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DHULIKHEL, KAVRE

A Project Report on

"Monitoring Air Pollution Variations Every Two Months over Two Years in Bhaktapur District, Nepal"

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Additionally, we extend our thanks to our colleagues and friends who provided feedback and support during the project.

ABSTRACT

This report, titled "Monitoring Air Pollution Variations Every Two Months over Two Years in Bhaktapur District, Nepal," investigates the temporal and spatial variations in air pollution levels, specifically focusing on particulate matter (PM2.5 and PM10). The study spanned from June 2022 to June 2024, utilizing data collected from various monitoring stations throughout Bhaktapur District. The primary objective was to prepare thematic maps of PM2.5 and PM10 data using the Inverse Distance Weighting (IDW) technique and to develop comprehensive spatial and temporal air quality maps to visualize and analyze pollution patterns and trends. Also, the secondary objective was to explore the potential sources and factors contributing to elevated pollution levels in different parts of Bhaktapur

The research involved the collection of PM2.5 and PM10 concentrations from multiple air quality monitoring stations within the district. Geographic Information Systems (GIS) software, specifically the IDW tool, was used to analyze and create thematic maps representing the AQI of these pollutants. The analysis revealed both improvements and deteriorations in air quality, influenced by factor such as industrial activities.

Key findings include the identification of pollution hotspots and regions with consistently good air quality, as well as two year trends in PM2.5 and PM10 levels. The study concluded that air quality in Bhaktapur is heavily influenced by seasonal variations, with higher pollution levels observed during the winter and lower levels during the monsoon season. The thematic maps created through spatial interpolation and analysis provide a clear visual representation of these trends and can serve as a valuable tool for local authorities and policymakers in their efforts to improve air quality and public health in the region.

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LIST OF ABBREVIATIONS

PM: Particulate Matter

AQI: Air Quality Index

BK: Bhaktapur

CO: Carbon monoxide

VOCs: Volatile Organic Components

SO2: Sulfur Dioxide

NO2: Nitrogen Dioxide

EPA: Environmental Protection Agency

IDW: Inverse Distance Weighting

GIS: Geographic Information System

API: Application Programming Interface

WGS: World Geodetic System

UTM: Universal Transverse Mercator

1 Introduction

1.1 Background

Bhaktapur is the smallest district of Nepal, which occupies an area of 119 square kilometers. It is surrounded by Kavrepalnchowk district in east, Kathmandu and Lalitpur district in west, Kathmandu and Kavrepalanchowk district in the north and Lalitpur district in the south. The total population of Bhaktapur district is 432,132 according to census 2078 BS.

Bhaktapur, a historic district in the Kathmandu Valley of Nepal, is renowned for its cultural heritage and traditional architecture. However, like many urban areas in developing countries, Bhaktapur faces significant challenges related to air pollution. Rapid urbanization, increased vehicular traffic, industrial activities, and the use of solid fuels for cooking and heating contribute to deteriorating air quality in the district.

The Kathmandu Valley in Nepal is home to more than 3.5 million residents who suffer from high levels of air pollutants, including particulate matter (PM), ozone (O3), carbon monoxide (CO), and volatile organic compounds (VOCs) (Bhardwaj et al., 2018; 70 Kiros et al., 2016; Mahata et al., 2018; Putero et al., 2015; Sarkar et al., 2016; Wan et al., 2019) that are expected to have severe health impacts (Gurung and Bell, 2013).

Air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution. An air pollutant is a material in the air that can have many effects on humans and the ecosystem. The key pollutants in Bhaktapur district are Particulate Matter ($PM_{2.5}$ and PM_{10}), Particulate matter (PM), particularly fine particles like PM2.5 and PM10, is a primary pollutant of concern due to its pervasive nature and adverse health impacts. PM2.5 and PM10 are capable of penetrating deep into the lungs and entering the bloodstream, leading to respiratory and cardiovascular diseases, reduced lung function, and increased mortality.

1.2 Problem Statement

The Bhaktapur District in Nepal faces significant air pollution challenges that pose serious health risks to its residents and impact the environment. Despite various efforts to improve air quality, the district continues to experience high levels of air pollution. The pollution vary seasonally and annually, with notable spikes during the winter months due to temperature inversions and increased use of solid fuels for heating.

The primary sources of air pollution in Bhaktapur include vehicular emissions, industrial activities, residential heating and cooking, and construction projects. These sources are exacerbated by rapid urbanization and insufficient regulatory enforcement. The health implications of prolonged exposure to poor air quality include respiratory infections, cardiovascular diseases, and other serious conditions, particularly affecting vulnerable populations such as children and the elderly.

1.3 Objectives

Primary objective:

- To prepare thematic maps of PM2.5 and PM10 AQI data using IDW interpolation technique.
- To develop spatial and temporal air quality maps to visualize pollution patterns and trends for every two months over two years.

Secondary objective:

- To explore the potential sources and factors contributing to elevated pollution levels in different parts of Bhaktapur.

1.4 Scope

This study focused on assessing air quality in Bhaktapur, Nepal, over a two-year period from June 1, 2022, to June 1, 2024. Data collection involved bi-monthly measurements of particulate matter (PM2.5 and PM10) using PurpleAir sensors deployed across 28 monitoring stations strategically located throughout the city. The study aimed to map spatial variations in PM2.5 and PM10 concentrations, analyze temporal trends in air quality, and identify sources contributing to pollution levels..Limitations included the study's focus solely on PM2.5 and PM10 and its geographic confinement to Bhaktapur, which may have affected the generalizability of findings beyond the study area.

2 Literature Review

Air pollution is a critical environmental issue affecting urban areas worldwide, including Bhaktapur District in Nepal. Numerous studies have highlighted the adverse health effects of air pollution, particularly on respiratory and cardiovascular health. Key pollutants such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) have been shown to contribute to a range of health problems, including asthma, bronchitis, lung cancer, and heart disease (Dockery et al., 1993; Pope et al., 2002).

Nepal, particularly the Kathmandu Valley where Bhaktapur is located, has been the subject of various air quality studies. Shrestha et al. (2013) investigated the sources and seasonal variations of air pollution in the Kathmandu Valley, identifying vehicular emissions, industrial activities, and biomass burning as major contributors. The study highlighted significant seasonal variations, with higher pollution levels in winter due to temperature inversions and increased use of biomass for heating.Seasonal variations in air pollution are well-documented in the literature. A study by Aryal et al. (2008) observed that winter months in the Kathmandu Valley experience higher pollution levels due to temperature inversions and increased use of biomass for heating. Similarly, Gupta et al. (2013) found that monsoon rains help to reduce particulate matter concentrations by washing away pollutants.

Effective air quality management requires robust policy and regulatory frameworks. The Government of Nepal has implemented various measures, such as vehicle emission standards and industrial regulations, to combat air pollution (Nepal Environmental Protection Act, 1996). However, enforcement remains a challenge. A review by Karki et al. (2016) emphasized the need for stricter enforcement and the promotion of cleaner technologies.

PM10 and PM2.5 refer to particulate matter suspended in the air, with PM10 particles having a diameter of 10 micrometers or smaller, and PM2.5 particles having a diameter of 2.5 micrometers or smaller. These particles come from various sources like vehicle exhaust, industrial processes, construction, agricultural activities, and natural sources such as wildfires or volcanic eruptions.

An air quality index (AQI) is an indicator developed by government agencies to communicate to the public how polluted the air currently is or how polluted it is forecast to become.

Table 1: Air Quality Index Table

Air Quality Index (AQI) Values	Level of Health Concern	Color	PM2.5 (µg/m^3)	PM10(µg/m^3)
0-50	Good	Green	0-15.4	0-54
51-100	Moderate	Yellow	12.1-35.4	55-154
101-150	Unhealthy for Sensitive Groups	Orange	35.5.5-55.4	155-254
151-200	Unhealthy for all	Red	55.5-150.4	255-354
201-300	Very Unhealthy	Purple	150.5-250.4	355-424
301-500	Hazardous	Maroon	>250.4	>424

2.1 Spatial Interpolation

IDW method has been employed in environmental studies to estimate air quality parameters. Inverse Distance Weighting (IDW) calculates values based on the proximity of sample points (Shepard, 1968). Inverse Distance Weighting (IDW**)** is a spatial interpolation method used to estimate unknown values at specific locations based on known values at surrounding points. It is widely applied in fields like meteorology, environmental science, and geo-statistics for creating continuous surfaces from discrete data points.

IDW operates on the principle that points closer to the location of interest have a greater influence on the estimated value than points farther away. This is based on Tobler's First Law of Geography, which states, "everything is related to everything else, but near things are more related than distant things."

The IDW interpolation method assigns weights to the known data points inversely proportional to their distance from the point of interest. The estimated value at an unknown location $Z(x_0, y_0)$ is calculated using the following formula:

$$Z(x_0, y_0) = \frac{\sum_{i=1}^{n} \frac{Z(x_i, y_i)}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}}$$

$\mathrm{Z(x_0, y_0)}$: The estimated value at the location $((\mathrm{x_0, y_0}))$

$\mathrm{Z(x_i, y_i)}$: The known value at the $\mathrm{i-th}$ datapoint $((\mathrm{x_i, y_i}))$.

$(\mathrm{d_i})$: The distance between the $(\mathrm{i-th}$ data point and the location$((\mathrm{x_0, y_0}))$.

(p): The power parameter that controls the significance of the distance(typically$(\mathrm{p} = 2)$).

(n): The number of known data points used for interpolation.

3 Methodology

3.1 Study Area

The study area encompassed the entire Bhaktapur district, located in Bagmati province of Nepal. Bhaktapur covers the region between the northern latitude of 27°36'N - 27°44'N and the eastern longitude of 85°21'E - 85°32'E. The district, with Bhaktapur as its district headquarters, covers an area of 119 km^2 and in 2078 BS had a population of 430,408. In total, 28 air quality monitoring sensor stations were selected in Bhaktapur district.

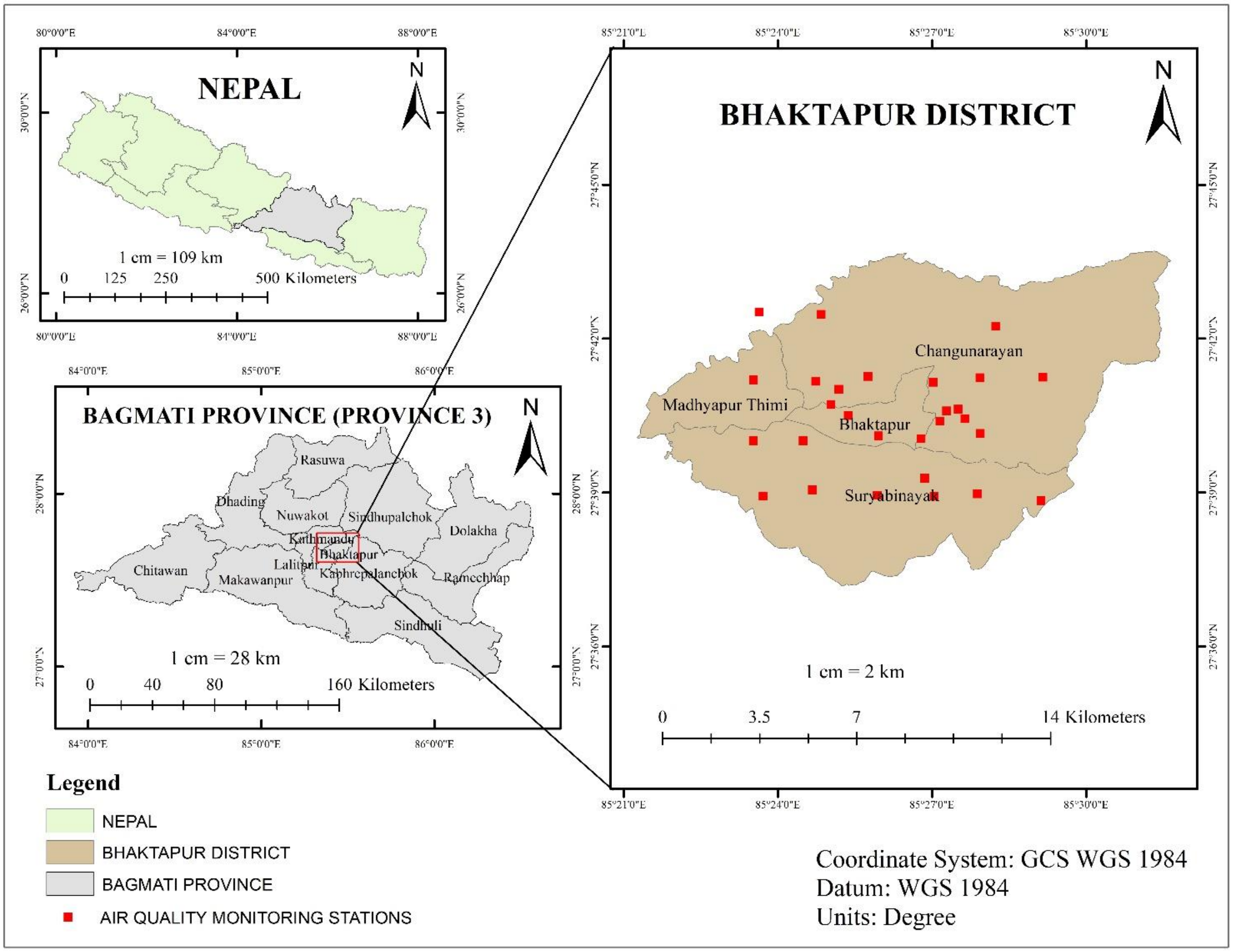


Figure 1: Study Area

3.2 Stations Used

Latitude and Longitude of air quality monitoring stations.

Table 2: Data Used

S.N.	Station Name	Latitude	Longitude
1	AHW Office	27.675	85.42278
2	Besi Gouan	27.70787	85.41403
3	BK-02	27.65462	85.44762
4	BK-07	27.6786	85.41717
5	BK-11	27.68355	85.41973
6	BK-16	27.6732	85.45258
7	BK-4	27.67405	85.46068
8	BK-50	27.67705	85.45847
9	BK-55	27.67652	85.45468
10	Chakkupath	27.66682	85.39201
11	Dadikot	27.64881	85.39515
12	Duwakot (KMC)	27.68611	85.41227
13	Grid 06	27.68766	85.42921
14	Gundu	27.65086	85.41114
15	Ithuli	27.66749	85.44646
16	Kathmandu Cancer Hospital	27.66921	85.46567
17	Khadka gaun	27.68735	85.46558
18	Kharipati	27.70405	85.47065
19	Madhyapur Thimi	27.68658	85.39204
20	Mulpani	27.70866	85.39388
21	Nakhel	27.64875	85.45066
22	Nalinchowk	27.64959	85.46467
23	Nepal Military Academy	27.68577	85.45035
24	Sallaghari	27.66683	85.40814
25	Sanga-Bangal	27.64738	85.4854
26	Sarsuretisthan	27.68744	85.48597
27	Siddhi Memorial Hospital	27.6684	85.43263
28	Sipadol	27.64911	85.43221

3.3 Source of Data

The source of PM data for this project was PurpleAir official website where AQI data is recorded through PurpleAir sensors. The latitude and longitude of stations were extracted from Google Earth.

3.4 Software Used

- ArcGIS:

  ArcGIS was the main software used in the project. With the help of ArcGIS, it was possible to integrate, visualize, and analyze the spatial data and perform interpolation.

3.5 Methods

3.5.1 Data Collection

- Selection of Monitoring Site
  - Sites were chosen based on growing population and industrialization with the availability of air quality monitoring stations.
  - We selected 28 monitoring stations across the study area to collect PM2.5 and PM10 data.

- Temporal Scope
  - Data collection spans two years, with measurements taken every two months, resulting in a total of 13 datasets for each parameter.

3.5.2 Data Preprocessing

- Data Cleaning
  - Raw data were inspected for anomalies such as outliers and missing values. The random

and abnormal highs were removed and the missing values were predicted by interpolations method.There were 33 stations data in Bhaktapur district but only 28 of them were selected because of data unavailability and sensor malfunctions.

➢ Spatial Referencing

- Each monitoring site was geo-referenced using GPS coordinates.
- The spatial reference system for the project was set to WGS-84 to maintain consistency in mapping.

3.5.3 Data Interpolation and Analysis

➢ Initial Data Analysis

- Using Microsoft Excel, the data were visualized and managed by monthly variations.

➢ IDW Interpolation

- Using Arcgis feature, IDW interpolation was applied to create continuous surface maps of PM2.5 and PM10 concentrations from the point data. The IDW tool in ArcGIS was configured with the selected parameters to generate interpolated surfaces for each bi-monthly interval. Separate interpolations were conducted for PM2.5 and PM10 for each time step.

➢ Temporal Analysis

- Temporal changes in air quality were analyzed by comparing the interpolated maps at different time intervals.

3.5.4 Result Interpretation

- Spatial Patterns

- Maps showing the spatial distribution of PM2.5 and PM10 over time were analyzed to identify pollution hotspots and regions with consistently good air quality.

- Trend Analysis

- Long-term trends in PM2.5 and PM10 levels were examined to potential causes, such as changes in local industrial activity, traffic patterns, or regulatory impacts.

3.5.5 Reporting and Visualization

- The final results were compiled into a series of maps and graphs that clearly communicate the spatial and temporal dynamics of air quality in the study area.

3.6 Workflow Diagram

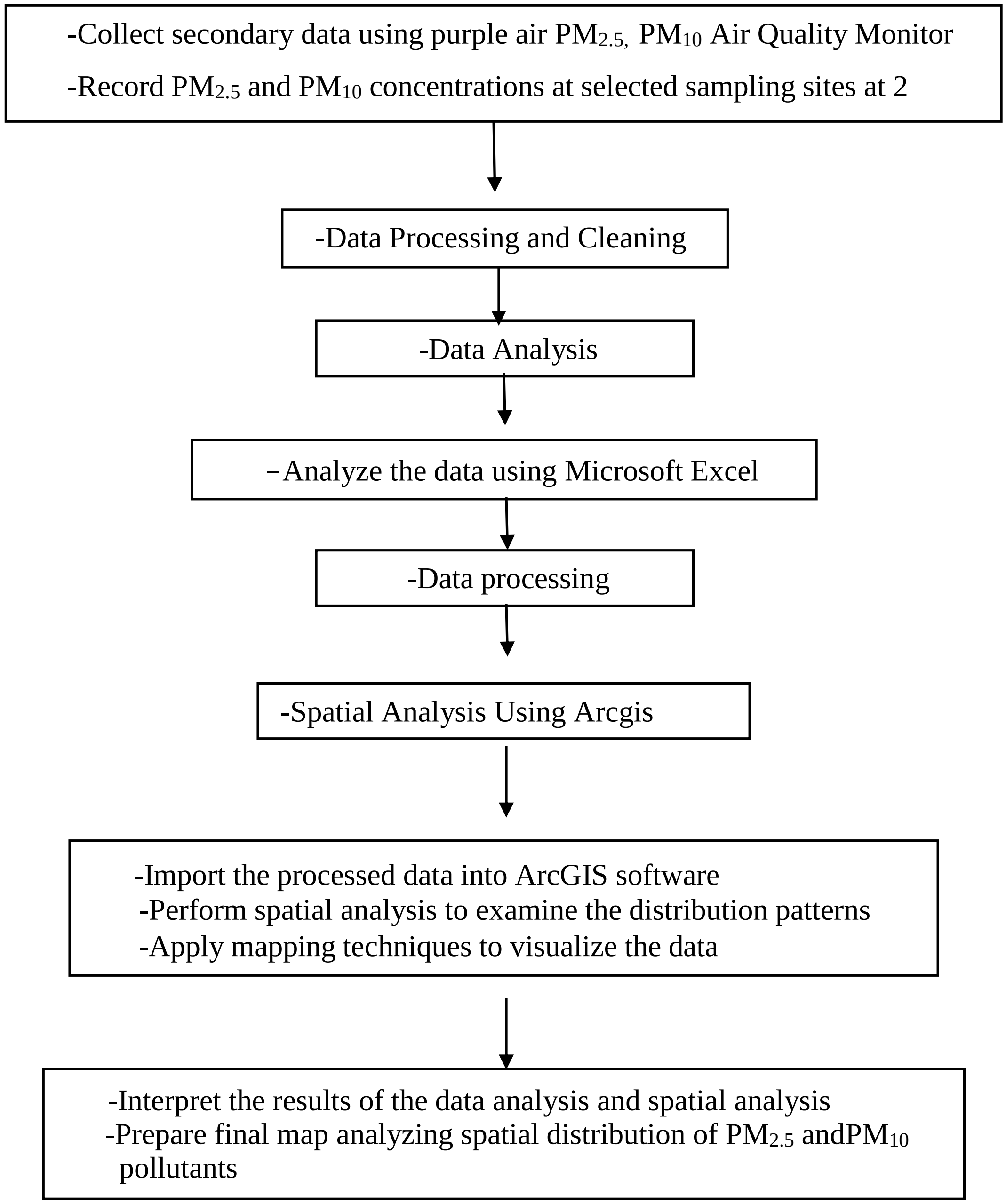
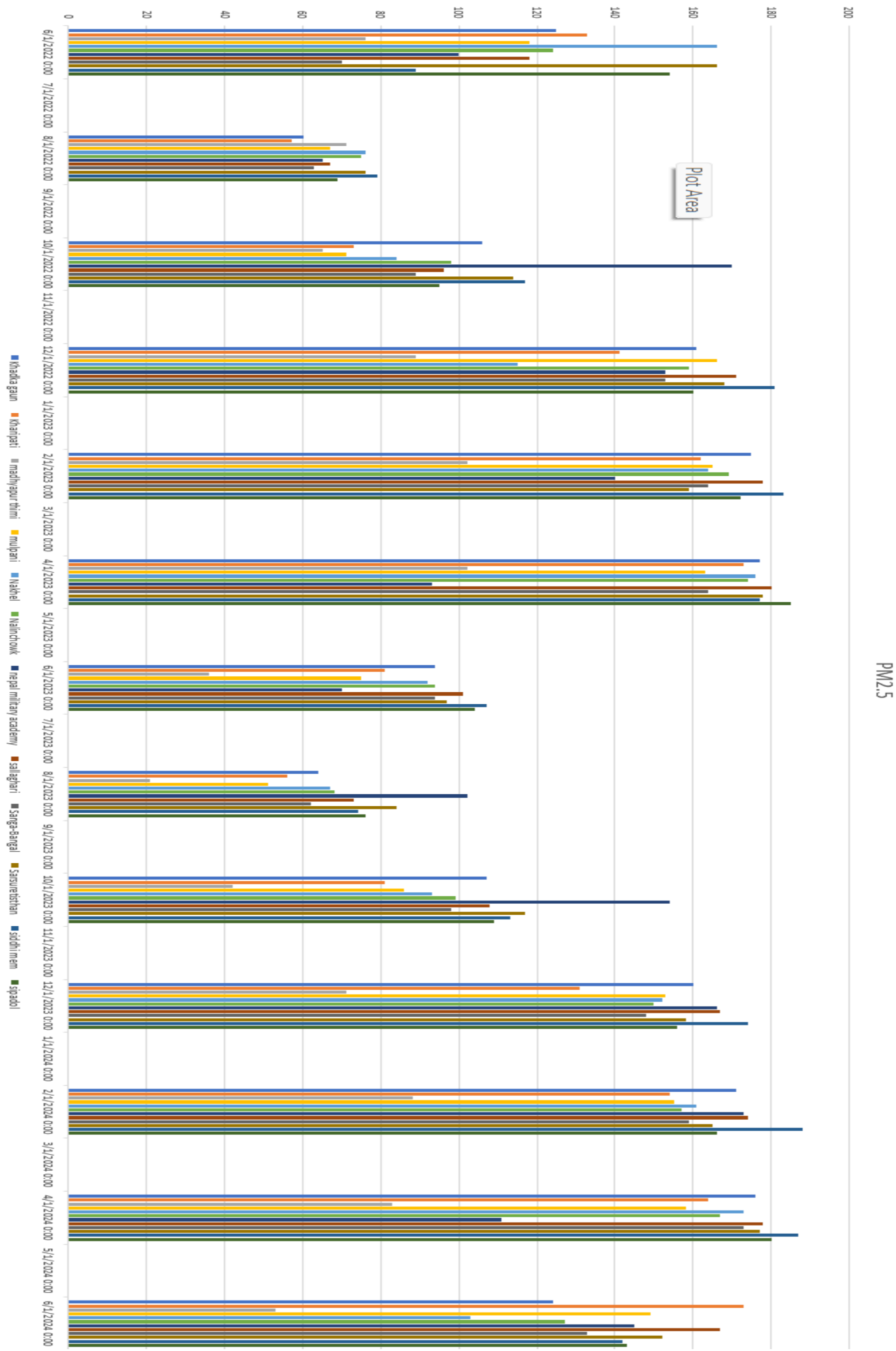


Figure 2: Work Flow Diagram

4 OUTPUT AND ANALYSIS

4.1 PM2.5 Monthly



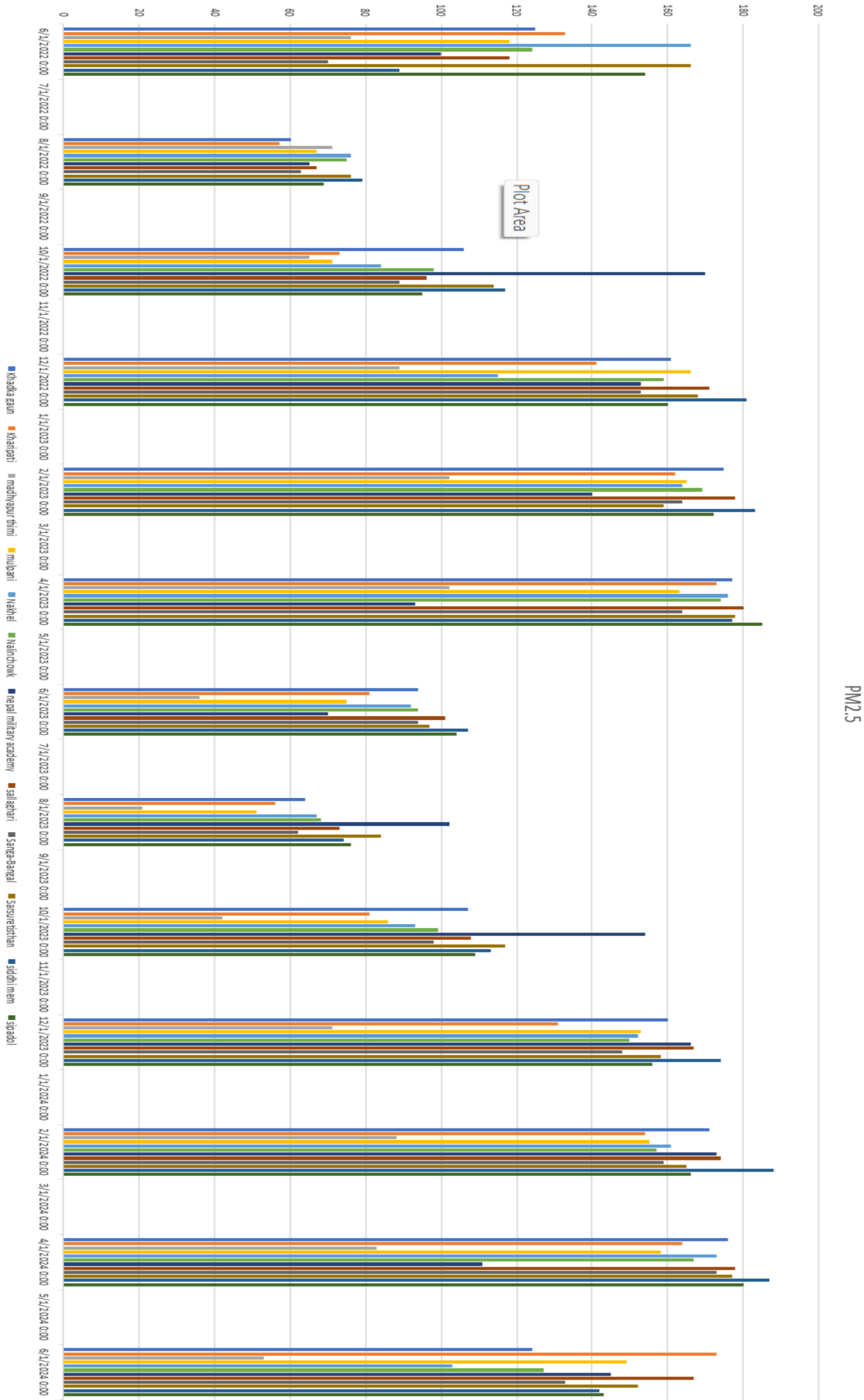
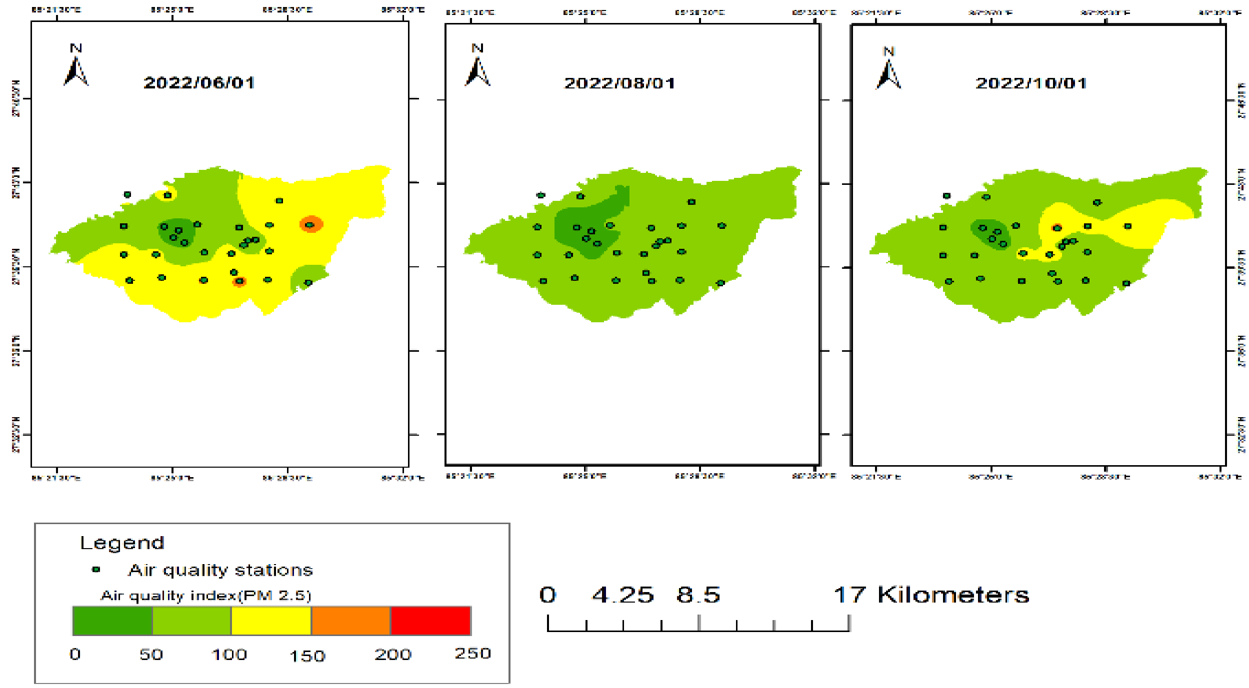
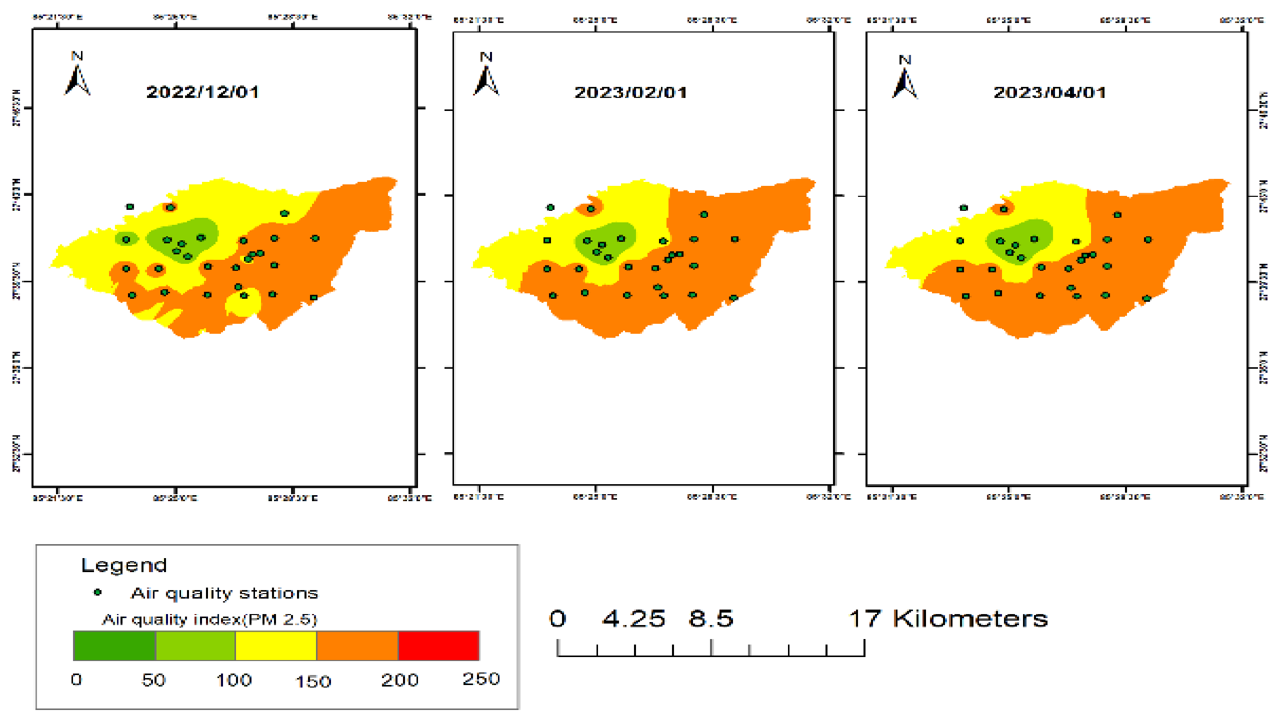


Figure 3: Bar Chart of PM2.5


2022/06/01
2022/08/01
2022/10/01
N
Legend
Air quality stations
Air quality index(PM 2.5)
0 50 100 150 200 250
0 4.25 8.5 17 Kilometers


2022/12/01
2023/02/01
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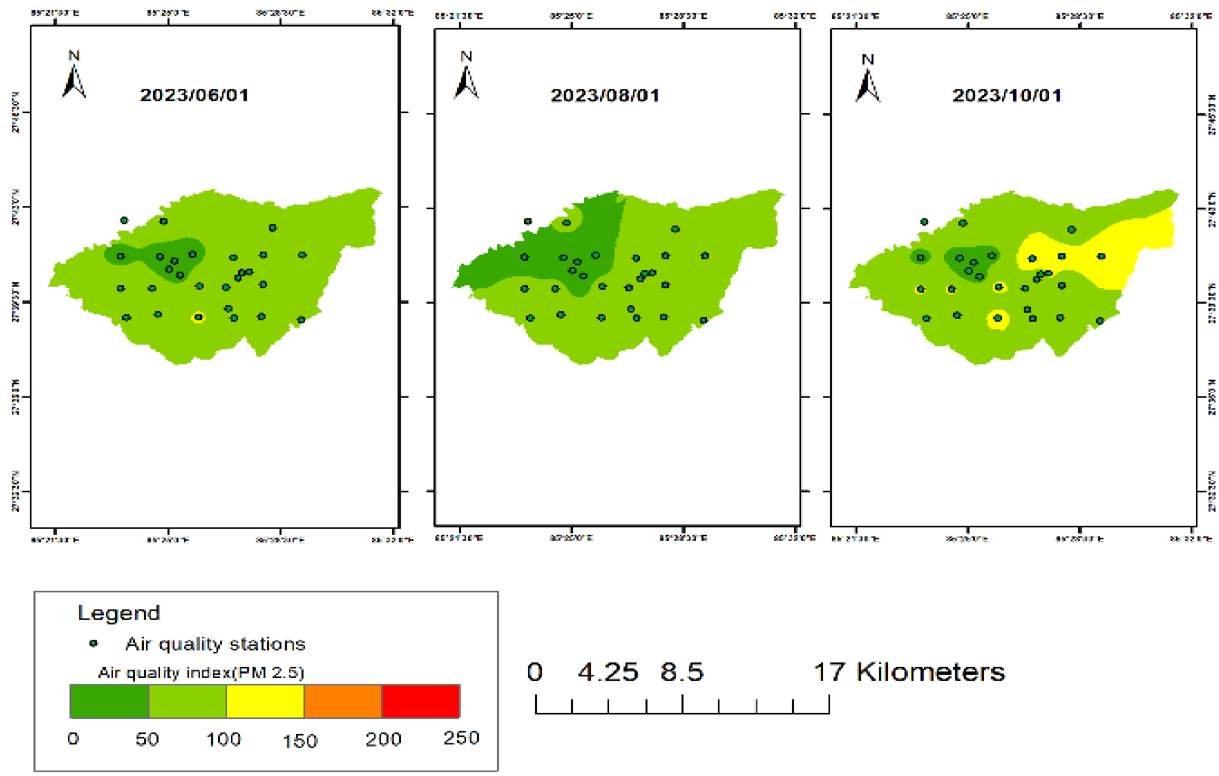
Air quality stations
Air quality index(PM 2.5)
0 50 100 150 200 250
0 4.25 8.5 17 Kilometers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Air quality stations
Air quality index(PM 2.5)
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50
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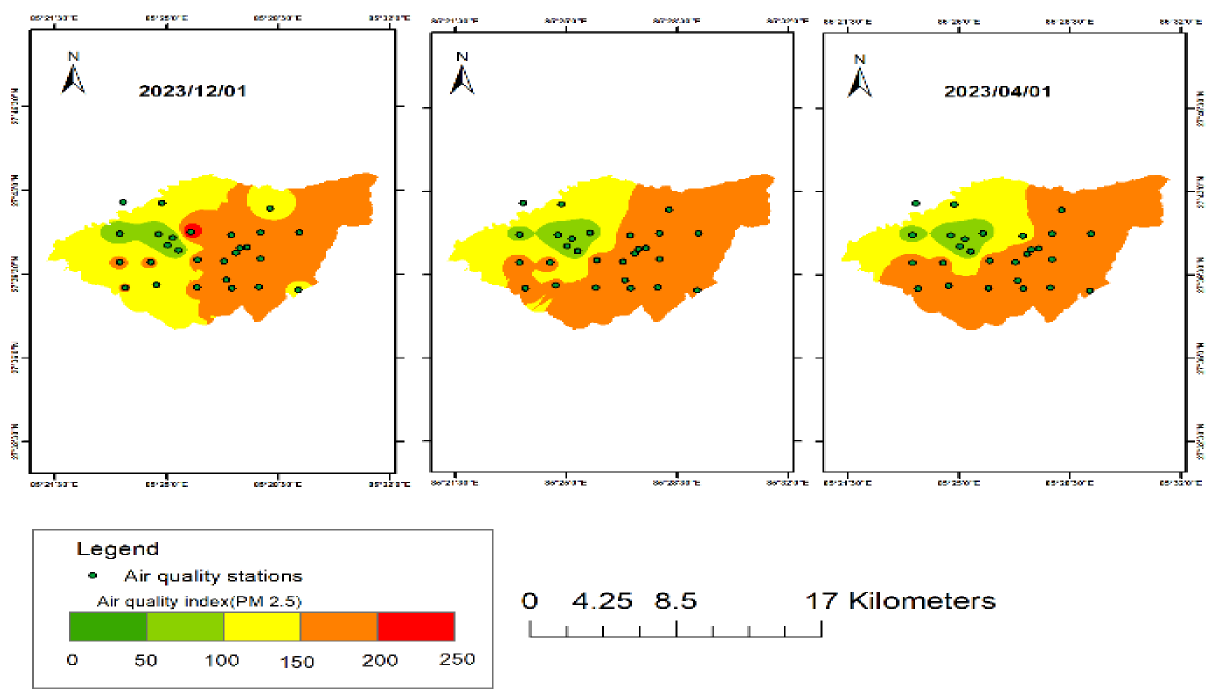
0 4.25 8.5 17 Kilometers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Air quality stations
Air quality index(PM 2.5)
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0 4.25 8.5 17 Kilometers

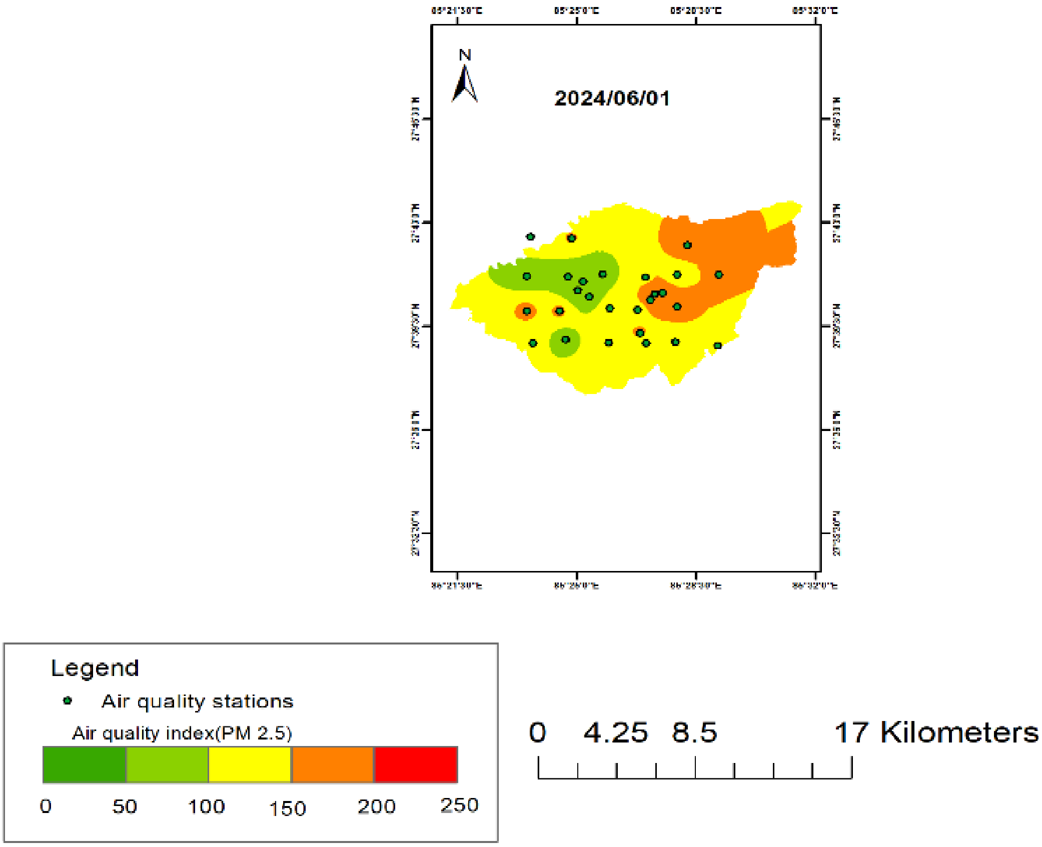
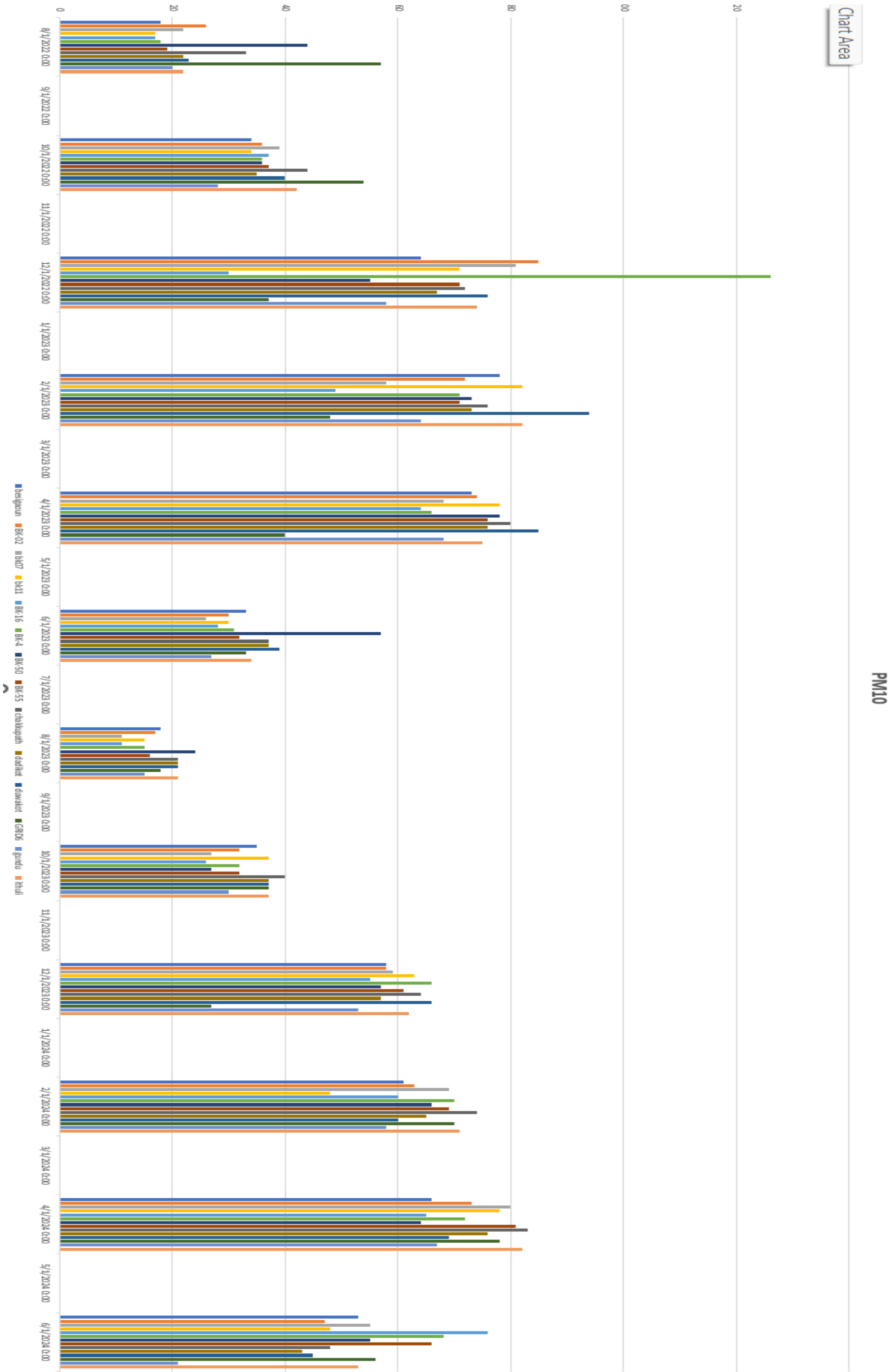


Figure 4: Every Two Month Thematic Map of PM2.5 over Two Years

The map depicts the spatial distribution of PM 2.5 concentration in the Bhaktapur district from June of 2022 to June of 2024, two year span. It is divided to into distinct zones, each represented by a unique color or shading, indicating different levels of particulate pollution. Analyzing the collected data shows PM 2.5 concentration ranging from 11 to 248 µg/m³. The highest PM 2.5 concentration of 248 µg/m³ is observed at GRID6 station on December of 2023 while the lowest concentration of 11µg/m³ is observed at bk-07 station on August of same year. The legend accompanying the map provides a color scale for interpreting pollution levels. Green color represent cleaner air, while red colors indicates higher PM 2.5 concentration and potential health risks. Furthermore it is seen that PM2.5 concentration increases during winter season and decrease during monsoon season.

4.2 PM10 Monthly



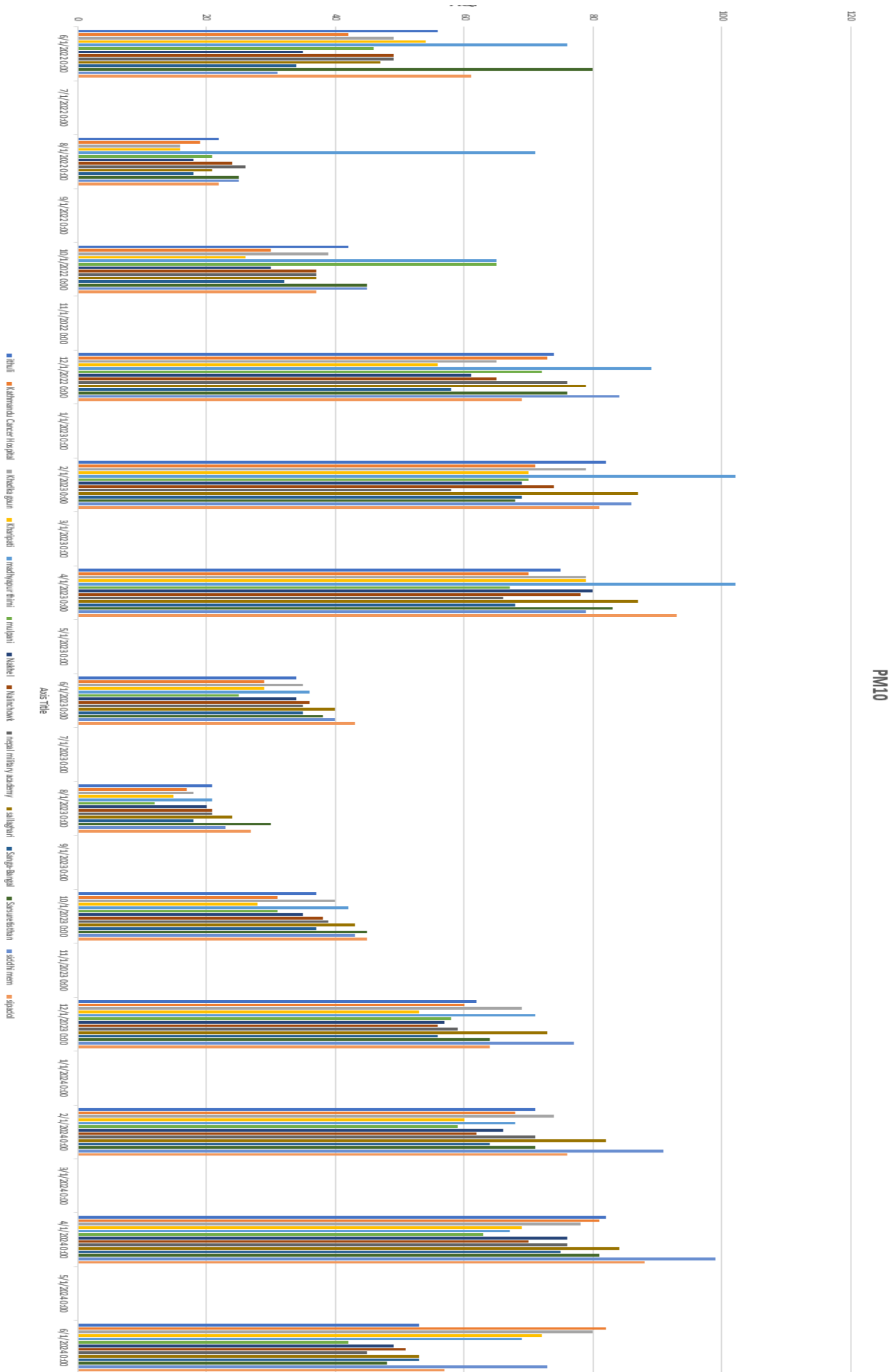
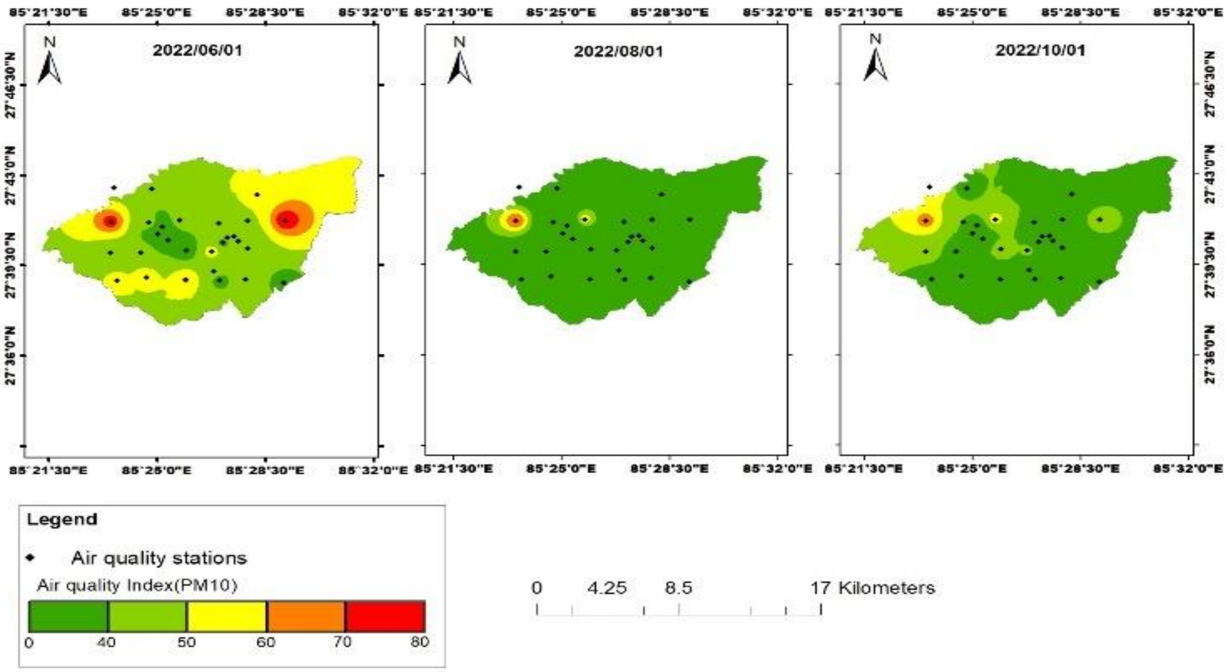


Figure 5: Bar Chart of PM10


2022/06/01
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85°21'30"E
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85°28'30"E
85°32'0"E
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Legend
Air quality stations
Air quality Index(PM10)
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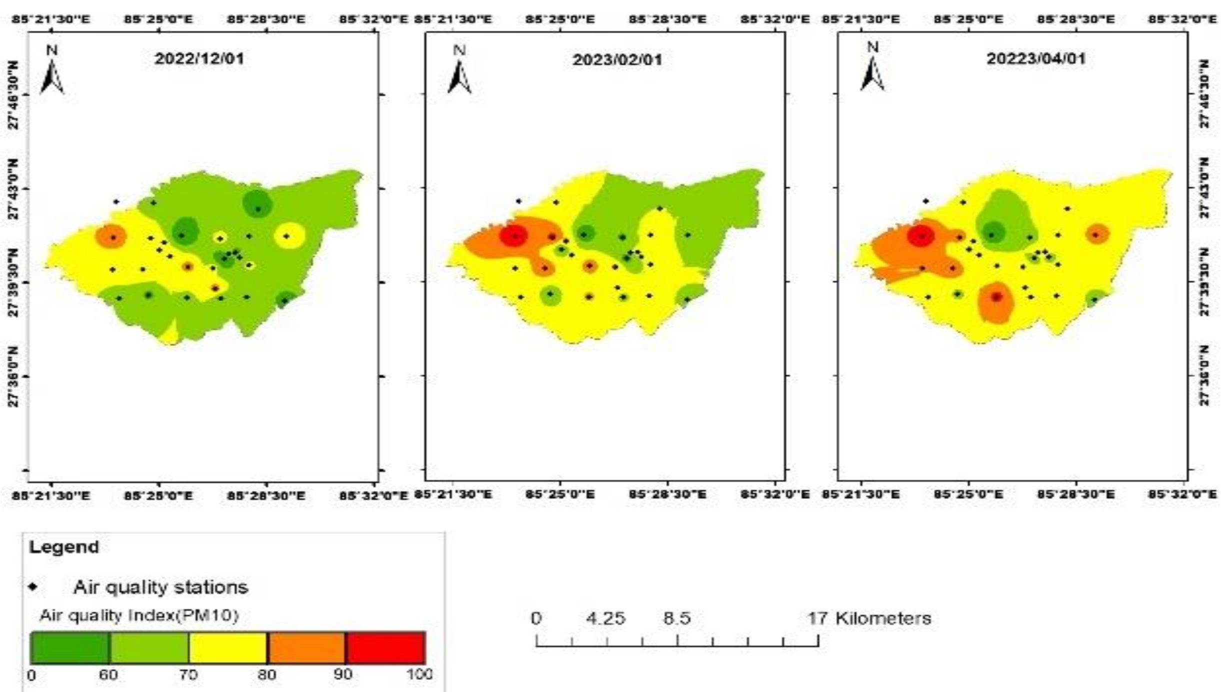
80
0 4.25 8.5 17 Kilometers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27°43'0"N
27°39'30"N
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Legend
Air quality stations
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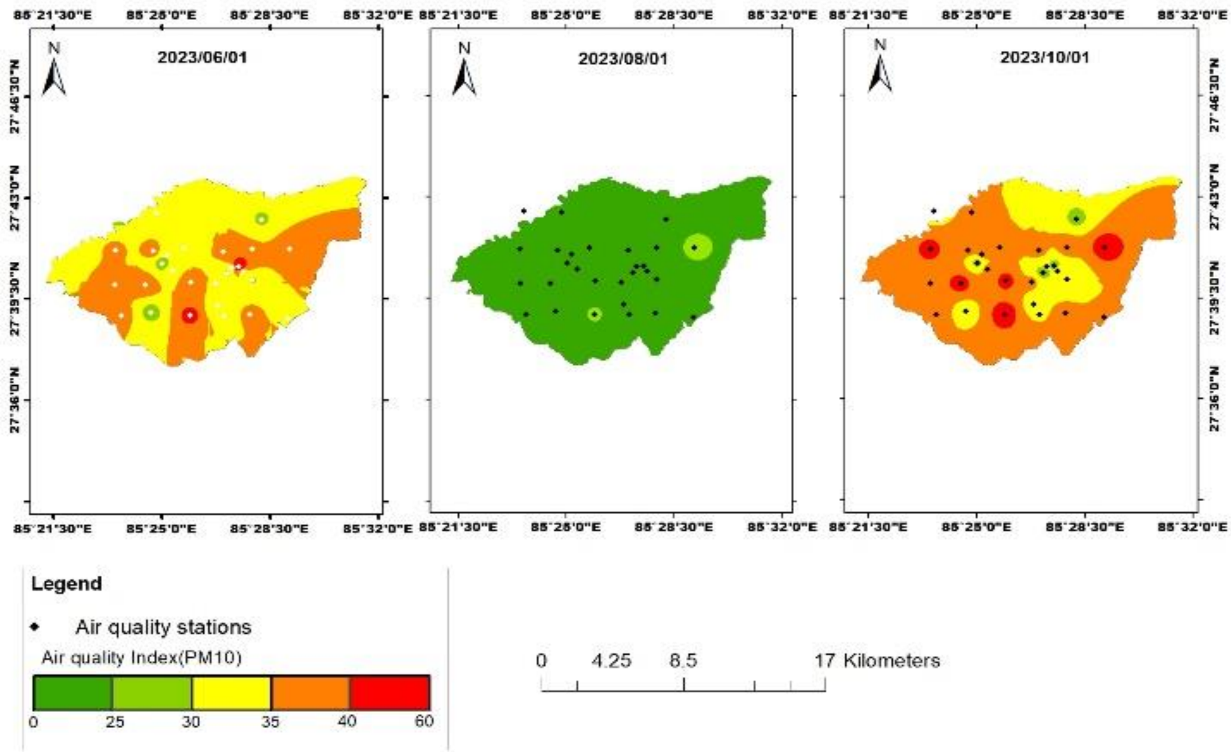
70
80
90
100
0 4.25 8.5 17 Kilometers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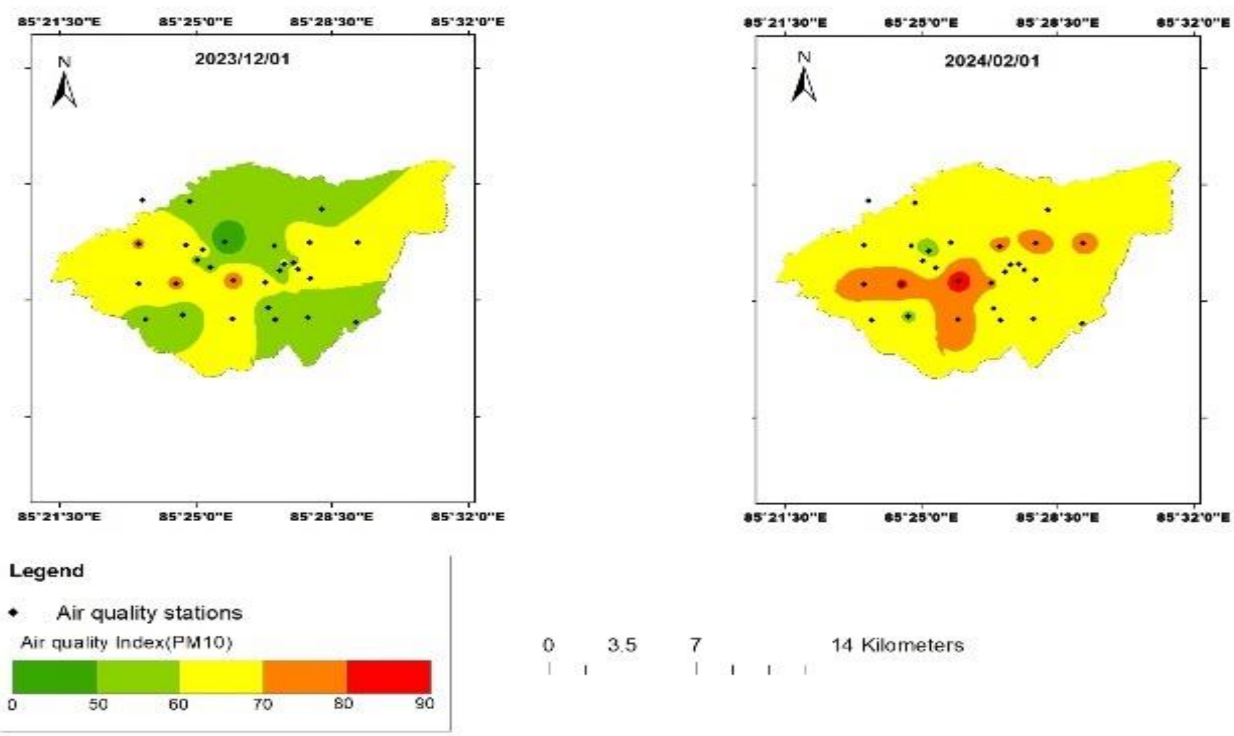
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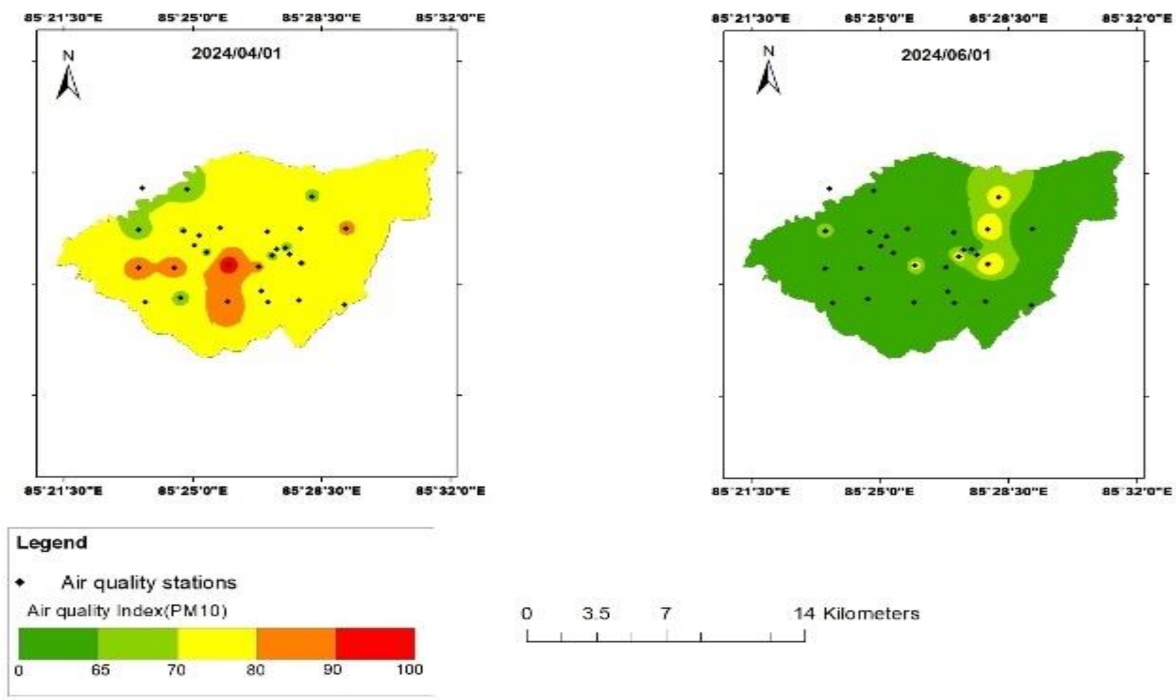

Figure 6: Every Two Month Thematic Map of PM10 over Two Years

The map depicts the spatial distribution of PM 10 concentration in the Bhaktapur district from June of 2022 to June of 2024, two-year span. It is divided to into distinct zones, each represented by a unique color or shading, indicating different levels of particulate pollution. Analyzing the collected data shows PM 10 concentration ranging from 11 to 126 µg/m³. The highest PM 2.5 concentration of 126 µg/m³ is observed at bk-4 station on December of 2022 while the lowest concentration of 11µg/m³ is observed at bk-16 station on August of 2023. The legend accompanying the map provides a color scale for interpreting pollution levels. Green color represent cleaner air, while red colors indicates higher PM 10 concentration and potential health risks. Furthermore it is seen that PM 10 concentration is low on monsoon season increases on winter and at its peak at post monsoon.

4.3 Causing Factor of Particulate Matter (PM)

Brick kilns:

Bhaktapur has numerous brick kilns, with 60 registered and 40 currently operating. The study found that specific locations near brick kilns had the highest AQI of Particulate matter (PM 2.5 and PM 10), reaching beyond limits. These emissions are particulary pronounced during the brick-making season (October to march). Brick Kilns uses various fuels (old tires, wood, motor oil, coal, plastics), leading to incomplete combustion and increased PM.

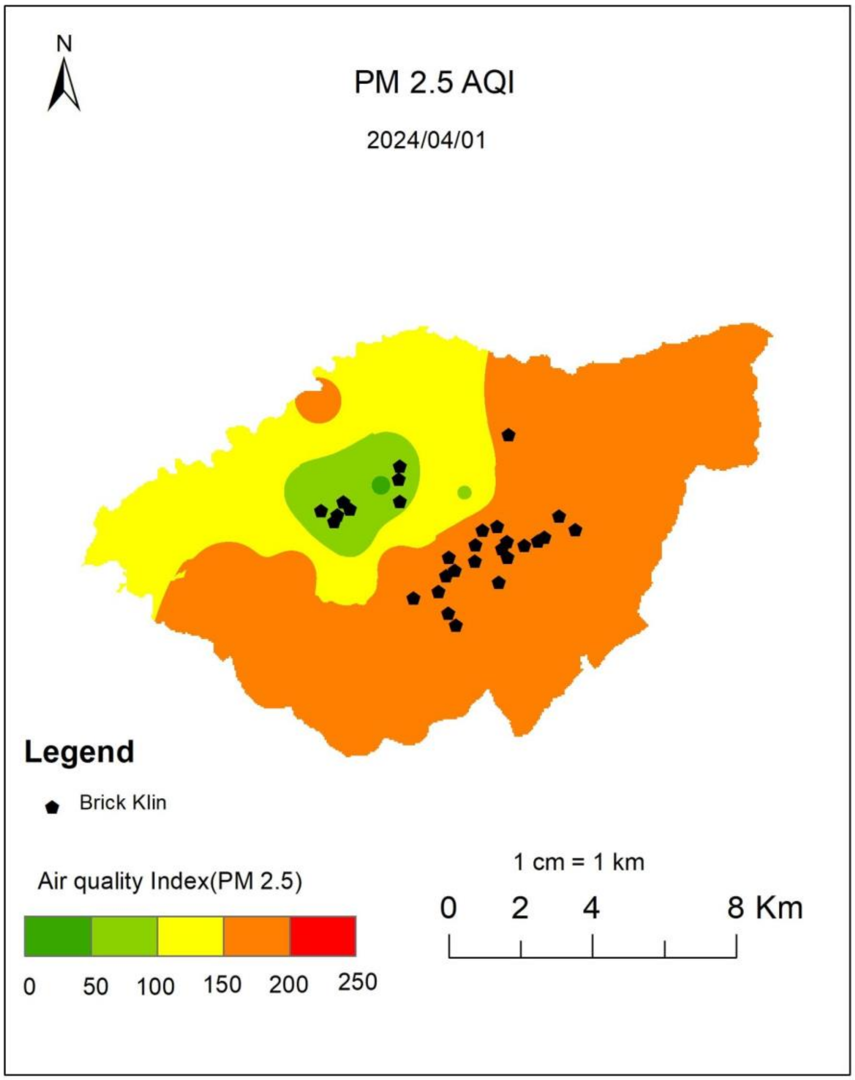

Figure 7: Effect of Brick Kilns (P2.5)

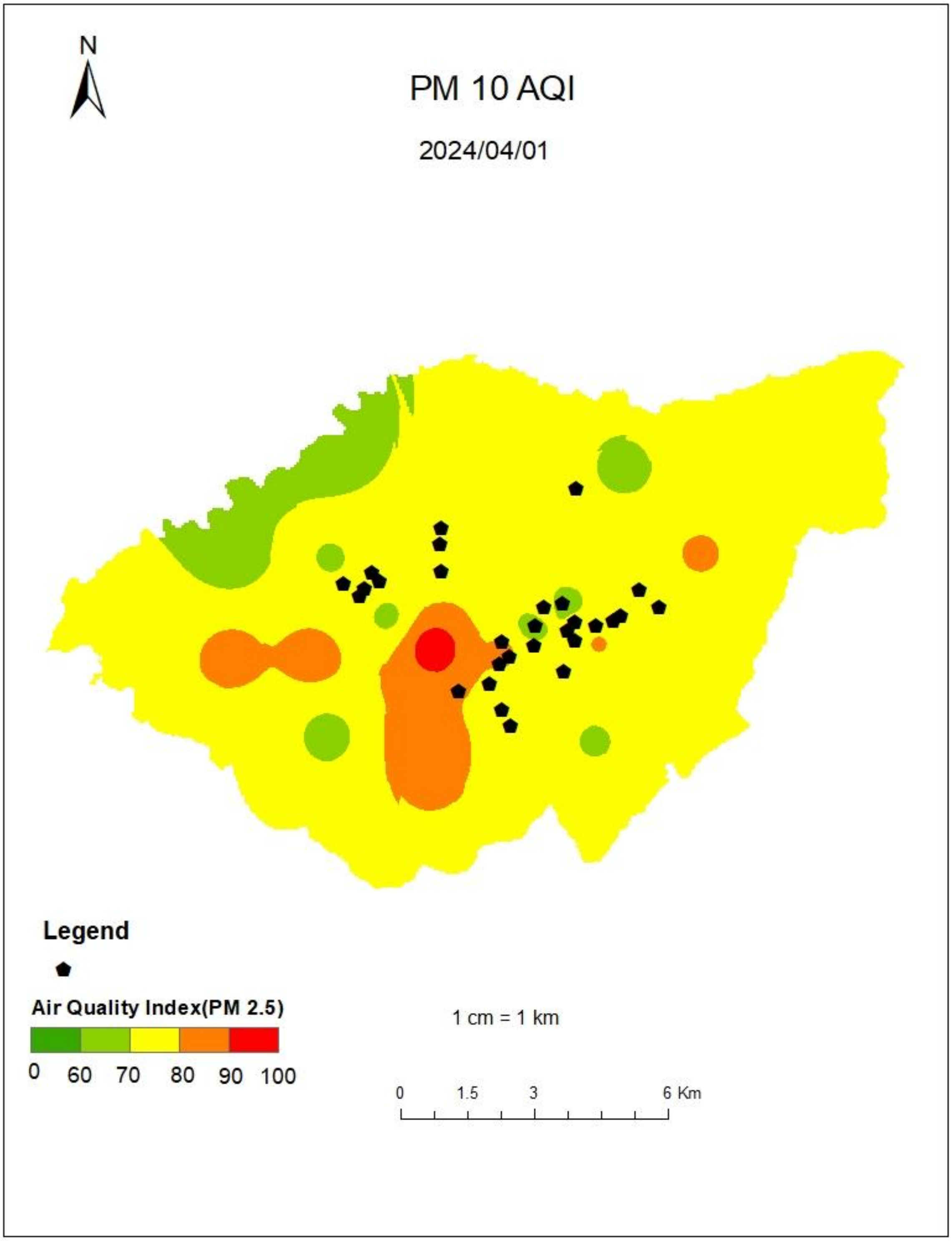

Figure 8: Effect of Brick Kilns (PM10)

5 RESULTS AND CONCLUSION

The analysis of PM2.5 and PM10 concentrations in Bhaktapur district from June 2022 to June 2024 reveals several key findings:

1. Seasonal Variations: Both PM2.5 and PM10 concentrations show clear seasonal patterns. The highest levels are observed during winter months, particularly December, while the lowest levels occur during the monsoon season, typically in August. This seasonal variation can be attributed to:

- Winter temperature inversions trapping pollutants close to the ground
- Increased use of biomass for heating in winter
- Reduced dispersion of pollutants due to low wind speeds in winter
- Washing effect of monsoon rains in summer, reducing particulate matter in the air

2. Concentration Ranges:

- PM2.5 concentrations ranged from 11 $\mu g/m^3$ to 248 $\mu g/m^3$
- PM10 concentrations ranged from 11 $\mu g/m^3$ to 126 $\mu g/m^3$

These ranges indicate periods of both relatively clean air and severely polluted conditions, often exceeding WHO guidelines and national standards.

3. Spatial Distribution: The interpolated maps show that pollution is not uniformly distributed across Bhaktapur. Some areas consistently experience higher concentrations, likely due to local emission sources or topographical factors affecting pollutant dispersion.

4. Health Implications: The observed concentrations, particularly during winter months, fall into the "Unhealthy" to "Very Unhealthy" categories of the U.S. EPA Air Quality Index. This indicates significant health risks for the population of Bhaktapur, especially vulnerable groups such as children, the elderly, and those with pre-existing respiratory conditions.

5. Pollution Sources: While this study did not directly measure emission sources, the patterns observed are consistent with known pollution sources in the area, including vehicular emissions, industrial activities, construction, and residential biomass burning.

6. Effectiveness of Current Measures: The persistence of high pollution levels, particularly in winter, suggests that current air quality management strategies may be insufficient. More aggressive and comprehensive measures may be needed to address the multiple sources of air pollution in Bhaktapur.

These findings highlight the complex nature of air pollution in Bhaktapur and underscore the need for continued monitoring, research, and policy interventions to improve air quality and protect public health. Future studies should focus on source apportionment, health impact assessments, and evaluation of specific pollution control measures to inform more effective air quality management strategies.

6 References

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