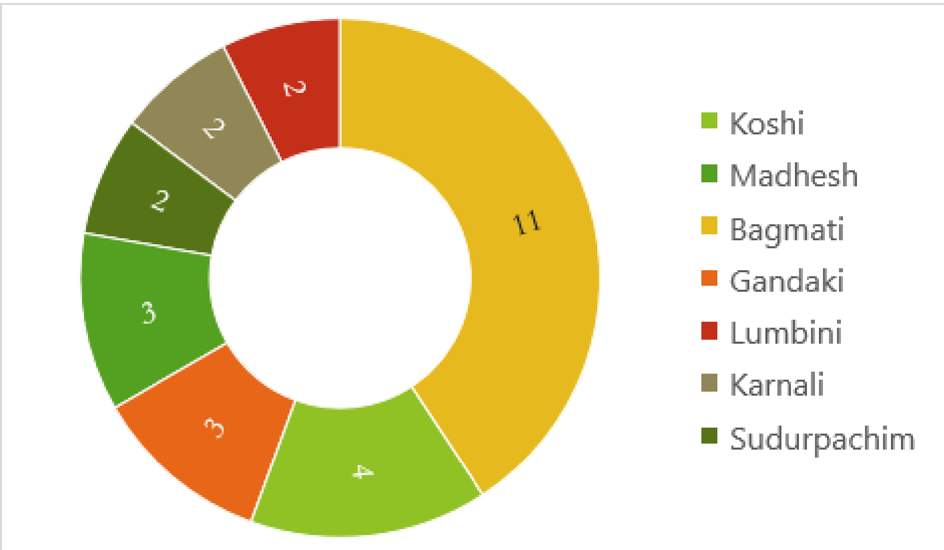


Figure 3: Provincial distribution of AQMS

In this report- "Status of Air Quality in Nepal; Annual Report 2023", air quality data from only 10 AQMS (Table 1) were analyzed. Data from the remaining AQMS were excluded due to limited data availability.

Table 1: List of AQMS considered in this study for the analysis of particulate matter

SN	Name of Air Quality Monitoring Station	Province Name
1	Dhankuta	Koshi
2	Bhaisepati	Bagmati
3	Hetauda	Bagmati
4	Khumaltar	Bagmati
5	Pulchowk	Bagmati
6	Ratnapark	Bagmati
7	Shankapark	Bagmati
8	Tribhuvan University, Kritipur	Bagmati
9	Rara	Karnali
10	Mahendranagar	Sudurpaschim

1.2 OBJECTIVES

The overall objective of this report is to present the air quality status based on the data collected from the 10 AQMS distributed throughout the country for the year 2023.

The specific objectives are:

- To analyze $PM_{2.5}$, PM_{10} and the Total Suspended Particulate (TSP) data generated from the stations listed on table 1.
- To analyze the compliance status of $PM_{2.5}$, PM_{10} and TSP that are generated from the stations listed on table 1.
- To assess the regional air quality over Nepal using models and satellite data.

1.3 ANALYZED AIR QUALITY PARAMETERS

The following parameters were analyzed in this report.

- $PM_{2.5}$: Includes particulate matter with an aerodynamic diameter less than or equal to 2.5 µm and is important in terms of health impacts.
- PM_{10}: Includes particulate matter with an aerodynamic diameter less than or equal to 10 µm.
- TSP: Includes all solid and liquid droplet particulate present in the air.

1.4 COMMITTEE FOR GIVING DIRECTION AND GUIDANCE

A committee was formed that made several decisions and provide directions and guidance for data analysis and report preparation (Annex 1). Similarly, experts representing different institutions were also invited to contribute and provide feedback on the report prepared (Annex 2).

1.4.1 DATA AVERAGING

Daily data is calculated by averaging the minute data, which is done only when the availability of minute data is equal to or more than 80%. Similarly, monthly average is calculated from daily average only for those months where daily data availability is equal to or more than 50%. The seasonal average was calculated from the daily average only if the monthly average of at least two months of that season was available for winter, pre-monsoon, and monsoon seasons which were at least one month for the post-monsoon season.

The following months are considered for different seasons for seasonal data analysis:

- Winter season: - December of the preceding year, January and February
- Pre-monsoon season: - March, April and May
- Monsoon season: - June, July, August and September
- Post-monsoon season: - October and November

1.5 METHODS OF AIR QUALITY MONITORING AND DATA ANALYSIS

The Environmental Dust Monitor (Grimm EDM 180+) is used for ambient dust measurement. It uses laser light-scattering technology for particle count. Particles contained in the sample air are classified by size and number in the measuring chamber using scattered light measurement. During the process, a small measuring volume is exposed to a laser with downstream optics. For environmental measurements, the concentration of solids is so low that statistically there is only one particle in the sensing volume. The scattered light emitted by each particle is captured by a second set of optics with an opening angle and a scattering angle, deflected to a detector by a mirror, and the light intensity is measured. The particle size is proportional to the intensity of the reflected beam of light. The count rate is derived from the number of particles and the volume flow rate. When the particle diameter and density are known; the particle mass can be derived from the particle count based on the assumption of a spherical shape.

A semiconductor laser serves as the light source in the EDM 180 spectrometer. To minimize the influence of the refraction indexes, the 90° scattered light is guided to a receiver diode by a mirror with an opening angle of approximately 120°. After amplification, the electrical signal of the diode is classified in 31 sized channels according to the signal strength. This makes it possible to determine the grain size distribution of the particles. The sample flow rate of this instrument is 1.2 L/min.

1.5.1 DATA ACQUISITION

This EDM instrument has the highest measurement resolution of six seconds, but we are taking measurements every minute. The data is logged as one-minute averaged data into the data logger installed at each AQMS which stored data in CSV format. This data logger system then transmits the data to the central server located at the National Information Technology Centre (NITC), Singha Durbar, Kathmandu from where the point (per minute) data were downloaded.

1.5.2 DATA CLEANING

For data analysis, per minute data obtained from the central server were first cleaned. For this purpose, threshold value of 1500 µg m^{-3} was set for all three parameters ($PM_{2.5}$, PM_{10} and TSP). All repeated data, along with negative and null data were removed for further analysis.

1.5.3 DATA ANALYSIS METHOD AND PLOTS/GRAPHS USED IN THE REPORT

Python programming was used to automate the download of large datasets from the central server while different packages of R programming (Team, 2024) such as open air (Carslaw, 2019) was used for data analysis. HYSPLIT, Google Earth Engine, and QGIS were used for satellite data analysis.

The **histogram,** monthly **box-plot** and hourly box-plot are made from the hourly data. The **pollution rose** diagram illustrates the frequency distribution of wind direction correlated with a chosen pollutant. In this report, the pollution rose diagram of hourly concentration of $PM_{2.5}$ for few chosen stations were prepared.

Calendar plot was constructed to visualize the daily Air Quality Index (AQI) based on $PM_{2.5}$ data only. The break point as shown in Table 2 were used for the calculation.

Table 2 : Air Quality Index break points for $PM_{2.5}$

$PM_{2.5}$ (µg m^{-3}) 24-hours average	AQI	AQI Category
0.0-20.0	0-50	Good
20.0-40.0	51-100	Moderate
41.0-60.0	101-150	Unhealthy for sensitive group
61.0-160.0	151-200	Unhealthy
161.0-260.0	201-300	Very unhealthy
261.0-360.0	301-400	Hazardous
>360.0	401-500	Very hazardous

The AQI group and their respective colour codes is as follows.

Each category corresponds to a different level of health concern. The seven levels of health concern can be described as:

- "Good" AQI is 0 to 50. Air quality is considered satisfactory, and air pollution poses little or no risk.
- "Moderate" AQI is 51 to 100. Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people.
- "Unhealthy for Sensitive Groups" AQI is 101 to 150. Although general public is not likely to be affected at this AQI ranges, people with lung disease, older adults and children are at a greater risk from exposure to ozone, whereas persons with heart and lung disease, older adults and children are at greater risk from the presence of particles in the air.
- "Unhealthy" AQI is 151 to 200. Everyone may begin to experience some adverse health effects, and members of the sensitive groups may experience more serious effects.
- "Very Unhealthy" AQI is 201 to 300. This would trigger a health alert signifying that everyone may experience more serious health effects.
- "Hazardous" AQI is 301 to 400. This would trigger a health warnings of emergency conditions. The entire population is more likely to be affected.
- "Very Hazardous" AQI is 401 to 500. This would trigger health warnings of emergency conditions. The entire population is more likely to be affected.

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Oranges
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 400	Hazardous	Maroon
401 to 500	Very Hazardous	Maroon

1.5.4 SATELLITE DATA ANALYSIS

The image of forest fire event was taken from NASA Firms (Fire information for resource management system) website. NASA FIRMS uses satellite observations from the MODIS and VIIRS instruments to detect active fires and thermal anomalies and deliver this information in near real-time to decision makers through email alerts, analysis ready data, online maps and web services. Similarly, true colour satellite imagery was also downloaded from Firms website. NASA Worldview Snapshots interface generates a true colour or derived data product satellite imagery subset at a spatial resolution of 250 meters. Subsets can be generated from the data record of daily corrected reflectance satellite imagery for listed satellite/sensor assets. Subsets are dynamically generated with the NASA Worldview Snapshots application using source imagery provided by the Global Imagery Browse Services (GIBS).

The Data from the ESA Copernicus TROPOMI instrument onboard the Sentinel 5p satellite was used. The CO and NO_2 data of various time periods were downloaded from the Copernicus Sentinel-5P Mapping Portal. Then further analysis and visualization was done using QGIS.

Analysis of AOD

The MCD19A2 V6.1 data product is used for analysis of Aerosol Optical Depth (AOD). This is a MODIS Terra and Aqua combined Multi-angle Implementation of Atmospheric Correction (MAIAC) Land AOD gridded Level 2 product produced daily at 1 km resolution. Here AOD over land retrieved in the MODIS Green band (0.55 µm) is selected for the AOD analysis. Mean AOD for different periods is calculated using the Google Earth engine. From Google Earth engine geo Tiff files were downloaded and further analysis and visualization were done using QGIS.

1.5.5 NATIONAL AMBIENT AIR QUALITY STANDARDS, 2012 (NAAQS)

The Government of Nepal (GoN) has endorsed National Ambient Air Quality Standards (NAAQS) in 2012. The NAAQS gives maximum concentration for major nine parameters including particulate matter, trace gases, heavy metal and others as shown in the Table 3.

Table 3: National Ambient Air Quality Standards, 2012

SN	Parameters	Units	Averaging time	Maximum concentration
1	$PM_{2.5}$	µg m^{-3}	24-hr	40
2	PM_{10}	µg m^{-3}	24-hr	120
3	TSP	µg m^{-3}	24-hr	230
4	Ozone	µg m^{-3}	8-hr	157
5	Sulphur Dioxide	µg m^{-3}	Annual	50
			24-hr	70
6	Nitrogen Dioxide	µg m^{-3}	Annual	40
			24-hr	80
7	Carbon monoxide	µg m^{-3}	8-hr	10,000
8	Lead	µg m^{-3}	Annual	0.5
9	Benzene	µg m^{-3}	Annual	5

CHAPTER 2: RESULTS

2.1 KOSHI PROVINCE

2.1.1 DHANKUTA AIR QUALITY MONITORING STATION

Dhankuta AQMS was established in 2019 adjacent to the Dhankuta municipality office in Dhankuta district, Koshi Province and represents the urban area. Emissions from vehicles, forest fires in nearby regions and pollutants transported from surrounding regions are the major sources of air pollution in this area.

2.1.1.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.1 µg m^{-3} to 155.3 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 4.

Table 4: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Dhankuta Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.1	9.2	24.0	31.6 ± 25.3	49.9	155.3

Diurnal variation:

The hourly mean of $PM_{2.5}$ gains first peak at 7:00 and second at around 18:00 (Figure 4).

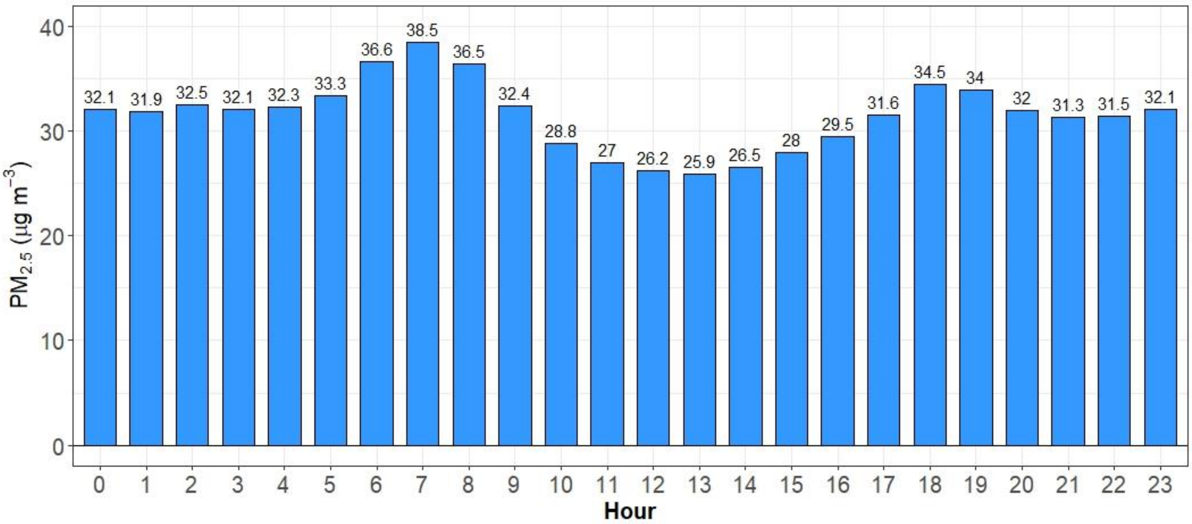


Figure 4: Diurnal variation of $PM_{2.5}$ for Dhankuta Station

Daily average:

The daily average data was available for 222 days. Figure 5 explains the daily trend of $PM_{2.5}$.

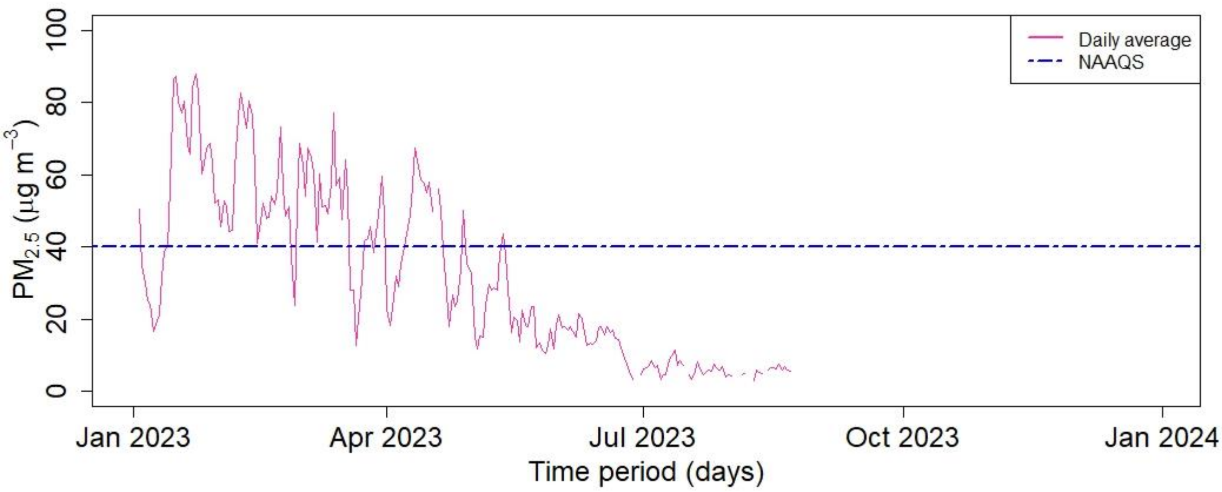


Figure 5: Daily average of $PM_{2.5}$ for Dhankuta Station

Table 5: Summary of daily average of $PM_{2.5}$ (µg m^{-3}) Dhankuta Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
2.9	12.0	26.8	32.7 ± 23.6	51.6	87

Within the available data, the lowest and highest concentration of $PM_{2.5}$ was observed to be 2.9 µg m^{-3} and 87.0 µg m^{-3}.

Monthly average:

Figure 6 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in February (56 µg m^{-3}) and lowest in August (5.6 µg m^{-3}).

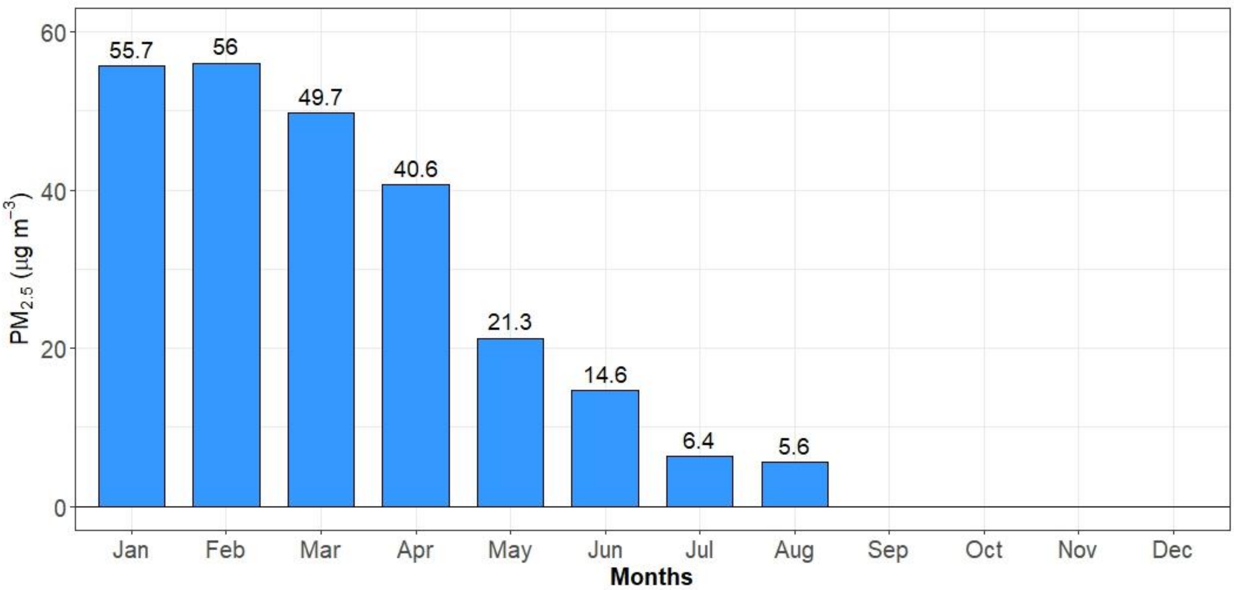


Figure 6: Monthly average of $PM_{2.5}$ for Dhankuta Station

Seasonal average:

Figure 7 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Winter season was observed with the highest seasonal average (51.7 µg m^{-3}), while monsoon showed the lowest seasonal average (9.3 µg m^{-3}).

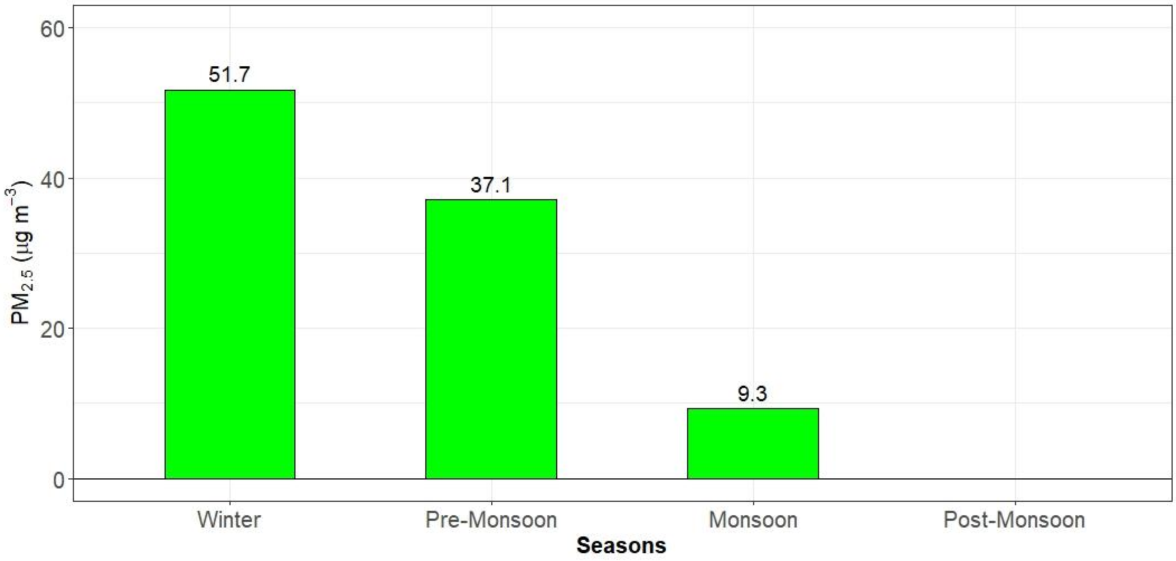


Figure 7: Seasonal average of $PM_{2.5}$ for Dhankuta Station

Compliance status:

Out of the total 222 days of valid measurements, 86 days exceeded the NAAQS (Figure 8). The compliance status is poor during January to March. In January, 20 days out of 29 days with valid measurements exceeded the NAAQS. Similarly, in February 26 days out of 28 days and in March 25 days out of 31 days exceeded the NAAQS. The entire days during June to August meets the NAAQS.

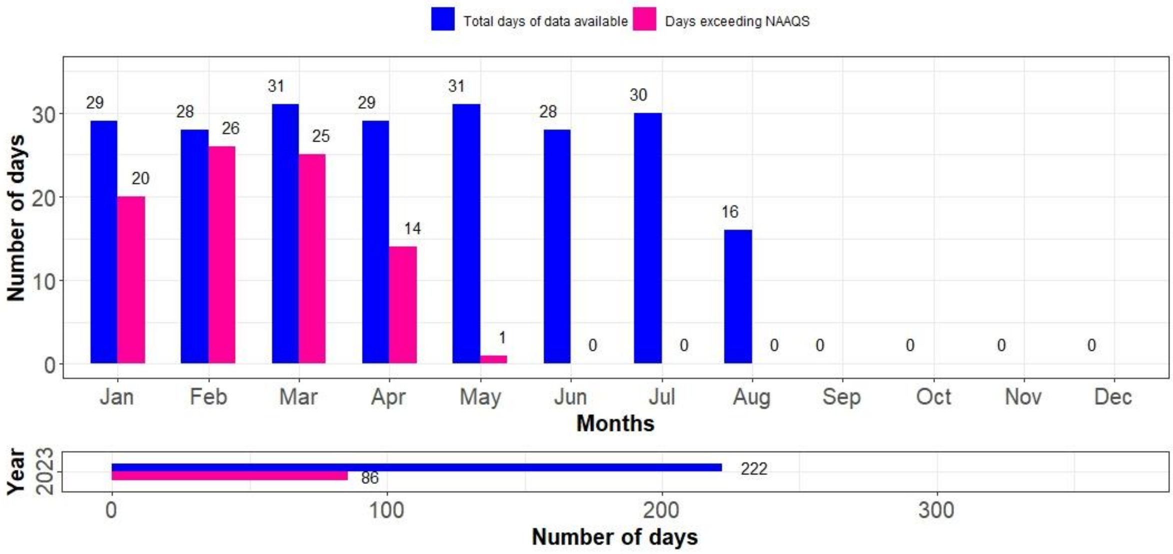


Figure 8: Compliance status of $PM_{2.5}$ for Dhankuta Station

Calendar plot

Calendar plot based only on $PM_{2.5}$ (Figure 9) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during January to April. During June (except for three days), July and August, almost all of the days were with good air quality category.

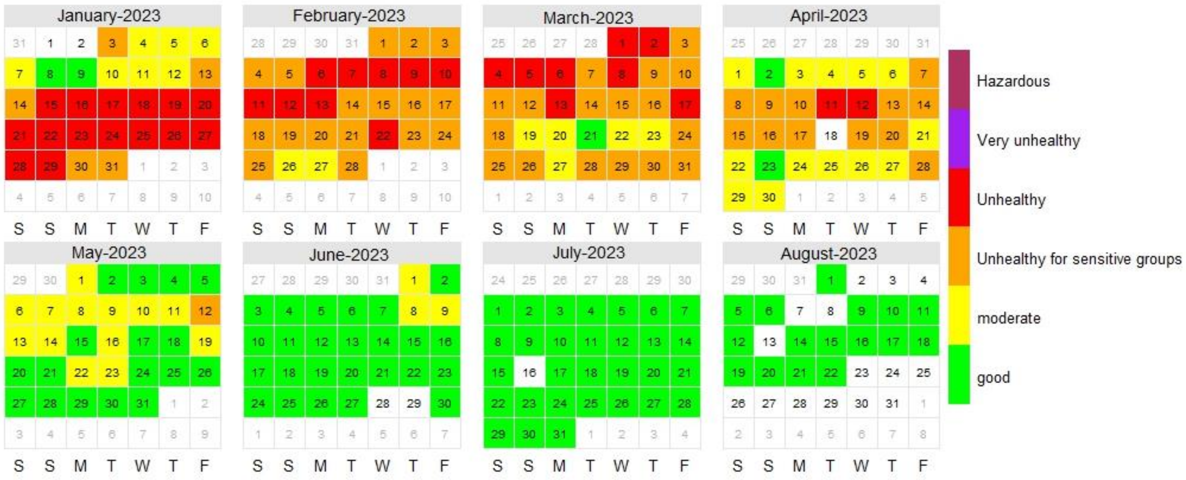


Figure 9: Calendar plot of $PM_{2.5}$ for Dhankuta Station

2.1.1.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.2 µg m^{-3} to 203.9 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 6.

Table 6: Summary of hourly average of PM_{10} (µg m^{-3}) for Dhankuta station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.2	9.9	31.7	38.7 ± 30.4	63.6	203.9

Diurnal variation:

The hourly mean of PM_{10} reaches to its peak at 7:00 and at18:00 (Figure 10).

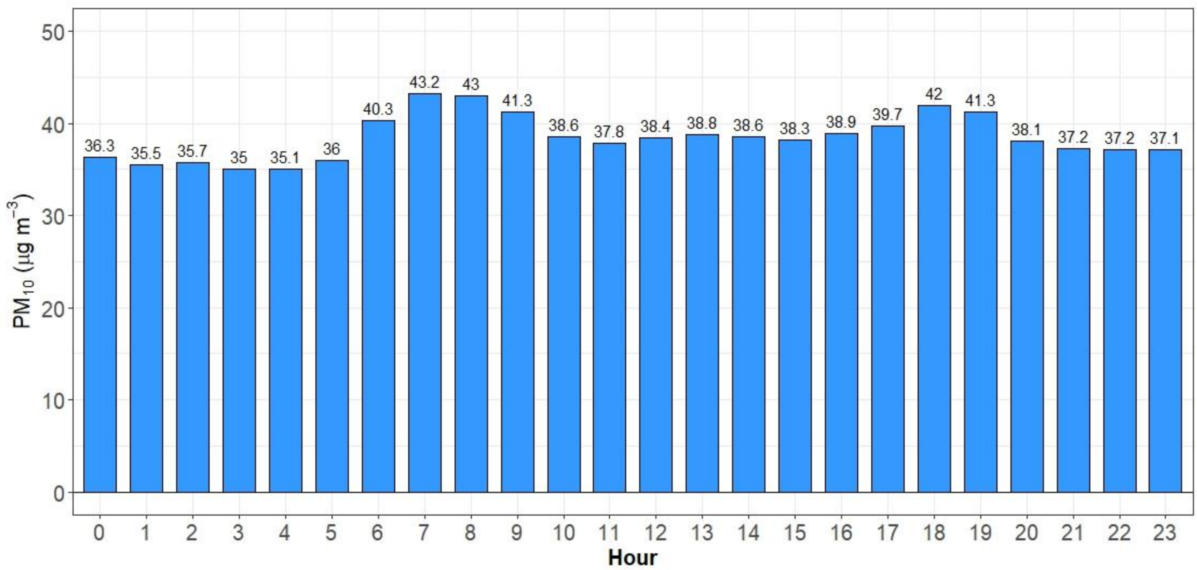


Figure 10: Diurnal variation of PM_{10} for Dhankuta Station

Daily average:

The daily average data was available for 222 days. Figure 11 explains the daily trend of PM_{10} throughout the year.

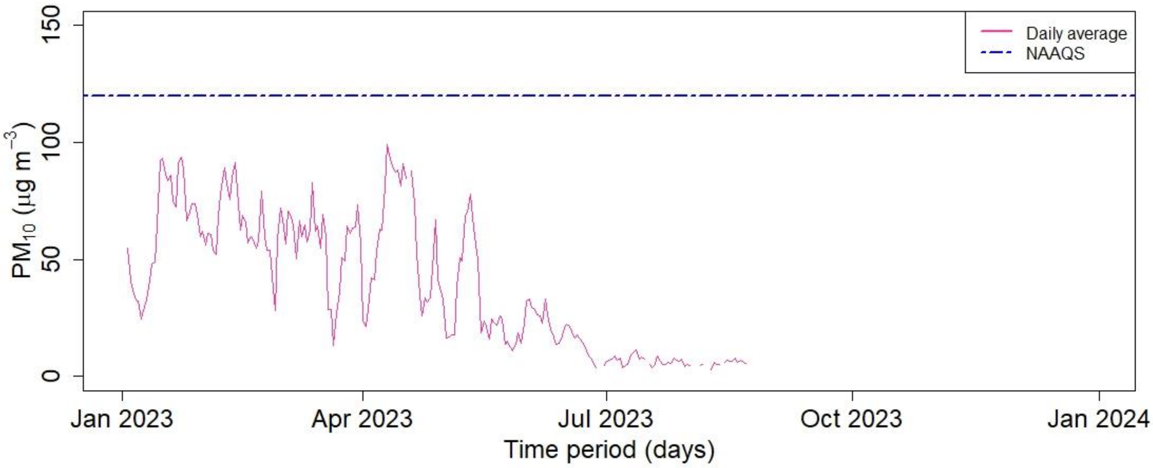


Figure 11: Daily average of PM_{10} for Dhankuta Station

Table 7: Summary of daily average of PM_{10} (µg m^{-3}) for Dhankuta Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
2.9	13.6	33.4	39.9 ± 28.3	63.7	99.1

Within the available data, the lowest and the highest concentration of PM_{10} was found to be 2.9 µg m^{-3} to 99.1 µg m^{-3} (Table 7).

Monthly average:

Figure 12 illustrates the monthly average concentration of PM_{10}. The monthly average of PM_{10} was the highest in February (64.3 µg m^{-3}) and lowest in August (5.7 µg m^{-3}).

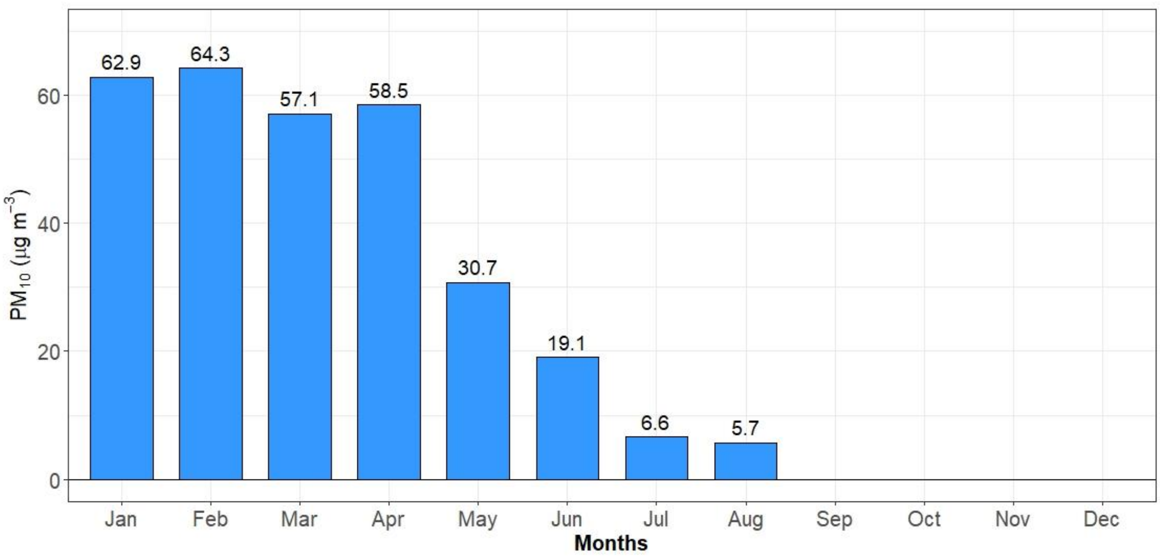


Figure 12: Monthly average of PM_{10} for Dhankuta Station

Seasonal average:

Figure 13 illustrates the seasonal distribution of the concentration of PM_{10}. Winter season was observed with the highest seasonal average (59.3 µg m^{-3}), while monsoon showed the lowest seasonal average (11.1 µg m^{-3}).

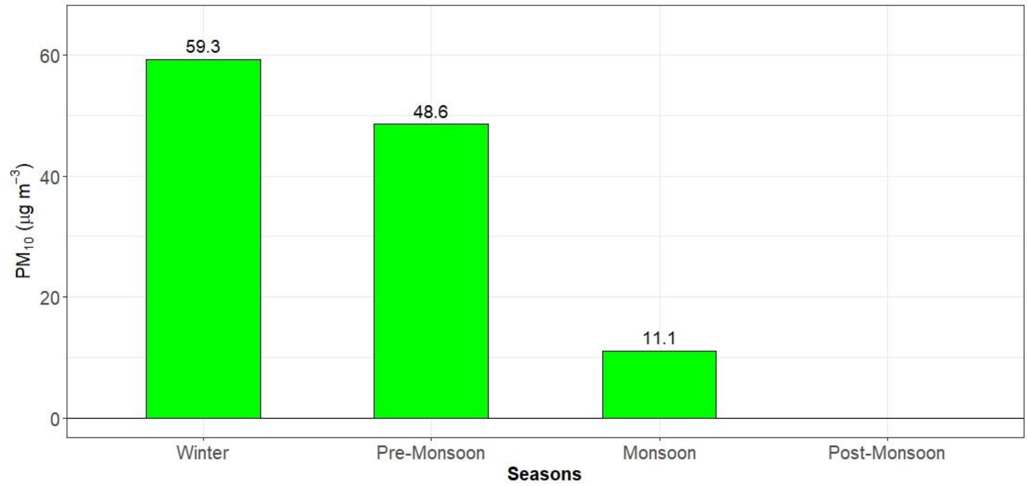


Figure 13: Seasonal average of PM_{10} for Dhankuta Station

Compliance status:

Out of the total 222 days of valid measurements, none of the days exceeded the NAAQS.

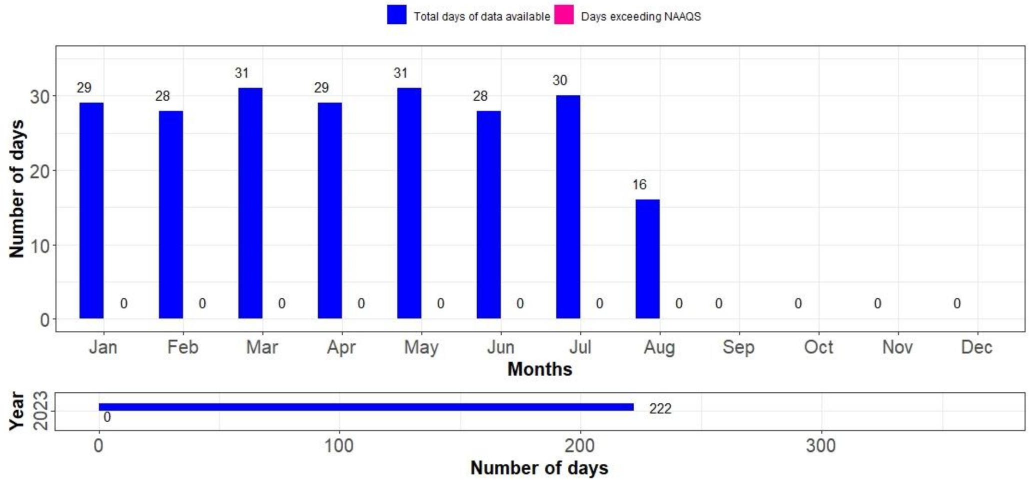


Figure 14: Compliance status of PM_{10} for Dhankuta Station

2.1.1.3 Data analysis for TSP

Hourly average:

The hourly average ranges from 1.2 µg m^{-3} to 876.8 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 8.

Table 8: Summary of hourly average TSP (µg m^{-3}) for Dhankuta Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.2	10.9	48.2	69.0 ± 78.1	96.8	876.8

Diurnal variation:

The hourly mean of TSP progressively increased with time and reached to its peaks at 13:00 which then decreases with time.

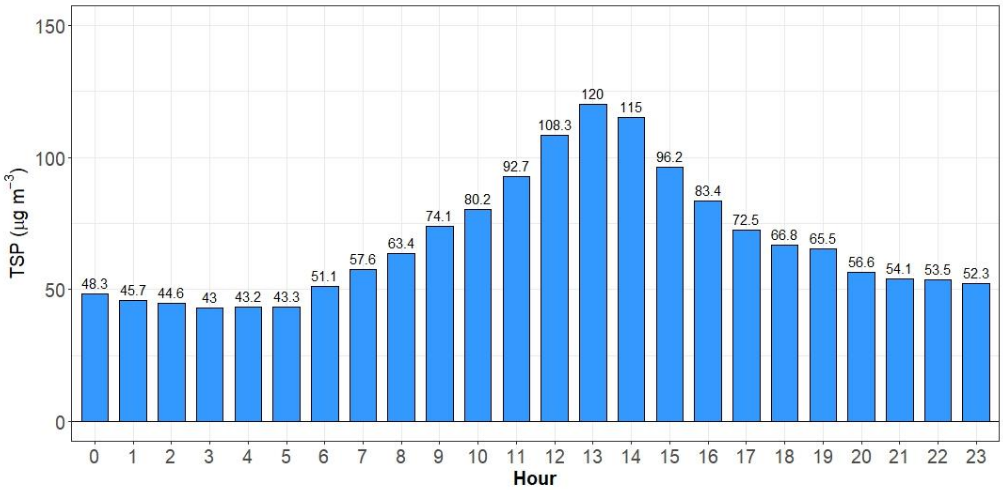


Figure 15: Diurnal variation of TSP for Dhankuta Station

Daily average:

The daily average data was available for 222 days. Figure 16 shows the daily trend of TSP throughout the year.

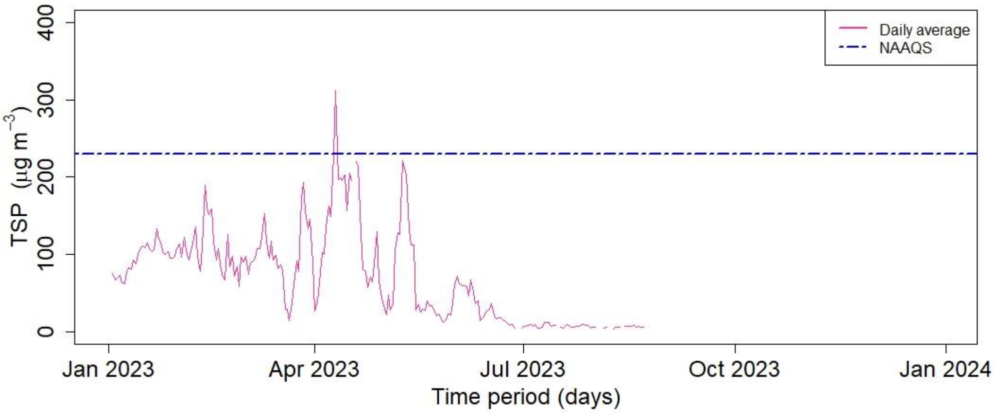


Figure 16: Daily average of TSP for Dhankuta Station

Table 9: Summary of daily average TSP for Dhankuta Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
2.9	15.3	66.7	71.3 ± 59.5	106.6	311.5

Within the available data, the lowest and highest concentration of TSP was found to be 2.9 µg m^{-3} to 311.5 µg m^{-3} (Table 9).

Monthly average:

Figure 17 illustrates the monthly average concentration of TSP. The monthly average of TSP was the highest in April (134.7 µg m^{-3}) and lowest in August (6 µg m^{-3}). The monthly average of TSP for September to December was not available.

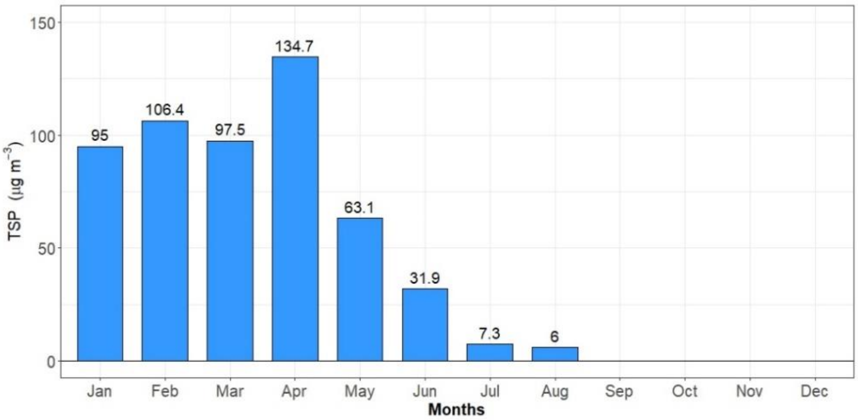


Figure 17: Monthly average of TSP for Dhankuta Station

Seasonal average:

Figure 18 illustrates the seasonal distribution of the concentration of TSP. Pre-monsoon was observed with the highest seasonal average (97.6 µg m^{-3}), while monsoon showed the lowest seasonal average (16.3 µg m^{-3}).

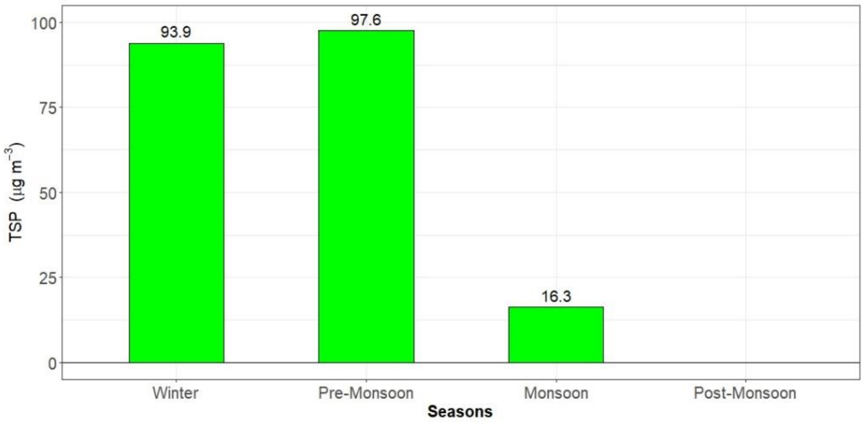


Figure 18: Seasonal average of TSP for Dhankuta Station

Compliance status:

Out of the total 222 days of valid measurements, only one day on April exceeded the NAAQS (Figure 19).

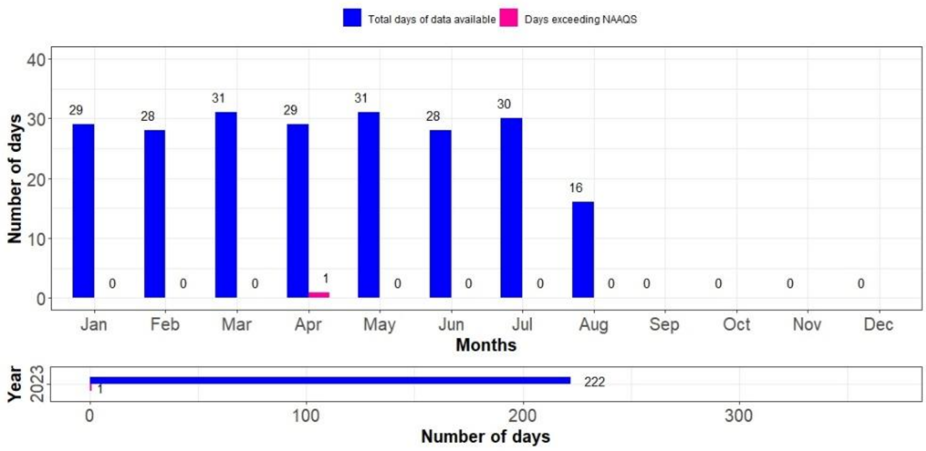


Figure 19: Compliance status of TSP for Dhankuta Station

2.2 BAGMATI PROVINCE

2.2.1 BHAISEPATI AIR QUALITY MONITORING STATION

Bhaisepati AQMS was established in 2017 at Bhaisepati, Lalitpur metropolitan city, Bagmati Province. This station is located in the compound of Bhaisepati residential area office at Lalitpur. This station represents the urban residential area. Emission from vehicles can be considered as major sources of pollution in the area.

2.2.1.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.4 µg m^{-3} to 247.9 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 10.

Table 10: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Bhaisepati Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.4	16.1	30.1	38.8 ± 29.8	53.5	247.9

Diurnal variation:

The hourly mean of $PM_{2.5}$ progressively decreased from 0:00 till 2:00 then increased with time and reached to its peak at 8:00 after that it decreased till 13:00, and again started to rise and peaks at 19:00 (Figure 20).

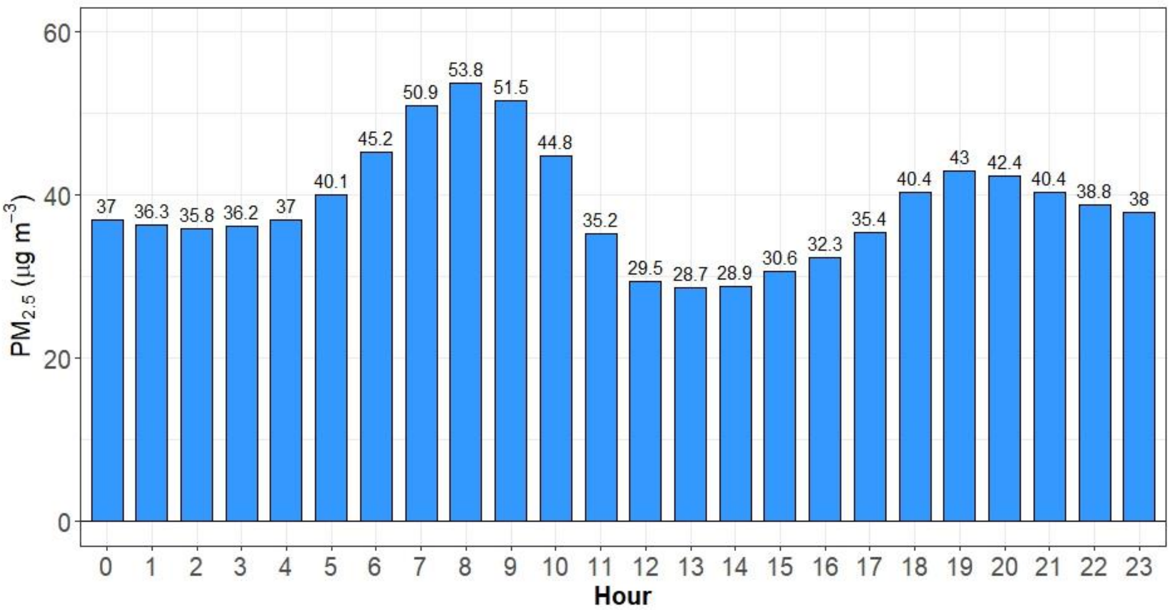


Figure 20: Diurnal variation of $PM_{2.5}$ for Bhaisepati Station

Daily average:

The daily average data was available for 317 days. Figure 21 shows the daily trend of $PM_{2.5}$ throughout the year.

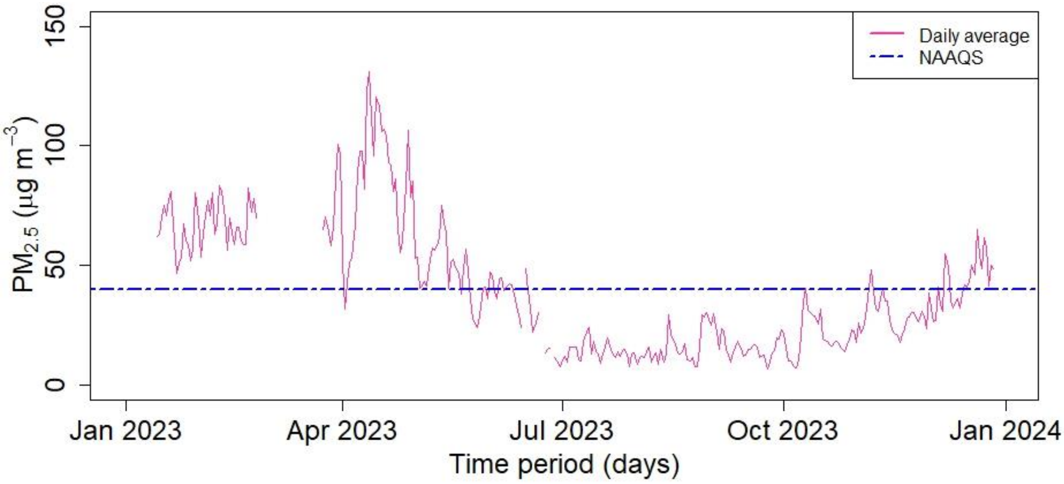


Figure 21: Daily average of $PM_{2.5}$ for Bhaisepati Station

Table 11: Summary of daily average of $PM_{2.5}$ ($\mu g\ m^{-3}$) for Bhaisepati Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
6.7	16.2	31.1	38.9 ± 26.3	56.3	130.9

Within the available data, the lowest and highest concentration of $PM_{2.5}$ were found to be 6.7 $\mu g\ m^{-3}$ to 130.9 $\mu g\ m^{-3}$ respectively (Table 11).

Monthly average:

Figure 22 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in April (85.6 $\mu g\ m^{-3}$) and lowest in July (14.2 $\mu g\ m^{-3}$).

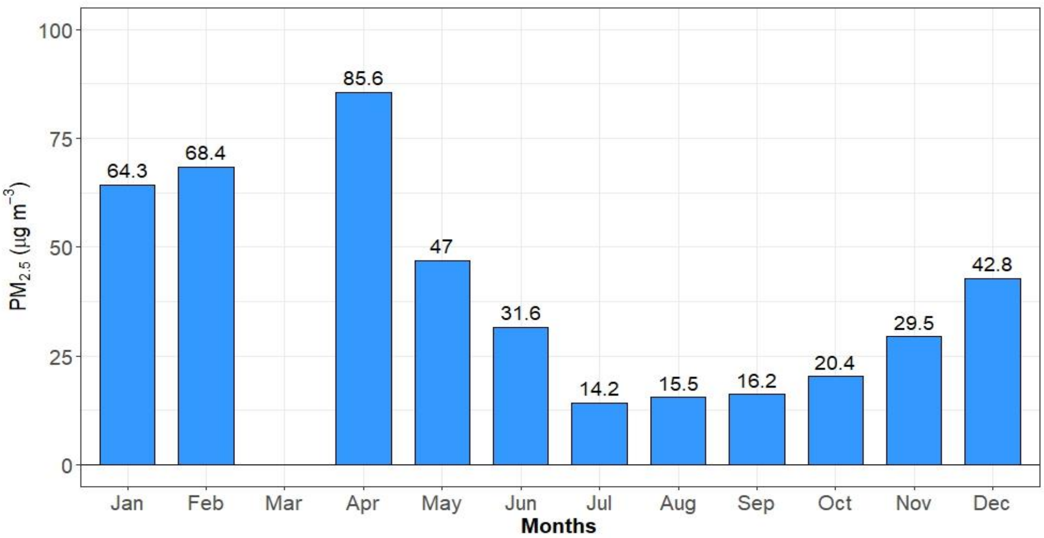


Figure 22: Monthly average of $PM_{2.5}$ for Bhaisepati Station

Seasonal average:

Figure 23 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Pre-monsoon was observed with the highest seasonal average (67.1 $\mu g\ m^{-3}$), while monsoon showed the lowest seasonal average (18.9 $\mu g\ m^{-3}$).

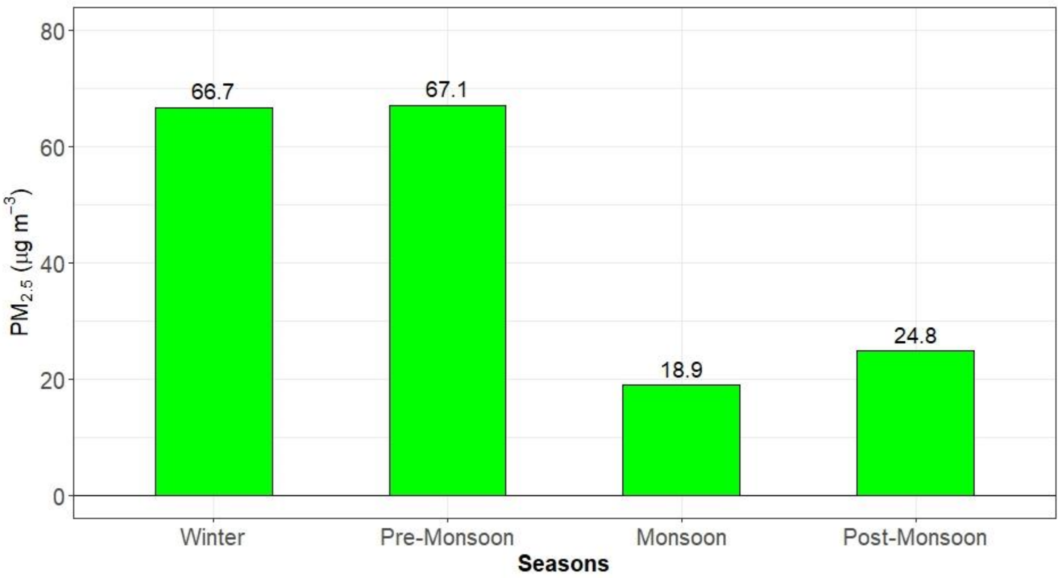


Figure 23: Seasonal average of $PM_{2.5}$ for Bhaisepati Station

Compliance status:

Out of the total 317 days of valid measurements, 130 days exceeded the NAAQS (Figure 24). The compliance status is poor during January to May and December. In January to March total days of valid measurements exceeded the NAAQS. Similarly, in April 29 days out of 30 days, in May 24 days out of 31 days, and in December 16 days out of 27 days exceeded the NAAQS. The entire days during July to September meets the NAAQS.

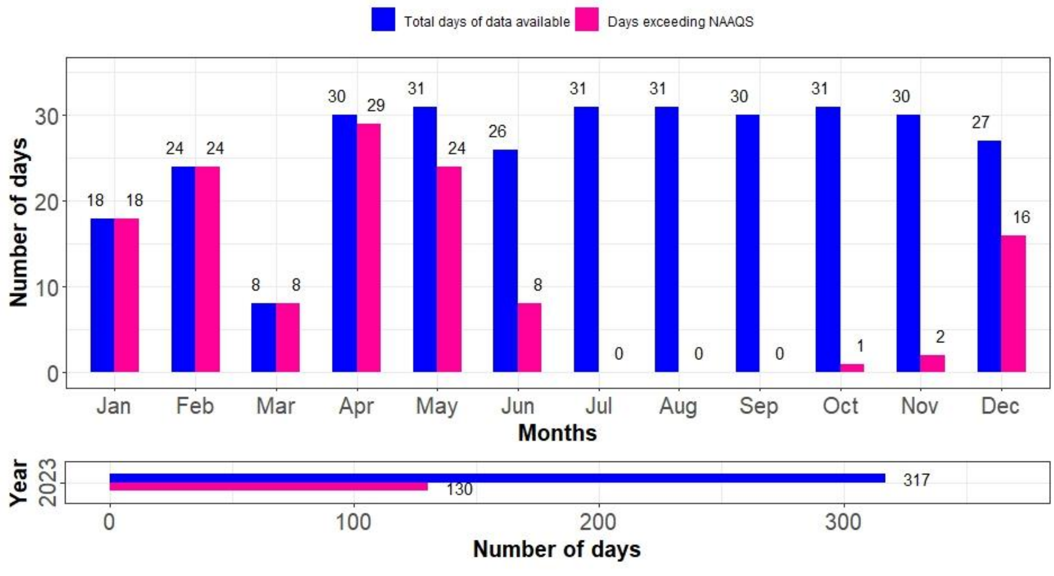


Figure 24: Compliance status of $PM_{2.5}$ for Bhaisepati Station

Calendar plot

Calendar plot based only on $PM_{2.5}$ concentration (Figure 25) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during January, February, March, April, May, and December. During July, August and September, almost all of the days were with good air pollution category.

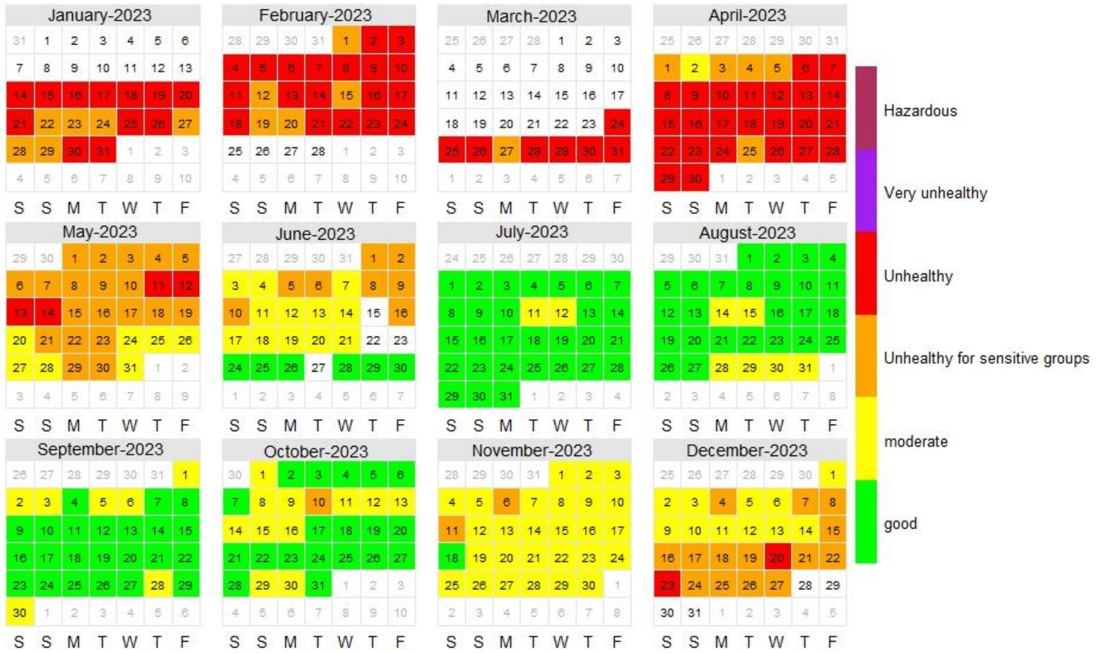


Figure 25: Calendar plot of $PM_{2.5}$ for Bhaisepati Station

2.2.1.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.5 µg m^{-3} to 1015.7 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 12.

Table 12: Summary of hourly average of PM_{10} (µg m^{-3}) for Bhaisepati Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.5	24.7	46.5	69.5 ± 70.6	87.8	1015.7

Diurnal variation:

The hourly mean of PM_{10} progressively decreased from 0:00 till 2:00 then increased with time and reaches to its peak at 9:00 after that it decreased till 11:00, and again starts to rise and peaks at 15:00 (Figure 26).

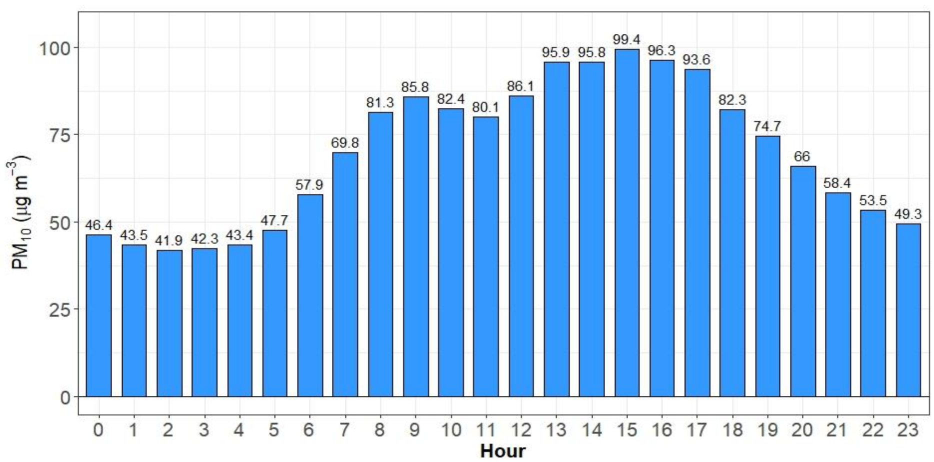


Figure 26: Diurnal variation of PM_{10} for Bhaisepati Station

Daily average:

The daily average data was available for 317 days. Figure 27 explains the daily trend of PM_{10} throughout the year.

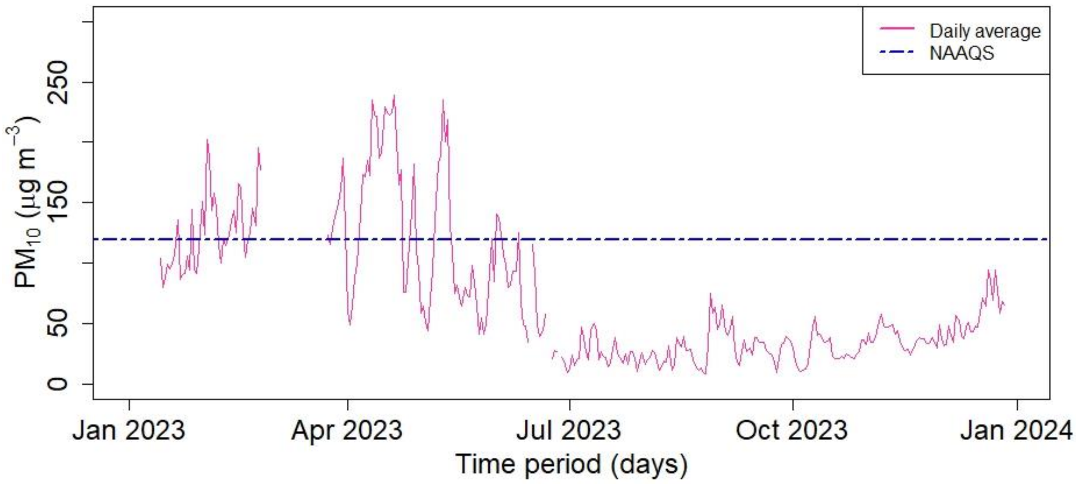


Figure 27: Daily average of PM_{10} for Bhaisepati Station

Table 13: Summary of daily average of PM_{10} ($\mu g\ m^{-3}$) for Bhaisepati Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
9.0	28.3	47.1	69.9 ± 55.7	99.0	239.4

Within the available data, the lowest and the highest concentration of PM_{10} was found to be 9.0 $\mu g\ m^{-3}$ to 239.4 $\mu g\ m^{-3}$ (Table 13).

Monthly average:

Figure 28 illustrates the monthly average concentration of PM_{10}. The monthly average of PM_{10} was the highest in April (157.7 $\mu g\ m^{-3}$) and lowest in July (25.6 $\mu g\ m^{-3}$).

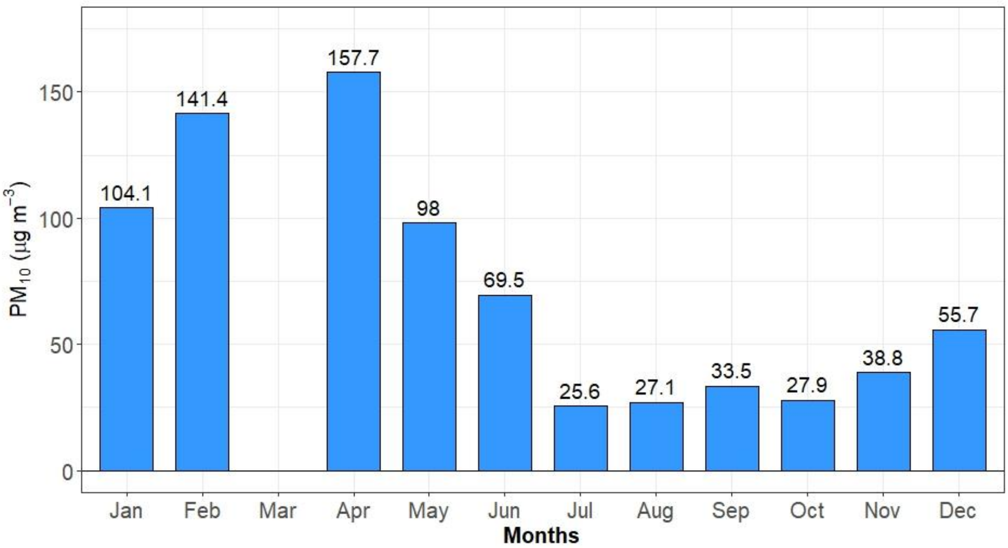


Figure 28: Monthly average of PM_{10} for Bhaisepati Station

Seasonal average:

Figure 29 illustrates the seasonal distribution of the concentration of PM_{10}. Pre-monsoon was observed with the highest seasonal average (129.2 µg m^{-3}), while post-monsoon showed the lowest seasonal average (33.2 µg m^{-3}).

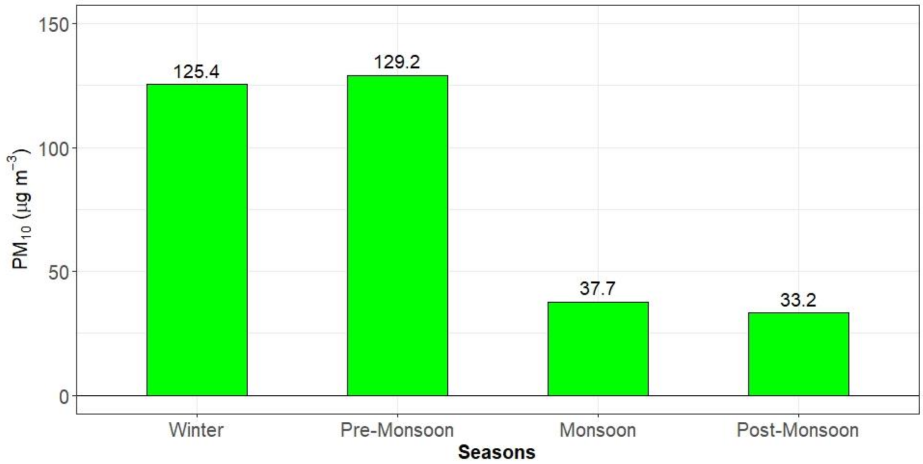


Figure 29: Seasonal average of PM_{10} for Bhaisepati Station

Compliance status:

Out of the total 317 days of valid measurements, 61 days exceeded the NAAQS. The majority days exceeding NAAQS were from January to June as shown in Figure 30.

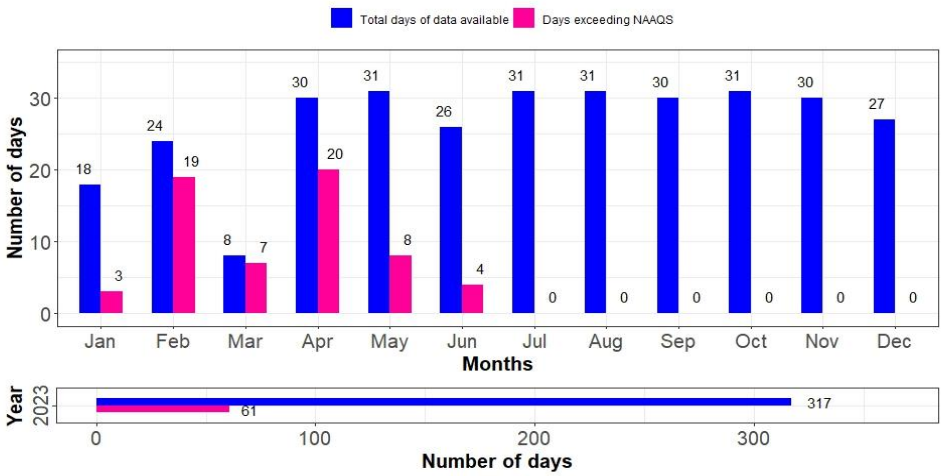


Figure 30: Compliance status of PM_{10} for Bhaisepati Station

2.2.1.3 Data analysis for TSP

Hourly average:

The hourly average ranges from 1.5 µg m^{-3} to 1491.3 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 14.

Table 14: Summary of hourly average of TSP (µg m^{-3}) for Bhaisepati Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.5	30.0	74.1	171.9 ± 230.2	218.1	1491.3

Diurnal variation:

The hourly mean of TSP progressively increases with time and reached to its peaks at 15:00 (Figure 31).

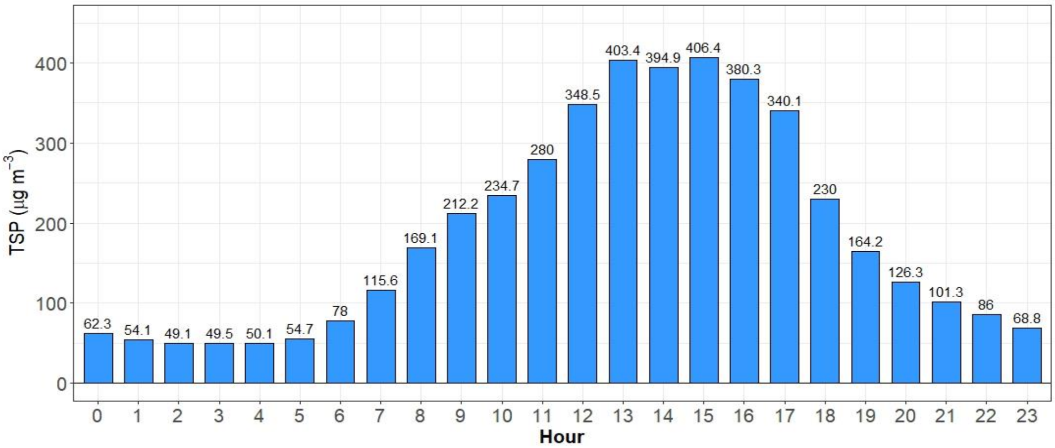


Figure 31: Diurnal variation of TSP for Bhaisepati Station

Daily average:

The daily average data was available only for 317 days. Figure 32 explains the daily trend of TSP throughout the year.

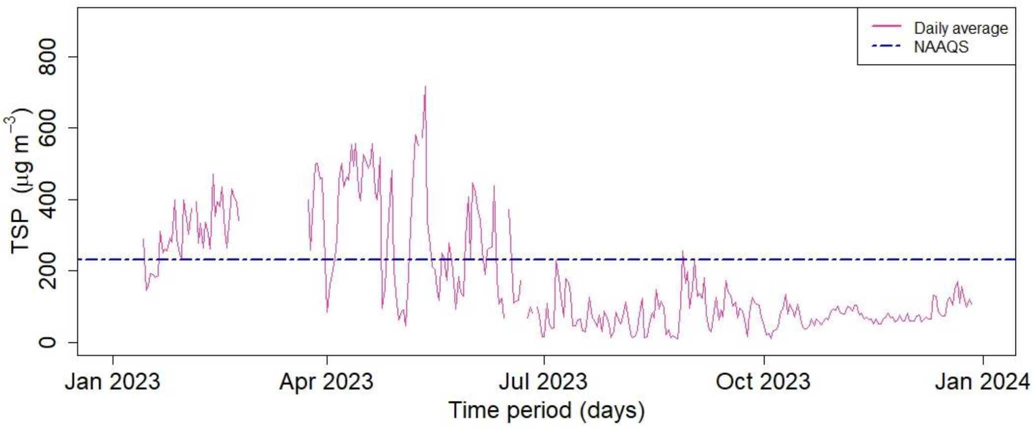


Figure 32: Daily average of TSP for Bhaisepati Station

Table 15: Summary of daily average of TSP (µg m^{-3}) for Bhaisepati Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
10.4	67.6	108.5	173.5 ± 147.1	257.4	717.3

Within the available data, the lowest and highest concentration of TSP was found to be 10.4 µg m^{-3} to 717.3 µg m^{-3} (Table 15).

Monthly average:

Figure 33 illustrates the monthly average concentration of TSP. The monthly average of TSP was the highest in April (375.5 µg m^{-3}) and lowest in October (63.3 µg m^{-3}). The monthly average of TSP for March was not available.

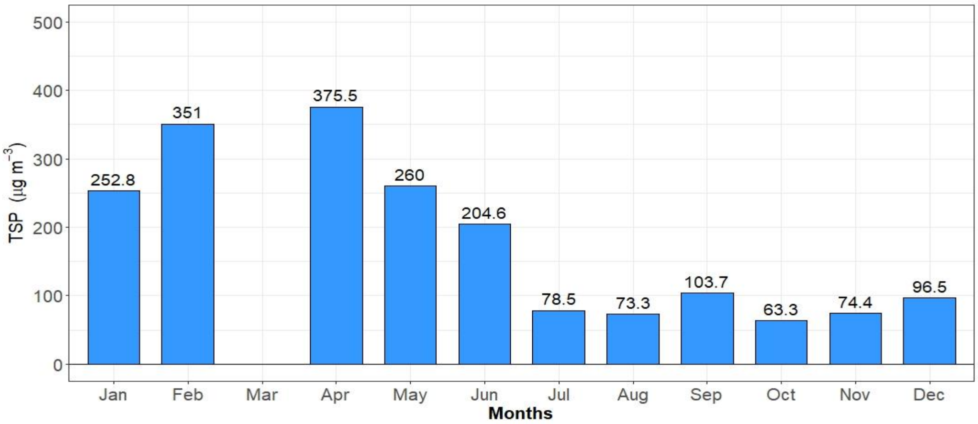


Figure 33: Monthly average of TSP for Bhaisepati Station

Seasonal average:

Figure 34 illustrates the seasonal distribution of the concentration of TSP. Pre-monsoon was observed with the highest seasonal average (327.3 µg m^{-3}), while post-monsoon showed the lowest seasonal average (68.7 µg m^{-3}).

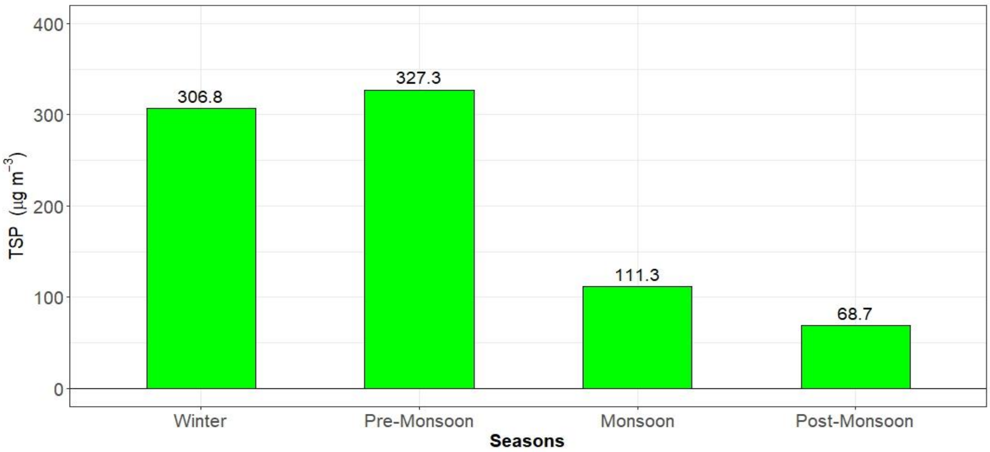


Figure 34: Seasonal average of TSP for Bhaisepati Station

Compliance status:

Out of the total 314 days of valid measurements, 91 days exceeded the NAAQS (Figure 35), most of which were on January to June.

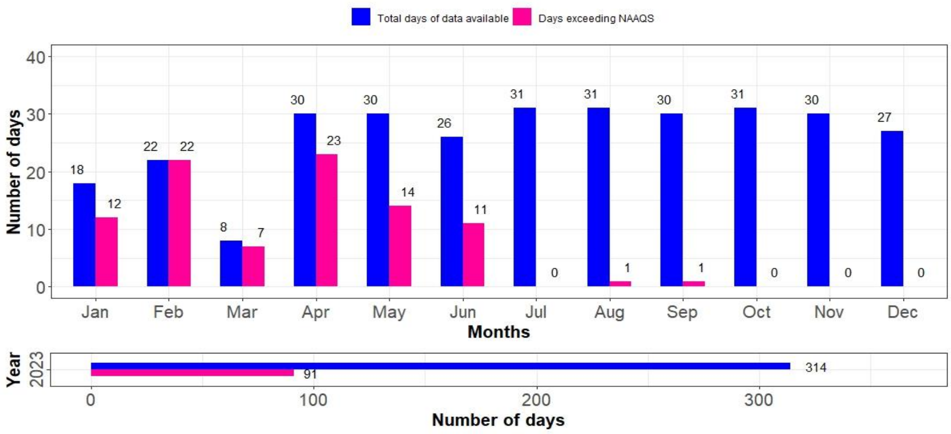


Figure 35: Compliance status of TSP for Bhaisepati Station

2.2.2 HETAUDA AIR QUALITY MONITORING STATION

Hetauda AQMS was established in 2020 at Hetauda sub metropolitan city in Makawanpur district, Bagmati Province. This station is located adjacent to the office of ward number 4, on the football ground at Hupra chaur by the side of the road. This station represents the urban area.

Emission from the vehicles and industries are the main sources of pollution in the area around the station. Dust form the football ground might also contribute to the particulate measured by this station.

2.2.2.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.4 µg m^{-3} to 190.9 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 16.

Table 16: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Hetauda Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.4	9.6	18.1	21.7 ± 15.9	29.6	190.9

Diurnal variation:

The hourly mean of $PM_{2.5}$ progressively decreased from 0:00 till 4:00 then increased with time and reaches to its peak at 7:00 after that it decreased till 13:00, and again starts to rise and peaks at 21:00 (Figure 36).

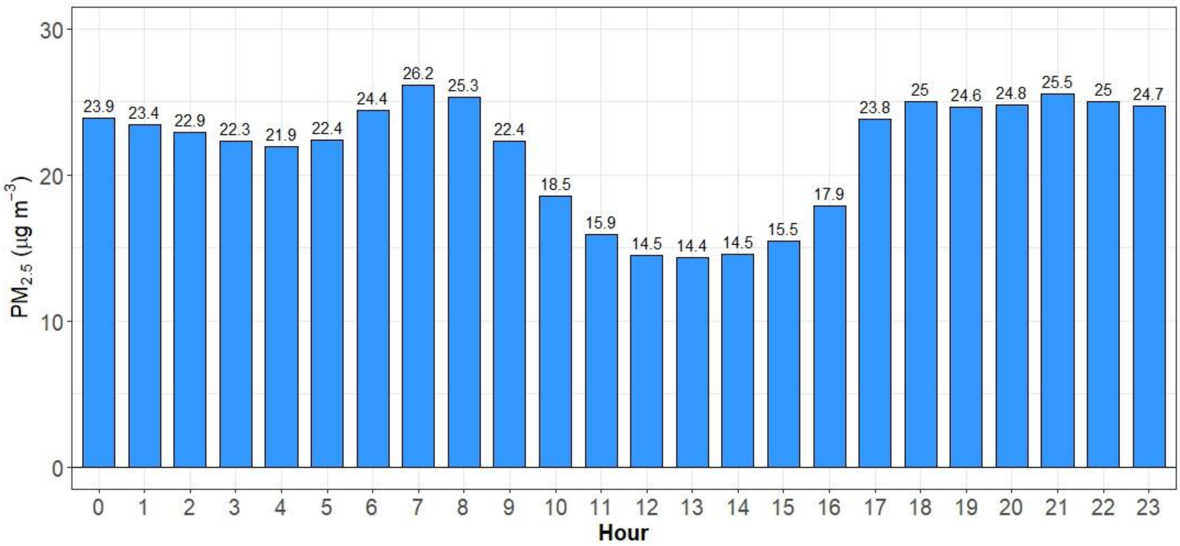


Figure 36: Diurnal variation of $PM_{2.5}$ for Hetauda Station

Daily average:

The daily average data was available for 321 days. Figure 37 shows the daily trend of $PM_{2.5}$ throughout the year.

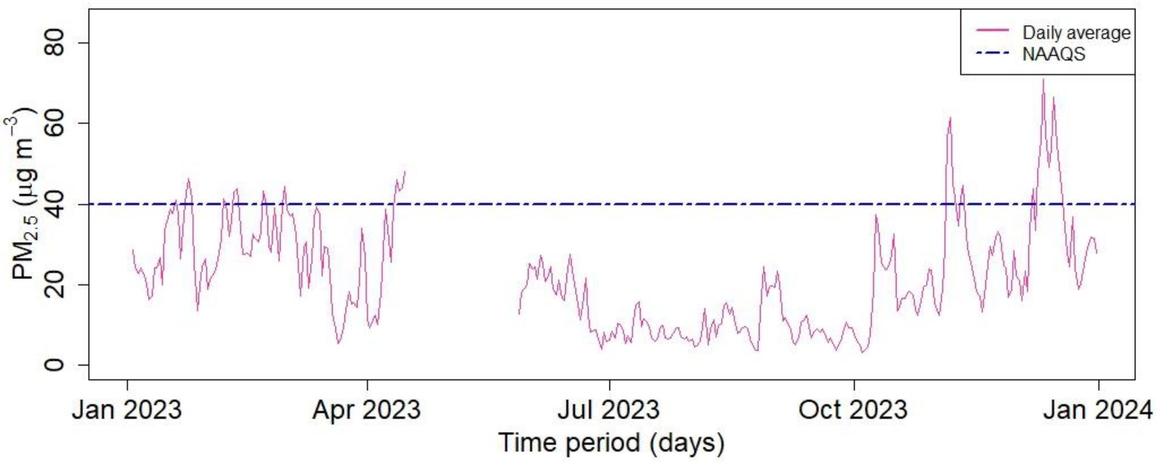


Figure 37: Daily average of $PM_{2.5}$ for Hetauda Station

Table 17: Summary of daily average of $PM_{2.5}$ ($\mu g\ m^{-3}$) for Hetauda Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
3.1	10.0	19.7	21.6 ± 13.1	28.9	71.0

Within the available data, the lowest and highest concentration of $PM_{2.5}$ was found to be 3.1 $\mu g\ m^{-3}$ to 71.0 $\mu g\ m^{-3}$ (Table 17).

Monthly average:

Figure 38 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in December (36.2 $\mu g\ m^{-3}$) and lowest in July (8.6 $\mu g\ m^{-3}$).

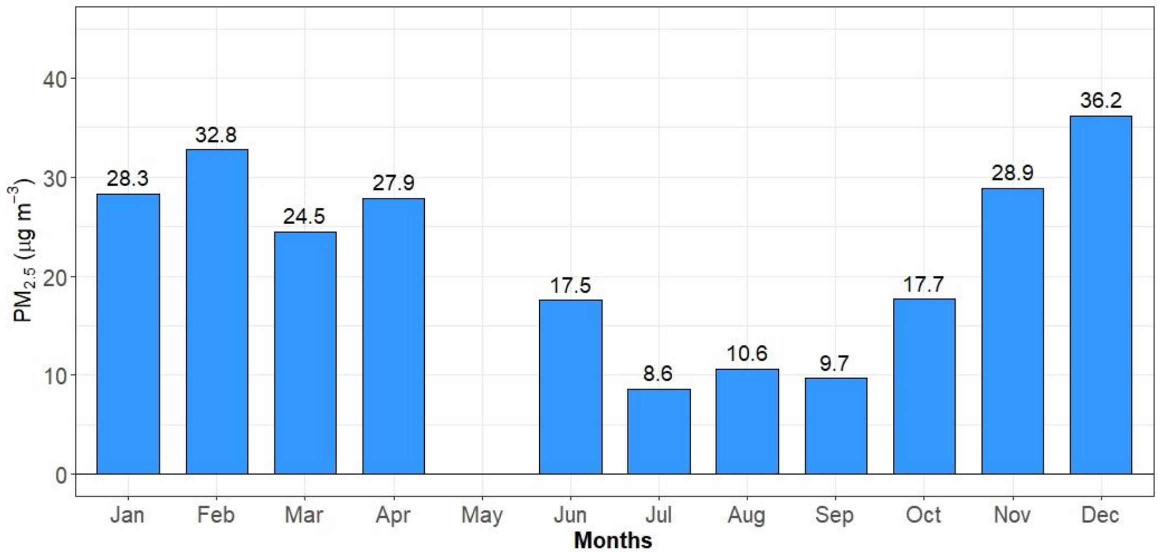


Figure 38: Monthly average of $PM_{2.5}$ for Hetauda Station

Seasonal average:

Figure 39 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Winter was observed with the highest seasonal average (29 $\mu g\ m^{-3}$), while monsoon showed the lowest seasonal average (11.6 $\mu g\ m^{-3}$).

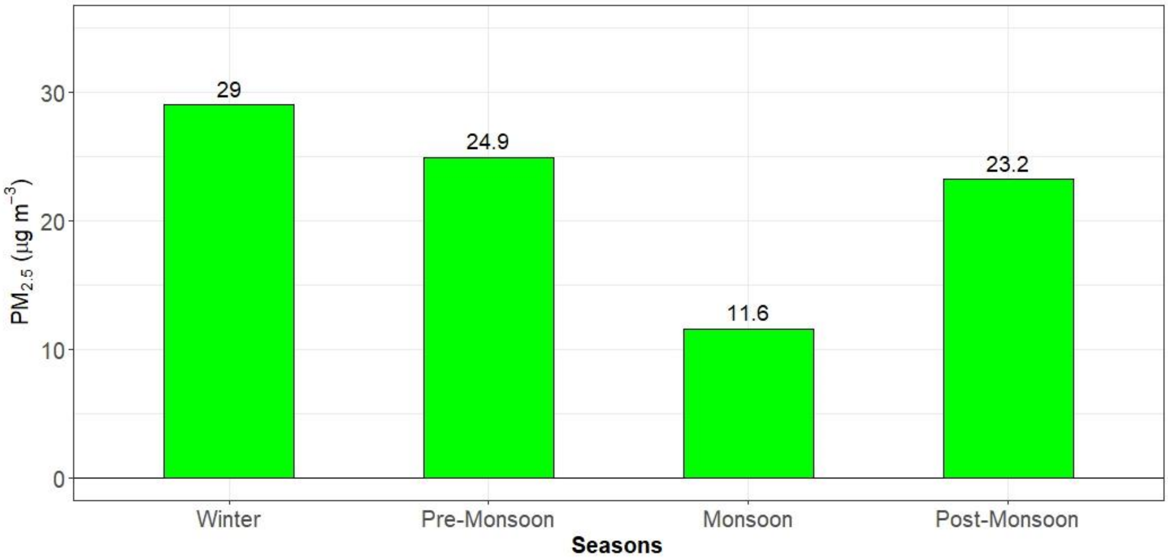


Figure 39: Seasonal average of $PM_{2.5}$ for Hetauda Station

Compliance status:

Out of the total 321 days of valid measurements, 33 days exceeded the NAAQS (Figure 40). In January 4 days out of 29 days, in February 7 days out of 28 days, in March 1 day out of 31 days, in April 4 days out of 16 days, in November 6 days out of 30 days, and in December 11 days out of 31 days exceeded the NAAQS. The entire days during May to October meets the NAAQS.

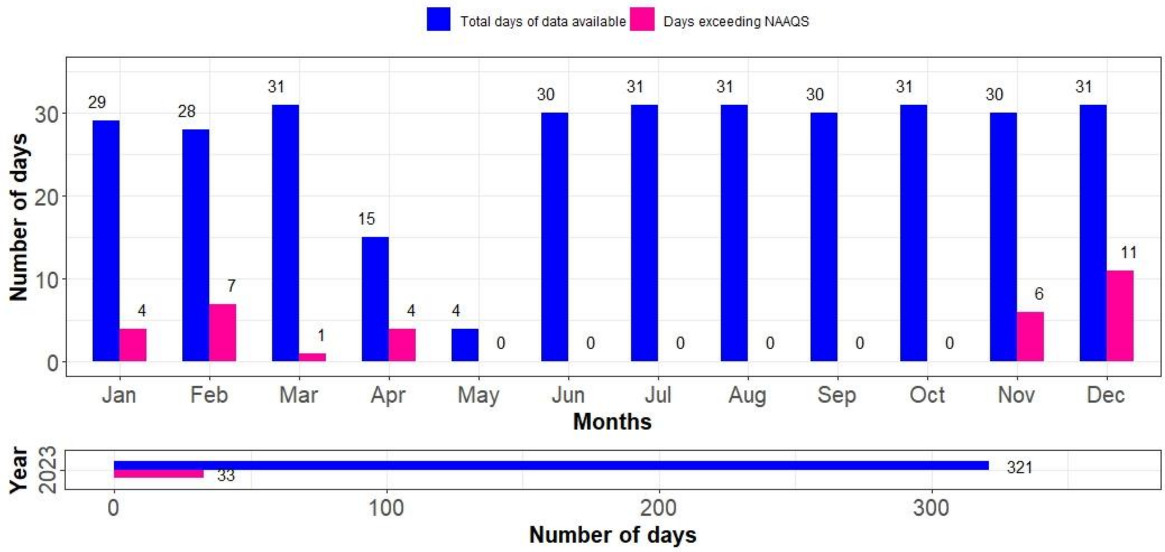


Figure 40: Compliance status of $PM_{2.5}$ for Hetauda Station

Calendar plot

Calendar plot based only on $PM_{2.5}$ concentration (Figure 41) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during November and December.

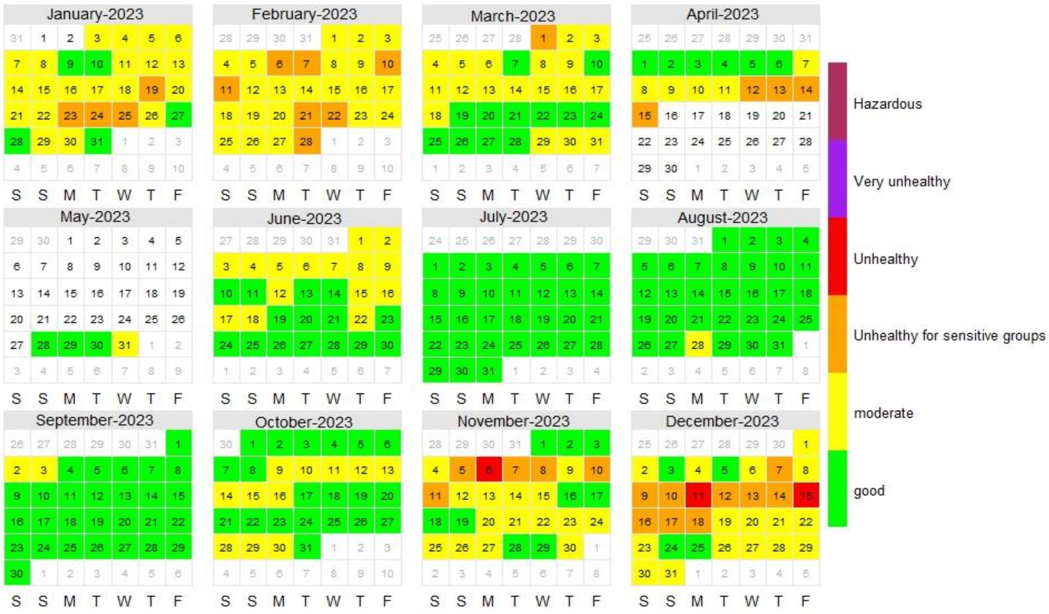


Figure 41: Calendar plot of $PM_{2.5}$ for Hetauda Station

2.2.2.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.6 µg m^{-3} to 427.6 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 18.

Table 18: Summary of hourly average of PM_{10} (µg m^{-3}) for Hetauda Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.6	14.5	26.2	32.5 ± 27.9	41.6	427.6

Diurnal variation:

The hourly mean of PM_{10} progressively decreased from 0:00 till 3:00-4:00 then increased with time and reaches to its peak at 9:00 after that it decreased till 14:00, and again starts to rise and peaks at 17:00 (Figure 42).

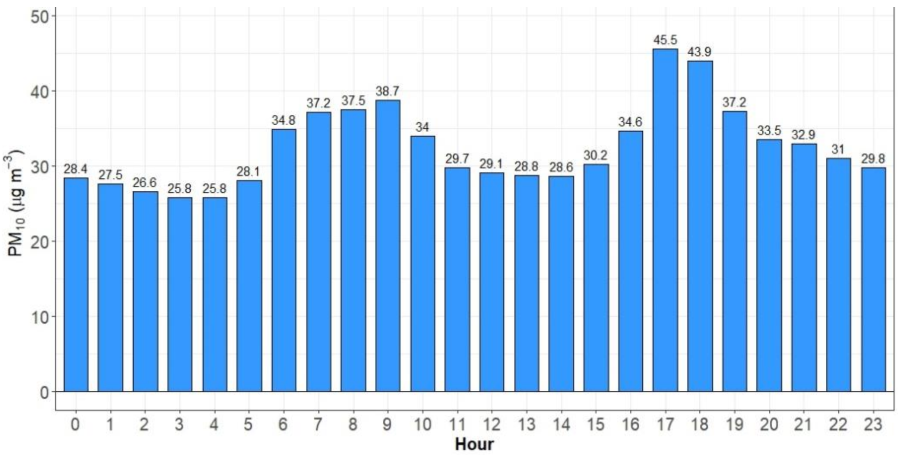


Figure 42: Diurnal variation of PM_{10} for Hetauda Station

Daily average:

The daily average data was available for 321 days. Figure 43 explains the daily trend of PM_{10} throughout the year.

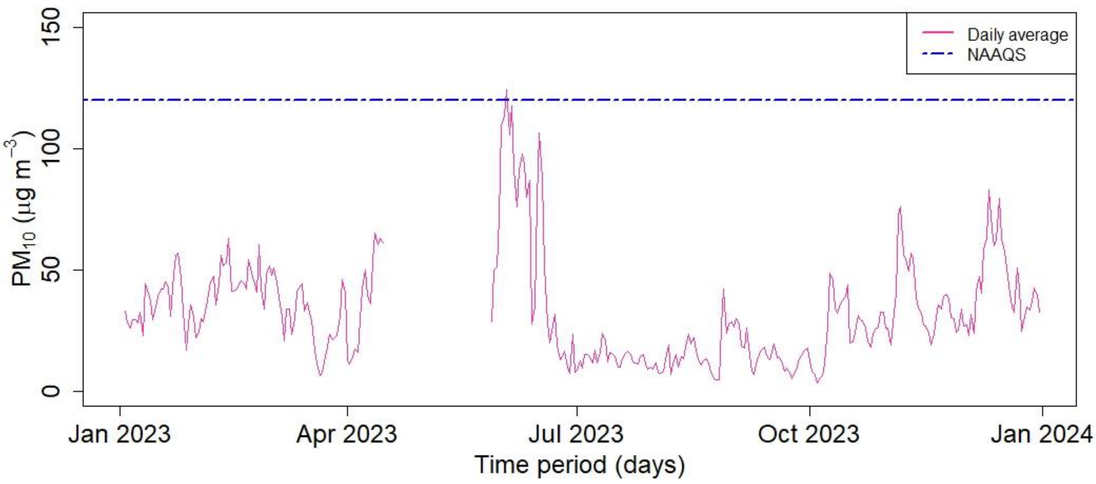


Figure 43: Daily average of PM_{10} for Hetauda Station

Table 19: Summary of daily average of PM_{10} (µg m^{-3}) for Hetauda Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
3.6	15.7	28.5	32.4 ± 21.7	42.3	124.2

Within the available data, the lowest and the highest daily average concentration of PM_{10} was found to be 3.6 µg m^{-3} to 124.2 µg m^{-3} (Table 19).

Monthly average:

Figure 44 illustrates the monthly average concentration of PM_{10}. The monthly average of PM_{10} was the highest in June (59.7 µg m^{-3}) and lowest in July (13.5 µg m^{-3}).

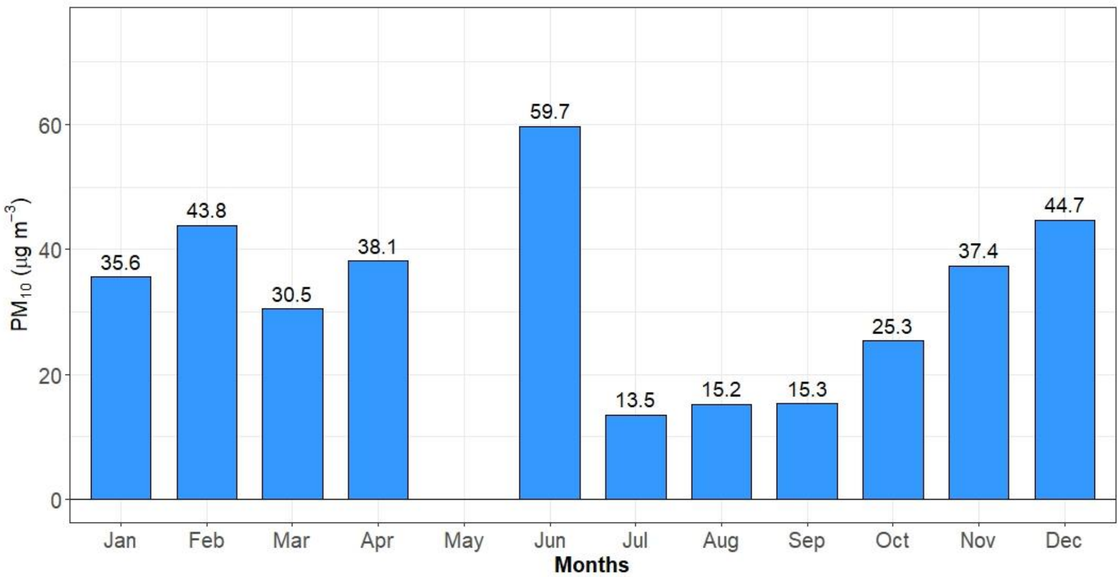


Figure 44: Monthly average of PM_{10} for Hetauda Station

Seasonal average:

Figure 45 illustrates the seasonal distribution of the concentration of PM_{10}. Winter was observed with the highest seasonal average (36.7 μg m^{-3}), while monsoon showed the lowest seasonal average (25.7 μg m^{-3}).

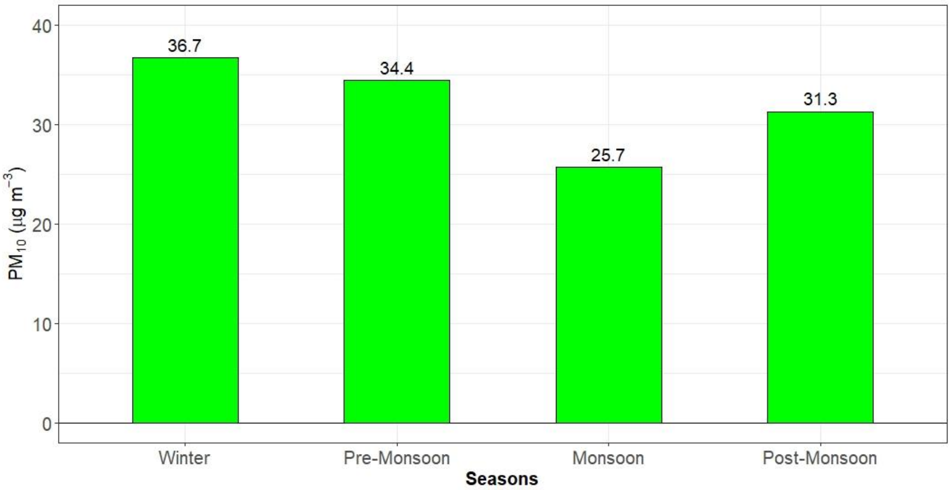


Figure 45: Seasonal average of PM_{10} for Hetauda Station

Compliance status:

Out of the total 321 days of valid measurements, only one day exceeded the NAAQS Figure 46.

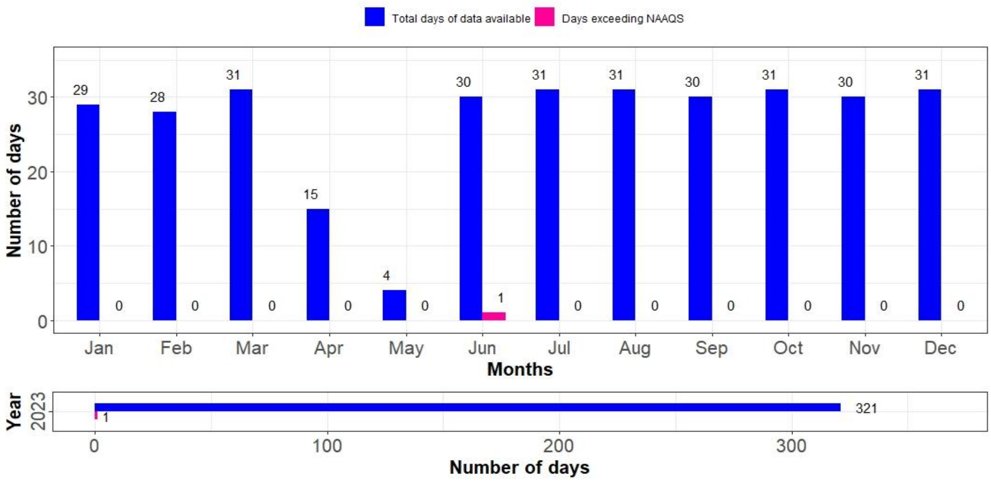


Figure 46: Compliance status of PM_{10} for Hetauda Station

2.2.2.3 Data analysis for TSP

Hourly average:

The hourly average ranges from 1.8 μg m^{-3} to 1483.4 μg m^{-3}. The statistical summary of the hourly average is presented in the Table 20.

Table 20: Summary of hourly average of TSP (μg m^{-3}) for Hetauda Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.8	19.7	36.6	65.7 ± 100.2	66.1	1483.4

Diurnal variation:

The hourly mean of TSP progressively decreased from 0:00 till 4:00 then increased with time and reaches to its peak at 9:00 after that it decreased till 14:00, after which it increases and reached to maximum at 17:00 (Figure 47).

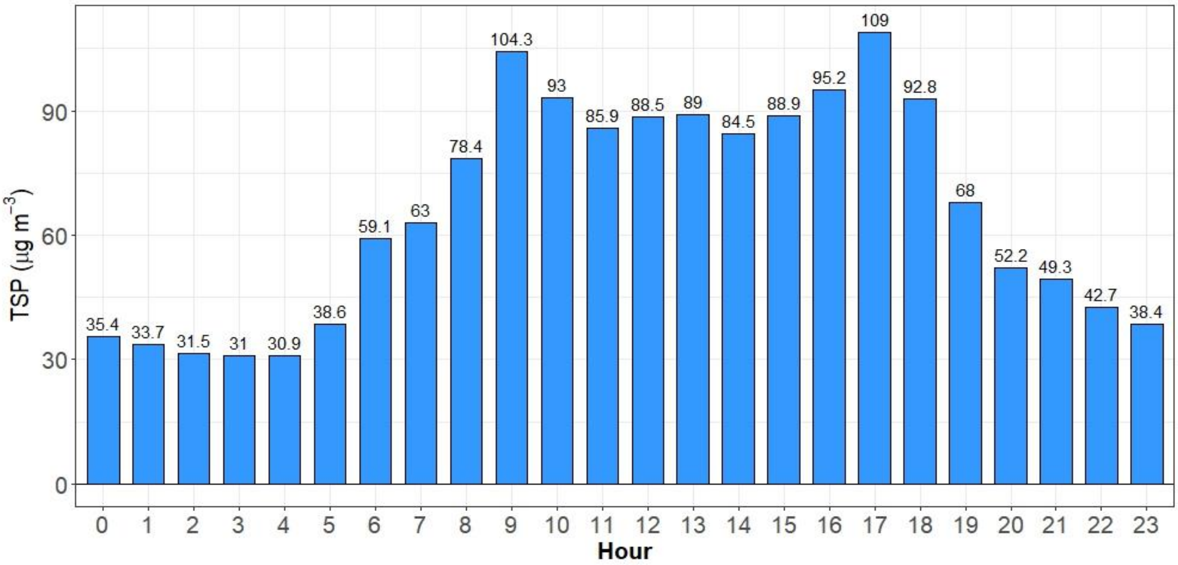


Figure 47: Diurnal variation of TSP for Hetauda Station

Daily average:

The daily average data was available for 321 days. Figure 48 shows the daily trend of TSP throughout the year.

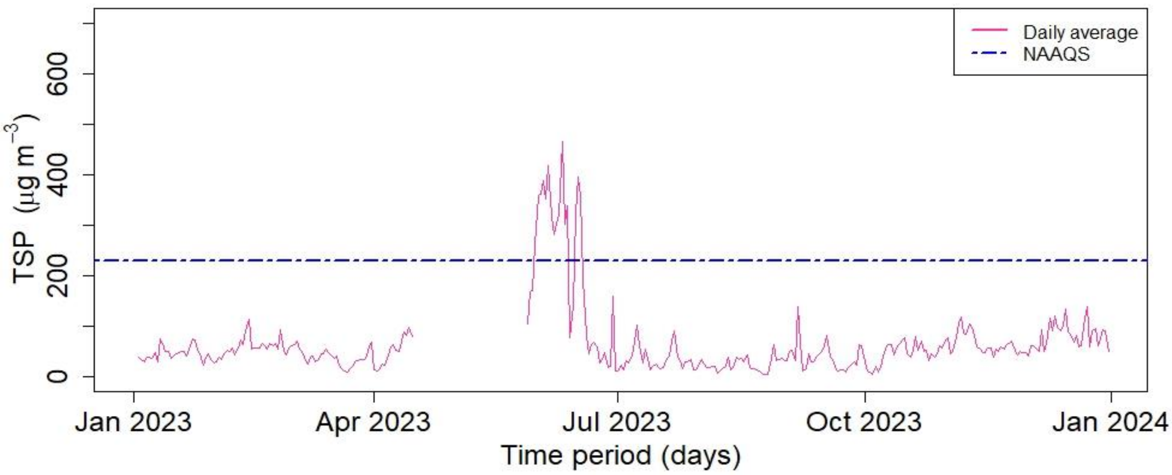


Figure 48: Daily average of TSP for Hetauda Station

Table 21: Summary of daily average of TSP (µg m^{-3}) for Hetauda Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
3.9	31.9	49.6	65.6 ± 71.7	67.3	465.2

Within the available data, the lowest and highest daily average concentration of TSP was found to be 3.9 µg m^{-3} to 465.2 µg m^{-3} (Table 21).

Monthly average:

Figure 49 illustrates the monthly average concentration of TSP. The monthly average of TSP was the highest in June (211.2 µg m^{-3}) and lowest in August (24.2 µg m^{-3}). The monthly average of TSP for May was not available.

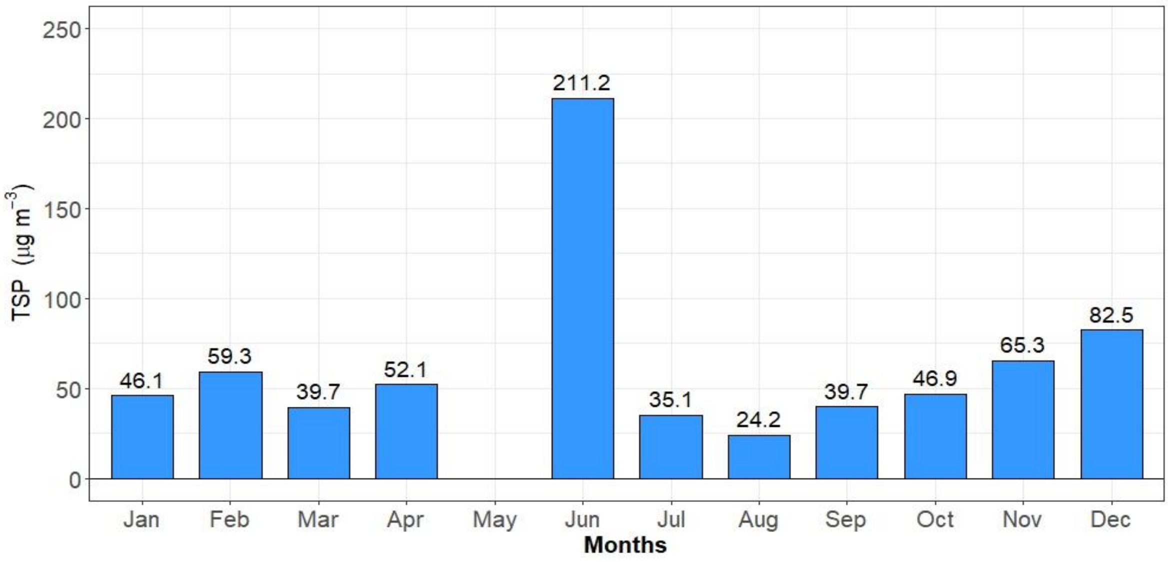


Figure 49: Monthly average of TSP for Hetauda Station

Seasonal average:

Figure 50 illustrates the seasonal distribution of the concentration of TSP. Monsoon was observed with the highest seasonal average (76.8 µg m^{-3}), while winter showed the lowest seasonal average (47.9 µg m^{-3}).

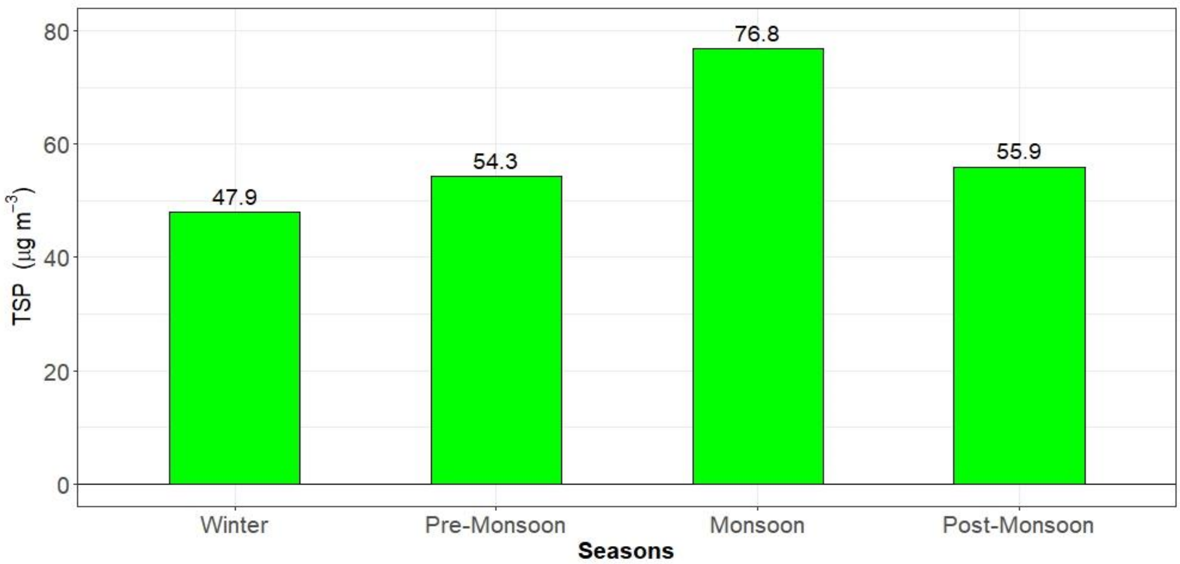


Figure 50: Seasonal average of TSP for Hetauda Station

Compliance status:

Out of the total 321 days of measurement, 16 days exceeded the NAAQS as shown in Figure 51.

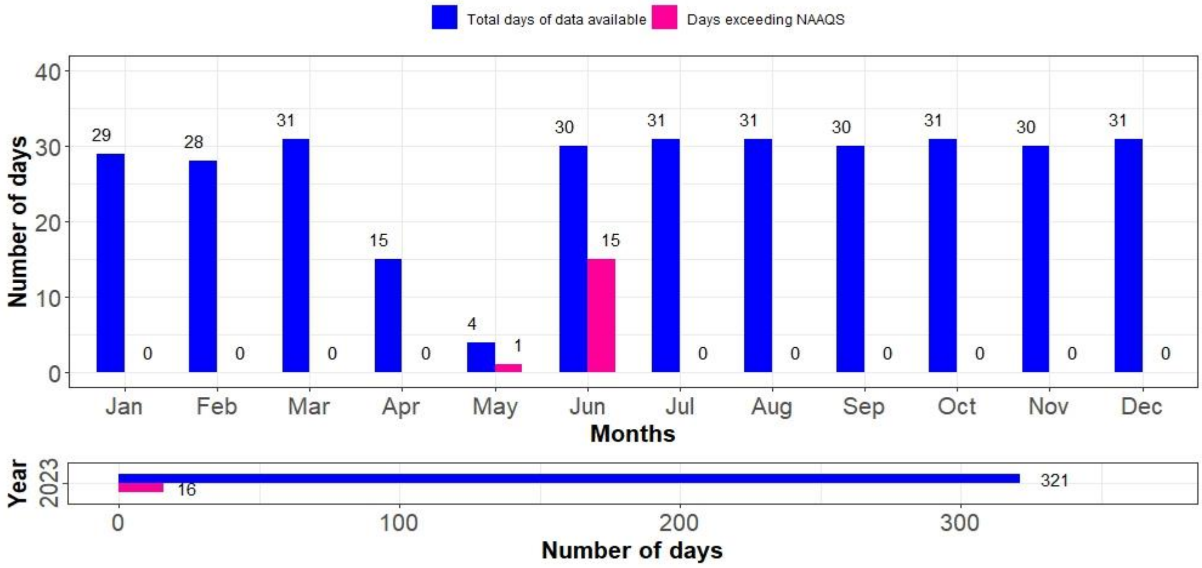


Figure 51: Compliance status of TSP for Hetauda Station

2.2.3 KHUMALTAR AIR QUALITY MONITORING STATION

Khumaltar AQMS is established in 2022 at Lalitpur Municipality in Lalitpur district, Bagmati Province. It is located on the rooftop of ICIMOD's building and it represents the urban area. Emissions from vehicles are the main source of pollution in this area. Occasional construction activities around the area also contribute to the particulate matter measured by this station.

2.2.3.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 0.6 µg m^{-3} to 187.9 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 22.

Table 22: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Khumaltar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
0.6	18.2	38.3	46.0 ± 33.9	65.9	187.9

Diurnal variation:

The hourly mean of $PM_{2.5}$ progressively decreased from 0:00 till 1:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 14:00, and again starts to rise and peaks at 20:00 (Figure 52).

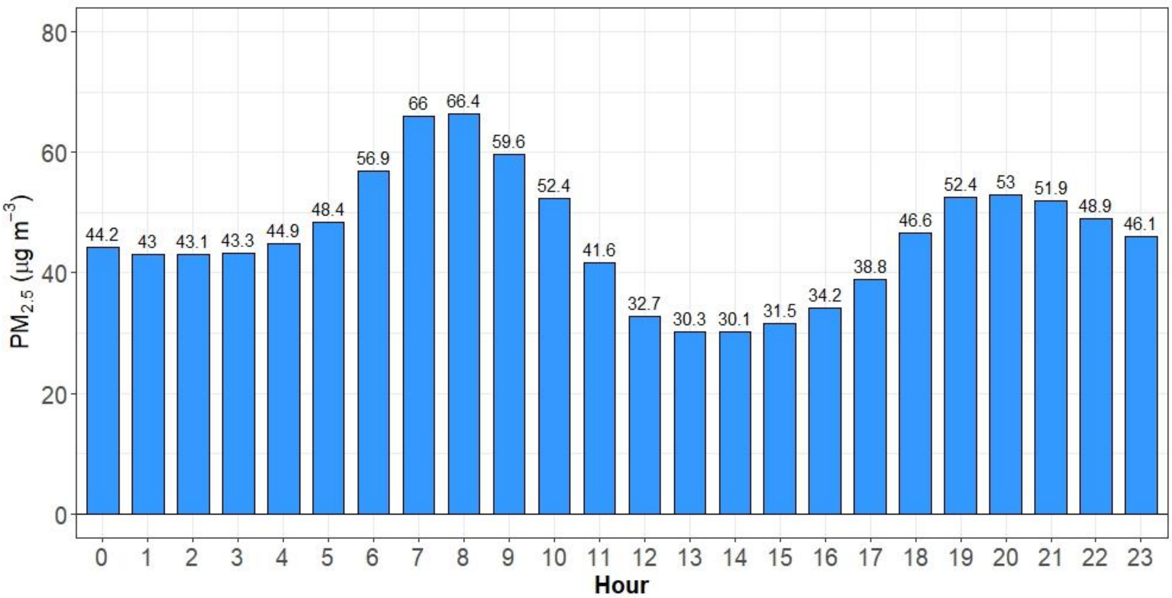


Figure 52: Diurnal variation of $PM_{2.5}$ for Khumaltar Station

Daily average:

The daily average data was available for 355 days. Figure 53 explains the daily trend of $PM_{2.5}$ throughout the year.

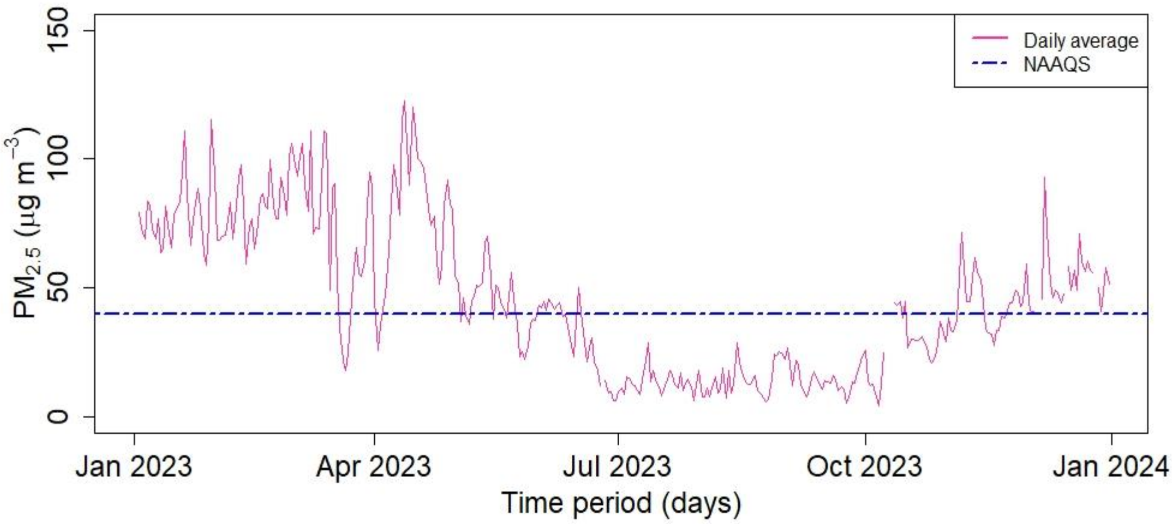


Figure 53: Daily average of $PM_{2.5}$ for Khumaltar Station

Table 23: Summary of daily average of $PM_{2.5}$ (µg m^{-3}) for Khumaltar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
4.6	18.3	43.2	46.0 ± 29.3	69.6	122.4

Within the available data, the lowest and highest concentration of $PM_{2.5}$ was found to be 4.6 µg m^{-3} to 122.4 µg m^{-3} (Table 23).

Monthly average:

Figure 54 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in April (80.1 µg m^{-3}) and lowest in July (13.7 µg m^{-3}).

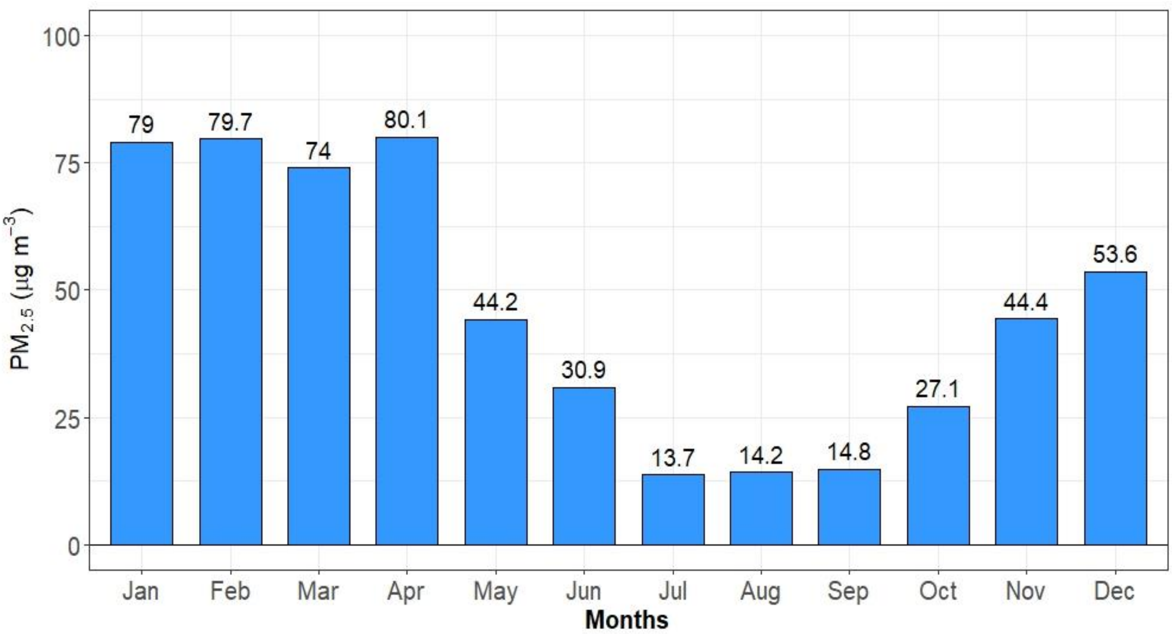


Figure 54: Monthly average of $PM_{2.5}$ for Khumaltar Station

Seasonal average:

Figure 55 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Winter was observed with the highest seasonal average (74.8 µg m^{-3}), while monsoon showed the lowest seasonal average (18.2 µg m^{-3}).

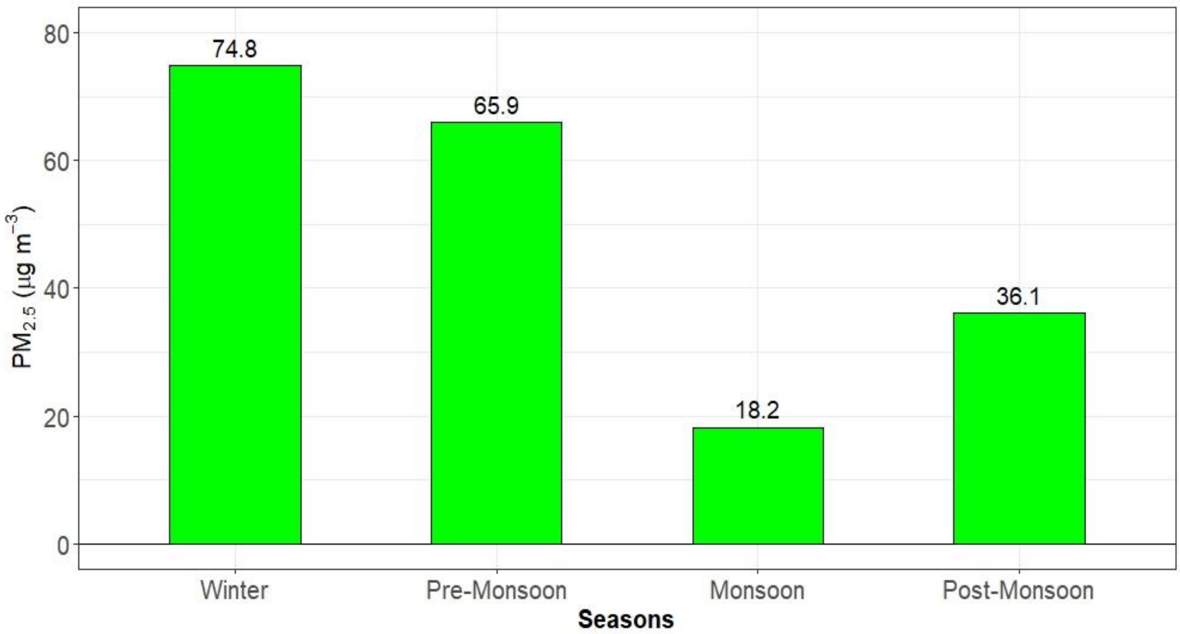


Figure 55: Seasonal average of $PM_{2.5}$ for Khumaltar Station

Compliance status:

Out of the total 355 days of valid measurements, 189 days exceeded the NAAQS (Figure 56). The compliance status is poor during January to May and November and December. In January February and December, total valid measurements exceeded the NAAQS. Similarly, in March, April, May, and November more than 50% of valid measurement exceeded the NAAQS. The entire days during July to September meets the NAAQS.

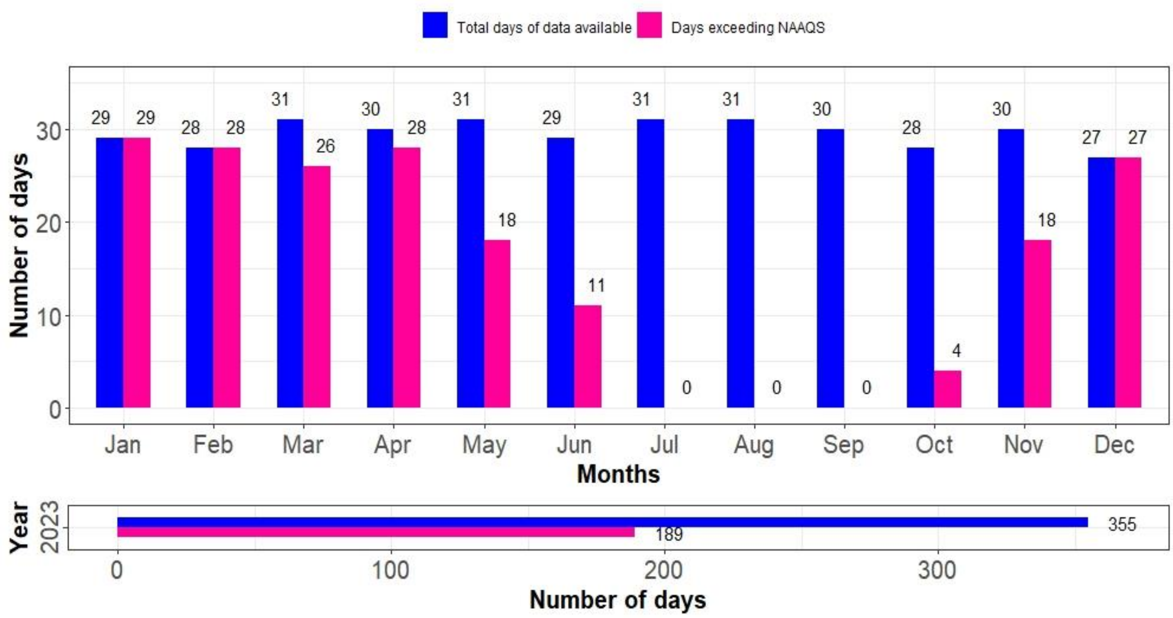


Figure 56: Compliance status of $PM_{2.5}$ for Khumaltar Station

Calendar plot

Calendar plot for $PM_{2.5}$ (Figure 57) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during January, February, March, April, May, November and December. During July, August and September, almost all of the days were within good air pollution category.

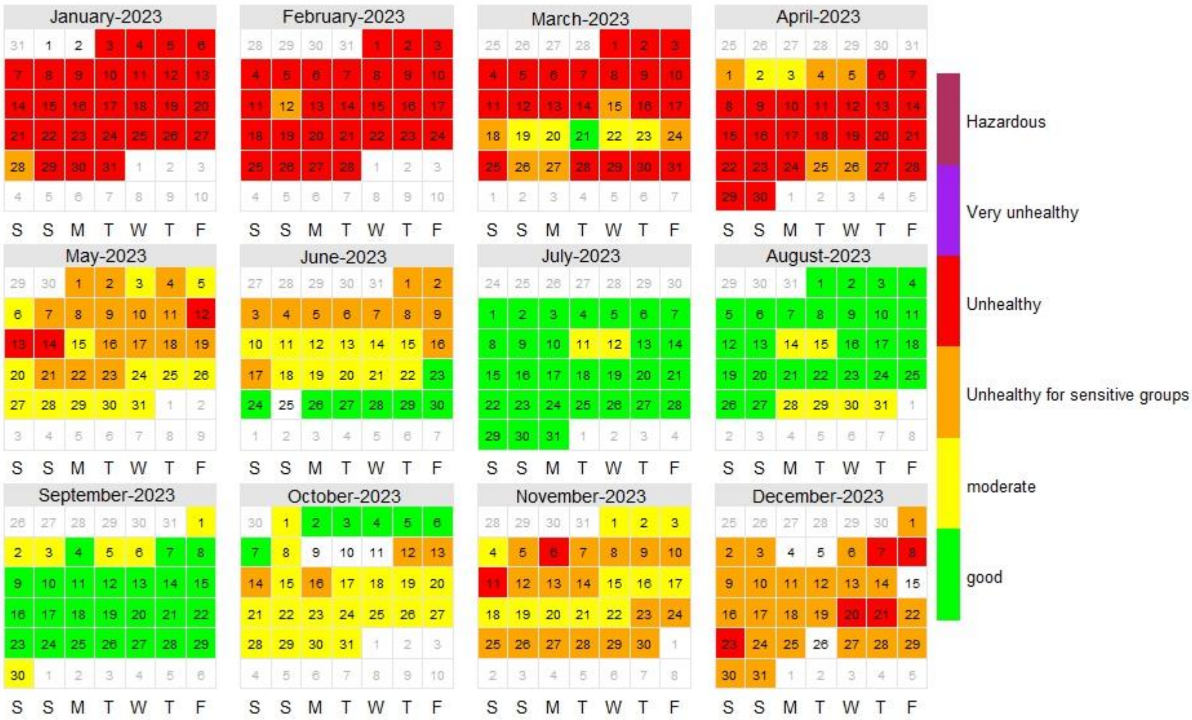


Figure 57: Calendar plot of $PM_{2.5}$ for Khumaltar Station

2.2.3.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 0.8 µg m^{-3} to 645.2 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 24.

Table 24: Summary of hourly average of PM_{10} (µg m^{-3}) for Khumaltar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
0.8	30.4	71.6	88.4 ± 71.8	128.2	645.2

Diurnal variation:

The hourly mean of PM_{10} progressively decreased from 0:00 till 3:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 14:00, and again starts to rise and peaks at 19:00 (Figure 58).

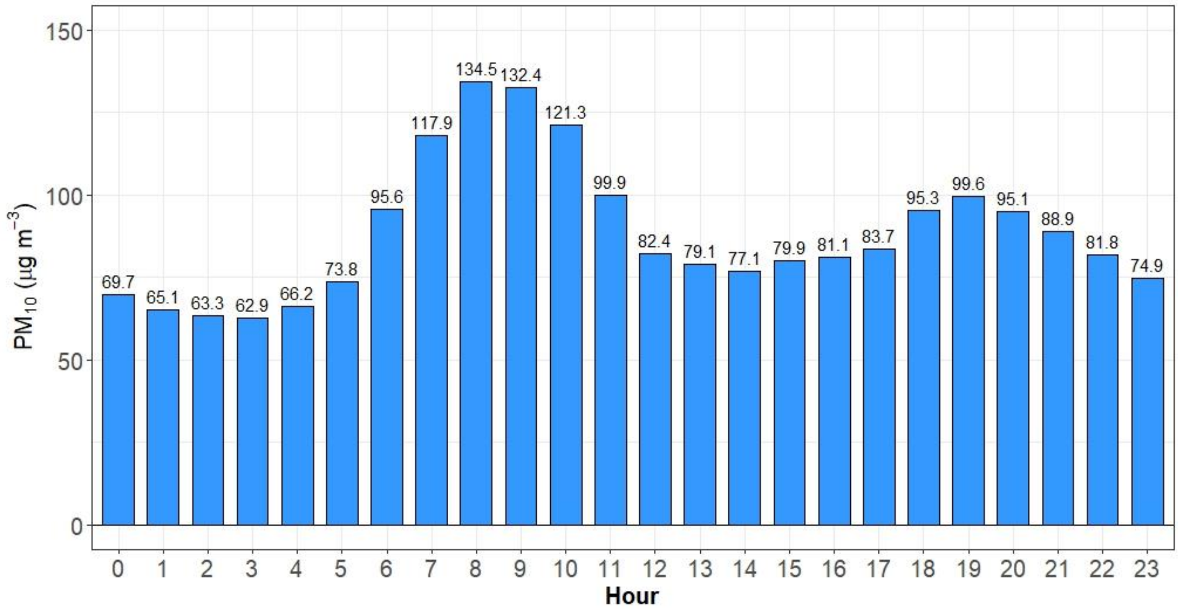


Figure 58: Diurnal variation of PM$_{10}$ for Khumaltar Station

Daily average:

The daily average data was available for 355 days. Figure 59 explains the daily trend of PM$_{10}$ throughout the year.

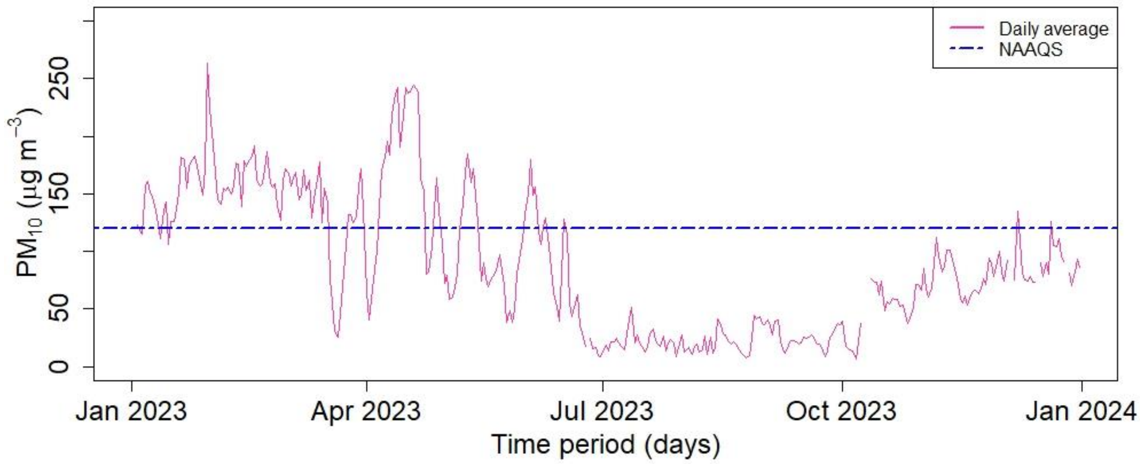


Figure 59: Daily average of PM$_{10}$ for Khumaltar Station

Table 25: Summary of daily average of PM$_{10}$ (µg m^{-3}) for Khumaltar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
6.2	30.5	76.4	88.3 ± 61.3	139.0	263.2

Within the available data, the lowest and the highest concentration of PM$_{10}$ was found to be 6.2 µg m^{-3} to 263.2 µg m^{-3} (Table 25).

Monthly average:

Figure 60 illustrates the monthly average concentration of PM$_{10}$. The monthly average of PM$_{10}$ was the highest in April (163.1 µg m^{-3}) and lowest in August (21.4 µg m^{-3}).

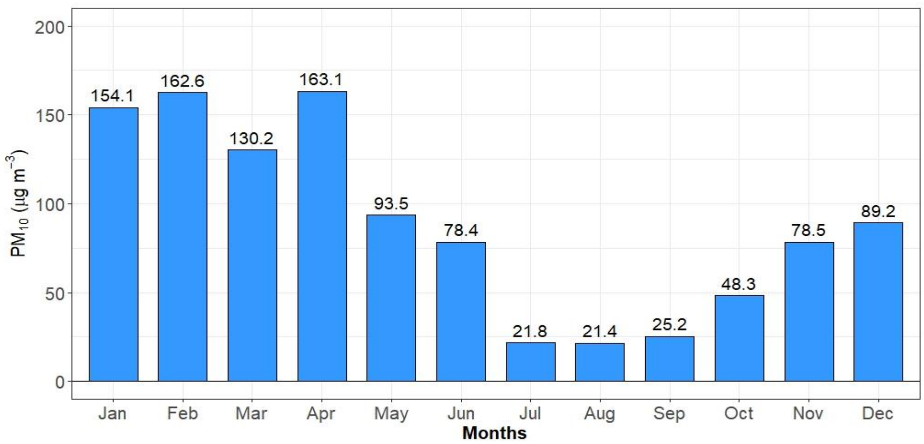


Figure 60: Monthly average of PM_{10} for Khumaltar Station

Seasonal average:

Figure 61 illustrates the seasonal distribution of the concentration of PM_{10}. Winter was observed with the highest seasonal average (142.1 µg m^{-3}), while monsoon showed the lowest seasonal average (36.1 µg m^{-3}).

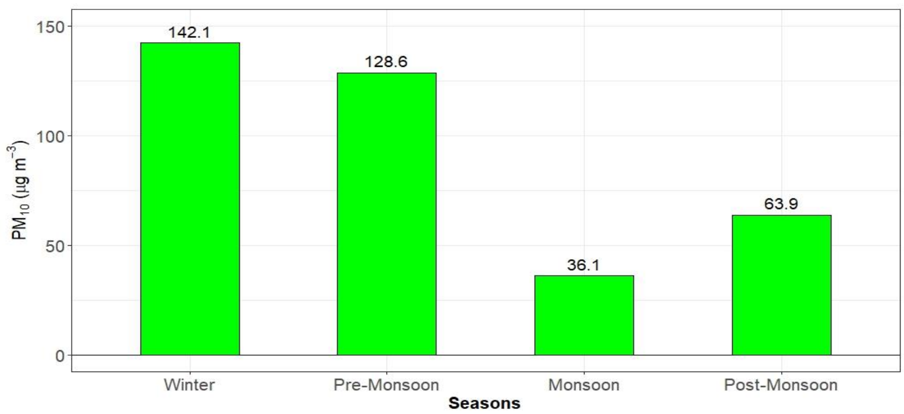


Figure 61: Seasonal average of PM_{10} for Khumaltar Station

Compliance status:

Out of the total 355 days of valid measurements, 115 days exceeded the NAAQS. The majority days exceeding NAAQS were from January to April Figure 62.

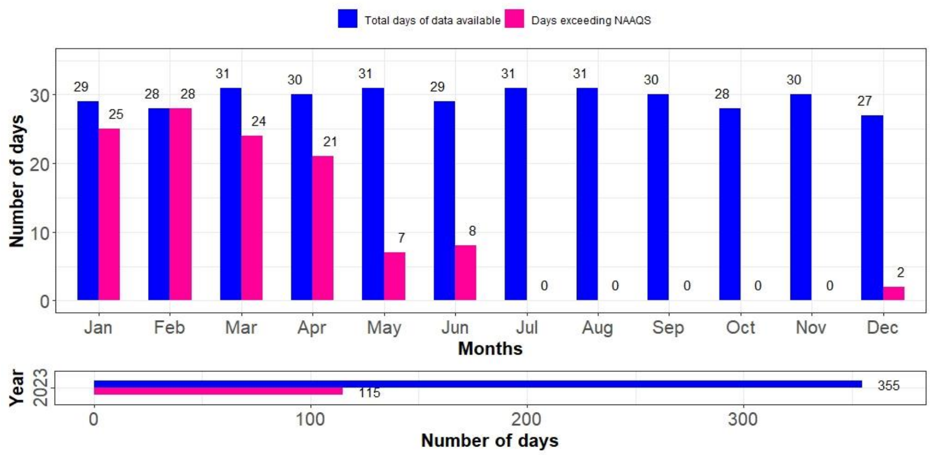


Figure 62: Compliance status of PM_{10} for Khumaltar Station

2.2.4 PULCHOWK AIR QUALITY MONITORING STATION

Pulchowk AQMS was established in the year 2016 on the roof top of Pulchowk Engineering College. This station is situated at the center of the Kathmandu and represents the urban area.

2.2.4.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.5 µg m^{-3} to 103.7 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 26.

Table 26: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Pulchowk Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.5	9.5	16.9	23.0 ± 17.5	33.3	103.7

Diurnal variation:

The hourly mean of $PM_{2.5}$ progressively decreased from 0:00 till 1:00 then increased with time and reaches to its peak at 9:00 after that it decreased till 13:00, and again starts to rise and peaks at 20:00 (Figure 63).

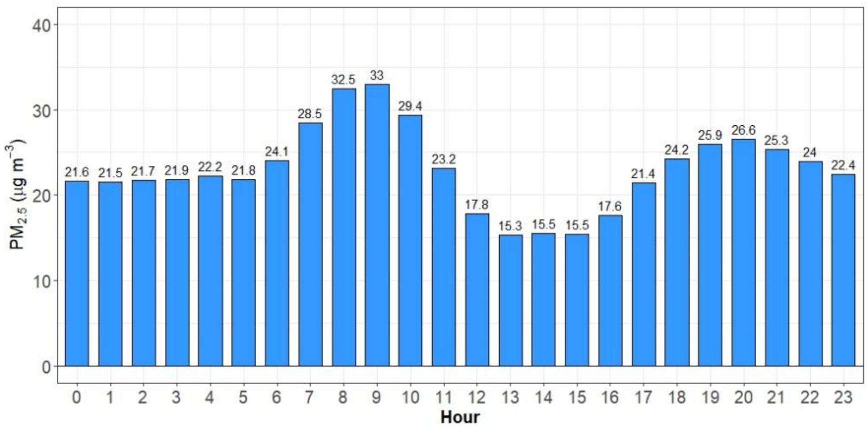


Figure 63: Diurnal variation of $PM_{2.5}$ for Pulchowk Station

Daily average:

The daily average data was available for 179 days. Figure 64 shows the daily trend of $PM_{2.5}$ throughout the year.

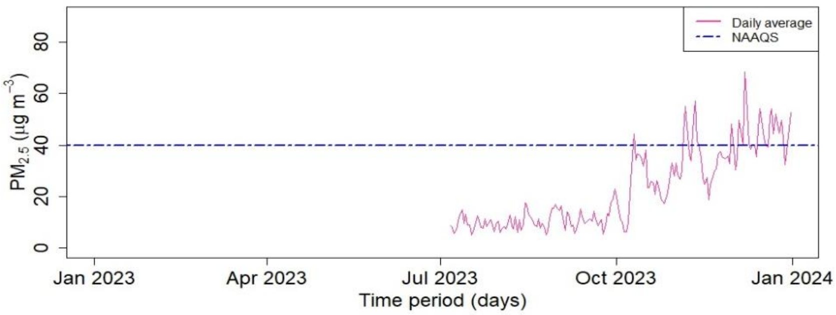


Figure 64: Daily average of $PM_{2.5}$ for Pulchowk Station

Table 27: Summary of daily average of $PM_{2.5}$ (µg m^{-3}) for Pulchowk Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
5.1	10.0	17.2	23.1 ± 15.2	35.5	68.5

Within the available data, the lowest and highest concentration of $PM_{2.5}$ was found to be 5.1 µg m^{-3} to 68.5 µg m^{-3} (Table 27).

Monthly average:

Figure 65 illustrates the monthly average concentration of $PM_{2.5}$. The monthly average of $PM_{2.5}$ was the highest in December (44.8 µg m^{-3}) and lowest in July (9.5 µg m^{-3}).

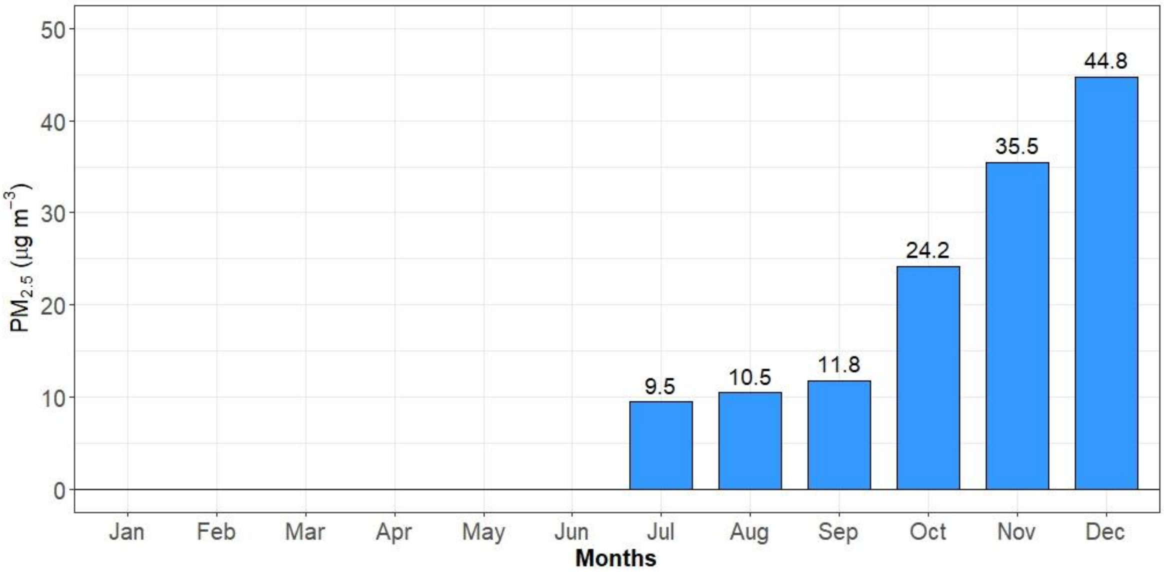


Figure 65: Monthly average of $PM_{2.5}$ for Pulchowk Station

Seasonal average:

Figure 66 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Post-monsoon was observed with higher seasonal average (29.7 µg m^{-3}) than monsoon (10.6 µg m^{-3}).

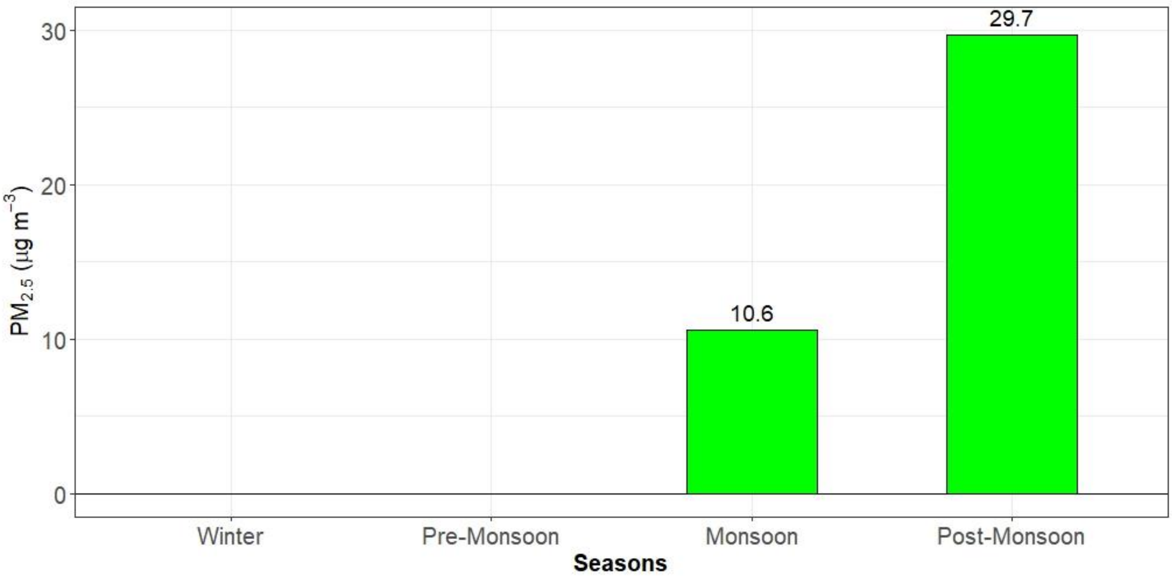


Figure 66: Seasonal average of $PM_{2.5}$ for Pulchowk Station

Compliance status:

Out of the total 179 days of valid measurements, 32 days exceeded the NAAQS (Figure 67). The compliance status was poor during December. The entire days during July to September meets the NAAQS.

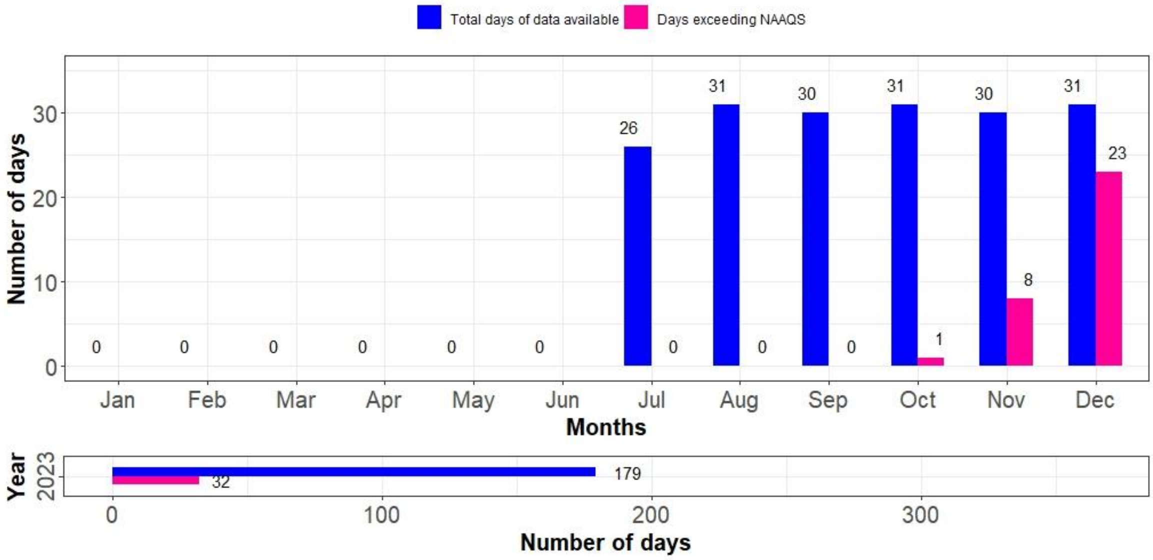


Figure 67: Compliance status of $PM_{2.5}$ for Pulchowk Station

Calendar plot

Calendar plot for $PM_{2.5}$ (Figure 68) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during December. During July, August and September, almost all of the days were with good air pollution category.

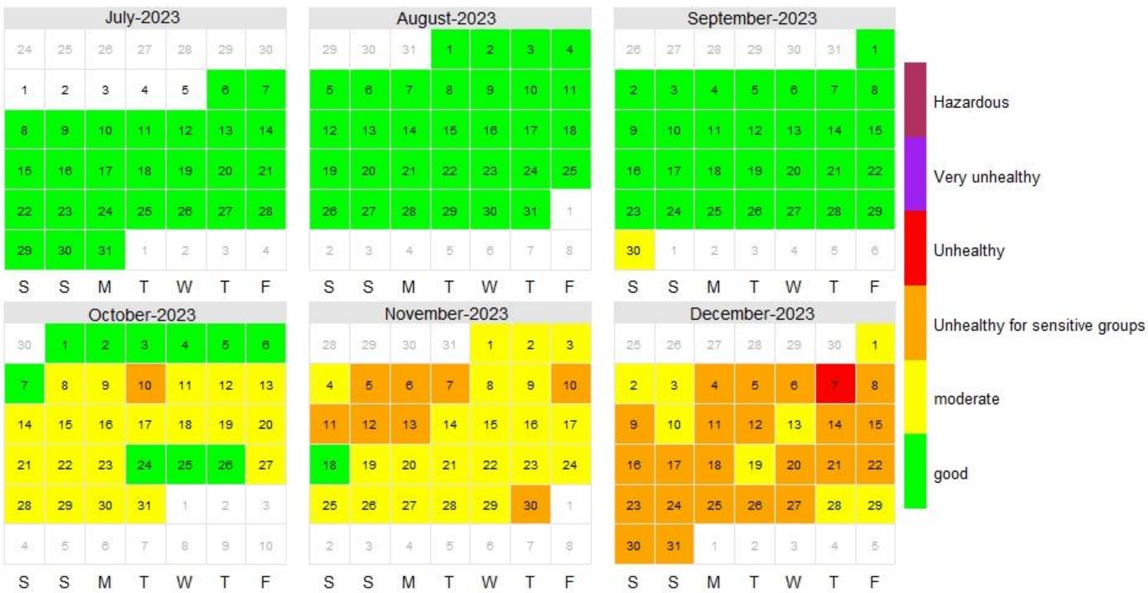


Figure 68: Calendar plot of $PM_{2.5}$ for Pulchowk Station

2.2.4.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.6 µg m^{-3} to 123.9 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 28.

Table 28: Summary of hourly average of PM_{10} (µg m^{-3}) for Pulchowk Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.6	12.9	23.0	28.0 ± 19.6	38.7	123.9

Diurnal variation:

The hourly mean of PM_{10} progressively decreased from 0:00 till 3:00 then increased with time and reaches to its peak at 9:00 after that it decreased till 13:00, and again starts to rise and peaks at 20:00 (Figure 69).

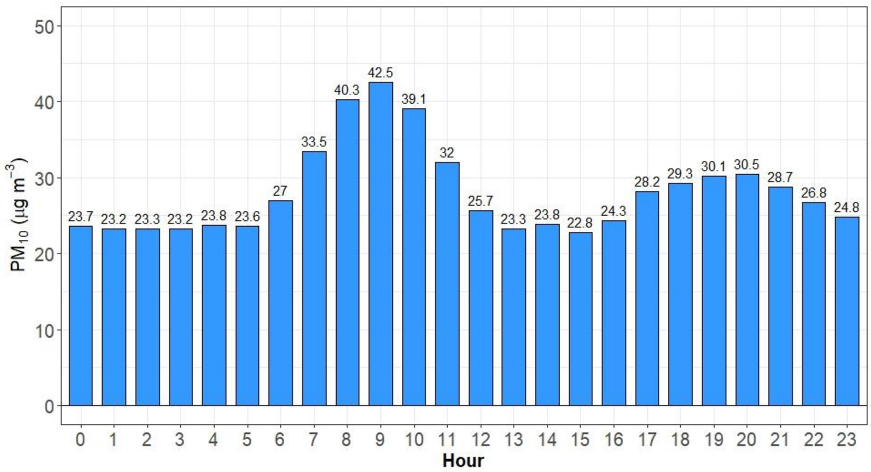


Figure 69: Diurnal variation of PM_{10} for Pulchowk Station

Daily average:

The daily average data was available for 179 days. Figure 70 explains the daily trend of PM_{10} throughout the year.

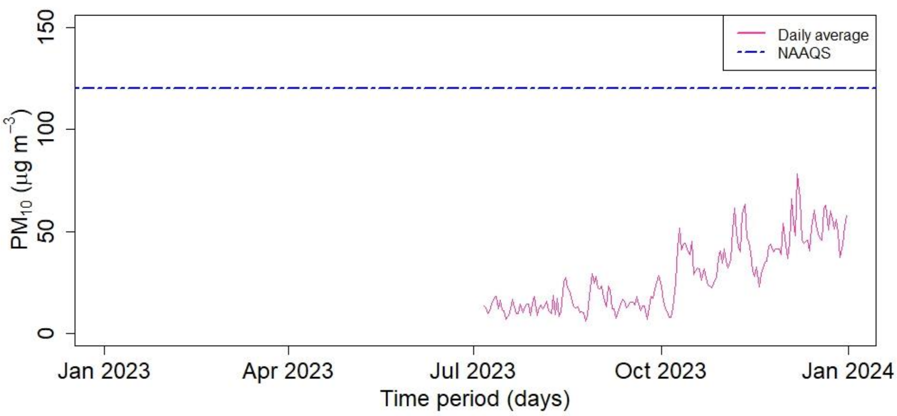


Figure 70: Daily average of PM_{10} for Pulchowk Station

Table 29: Summary of daily average of PM_{10} ($\mu g\ m^{-3}$) for Pulchowk Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
5.8	13.3	23.4	28.1 ± 16.7	41.6	78.1

Within the available data, the lowest and the highest concentration of PM_{10} was found to be 5.8 $\mu g\ m^{-3}$ to 78.1 $\mu g\ m^{-3}$ (Table 29).

Monthly average:

Figure 71 illustrates the monthly average concentration of PM_{10}. The monthly average of PM_{10} was the highest in December (51.7 $\mu g\ m^{-3}$) and lowest in July (12.8 $\mu g\ m^{-3}$).

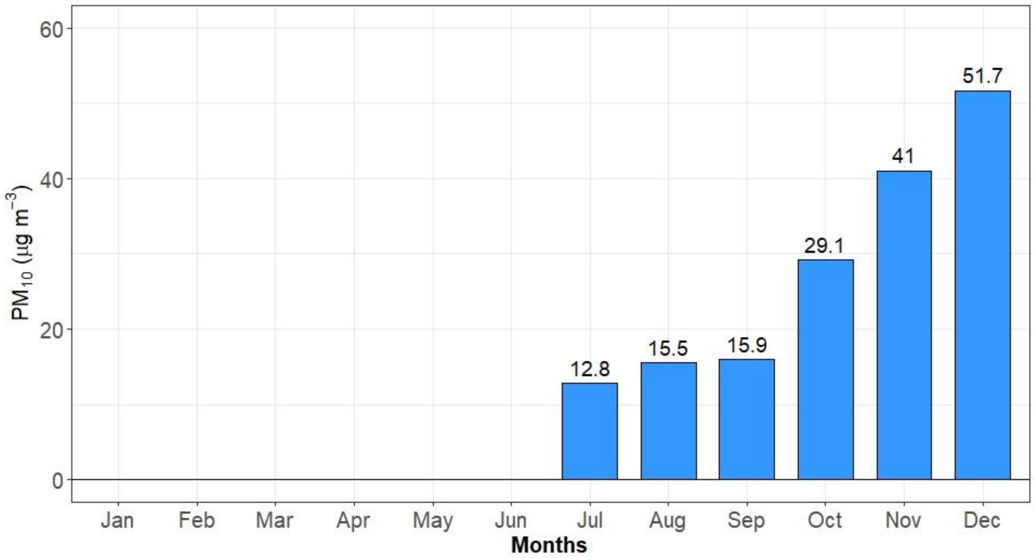


Figure 71: Monthly average of PM_{10} for Pulchowk Station

Seasonal average:

Figure 72 illustrates the seasonal distribution of the concentration of PM_{10}. Post-monsoon was observed with higher seasonal average (35.0 $\mu g\ m^{-3}$) than monsoon (14.8 $\mu g\ m^{-3}$).

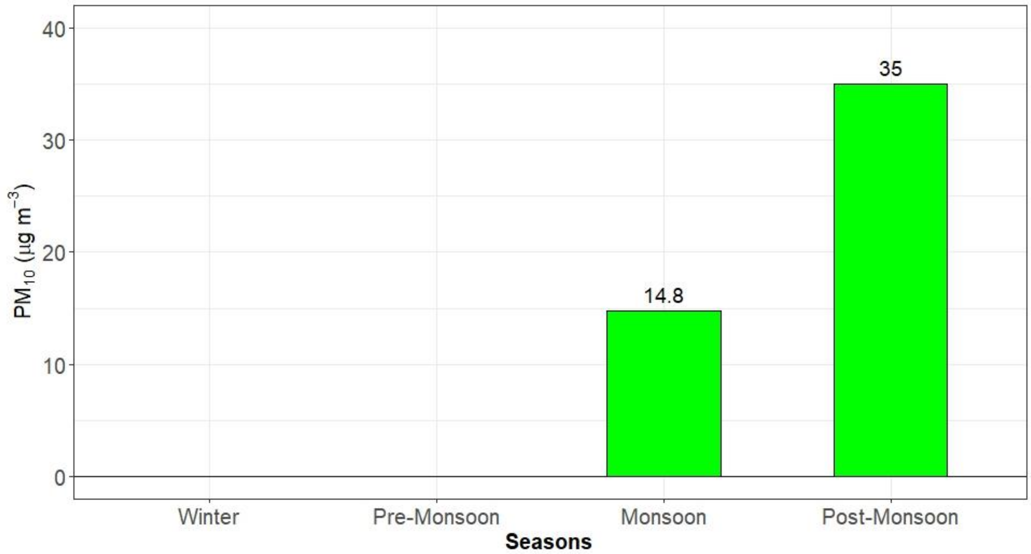


Figure 72: Seasonal average of PM_{10} for Pulchowk Station

Compliance status:

Out of the total 179 days of valid measurements, none of the days exceeded the NAAQS Figure 73.

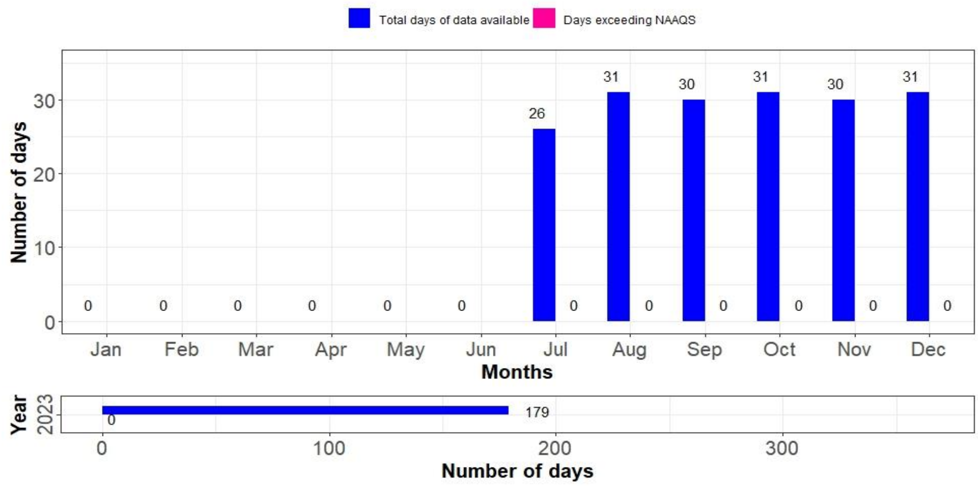


Figure 73: Compliance status of PM_{10} for Pulchowk Station

2.2.4.3 Data analysis for TSP

Hourly average:

The hourly average ranges from 1.6 μg m^{-3} to 351.9 μg m^{-3}. The statistical summary of the hourly average is presented in the Table 30.

Table 30: Summary of hourly average of TSP (μg m^{-3}) for Pulchowk Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.6	16.8	34.7	39.5 ± 28.0	55.2	351.9

Diurnal variation:

The hourly mean of TSP remain almost constant from 0:00 till 5:00 then increased with time and reaches to its peak at 10:00, after which distinct pattern was not followed (Figure 74).

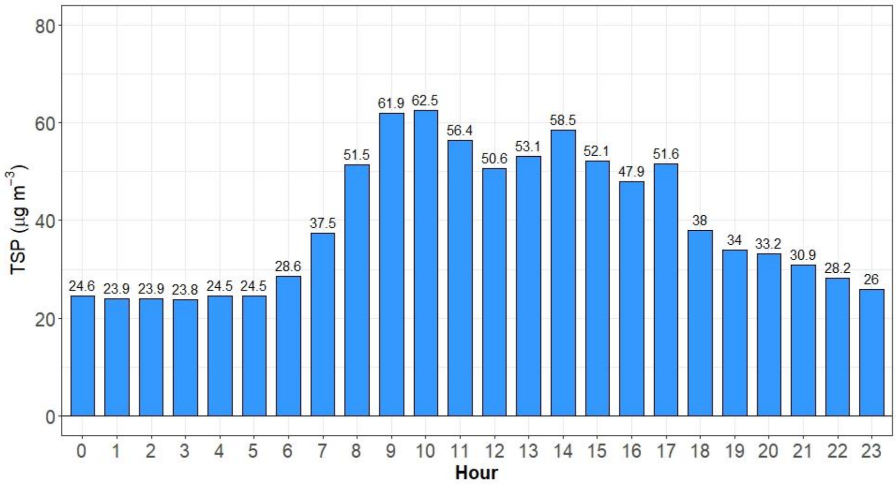


Figure 74: Diurnal variation of TSP for Pulchowk Station

Daily average:

The daily average data was available for 179 days. Figure 75 shows the daily trend of TSP throughout the year.

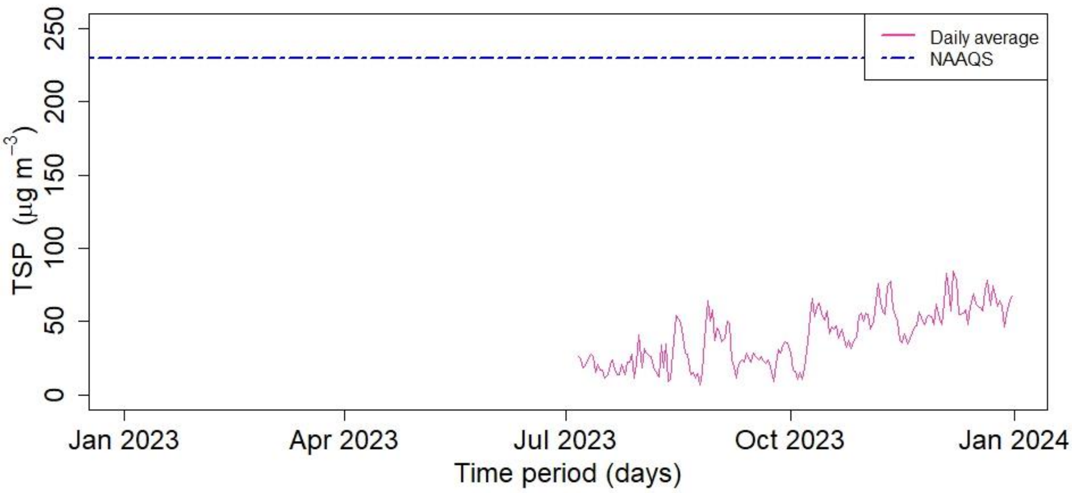


Figure 75: Daily average of TSP for Pulchowk Station

Table 31: Summary of daily average of TSP (µg m^{-3}) for Pulchowk Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
6.8	22.5	38.7	39.5 ± 19.1	54.9	84.8

Within the available data, the lowest and highest concentration of TSP was found to be 6.8 µg m^{-3} to 84.8 µg m^{-3} (Table 31).

Monthly average:

Figure 76 illustrates the monthly average concentration of TSP. The monthly average of TSP was the highest in December (63.0 µg m^{-3}) and lowest in July (20.4 µg m^{-3}).

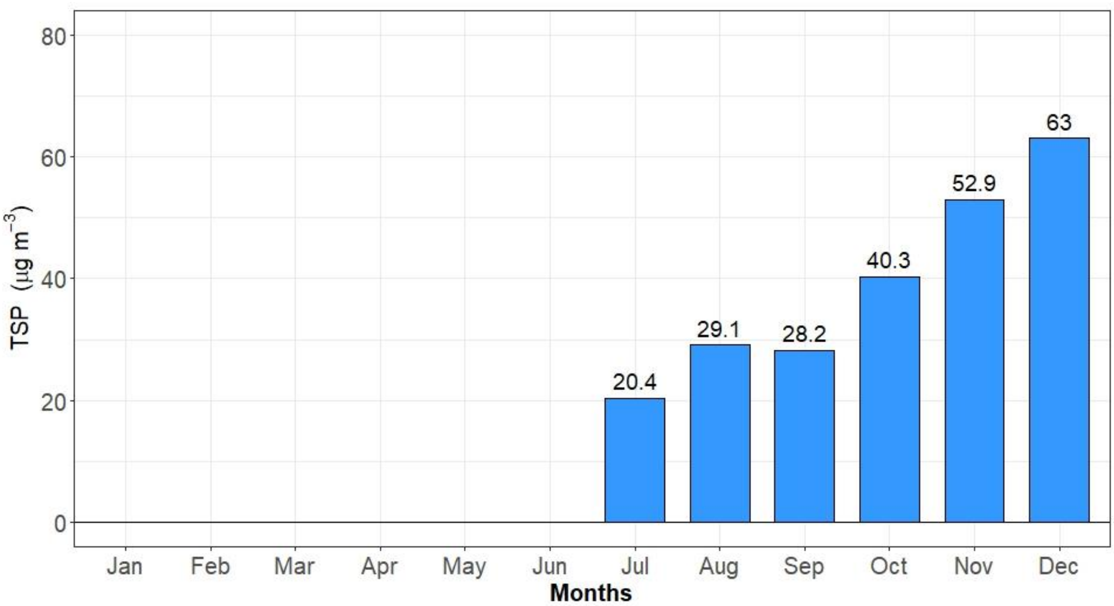


Figure 76: Monthly average of TSP for Pulchowk Station

Seasonal average:

Figure 77 illustrates the seasonal distribution of the concentration of TSP. Post-monsoon was observed with higher seasonal average (46.5 µg m^{-3}), than monsoon (26.2 µg m^{-3}).

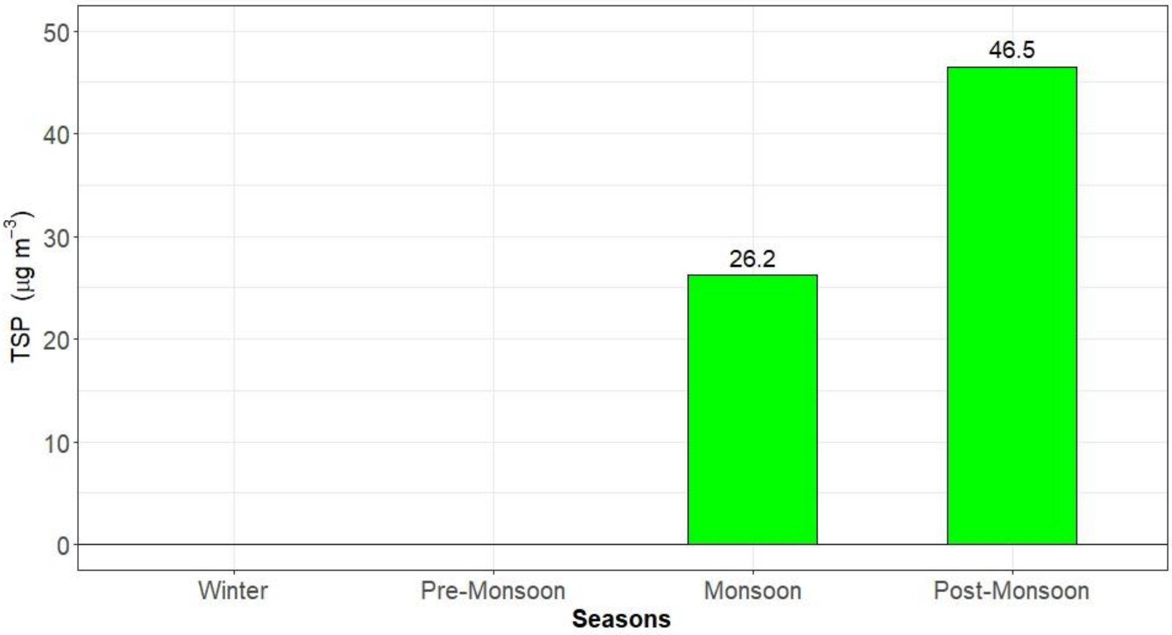


Figure 77: Seasonal average of TSP for Pulchowk Station

Compliance status:

Out of the total 179 days of measurement, none of the measured days exceeded the NAAQS (Figure 78).

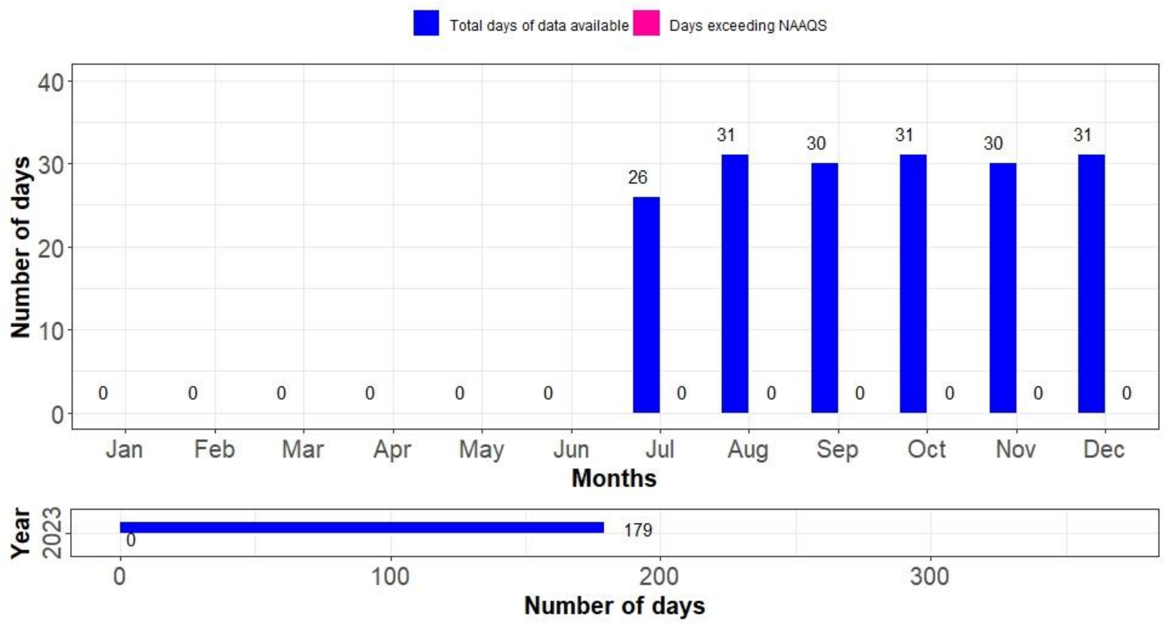


Figure 78: Compliance status of TSP for Pulchowk Station

2.2.5 RATNAPARK AIR QUALITY MONITORING STATION

Ratnapark AQMS was established in 2016 at Shankhadhar Park near Rani Pokhari. This station is situated at the center of Kathmandu and represents the urban area.

Emission from the vehicles is the major source of pollution in the area. Particle re-suspension and solid waste burning are other contributing sources of air pollution in the winter season. Regional haze is a common problem in this location. In the pre-monsoon season pollution from forest fires in different parts of the country becomes one of the major sources of the pollution.

2.2.5.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.1 μg m^{-3} to 202.4 μg m^{-3}. The statistical summary of the hourly average is presented in the Table 32.

Table 32: Summary of hourly average of $PM_{2.5}$ (μg m^{-3}) for Ratnapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.1	14.4	28.9	39.3 ± 32.3	54.9	202.4

Diurnal variation:

The hourly mean of $PM_{2.5}$ progressively decreased from 0:00 till 3:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 13:00, and again starts to rise and peaks at 21:00 (Figure 79).

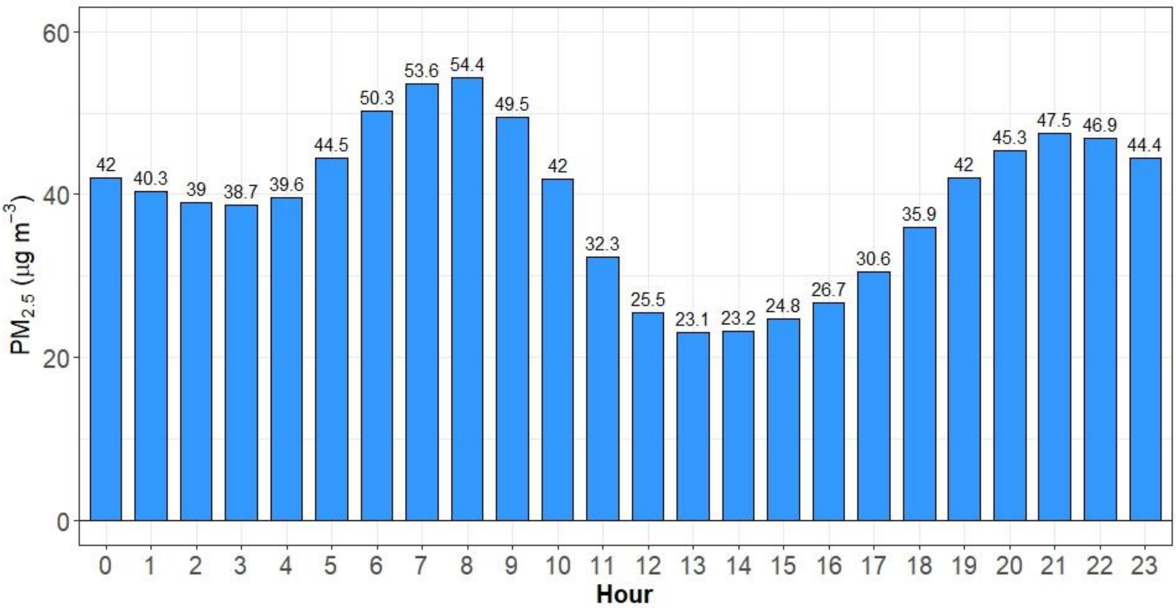


Figure 79: Diurnal variation of $PM_{2.5}$ for Ratnapark Station

Daily average:

The daily average data was available for 325 days. Figure 80 shows the daily trend of $PM_{2.5}$ throughout the year.

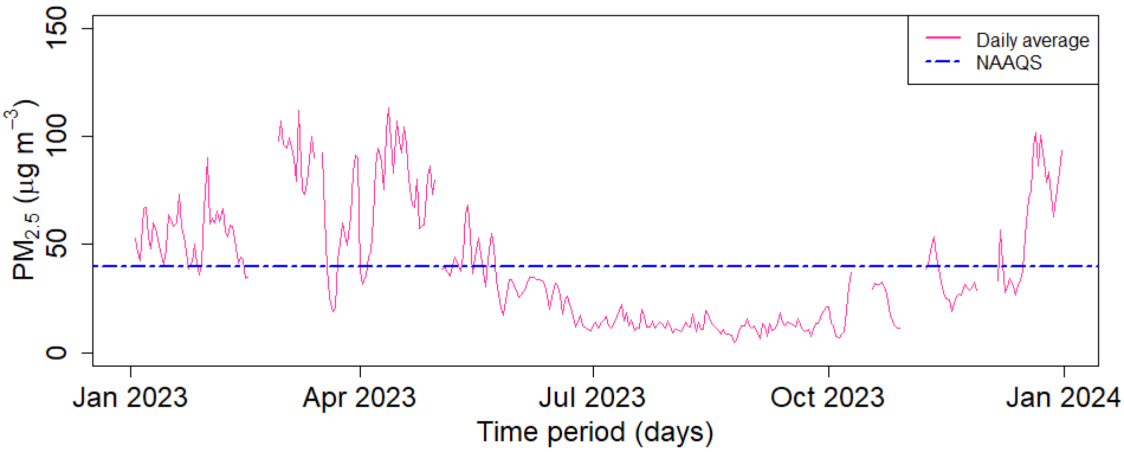


Figure 80: Daily average of $PM_{2.5}$ for Ratnapark Station

Table 33: Summary of daily average of $PM_{2.5}$ ($\mu g\ m^{-3}$) for Ratnapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
4.8	14.1	32.2	39.2 ± 27.7	58.0	113.5µg

Within the available data, the lowest and highest concentrations of $PM_{2.5}$ was 4.8 $\mu g\ m^{-3}$ and 113.5 $\mu g\ m^{-3}$ respectively (Table 33).

Monthly average:

Figure 81 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in April (76.4 $\mu g\ m^{-3}$) and lowest in August (11.5 $\mu g\ m^{-3}$).

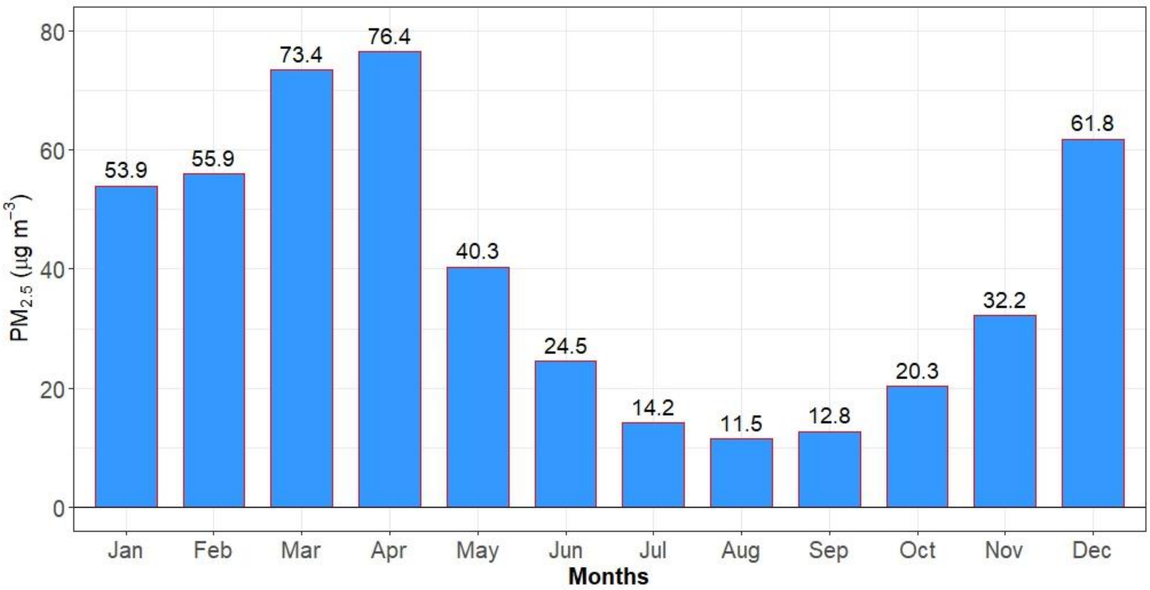


Figure 81: Monthly average of $PM_{2.5}$ for Ratnapark Station

Seasonal average:

Figure 82 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Pre-monsoon was observed with the highest seasonal average (63.5 $\mu g\ m^{-3}$), while monsoon showed the lowest seasonal average (15.7 $\mu g\ m^{-3}$).

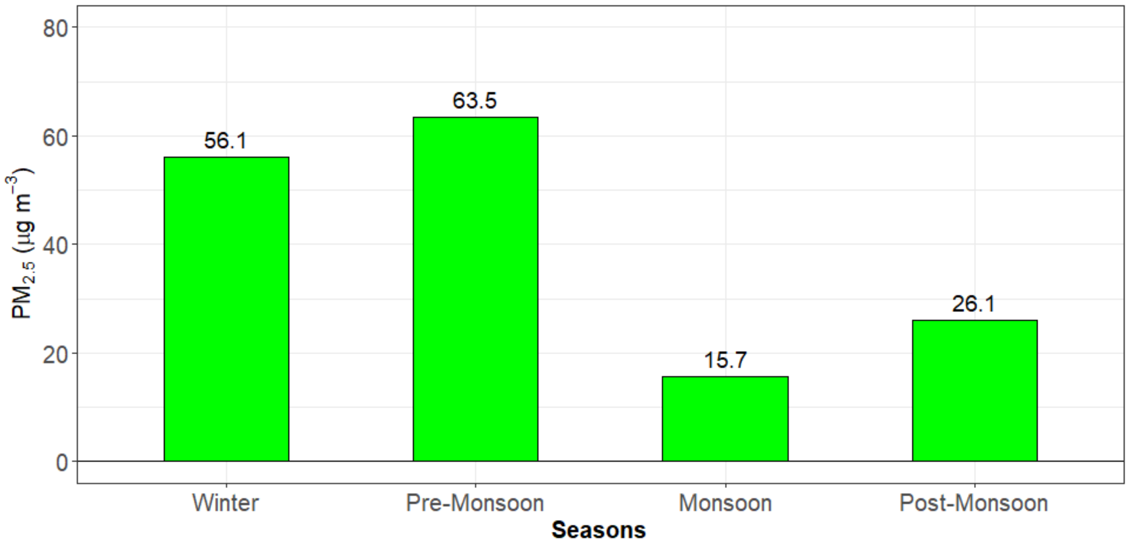


Figure 82: Seasonal average of $PM_{2.5}$ for Ratnapark Station

Compliance status:

Out of the total 325 days of valid measurements, 128 days exceeded the NAAQS (Figure 83). The compliance status is poor during January to May, November and December. In January 27 days out of 29 days with valid measurements exceeded the NAAQS. Similarly, in February 15 days out of 17 days, in March 25 days out of 29 days, in April 27 days out of 30 days, 4 days out of 21 days in November and 17 days out of 26 days exceeded the NAAQS. The none of the days exceed the NAAQS values during June to October.

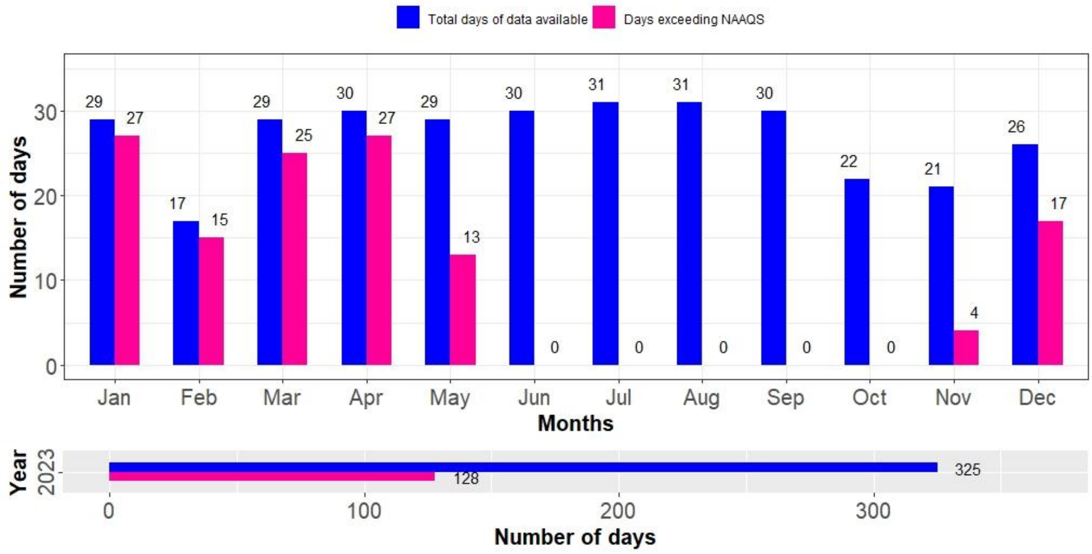


Figure 83: Compliance status of $PM_{2.5}$ for Ratnapark Station

Calendar plot

Calendar plot for $PM_{2.5}$ (Figure 84) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during January, February, March, April, May, and December. During July, August and September, almost all of the days were with good air pollution category.

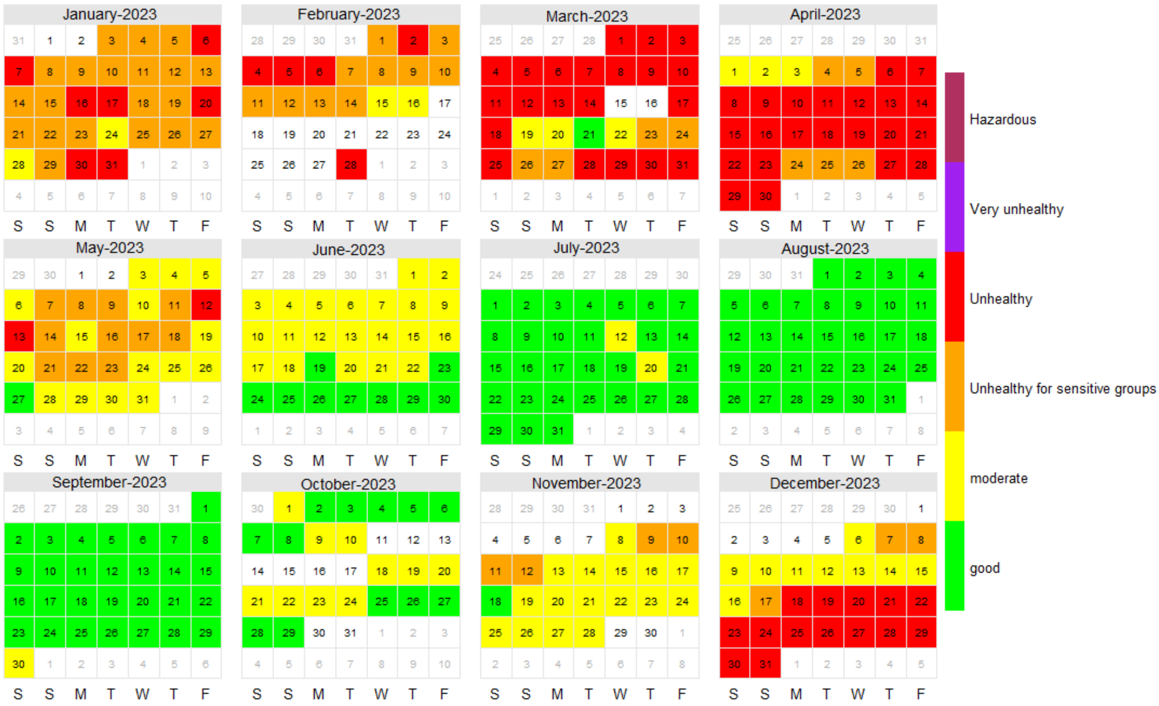


Figure 84: Calendar plot of $PM_{2.5}$ for Ratnapark Station

2.2.5.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.1 µg m^{-3} to 356.2 µg m^{-3}. The statistical summary of the hourly average is presented in Table 34.

Table 34: Summary of hourly average of PM_{10} (µg m^{-3}) for Ratnapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.1	17.0	35.2	52.7± 48.4	71.9	356.2

Diurnal variation:

The hourly mean of PM_{10} progressively decreased from 0:00 till 3:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 13:00, and again starts to rise and peaks at 21:00 (Figure 85).

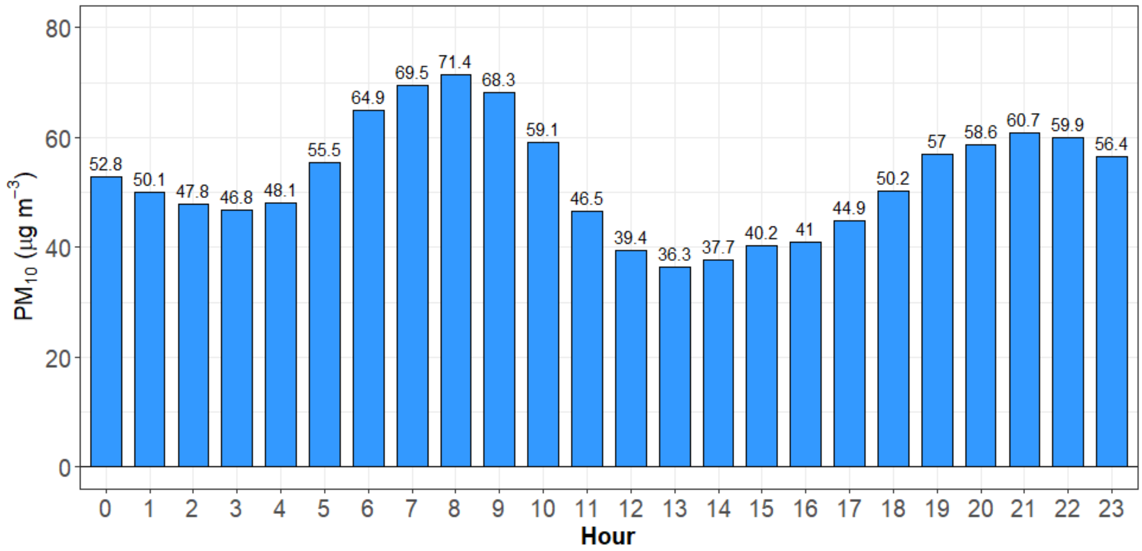


Figure 85: Diurnal variation of PM_{10} for Ratnapark Station

Daily average:

The daily average data was available for 332 days. Figure 86 explains the daily trend of PM_{10} throughout the year.

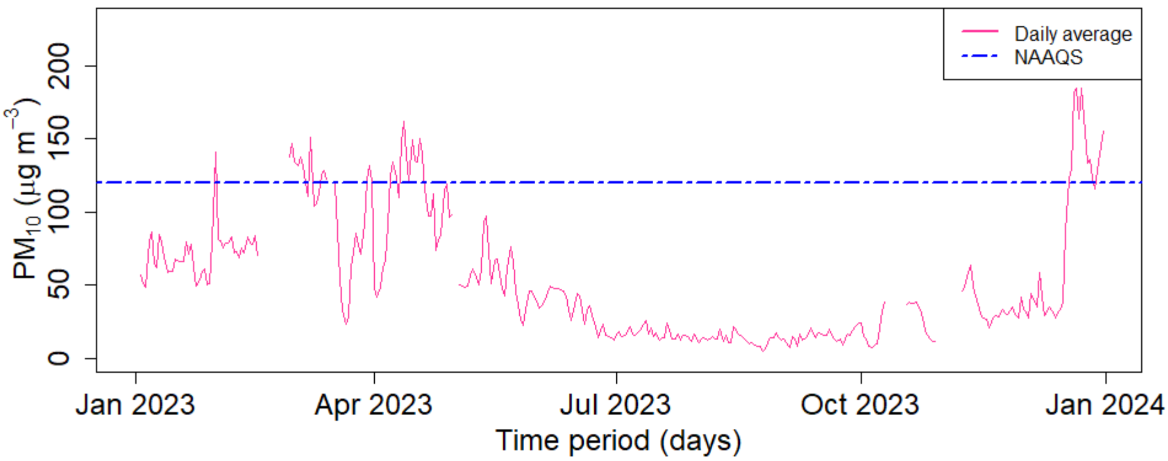


Figure 86: Daily average of PM_{10} for Ratnapark Station

Table 35: Summary of daily average of PM_{10} ($\mu g\ m^{-3}$) for Ratnapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
5.1	16.5	38.6	52.6± 27.7	75.2	184.7

Within the available data, the lowest and highest concentrations of PM_{10} was 5.1 $\mu g\ m^{-3}$ and 184.7 $\mu g\ m^{-3}$, respectively (Table 35).

Monthly average:

Figure 87 illustrates the monthly average concentration of PM_{10}. The monthly average of PM_{10} was the highest in April (107.2 $\mu g\ m^{-3}$) and lowest in August (12.9 $\mu g\ m^{-3}$).

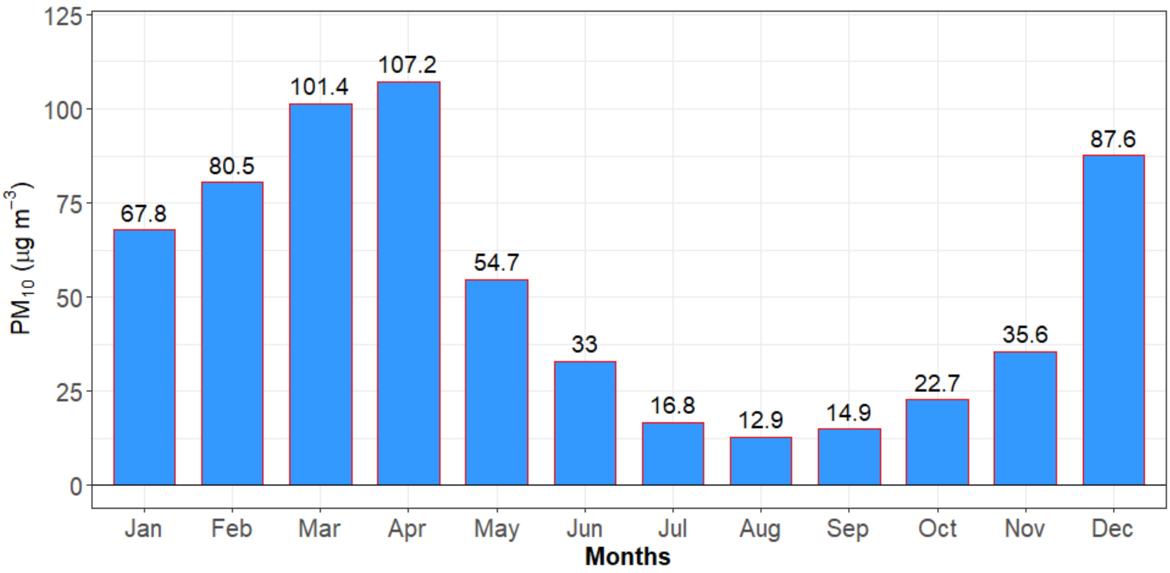


Figure 87: Monthly average of PM_{10} for Ratnapark Station

Seasonal average:

Figure 88 illustrates the seasonal distribution of the concentration of PM_{10}. Pre-monsoon was observed with the highest seasonal average (88.0 µg m^{-3}), while monsoon showed the lowest seasonal average (19.3 µg m^{-3}).

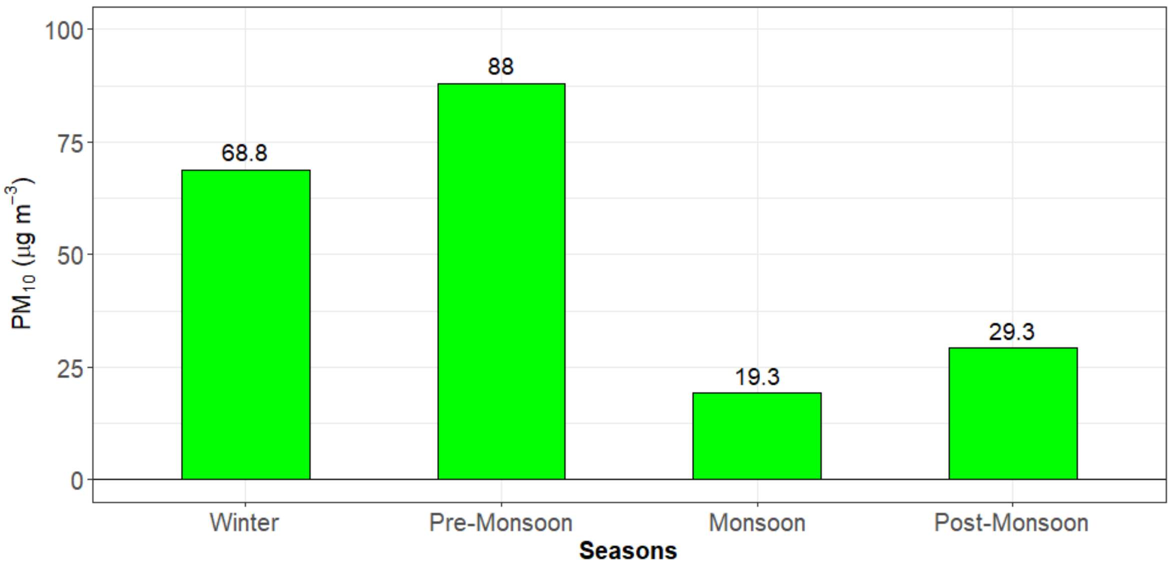


Figure 88: Seasonal average of PM_{10} for Ratnapark Station

Compliance status:

Out of the total 332 days of valid measurements, 39 days exceeded the NAAQS. The majority days exceeding NAAQS were from March, April and December Figure 89.

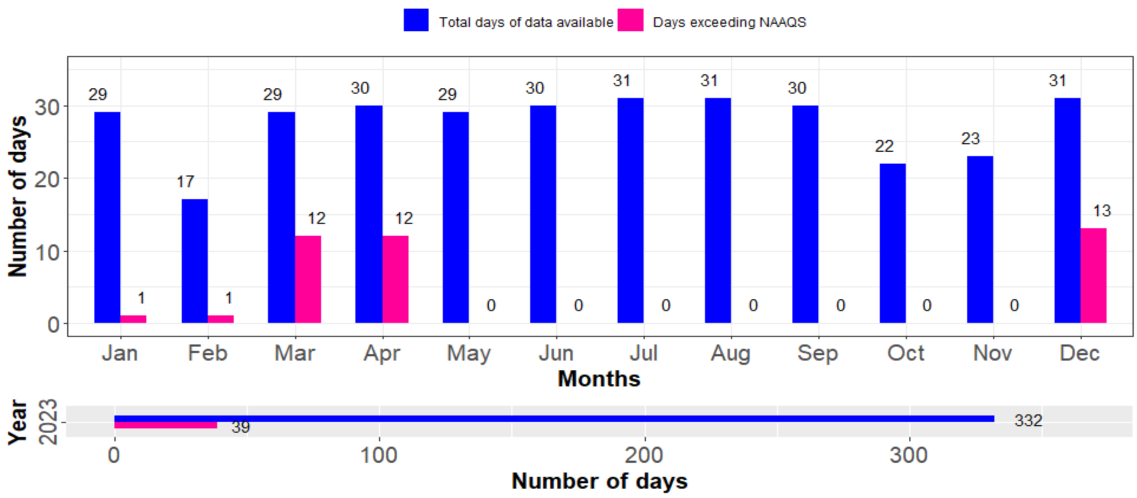


Figure 89: Compliance status of PM_{10} for Ratnapark Station

2.2.5.3 Data Analysis for TSP

Hourly average:

The hourly average ranges from 1.1 μg m^{-3} to 1253.9 μg m^{-3}. The statistical summary of the hourly average is presented in Table 36.

Table 36: Summary of hourly average of $PM_{2.5}$ (μg m^{-3}) for Ratnapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.1	17.0	41.5	66.4 ± 69.0	94.2	1253.9

Diurnal variation:

The hourly mean of TSP progressively decreased from 0:00 till 3:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 13:00, after which distinct pattern was not followed (Figure 90).

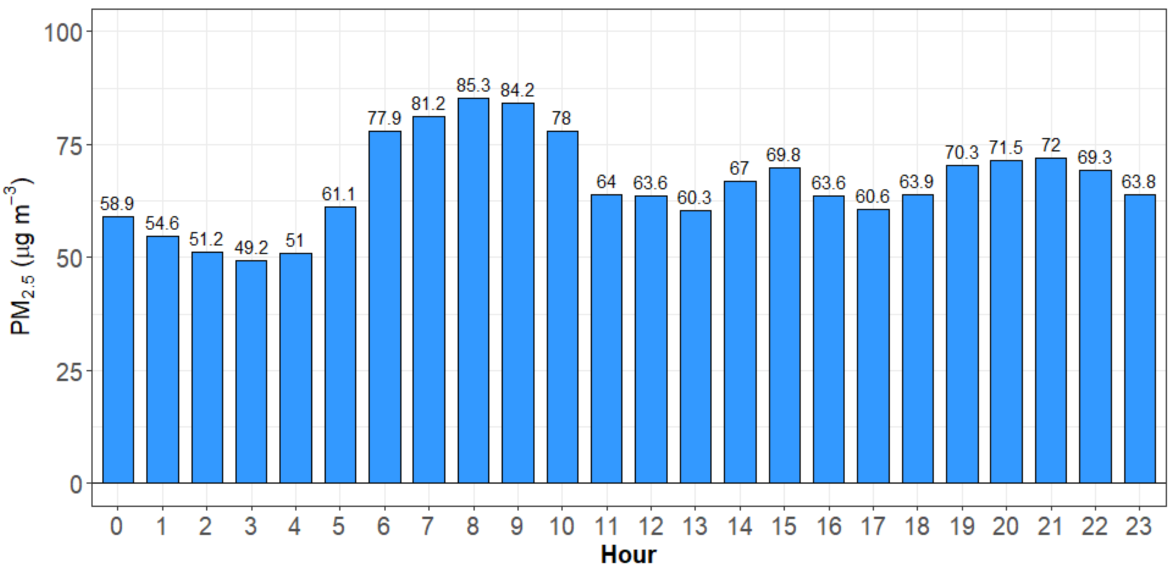


Figure 90: Diurnal variation of TSP for Ratnapark Station

Daily average:

The daily average data was available for 284 days. Figure 91 shows the daily trend of TSP throughout the year.

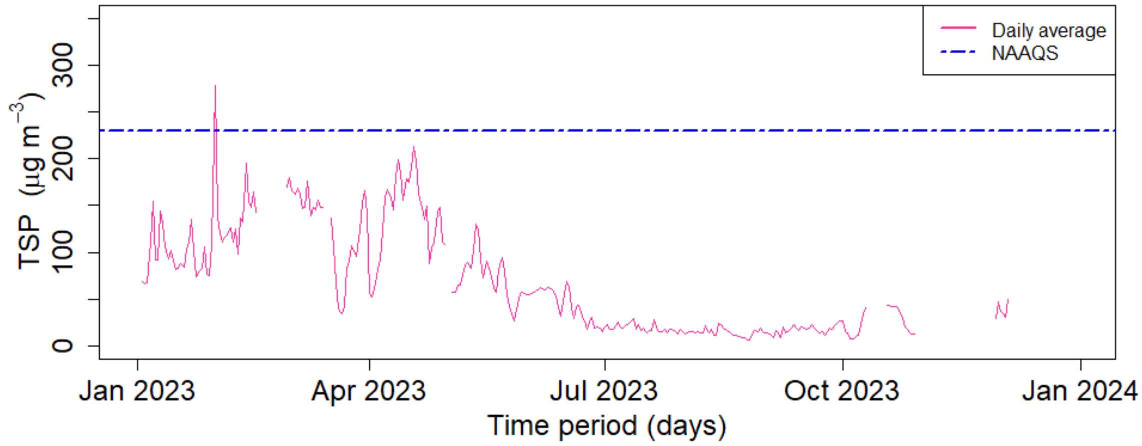


Figure 91: Daily average of TSP for Ratnapark Station

Table 37: Summary of daily average of TSP (µg m^{-3}) for Ratnapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
5.3	18.0	48.7	66.4± 55.5	105.4	278.4

Within the available data, the lowest and highest concentration of TSP was 5.3 µg m^{-3} and 278.4 µg m^{-3}, respectively (Table 37).

Monthly average:

Figure 92 illustrates the monthly average concentration of TSP. The monthly average of TSP was the highest in April (139.6 µg m^{-3}) and lowest in August (13.8 µg m^{-3}). The monthly average of TSP for November and December was not available.

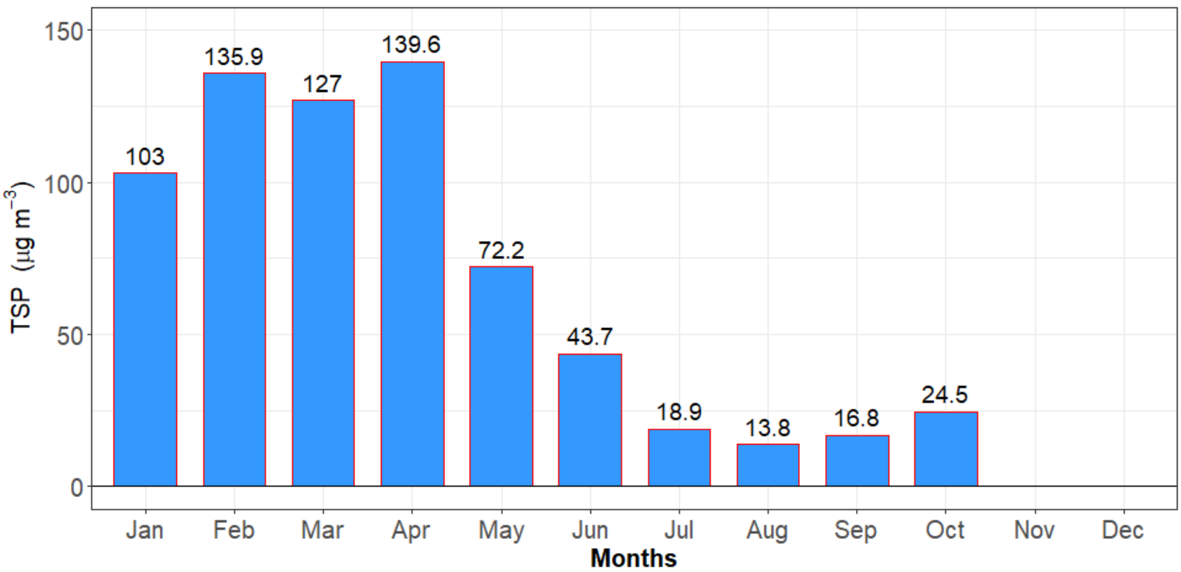


Figure 92: Monthly average of TSP for Ratnapark Station

Seasonal average:

Figure 93 illustrates the seasonal distribution of the concentration of TSP. Pre-monsoon was observed with the highest seasonal average (113.3 µg m^{-3}), while monsoon showed the lowest seasonal average (23.2 µg m^{-3}).

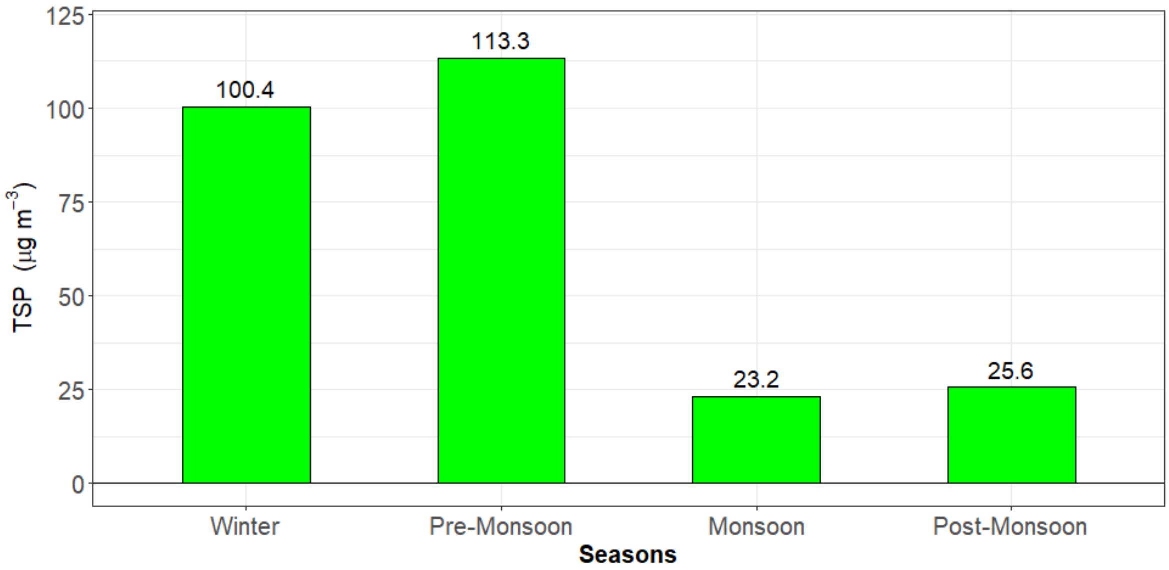


Figure 93: Seasonal average of TSP for Ratnapark Station

Compliance status:

Out of the total 284 days of valid measurements, only one day on January exceeded the NAAQS (Figure 94).

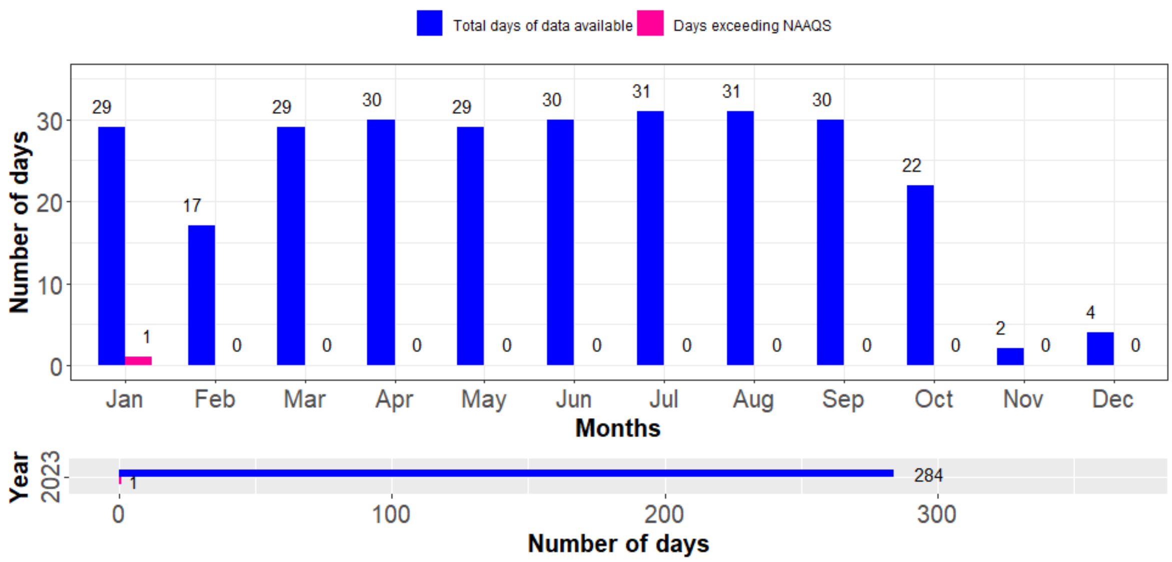


Figure 94: Compliance status of TSP for Ratnapark Station

2.2.6 SHANKHAPARK AIR QUALITY MONITORING STATION

Shankhapark AQMS was established in the year 2017 at Shankhapark near Ring road in Kathmandu. It represents the urban area.

Emissions from the vehicles and re-suspended dust from road along with solid waste burning in winter season is the main source of pollution in the area. In Pre-monsoon season, pollution from forest fire in different parts of the country become one of the major source of pollution.

2.2.6.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.1 µg m^{-3} to 184.2 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 38.

Table 38: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Shankhapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.1	29.1	43.6	49.4 ± 29.2	63.2	184.2

Diurnal variation:

The hourly mean of $PM_{2.5}$ progressively decreased from 0:00 till 2:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 14:00, and again starts to rise and peaks at 21:00 (Figure 95).

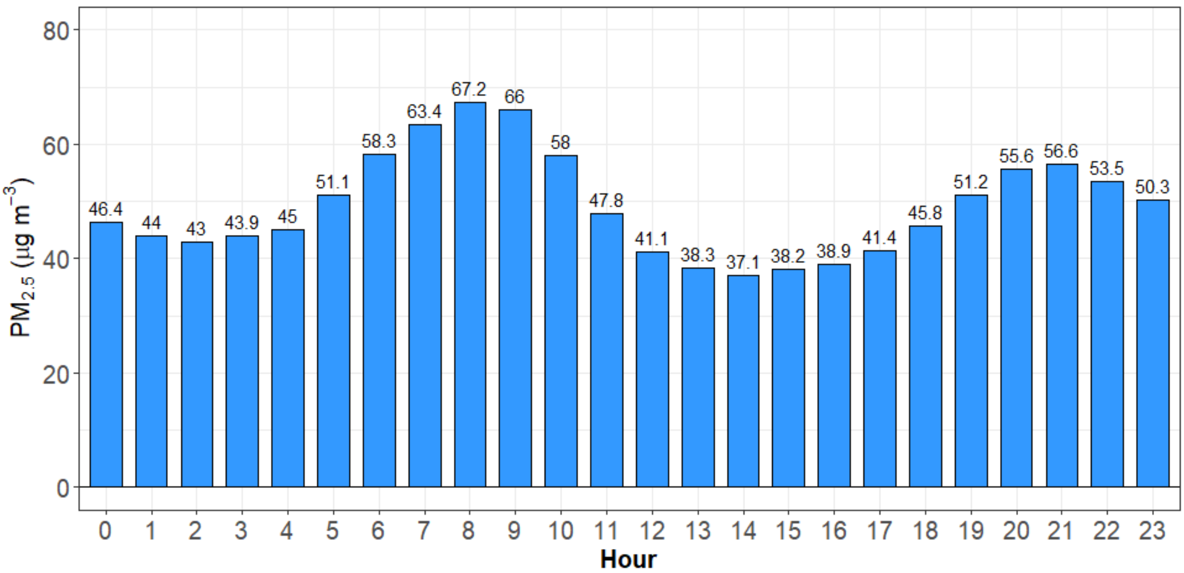


Figure 95: Diurnal variation of $PM_{2.5}$ for Shankhapark Station

Daily average:

The daily average data was available for 283 days. Figure 96 shows the daily trend of $PM_{2.5}$ throughout the year.

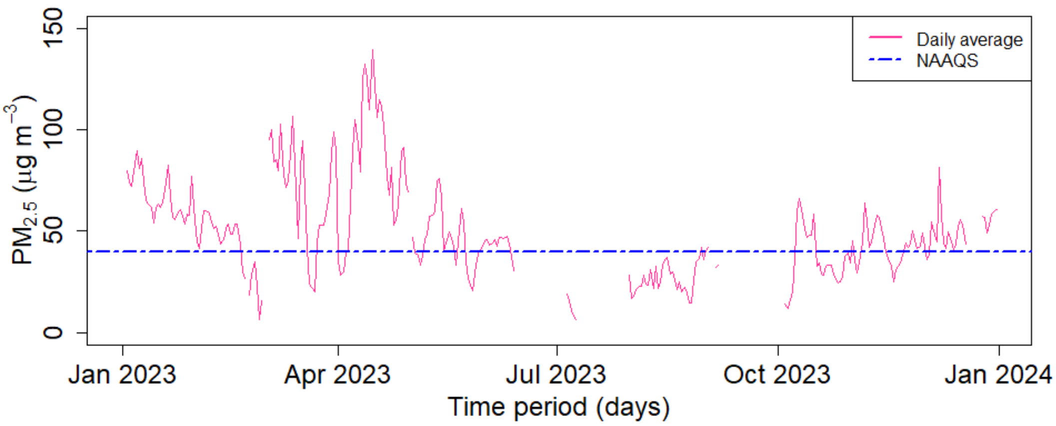


Figure 96: Daily average of $PM_{2.5}$ for Shankhapark Station

Table 39: Summary of daily average of $PM_{2.5}$ (µg m^{-3}) for Shankhapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
6.4	33.4	45.9	50.3 ± 24.3	60.3	139.7µg

Within the available data, the lowest and highest concentrations of $PM_{2.5}$ was 6.4 µg m^{-3} and 139.7 µg m^{-3} respectively (Table 39).

Monthly average:

Figure 97 illustrates the monthly average concentration of $PM_{2.5}$. Among the available monthly average values, the monthly average of $PM_{2.5}$ was the highest in April (83.9 µg m^{-3}) and lowest in August (26.2 µg m^{-3}).

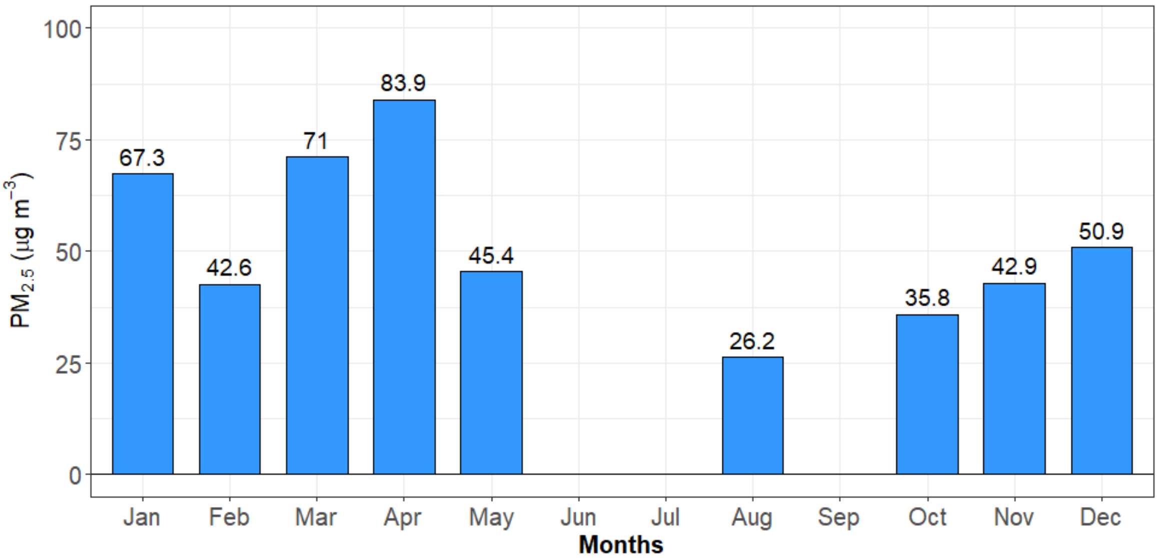


Figure 97: Monthly average of $PM_{2.5}$ for Shankhapark Station

Seasonal average:

Figure 98 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Among three seasons having seasonal average values, pre-monsoon was observed with the highest seasonal average (66.8 µg m^{-3}), while post-monsoon showed the lowest seasonal average (39.5 µg m^{-3}).

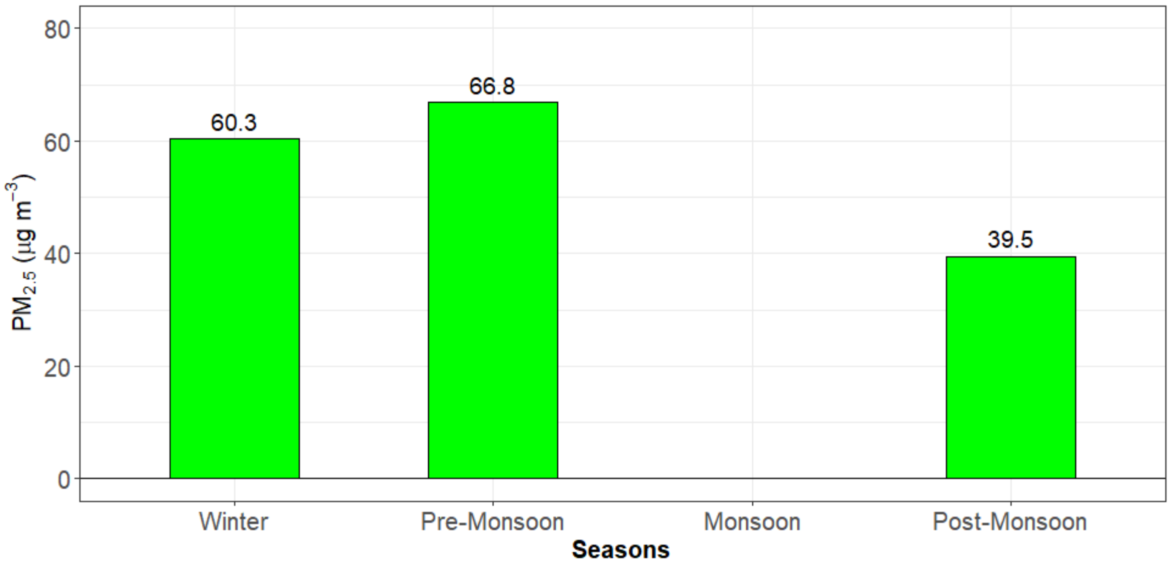


Figure 98: Seasonal average of $PM_{2.5}$ for Shankhapark Station

Compliance status:

Out of the total 283 days of valid measurements, 184 days exceeded the NAAQS (Figure 99). The compliance status was observed poor during January to May and also in November and December. In January 29 days out of 29 days with valid measurements exceeded the NAAQS. Similarly, in February 19 days out of 27 days, in March 26 days out of 29 days and in April 27 days out of 30 days exceeded the NAAQS. Similarly, in November 19 days out of 30 days and in December 23 days out of 25 days exceeded the NAAQS.

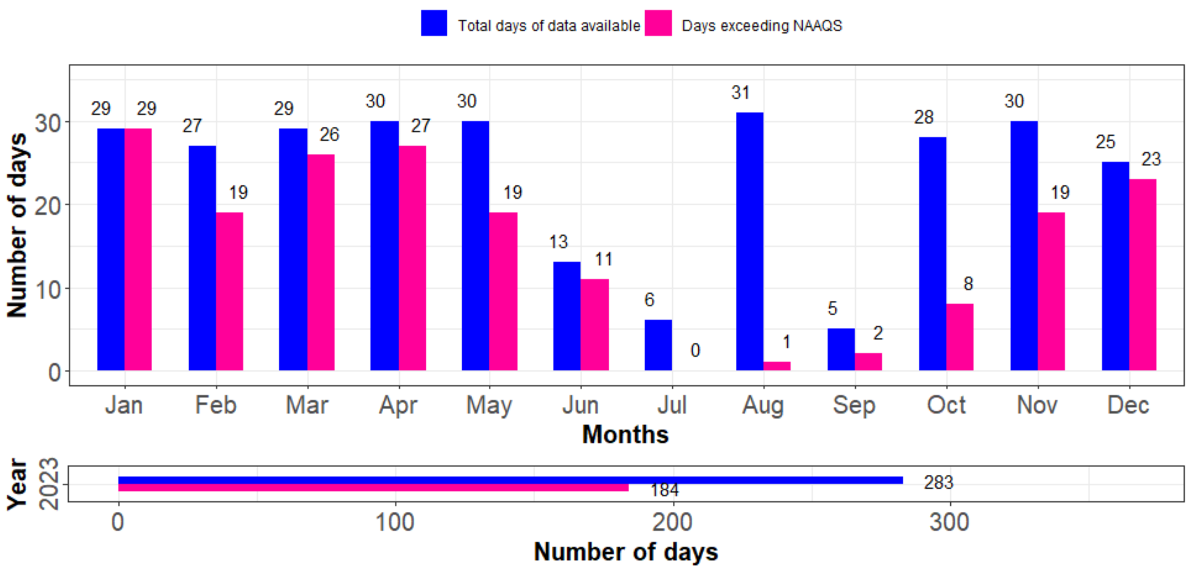


Figure 99: Compliance status of $PM_{2.5}$ for Shankhapark Station

Calendar plot

Calendar plot for $PM_{2.5}$ (Figure 100) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during January, February, March, April, May, October, November and December.

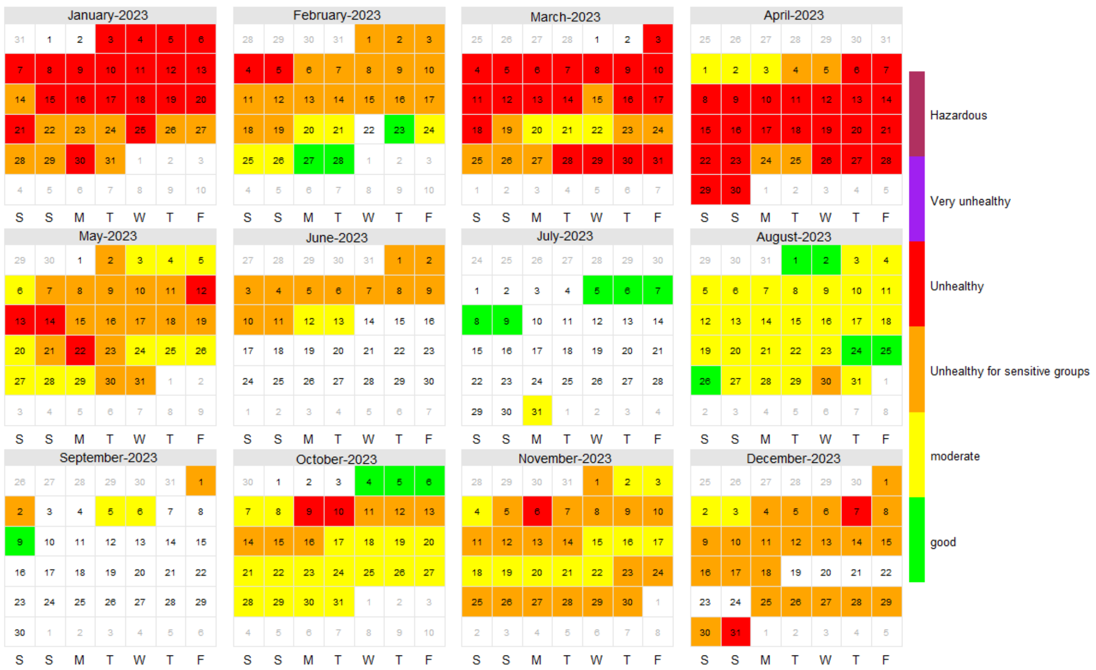


Figure 100: Calendar plot of $PM_{2.5}$ for Shankhapark Station

2.2.6.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.1 µg m^{-3} to 499.3 µg m^{-3}. The statistical summary of the hourly average is presented in Table 40.

Table 40: Summary of hourly average of PM_{10} (µg m^{-3}) for Shankhapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.1	45.7	67.9	77.3± 45.6	102.1	499.3

Diurnal variation:

The hourly mean of PM_{10} decreased from 0:00 till 2:00 then increased with time and reaches to its peak at 9:00 and after slight increase and decrease was observed throughout the day (Figure 101).

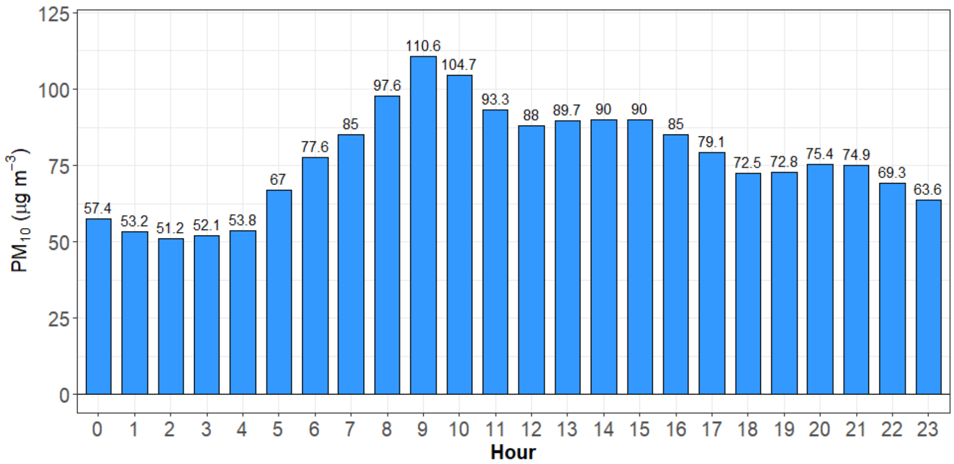


Figure 101: Diurnal variation of PM_{10} for Shankhapark Station

Daily average:

The daily average data was available for 283 days. Figure 102 explains the daily trend of PM_{10} throughout the year.

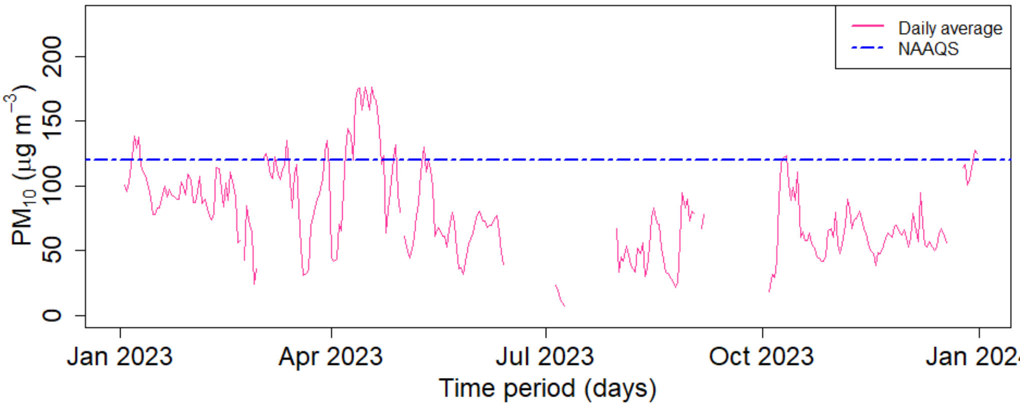


Figure 102: Daily average of PM_{10} for Shankhapark Station

Table 41: Summary of daily average of PM_{10} (µg m^{-3}) for Shankhapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
7.6	54.6	73.7	78.7± 33.8	100.4	176.6

Within the available data, the lowest and highest concentrations of PM_{10} was 7.6 µg m^{-3} and 176.6 µg m^{-3}, respectively (Table 41).

Monthly average:

Figure 103 illustrates the monthly average concentration of PM_{10}. Among the month with available monthly average value monthly average of PM_{10} was the highest in April (121.1µg m^{-3}) and lowest in August (50.2 µg m^{-3}).

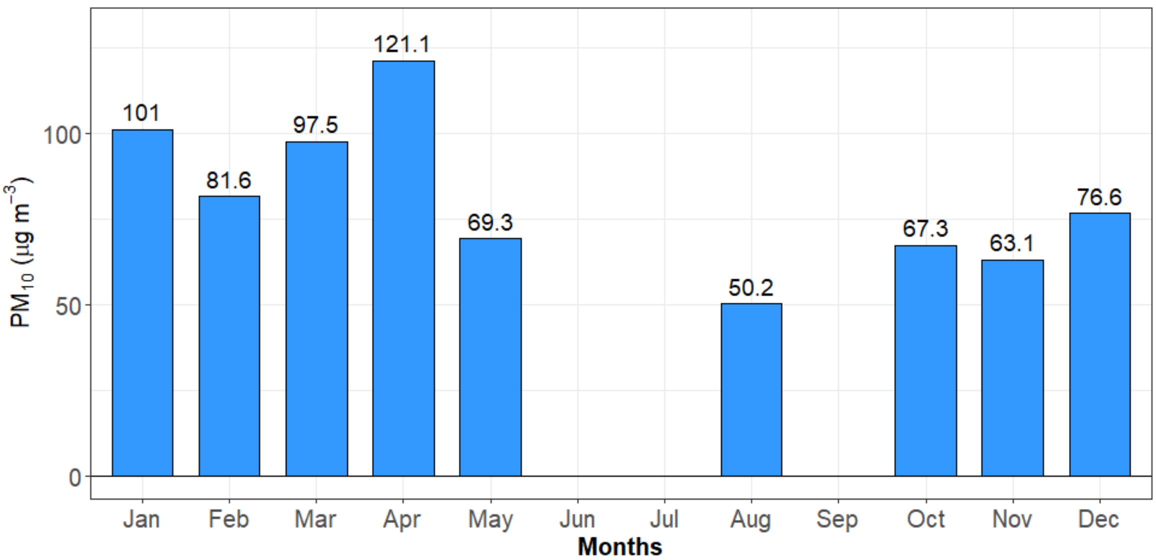


Figure 103: Monthly average of PM_{10} for Shankhapark Station

Seasonal average:

Figure 104 illustrates the seasonal distribution of the concentration of PM_{10}. Among the three seasons with available seasonal average, Pre-monsoon was observed with the highest seasonal average (95.9 µg m^{-3}), while post- monsoon showed the lowest seasonal average (65.1 µg m^{-3}).

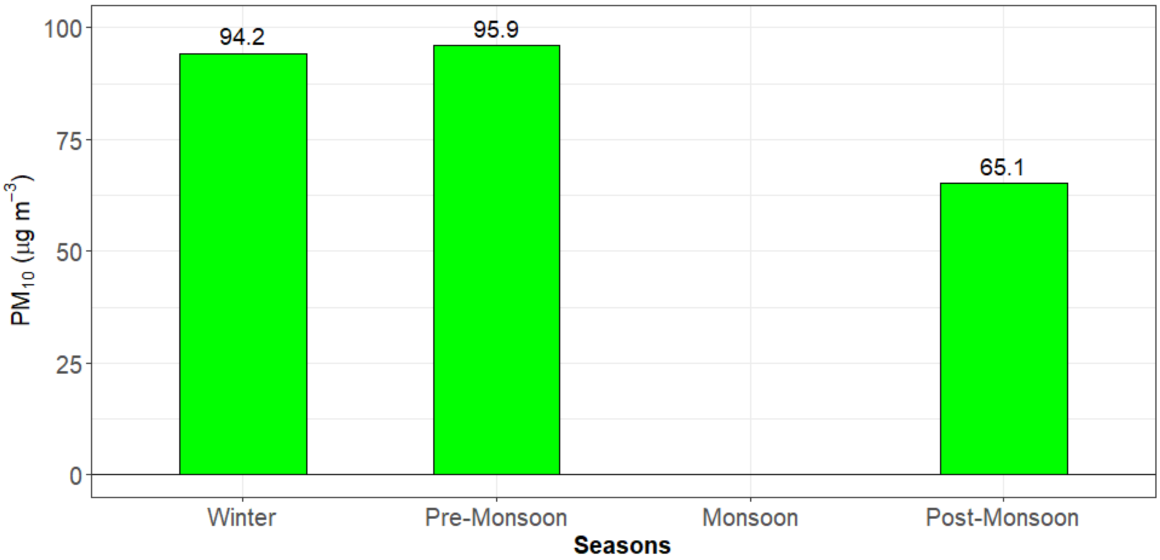


Figure 104: Seasonal average of PM_{10} for Shankhapark Station

Compliance status:

Out of the total 283 days of valid measurements, 32 days exceeded the NAAQS. The majority days in April exceeding NAAQS (Figure 105) .

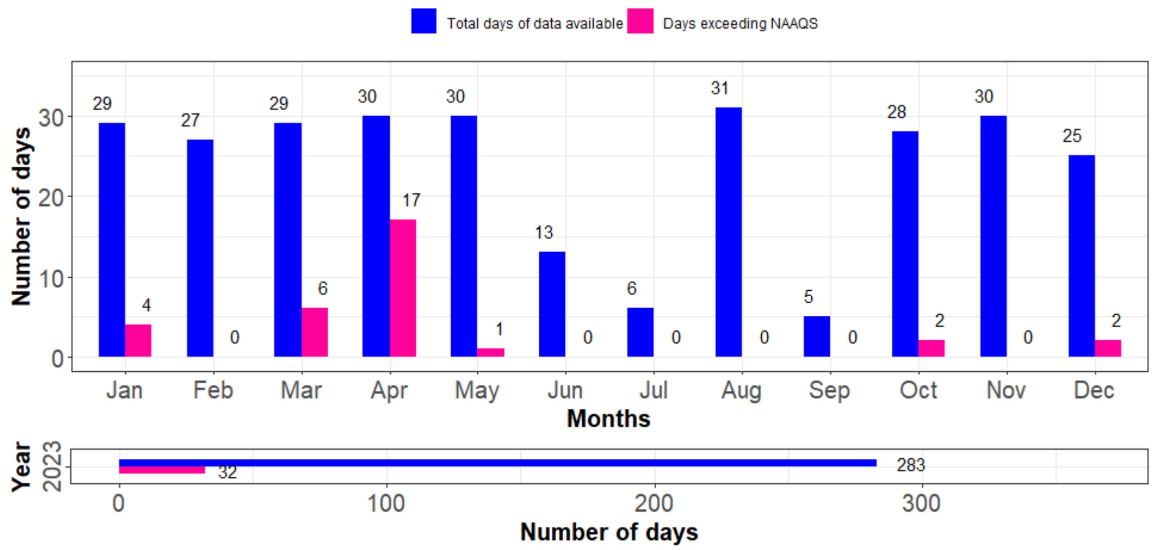


Figure 105: Compliance status of PM_{10} for Shankhapark Station

2.2.6.3 Data Analysis for TSP

Hourly average:

The hourly average ranges from 1.1 µg m^{-3} to 1354.9 µg m^{-3}. The statistical summary of the hourly average is presented in Table 42.

Table 42: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Shankhapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.1	61.0	113.2	160.9±146.3	220.1	1354.9

Diurnal variation:

The hourly mean of TSP progressively decreased from 0:00 till 3:00. After 3 it increased with time and reaches to its peak at 15:00 after that it decreased throughout the day (Figure 106).

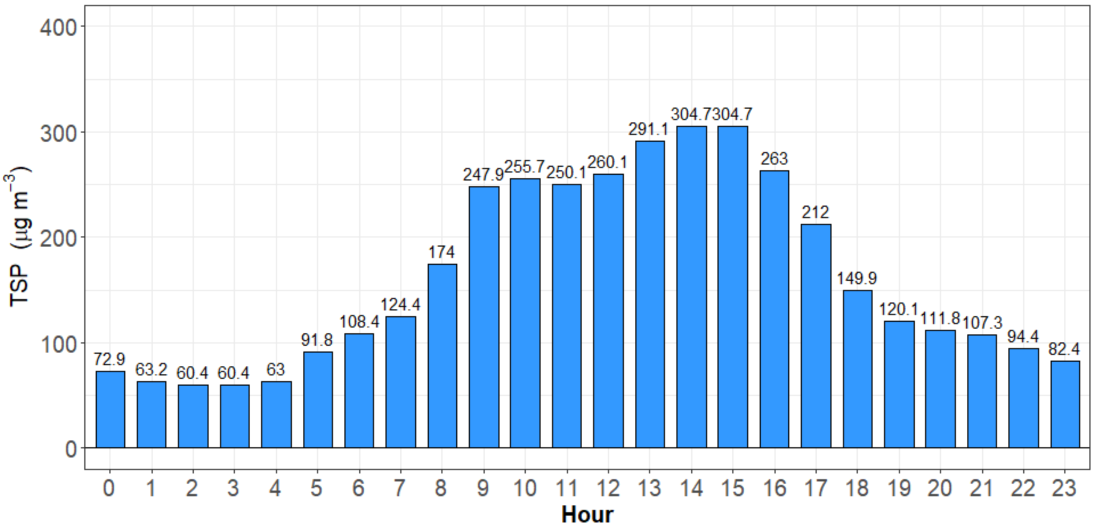


Figure 106: Diurnal variation of TSP for Shankhapark Station

Daily average:

The daily average data was available for 283 days. Figure 107 shows the daily trend of TSP throughout the year.

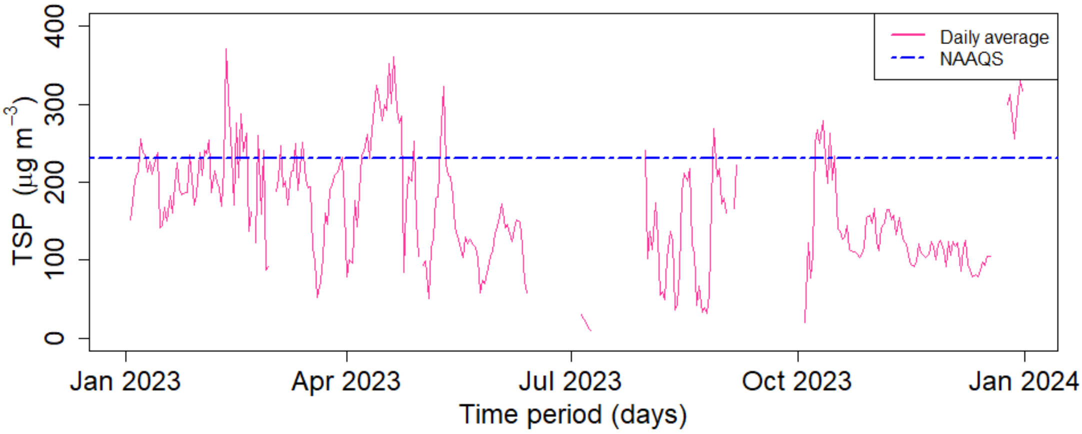


Figure 107: Daily average of TSP for Shankhapark Station

Table 43: Summary of daily average of TSP (µg m^{-3}) for Shankhapark Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
9.1	109.4	154.1	163.6± 72.8	214.0	371.6

Within the available data, the lowest and highest concentration of TSP was 9.1 µg m^{-3} and 371.6 µg m^{-3}, respectively (Table 43).

Monthly average:

Figure 108 illustrates the monthly average concentration of TSP. Among the months for which monthly average is available the monthly average of TSP was the highest in April (228.5 µg m^{-3}) and lowest in August (119.5 µg m^{-3}). The monthly average of TSP for June and July was not available.

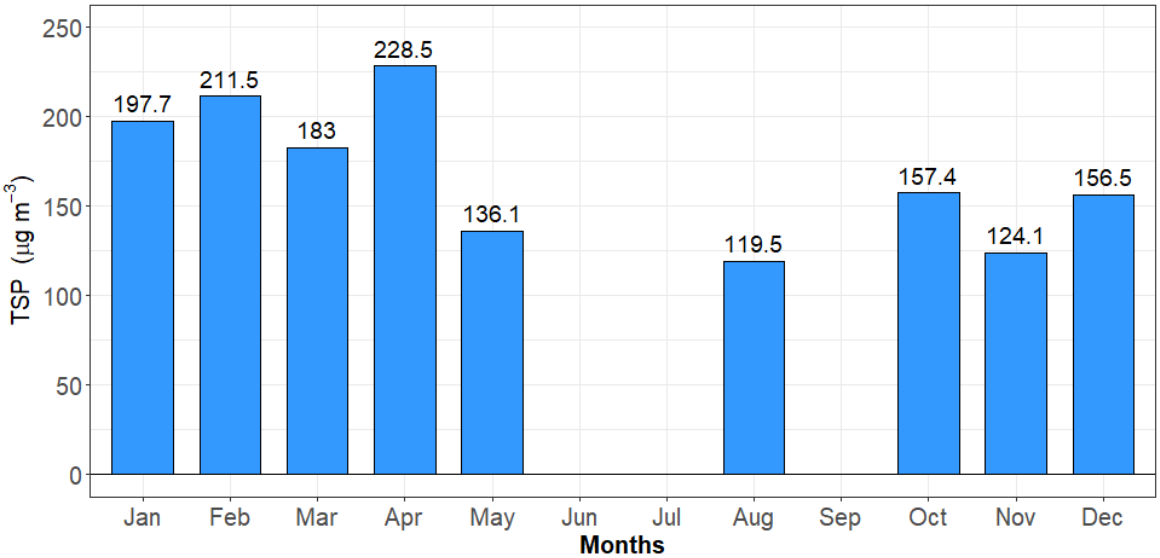


Figure 108: Monthly average of TSP for Shankhapark Station

Seasonal average:

Figure 109 illustrates the seasonal distribution of the concentration of TSP. Among three months with seasonal average value winter was observed with the highest seasonal average (198.6µg m^{-3}), while post-monsoon showed the lowest seasonal average (140.2 µg m^{-3}).

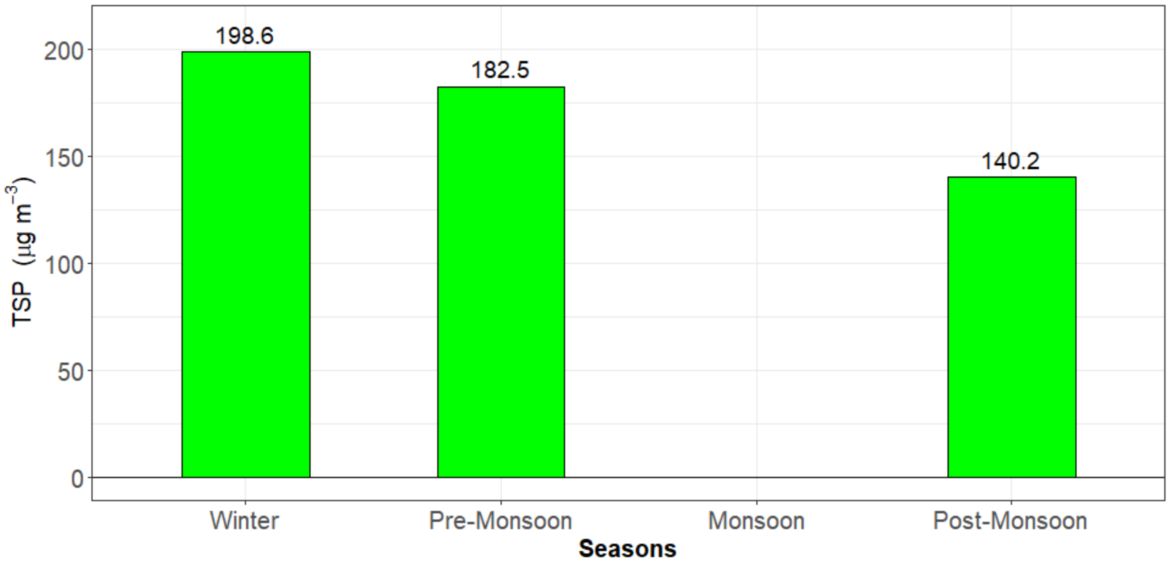


Figure 109: Seasonal average of TSP for Shankhapark Station

Compliance status:

Out of the total 283 days of valid measurements, 58 days exceeded the NAAQS (Figure 110).

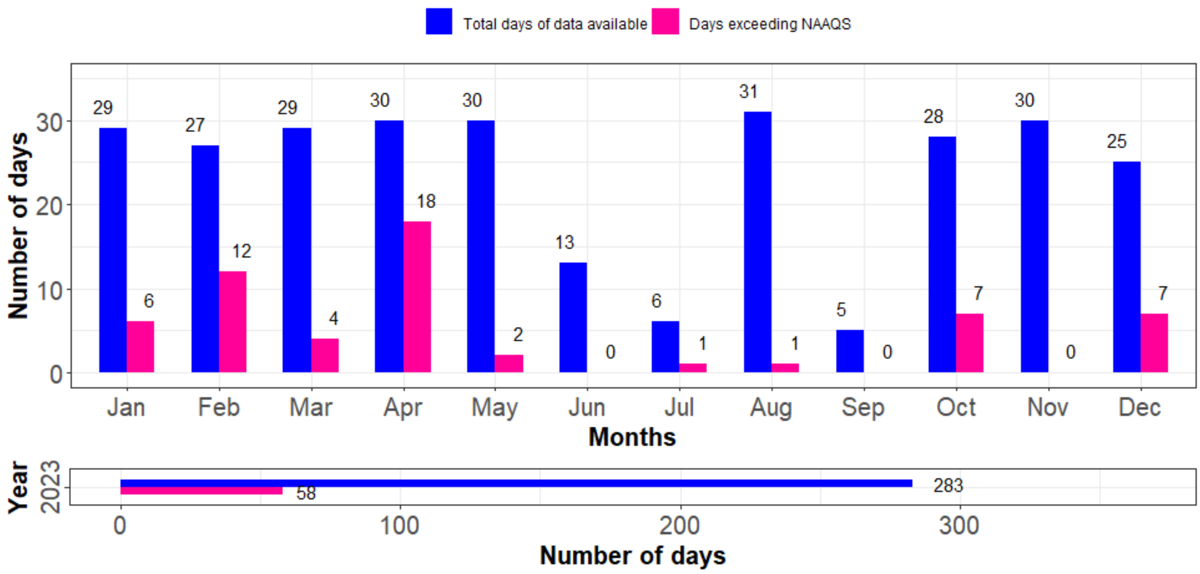


Figure 110: Compliance status of TSP for Shankhapark Station

2.2.7 TU KIRTIPUR AIR QUALITY MONITORING STATION

TU Kirtipur AQMS was established in the year 2016. It lies inside the premises of Tribhuvan university near DHM weather station.

Being situated within the university premises, there is relatively low traffic in the immediate vicinity of the station. However, the Ring road is nearby, within a distance of less than 1 kilometer. The station is positioned on the eastern side of Kirtipur municipality, with Kathmandu Metropolitan City lying to the east, signifying its urban setting. Emissions from the vehicles is the main source of pollution in the area. Besides emission from industries is another main source. In the winter season solid waste burning is also major source. Sometimes pollution from other parts of the country enters the city. In Pre-monsoon season pollution from forest fire in different parts of the country become one of the major source of pollution.

2.2.7.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.6 µg m^{-3} to 276.1 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 44.

Table 44: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for TU Kirtipur Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.6	14.6	30.6	37.2 ± 28.8	51.6	276.1

Diurnal variation:

The hourly mean of $PM_{2.5}$ reaches to its first peak at 8:00 after that it decreased till 14:00, and from 14:00 again starts to rise and peaks at 21:00 (Figure 111).

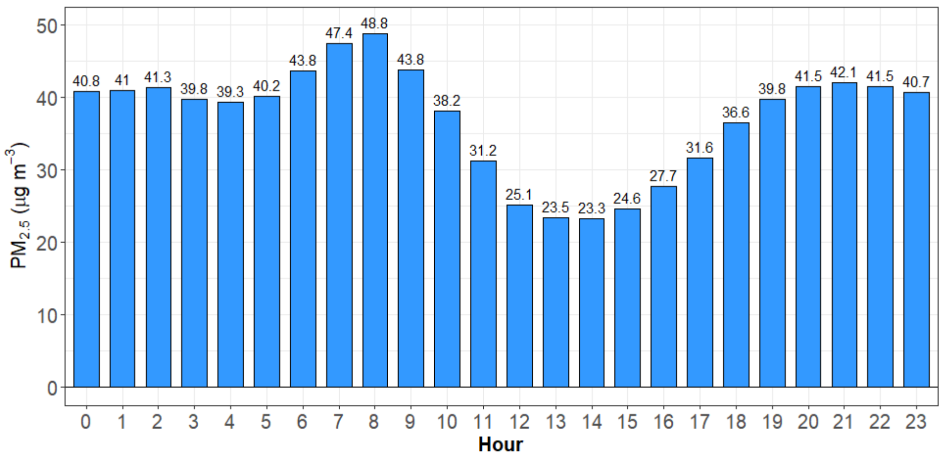


Figure 111: Diurnal variation of $PM_{2.5}$ for TU Kirtipur Station

Daily average:

The daily average data was available for 354 days. Figure 112 shows the daily trend of $PM_{2.5}$ throughout the year.

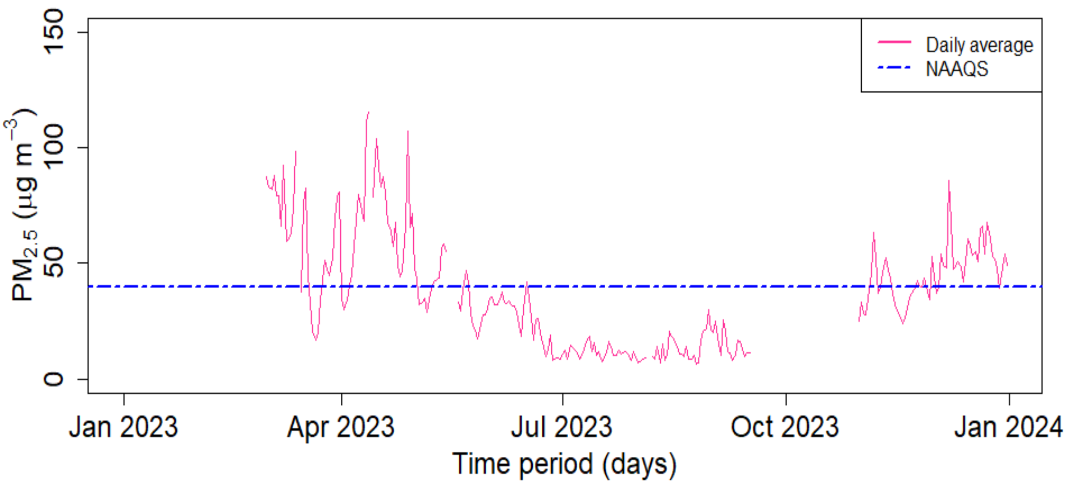


Figure 112: Daily average of $PM_{2.5}$ for TU Kirtipur Station

Table 45: Summary of daily average of $PM_{2.5}$ (µg m^{-3}) for TU Kirtipur Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
6.5	15.2	33.6	37.0 ± 24.2	51.0	115.4

Within the available data, the lowest and highest concentrations of $PM_{2.5}$ was 6.5 µg m^{-3} and 115.4 µg m^{-3} respectively (Table 45).

Monthly average:

Figure 113 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in April (68.7 µg m^{-3}) and lowest in July (11.9 µg m^{-3}).

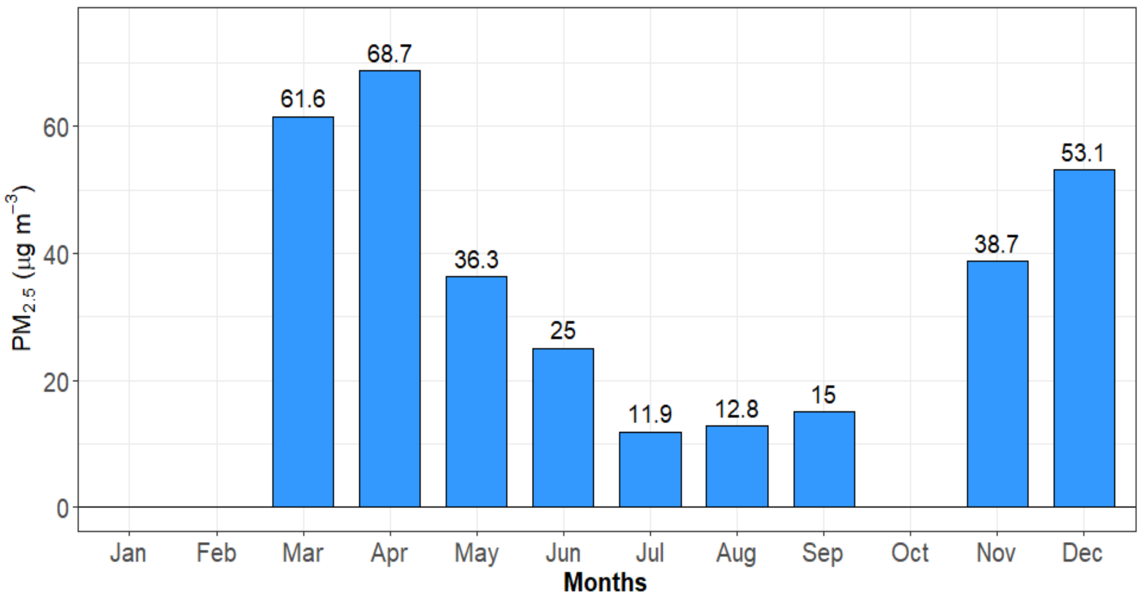


Figure 113: Monthly average of $PM_{2.5}$ for TU Kirtipur Station

Seasonal average:

Figure 114 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Among three seasons for which seasonal average is available Pre-monsoon was observed with the highest seasonal average (56.1 µg m^{-3}), while monsoon showed the lowest seasonal average (16.3 µg m^{-3}).

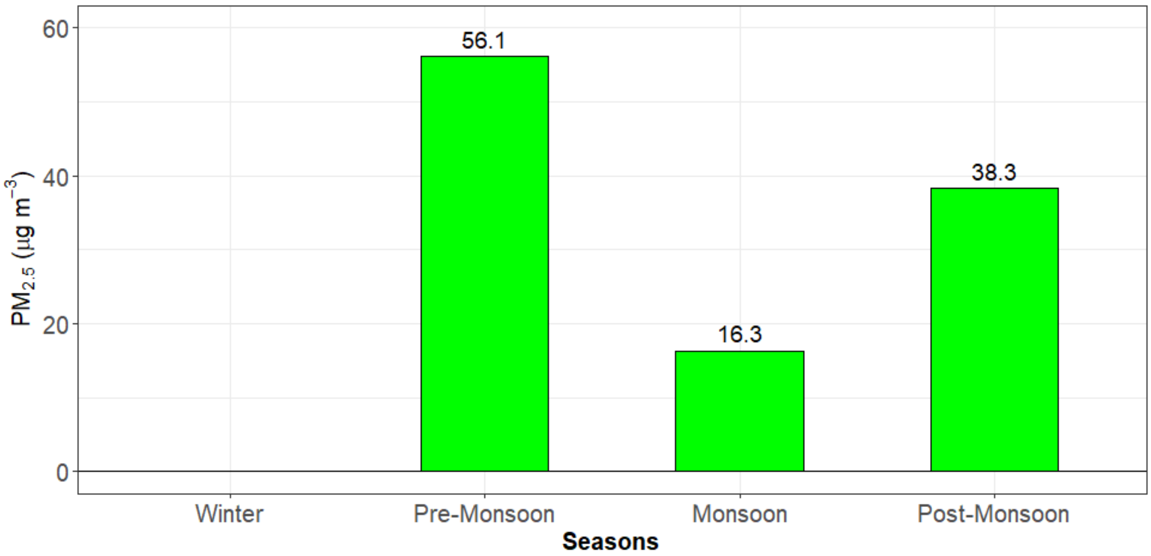


Figure 114: Seasonal average of $PM_{2.5}$ for TU Kirtipur Station

Compliance status:

Out of the total 254 days of valid measurements, 100 days exceeded the NAAQS (Figure 115). None of the days during June to October exceeded the NAAQS.

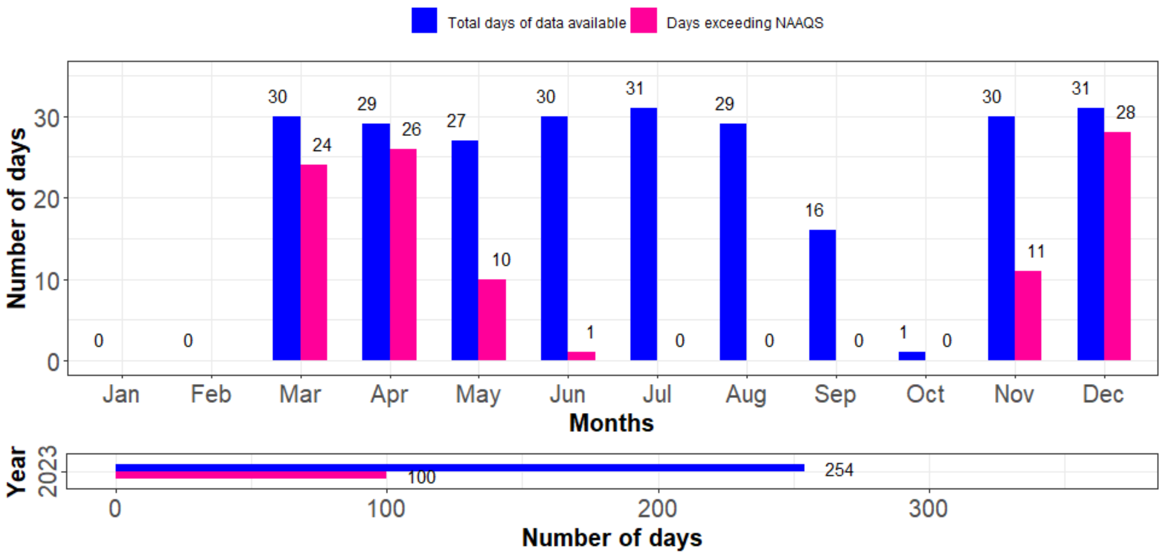


Figure 115: Compliance status of $PM_{2.5}$ for TU Kirtipur Station

Calendar plot

Calendar plot for $PM_{2.5}$ (Figure 116) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during March, April, November, and December. During July, August and September, almost all of the days were with good air pollution category.

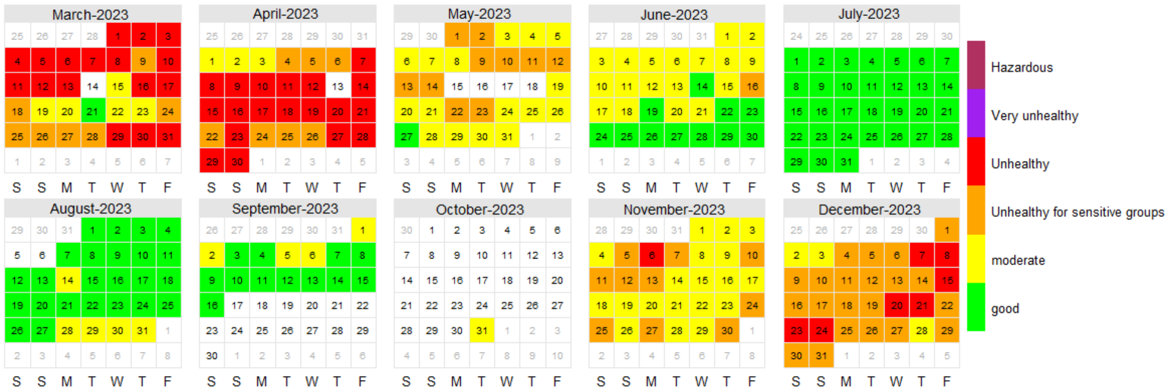


Figure 116: Calendar plot of $PM_{2.5}$ for TU Kirtipur Station

2.2.7.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.8 µg m^{-3} to 388.2 µg m^{-3}. The statistical summary of the hourly average is presented in Table 46.

Table 46: Summary of hourly average of PM_{10} (µg m^{-3}) for TU Kirtipur Station

Minimum	1^{st} quartile	Median	Mean ± SD	3^{rd} quartile	Maximum
1.8	22.3	51.8	63.9± 52.2	87.6	388.2

Diurnal variation:

The hourly mean of PM_{10} progressively decreased from 0:00 till 4:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 14:00, and again starts to rise and peaks at 19:00 (Figure 117).

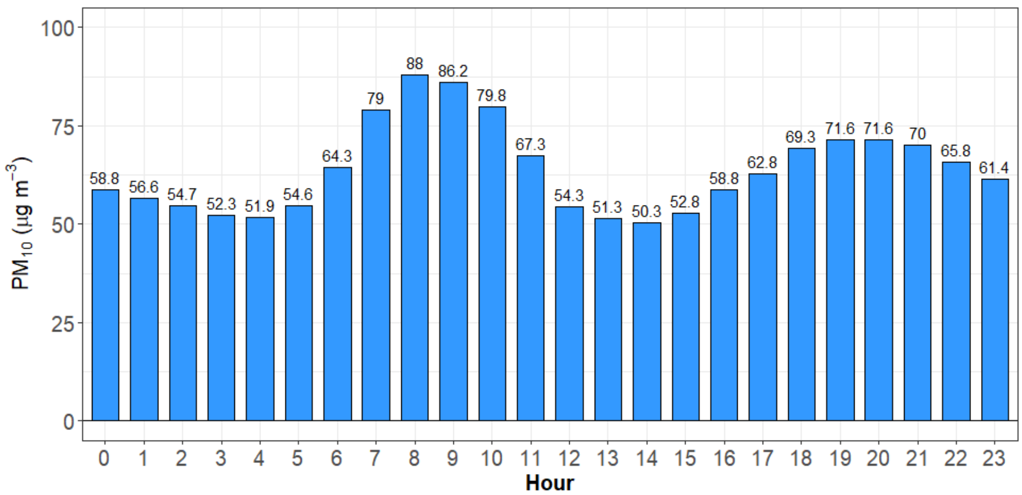


Figure 117: Diurnal variation of PM_{10} for TU Kirtipur Station

Daily average:

The daily average data was available for 254 days. Figure 118 explains the daily trend of PM_{10} throughout the year.

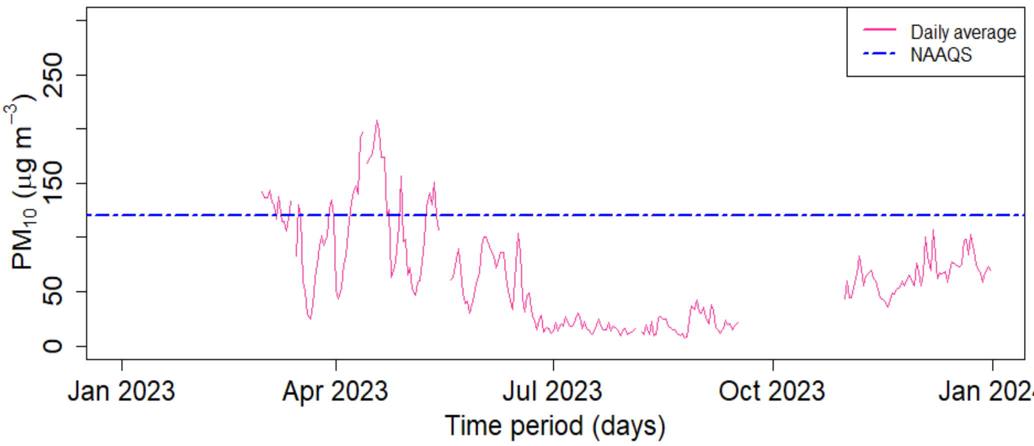


Figure 118: Daily average of PM_{10} for TU Kirtipur Station

Table 47: Summary of daily average of PM_{10} ($\mu g\ m^{-3}$) for TU Kirtipur Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
7.3	23.9	58.9	63.4± 45.0	86.4	208.0

Within the available data, the lowest and highest concentrations of PM_{10} was 7.3 $\mu g\ m^{-3}$ and 208.0 $\mu g\ m^{-3}$, respectively (Table 47).

Monthly average:

Figure 119 illustrates the monthly average concentration of PM_{10}. Among the months for which monthly average is available, the monthly average of PM_{10} was the highest in April (129 $\mu g\ m^{-3}$) and lowest in July (18.3 $\mu g\ m^{-3}$).

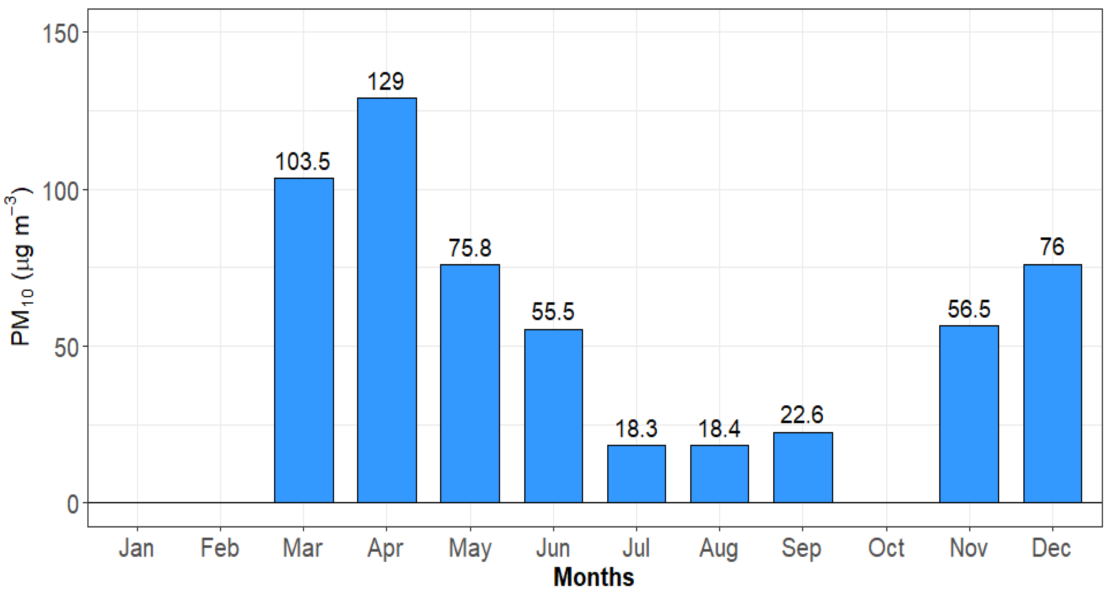


Figure 119: Monthly average of PM_{10} for TU Kirtipur Station

Seasonal average:

Figure 120 illustrates the seasonal distribution of the concentration of PM_{10}. Among the seasons for which seasonal average is available Pre-monsoon was observed with the highest seasonal average (103.4 $\mu g\ m^{-3}$), while monsoon showed the lowest seasonal average (29.5$\mu g\ m^{-3}$).

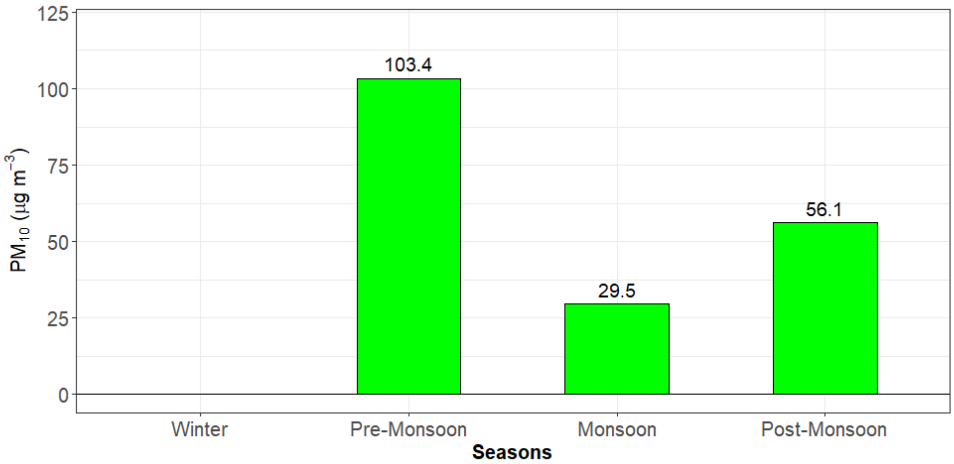


Figure 120: Seasonal average of PM_{10} for TU Kirtipur Station

Compliance status:

Out of the total 254 days of valid measurements, 34 days exceeded the NAAQS. Those days exceeding NAAQS were from March, April and May (Figure 121).

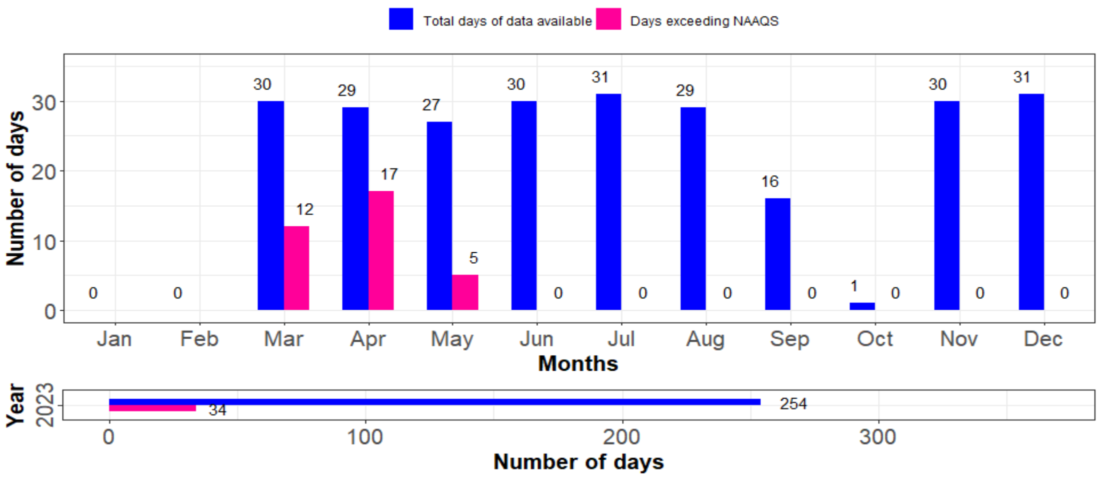


Figure 121: Compliance status of PM_{10} for TU Kirtipur Station

2.2.7.3 Data Analysis for TSP

Hourly average:

The hourly average ranges from 1.8 µg m^{-3} to 1069.2 µg m^{-3}. The statistical summary of the hourly average is presented in Table 48.

Table 48: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for TU Kirtipur Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.8	32.7	79.5	113.0 ± 103.8	166.8	1069.2

Diurnal variation:

The hourly mean of TSP progressively decreased from 0:00 till 4:00 then increased with time and reaches to its peak at 10:00 after that it decreased till 12:00, after this it is almost similar till 15:00.

From 15:00 it increases slightly after which it progressively decreased throughout the day (Figure 122).

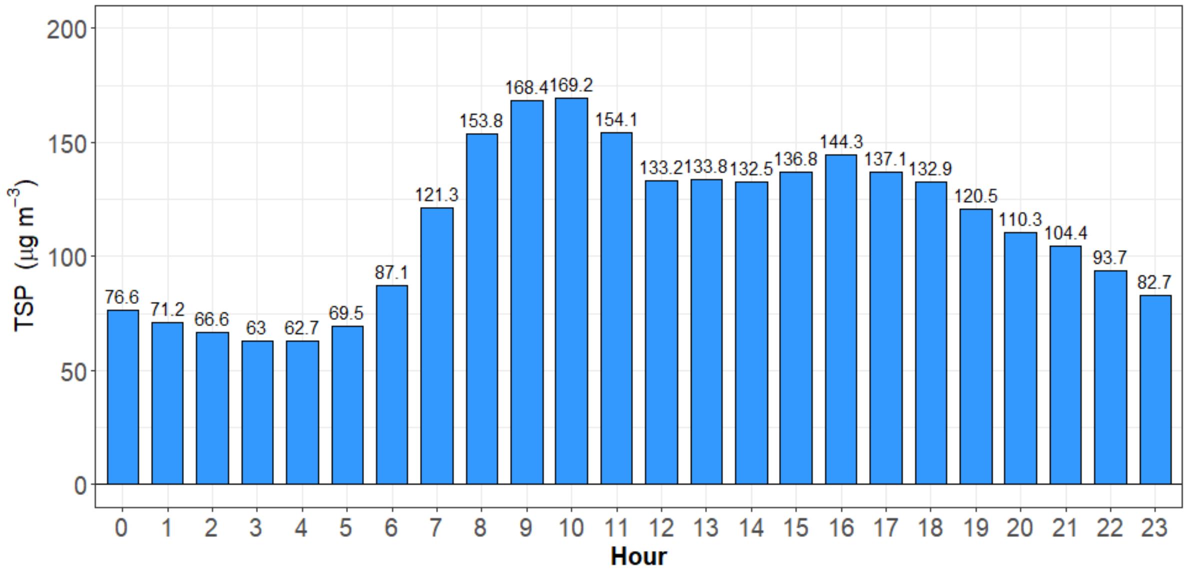


Figure 122: Diurnal variation of TSP for TU Kirtipur Station

Daily average:

The daily average data was available for 253 days. Figure 123 shows the daily trend of TSP throughout the year.

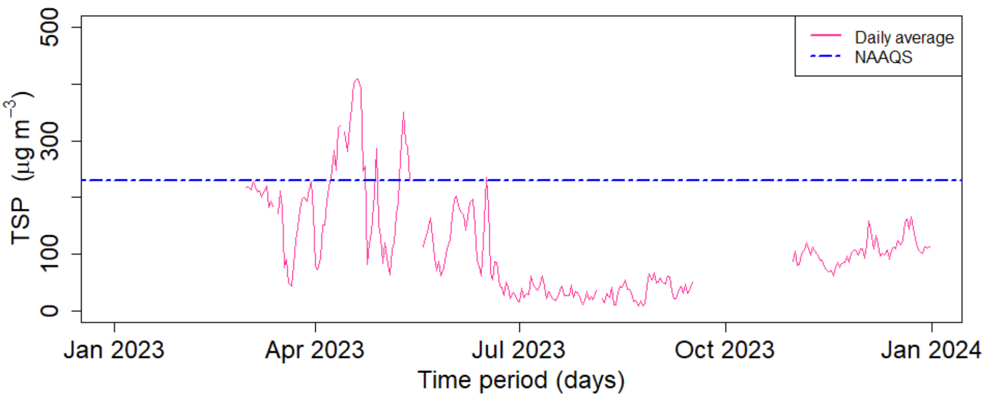


Figure 123: Daily average of TSP for TU Kirtipur Station

Table 49: Summary of daily average of TSP (µg m^{-3}) for TU Kirtipur Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
8.1	43.1	95.2	112.0±85.0	158.9	408.2

Within the available data, the lowest and highest concentration of TSP was 8.1 µg m^{-3} and 408.2 µg m^{-3}, respectively (Table 49).

Monthly average:

Figure 124 illustrates the monthly average concentration of TSP. Among the months for which monthly average is available, the monthly average of TSP was the highest in April (237.2 µg m^{-3}) and lowest in August (30.7 µg m^{-3}). The monthly average of TSP for January, February and October was not available.

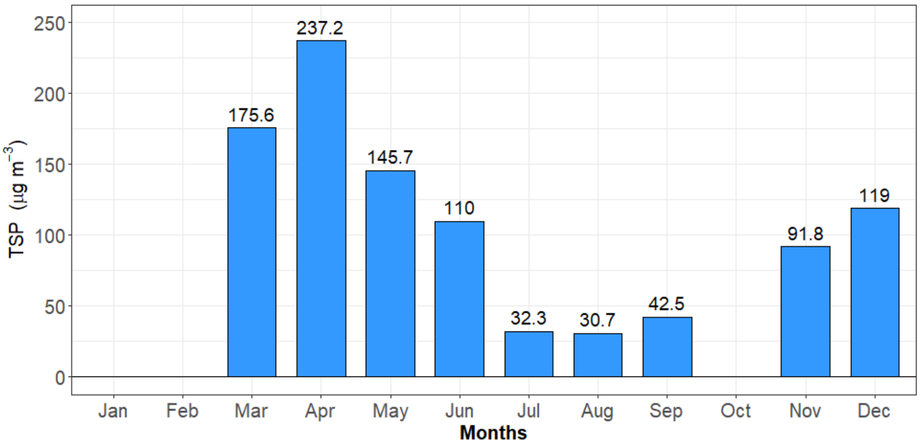


Figure 124: Monthly average of TSP for TU Kirtipur Station

Seasonal average:

Figure 125 illustrates the seasonal distribution of the concentration of TSP. Among the three seasons for which seasonal average is available Pre-monsoon was observed with the highest seasonal average (187.5 µg m^{-3}), while monsoon showed the lowest seasonal average (55.4 µg m^{-3}).

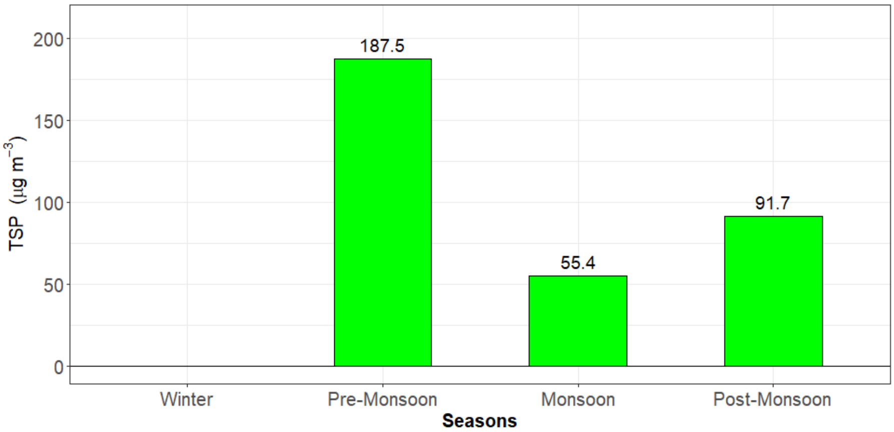


Figure 125: Seasonal average of TSP for TU Kirtipur Station

Compliance status:

Out of the total 253 days of valid measurements, 21 days exceeded the NAAQS. Those days were from March, April and June (Figure 126).

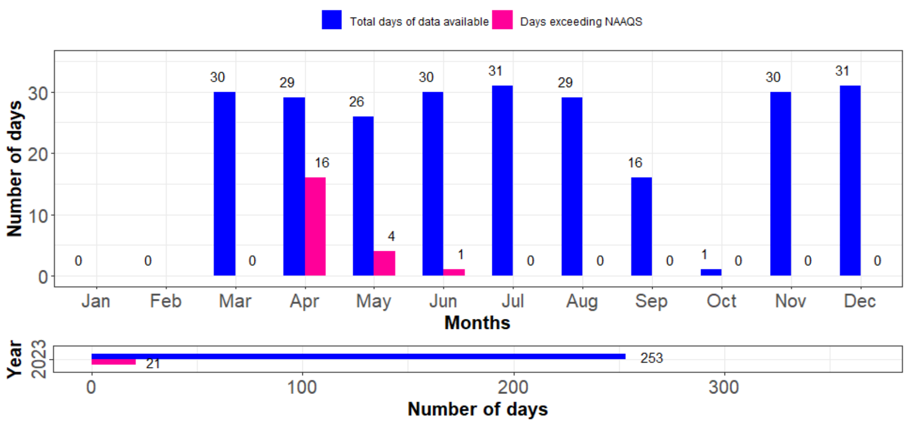


Figure 126: Compliance status of TSP for TU Kirtipur Station

2.3 KARNALI PROVINCE

2.3.1 RARA AIR QUALITY MONITORING STATION

Inside the premises of Rara National Park, the Rara AQMS was established in the year 2020. It lies in Mugu district of Karnali Province. This station represents air quality of high mountain (also stated as background AQMS). The local air quality might be influenced by regional haze, regional fire and local emission activities.

2.3.1.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 1.2 µg m^{-3} to 69.7 µg m^{-3}. The statistical summary of the hourly average is presented in the Table 50.

Table 50: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Rara Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.2	4.4	7.7	10.2 ± 8.6	13.1	69.7

Diurnal variation:

The hourly mean of $PM_{2.5}$ remain almost constant throughout the day. It gains the lowest value at 13:00 (Figure 127).

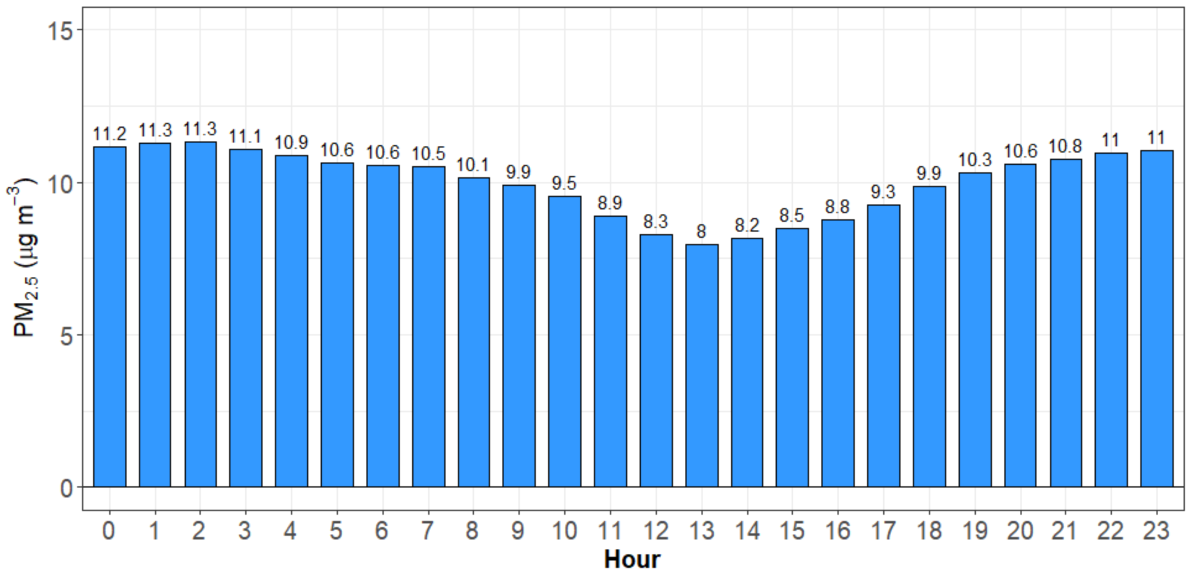


Figure 127: Diurnal variation of $PM_{2.5}$ for Rara Station

Daily average:

The daily average data was available for 327 days. Figure 128 shows the daily trend of $PM_{2.5}$ throughout the year.

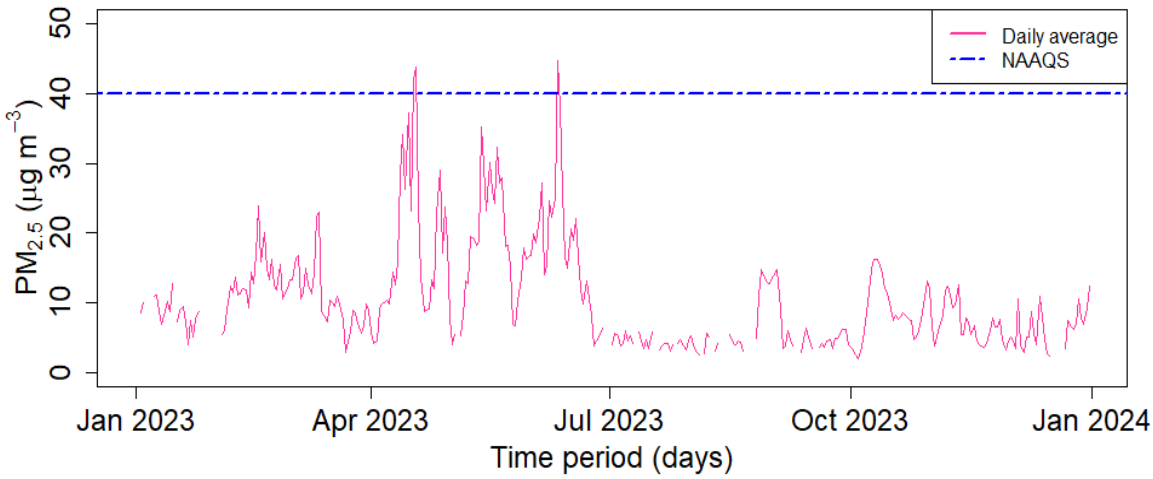


Figure 128: Daily average of $PM_{2.5}$ for Rara Station

Table 51: Summary of daily average of $PM_{2.5}$ ($\mu g\ m^{-3}$) for Rara Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
2.0	5.0	8.6	10.5 ±7.6	13.2	44.7

Within the available data, the lowest and highest daily average of $PM_{2.5}$ was 2.0 $\mu g\ m^{-3}$ and 44.7 $\mu g\ m^{-3}$ respectively (Table 51).

Monthly average:

Figure 129 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in April (18.1 $\mu g\ m^{-3}$) and lowest in July (4.3 $\mu g\ m^{-3}$).

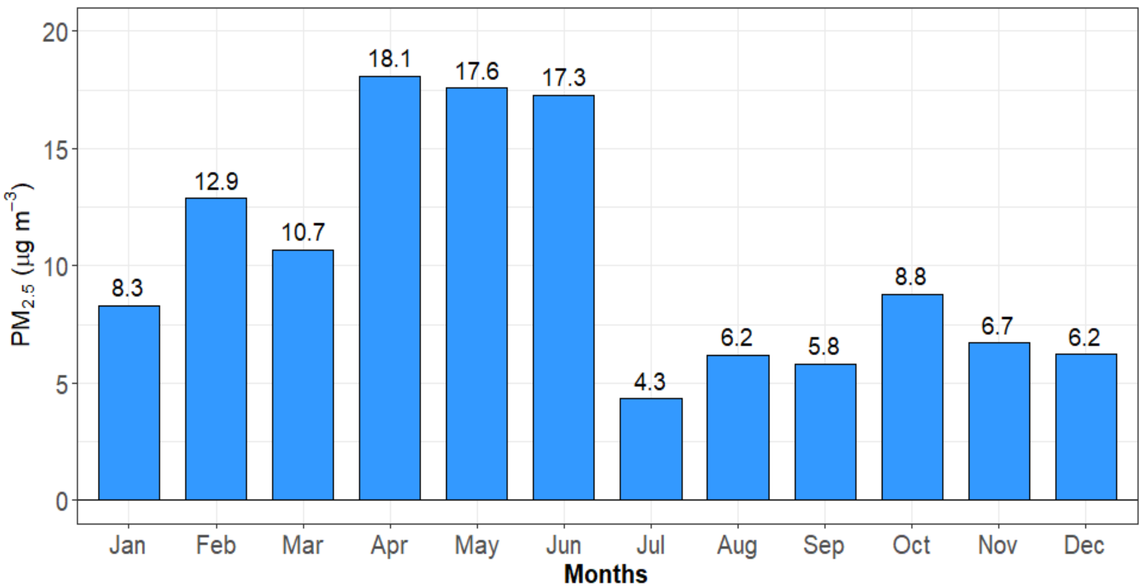


Figure 129: Monthly average of $PM_{2.5}$ for Rara Station

Seasonal average:

Figure 130 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Pre-monsoon was observed with the highest seasonal average (15.4$\mu g\ m^{-3}$), while post monsoon showed the lowest seasonal average (7.8 $\mu g\ m^{-3}$).

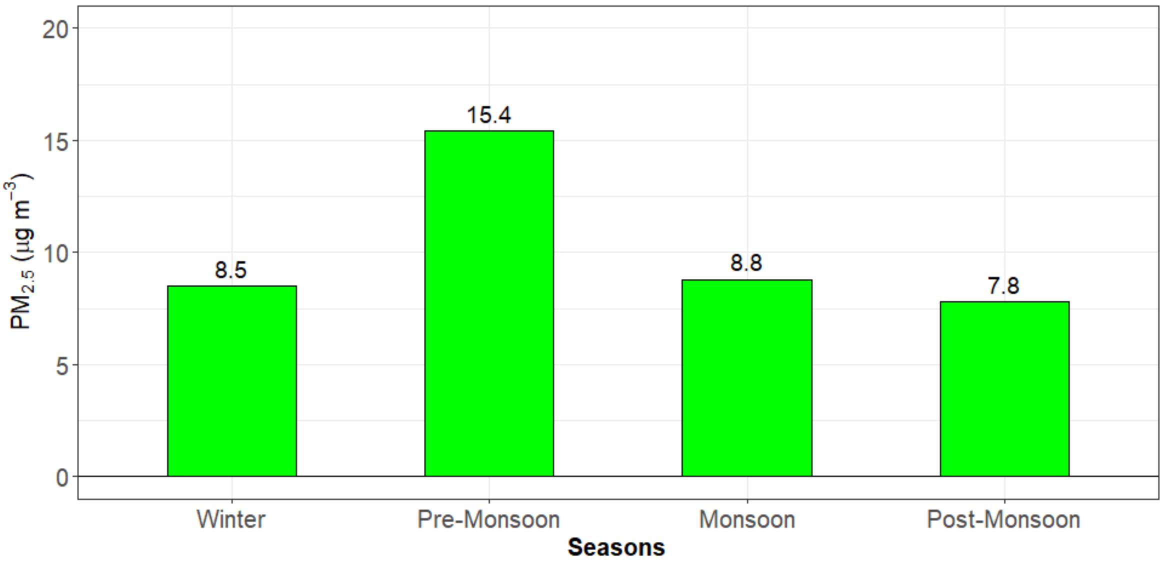


Figure 130: Seasonal average of $PM_{2.5}$ for Rara Station

Compliance status:

Out of the total 327 days of valid measurements, 3 days exceeded the NAAQS (Figure 131). Out of those three days two days are from April and 1 days from June.

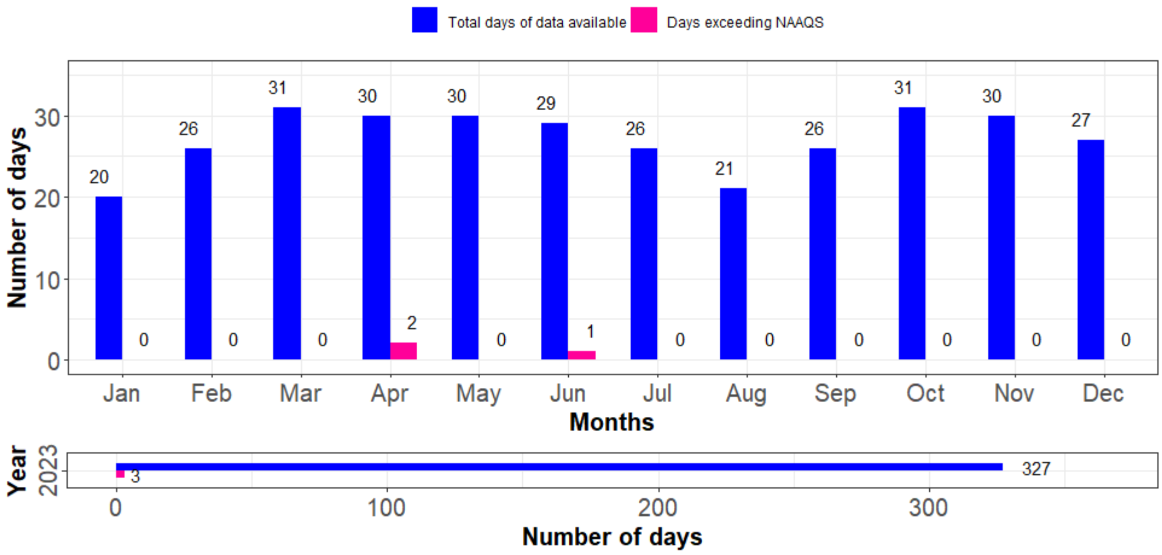


Figure 131: Compliance status of $PM_{2.5}$ for Rara Station

Calendar plot

Calendar plot for $PM_{2.5}$ (Figure 132) for the station shows the worst category of AQI as Unhealthy for sensitive groups. All together 3 days (two days in April and one day in June) were observed with unhealthy AQI

Figure 132: Calendar plot of $PM_{2.5}$ for Rara Station

2.3.1.2 Data analysis for PM_{10}

Hourly average:

The hourly average ranges from 1.2 µg m^{-3} to 106.3 µg m^{-3}. The statistical summary of the hourly average is presented in Table 52.

Table 52: Summary of hourly average of PM_{10} (µg m^{-3}) for Rara Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.2	5.5	10.0	14.0± 12.8	17.8	106.3

Diurnal variation:

The hourly mean of PM_{10} fluctuate slight throughout the day and gain the lowest value at 13:00 (Figure 133).

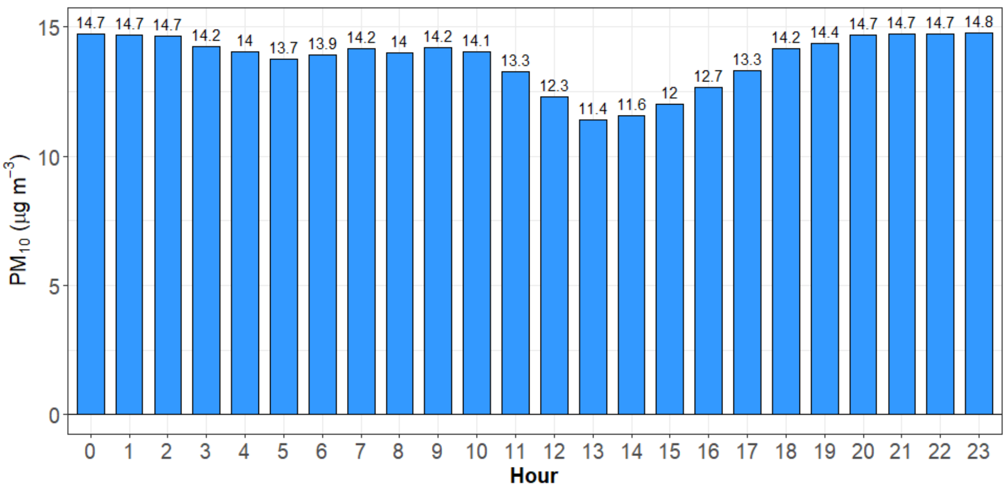


Figure 133: Diurnal variation of PM_{10} for Rara Station

Daily average:

The daily average data was available for 327 days. Figure 134 explains the daily trend of PM_{10} throughout the year. From the graph at can be seen that daily average values of all days are much lower than the National ambient air quality standard.

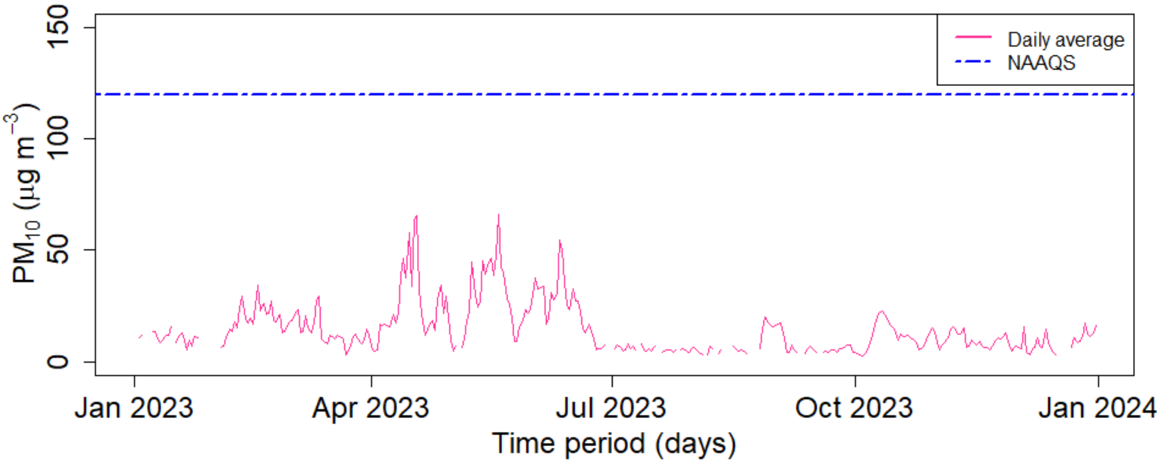


Figure 134: Daily average of PM_{10} for Rara Station

Table 53: Summary of daily average of PM_{10} (µg m^{-3}) for Rara Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
2.3	6.2	11.1	14.5± 11.4	18.1	66.1

Within the available data, the lowest and highest concentrations of PM_{10} was 2.3 µg m^{-3} and 66.1 µg m^{-3}, respectively (Table 53).

Monthly average:

Figure 135 illustrates the monthly average concentration of PM_{10}. The monthly average of PM_{10} was the highest in May (27 µg m^{-3}) and lowest in July (5.6 µg m^{-3}).

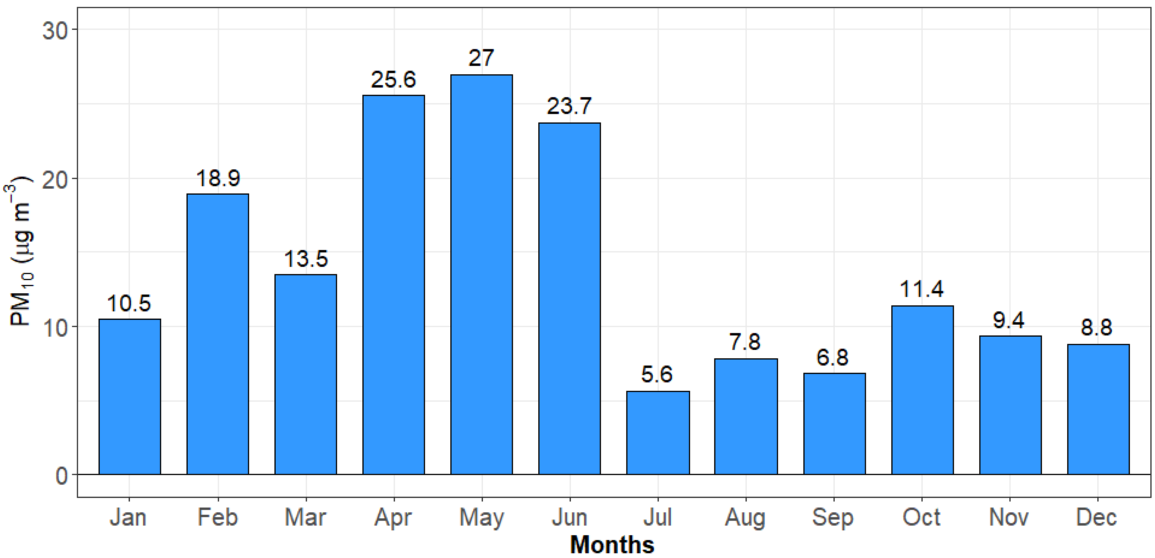


Figure 135: Monthly average of PM_{10} for Rara Station

Seasonal average:

Figure 136 illustrates the seasonal distribution of the concentration of PM_{10}. Pre-monsoon was observed with the highest seasonal average (21.9 µg m^{-3}), while post-monsoon showed the lowest seasonal average (10.4 µg m^{-3}).

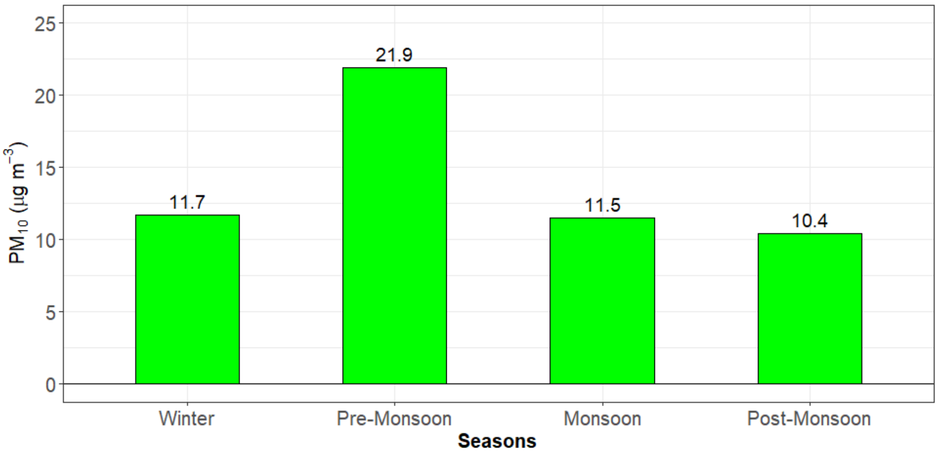


Figure 136: Seasonal average of PM_{10} for Rara Station

Compliance status:

Out of the total 327 days of valid measurements, all days meet the NAAQS (Figure 137).

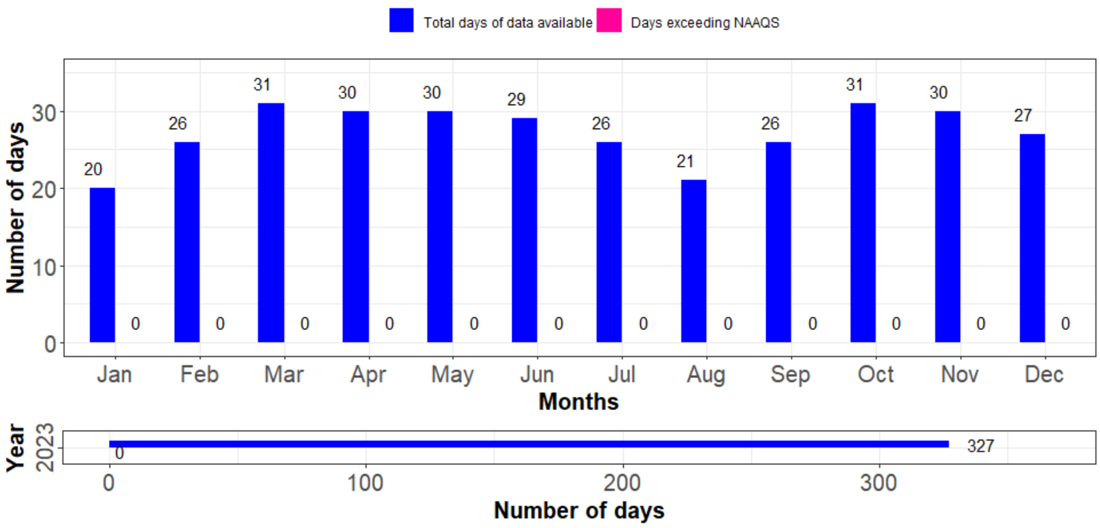


Figure 137: Compliance status of PM_{10} for Rara Station

2.3.1.3 Data Analysis for TSP

Hourly average:

The hourly average ranges from 1.2 µg m^{-3} to 784.8 µg m^{-3}. The statistical summary of the hourly average is presented in Table 54.

Table 54: Summary of hourly average of $PM_{2.5}$ (µg m^{-3}) for Rara Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.2	6.5	13.3	22.9± 28.4	27.8	784.8

Diurnal variation:

The hourly mean of TSP progressively increased from 4 in the morning and reached peak at 10. There after it starts decreasing till 13:00 after that it starts increasing till 16:00. After 18:00 in the evening it decreases continuously (Figure 138).

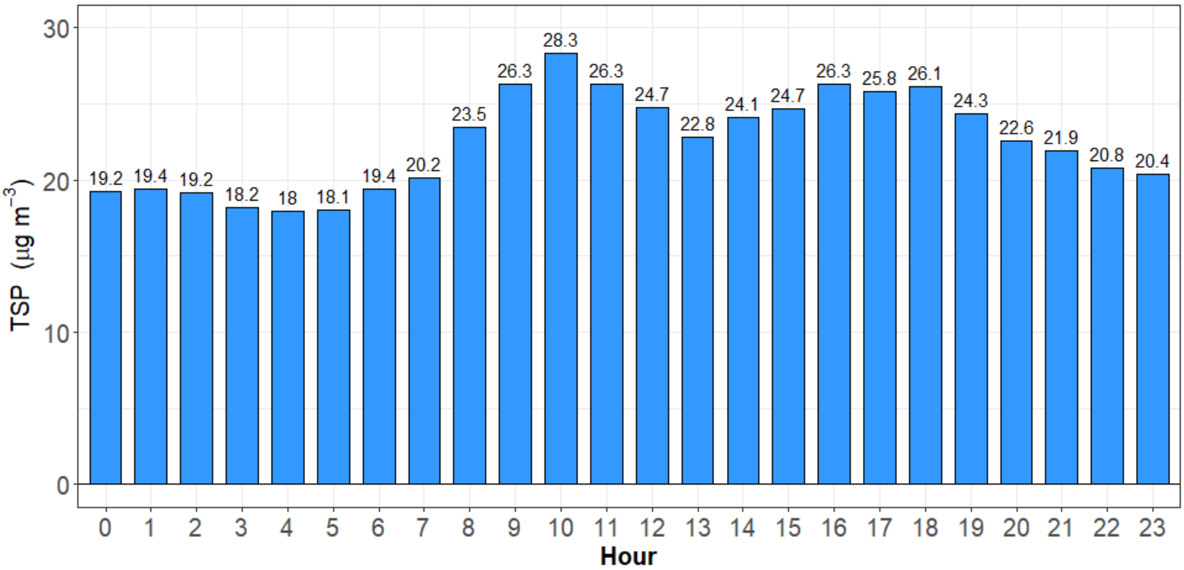


Figure 138: Diurnal variation of TSP for Rara Station

Daily average:

The daily average data was available for 327 days. Figure 139 shows the daily trend of TSP throughout the year.

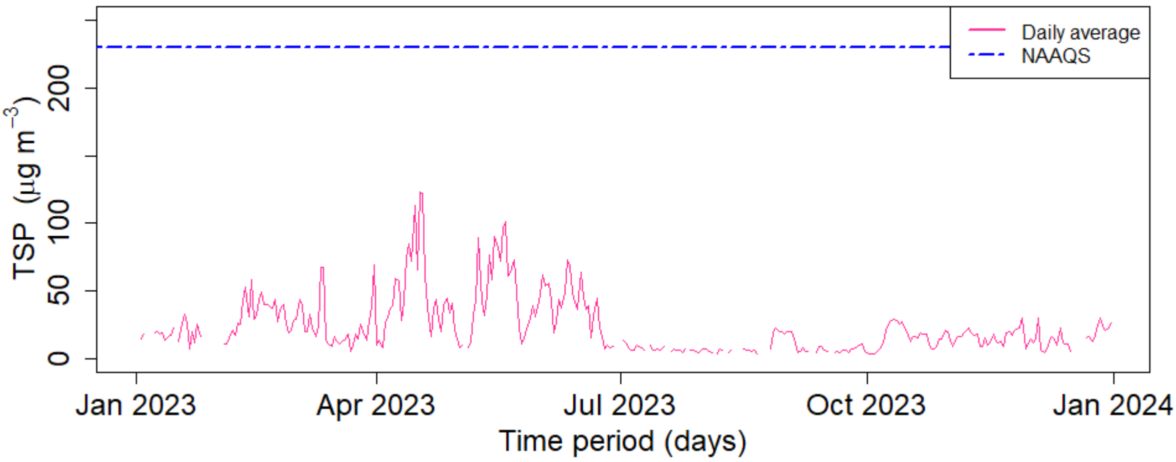


Figure 139: Daily average of TSP for Rara Station

Table 55: Summary of daily average of TSP (µg m^{-3}) for Rara Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
3.3	8.9	17.6	23.7± 21.1	30.2	123.5

Within the available data, the lowest and highest concentration of TSP was 3.3 µg m^{-3} and 123.5 µg m^{-3}, respectively (Table 55).

Monthly average:

Figure 140 illustrates the monthly average concentration of TSP. The monthly average of TSP was highest in April (47.6 µg m^{-3}) and lowest in July (7 µg m^{-3}).

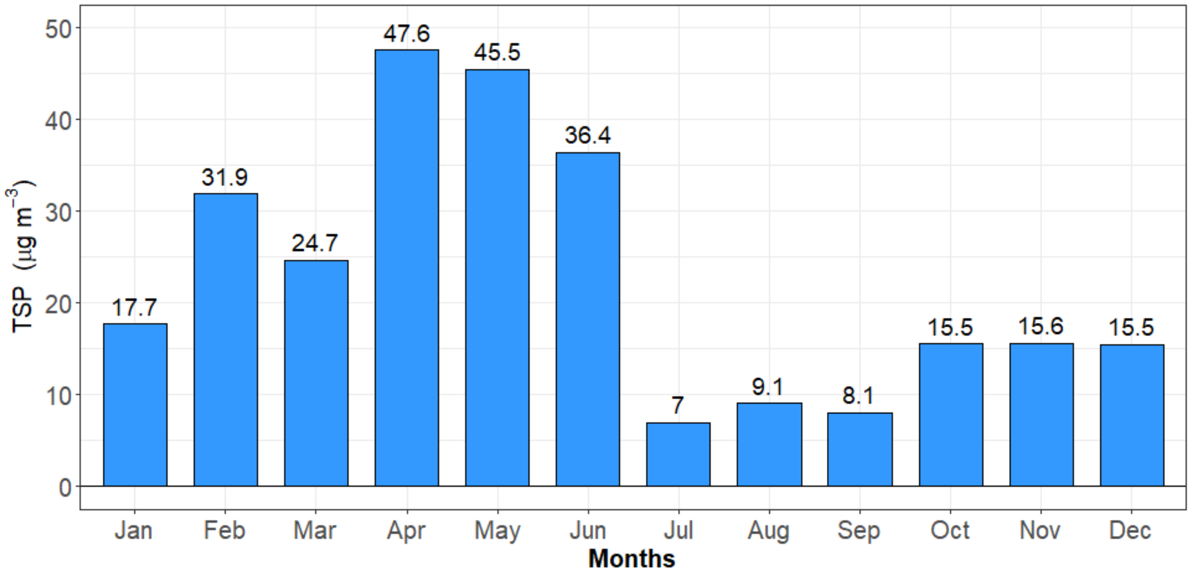


Figure 140: Monthly average of TSP for Rara Station

Seasonal average:

Figure 141 illustrates the seasonal distribution of the concentration of TSP. Pre-monsoon was observed with the highest seasonal average (39.1 µg m^{-3}), while post-monsoon showed the lowest seasonal average (15.6 µg m^{-3}).

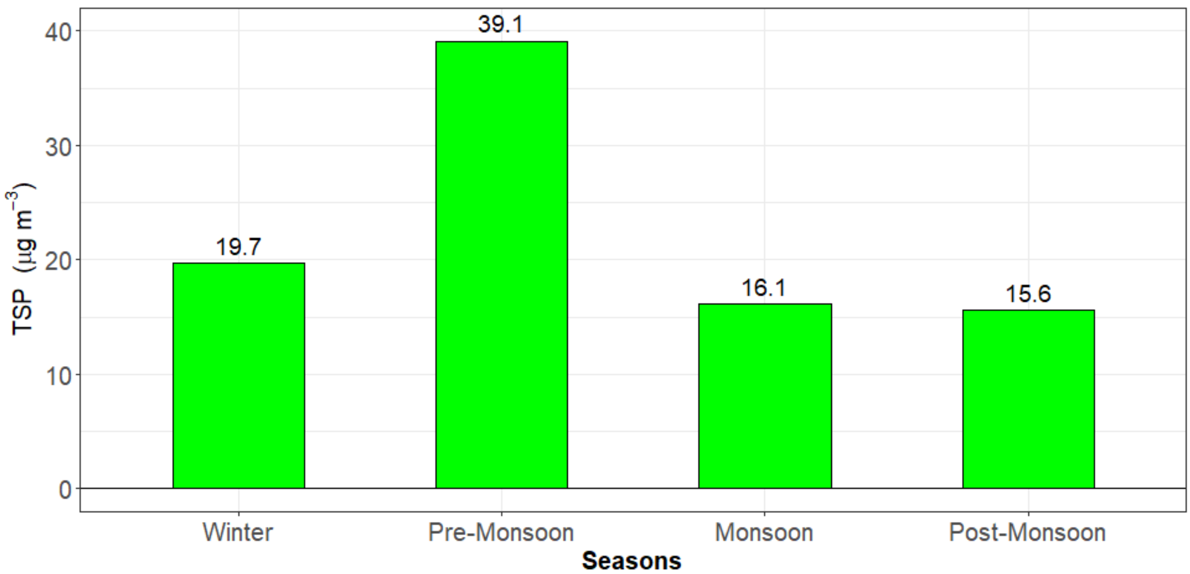


Figure 141: Seasonal average of TSP for Rara Station

Compliance status:

Out of the total 327 days of valid measurements, all days met the NAAQS (Figure 142).

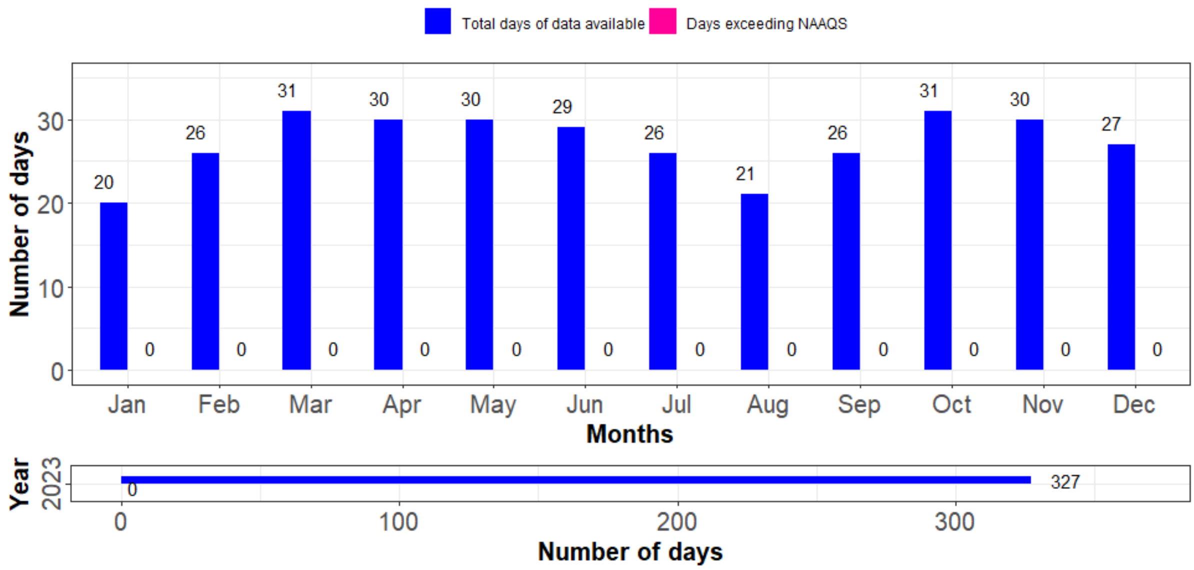


Figure 142: Compliance status of TSP for Rara Station

2.4 SUDURPASCHIM PROVINCE

2.4.1 MAHENDRANAGAR AIR QUALITY MONITORING STATION

Mahendranagar AQMS was established in the year 2018 in the premises of municipality administration office of Bhimdatta, Sudurpaschim Province. It represents the urban area. The main sources of pollution in this region are vehicles and industries. Agriculture residue burning and transboundary air pollution sources also affects concentration of pollutant in this station.

2.4.1.1 Data analysis for $PM_{2.5}$

Hourly average:

The hourly average ranges from 2.2 μg m^{-3} to 345.4 μg m^{-3}. The statistical summary of hourly average was presented in the Table 56.

Table 56: Summary of hourly average of $PM_{2.5}$ (μg m^{-3}) for Mahendranagar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
1.8	12.8	25.4	32.1 ± 25.4	44.5	184.4

Diurnal variation:

The hourly mean of $PM_{2.5}$ progressively decreased from 0:00 till 4:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 14:00, and again starts to rise and peaks at 19:00 (Figure 143).

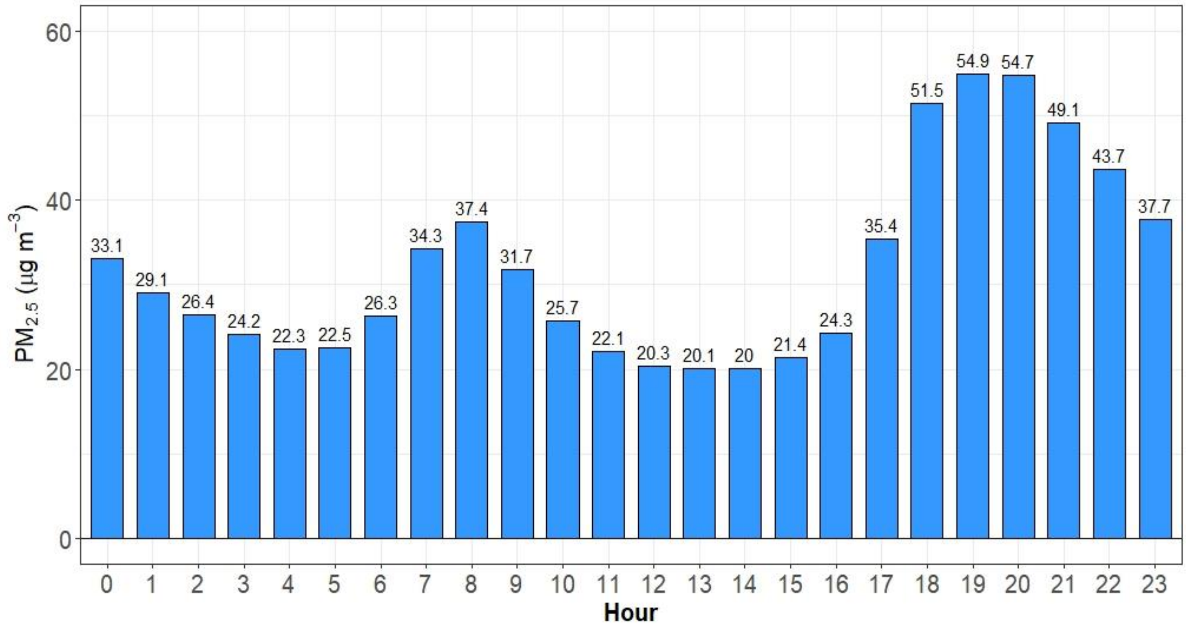


Figure 143: Diurnal variation of $PM_{2.5}$ for Mahendranagar Station

Daily average:

The daily average data was available for 203 days. Figure 144 shows the daily trend of $PM_{2.5}$ throughout the year.

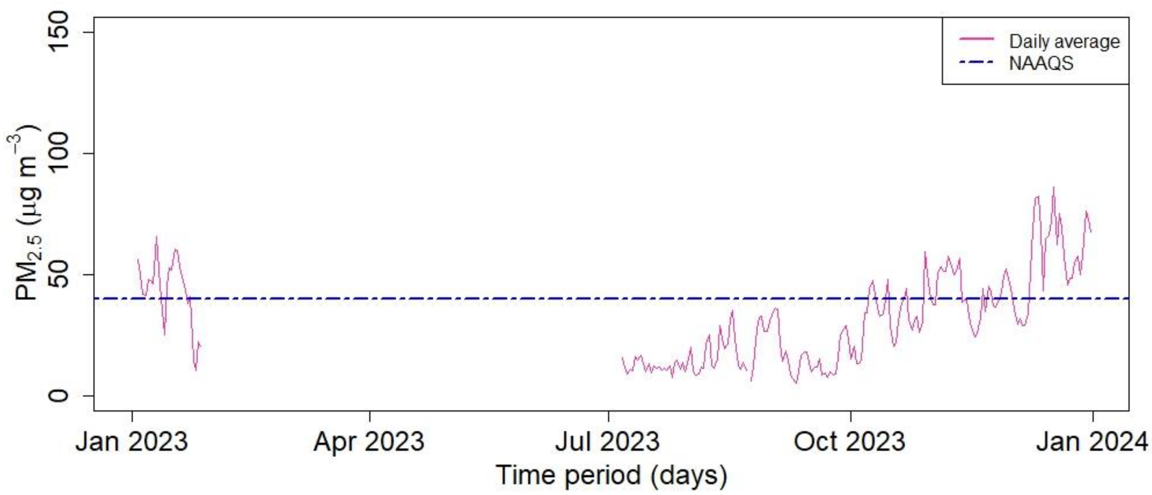


Figure 144: Daily average of $PM_{2.5}$ for Mahendranagar Station

Table 57: Summary of daily average of $PM_{2.5}$ ($\mu g\ m^{-3}$) for Mahendranagar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
5.2	14.6	30.8	32.2 ± 18.9	45.8	86.3

Within the available data, the lowest and the highest concentration of $PM_{2.5}$ was found to be 5.2 $\mu g\ m^{-3}$ and 86.3 $\mu g\ m^{-3}$ (Table 57).

Monthly average:

Figure 145 illustrates the monthly average concentration of $PM_{2.5}$.The monthly average of $PM_{2.5}$ was the highest in December (56.8 $\mu g\ m^{-3}$) and lowest in July (12.3 $\mu g\ m^{-3}$).

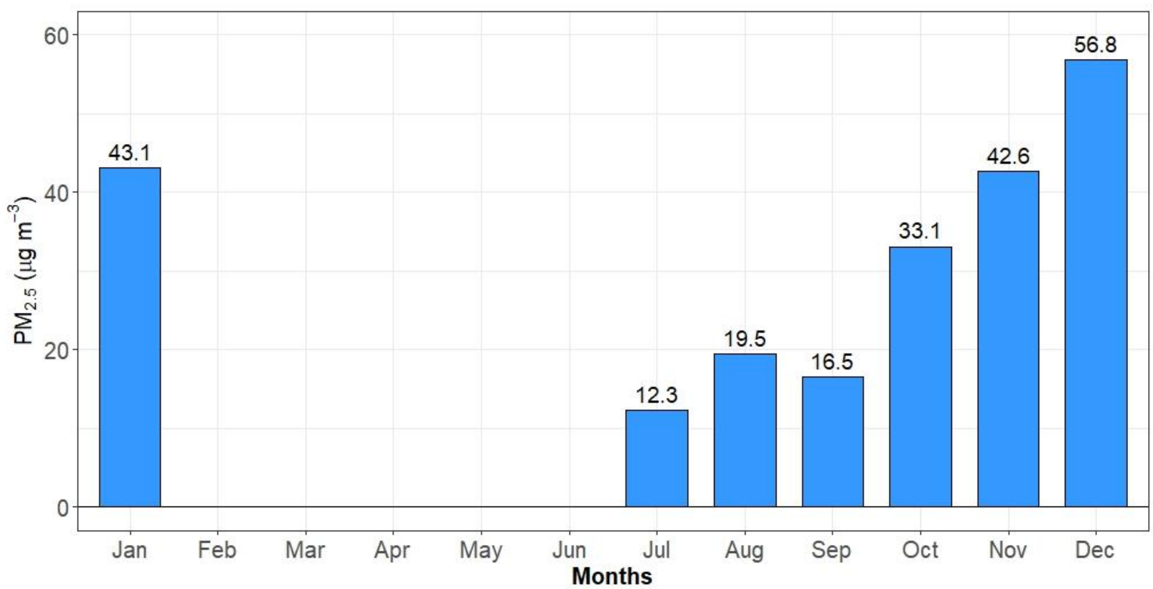


Figure 145: Monthly average of $PM_{2.5}$ for Mahendranagar Station

Seasonal average:

Figure 146 illustrates the seasonal distribution of the concentration of $PM_{2.5}$. Pre-monsoon was observed with higher seasonal average (37.8 $\mu g\ m^{-3}$) than monsoon (16.2 $\mu g\ m^{-3}$).

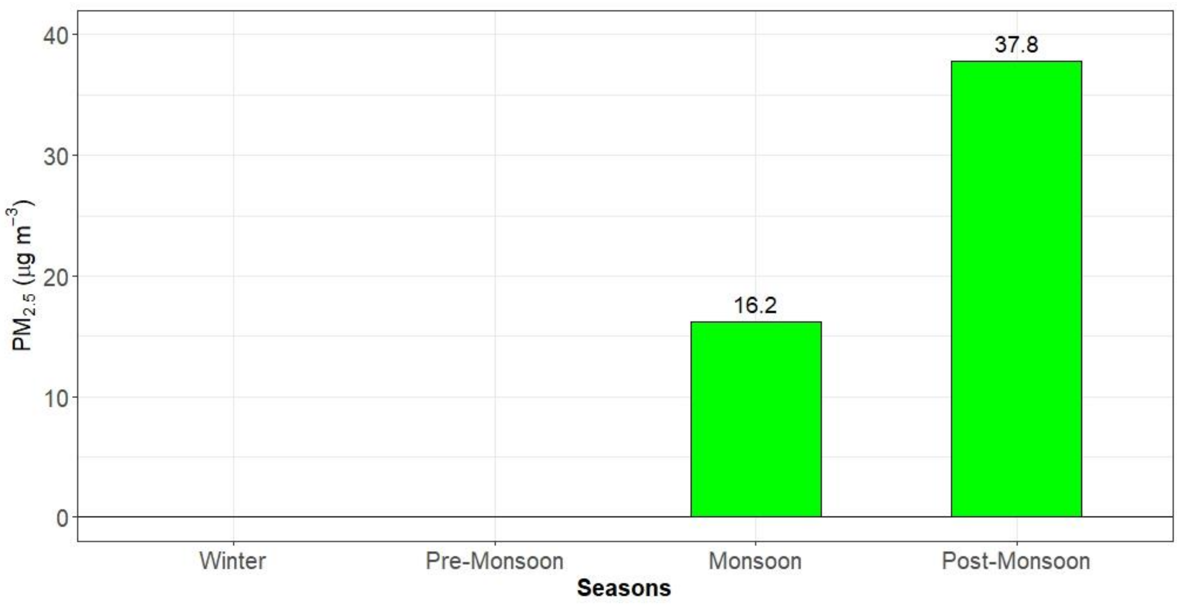


Figure 146: Seasonal average of $PM_{2.5}$ for Mahendranagar Station

Compliance status:

Out of the total 203 days of valid measurements, 68 days exceeded the NAAQS (Figure 147). The compliance status was poor during January, November and December. In January 19 days out of 25 days with valid measurements exceeded the NAAQS. Similarly, in October 8 days out of 31 days, in November 16 days out of 30 days and in December 25 days out of 31 days exceeded the NAAQS. The entire days during July to September meet the NAAQS.

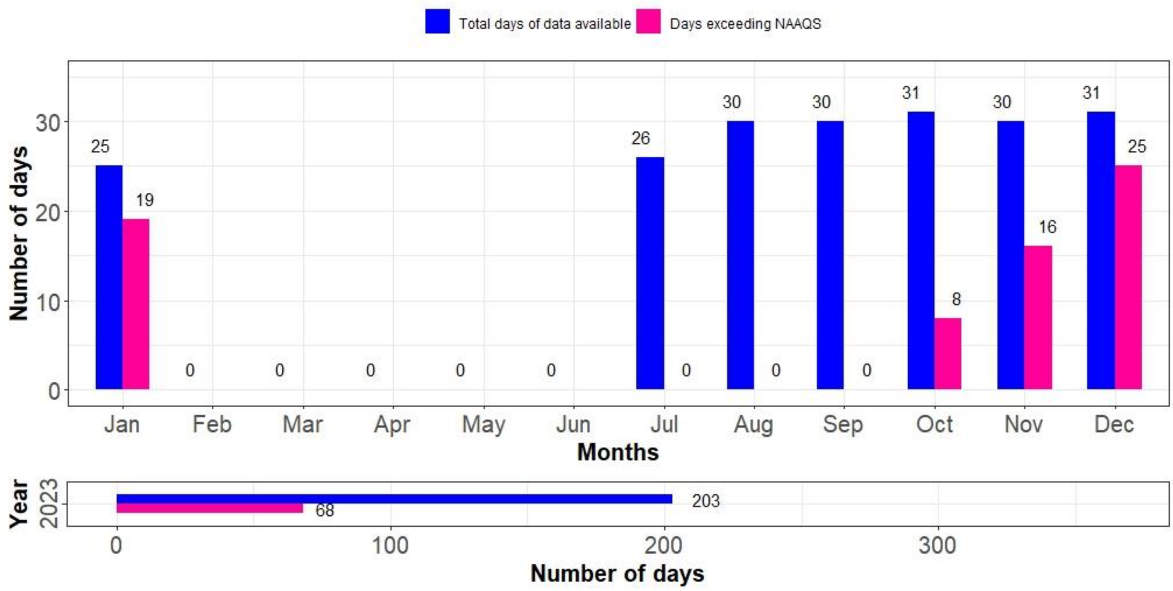


Figure 147: Compliance status of $PM_{2.5}$ for Mahendranagar Station

Calendar plot

Calendar plot for $PM_{2.5}$ (Figure 148) for the station shows the worst category of AQI as Unhealthy. Unhealthy category of AQI was observed during January and December.

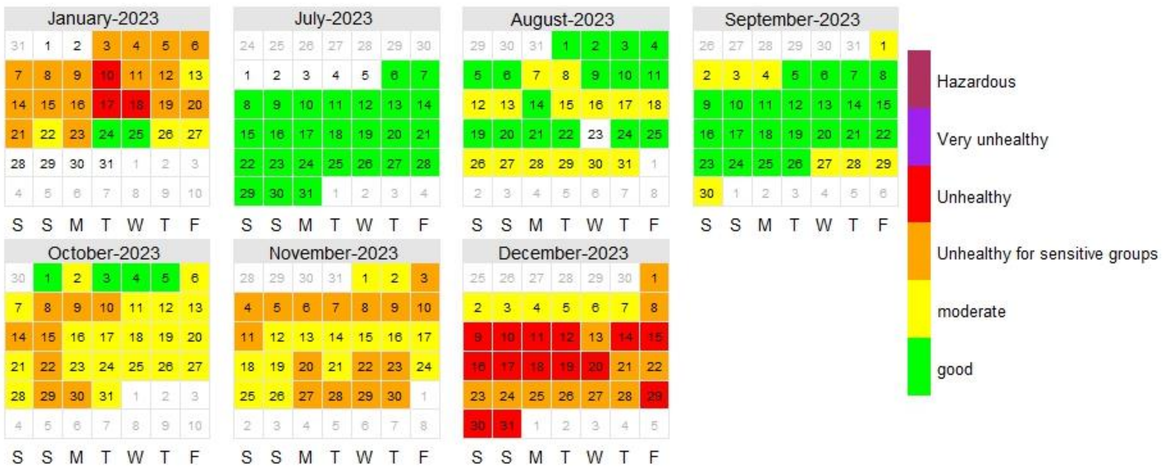


Figure 148: Calendar plot of $PM_{2.5}$ for Mahendranagar Station

2.4.1.2 data analysis for PM_{10}

Hourly average:

The hourly average ranges from 2.2 µg m^{-3} to 345.4 µg m^{-3}. The statistical summary of hourly average is presented in the Table 58.

Table 58: Summary of hourly average of PM_{10} (µg m^{-3}) for Mahendranagar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
2.2	19.3	36.9	44.5 ± 33.8	59.9	345.4

Diurnal variation:

The hourly mean of PM_{10} progressively decreased from 0:00 till 4:00 then increased with time and reaches to its peak at 8:00 after that it decreased till 12:00, and again starts to rise and peaks at 18:00 (Figure 149).

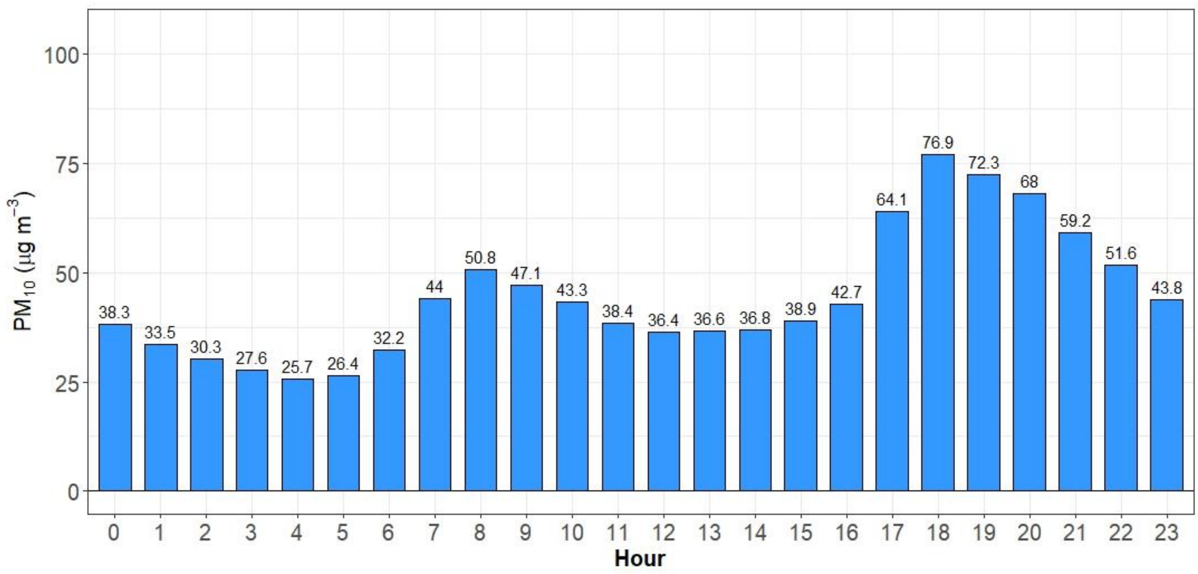


Figure 149: Diurnal variation of PM_{10} for Mahendranagar Station

Daily average:

The daily average data was available for 202 days. Figure 150 explains the daily trend of PM_{10} throughout the year.

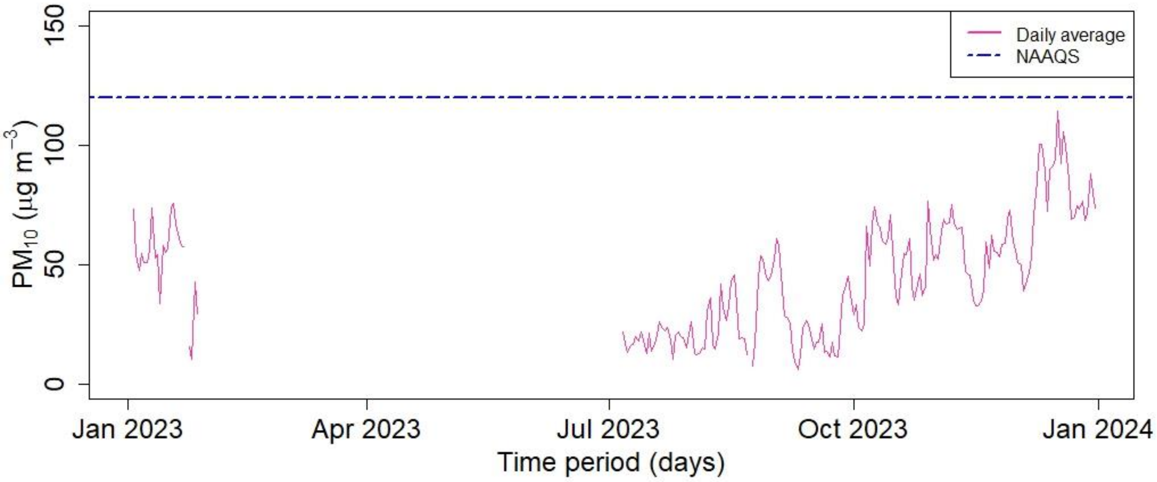


Figure 150: Daily average of PM_{10} for Mahendranagar Station

Table 59: Summary of daily average of PM_{10} ($\mu g\ m^{-3}$) for Mahendranagar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
6.4	21.9	44.7	44.4 ± 23.9	60.9	114.4

Within the available data, the lowest and the highest concentration of PM_{10} was found to be 6.4 $\mu g\ m^{-3}$ and 114.4 $\mu g\ m^{-3}$ (Table 59).

Monthly average:

Figure 151 illustrates the monthly average concentration of PM_{10}. The monthly average of PM_{10} was the highest in December (76.6 $\mu g\ m^{-3}$) and lowest in July (19.0 $\mu g\ m^{-3}$).

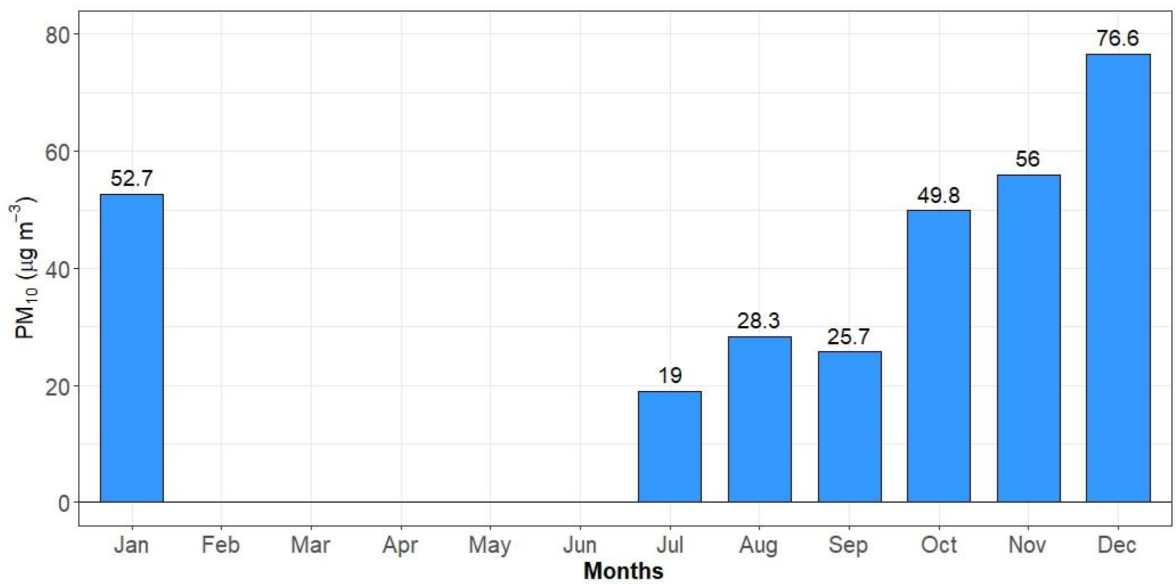


Figure 151: Monthly average of PM_{10} for Mahendranagar Station

Seasonal average:

Figure 152 illustrates the seasonal distribution of the concentration of PM_{10}. Post-monsoon was observed with the higher seasonal average (52.9 µg m^{-3}) than monsoon (24.6 µg m^{-3}).

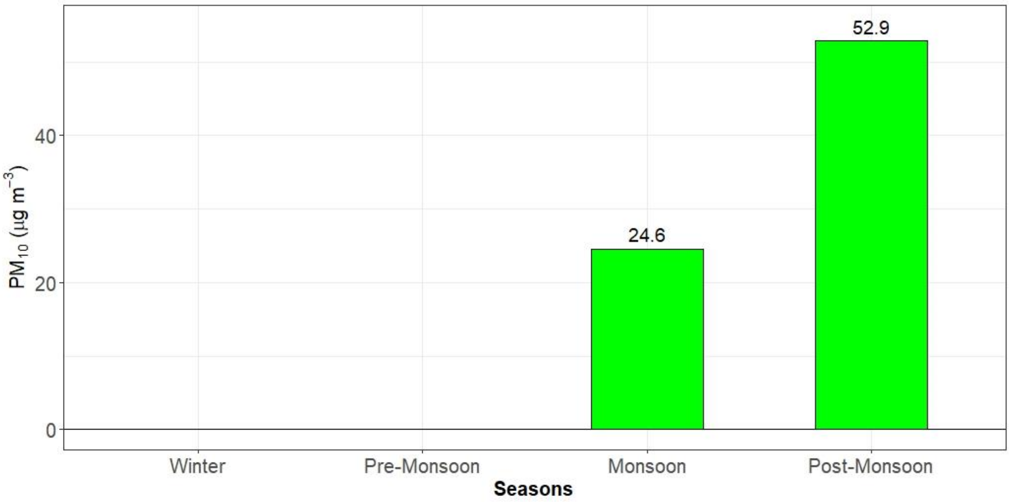


Figure 152: Seasonal average of PM_{10} for Mahendranagar Station

Compliance status:

Out of the total 202 days of valid measurements, none of days exceeded the NAAQS (Figure 153).

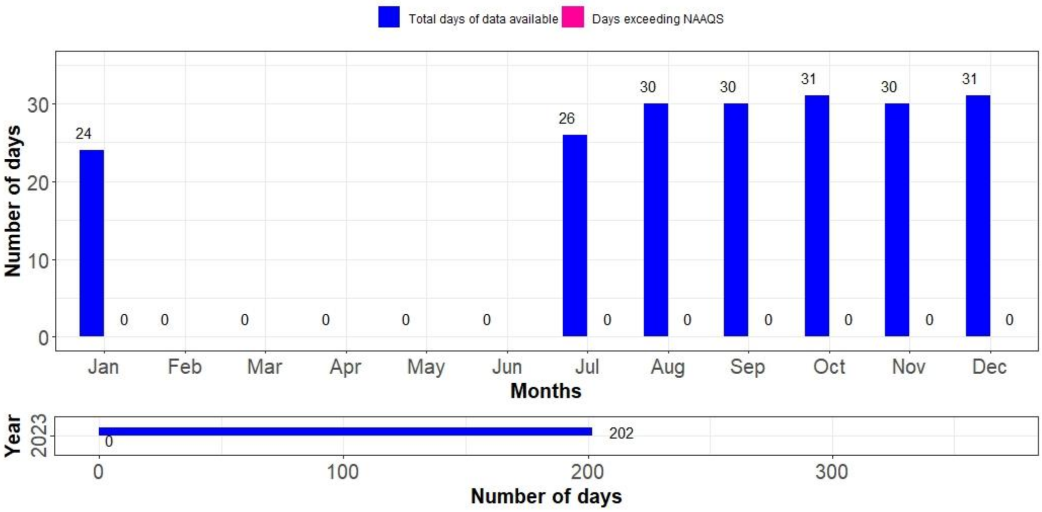


Figure 153: Compliance status of PM_{10} for Mahendranagar Station

2.4.1.3 Data analysis for TSP

Hourly average:

The hourly average ranges from 2.3 µg m^{-3} to 585.3 µg m^{-3}. The statistical summary of hourly average is presented in the Table 60.

Table 60: Summary of hourly average of TSP (µg m^{-3}) for Mahendranagar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
2.3	25.0	50.2	67.8 ± 59.1	92.1	585.3

Diurnal variation:

The hourly mean of TSP progressively decreased from 0:00 till 4:00 then increased with time and reaches to its peak at 10:00 after which distinct pattern was not followed (Figure 154).

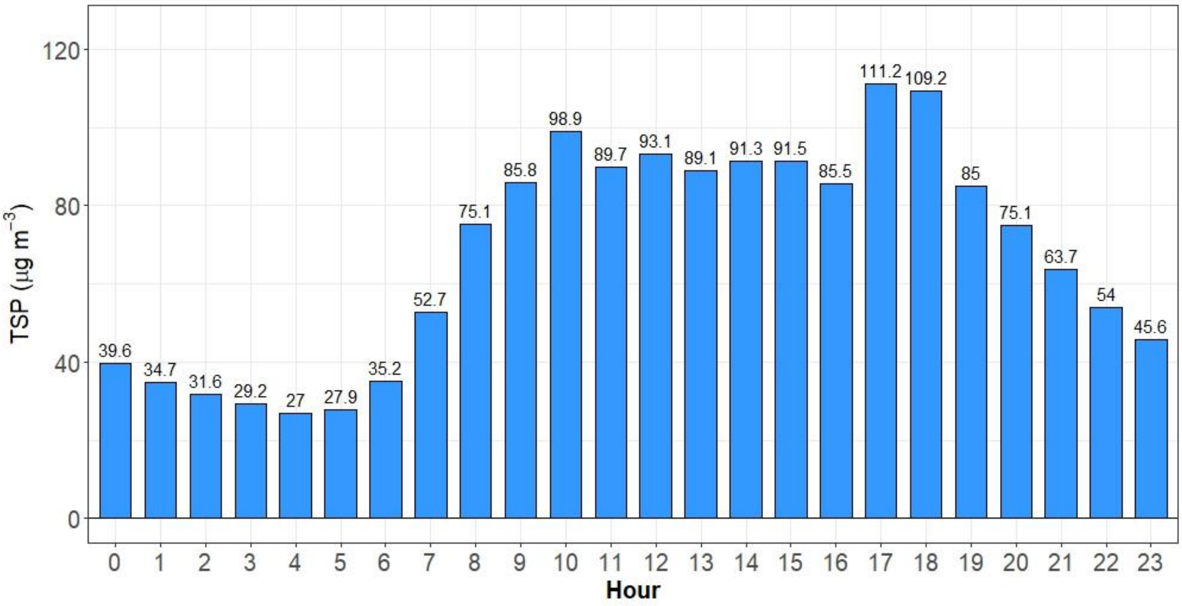


Figure 154: Diurnal variation of TSP for Mahendranagar Station

Daily average:

The daily average data was available for 203 days. Figure 155 shows the daily trend of TSP throughout the year.

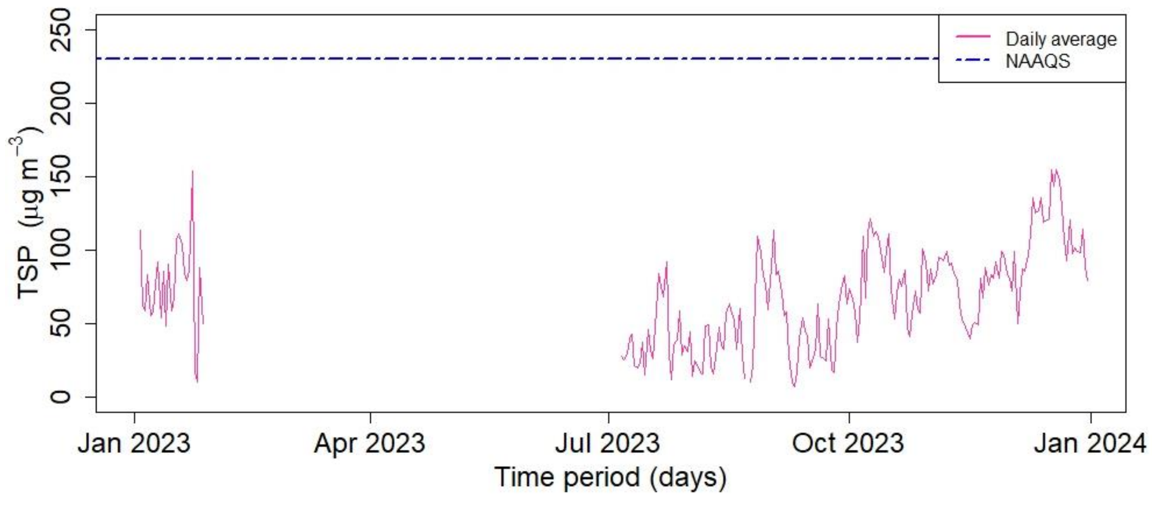


Figure 155: Daily average of TSP for Mahendranagar Station

Table 61: Summary of daily average of TSP (µg m^{-3}) for Mahendranagar Station

Minimum	1st quartile	Median	Mean ± SD	3rd quartile	Maximum
6.8	41.6	67.1	68.0 ± 33.9	91.6	154.9

Within the available data, the lowest and the highest concentration of TSP was found to be 6.8 µg m^{-3} and 154.9 µg m^{-3} (Table 61).

Monthly average:

Figure 156 illustrates the monthly average concentration of TSP. The monthly average of TSP was the highest in December (108.5 µg m^{-3}) and lowest in July (39.8 µg m^{-3}).

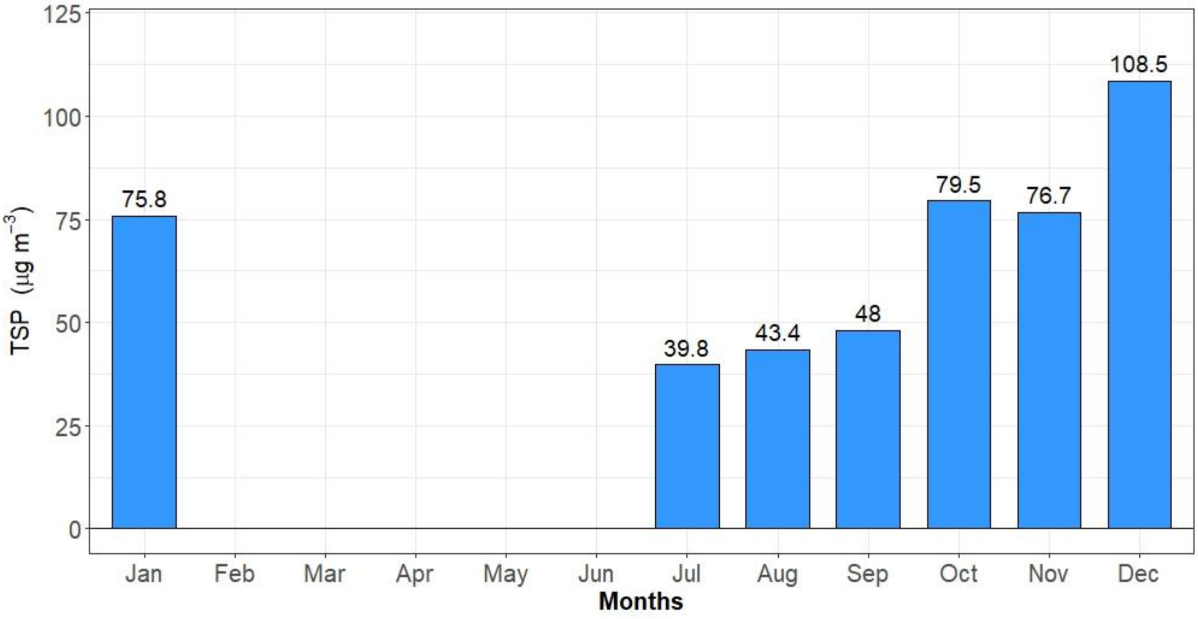


Figure 156: Monthly average of TSP for Mahendranagar Station

Seasonal average:

Figure 157 illustrates the seasonal distribution of the concentration of TSP. Post-monsoon was observed with higher seasonal average (78.1 µg m^{-3}) than monsoon (43.9 µg m^{-3}).

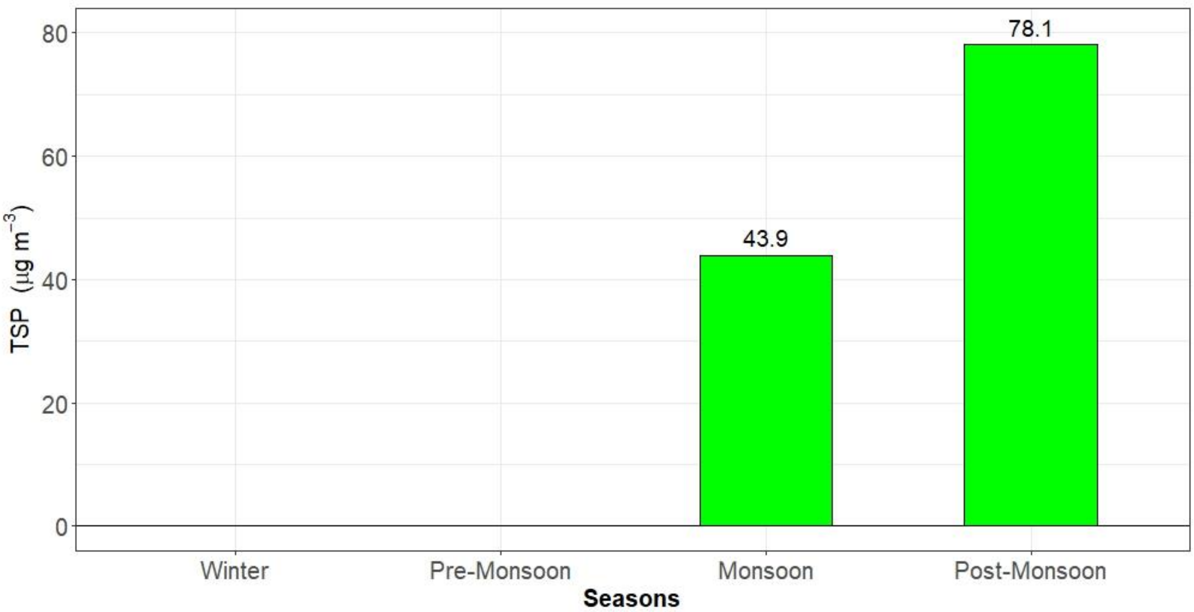


Figure 157: Seasonal average of TSP for Mahendranagar Station

Compliance status:

Out of the total 203 days of valid measurement, none of the day exceeded the NAAQS (Figure 158).

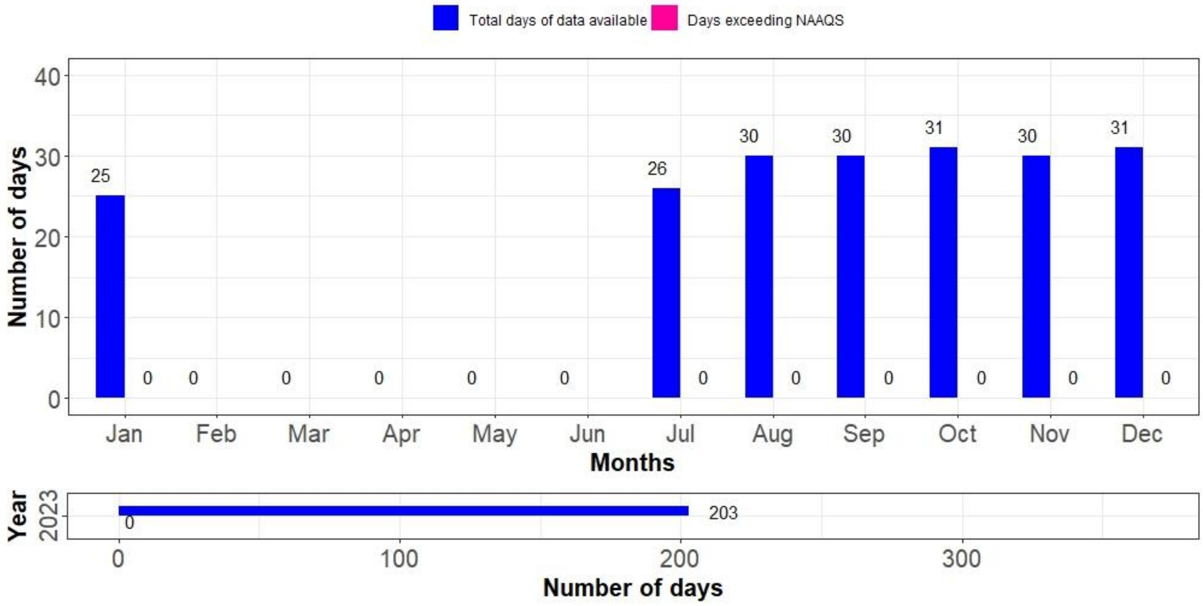


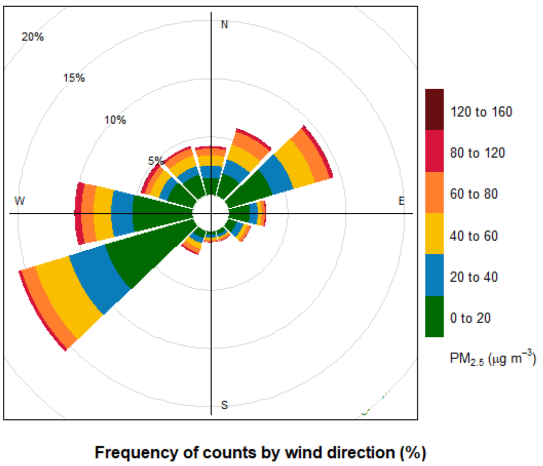
Figure 158: Compliance status of TSP for Mahendranagar Station

2.5 REGIONAL LEVEL AIR POLLUTION OVER NEPAL

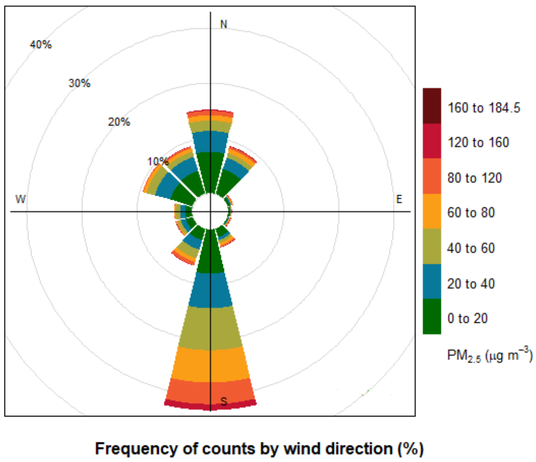
2.5.1 WIND PATTERN AND PM POLLUTION

Pollution rose diagram shows dominant wind direction that contributes to overall concentration of pollutants (Carslaw, 2019). In this report pollution rose diagram of few AQMS representing eastern, central and western Nepal are presented. Though the wind pattern at particular site can be affected by various hyper local climatic conditions pollution rose diagram can be useful to understand flow of pollutants. Usually, south west is the pre dominant wind direction for Kathmandu valley (Putero et al., 2015).

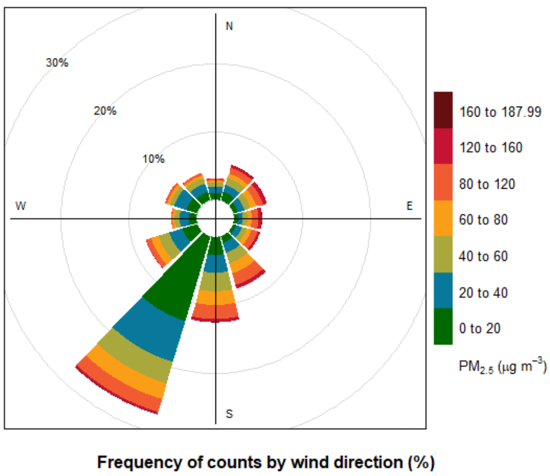
The annual pollution rose diagram of most of the stations shows the high levels of $PM_{2.5}$ seem to be associated with winds from the south west direction (Figure 159). Highly polluted months for different stations also seem to be linked with south westerly winds and monsoon months have major winds from eastern sides (Annex 4).



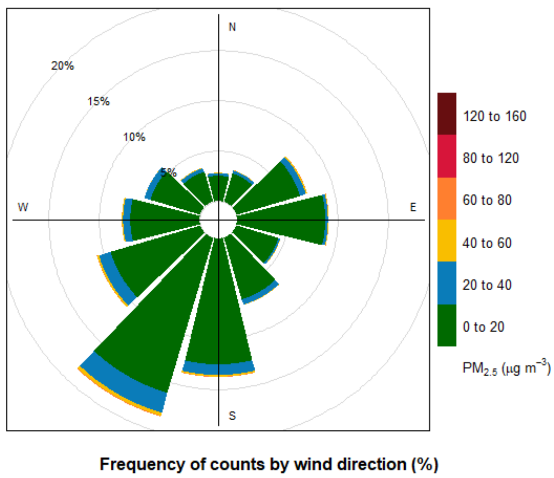
a. Dhankuta AQMS



b. Ratnapark AQMS



c. Khumaltar AQMS



d. Rara AQMS

Figure 159: Pollution rose diagram for various AQMS

Models like HYSPLIT can be used to observe the wind pattern of the site in absence of ground data. Frequency analysis of the backward trajectory in the Kathmandu valley for the months of January, April, September and November 2023 was done using the HYSPLIT model (Figure 160) as each of these months represent four different seasons. The global reanalysis file was used and the 48-hour backward trajectory at 100m height was performed.

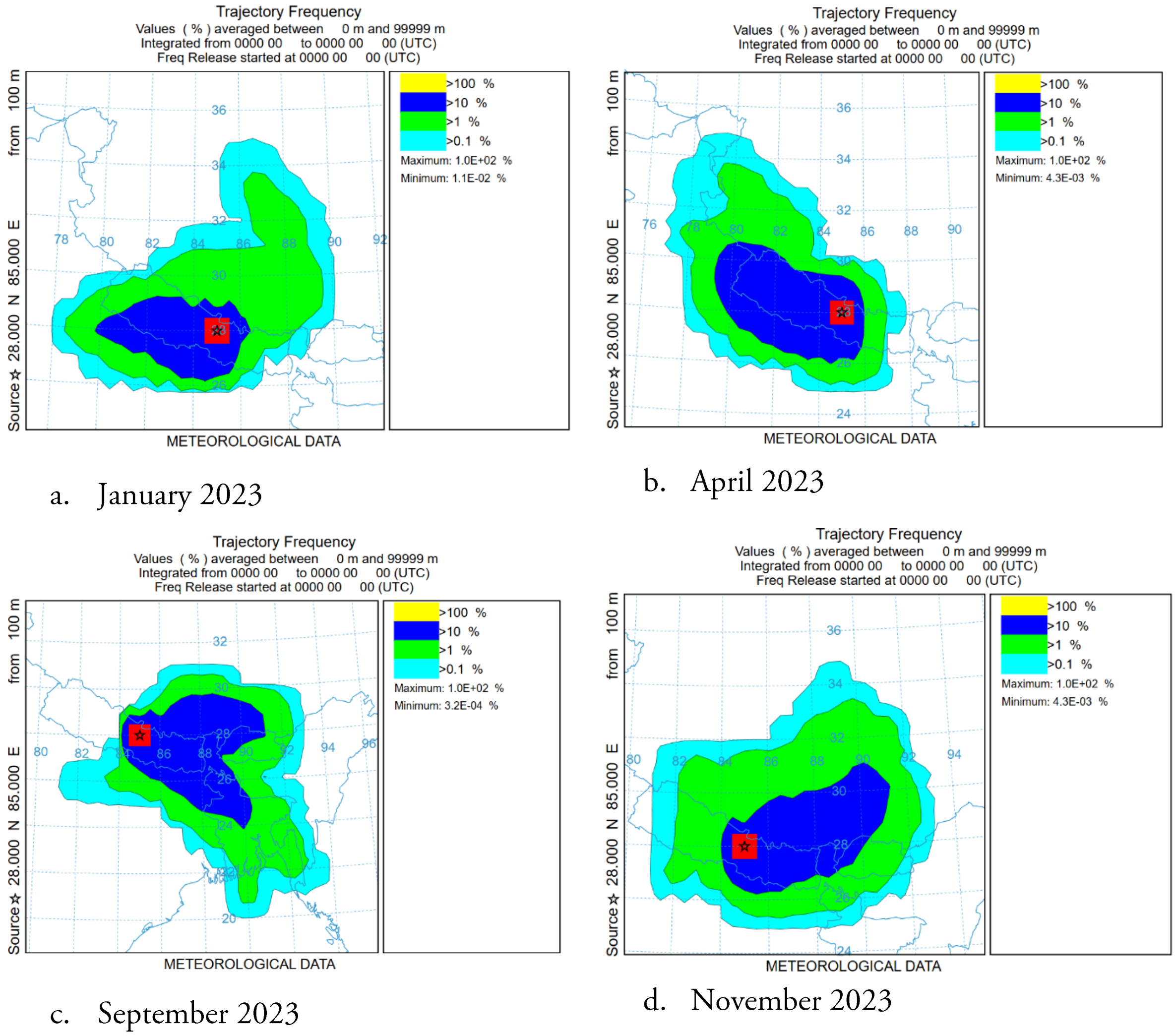


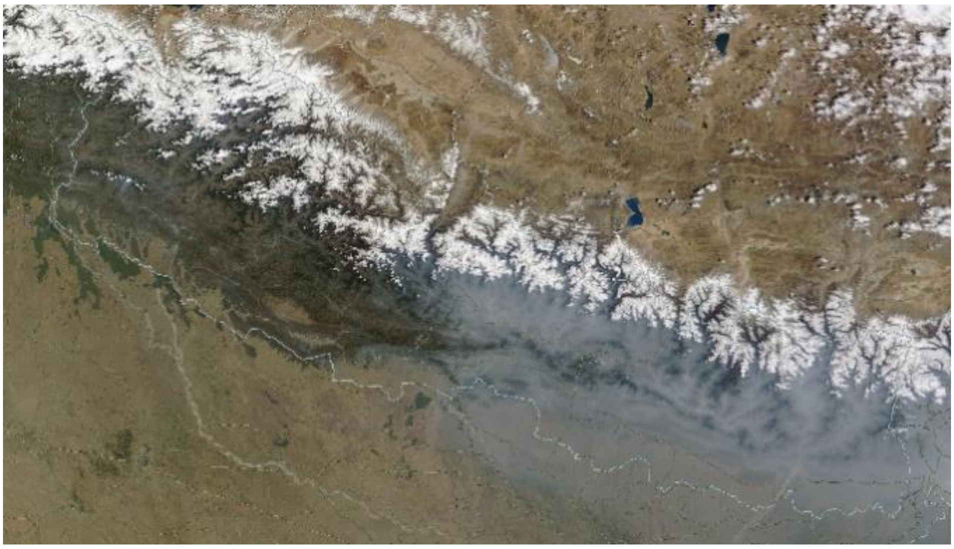
Figure 160: Backward trajectory frequency for Kathmandu in different months

The blue color on the map is the area from where wind enters to Kathmandu valley at 90% of the total time in last 48 hours. In January, wind enters to Kathmandu valley mostly from south west direction, whereas during April, most of the wind enters form western direction. But during September, easterly wind seems to be more prevalent whereas north east wind seems to be dominant during November.

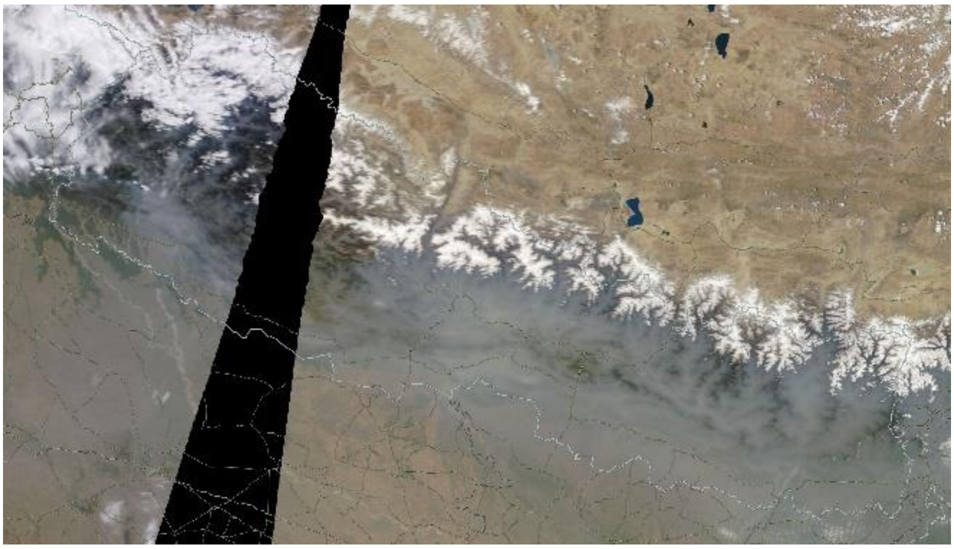
During months of high PM pollution (January and April) most of the time wind seems to come from west or south direction.

2.5.2 SATELLITE IMAGES AND DATA

Satellite images and satellite-based products show spatial extent of urban and regional pollution. In this report, pollution caused by fire events were taken as an example. For example, following true color imagery from MODIS satellite shows the extent of high PM pollution at regional level (Figure 161).



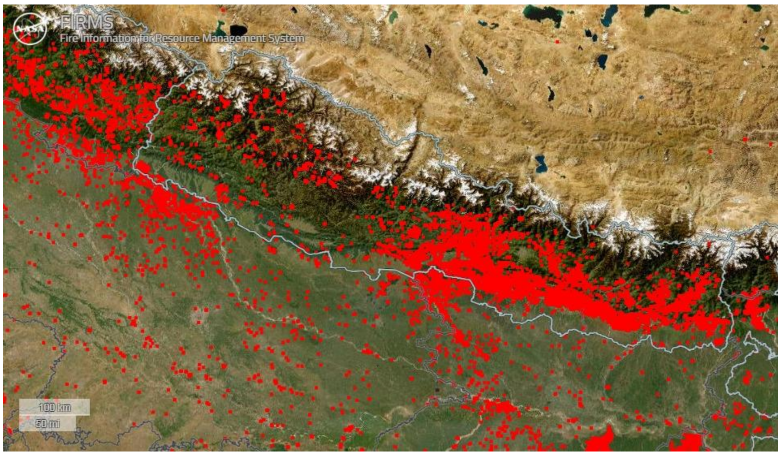
a. True color image from Terra Modis on April 18



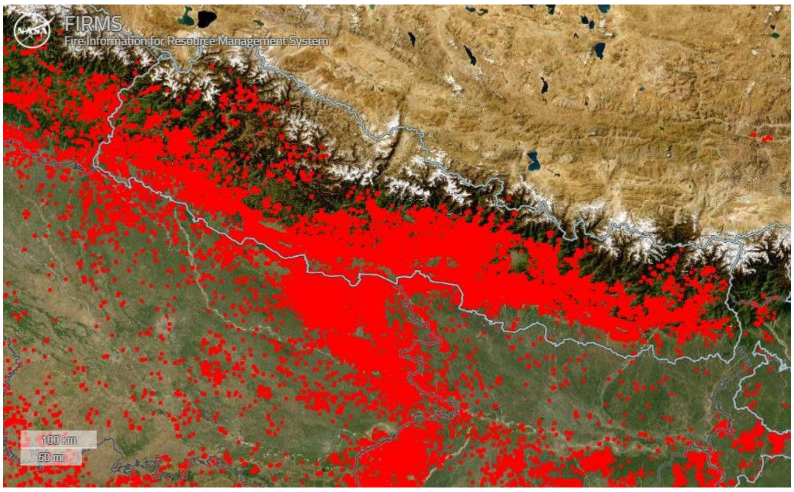
b. True color image from Terra Modis on April 19

Figure 161: True color images on different dates

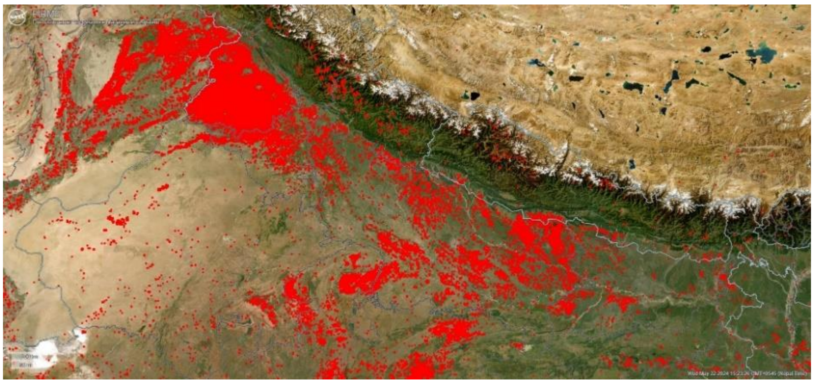
The high number of fire events during March and April (Bhujel et al., 2022) can be linked to high level of air pollution. NASA FIRMS uses satellite observations from the MODIS and VIIRS instruments to detect active fires and thermal anomalies and deliver this information in near real-time. The following images from FIRMS show the fire events throughout country in three different months-March, April and November (Figure 162). Fire events includes intentional as well as unintentional burning of biomass as well as waste. Fire events have a significant effect on the air quality. Both forest fires and agricultural residue burning contribute significantly to the air pollutant emissions. Smoke from fire events is easily detected in the satellite images as shown above in true color image. As fire events in November are not common in Nepal, there are high number of fire events in the neighbouring country that may also affects air quality of Nepal.



a. March, 2023



b. April, 2023



c. November, 2023

Figure 162: Fire events detected by satellite in different months

NO_2 and CO concentration over Nepal

Satellite data also allows us to examine sources of some of the air pollution. For example, there are some satellite products that can quickly tell us whether open burning or forest fire is responsible for this air pollution and it may also indicate economic hot spots. NO_2 and CO both play important role in formation of ground level ozone and related to various health disorders (Banaji, 2023; Karki et al., 2015).

The high level of NO_2 is a good indicator of high economic activities (Banaji, 2023). The major sources of NO_2 are vehicles, industries, forest fires, etc. The monthly average of NO_2 from TROPOMI seems to be affected by forest fire in April. During April, the NO_2 concentration was also high over the area with extensive fire events (Figure 163). Even though fire events were detected throughout the country, NO_2 level was not high all over the country. This may be because all fire events detected by satellites are not of equal intensity. While the annual mean tropospheric NO_2 level was high in some places where economic activities are relatively higher (Figure 164). One of the places having higher level of NO_2 is Kathmandu valley the capital city of Nepal, which might be attributed to higher level of traffic. The high level of NO_2 in other places might be due to higher industrial activities.

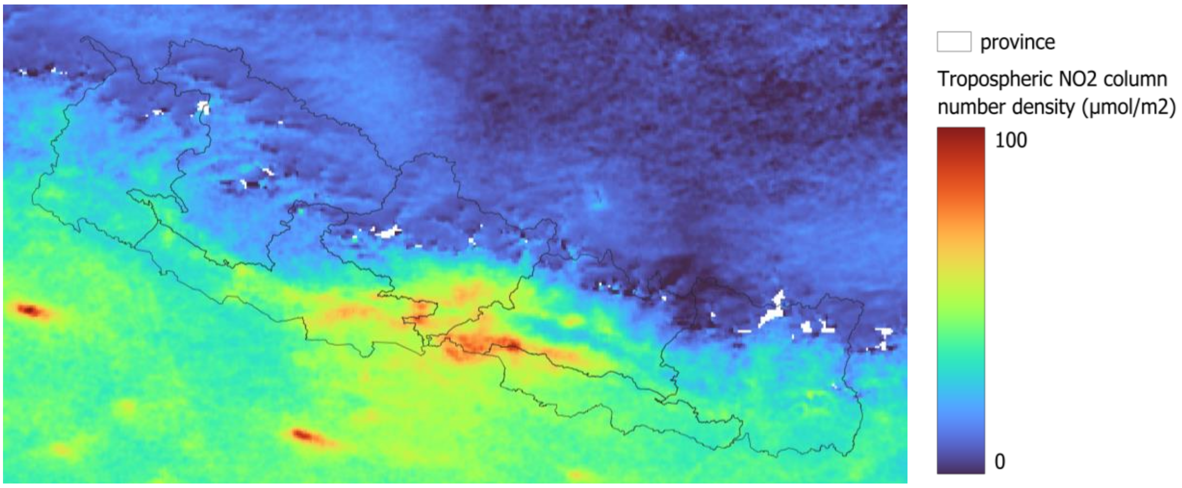


Figure 163: NO_2 concentration in April 2023

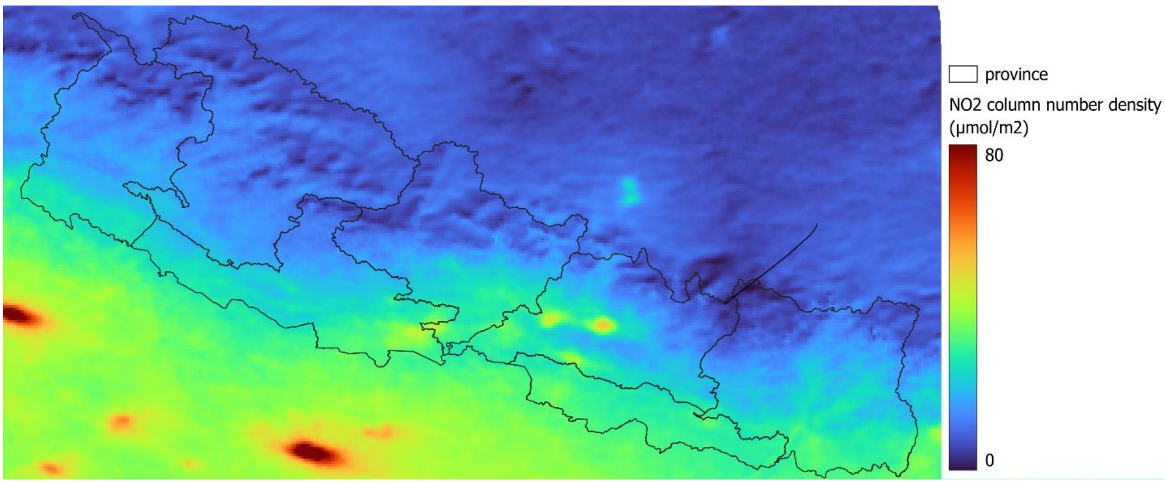


Figure 164: Annual NO_2 concentration in 2023

For other regulated pollutants such as CO, satellite data is available to look at their contribution on monthly as well as annual basis. In April, similar to NO_2, CO is higher in some places indicating different level of emission from fires in different places. The CO data for April 2023 seem to be very high in the area with high fire events.

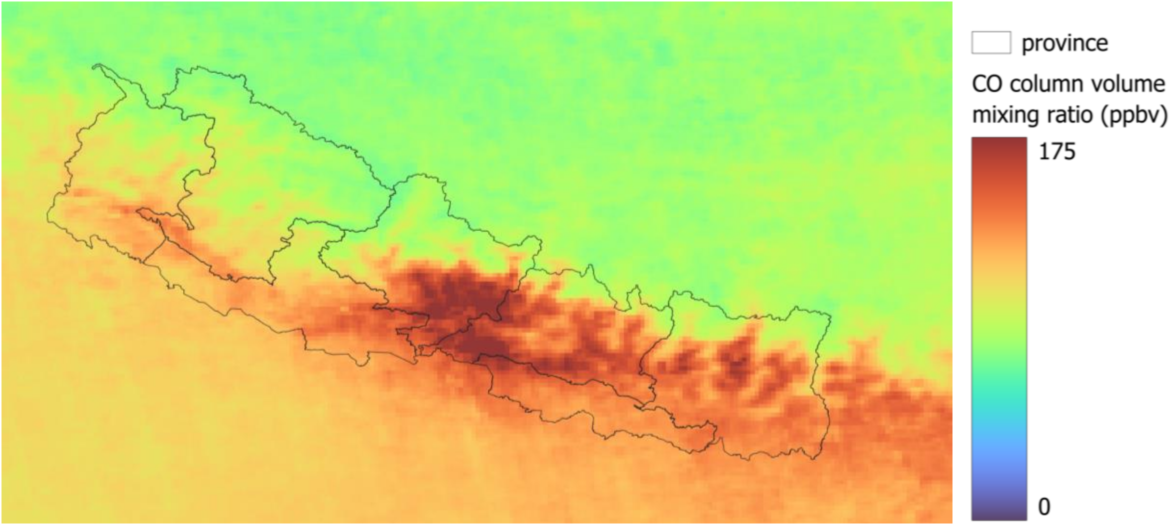


Figure 165: CO concentration in April 2023

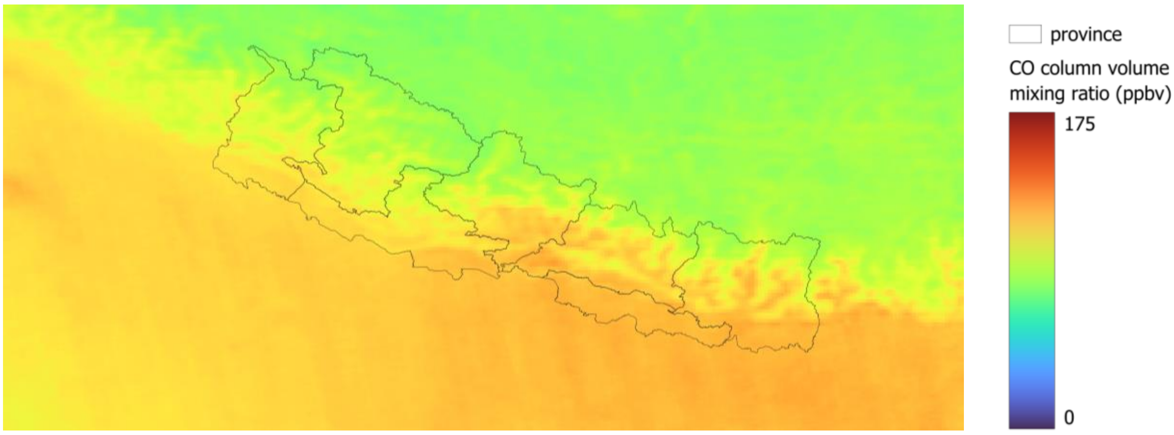


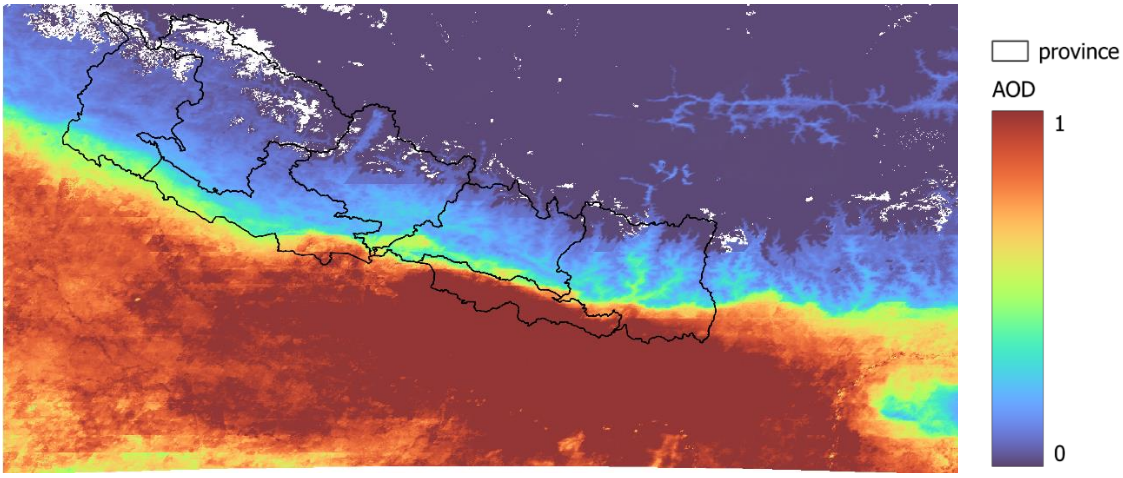
Figure 166: Annual CO concentration in 2023

Spatial and Temporal variability of AOD

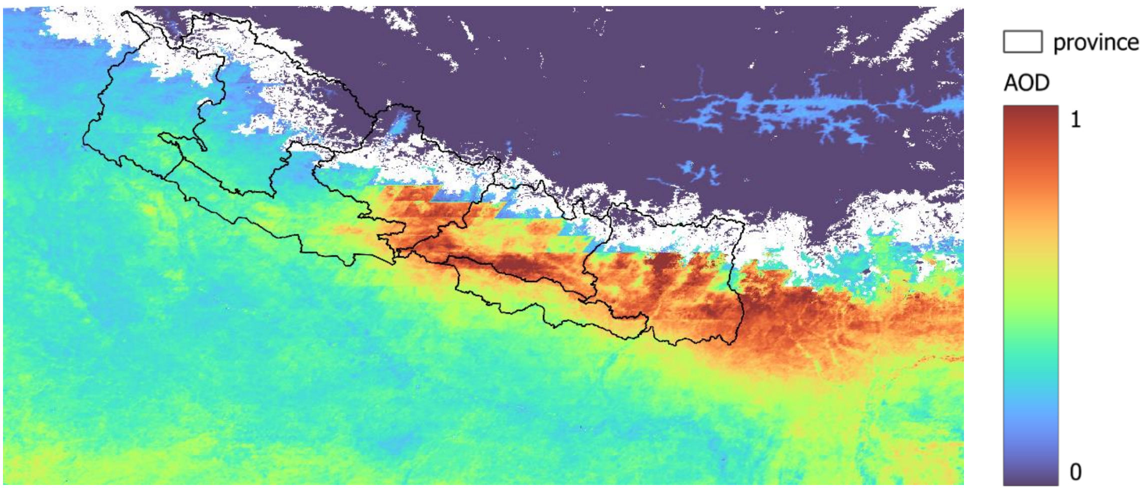
The AOD measures aerosols distributed within a column of air from surface of earth to the top of atmosphere (https://aeronet.gsfc.nasa.gov/new_web/Documents/Aerosol_Optical_Depth.pdf). Aerosols are fine particulate matters including urban haze, smoke particles, desert dust, seas salt which remain suspended in atmosphere. AOD also known as aerosol optical thickness indicates level at which aerosols hinder sunlight to travel through atmosphere either by scattering or by absorbing the sunlight. AOD less than 0.1 is considered "clean" with clear blue sky and maximum visibility whereas as visibility decreases with increase in AOD value from 0.5 to 1.0. The AOD with greater than 3.0 indicates presence of dense aerosols that covers the Sun (https://www.earthdata.nasa.gov/worldview/worldview-image-archive/high-aod-india-15-nov-2023). Higher the AOD higher the air pollution with particulate matter specially $PM_{2.5}$ (https://aaqr.org/articles/aaqr-22-09-oa-0311).

AOD provides information about aerosol loading and distribution that affects radiation balance, visibility, air quality and climate. It is an important tool that uses satellite monitoring for air quality data analysis. AOD may be utilized in different elements of air quality, including forecasting, research, policy formation, and many more. Air quality data analysis done with both ground as well as satellite data is considered to have the best result.

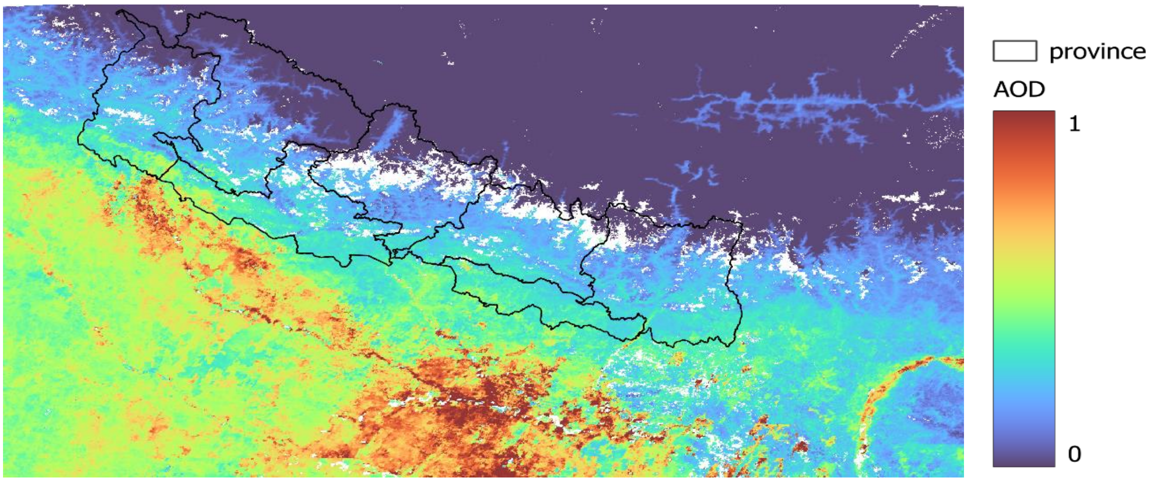
Mean AOD for single month from each season- January, April, September and November was calculated using google earth engine (Figure 167). Generally, Air pollution scenario is worst during early morning and evening but the calculation of AOD is based on data taken by satellite at particular time of day. In this case at 10:30 and 13:30 local time. That is why the pollution hot spots might not be clearly visible in the AOD maps. However, AOD is very useful for assessing regional level of pollution.



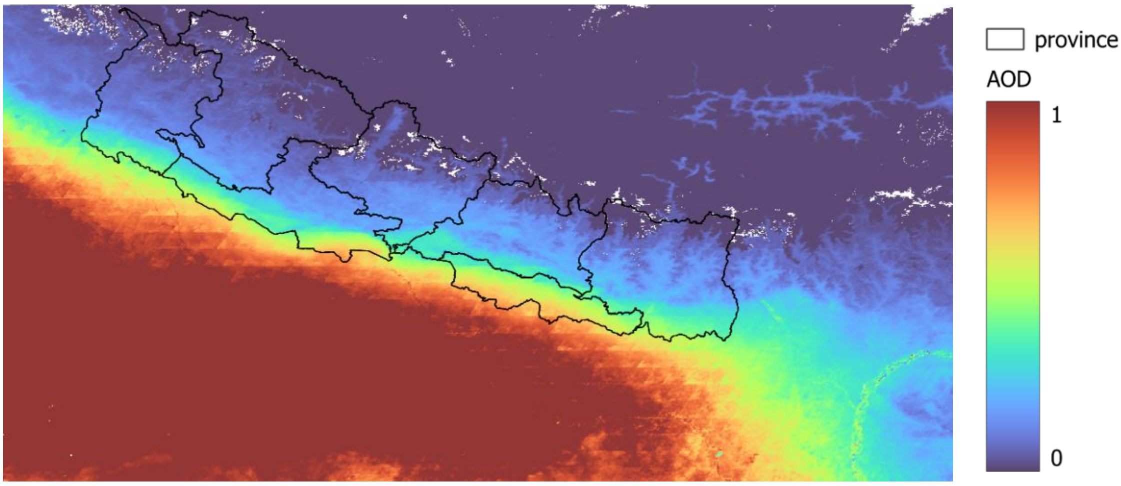
a. January 2023



b. April 2023



c. September 2023

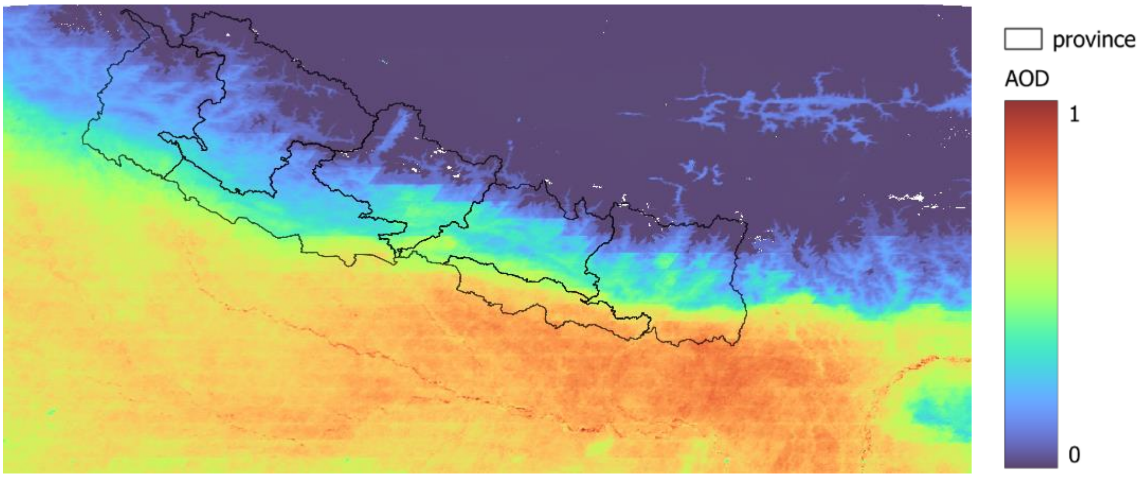


d. November 2023

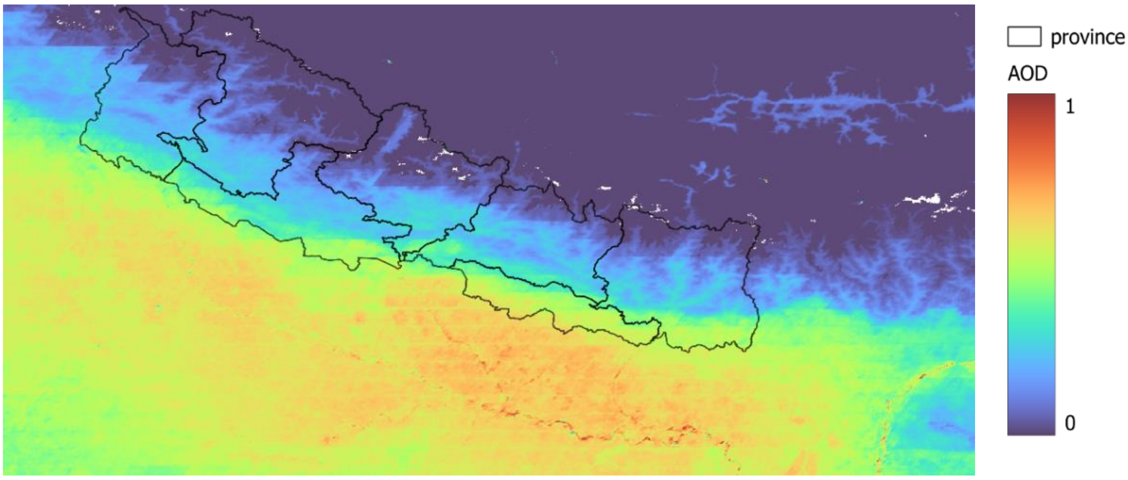
Figure 167: Monthly AOD analysis for different months

Monthly AOD was relatively high in the Terai region during January and November. During January, AOD is higher in Madhesh Province than other regions of the country. AOD for September was low throughout the country. In April higher AOD was seen on the eastern to mid-western hilly regions of the country in April. AOD seems to be affected by forest fire in April.

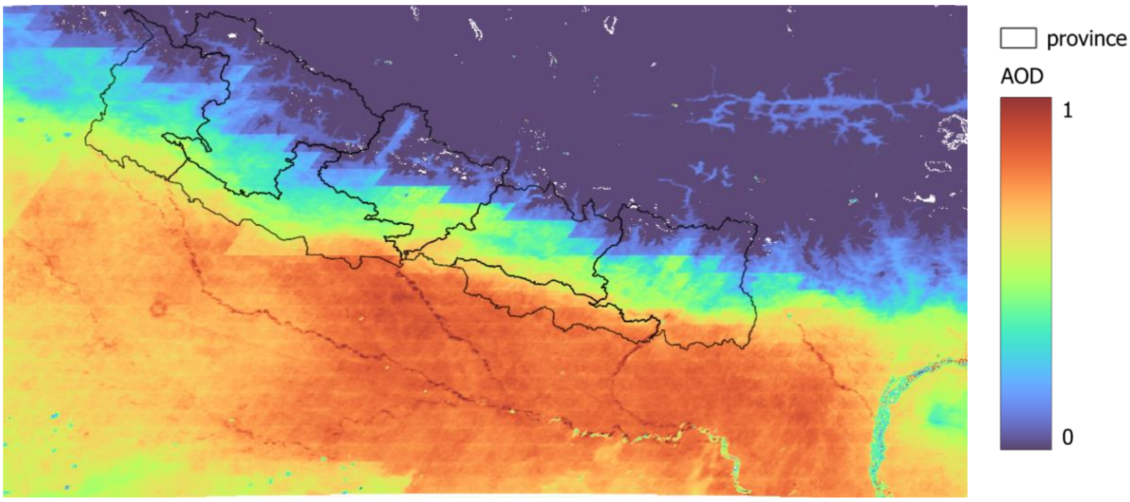
Annual AOD for three years 2021, 2022 and 2023 were also analyzed in this report (Figure 168). In 2023, higher level of AOD was seen in Terai region of country, especially in the eastern Terai. The annual average of AOD in 2023 over different Provinces is showed in Annex 5. In all three years, Madhesh Province along with Terai region of Koshi Province were seen with higher level of AOD as shown in Figure 168.



a. Year 2023



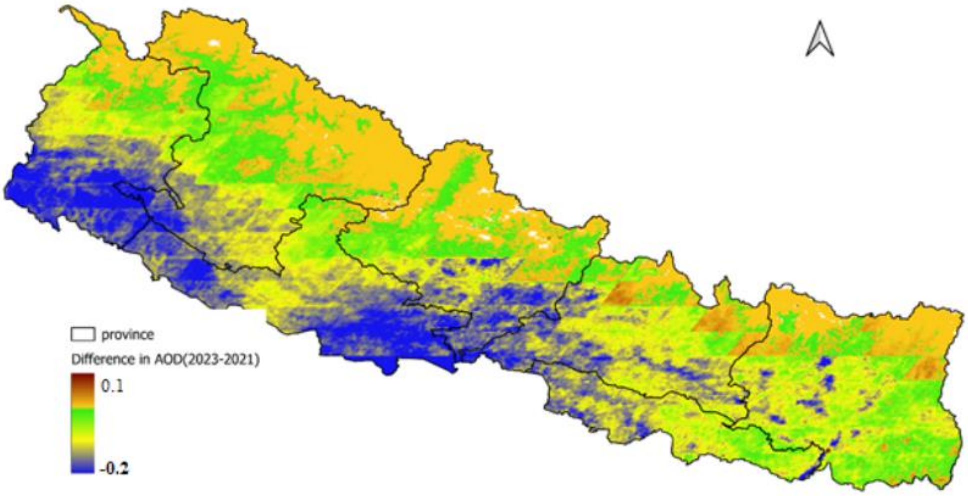
b. Year 2022



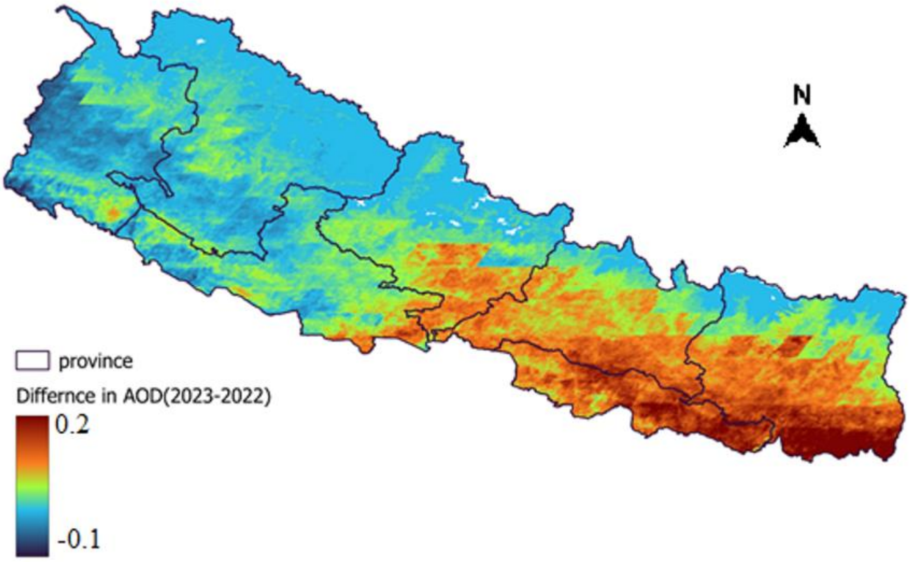
c. Year 2021

Figure 168: Annual AOD analysis for different years

The difference in annual AOD between different years showed how level of particulate pollutant changes over time. On one hand, significant decreases in AOD can be identified in the Lumbini and Sudurpaschim Province between 2021 to 2023 (Figure 169). Whereas on other hand, a significant increase in average AOD can be detected in the eastern part of the country between 2022 to 2023.



a. Mean AOD in 2023 minus mean AOD in 2021



b. Mean AOD in 2023 minus mean AOD in 2022

Figure 169: Difference in annual mean AOD at different time period

CHAPTER 3: CONCLUSION

This report delves into PM pollution data collected from nine air quality monitoring stations operated by Department of Environment and one station operated by ICIMOD for 2023. These ten stations represent four Provinces of Nepal- Koshi Province, Bagmati Province, Karnali Province, and Sudurpaschim Province. In addition to ground-based monitoring, satellite data was utilized to enhance the assessment of the country's overall air pollution status.

The condition of air quality varied both temporally and spatially. Typically, particulate pollution was found highest during winter season except in Rara Station where pre-monsoon season exhibited high pollution levels. The daily fluctuation of $PM_{2.5}$ and PM_{10} shows bimodal distribution, spiking in morning (5-10) and evening (17-23) time and low during day time. In contrast, Total suspended particulate (TSP) however shows unimodal distribution peaking during day time (12-17). Among three parameters analyzed this report revealed that $PM_{2.5}$ had the lowest compliance with NAAQS while TSP had the highest compliance. As $PM_{2.5}$ can be transported to the larger distances than PM_{10} and TSP, only local level initiatives are not sufficient for air pollution control.

Annual pollution rose diagrams for selected monitoring stations (Dhankuta, Ratnapark, Khumaltar and Rara) indicate that wind form south to south west direction is associated with higher concentration of $PM_{2.5}$ pollutions. HYSPLIT model analysis of Kathmandu Valley showed high PM pollution during January and April seems to be linked to wind primarily originated from the west or south direction. High concentrations of particulate pollution during March and April can be attributed to fire events as shown by the satellite images and satellite based data. The annual tropospheric NO_2 level was relatively higher in high economic activities areas. Additionally, AOD data analysis showed high concentration of $PM_{2.5}$ in the Terai regions of central and eastern Nepal. There was a visible decrease in AOD in the Lumbini and Sudurpaschim Province between 2021to 2023 and increase in eastern Nepal between 2022 to 2023.

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ANNEX 1: MEMBERS OF AIR QUALITY DATA ANALYSIS COMMITTEE, 2023

SN	Name	Organization
1	Mr. Deepak Gyawali, Senior Divisional Chemist	Department of Environment
2	Dr. Ramesh Prasad Sapkota, Associate Professor	Tribhuvan University, Central Department of Environment Science
3	Mr. Keshab Raj Joshi, Environment Inspector	Ministry of Forests and Environment
4	Mr. Sangha Ratna Shakya, Meteorologist	Department of Hydrology and Meteorology
5	Mr. Suresh Pokheral, Senior Research Associate	ICIMOD
6	Mr. Ramesh Karki, Account Officer	Department of Environment
7	Mr. Govinda Prasad Lamichhane, Environment Inspector	Department of Environment
8	Ms. Nabina Maharjan, Environment Inspector	Department of Environment

ANNEX 2: LIST OF EXPERTS WHO CONTRIBUTED AND REVIEWED IN THE REPORT

SN	Name of Expert	Organization
1	Mr. Shankar Prasad Paudel, Senior Divisional Chemist	Department of Hydrology and Meteorology
2	Dr. Bhupesh Adhikary, Senior Air Quality Specialist	ICIMOD
3	Dr. Ravi Sahu, Air Quality Specialist	ICIMOD
4	Mr. Sagar Adhikari, Air Pollution Analyst- Mitigation	ICIMOD
5	Dr. Arshini Saikia, Air quality Modelling Analyst	ICIMOD
6	Dr. Khushboo Sharma, Air Pollution Analyst- Observation	ICIMOD
7	Mr. Niroj Timalsina, GIS Expert	Independent Expert
8	Mr. Prakash K.C., Environment Inspector	Department of Environment
9	Mr. Rajeshwor Paudel, Environment Inspector	Department of Irrigation
10	Ms. Bina Ghimire, Environment Inspector	Department of Environment
11	Ms. Arati Shrestha, Environment Inspector	Department of Environment
12	Ms. Swasti Shrestha, Environment Inspector	Department of Environment
13	Ms. Hasana Shrestha, Environment Inspector	Department of Environment
14	Mr. Sabit Deshar, Environment Inspector	Department of Environment

ANNEX 3: FIGURES OF DIFFERENT STATIONS

HISTOGRAM

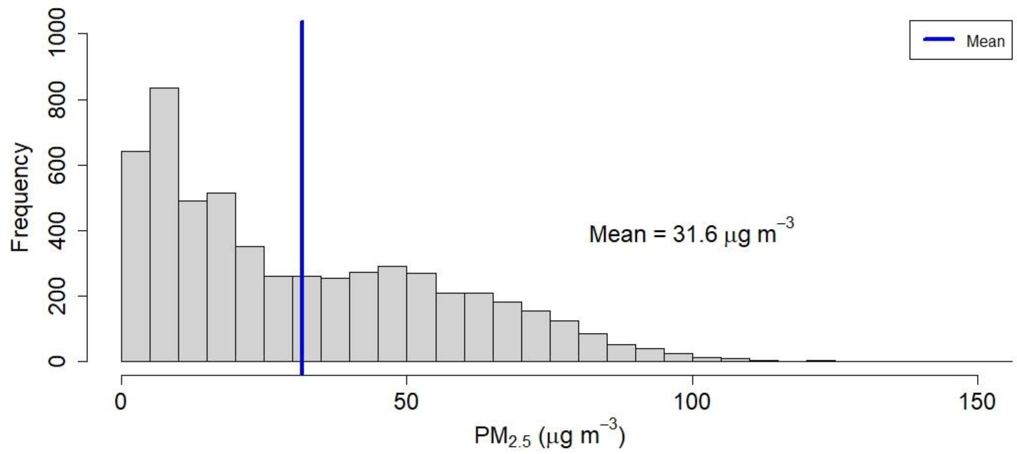


Figure 170: Histogram of $PM_{2.5}$ for Dhankuta Station

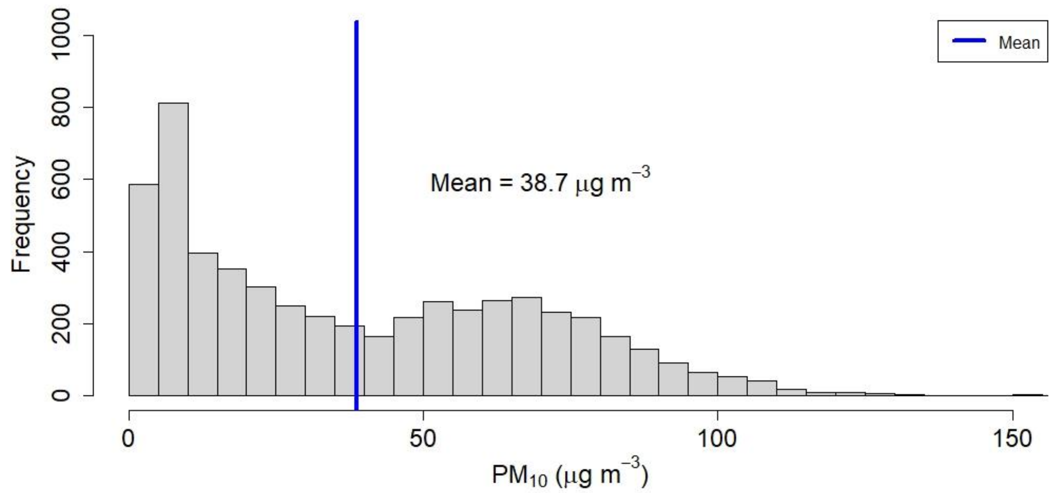


Figure 171: Histogram of PM_{10} for Dhankuta Station

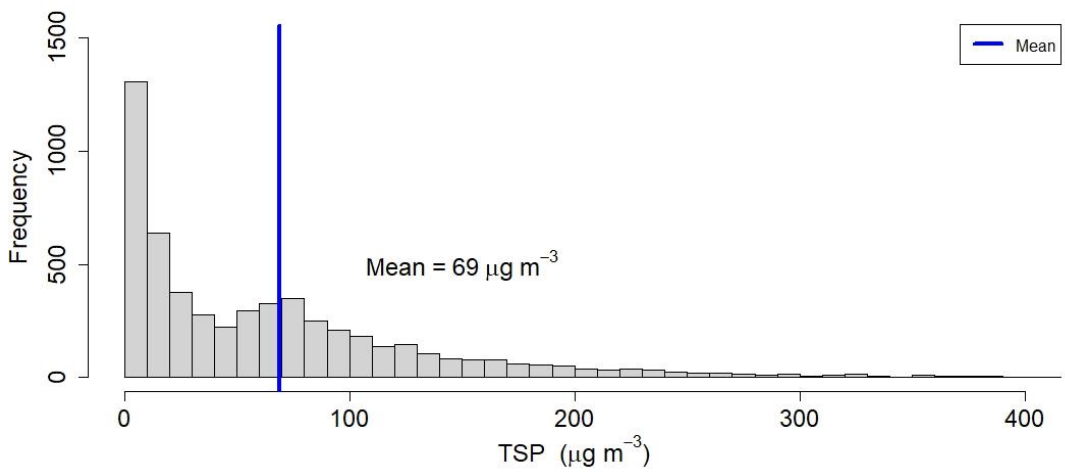


Figure 172: Histogram of TSP for Dhankuta Station

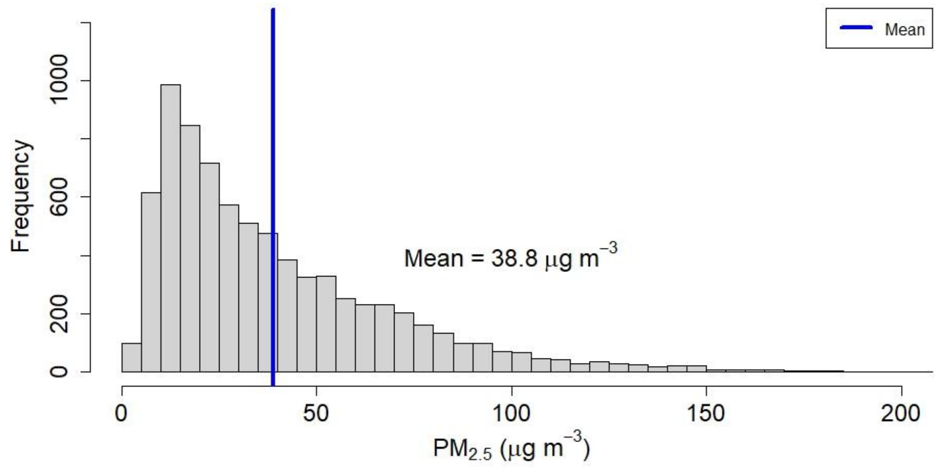


Figure 173: Histogram of $PM_{2.5}$ for Bhaisepati Station

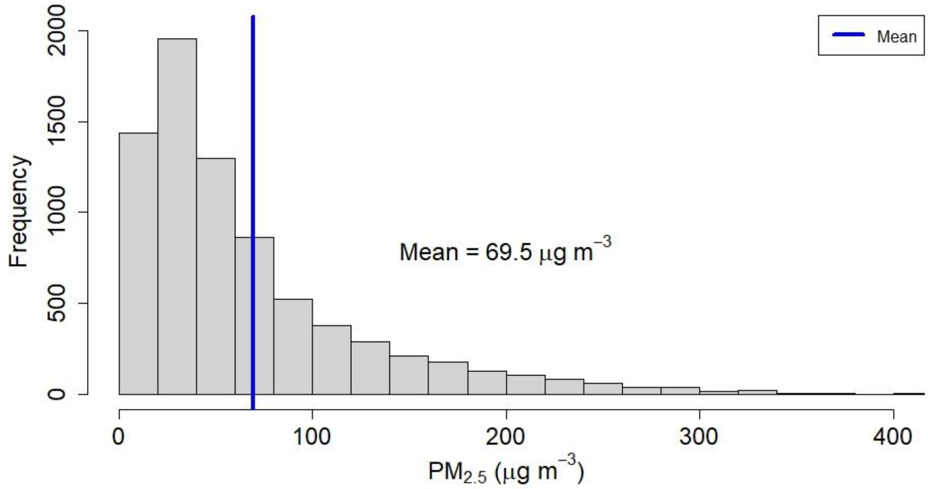


Figure 174: Histogram of PM_{10} for Bhaisepati Station

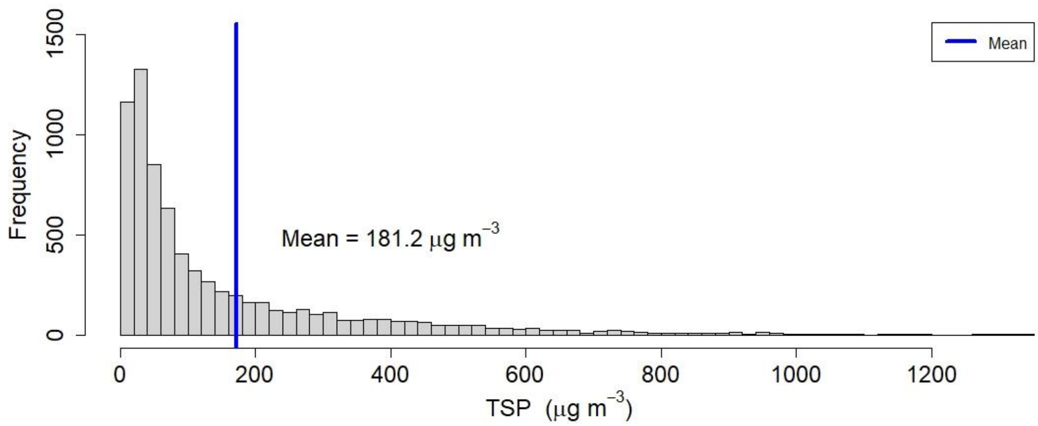


Figure 175: Histogram of TSP for Bhaisepati Station

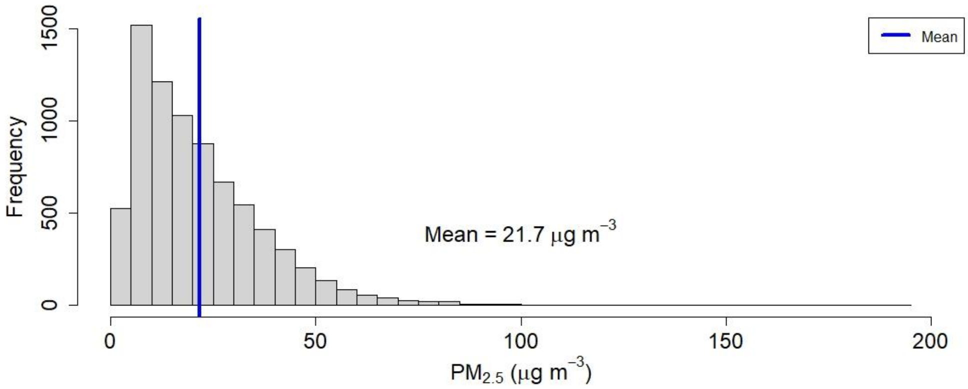


Figure 176: Histogram of $PM_{2.5}$ for Hetauda Station

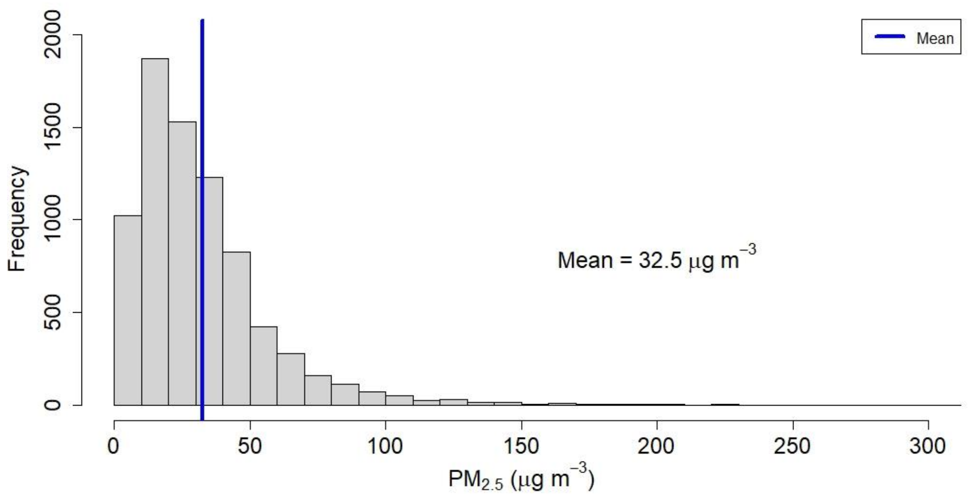


Figure 177: Histogram of PM_{10} for Hetauda Station

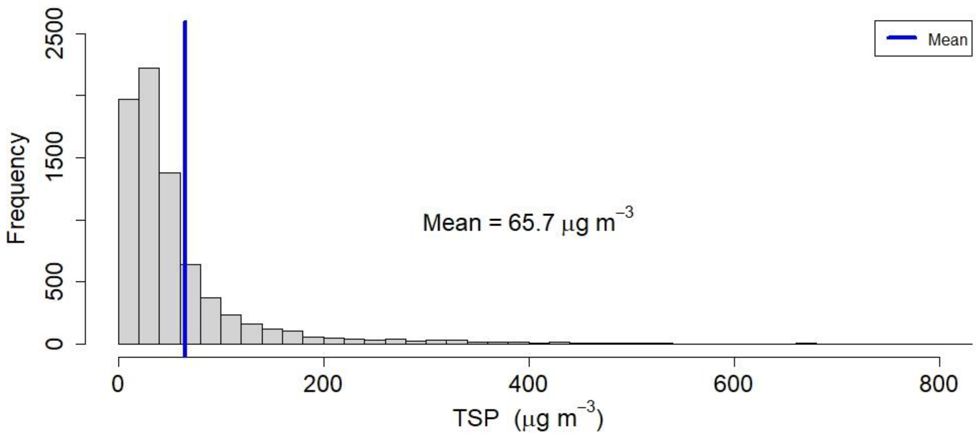


Figure 178: Histogram of TSP for Hetauda Station

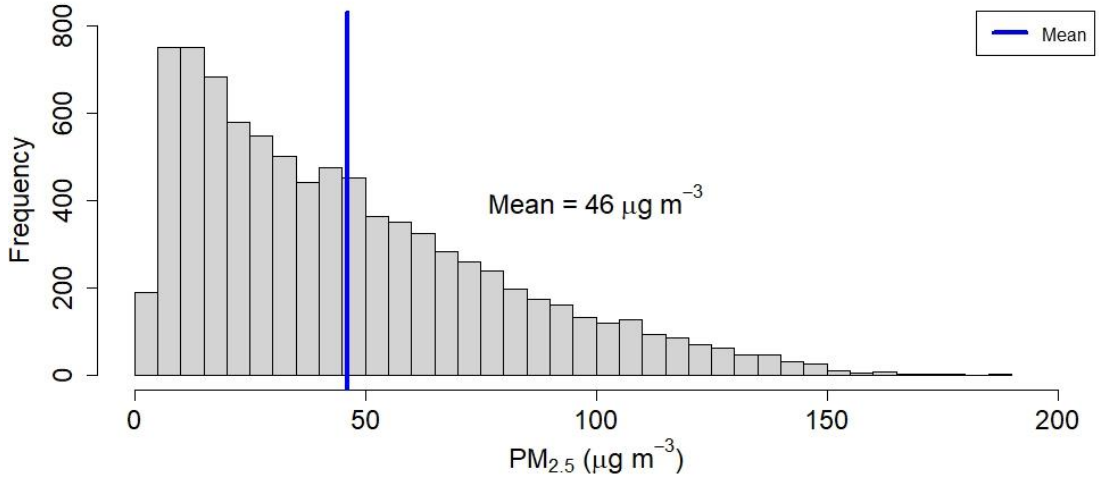


Figure 179: Histogram of $PM_{2.5}$ for Khumaltar Station

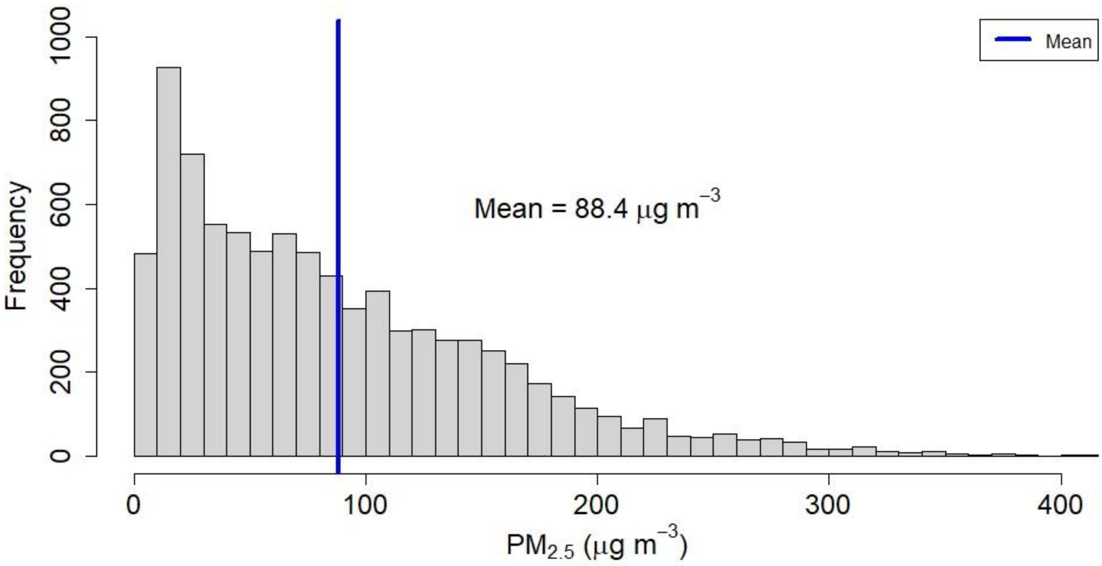


Figure 180: Histogram of PM_{10} for Khumaltar Station

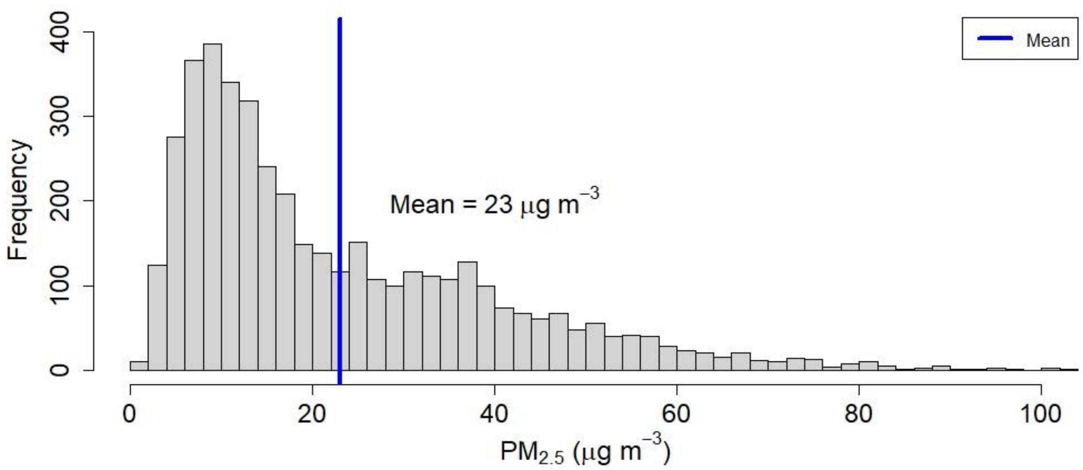


Figure 181: Histogram of $PM_{2.5}$ for Pulchowk Station

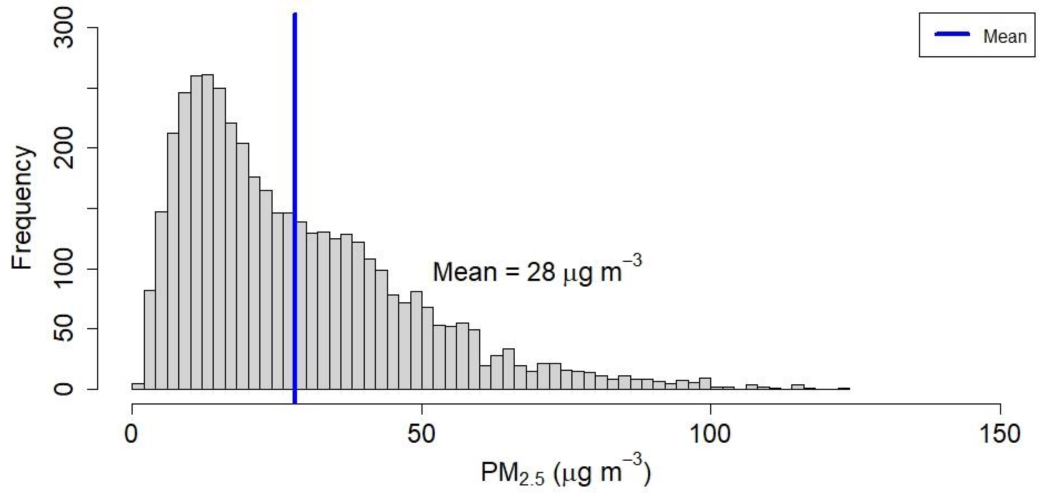


Figure 182: Histogram of PM_{10} for Pulchowk Station

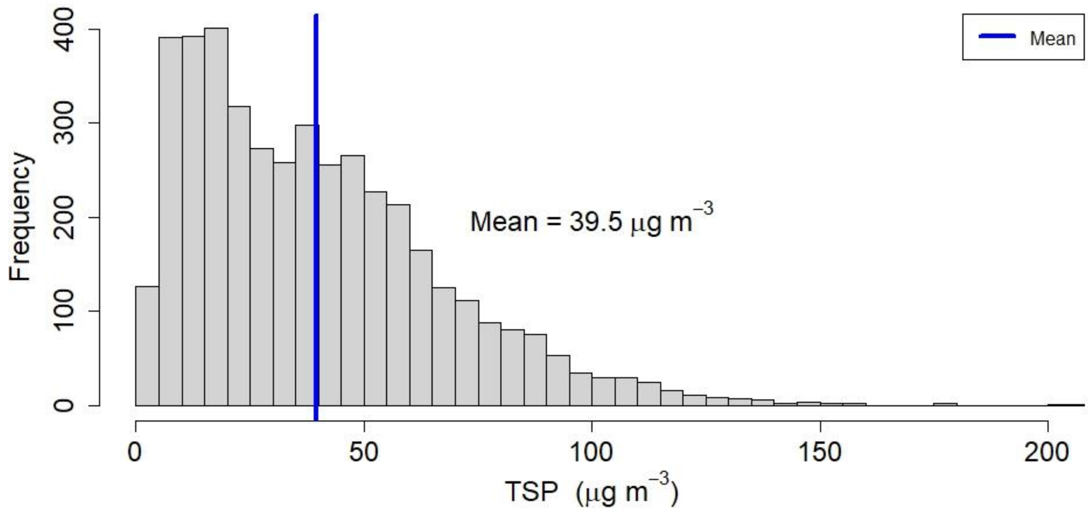


Figure 183: Histogram of TSP for Pulchowk Station

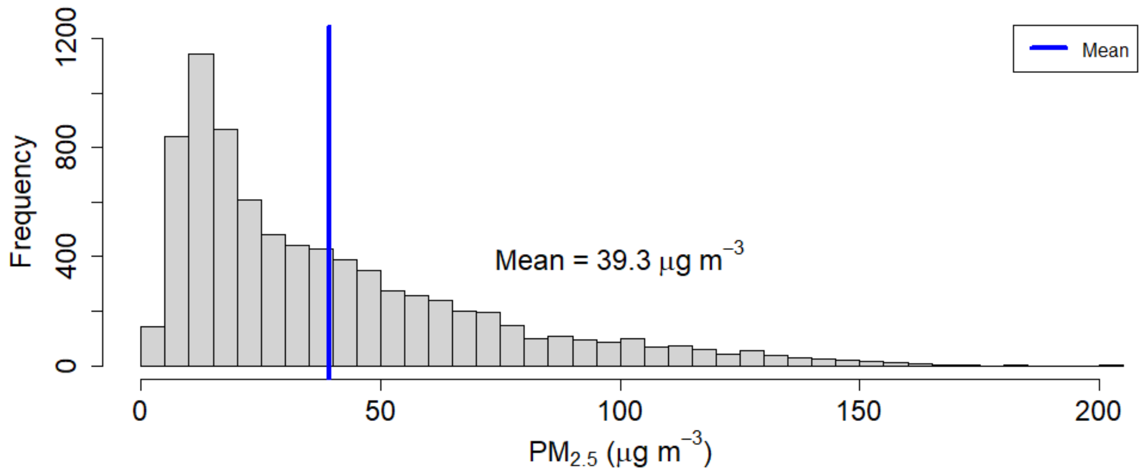


Figure 184: Histogram of $PM_{2.5}$ for Ratnapark Station

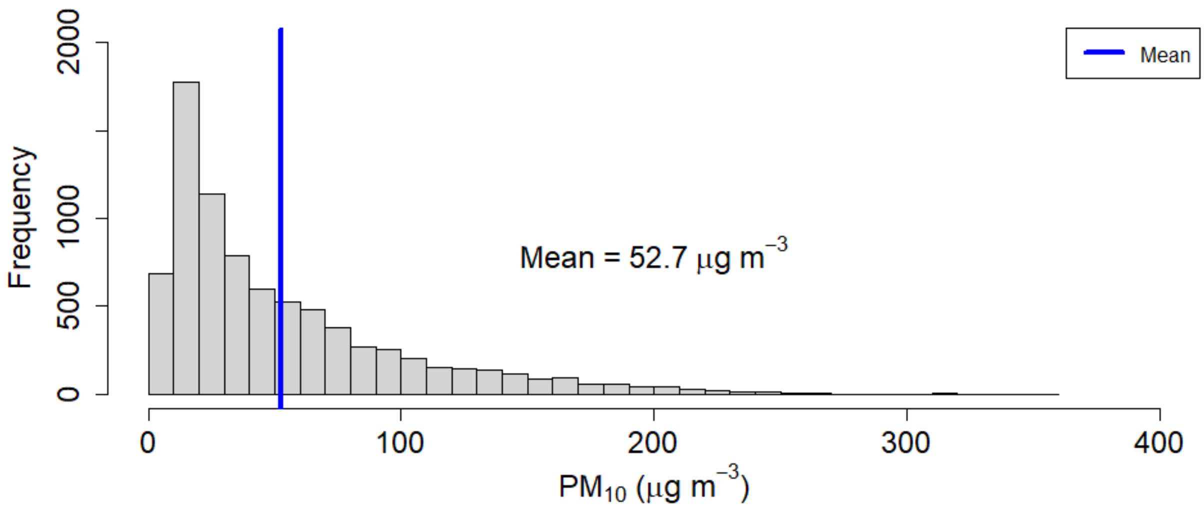


Figure 185: Histogram of PM_{10} for Ratnapark Station

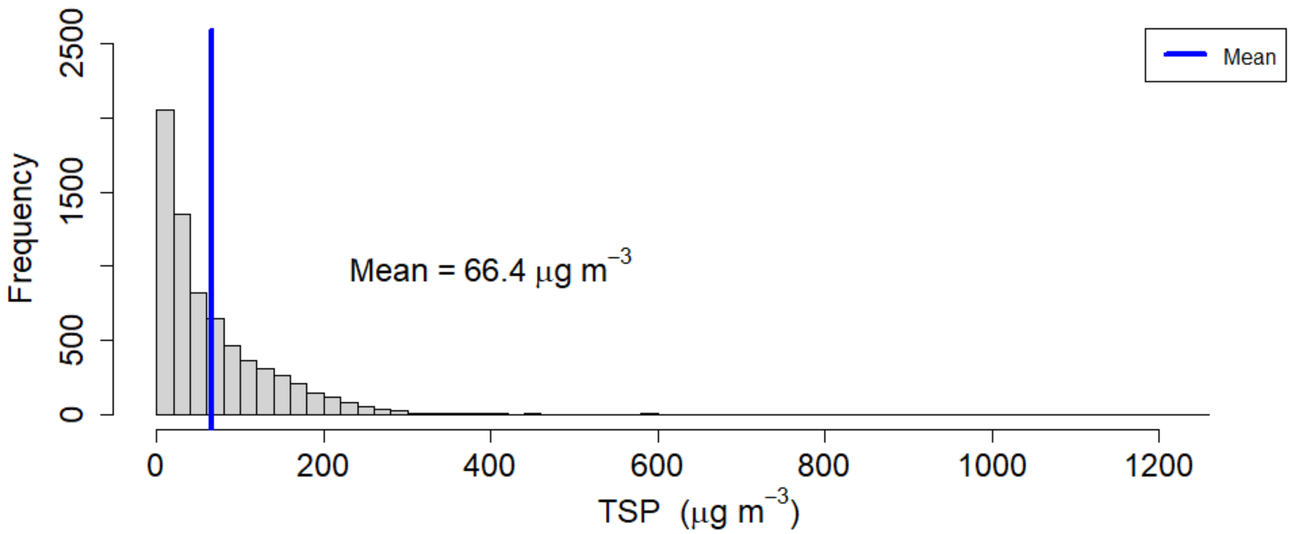


Figure 186: Histogram of TSP for Ratnapark Station

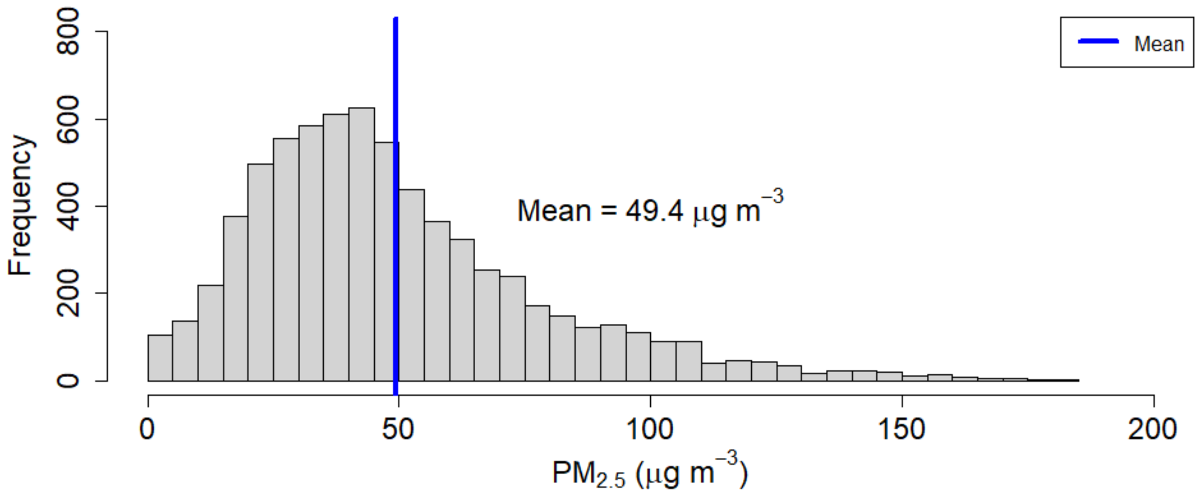


Figure 187: Histogram of $PM_{2.5}$ for Shankhapark Station

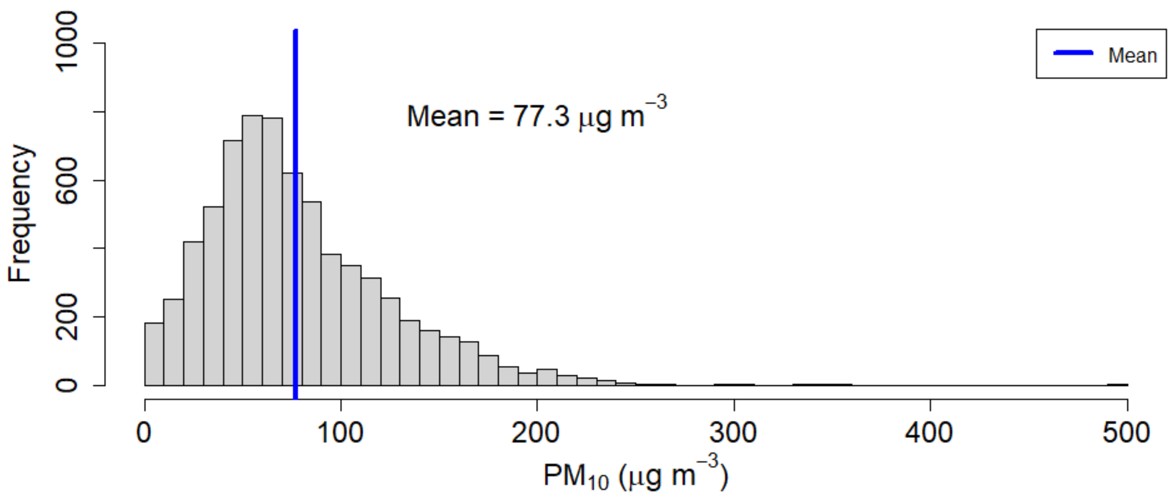


Figure 188: Histogram of PM_{10} for Shankhapark Station

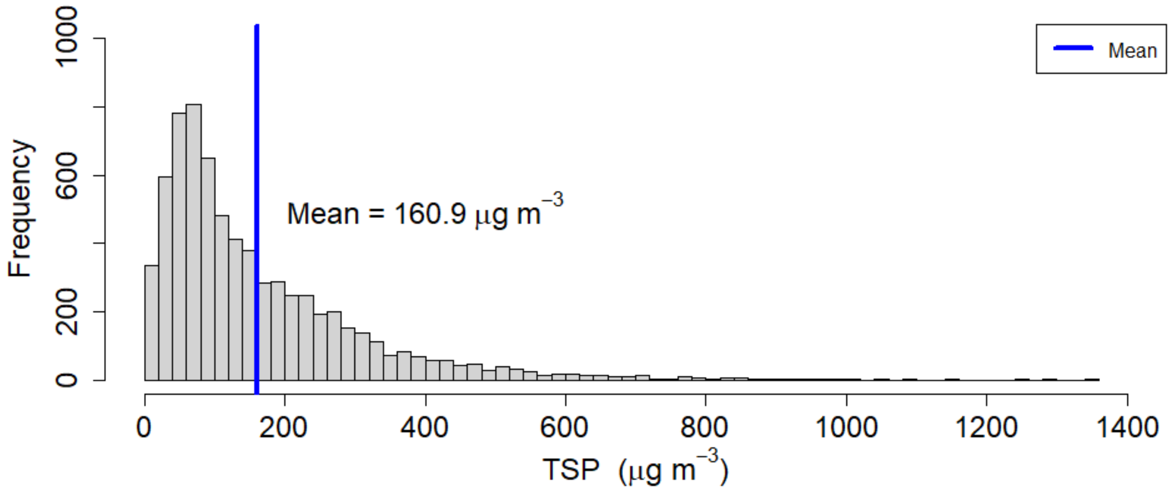


Figure 189: Histogram of TSP for Shankhapark Station

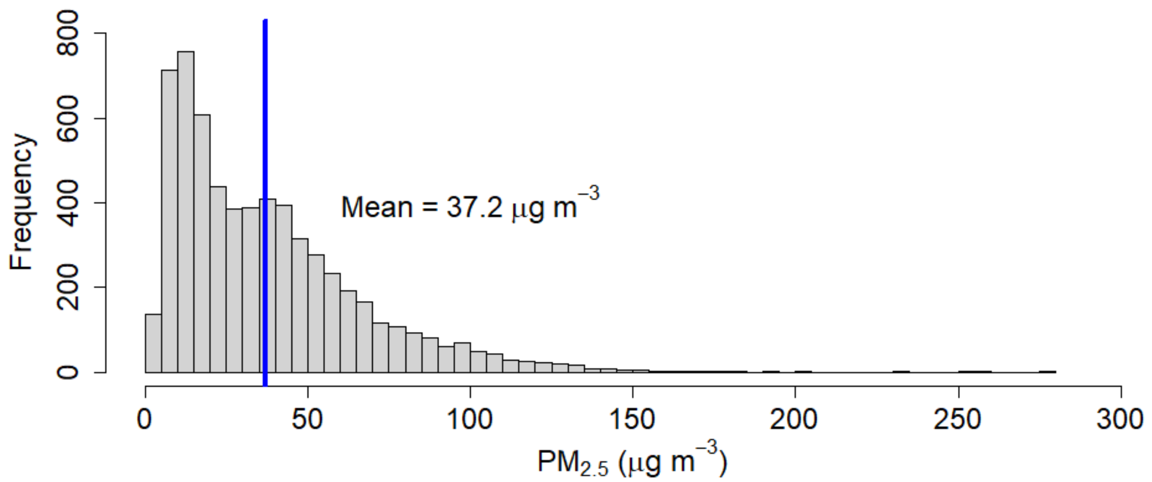


Figure 190: Histogram of $PM_{2.5}$ for TU Kirtipur Station

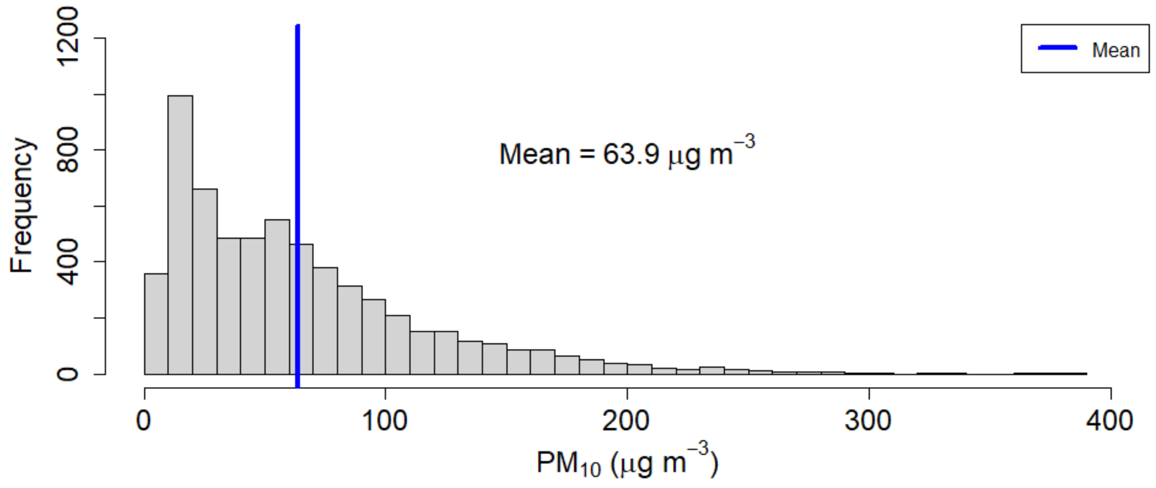


Figure 191: Histogram of PM_{10} for TU Kirtipur Station

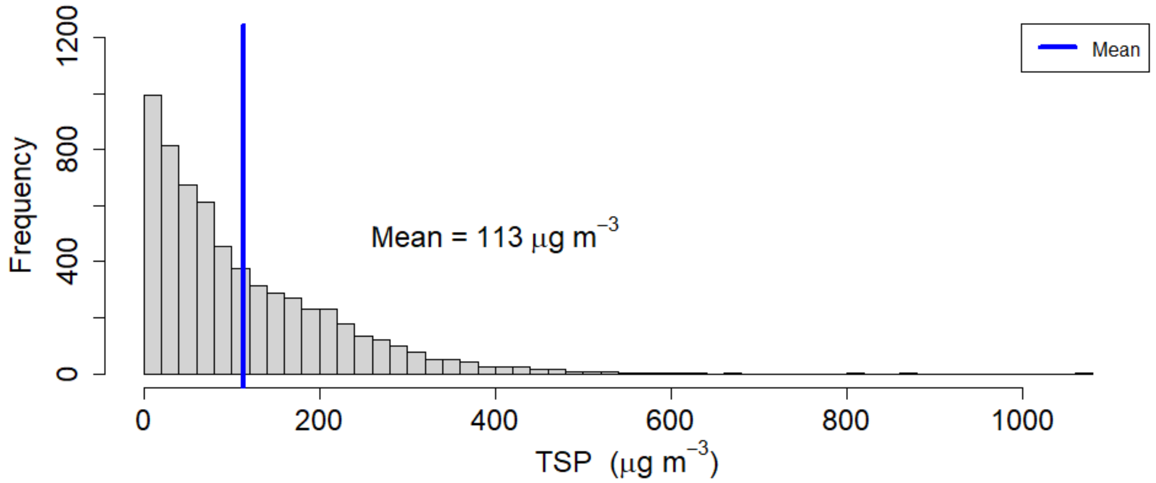


Figure 192: Histogram of TSP for TU Kirtipur Station

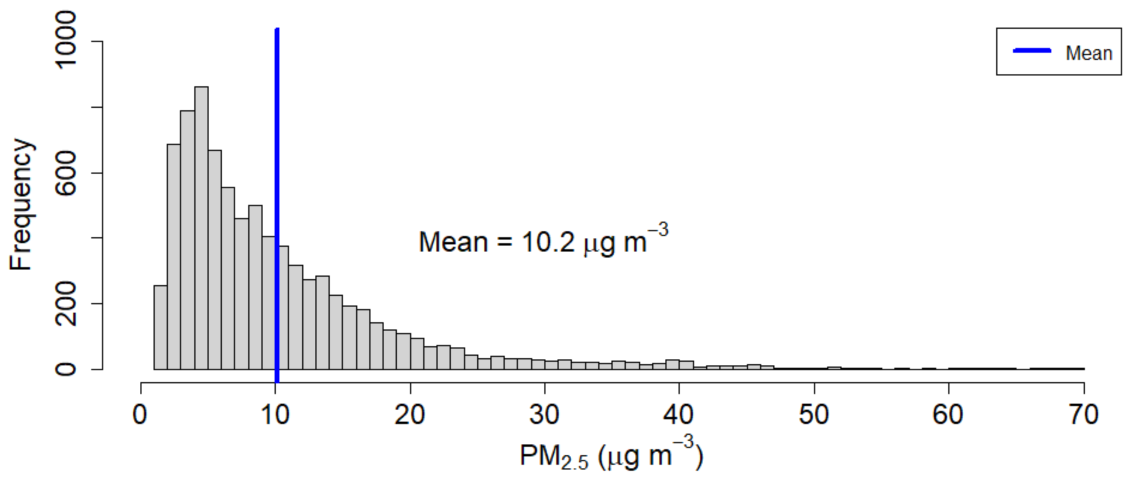


Figure 193: Histogram of $PM_{2.5}$ for Rara Station

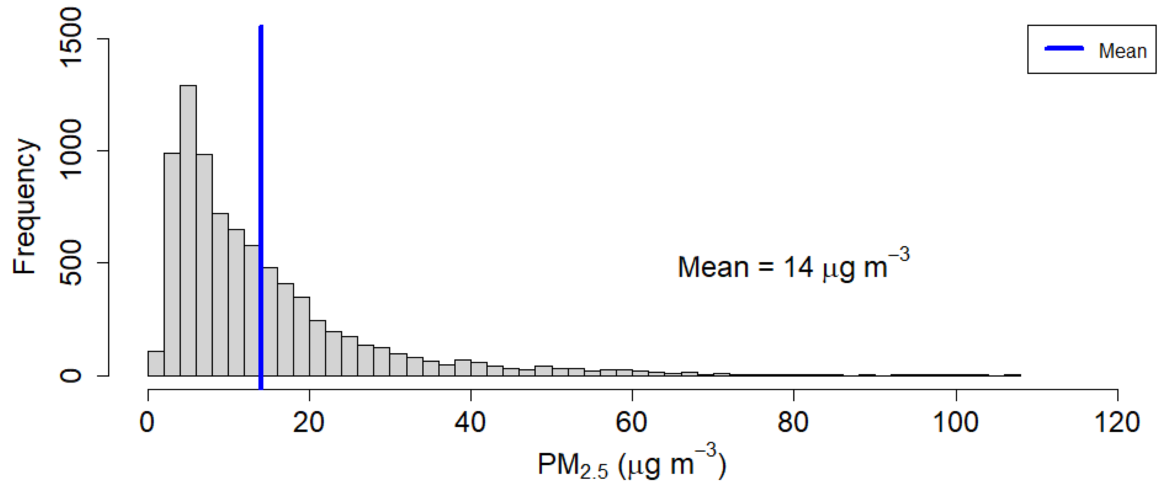


Figure 194: Histogram of PM_{10} for Rara Station

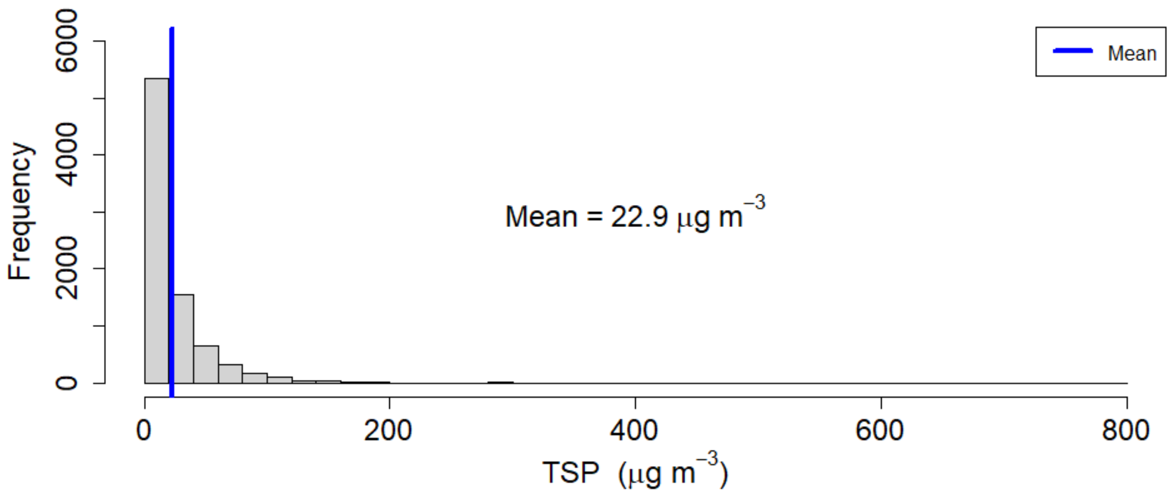


Figure 195: Histogram of TSP for Rara Station

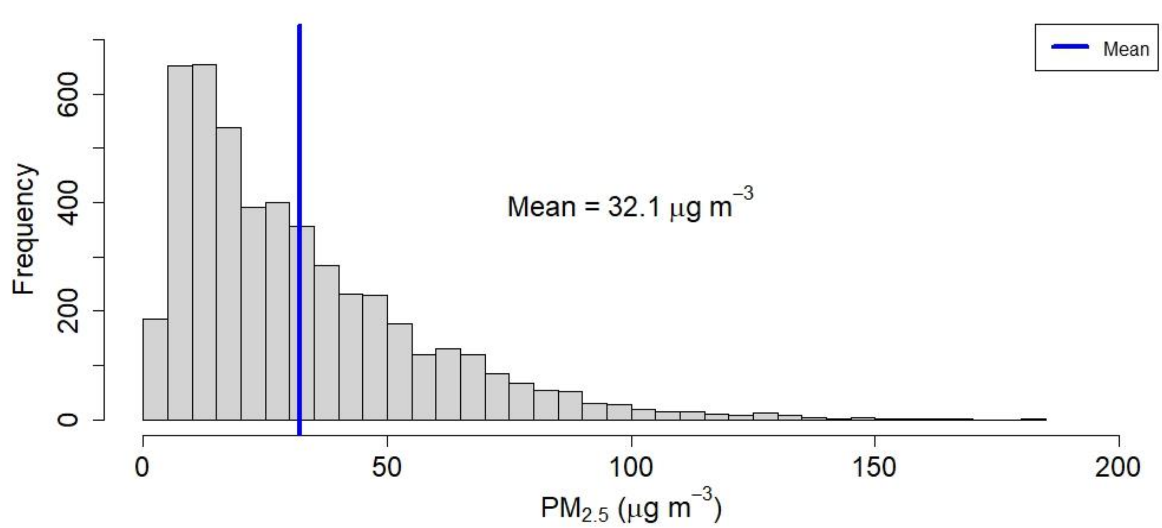


Figure 196: Histogram of $PM_{2.5}$ for Mahendranagar Station

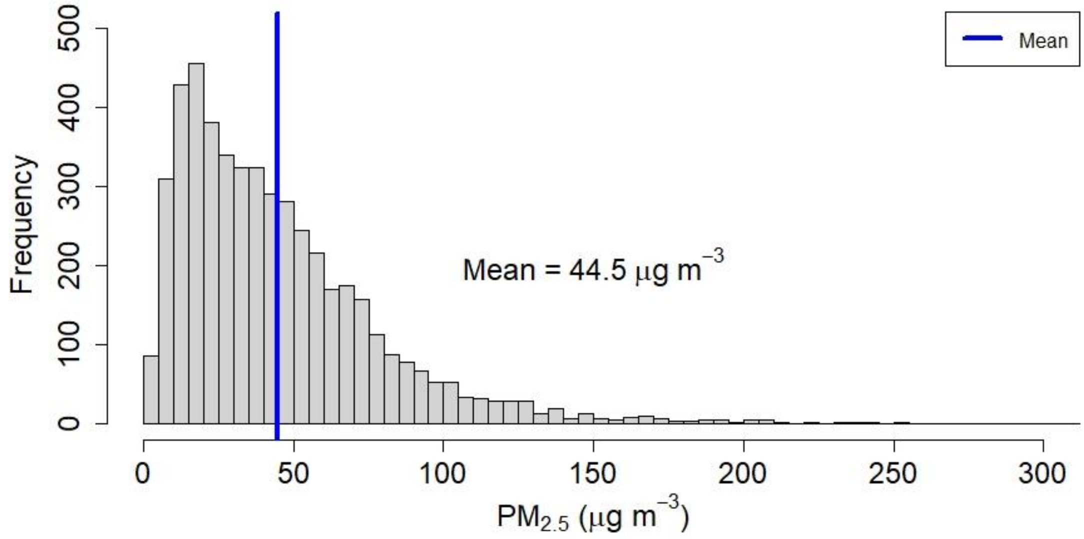


Figure 197: Histogram of PM_{10} for Mahendranagar Station

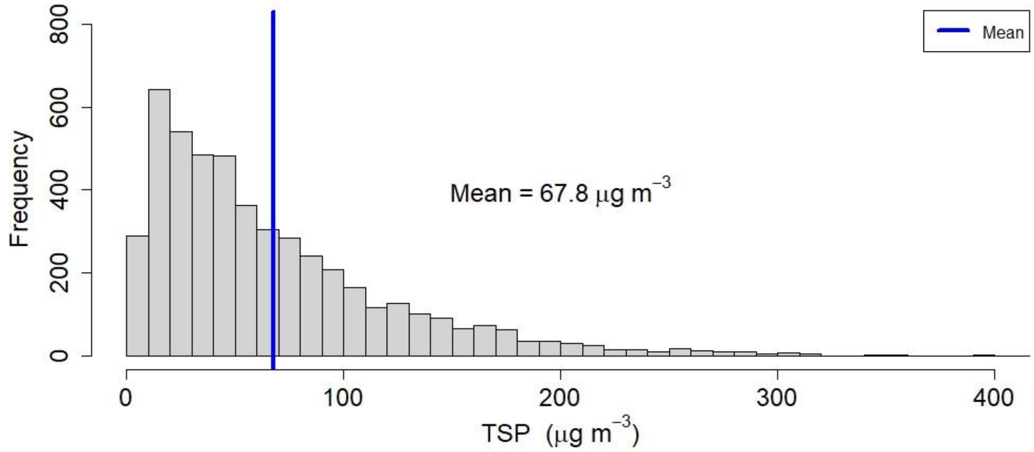


Figure 198: Histogram of TSP for Mahendranagar Station

DIURNAL VARIATION

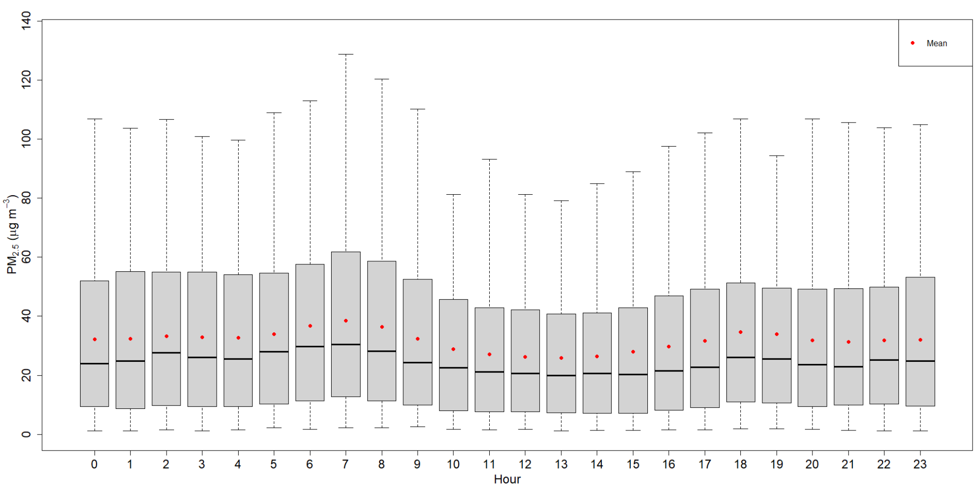


Figure 199: Diurnal variation of $PM_{2.5}$ for Dhankuta Station

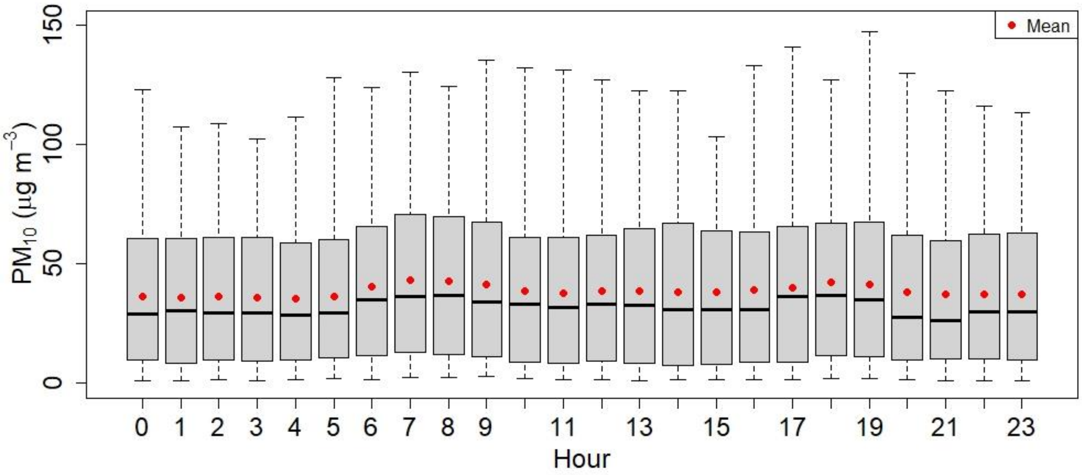


Figure 200: Diurnal variation of PM_{10} for Dhankuta Station

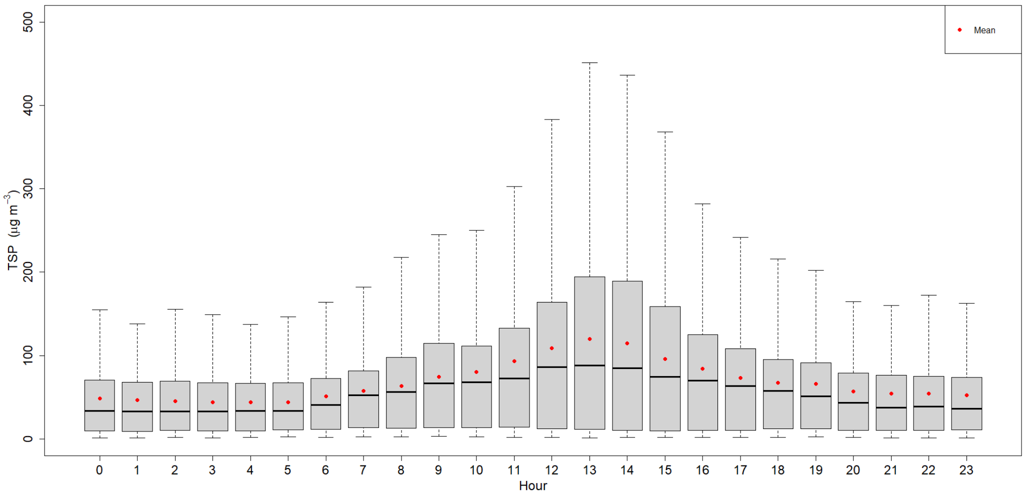


Figure 201: Diurnal variation of TSP for Dhankuta Station

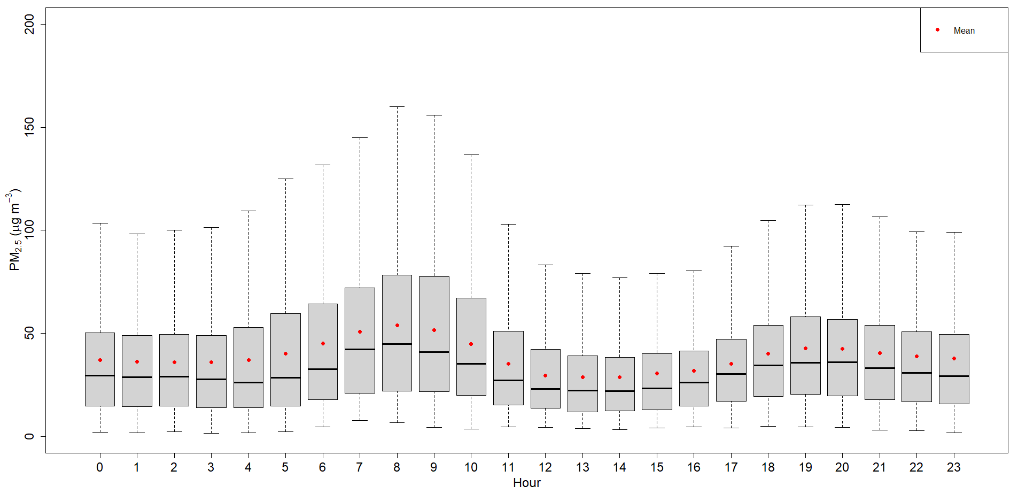


Figure 202: Diurnal variation of $PM_{2.5}$ for Bhaisepati Station

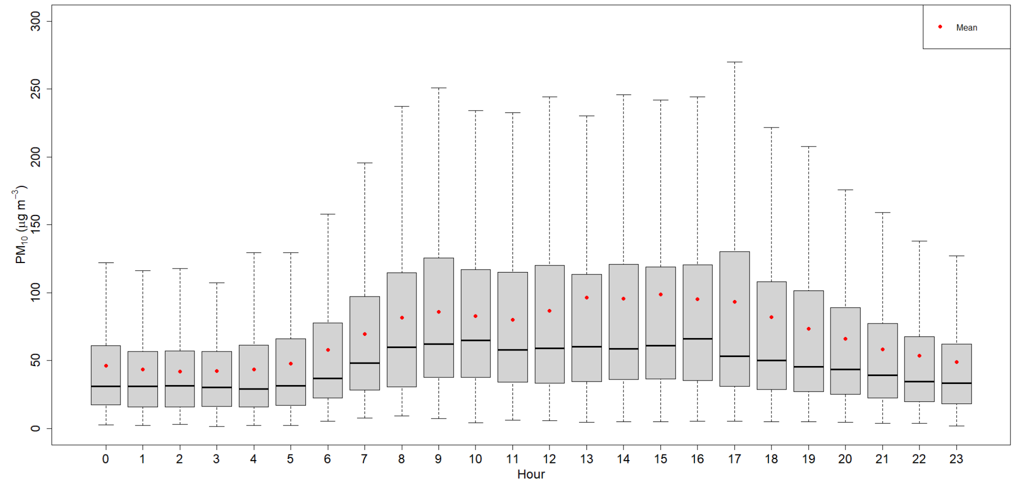


Figure 203: Diurnal variation of PM_{10} for Bhaisepati Station

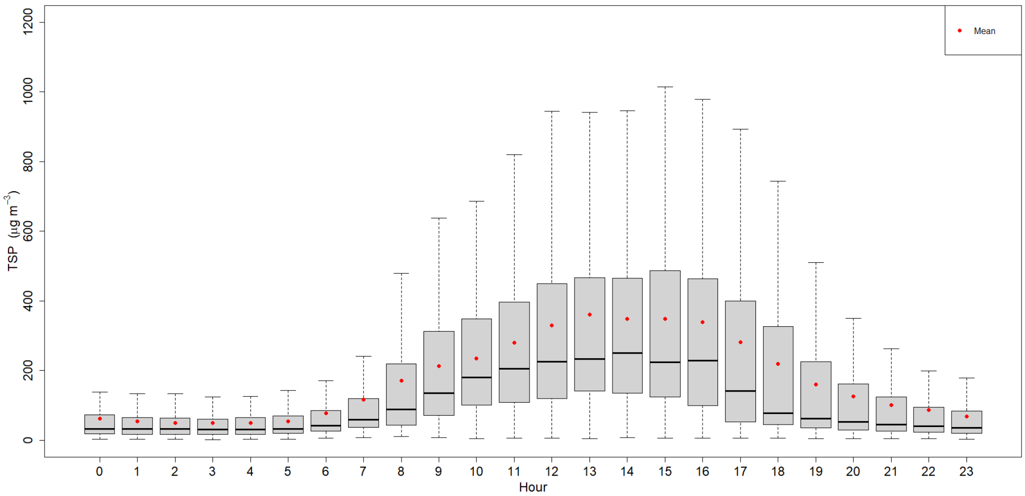


Figure 204: Diurnal variation of TSP for Bhaisepati Station

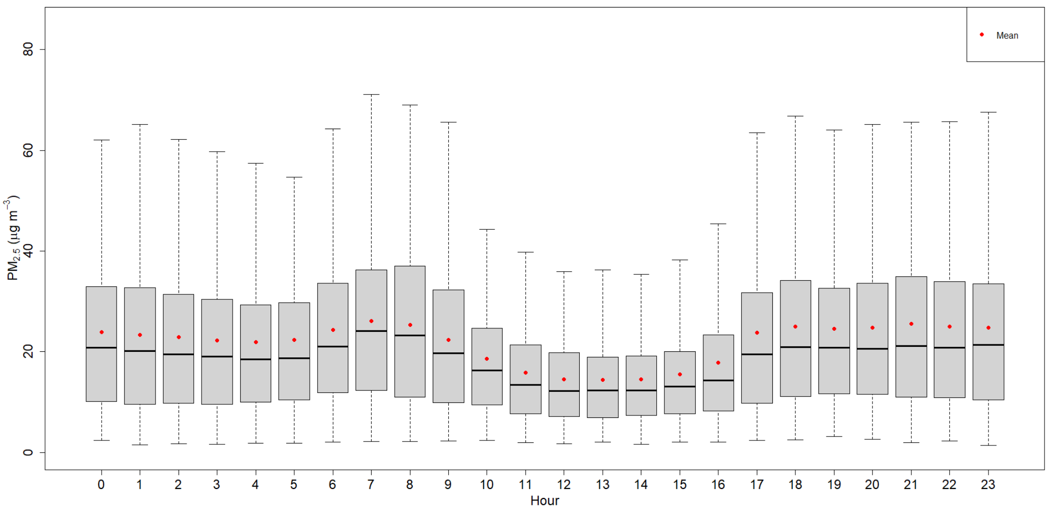


Figure 205: Diurnal variation of $PM_{2.5}$ for Hetauda Station

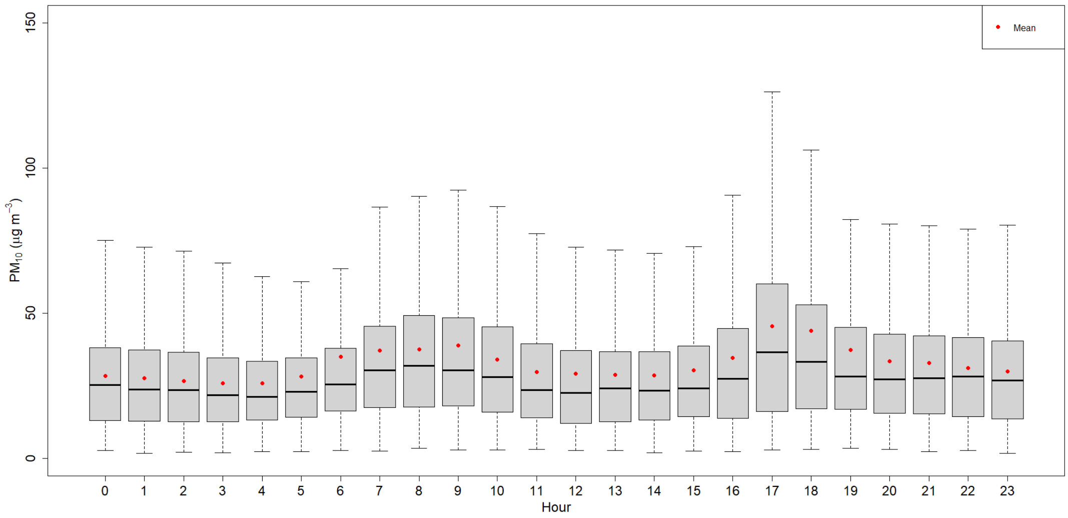


Figure 206: Diurnal variation of PM_{10} for Hetauda Station

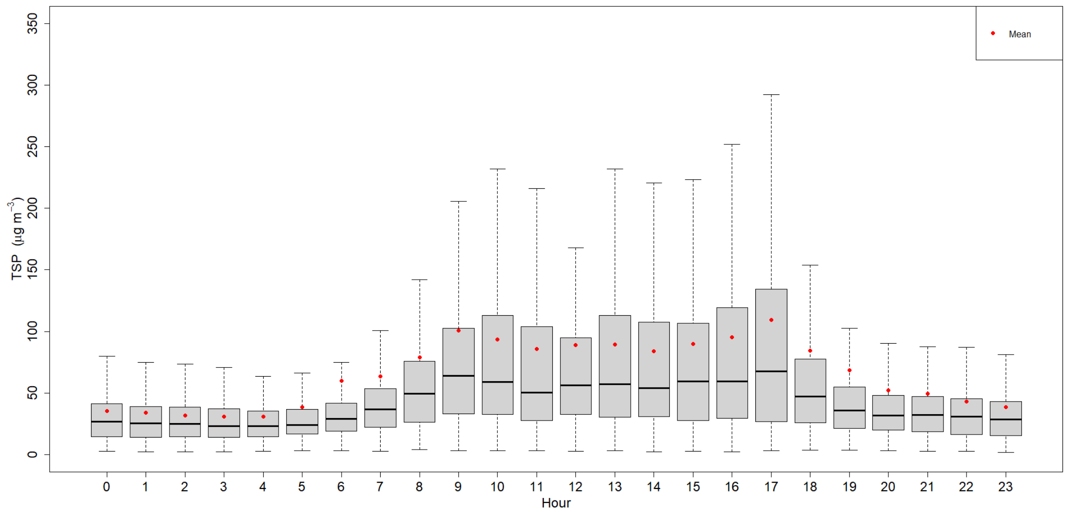


Figure 207: Diurnal variation of TSP for Hetauda Station

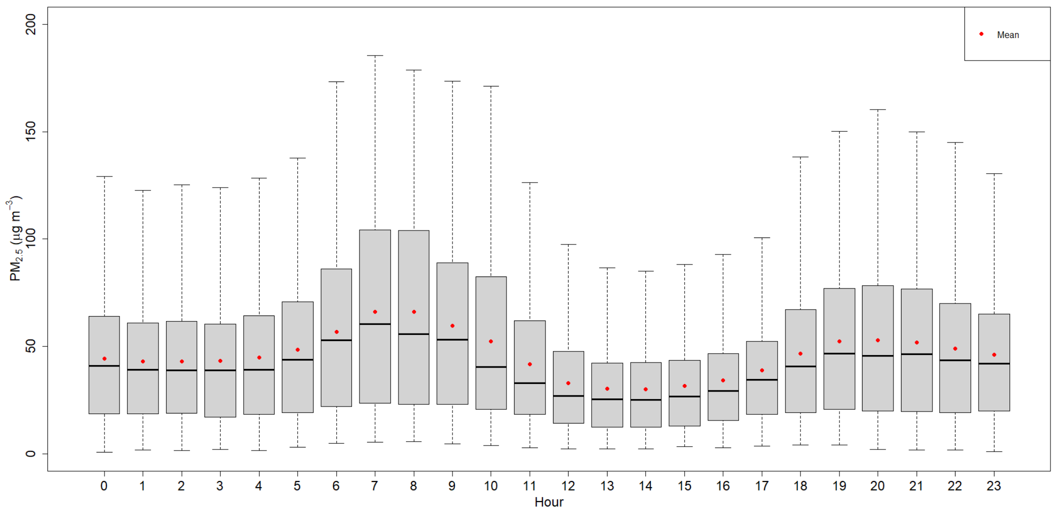


Figure 208: Diurnal variation of $PM_{2.5}$ for Khumaltar Station

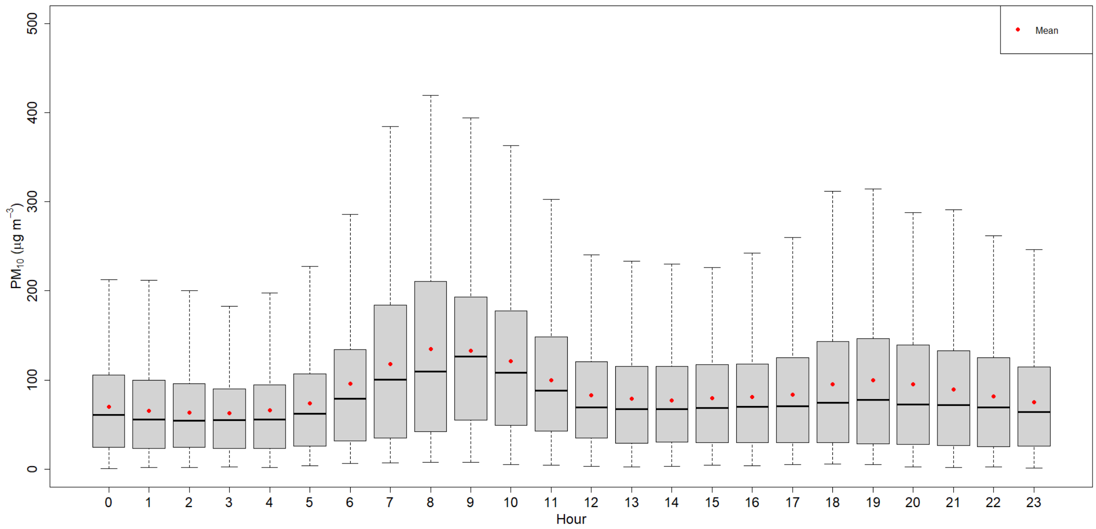


Figure 209: Diurnal variation of PM_{10} for Khumaltar Station

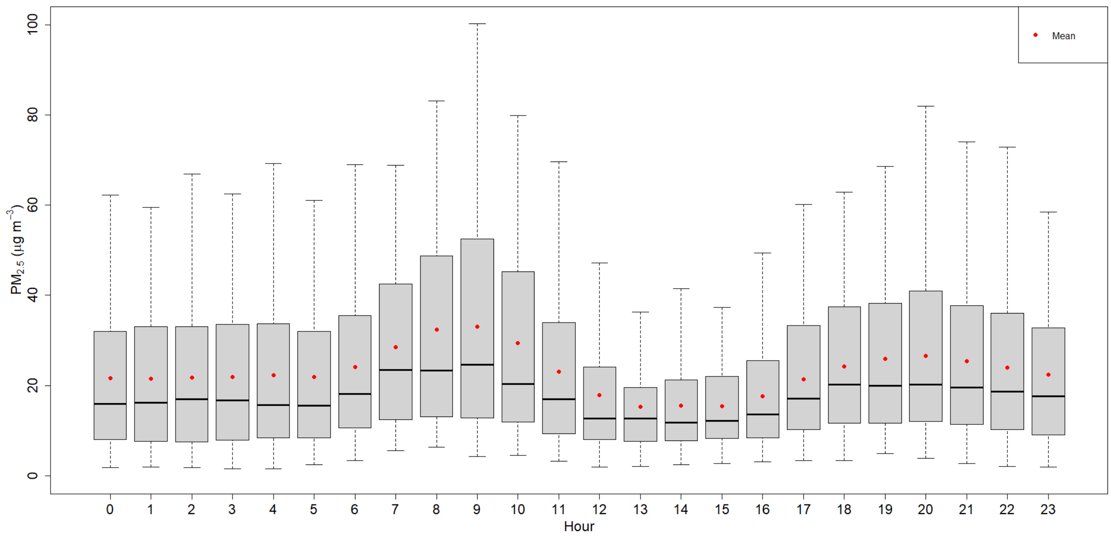


Figure 210: Diurnal variation of $PM_{2.5}$ for Pulchowk Station

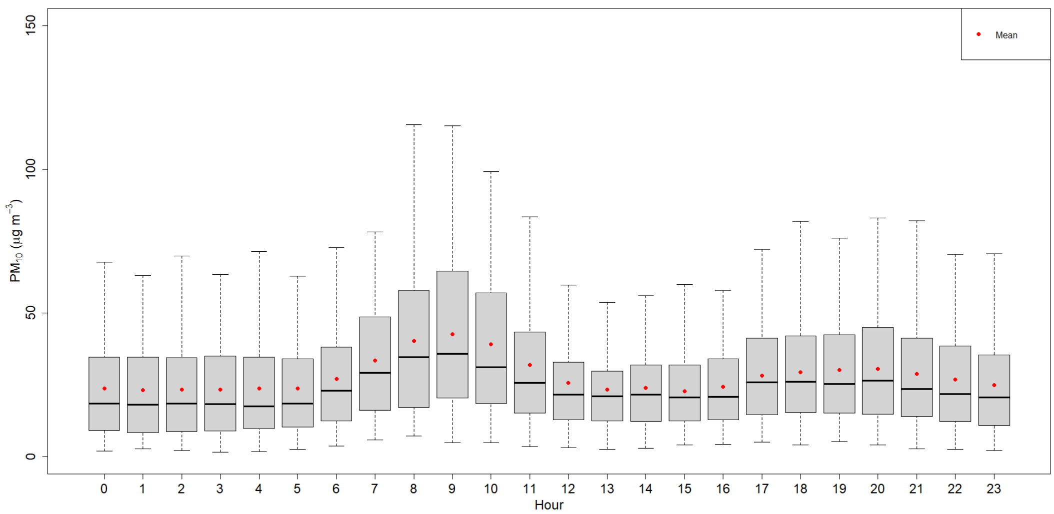


Figure 211: Diurnal variation of PM_{10} for Pulchowk Station

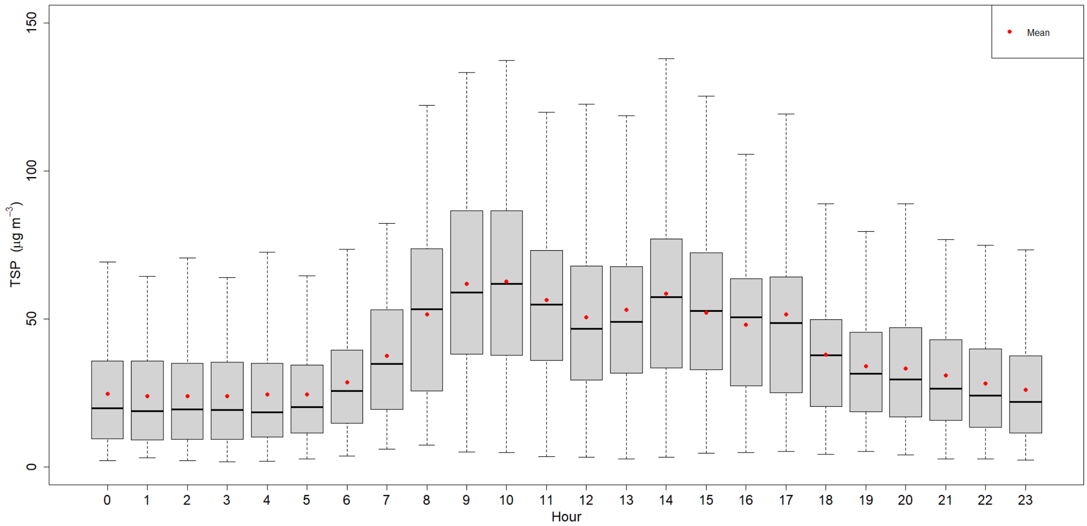


Figure 212: Diurnal variation of TSP for Pulchowk Station

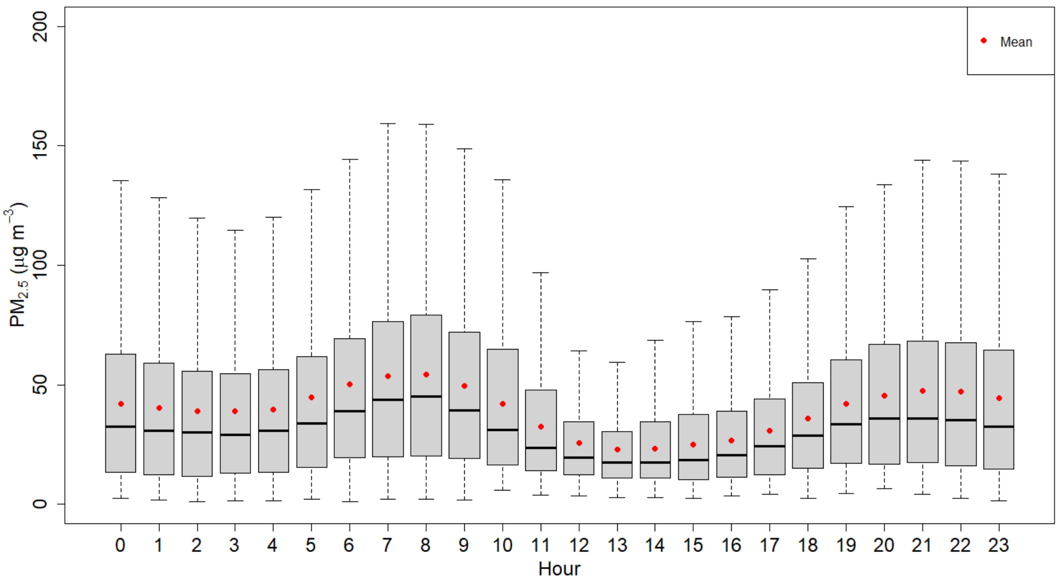


Figure 213: Diurnal variation of $PM_{2.5}$ for Pulchowk Station

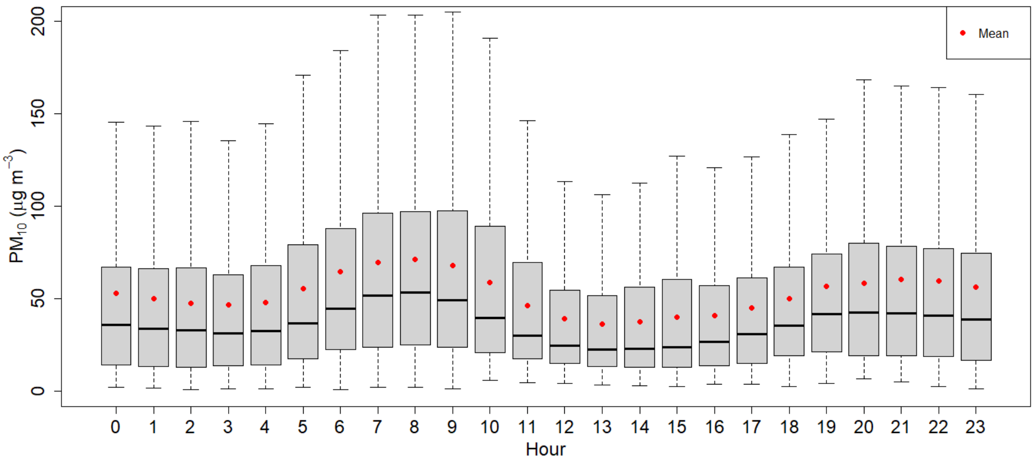


Figure 214: Diurnal variation of PM_{10} for Pulchowk Station

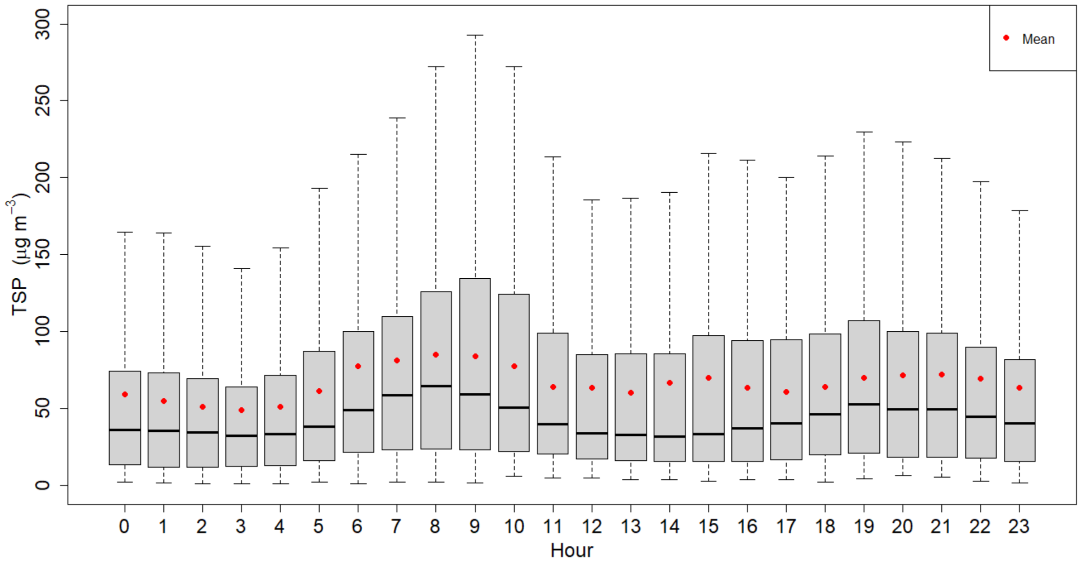


Figure 215: Diurnal variation of TSP for Pulchowk Station

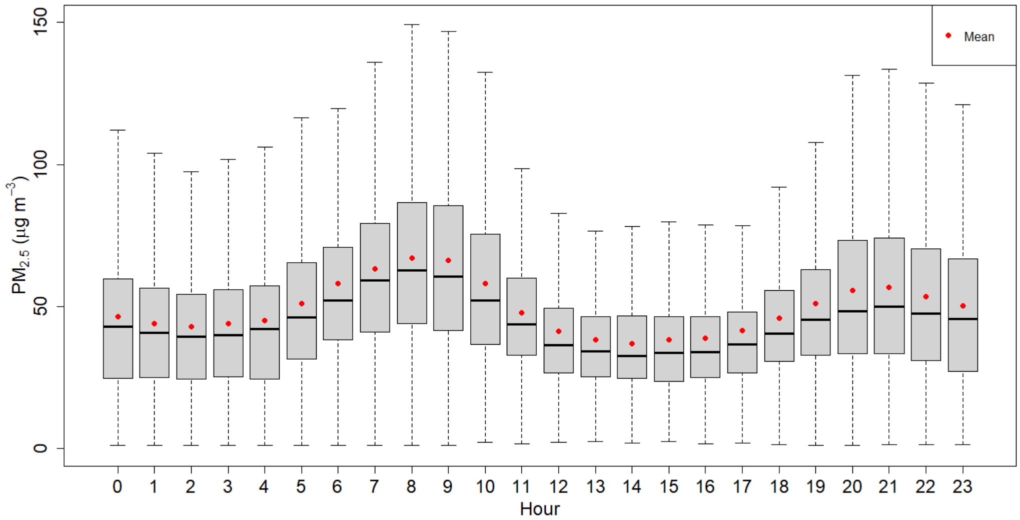


Figure 216: Diurnal variation of $PM_{2.5}$ for Shankhapark Station

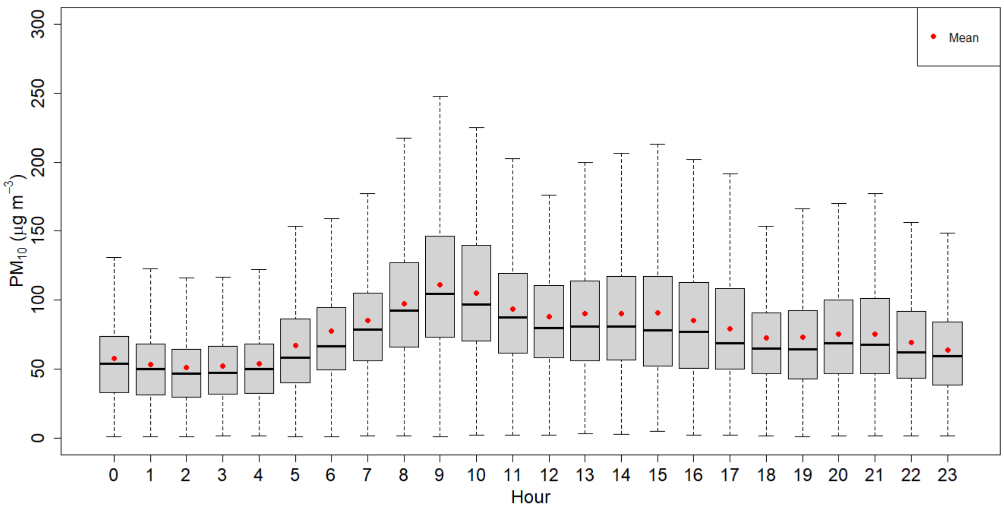


Figure 217: Diurnal variation of PM_{10} for Shankhapark Station

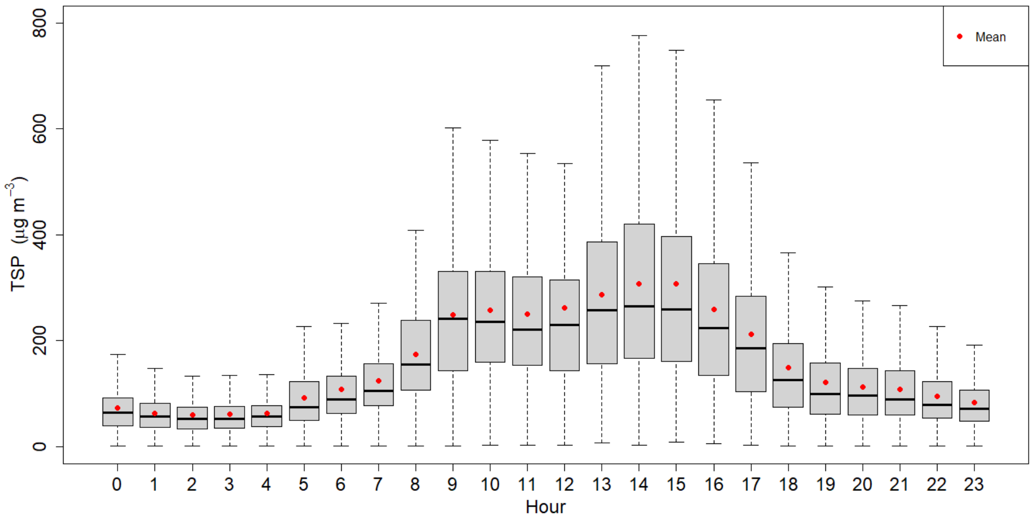


Figure 218: Diurnal variation of TSP for Shankhapark Station

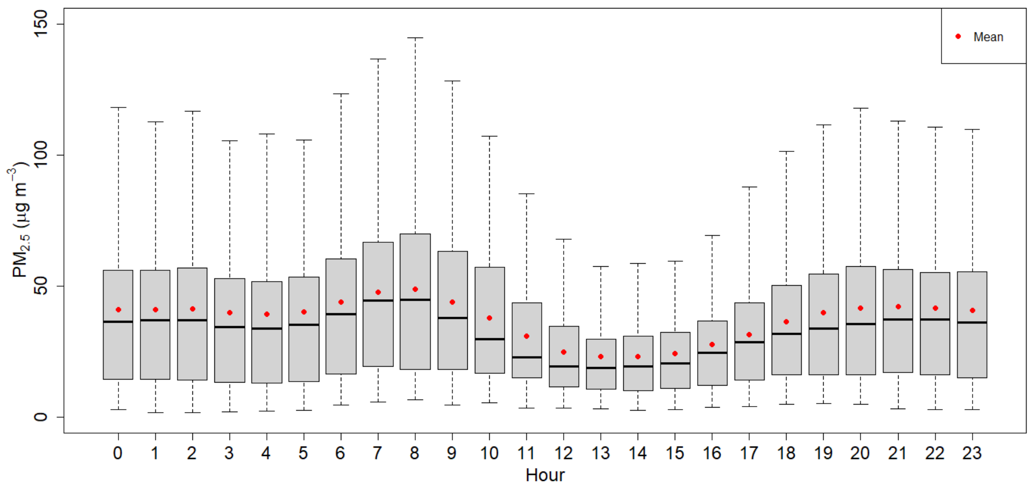


Figure 219: Diurnal variation of $PM_{2.5}$ for TU Kirtipur Station

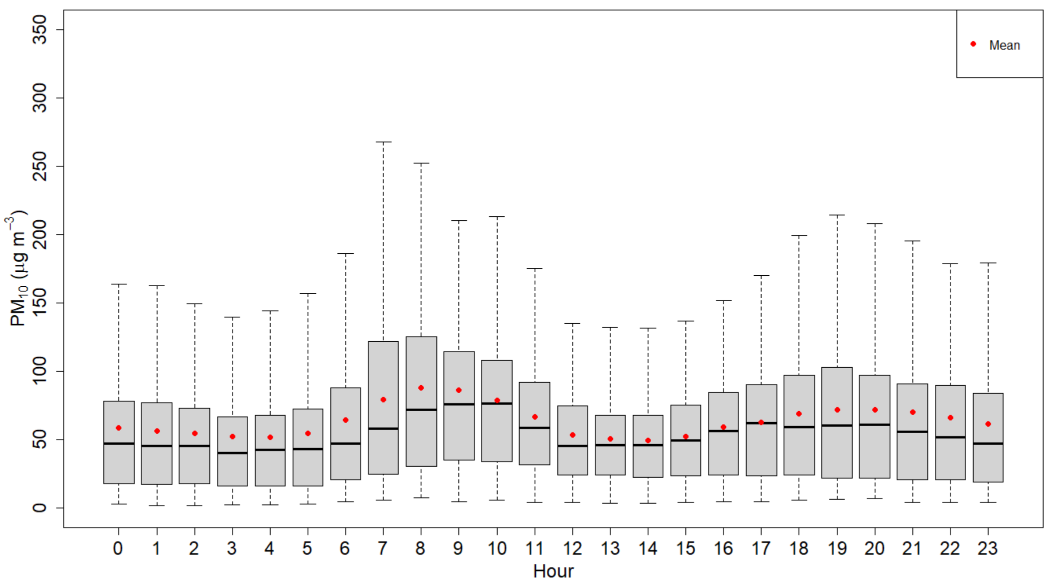


Figure 220: Diurnal variation of PM_{10} for TU Kirtipur Station

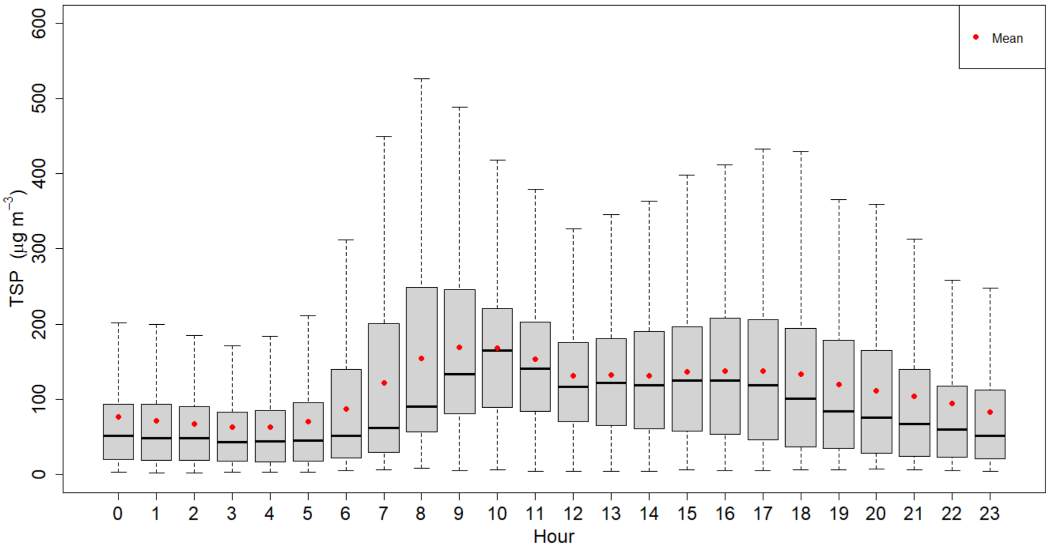


Figure 221: Diurnal variation of TSP for TU Kirtipur Station

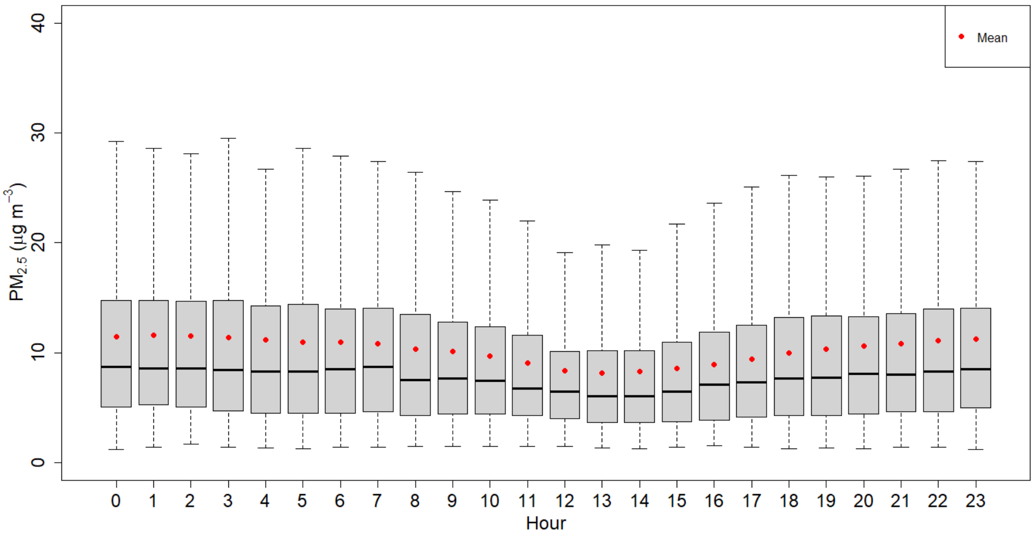


Figure 222: Diurnal variation of $PM_{2.5}$ for Rara Station

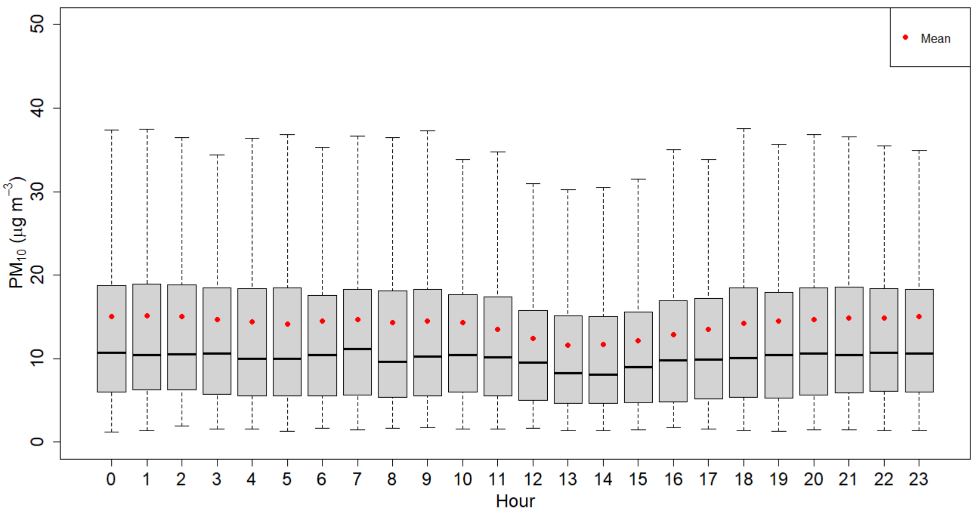


Figure 223: Diurnal variation of PM_{10} for Rara Station

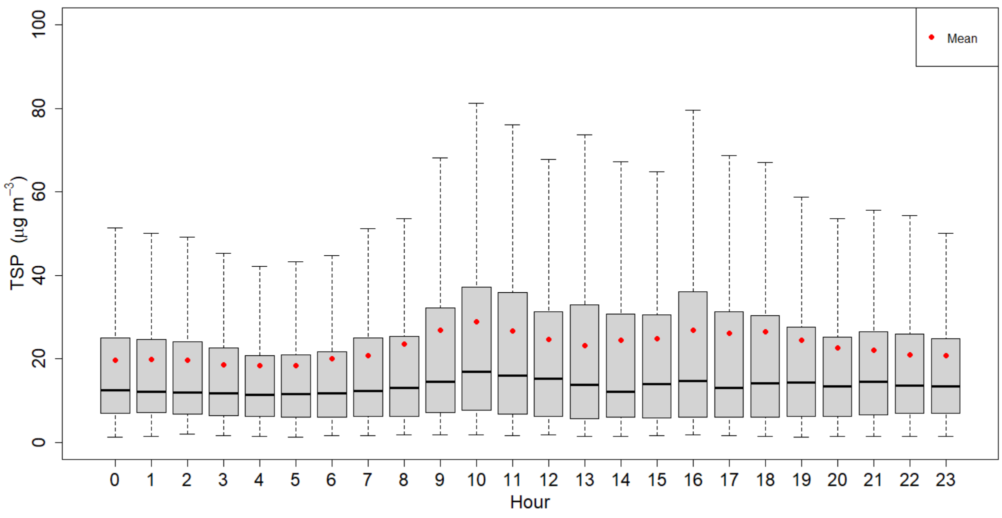


Figure 224: Diurnal variation of TSP for Rara Station

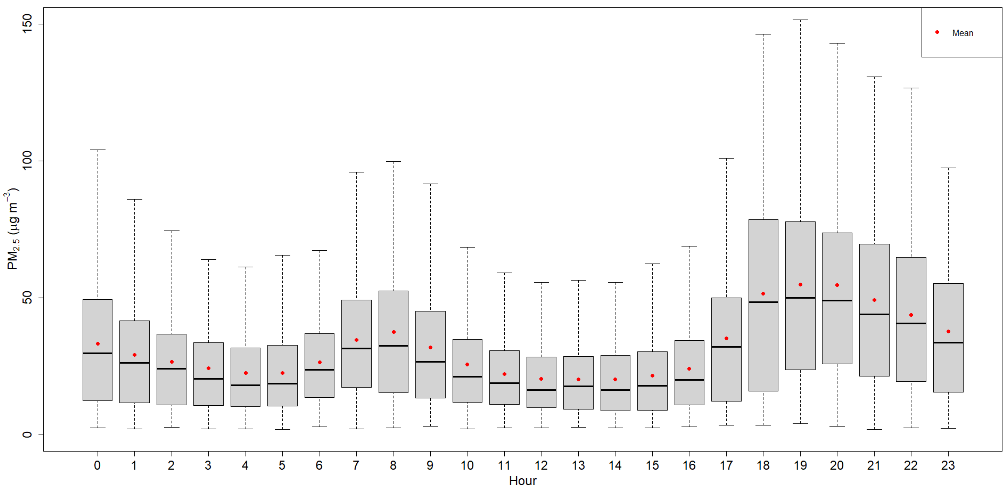


Figure 225: Diurnal variation of $PM_{2.5}$ for Mahendranagar Station

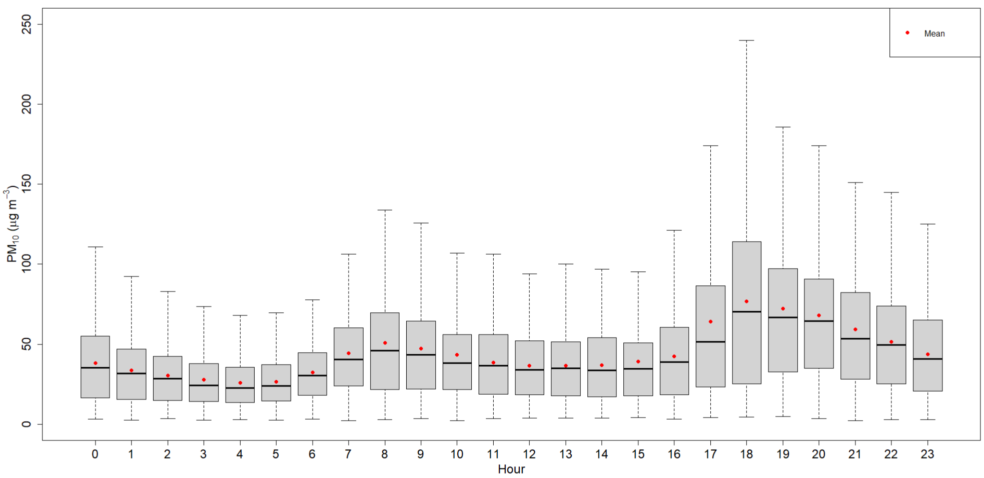


Figure 226: Diurnal variation of PM_{10} for Mahendranagar Station

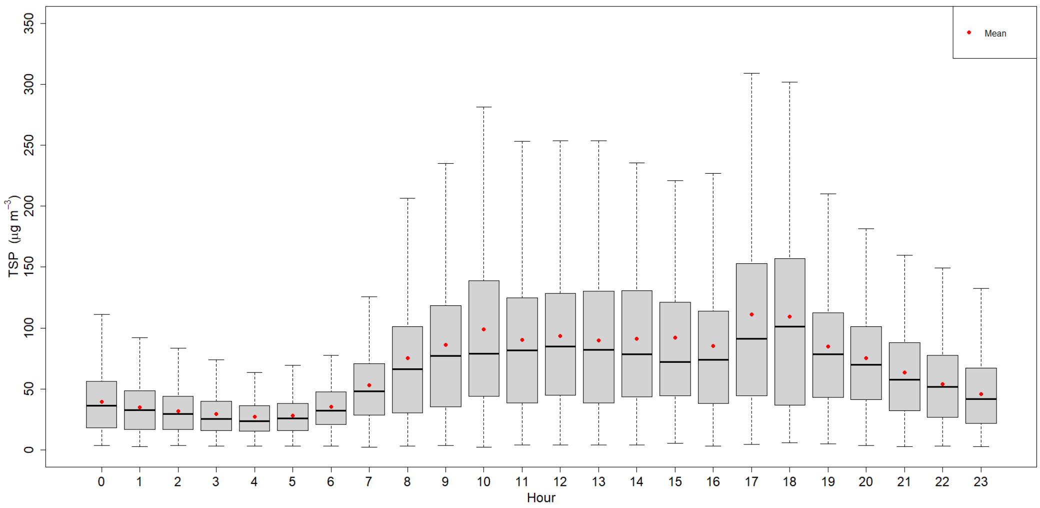


Figure 227: Diurnal variation of TSP for Mahendranagar Station

MONTHLY VARIATION

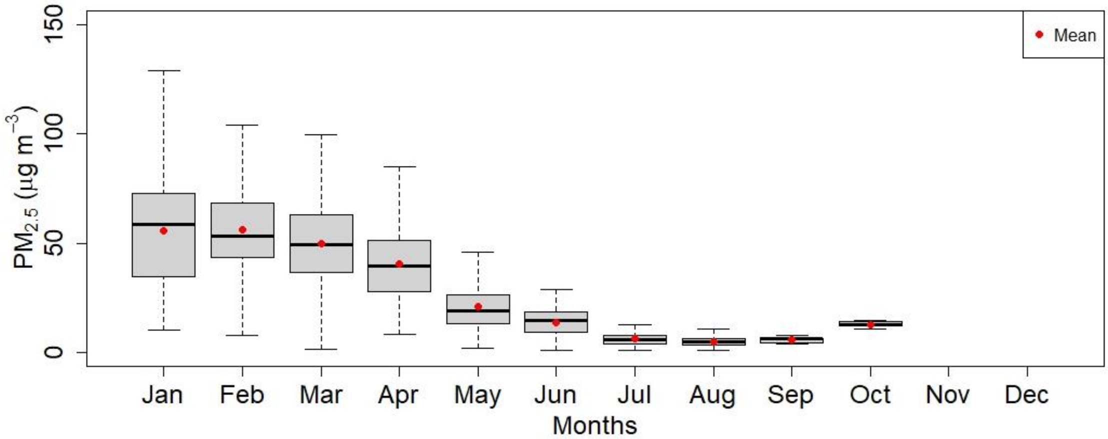


Figure 228: Monthly variation of $PM_{2.5}$ for Dhankuta Station

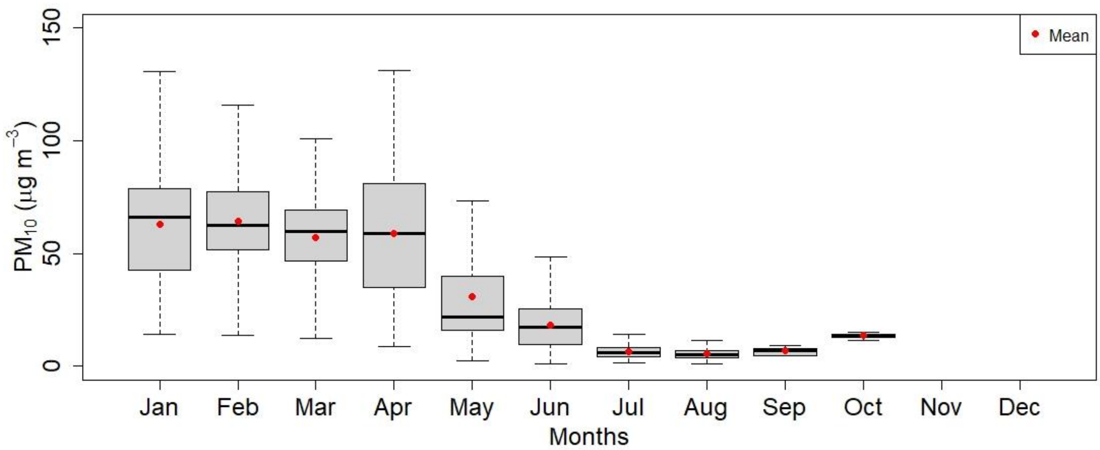


Figure 229: Monthly variation of PM_{10} for Dhankuta Station

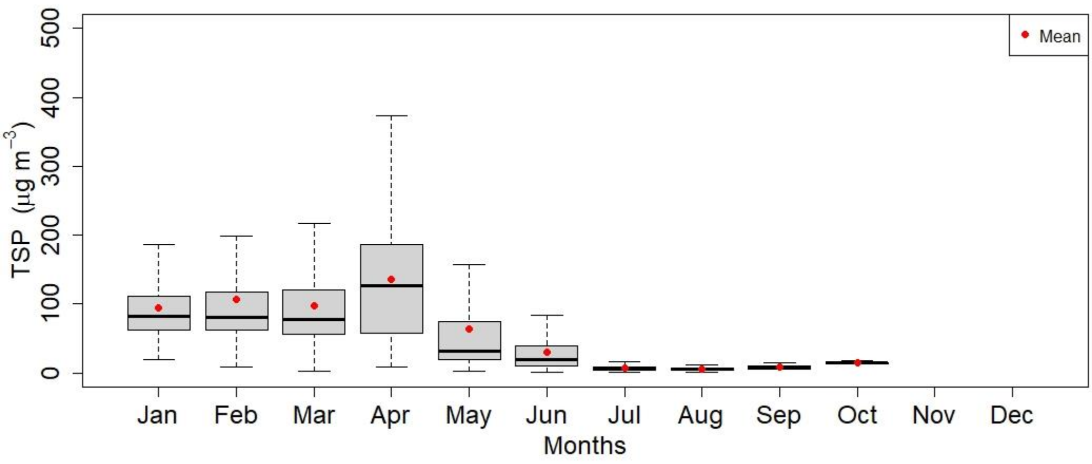


Figure 230: Monthly variation of TSP for Dhankuta Station

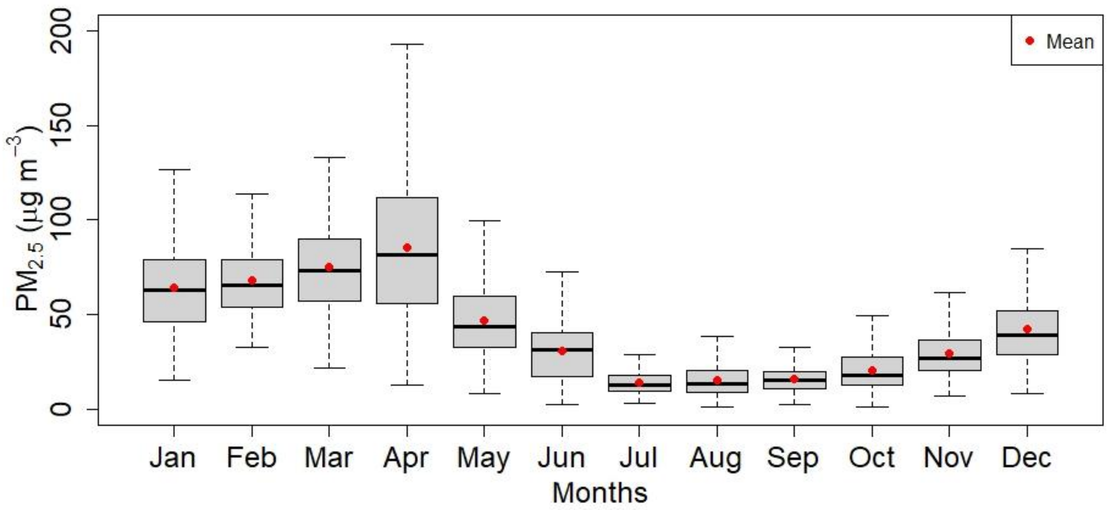


Figure 231: Monthly variation of $PM_{2.5}$ for Bhaisepati Station

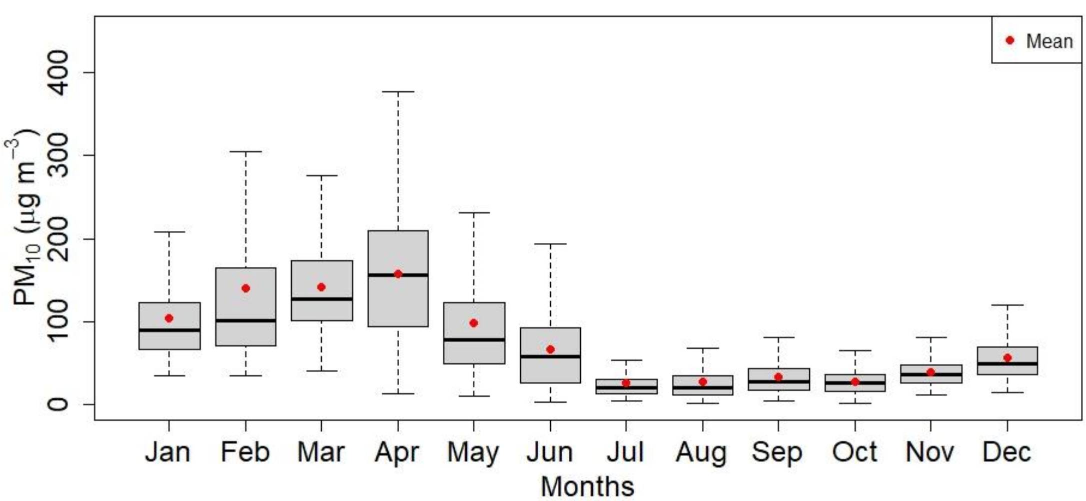


Figure 232: Monthly variation of PM_{10} for Bhaisepati Station

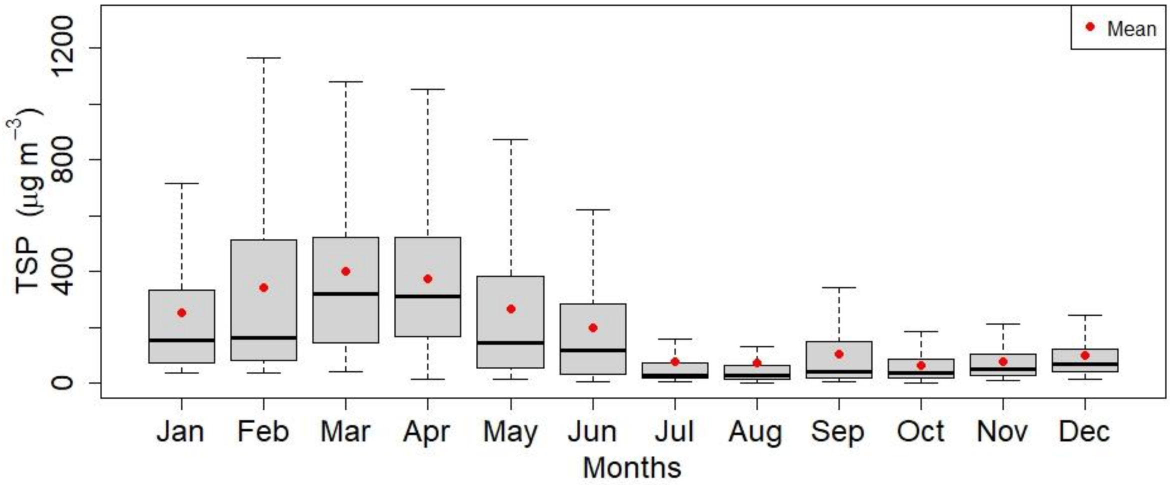


Figure 233: Monthly variation of TSP for Bhaisepati Station

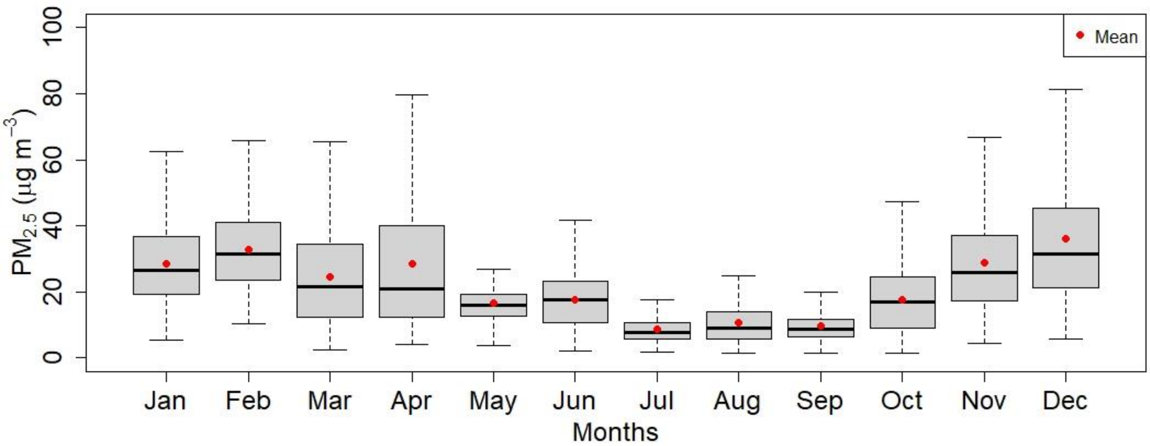


Figure 234: Monthly variation of $PM_{2.5}$ for Hetauda Station

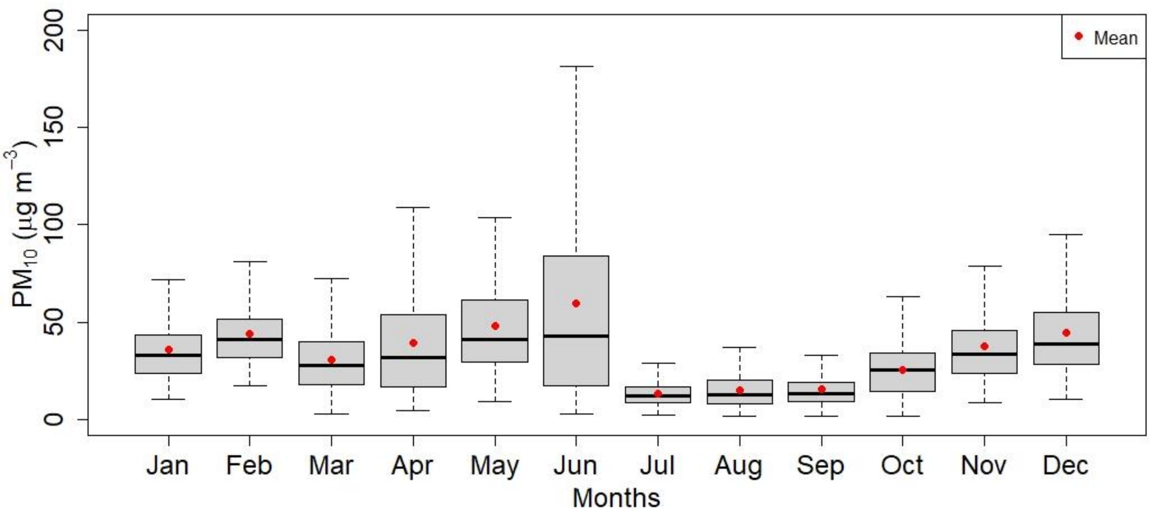


Figure 235: Monthly variation of PM_{10} for Hetauda Station

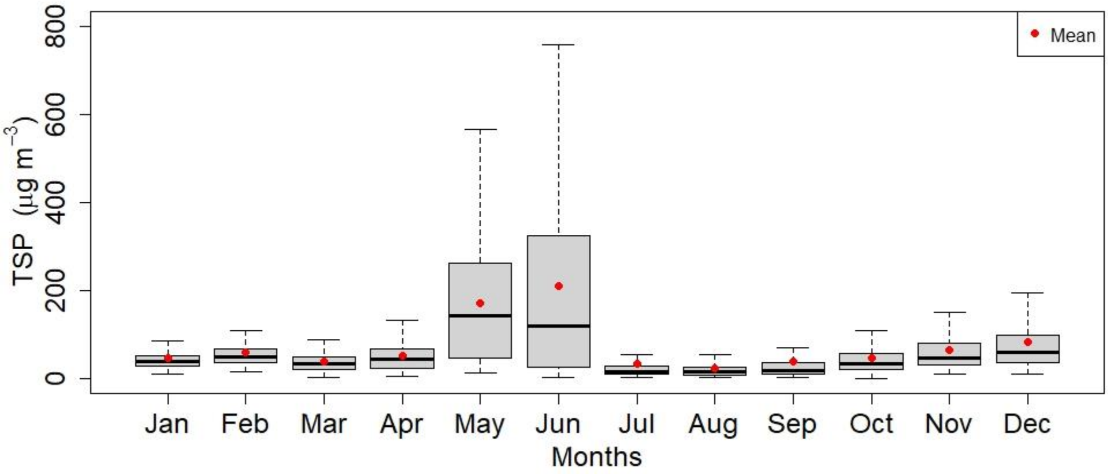


Figure 236: Monthly variation of TSP for Hetauda Station

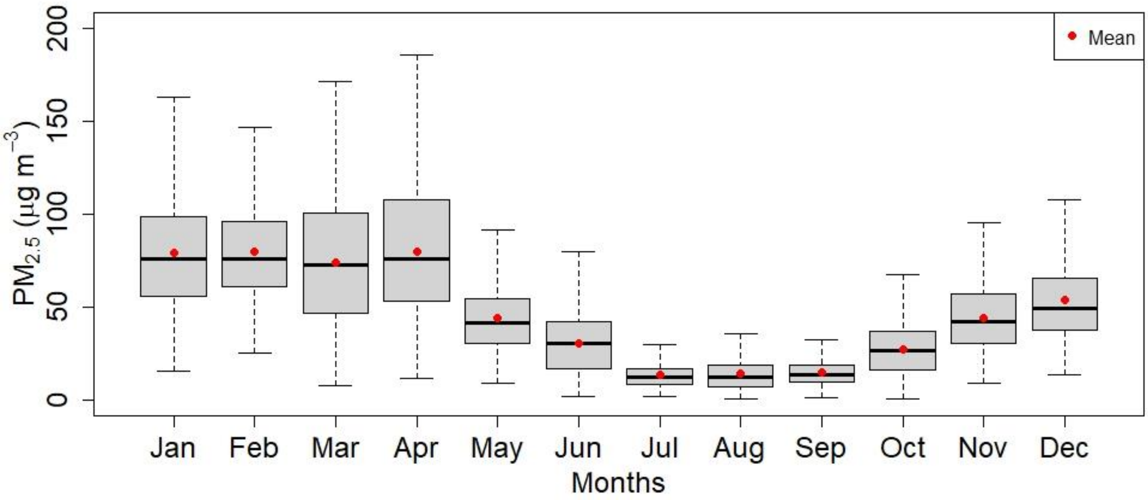


Figure 237: Monthly variation of $PM_{2.5}$ for Khumaltar Station

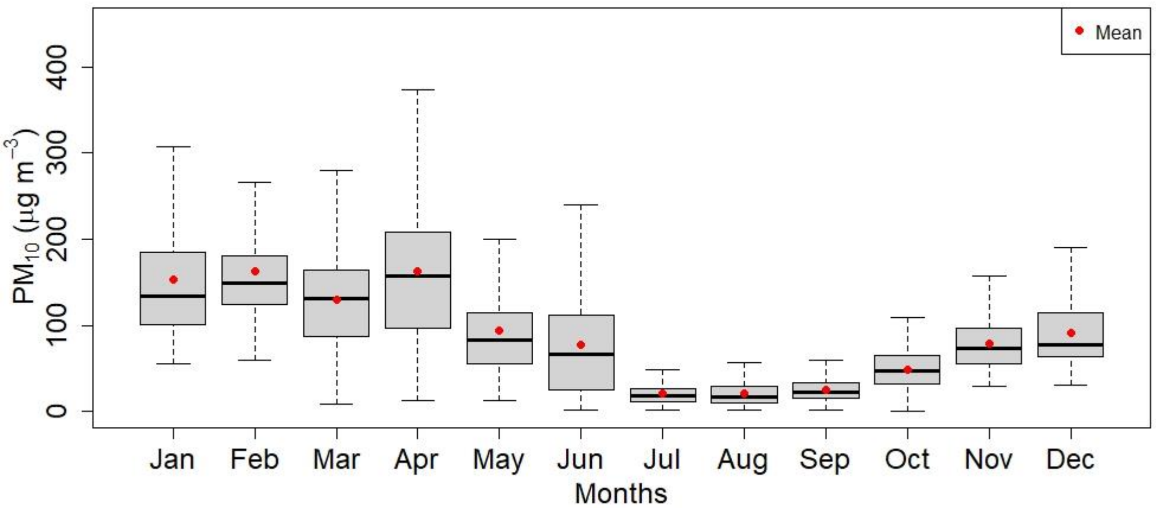


Figure 238: Monthly variation of PM_{10} for Khumaltar Station

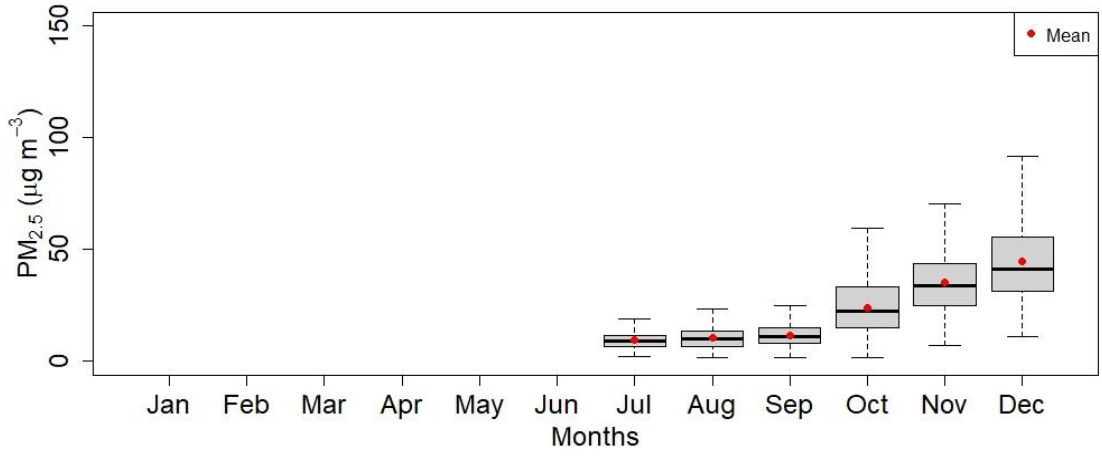


Figure 239: Monthly variation of $PM_{2.5}$ for Pulchowk Station

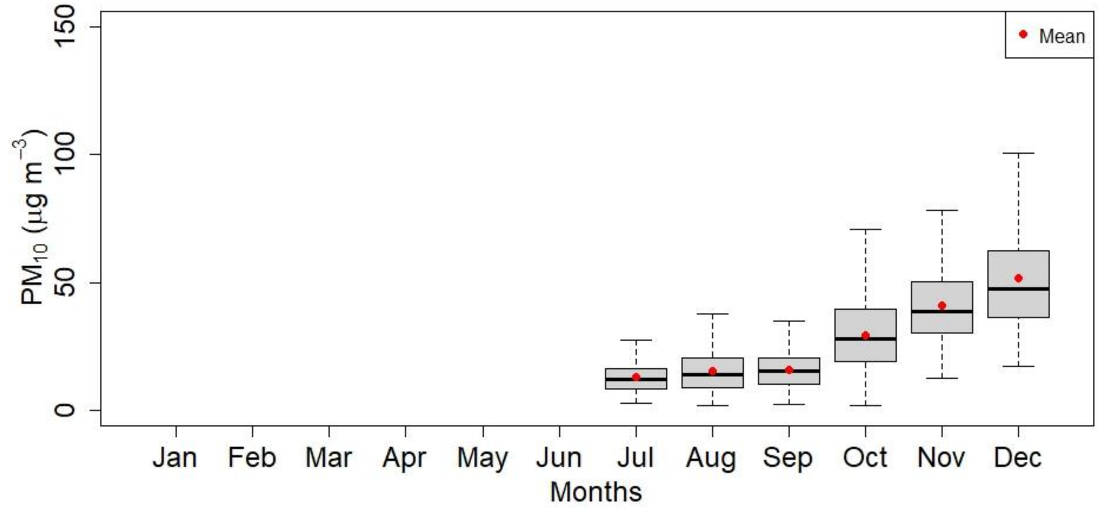


Figure 240: Monthly variation of PM_{10} for Pulchowk Station

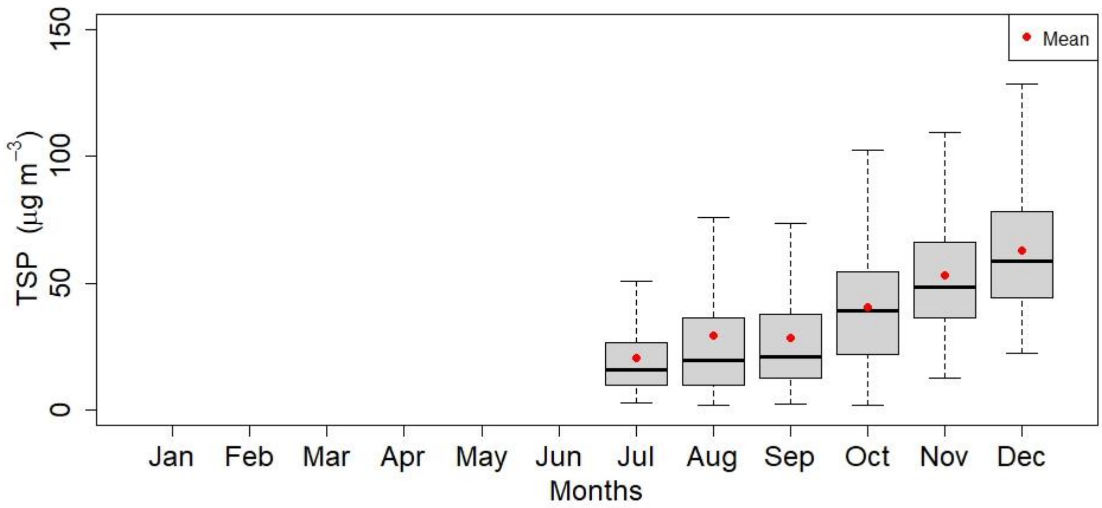


Figure 241: Monthly variation of TSP for Pulchowk Station

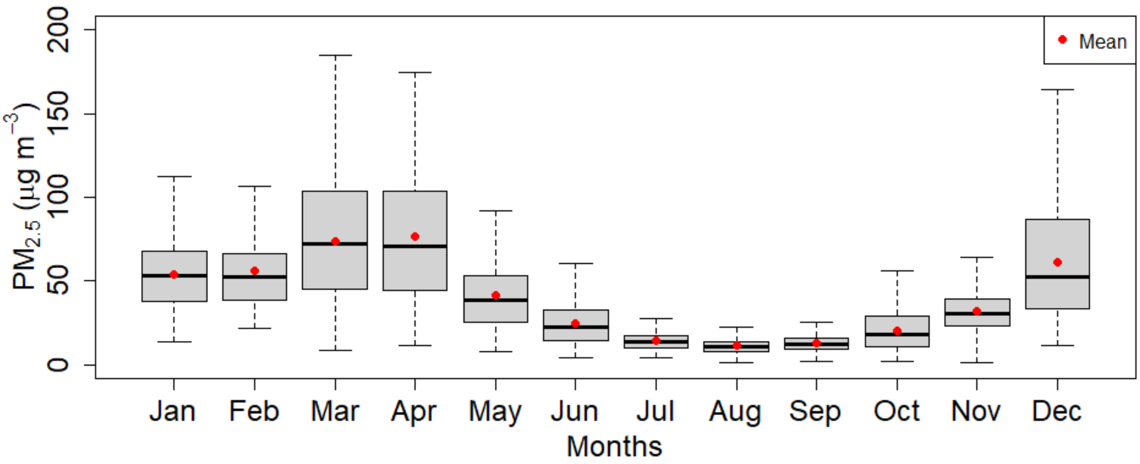


Figure 242: Monthly variation of $PM_{2.5}$ for Ratnapark Station

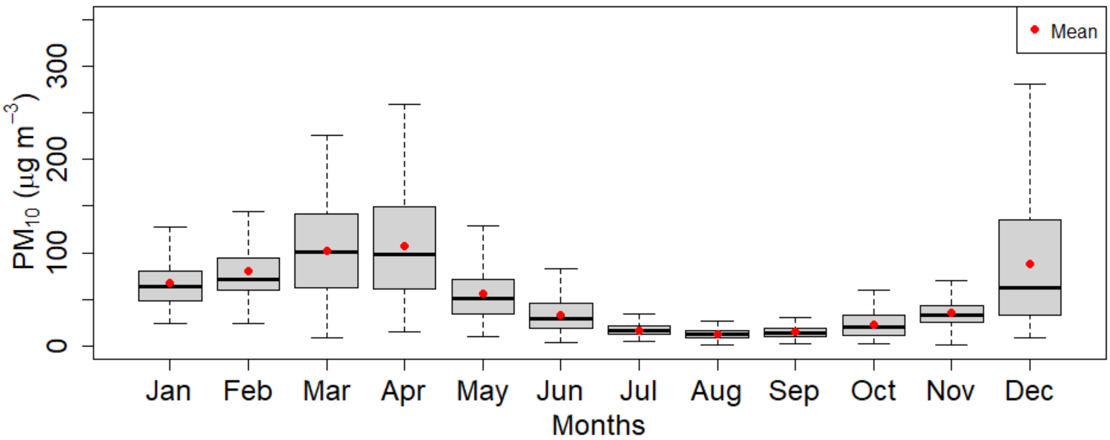


Figure 243: Monthly variation of PM_{10} for Ratnapark Station

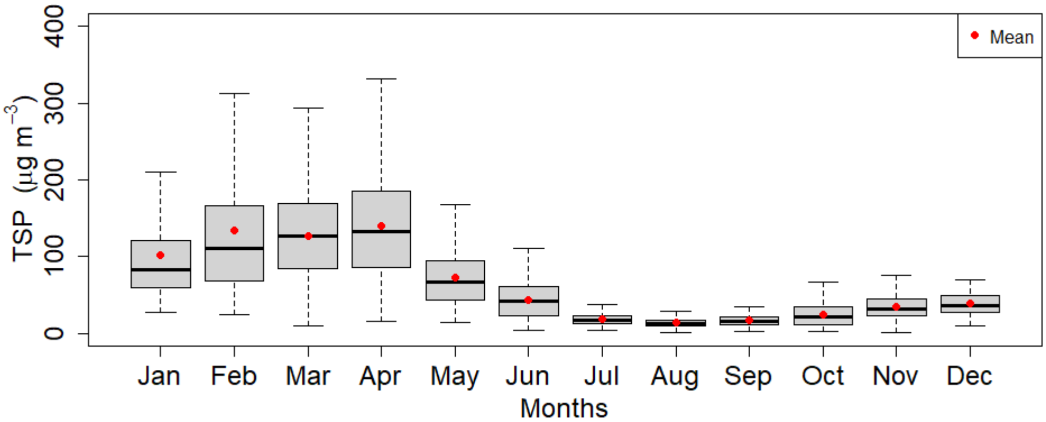


Figure 244: Monthly variation of TSP for Ratnapark Station

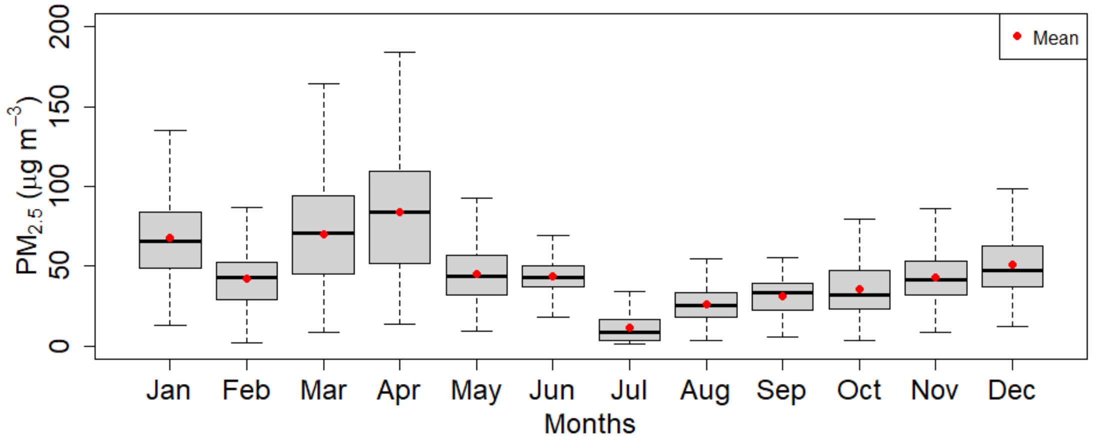


Figure 245: Monthly variation of $PM_{2.5}$ for Shankhapark Station

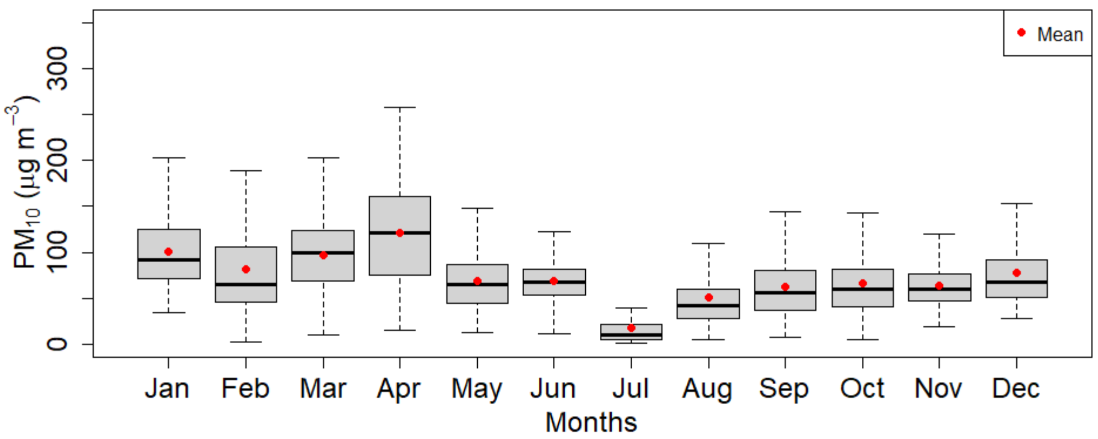


Figure 246: Monthly variation of PM_{10} for Shankhapark Station

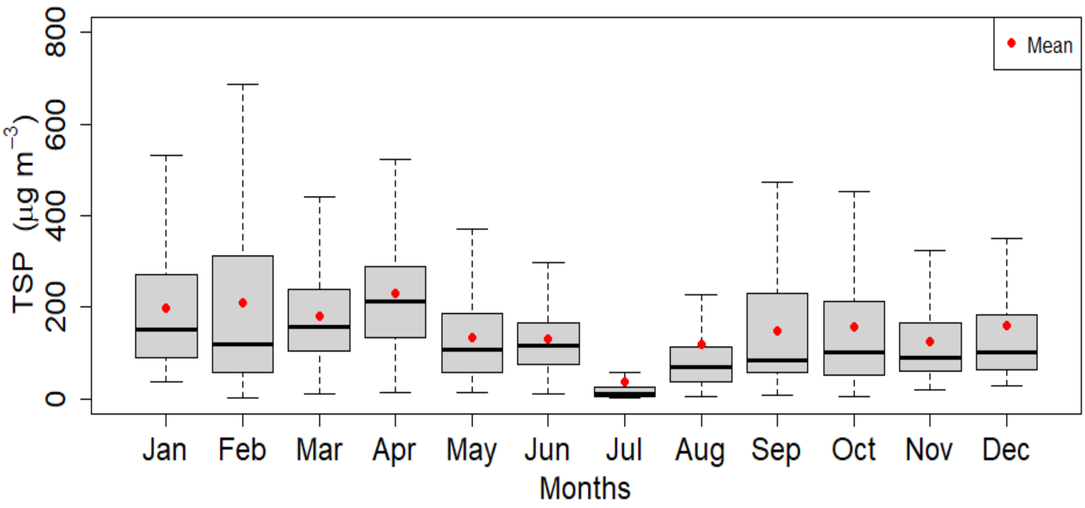


Figure 247: Monthly variation of TSP for Shankhapark Station

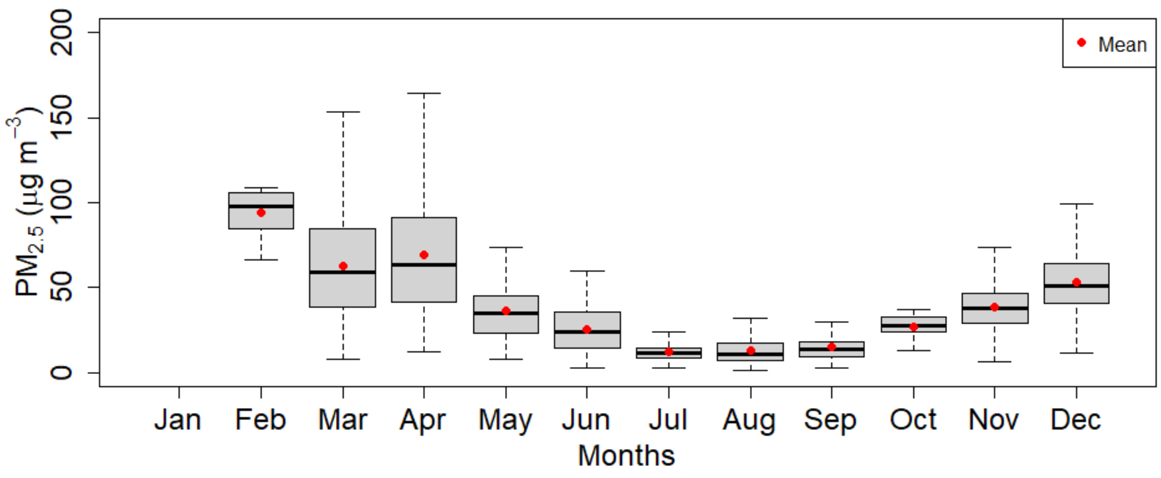


Figure 248: Monthly variation of $PM_{2.5}$ for TU Kritipur Station

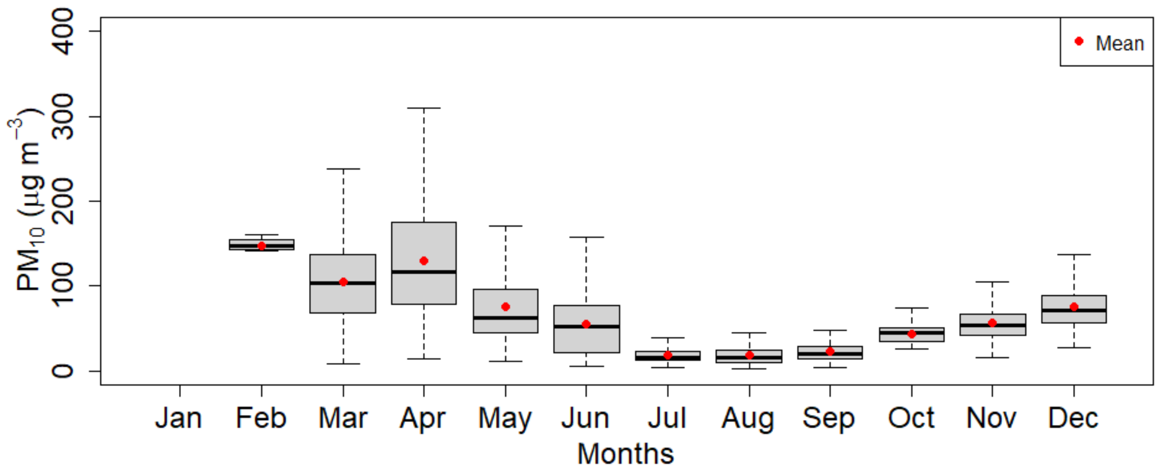


Figure 249: Monthly variation of PM_{10} for TU Kritipur Station

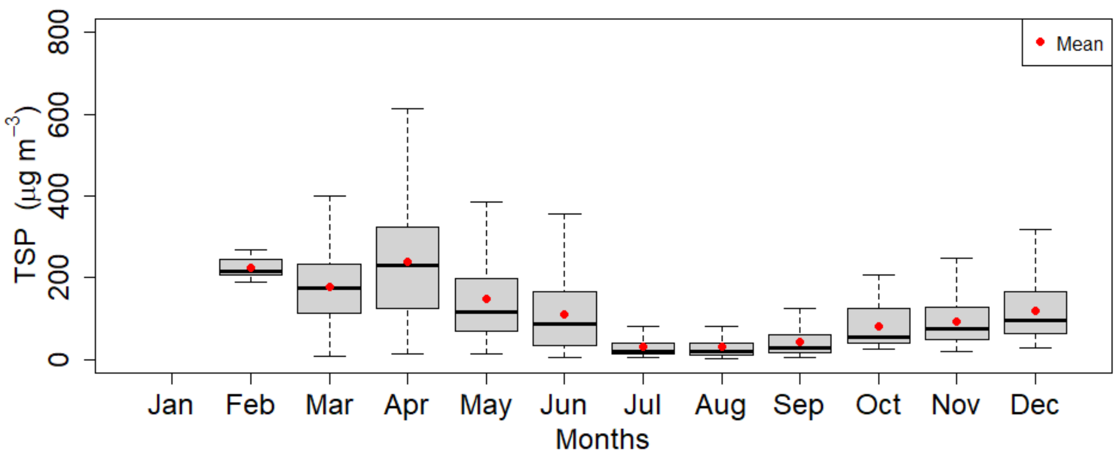


Figure 250: Monthly variation of TSP for TU Kritipur Station

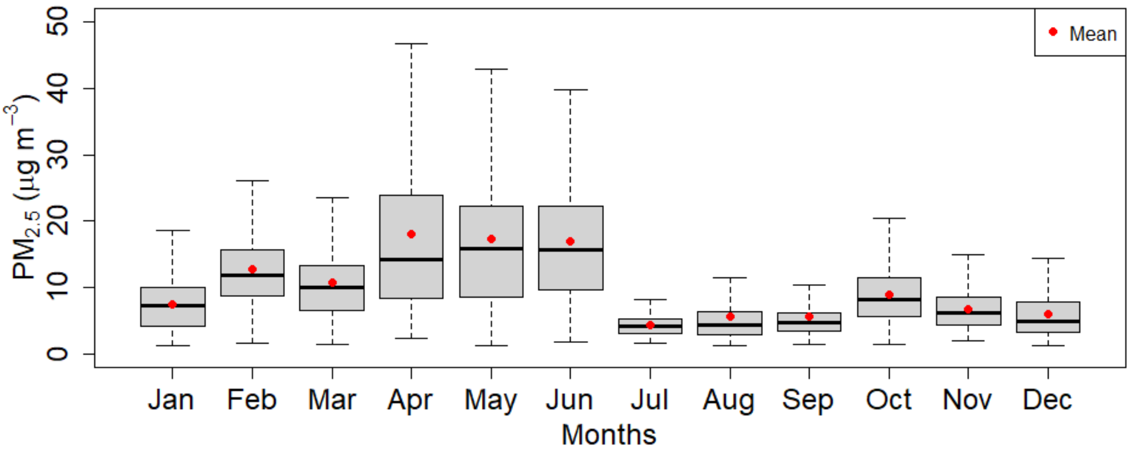


Figure 251: Monthly variation of $PM_{2.5}$ for Rara Station

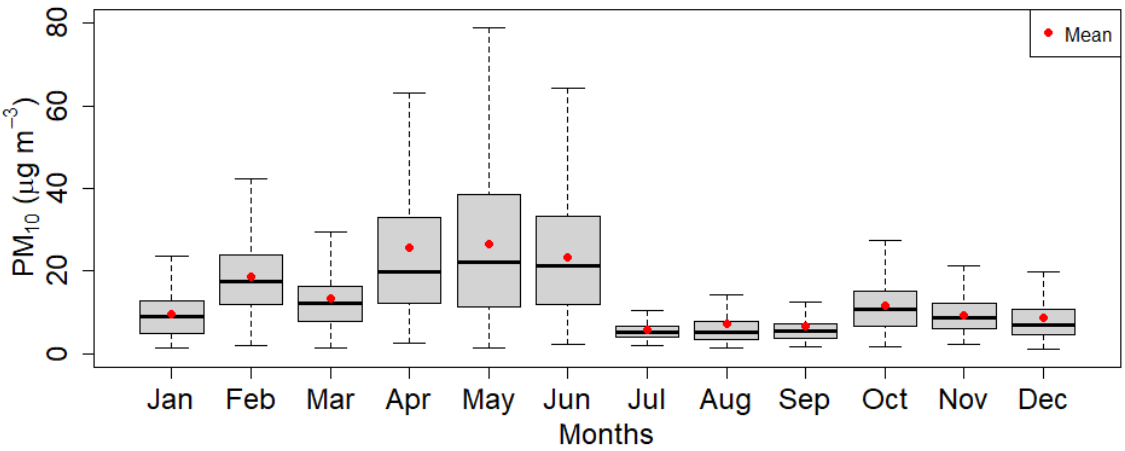


Figure 252: Monthly variation of PM_{10} for Rara Station

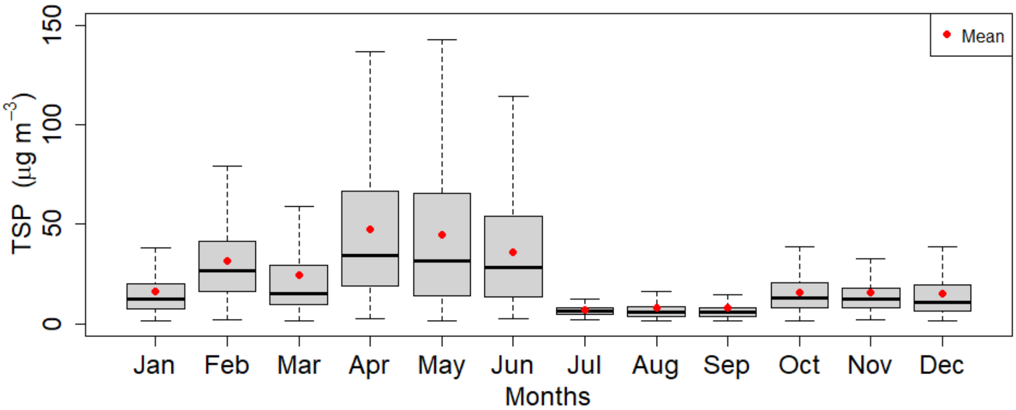


Figure 253: Monthly variation of TSP for Rara Station

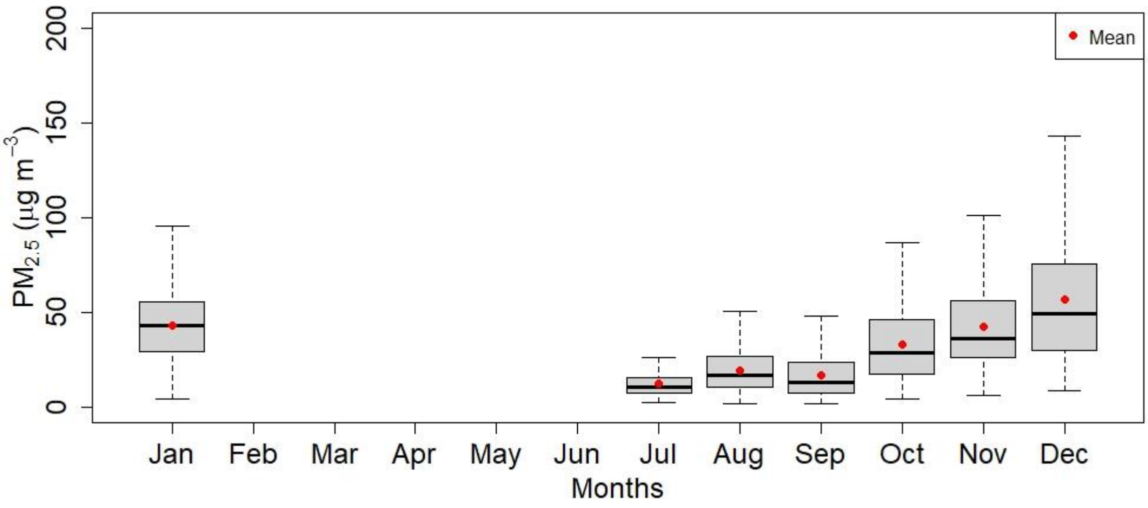


Figure 254: Monthly variation of $PM_{2.5}$ for Mahendranagar Station

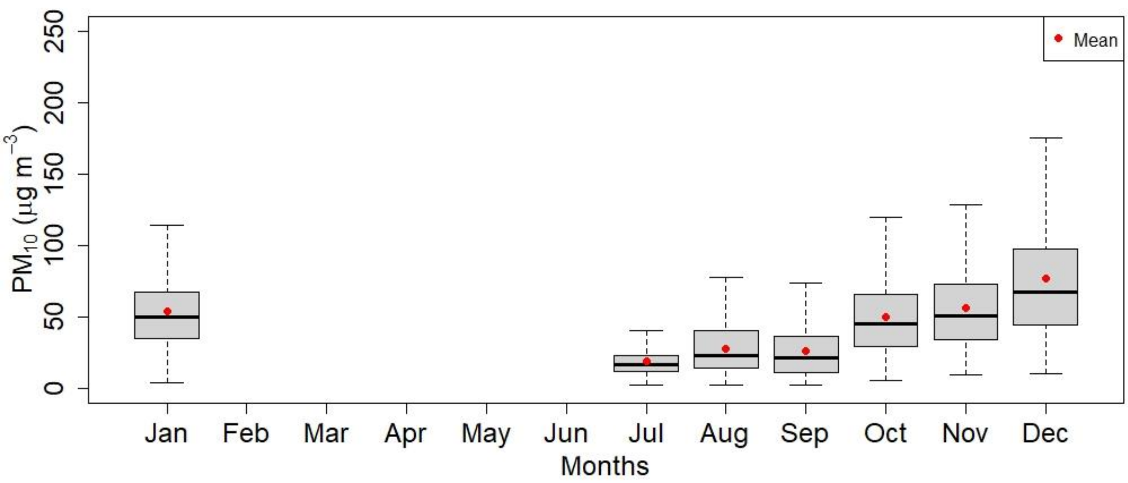


Figure 255: Monthly variation of PM_{10} for Mahendranagar Station

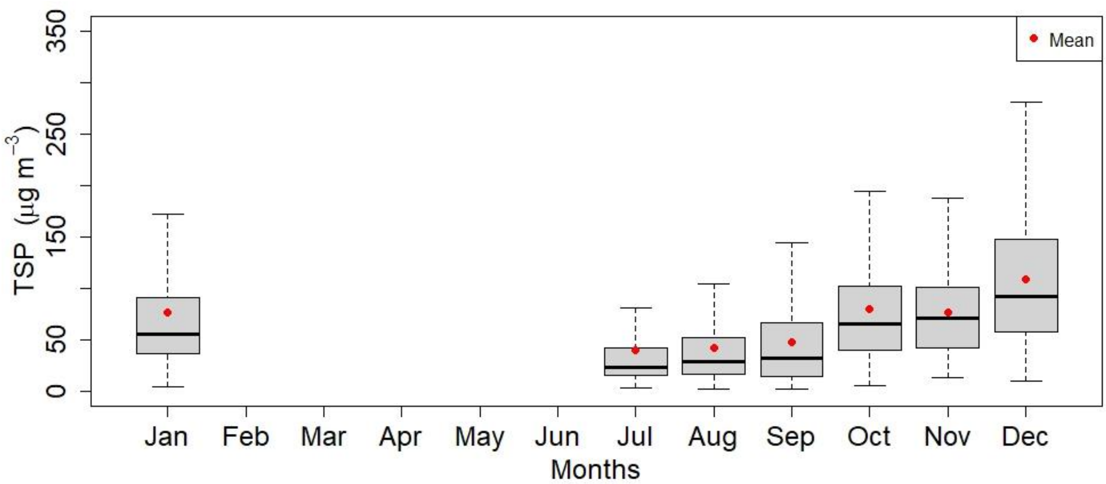
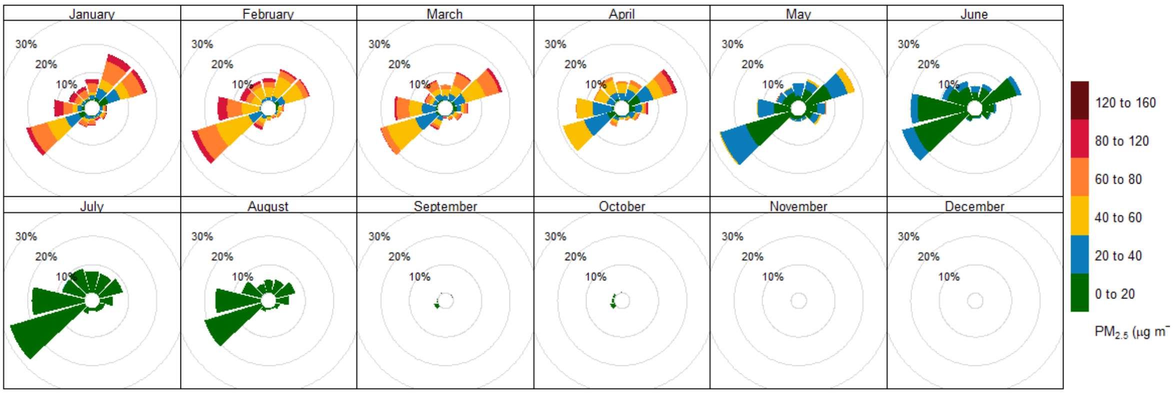


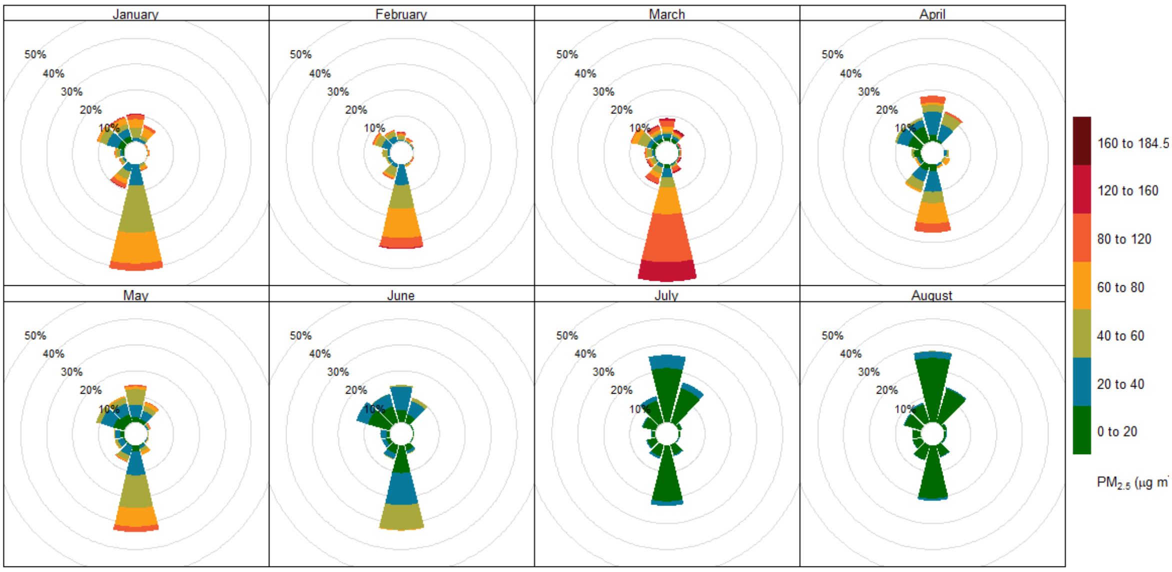
Figure 256: Monthly variation of TSP for Mahendranagar Station

ANNEX 4: MONTHLY POLLUTION ROSE DIAGRAM OF DIFFERENT STATIONS



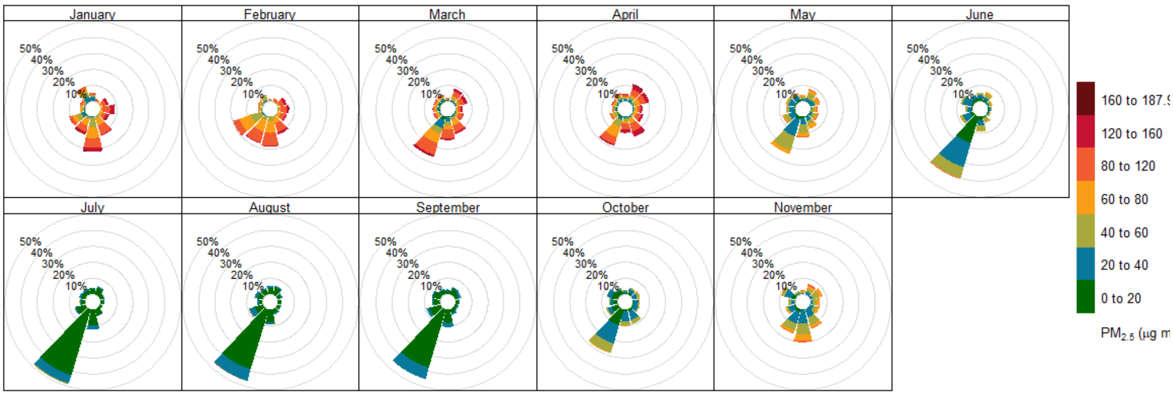
Frequency of counts by wind direction (%)

Figure 257: Monthly pollution rose for Dhankuta AQMS



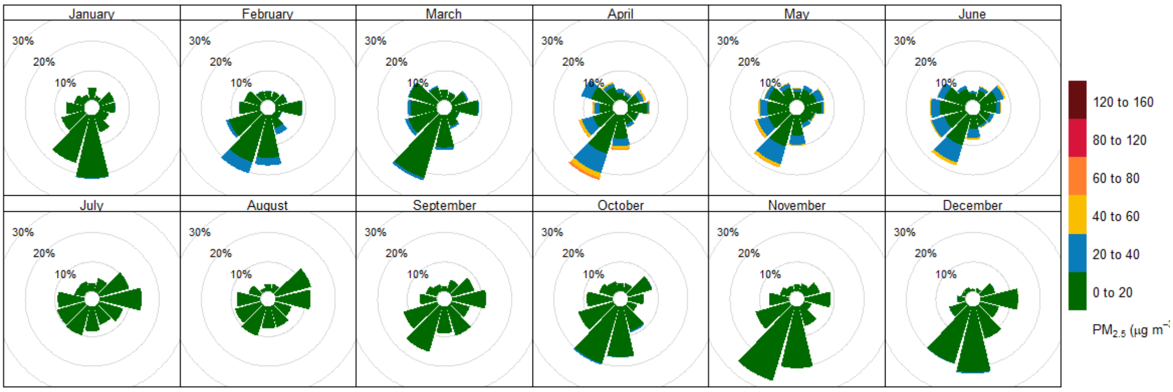
Frequency of counts by wind direction (%)

Figure 258: Monthly pollution rose for Ratnapark AQMS



Frequency of counts by wind direction (%)

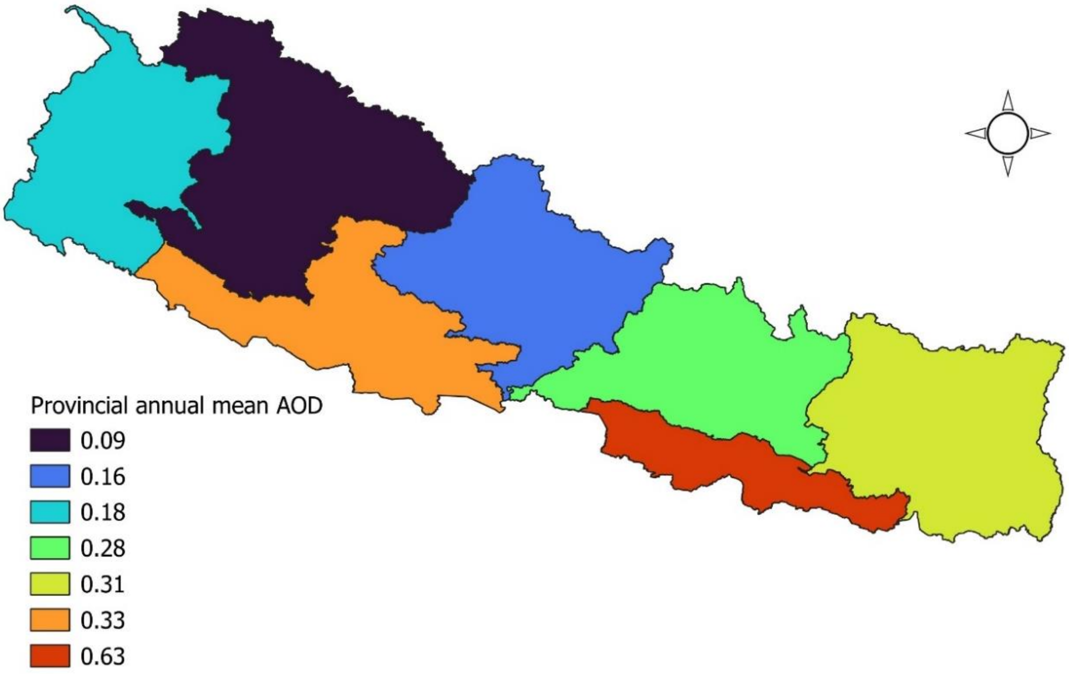
Figure 259: Monthly pollution rose for Khumaltar AQMS



Frequency of counts by wind direction (%)

Figure 260: Monthly pollution rose for Rara AQMS

ANNEX 5: PROVINCE WISE ANNUAL AVERAGE AOD LEVEL IN NEPAL, 2023



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