ANALYSIS OF AMBIENT AIR POLLUTANT CONCENTRATIONS OVER AKOLA CITY USING QGIS

Dissertation submitted to

Visvesvaraya National Institute of Technology, Nagpur

In fulfilment of the requirements for the award of

the degree

MASTER OF TECHNOLOGY

IN

ENVIRONMENTAL ENGINEERING

Submitted by

SHRADDHA BALUJI MALVE

(MT19ENV017)

under the guidance of

DR. DILIP H. LATAYE

Department of Civil Engineering
Visvesvaraya National Institute of Technology
Nagpur 440010 (India)
2019-2021

VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY

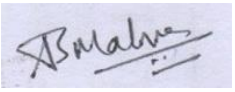
NAGPUR

DEPARTMENT OF CIVIL ENGINEERING

DECLARATION

I, hereby declare that the dissertation titled **"Analysis of Ambient Air Pollutant Concentrations over Akola City using QGIS"** submitted here in for the award of degree of Master of Technology has been carried out by me in the Department of Civil Engineering of Visvesvaraya National Institute of Technology, Nagpur. The work is original and has not been submitted earlier whole or in part for the award of any degree/diploma at this or any other Institution/ University.

I also have made sure that all ideas, expression, graphs, diagrams etc., that are not result of my work are properly credited.



Shraddha Baluji Malve

Date: 01/06/2021

Place: Nagpur

VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY

NAGPUR

DEPARTMENT OF CIVIL ENGINEERING

CERTIFICATE

This is to certify that the dissertation titled **"Analysis of Ambient Air Pollutant Concentrations over Akola City using QGIS"**, submitted by **Ms. Shraddha Baluji Malve** to Visvesvaraya National Institute of Technology, Nagpur is a record of bonafide project work carried out by her under my supervision and guidance and is worthy of consideration for the award of degree of **Master of Technology** in **"Civil Engineering"** with specialization in **"Environmental Engineering"**.

Dr. Yashwant Katpatal

Prof. & Head

Department of Civil Engineering

Dr. Dilip. H. Lataye

Professor

Department of Civil Engineering

Date: 01/06/2021

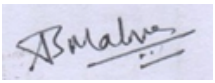
Place: Nagpur

VISVESWARAYA NATIONAL INSTITUTE OF TECHNOLOGY

NAGPUR

NON-PLAGIARISM CERTIFICATE

Certified that M. Tech Dissertation titled **"Analysis of Ambient Air Pollutant Concentrations over Akola City using QGIS"** submitted by **Ms. Shraddha Baluji Malve** Enrollment No.**MT19ENV017** ID No.**23539** has been checked for plagiarism and the overlap is found within prescribed limits.

Signature: 

Student name: **Shraddha Baluji Malve**

Enrollment No: **MT19ENV017**

ID No: **23539**

Signature:

Name of Supervisor: **Dr. Dilip H. Lataye**

ACKNOWLEDGEMENT

I would like to take this opportunity to thank **VNIT Nagpur** for providing us with such a vibrant and learning atmosphere.

First and foremost, I want to convey my most sincere gratitude to **Dr. Dilip H. Lataye**, Professor of Department of Civil Engineering, VNIT Nagpur for taking out time from the hectic schedule and guiding me in the warmest and most friendly manner.

I thank my parents for shedding their sweat to bring me up to this position with their continuous support and encouragement.

I would also like to extend my thankfulness to all the professors of the Department of Civil Engineering for the collective knowledge imparted to me, making me capable enough to see through the entire process.

I am grateful to the staff and members of the **Environmental Engineering Laboratory,** in particular, **Divyanshu Saini (PhD), Upendra Darla (PhD), Aditya Raulwar (PhD), Pulkit Dixit (M. Tech), Namrata Mishra (M. Tech)** for their relentless assistance and cooperation with me.

Last but not the least; I appreciate all my friends just for being there and extending their moral support.

Date: 01/06/2021 **Shraddha Baluji Malve**

TABLE OF CONTENT

NOMENCLATURE

N	North
NNE	North of north-east
NE	North-east
ENE	East of north-east
E	East
ESE	East of south-east
SE	South-east
SSE	South of south-east
S	South
SSW	South of south-west
SW	South-west
WSW	West of south-west
W	West
WNW	West of north-west
NW	North-west
NNW	North of north-west
◦C	Temperature in Celsius Scale
mm	Precipitation in Millimetres
kmph	Wind Speed in Kilometre per Hour
ppb	Parts Per Billion
EF	Exceedance Factor

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In this thesis, the recent developments in the field of atmospheric research have been accumulated by analysing the data of air pollutants. Geographic Information System (GIS) has been put to use as a tool for analysis. The main objective of this study is to analyse the effects of air pollutant concentrations on the air quality and the spatial variability of these air pollutants in the Akola city of Maharashtra, India for the study period from year 2012 to 2020. Akola is located at latitude 20.7ºN and longitude 77.07ºE on the globe. It is a developing city with increasing urbanisation and industrialisation. These processes, over the time, degrade the air quality and harm human health as well as others. The air pollutants for which entire analysis has been done, include PM_{10}, SO_2 and NOx and are some of the major criteria pollutants.

The analysis of these pollutants data helped to recognise the annual and seasonal trends in their levels in the city over the study period of nine years. The Air Quality Index data for the city has been utilised to study the variation in air quality over the study period and the seasonal changes in air quality that occur throughout the year. Exceedance factor for each pollutant has been calculated to understand the contribution of the respective pollutants in air pollution in the city of Akola. A Correlation test has been performed to evaluate the effect of meteorological parameters along with their significance on the pollutant levels in the city. Further, IDW interpolation feature of QGIS software has been employed to generate spatial distribution maps of each pollutant in Akola for every year. These maps have been further utilised to identify the regions with maximum pollutant levels which might become potential zones in the future and require measures for prevention and mitigation to avoid any air pollution episode.

CHAPTER-1
INTRODUCTION

1.1 Air Pollution

Air pollution is the presence of matter (gases, particulate matter, smoke, fumes) in the air in such a quantity, duration and characteristics which is injurious or tend to be injurious to human, plants, animals or materials. These substances which interact with the environment to cause toxicity, disease, aesthetic distress, physiological effects or environmental decay, has been labelled by man as an 'air pollutant'.

IS-4167 (1980) states that "Air pollution is the presence in ambient atmosphere of substances, generally resulting from the activity of man, in sufficient concentration, present for a sufficient time and under circumstances which interfere significantly with the comfort, health or welfare of persons or with the full use or enjoyment of property."

Air pollution is mainly caused by rapid industrialisation and urbanisation. Increase in use of automobiles also contributes to rise in pollution. It has been found that a significantly increasing volume of particulate matter entering the atmosphere, scatters the incoming sunlight and reduces the amount of heat that reaches the earth and tends to reduce its temperature.

A phenomenon commonly referred to as the "green-house effect" is caused by the increasing amounts of carbon dioxide found in the atmosphere. It has been estimated that if the carbon dioxide content in the atmosphere generated in combustion processes continues to increase at the present rate, the mean global temperature could rise by 4°C in the next five decades. There has been a conjecture that this might become a matter of great importance because small temperature increase could cause a partial melting of the ice caps of the earth causing continental flooding and devastating effects on man.

Air pollution can cause adverse health effects, affect visibility, increase co-morbidities and can also be fatal at times. It can lead to vast economic losses as well as intangible losses to historical monuments such as the Taj Mahal whose marble became yellow due to reaction with a pollutant called SO_2. Another such effect of air pollution is acid rain. Acid rain affects vegetation, animals, aquatic ecology, imbalance in proportion of oxygen in atmosphere, weather and rain patterns and much more. There have been episodes of Smog

formation at places like Los Angeles, London and more which occurred due to air pollution. Maintaining air quality requires regular monitoring, identification of sources of pollution and adoption and implementation of preventive measures.

1.2 Air Pollutants

In order to control air pollution, the air pollutants must be understood first. Air pollutants can be either natural or may be the result of various human activities like industrial operations. The contaminants released from industries can be either by-products of external combustion like smoke, dust, and sulphur oxides or by-products of internal combustion like the reactions in petrol and diesel engines.

Further, the emissions can be either primary air pollutants or secondary air pollutants. Primary air pollutants are those which are directly emitted from identifiable sources. Secondary air pollutants are those formed by combination of two or more primary air pollutants or by reaction between them. The various sources of pollutants can also be broadly grouped under either stationary sources or mobile sources.

Air pollutants can be classified as follows:

1. Natural contaminants: These include natural fog, pollen grains, bacteria, and products of volcanic eruption. Out of these, pollen grains ranging between 10 and 50 microns in size are capable of causing allergic responses in individuals.
2. Aerosols or particulates: These refer to dispersion of solid or liquid particles of microscopic size in gaseous media. These range from 0.01 micron to 100 microns.
    - Dust: It is made up of solid particles predominantly larger than those in colloids and suspended in air. It is produced by crushing, grinding of organic and inorganic materials. E.g., Fly ash from chimneys, cement, foundry dust.
    - Smoke: It consists of finely divided particles produced by incomplete combustion such as carbon particles.
    - Mists: It is low concentration dispersion of liquid particles of large size wherein the particles may coalesce.
    - Fog: These are visible aerosols in which the dispersed phase is liquid.

- Fumes: These are solid particles generated by condensation of gases generally after volatilisation and often accompanied by a chemical reaction such as oxidation.

3. Gases and vapours: The various gases and vapours, which are important air contaminants are given below:
    - Sulphur compounds: SO_2, SO_3, H_2S, mercaptans
    - Nitrogen compounds: NO, NO_2, NH_3
    - Oxygen compounds: O_3. CO, CO_2
    - Halogen compounds: HF, HCl
    - Organic compounds: Aldehydes, hydrocarbons
    - Radioactive compounds: Radioactive gases

1.3 Effects of Air Pollutants

1.3.1 Effects on Humans:

- Eye irritation
- Nose and throat irritation
- Irritation of respiratory tract
- Odour nuisance by H_2S, ammonia
- Increase in morbidity and mortality
- Reduction in oxygen carrying capacity of RBCs causing cardio-vascular diseases
- Asthmatic effects by pollen grains
- Chronic pulmonary diseases like bronchitis and asthma
- Fluorosis and decay in teeth
- Carcinogenic agents cause cancer
- Dust particles cause respiratory diseases like silicosis, asbestosis
- Heavy metals like lead cause poisoning
- Effects on Central nervous system

1.3.2 Effects on Plants:

- Necrosis: killing of cells and tissues in plants
- Chlorosis: loss of green pigment from leaves
- Abscission: dropping of leaves

- Bleaching: silver colouring in leaves
- Yellowing of leaves due to ammonia
- Bronze and brown coloured spots in leaves

1.3.3 Effects on Materials:

- Abrasion due to particulate matter spoiling appearance
- Chemical reaction after deposition on materials
- Cracking in rubber
- Yellowing in marble
- Adsorption of pollutant on surface
- Corrosion of building materials due to action of moisture
- Soiling and staining of clothes; fading of dye
- Disintegration of leather
- Damage to paper making it brittle
- Loss of transparency in glass and degradation of ceramic materials

1.4 Criteria Air Pollutants

These are the air pollutants regulated by the CPCB and are the ones mostly affecting biotics. They are as follows:

1.4.1 Sulphur Dioxide (SO_2)

This is one of the principal air pollutant. The main source of sulphur dioxide is the combustion of fuels which primarily includes coal. Therefore, the amount of SO_2 released in the atmosphere varies according to the sulphur content of the fuel. The sulphur content of fuels varies from less than 1% for good quality anthracite to over 4% for bituminous coal.

Most crude petroleum products contain less than 1% sulphur; some may contain up to 5%. Refining processes tend to concentrate sulphur compounds in the heavier fractions. Fuel gases also contain sulphur, but, in small quantities. About 80% of the sulphur in coal and nearly all that in liquid and gaseous fuels is found in flue gases in the form of sulphur dioxide. Generally, the concentration of sulphur dioxide in flue gases ranges from 0.05-0.25%, and occasionally is as high as 0.4%.

Another common source of sulphur dioxide in the atmosphere, is metallurgical operations. Many ores, like zinc, copper and lead, are primarily sulphides. During the smelting of these ores, sulphur dioxide is evolved in stack concentrations of 5-10% (SO_2). Other miscellaneous operations releasing sulphur dioxide into the atmosphere occur in sulphuric acid plants and paper manufacturing plants. The quantities are usually low and therefore easily amenable to control measures. The open burning of refuse and municipal incinerators also generate some amount of sulphur dioxide to the atmosphere.

Sulphur dioxide is a common pollutant to which we are exposed at very low levels every day by breathing air in cities and some industrial environments. Exposure to concentrations of 10 to 50 ppm for 5 to 15 minutes causes irritation of the eyes, nose and throat, choking and coughing. Those with impaired heart or lung function and asthmatics are at high risk. Repeated or prolonged exposure to moderate concentrations may cause inflammation of the respiratory tract, wheezing and lung damage. Even low concentrations of sulphur dioxide can harm plants and trees and reduce crop productivity. Necrosis and bleaching of leaves occur in plants. It contributes towards acid rain and secondary (sulphate-based) particulates. Higher levels, and especially the acidic deposits from acid rain, adversely affect both land and water ecosystems.

In 1990, the analysis of air quality data by National Environmental Engineering Research Institute (NEERI), India for annual average SO_2 concentrations discloses an increasing trend for concentrations (from 3.8 to 15.2 ppb) in most of the parts of northern region, except for a few cities including Delhi, that had higher average annual SO_2 concentration which was above 22.8 ppb after 1985 (Agarwal et al., 1999).

1.4.2 Oxides of Nitrogen (NO_X)

Nitrogen dioxide (NO_2) is a highly reactive gas and formed in the atmosphere through the oxidation of nitric oxide (NO), either naturally or due to human activities. Considering human activities nitrogen oxides are formed mainly by the burning of fossil fuels. It is due to a chemical reaction between atmospheric N_2 and O_2 in the presence of heat to form NO, which then reacts again with O_2 to form NO_2. The rate of this reaction is determined by the temperature of combustion. Thus, unlike SO_2, NO_2 is not due to a component of fossil fuel, but results from a catalytic reaction of heat with atmospheric N_2 and O_2 during the combustion process.

It is probable that oxides of nitrogen are the second most abundant contaminants in many cities, ranking next to sulphur dioxide. Generally, the highest concentration of nitrogen oxides in gaseous emissions occurs in effluents from industries where nitric acid is produced or used in chemical reactions. These industries can be nitrate fertilizer plants, nitric acid plants, metallurgical industries. The next highest concentration is in automobile exhausts. Then come effluents from large power plants, and then to a small extent those from low heat burners and furnaces. Burning of refuse can also lead to emission of NOx.

Out of seven oxides of nitrogen (N_2O, NO, NO_2, NO_3, N_2O_3, N_2O_4, N_2O_5), only nitric oxide NO and nitrogen dioxide NO_2 arise from many human activities and are classified as pollutants. In atmospheric analysis they are usually reported as 'total oxides of nitrogen' or "NOx".

Nitric oxide and nitrogen dioxide have multiple harmful effects on humans. These include irritation of eyes and nose, irritation to lungs, shortness of breath, tiredness and nausea, bronchitis. These pollutants lower the resistance to respiratory infections. Low level exposure of oxides of nitrogen can also result in a build-up of fluid in the lungs for 1-2 days after exposure. High level exposure of oxides of nitrogen can cause rapid burning, spasms and swelling of tissues in the throat and upper respiratory tract, reduced oxygenation of tissues, a build-up of fluid in the lungs, and maybe even death. They also play a major role in formation of ozone which is a secondary pollutant. They can lead to suppressed growth in plants. Also, they can cause bleaching and brown-black spots on leaves.

In Asia, NOx emissions have increased by about 2.5 times from the year 1980 to 2000. Monitoring of air quality in Indian cities is conducted by Central Pollution Control Board (CPCB). This has displayed a dramatically increasing trend in NOx concentrations since 1990, specifically in the metropolitan cities. According to the assessment done by Garg et al. (2001), the average annual growth rate in NOx emissions is about 5.5% per year in India.

1.4.3 Particulate matter

Particulate matter, also known as atmospheric aerosol particles are microscopic particles of solids or liquids such as dust, fly ash, soot, smoke, fumes, mists which are suspended in the air. Suspended particles, which are smaller than 10μm in diameter are

known as respirable suspended particulate matter RSPM or PM_{10}, and those smaller than 2.5μm are called fine particulate matter or $PM_{2.5}$.

A significant amount of particulate matter is generated from anthropogenic activities. These activities include agricultural operations, industrial processes, combustion of fossil fuels and wood, construction and demolition activities and road dust. The principal sources of particulate matter are vehicular emissions, particularly from heavy motor diesel vehicle, kerb-side dust, thermal power plants, industrial and residential combustion processes. The sources with their examples are stated below:

Table 1.1: Sources of particulate matter

Sr. No.	Sources	Examples
1.	Combustion	Burning of fuels such as coal, wood, fuel, oil; engine exhaust; Incineration (house and municipal garbage)
2.	Materials handling and processing	Loading and unloading of sand, gravel, ores, coal, cement; crushing and grinding of stone, rocks, ores; metallurgical (foundries, smelters)
3.	Earth moving operations	Construction of roads, buildings, dams, site clearance; mining, blasting; soil filling and land preparation in agriculture

The size of particulate matter particles affects health in different ways, and many researchers have shown that the tendency to affect human health increases as the size of particulates decreases. If particulate matter has diameter less than 1μ then it directly enters deep into lungs and may even get into bloodstream. Particulate matter with diameter size greater than 10μ gets restricted in the nose. Particulates ranging in size 1μ to 10μ get stuck in the respiratory tract and cause irritation of eyes, nose and throat. Thus, fine particulate matter is more hazardous to health than respirable particulate matter. Health effects include cardiovascular effects such as cardiac arrhythmias and heart attacks, and respiratory effects such as asthma attacks and bronchitis. Other effects include premature death in individuals with lung or heart disease, irregular heartbeat, decreased lung function, difficulty in breathing. People with heart or lung diseases, children and senior adults are most likely to be affected by particulates.

1.4.4 Carbon monoxide (CO)

Carbon monoxide (CO) is a colorless and odorless gas. It is chiefly emitted by motor vehicles due to combustion of fossil fuels. It is highly hazardous if released in large volumes such as a motor vehicle operating in or near a restricted area. If entered in human body, it interacts with the hemoglobin in human blood and reduces the circulation of oxygen in the bloodstream. When CO levels rise high, individuals suffering from cardiovascular diseases and chronic heart disease may experience pains in chest. As per WHO records from 2001, CO at elevated levels can damage visual power and affect mental ability and manual agility. It can even cause unconsciousness and death. In India, the National Ambient Air Quality Standard for CO is 2 mg/m^3 measured over a period of eight hours.

Incomplete combustion of fossil fuels like petrol, diesel in motor vehicles is the major contributor of carbon monoxide to the air. Also, older vehicles cause more emission of pollutants if they do not fulfil original specifications. Carbon monoxide can also lead to the formation of photochemical smog in certain areas.

1.4.5 Ozone (O_3)

Photochemical smog or oxidants are a composite mixture of gases formed in the atmosphere by the action of sunlight; Ozone (O_3) is one such gas. Ozone is a colorless and extremely reactive gas with a sharp odor. It is found 15 to 20 km above ground level in the stratosphere where it protects the Earth from the detrimental UV radiation from the Sun. Figure demonstrates the formulation of Ozone (O_3).

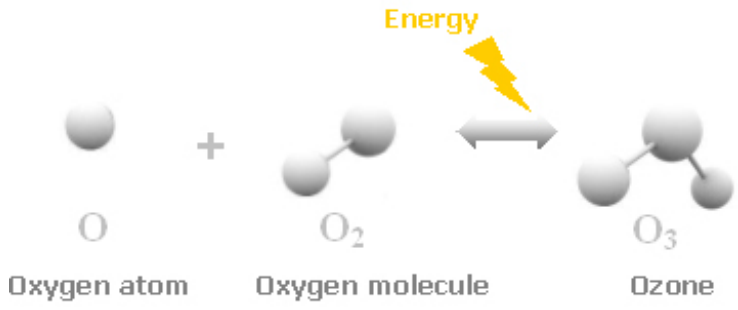


Figure 1.1 Reaction in the formation of ozone

In the lower atmosphere, it is a secondary pollutant and formed in certain meteorological conditions through a photo-chemical reaction. These photo-chemical

reactions involve oxides of nitrogen and reactive hydrocarbons emitted from automobiles as shown below.

$$2\,NO + 1/2O_2 \longrightarrow 2\,NO_2$$
$$NO_2 + h\nu \longrightarrow NO + O$$
$$O + O_2 \longrightarrow O_3$$

Due to the immense growth in transportation sector, an increased build-up of ozone has also been recorded throughout the world. During the past few decades, the problem of tropospheric O_3 as an air pollutant has intensified as a global concern. High levels of ozone may be found hundreds or thousands of kilometres away from the original sources and often affect remote rural areas.

The harmful effects of ozone are reduction in visibility and damage to vegetation. It leads to wheezing, coughing, sore throat, shortness of breath, chest pain and congestion. It can worsen bronchitis and asthma. Ozone is linked with temporary effects on the human respiratory system, especially in the pulmonary function of individuals. Repeated exposure may cause permanent damage in lung tissues. Several recent studies have associated ozone with premature mortality and other diseases. It causes necrosis, bleaching, collapse of leaves and suppressed growth in plants. Additionally, it contributes to the formation of photochemical smog along with oxides of nitrogen (NOx) and volatile organic compounds (VOCs). Photochemical smog has its own adverse effects on humans such difficulty in breathing, reduced lung function, increased sensitivity to allergens and may trigger asthma attacks.

1.4.6 Lead (Pb)

Lead is another criteria pollutant with automobiles as its main source in urban area. The concentration of inorganic lead in urban area is about 1-3μg/m^3 with higher values in area with heavy traffic. Inorganic lead can cause multiple health disorders in humans and animals. Exposure to high levels of lead can cause seizures, mental retardation and behavioural disorders. Foetus, infants and children are susceptible to even low dose of lead affecting central nervous system. Intake of lead can also cause high blood pressure and diseases of heart. Other effects include gastro-intestinal damage, liver and kidney damage, and abnormalities in fertility and pregnancy. Ingestion of lead can cause acute and chronic poisoning in animals and can be fatal at times.

1.5 Air Pollution in India

Air pollution is a very serious health issue in India. As per a study based on data of year 2016 by National Institute of Environmental Health Sciences, out of the world's 20 cities with the highest annual levels of air pollution 13 cities belonged to India. According to the WHO's report from 2016, India has 14 out of the 20 world's most polluted cities in terms of $PM_{2.5}$ concentrations. As per a report by Indian Express in 2019, the major sources of air pollution in India are dust & construction, waste burning, transport vehicles, diesel generators, industries and domestic cooking. Dust & construction are a major source in urban areas while waste burning is in rural areas. The contribution of these sources can be understood by:

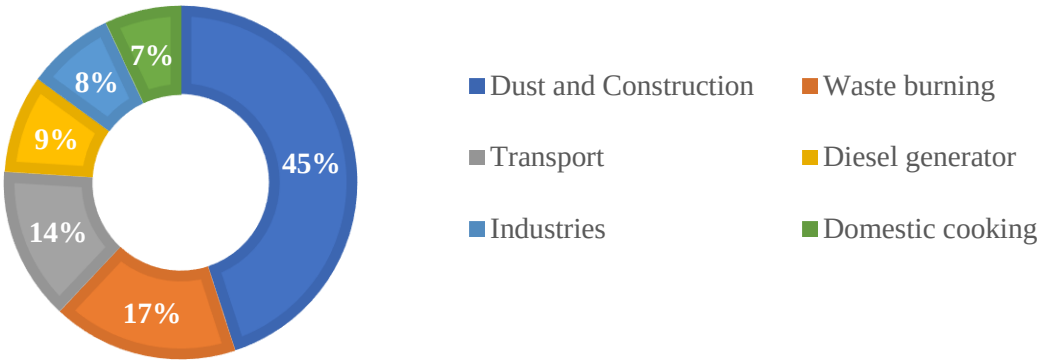


Figure 1.2 Sources of Air Pollution in India

Of the four major metropolitan cities in India, air pollution was consistently worse and highest in Delhi, every year over the 5-year period of 2004–2018. Kolkata was a close second, followed by Mumbai and Chennai. The AQI of Delhi reached 574 and was placed under the "severe-plus category" by the System of Air Quality and Weather Forecasting and Research in 2013. In May 2014 the WHO announced New Delhi as the most polluted city in the world. In November 2016, New Delhi and adjoining areas experienced a dense blanket of smog called as the Great smog of Delhi which was the worst in 17 years. The Lancet provided a report on The Global Burden of Disease Study of 2017 which indicated that 76.8% of Indians are exposed to higher ambient particulate matter over 40 $\mu g/m^3$, which is significantly above the limit recommended by national guidelines on ambient air pollution.

The most important reason for concern over worsening air pollution in India is its

adverse effects on the health of individuals. As per Times of India, asthma is the leading health concern for Indians and is responsible for more than half of the health issues caused by air pollution. In cities like Bangalore, around 50% of children suffer from asthma as stated in Times of India in July 2012. The statistics report released by the Global Burden of Disease (GBD) project at the University of Washington shows that mortality figures due to outdoor air pollution in India have surpassed those in China for the very first time in the year 2015. There were 3,283 premature deaths per day in India in 2015 due to particulate matter and ozone pollution, compared to 3,233 deaths per day in China.

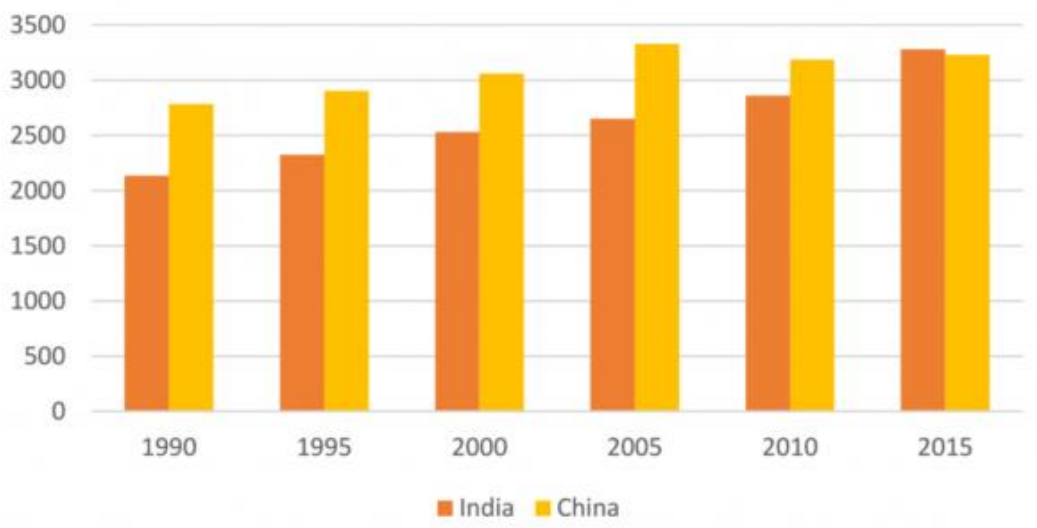


Figure 1.3 Deaths per day due to ambient air pollution

In terms of average life expectancy, it is proposed that average life expectancy in India would increase by 1.7 years if exposure was limited to national minimum recommendations. Thus, air quality monitoring becomes essential to improve air quality and minimize its impacts on the health and environment.

1.6 National Ambient Air Quality Standards

Under the Air (Prevention and Control of Pollution) Act, 1981, the Central Pollution Control Board has laid down limits for concentration of 12 atmospheric pollutants (criteria pollutants). These are called as National Ambient Air Quality Standards (NAAQS). As notified on 18th November 2009, they are as given ahead:

Table 1.2: National Ambient Air Quality Standards

Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)	
Sulphur Dioxide (SO_2), µg/m³	Annual * 24 Hours **	50 80	20 80	-Improved West and Gaeke Method -Ultraviolet Fluorescence
Nitrogen Dioxide (NO_2), µg/m³	Annual * 24 Hours **	40 80	30 80	-Jacob & Hochheiser modified (NaOH-$NaAsO_2$) Method -Gas Phase Chemiluminescence
Particulate Matter (Size less than 10µm) or PM_{10}, µg/m³	Annual * 24 Hours **	60 100	60 100	-Gravimetric -TEOM -Beta attenuation
Particulate Matter (Size less than 2.5µm) or $PM_{2.5}$, µg/m³	Annual * 24 Hours **	40 60	40 60	-Gravimetric -TEOM -Beta attenuation
Ozone (O_3) µg/m³	8 Hours * 1 Hour **	100 180	100 180	-UV Photometric -Chemiluminescence -Chemical Method
Lead (Pb) µg/m³	Annual * 24 Hours **	0.50 1.0	0.50 1.0	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper -ED-XRF using Teflon filter
Carbon Monoxide(CO), mg/m³	8 Hours ** 1 Hour **	02 04	02 04	-Non dispersive Infrared (NDIR) Spectroscopy
Ammonia (NH_3), µg/m³	Annual * 24 Hours **	100 400	100 400	-Chemiluminescence -Indophenol method
Benzene (C_6H_6), µg/m³	Annual *	05	05	-Gas Chromatography (GC) based continuous analyzer -Adsorption and desorption followed by GC analysis
Benzo(a)Pyrene (BaP) Particulate phase only, ng/m³	Annual *	01	01	-Solvent extraction followed by HPLC/GC analysis
Arsenic (As), ng/m³	Annual *	06	06	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper
Nickel (Ni), ng/m³	Annual *	20	20	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper

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

** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

NOTE: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigations.

CHAPTER – 2

LITERATURE REVIEW

V. Prathipa et al (2015)

This study reports the analysis of ambient air quality in Dindigul Town Tamil Nadu employing the Air Quality Index (AQI). The 24-hourly average concentrations of 4 major criteria pollutants viz., suspended particulate matter (SPM), Respirable Suspended particulate matter (RSPM), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) at three different locations in Dindigul town (Tannery-Thomaiyarpuram-by pass), (Commercial cum traffic - Dindigulbus stand) and (Residential Lakshmanapuram) are considered for this analysis. The AQIs were calculated using IND-AQI procedure. The mathematical equations for calculating sub-indices were developed by considering health criteria:

$$IP = \frac{(1H1 - 1LO)}{(BPH1 - BPLO)}(CP - BPLO) + 1LO$$

Where IP is AQI for pollutant "P" (Rounded to the closest integer), CP the actual ambient concentration of Pollutant "P", BPHI the upper and break point concentration that's greater than or equal to CP, BPLO the lower end break point concentration that's less than or equal to CP, ILO the sub index or AQI value such as BPLO, IHI the Sub index or AQI value corresponding to BPHI.

The indexes for every of the pollutants NO_2, O_3, PM_{10}, CO and SO_2 were obtained from above equation using their respective break points and associated AQI value. Having calculated IP of every pollutant, the EPAQI is evaluated by considering the most index value (IP) of the single pollutant. Mathematically, it is expressed as:

EPAQI = Max $_{IP}$

There are many alternative air quality indexes, which represent the worldwide urban air pollution situation. Although the index proposed by USEPA gives an overall assessment of air quality, it doesn't include the synergistic effects of the main air pollutants. So, an effort is additionally made to calculate the Air Quality Index based on factor analysis (NAQI) which covers up the deficiencies of USEPA method. The

seasonal air quality indexes were calculated by using both these methods. it is observed that a major difference exists between NAQI and EPAQI. However, NAQI followed the trends of EPAQI when plotted against season. The suspended particulate matter mainly liable for maximum AQI value at all three sites. The NAQI value ranked higher at traffic and tannery site during summer and winter season. Similarly, the EPAQI ranking shows higher ranking at (Commercial cum traffic- bus stand) at both seasons. it's well clear that Commercial cum traffic and tannery area are found to be unhealthy and thus the higher ranking showed the increased pollution levels and worsening of the air quality.

Joginder Singh Yadav, Amul Patwal (2015)

The study area chosen is Delhi, the capital of India with extreme air pollution especially in winters and on festivals like Diwali. Data for 40 monitoring stations is analysed by using Geographical Information System approach. The objective of the study is to map the air quality parameters for these monitoring stations on the day of Diwali for seven years from 2003-2009 of Delhi using GIS. The air quality parameters considered in the study are SPM, RSPM, SO_2, NO_X, CO. Another objective of this study is to understand the varying air quality trends in Delhi over these seven years.

ArcGIS 9.3 software is used for Geographical information system (GIS) aided mapping. The monitoring stations were mapped on the georeferenced Delhi city map using their respective longitude and latitude coordinates. MS-Excel is used to insert the air quality data in the ArcMap. The 24-hr average concentration for each of the parameters is calculated for the analysis of air quality. The concentration of each parameter for every year is normalized with their respective standard values in ArcMap. For the purpose of analysis of change of air quality for every year on Diwali, proportional symbols are used to create the map for each parameter of each year from 2003-2009.

A strict declining trend is recognized for all the pollutants from year 2007 to 2009 seen at each monitoring station on the day of Diwali. This might be due to health awareness among people. Concentration of SPM was observed to be very high in 2003, 2004 and 2005, but started dropping down in upcoming years 2006 to 2009. RSPM concentration went down from year 2003 to 2006, then suddenly jumped up in 2007 and again fell in 2008 and 2009. Both SPM and RSPM concentration were seen very high in 2003 but it

decreased along the upcoming years. SPM and RSPM average concentration were found to be nearly 2.5 times and 3.5 times of the permissible concentration respectively at all the monitoring stations in 2009. The SO_2 concentration was seen below the permissible standard of SO_2 as per CPCB for most of the monitoring stations for all the years from 2003 to 2009 on Diwali day. The study has also shown the same decline in CO concentration along with the years as other pollutants. NOx, SO_2 and CO concentration were seen within the permissible limit in 2009 on Diwali day.

Shiva Chandra Vaddiraju (2019)

Impact assessment of effects of air quality on plants, animals, natural ecosystems, and human health is important. Air quality management includes monitoring and analysis of pollutant concentration, spatial distribution of pollutant concentration, and assessment of multiple environmental factors affected by air pollutants and preparation of health risk map. Conventional monitoring and assessment of air quality is a tedious process and difficult to comprehend for many people. However, GIS is very useful for assessment of air quality. It helps in preparation of maps showing variations in various pollutants and present it in an easily understandable manner to even general public. It becomes very easy for the decision makers to identify which localities are affected by which type of pollutant and come up with suitable remedial measures.

The study area under consideration is Hyderabad city. Hyderabad has the worst air quality as far as pollution due to Particulate Matter is concerned among cities in south and west India. In the present study GIS has been used to map the air pollution data and analyse the areas which are most affected by what type of pollutant. Subsequently, conclusions can be drawn for making the Hyderabad a safe and sustainable area to live in. In the present study variations of Particulate Matter, SO_2, NOx, have been studied from year 2016 to 2018 and GIS Maps are prepared for PM_{10}, NO_X, SO_2 for these years and identified the localities in which pollution standards are beyond permissible limits.

The air quality data is collected from the Telangana pollution control board and entered into the excel sheets along with the latitude and longitudinal details of the sampling stations. The GIS software used here in this project is ARC GIS. For the further procedure of mapping ARC Map is used. The excel sheet of the air quality data with the latitude and longitudinal details is added to the software to consider the value taken for a pollutant for

the entire region. Thiessen polygons are created which assigns the value to the entire polygon which is near to it making the analysis easy and to compare the variation. Thematic maps are prepared for the pollutants under study. These maps help in comparing the variation of a pollutant through a period of three years and helps to analyse the reason of increase in value or decrease and giving an opportunity for the decision makers to identify ways in which the increasing pollutant value can be controlled.

It is clearly observed that all types of pollutants show an increasing trend across Hyderabad except in few pockets from 2016 to 2018. SO_2 concentration is within the defined limits, but it is observed that it is increasing annually. NO_2 concentration is within the limits in most of the localities except HCU, Sanathnagar, Zoo Park and Pashamylaram Areas. PM_{10} concentration is much higher than the WHO prescribed values of the order of 3 to 8 times which is highly alarming. Identifying which localities are within limits and which crossed limits is much easier using GIS when compared to conventional systems.

A. Kumar et al (2016)

Mumbai, which is an extremely populated city in India, has been selected for air quality mapping and assessment of health impact using monitored air quality data. National Environment Engineering Research Institute (NEERI), Maharashtra Pollution Control Board (MPCB), and Brihanmumbai Municipal Corporation (BMC) operate the air quality monitoring networks in Mumbai. Spatial variation is required for air quality management which uses data from monitoring stations.

One of the objects of this work was to estimate temporal and spatial variation of air pollution over the city of Mumbai. Air pollutant concentration data for SO_2, NO_2, and SPM were collected for the entire year of 2012 from air quality monitoring network system. These monitoring stations are operated continuously by Brihanmumbai Municipal Corporation (BMC), NEERI and Maharashtra Pollution Control Board (MPCB) in Mumbai city. The data obtained from NEERI and BMC were used to interpolate and compare with the data acquired from MPCB, as the temporal resolution of sample collection of MPCB is different from that of NEERI and BMC. Annual averages of air pollution data were calculated for all the locations using IDW, Kriging, and spline techniques. IDW has been used with power (p) value 2 and the regularized spline technique has been used with 0.1 weights. Spherical and Gaussian semi-variograms have been used

in the ordinary Kriging method. The interpolated results were compared with the data obtained from MPCB. This comparison displayed good agreement for resultant values from IDW and Kriging with observed data. The interpolated resultant that matched best with the observed concentrations were further used in cost estimation of health for each ward.

Finally, on the basis of exposed population health cost within a ward was projected. This study aids to predict the valuation of health damage due to air pollution for the year 2012. The number of cases of the health effect per year is then determined by multiplying the incidence rate with the corresponding population of the ward. Thus, cost was estimated for health damage due to air pollution for the Mumbai city. In order to understand the health impact due to air pollution, concentration response (CR) coefficients were used along with annual average concentrations for respective pollutants and population of particular ward. Cost was estimated for the total exposed population for the study of health damage. The health impact assessment was carried out using the following equation:

$$\Delta H_{jp} = b_{jp} * POP_i * \Delta AQ_p$$

where ΔHjp is the change in health impact j due to pollutant p, bjp is the CR coefficient for health effect j related to pollutant p, $POPi$ is population of the particular region of the city, and ΔAQp is change in the concentration of pollutant p.

The variations of pollutants were seen on seasonal and annual basis. SPM concentrations were always higher while SO_2 and NO_2 concentrations were less compared to the NAAQ standards. For seasonal variations, December, January, and February were considered the winter season; March, April, and May the pre monsoon season; June, July, August, and September were the monsoon season; and October and November comprised the post monsoon season. The maximum concentrations of all pollutants were observed in the winter season, while the minimum concentrations were observed in the monsoon season, which is as expected. The pre monsoon season has lower concentration than the post monsoon season for SO_2 and NO_2, while the pre monsoon has higher concentration than the post monsoon season for SPM.

From the interpolation study it is observed that IDW, Kriging spherical, and Kriging Gaussian techniques gave better interpolation than regularised spline technique. The

interpolated values by Kriging spherical and Kriging Gaussian were found very close to observed data. In most of the cases, IDW and Kriging performed better than the spline method. However, kriging performed best among all these interpolation techniques. Under health benefit estimates, the results direct huge health benefits if air pollution levels, particularly of PM_{10}, are capped down to the background level. Due to PM_{10}, COPD and allergic rhinitis have an equal impact on population at each location of Mumbai city. Total cost of health damage due to NO_2 and PM_{10} was estimated as USD8000 million (nearly 509 billion INR) for Mumbai city for the year 2012, which is 4.24% of GDP of Maharashtra state.

Aman Tyagi & Preetvanti Singh (2013)

In the present study, an effort has been made to map the pollution areas of Agra and forecast the pollution at unsampled location. For this, thirty places of Agra are selected for collection of air samples. Geographic Information System (GIS) and Kriging (Ordinary Kriging) approach is used to indicate the polluted and unpolluted areas in Agra (Dayalbagh) region. GIS tools play an important role in pollution detection methodology. Ordinary Kriging used here is an interpolation technique. The semi variogram is plotted to show the relation between lag distance and semi variance. The Ordinary Kriging is used to fill the map with different colours. Each colour correlates to different value of air pollution. Spatial Analysis and Decision Assistance (SADA) GIS software is used in the present work for the forecasting the pollutant levels at the location where sample is not taken.

Air pollutant concentrations were sampled at thirty places in various regions of Dayalbagh, Agra. In this program, some Polycyclic Aromatic Hydrocarbons (PAHS) samples are taken at sample points in Dayalbagh, Agra region. The analysis is done utilising Gas chromatography–mass spectrometry. In the present work Excel spreadsheet is used to insert data values in SADA in a tabular format. After this importing process is completed, the SADA software automatically portrays the sample points on the map. These places are marked as point on the map. At these points the value of air pollution is taken. The value of air pollution is in the range of 0 to 50 corresponding from no air pollution to higher air pollution. Red colour shows the higher air pollution (50) and purple colour shows no air pollution (0) and different colours show the values between 0 and 50.

Semi variogram is needed before applying kriging on the graph. In Semi variogram Lag number, Lag distance, Lag tol, Angle, Tol and Bandwidth are the required parameters. For the present work, Gaussian model is selected. After completing semi variogram, one can apply kriging. When Kriging is applied on the map, according to sample values the map will be filled with different colours. The red colour shows the highly polluted area while purple colour indicates no pollution area. There are different colours between red and purple. Each colour corresponds to different value of air pollution. This study demonstrates that if sample pollutant data for monitoring locations is available then kriging may be applied on them to determine and closely predict the pollutant values at unmonitored locations. The map is made to show polluted and unpolluted areas.

Sh. Rahmatizadeh (2004)

This paper puts forward the process of design and development of a customized temporal GIS for environmental management. A number of spatial and statistical analyses have been performed using hourly, daily and monthly data acquired from 7 air quality monitoring stations located in Tehran. This research has considered spatial correlation and distribution factors and their impact on environmental pollution. The initial results of the analysis disclosed that the developed customized system can be efficiently used in monitoring and managing different pollutants as an environmental decision support system (EDSS). Thus, geographical information systems (GIS) can be used as management and supporting systems and allow us to integrate and analyse various environmental data from different sources to model the overall impact of air pollutants on environment.

In this research, the monitored environmental data was collected from seven stations in Tehran for the year 2002. The accuracy of this data was evaluated using statistical analysis. To detect and remove errors in the recorded data, the specific domain of each pollutant was to be known. Accuracy of instrument in observation, records and transmission affect the data quality. Other parameter affecting data quality were also to be determined. The data was structured and stored in the temporal database. Tehran's digital map at a scale of 1:2000 was uploaded and topologically structured using ArcView and Arc Info GIS software. The location of stations on the map was determined. Attribute data were assigned to spatial objects and the system became ready for spatial-temporal analysis and management. The data from air pollution monitoring stations in Tehran in 2002 was

stored in Excel sheet. Then pollutant standard index (PSI) was calculated on daily, monthly and yearly basis by programming. Visual Basic was used for this purpose as discuss in [Rahmatizadeh, 2003]. Database was incorporated to the digital map. Spatial Analysis module was used for interpolation in three dimensions. Inverse distance interpolation is used for modelling for the area between the monitoring stations. This technique considers weighted moving average. Weights are calculated from a linear function of distance between sets of points and the points to be predicted.

For the air pollution monitoring stations in Tehran, a Voronoi diagram has been generated to demonstrate the spatial dispersion of the pollutants at the stations and their influenced area. The air pollution problems instigating from the various sources can be controlled by the development of such air quality management system. The seasonal air pollution surfaces are widely useful for purposes such as health risk assessment of the population within the study area, establishing and monitoring air quality standards, and evaluation of transport policies.

Thakur, Orient. J. Chem (2017)

The study area is Bengaluru which is a city in India and has grown in size and population lately due to growth of IT industry. This rapid growth and related civic activity have affected the ecology of the city. The objective of this study is to identify air pollution trend in Bengaluru and study the factors which contribute towards it. The data obtained from state pollution control board website has been used without any modification for analysis. Three criteria pollutants sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and respirable suspended particulate matter (PM_{10}) have been inspected for air quality analysis as they are measured regularly and for longest period of time.

The urban area of Bengaluru has grown by 466% and decadal population growth by 51.39% in the past few decades by occupying nearby villages and illegal conversion of the green belt area. Aim of this paper is to understand the changes in air quality in the past decade and the factors causing changes. Air pollutants in the city are measured under National Ambient Air Quality Program (NAMP) by monitoring stations on a regular basis. KSPCB publishes annual average of pollutants Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and respirable suspended particulate matter with diameters less than 10mm (PM_{10}

or RSPM). The Exceedance Factor (EF) has been calculated using this data for six monitoring stations. These stations represent mixed urban and industrial and sensitive area.

$$\text{EF} = \frac{\text{Observed Annual Mean of Criteria Pollutants}}{\text{Annual Standard for Respective Pollutant}}$$

Air quality can be low, moderate, high or critical based on the following criteria:

• Critical pollution (C): EF > 1.5

• High pollution (H): EF ϵ [1.0 - 1.5]

• Moderate pollution (M): EF ϵ [0.5- 1.0]

• Low pollution (L): EF < [0.5- 1.0]

Using the available data, the variations in SO_2, NO_2 and PM_{10} are obtained for the period 2006 – 2015 in the form of graphs. These graphs display a decrease in sulphur dioxide levels for all monitoring stations since 2006. SO_2 level has always been lower than the NAAQ value of 50 $\mu g/m^3$ for all the stations under study. The Exceedance Factor has been found to be under 0.5, which reflects low level of SO_2 in the air. In the sensitive area, EF for SO_2 ranges between 0.56 to 0.805 indicating moderate pollution level since the NAAQ value for SO_2 for a sensitive area is low i.e., 20 $\mu g/m^3$.

On the other hand, the NO_2 level is relatively higher and has shown an increasing trend during the study period. Data indicates that the NO_2 level is still under limit with Exceedance Factor (EF) under moderate category for all the monitoring stations. The concentration of RSPM (respirable suspended particulate matter) has been increasing during the study period. There is no regular pattern but for majority monitoring stations its concentration has crossed the standard of 60 $\mu g/m^3$. The data indicates that the air quality in Bengaluru is within acceptable limits set by CPCB but there is an alarming trend for NO_2 and RSPM.

According to Air quality assessment, emission inventory and source apportionment study conducted by Tata Energy Research Institute in 2010, road dust re-suspension and vehicular emission are the major contributors of RSPM load in the air. Also, NO_2 emission is due to emission from vehicle while SO_2 due to DG (diesel generator) sets and vehicle movement. Bengaluru has shown 101.34% increase vehicular population since 2006 to

2014 with 5.56 million registered vehicles in 2015. Vehicles not only emit the above-mentioned criteria pollutants but also other pollutants. Emission of RSPM, hydrocarbon (HC) and carbon monoxide (CO) from two stroke Petrol engine driven two and three wheelers is 29%, 73% and 42% respectively. This fact suggests that the concentration of hydrocarbon and carbon monoxide in air is higher as 69%.

Exhaust from diesel engines contribute more than 50% of RSPM (PM_{10}). Its contribution towards fine particulate matter with a diameter below 2.5 mm ($PM_{2.5}$) and ultra-fine particles with a diameter below 0.1 mm, is even higher. The increasing trend in NO_2 can be correlated with the diesel consumption trend. The observed declining trend in SO_2 level can be credited to adoption of Bharat Stage IV norms which are equivalent to Euro IV standards. Implementation of Bharat Stage IV norms has also helped in maintaining NO_2 level as the catalytic converters in vehicles which are responsible for converting NO_2 to N_2 and O_2 work efficiently in presence of low sulphur fuel.

Trend in RSPM is irregular and there are spurts of rise in its concentration for specific monitoring locations at specific time which might be caused by construction activity. High concentration of RSPM level due to construction activity can be managed if proper care is taken during construction.

CHAPTER-3

MATERIALS AND METHODS

3.1 Study Area

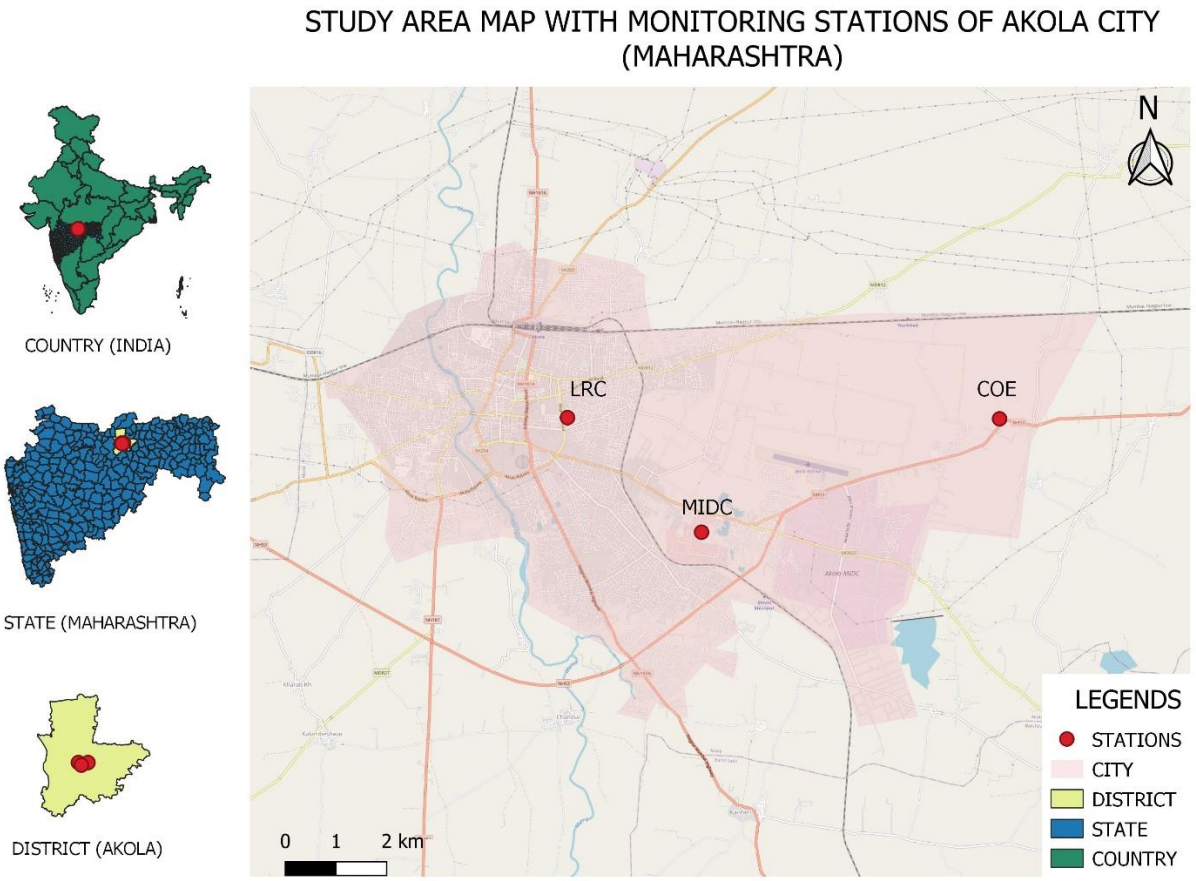


Figure 3.1 Study area map of Akola

The study area chosen for the project is the city of Akola situated north-central of state of Maharashtra, western India on the banks of Morna river. The city of Akola is located at latitude 20.7ºN and longitude 77.07ºE and at an altitude of 287 to 316 m above mean sea level. Akola city has an urban population of nearly 5.37 lakhs with an average population density of 4200 per sq.km. The city experiences a tropical savanna climate and lies near Tropic of Cancer, thus becoming very hot during the summer season. Annual temperatures vary from a high of 47.6 ºC to a low of 2.2 ºC. The annual average rainfall is 800 mm.

Akola is an important city for its history, culture, politics and agriculture. It has an important educational and commercial centre. The city is developing into a market centre. It has four prominent industrial zones in the outskirts of the city. There are nearly 25 factories currently located in these industrial zones while 10 factories are under construction. However, the economy is agriculture-based with cotton and jowar as the predominant crops in the district of Akola. Since Akola is a developing city with rising industrialisation and urbanisation, the aim of the project is analysis of its changing air quality status and trends in pollutant concentrations.

3.2 Air Quality Monitoring

The Central Pollution Control Board (CPCB) has set National Ambient Air Quality Standards (NAAQS) for various pollutants. These pollutants need to be monitored regularly according to the monitoring frequency stated by CPCB. To accomplish this purpose, the National Air Quality Monitoring Programme (NAMP) was initiated. Under this programme, a nationwide Ambient air quality monitoring network has been planned and established to assess spatial and temporal variations of ambient air concentrations for criteria pollutants like – Sulphur Dioxide, Oxides of nitrogen, Carbon monoxide, Particulate matter and secondary pollutants like Ozone. The monitoring results help in assessment of the level of air pollution with respect to the NAAQS and evolving a strategic management plan. The monitoring of pollutants is carried out for 24 hours (4-hourly sampling for gaseous and 8-hourly sampling for particulate matter) twice a week, to have total one hundred and four (104) observations annually. The data obtained is used to calculate the Air Quality Index (AQI) which is a comprehensive and easy way to represent the air quality status.

. Under the NAMP programme, the state of Maharashtra has active 84 ambient air quality monitoring stations set up across the different regions of the state, to provide a complete picture of air quality. Out of the total active AAQMS, 23 are Continuous Ambient Air Quality Monitoring Stations (CAAQMS), 60 are under NAMP and remaining 1 is under SAMP.

Three NAMP air quality monitoring stations are established in the city of Akola and are actively operating. The details of these monitoring stations are as follows:

Table 3.1: Monitoring Stations in Akola City

S. No.	Name of Station	Location	Notation	Type	Frequency
01	College of Engineering and Technology	Babhulgaon, Akola	**COE**	Commercial area	Two days in a week
02	L R College of Engineering	Ranpise Nagar, Akola	**LRC**	Residential area	Two days in a week
03	MIDC Water Works	MIDC Phase II, MIDC, Akola	**MIDC**	Industrial area	Two days in a week

The data collected at these monitoring stations has been obtained for this project over the years 2012 to 2020 from the official website of MPCB. This has data on primary pollutants such as SO_2, NOx, RSPM, SPM and Air Quality Index (AQI).

3.3 Sampling of Pollutants

3.3.1 Sampling and Analysis of SO_2: Modified West & Gaeke Method

IS 5182 (Part 2): 2001 prescribes the methods for the measurement of concentration of sulphur dioxide present in the atmosphere. Concentrations of sulphur dioxide in the range of 25 to 1050 $\mu g/m^3$ can be measured using this method. Concentrations below 25 μm^3 can be measured by sampling larger volumes of air.

Principle of the method:

Sulphur dioxide from air is absorbed in a solution of potassium tetrachloromercurate (TCM). A dichlorosulphitomercurate complex, which resists oxidation by the oxygen in the air, is formed. Once formed, this complex is stable to strong oxidants such as ozone and oxides of nitrogen and therefore, the absorber solution may be stored for some time prior to analysis. The complex is made to react with para-rosaniline and formaldehyde to form the intensely coloured pararosaniline methylsulphonic acid. The absorbance of the solution is measured by means of a suitable spectrophotometer.

Reagents:

1. Distilled Water free from oxidants
2. Potassium Tetrachloromercurate (TCM) - 0.04M with pH range 3 to 5
3. Fresh Sulphamic Acid - 0.6 percent
4. Fresh Formaldehyde - 0.2 percent approx.
5. Stock Iodine Solution - 0.1 N
6. Iodine Solution - 0.01 N
7. Starch Indicator Solution
8. Stock Sodium Thiosulphate Solution - 0.1 N
9. Sodium Thiosulphate Titrant - 0.01 N
10. Standardized Sulphite Solution for Preparation of Working Sulphite— TCM Solution
11. Working Sulphite — TCM Solution
12. Purified Para Rosaniline Stock Solution —0.2 percent concentration

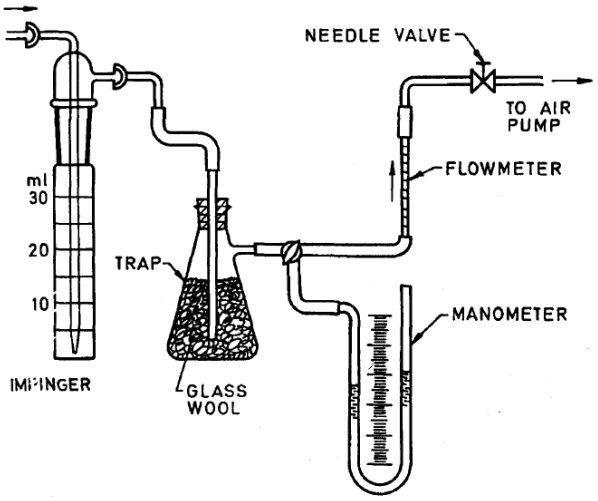


Figure 3.2 Sampling Train for SO_2

Apparatus:

The following items are necessary to perform the monitoring and analysis of sulphur dioxide in ambient air:

1. Absorbers acceptable for concentrations above 3 $\mu g/m^3$
2. Polypropylene Two-port Closures
3. Glass Impingers

4. Polypropylene tubes having a dimension of 164mm x 32 mm
5. Pump capable of maintaining an air pressure differential greater than 0.7 atm
6. Air Flowmeter of Critical Orifice
7. A spectrophotometer suitable for measurement of absorbance at 560 nm with art effective spectral band width of not more than 8 nm

Sampling:

Place 30 ml of absorbing solution in an impinger and sample for four hours at the flow rate of 1 L/min. After sampling measure the volume of sample and transfer to a sample storage bottle.

Procedure for measurement of SO_2:

1. Place 30 ml of absorbing media in an impinger.
2. Connect it to the gas-sampling manifold of gas sampling device (RDS/HVS).
3. Draw air at a sampling rate of 1 lpm for four hours.
4. Check the volume of sample at the end of sampling and record it.
5. Transfer the exposed samples in storage bottle and preserve.
6. Prepare calibration graph as recommended in method.
7. Take 10/20 ml. aliquot of sample in 25 ml. Vol. Flask.
8. Take 10/20 ml. of unexposed sample in 25 ml. Vol. Flask (blank).
9. Add 1 ml Sulphamic acid. Keep it 10 minutes.
10. Add 2 ml formaldehyde.
11. Add 2 ml working PRA.
12. Make up to mark (25 ml.) with distilled water.
13. Keep it 30 minutes for reaction.
14. Set Zero of spectrophotometer with Distilled water.
15. Measure absorbance at 560 nm.
16. Calculate concentration using calibration graph.
17. Calculate concentration of Sulphur dioxide in $\mu g/m^3$.

3.3.2 Sampling and Analysis of NO_2: Modified Jacob and Hochheiser Method

IS 5182 (Part 6): 2006 prescribes the methods for the measurement of concentration of nitrogen dioxide in ambient air.

The nominal range of the method is 6 to 750 $\mu g\ NO_2\ /m^3$.

Principle of the method:

Ambient nitrogen dioxide (NO_2) is collected by bubbling air through a solution of sodium hydroxide and sodium arsenite. The concentration of nitrite ion (NO_2) produced during sampling is determined colorimetrically by reacting the nitrite ion with phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDA) and measuring the absorbance of the highly coloured azo-dye at 540 nm.

Reagents:

All the chemicals should meet specifications of ACS Analytical Reagent grade.

1. Distilled water
2. Sodium hydroxide
3. Sodium Arsenite
4. Absorbing solution (Dissolve 4.0 g of sodium hydroxide in distilled water, add 1.0 g of sodium Arsenite, and dilute to 1,000 ml with distilled water)
5. Sulphanilamide - Melting point 165 to 167ºC
6. N-(1-Naphthyl)-ethylenediamine Di-hydrochloride (NEDA)
7. Hydrogen Peroxide - 30%
8. Phosphoric Acid - 85%
9. Sulphanilamide Solution
10. NEDA Solution - Dissolve 0.5 g of NEDA in 500 ml of distilled water.
11. Hydrogen Peroxide Solution - Dilute 0.2 ml of 30% hydrogen peroxide to 250 ml with distilled water.
12. Sodium nitrite - Assay of 97% $NaNO_2$ or greater
13. Sodium Nitrite stock solution (1000 µg NO_2 /ml)
14. Sodium Nitrite solution (10 µg NO_2 /ml)
15. Sodium Nitrite working solution (1 µg NO_2 /ml) (Dilute with absorbing reagent)

Apparatus:

The following items are necessary to perform the monitoring and analysis of nitrogen dioxide in ambient air:

1. Analytical balance

2. Vacuum pump: Capable of maintaining a vacuum of at least 0.6 atmospheres across the flow control device.
3. Calibrated flow measuring device: To control the airflow from 0.2 to 1 l/min
4. Absorber: a midget impinger
5. Spectrophotometer: Capable of measuring absorbance at 540 nm equipped with 1 cm path length cells.
6. Glass wares: low actinic glassware must be used for analysis

Sampling:

Place 30 ml of absorbing solution in an impinger and sample for four hours at the flow rate of 0.2 to 1 L/min. After sampling measure the volume of sample and transfer to a sample storage bottle.

Procedure for measurement of NO_2:

1. Place 30 ml of absorbing media in an impinger.
2. Connect it to the gas sampling manifold of gas sampling device (RDS/HVS).
3. Draw air at a sampling rate of 1 lpm for four hours.
4. Check the volume of sample at the end of sampling and record it.
5. Transfer the exposed samples in storage bottle and preserve.
6. Prepare calibration graph as recommended in method.
7. Take 10 ml. aliquot of sample in 50 ml. Vol. Flask.
8. Take 10 ml. of unexposed sample in 50 ml. Vol. Flask (blank).
9. Add 1 ml hydrogen peroxide, 10 ml sulphanilamide and 1.4 ml NEDA.
10. Make up to mark (50 ml.) with distilled water and keep it 10 minutes for reaction.
11. Set zero of spectrophotometer with distilled water and measure absorbance at 540 nm.
12. Calculate concentration using calibration graph.
13. Calculate concentration of Nitrogen dioxide in $\mu g/m^3$.

3.3.3 Sampling and Analysis of Particulate Matter (PM_{10}): Gravimetric Method

IS 5182 (part 23): 2006 prescribes the methods for the monitoring and analysis of particulate matter PM_{10} in ambient air.

Principle of the method:

Air is drawn through a size-selective inlet and through a 20.3 X 25.4 cm (8 X 10 in) filter at a flow rate, which is typically 1132 L/min. Particles with aerodynamic diameter less than the cut-point of the inlet are collected, by the filter. The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of PM in the designated size range is calculated by dividing the weight 10 gain of the filter by the volume of air sampled.

Reagents / Chemicals:

Filter Media - A Glass fibre filter of 20.3 X 25.4 cm (8 X 10 in) size

Sampling:

Field Sampling - Tilt back the inlet and secure it according to manufacturer's instructions. Loosen the faceplate wing nuts and remove the faceplate. Remove the filter from its jacket and centre it on the support screen with the rough side of the filter facing upwards. Replace the faceplate and tighten the wing nuts to secure the rubber gasket against the filter edge. Gently lower the inlet. For automatically flow controlled units, record the designated flow rate on the data sheet. Record the reading of the elapsed time meter. The specified length of sampling is commonly 8 hours or 24 hours. During this period, several reading (hourly) of flow rate should be taken. After the required time of sampling, record the flow meter reading, take out the filter media from the sampler, and put in a container or envelope.

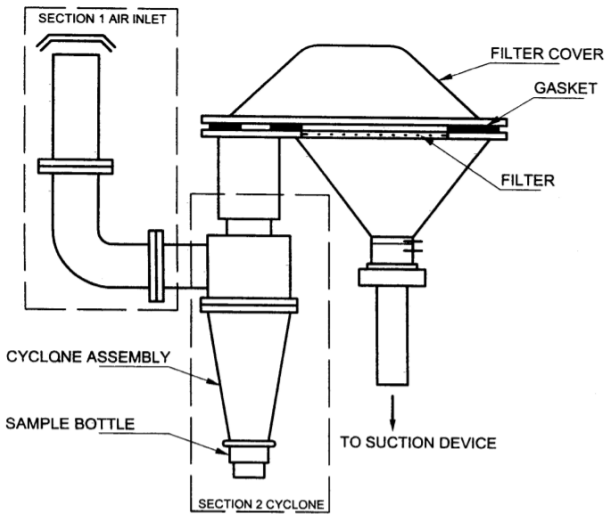


Figure 3.3 A Typical Schematic Sampler for RSPM

Procedure for measurement of PM_{10}:

1. Check the filter for any physical damages.
2. Mark identification number on the filter.
3. Condition the filter in conditioning room / desiccator for 24 hours.
4. Record initial weight.
5. Place the filter on the sampler.
6. Run the sampler for eight hours.
7. Record the flow rate on hourly basis.
8. Remove the filter from the sampler.
9. Keep the exposed filter in a proper container.
10. Record the total time of sampling & average flow rate.
11. Again, condition the filter in conditioning room / desiccator for 24 hours.
12. Record final weight.
13. Calculate the concentration of PM_{10} in $\mu g/m^3$.

3.4 Exceedance Factor

Exceedance factor (EF) is the criterion by which the NAMP (National ambient monitoring programme) categorizes current air quality conditions. As per the guidelines given by CPCB, Exceedance factor is the proportion of the annual average concentration of a pollutant and its particular standard.

$$EF = \frac{\text{Observed Annual Average of Criteria Pollutants}}{\text{Annual Standard for Respective Pollutant}}$$

It is an important tool helpful to indicate the pollution level due to a particular pollutant.

Table 3.2: Exceedance factor criteria

S. no.	Exceedance factor range	Pollution level
1	Greater than 1.5	Critical Pollution
2	1 to 1.5	High Pollution
3	0.5 to 1	Moderate Pollution
4	Less than 0.5	Low Pollution

3.5 Wind Rose Diagram

The wind rose is a traditional and well-established method of representing the wind conditions such as wind direction and wind speed, over a period of time at a specific location. A wind rose can be defined as, “Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location, over a considerable period”. Interpretation of a wind rose diagram gives the prevailing direction of wind.

The most common form consists of a circle from which eight or sixteen lines emerge, one for each direction. The length of each line is proportional to the frequency of wind from that direction and the frequency of calm conditions is entered in the centre. The wind rose diagram is prepared using an appropriate scale to represent percentage frequencies of wind directions and appropriate index shades, lines etc., to represent various wind speeds. Observations corresponding to wind speed below 1 km/h are recorded as calm.

Wind roses may be constructed from the data obtained over a given time period such as a particular month or season or a year. In constructing or interpreting wind roses, it is necessary to keep in mind the meteorological convention that wind direction refers to the direction from which the wind is blowing. A line or bar extending to the north on the wind rose indicates the frequency of winds blowing from the north.

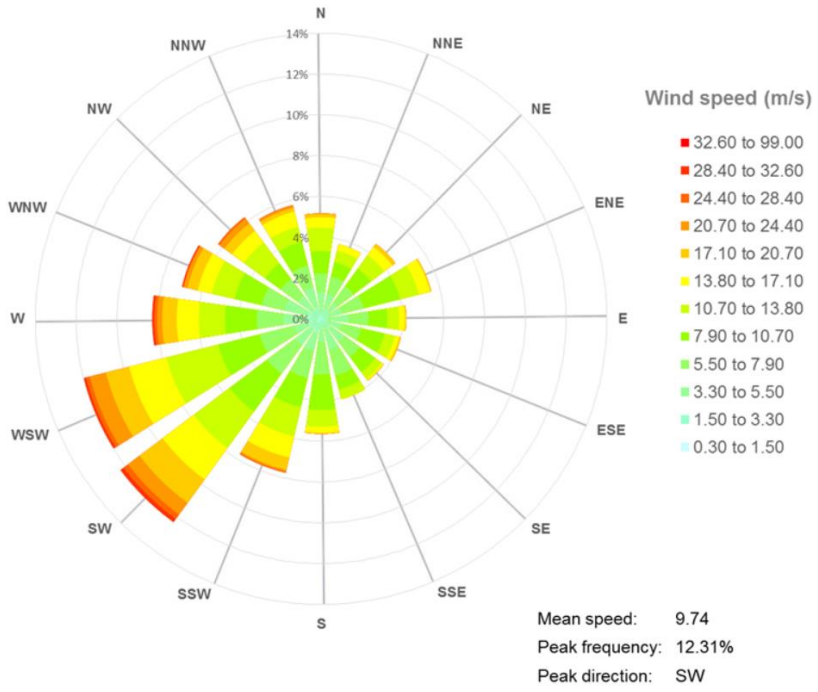


Figure 3.4 Sample Wind Rose Diagram

There are many variations in the construction of wind roses. Some indicate the range of wind speeds from each direction, and some relate wind direction with other meteorological conditions. Instead of wind speed the parameters of precipitation, smoke, sulphur dioxide, hydro carbons etc. are attached to the wind direction. These are known as 'Pollution Roses'. Special wind roses are sometimes constructed like precipitation wind rose, smoke wind rose, sulphur dioxide wind rose, hydrocarbons wind rose and more.

3.6 Air Quality Index (AQI)

Air Quality Index (AQI) is a comprehensive index value calculated by transforming weighted values of impacts of individual air pollutants (e.g., SO_2, CO, NOx,) into a single number or set of numbers. It reflects air quality of an area in terms of health impacts on the population. Thus, this makes it is an easy-to-understand parameter of air quality and can be communicated to the masses and used by decision makers for devising programs and policies on air pollution abatement. The standard AQI values in India are based on health breakpoints for the following eight pollutants- CO, NO_2, SO_2, PM_{10}, $PM_{2.5}$, O_3, Pb and NH_3.

AQI has diverse uses and applications for policy makers, researchers and the public. It is a key tool in air quality monitoring and regulation. Some of the applications of AQI are listed below:

- Resource allocation for controlling air pollution
- Ranking of locations based on potential risks of air pollution
- Enforcement of measures to improve air quality or maintain existing good conditions
- Analysis of trends in air quality of an area and devising suitable policy interventions
- Informing the public about the air quality and its possible health impacts, especially for sensitive individuals with underlying health issues
- Scientific research on air quality, source apportionment and environmental health

Calculation of AQI:

AQI is calculated using the AQ sub index and the health breakpoints which are evolved for eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb) for which

short-term (up to 24-hours) are prescribed by NAAQS. Based on the measured ambient concentrations of a pollutant, sub-index is calculated, which is a linear function of concentration (e.g., the sub-index for $PM_{2.5}$ will be 51 at concentration 31µg/m^3, 100 at concentration 60µg/m^3, and 75 at concentration of 45µg/m^3). The worst sub-index determines the overall AQI. The sub-indices for individual pollutants at a monitoring location are calculated using its 24-hourly average concentration value (8-hourly in case of CO and O_3) and health breakpoint concentration range given in the table below.

Table 3.3: Sub-Index and Break point pollutant concentration for Indian AQI

(units: µg/m^3 unless mentioned otherwise)

AQI Category (Range)	PM10 24-hr	PM2.5 24-hr	NO2 24-hr	O3 8-hr	CO 8-hr (mg/ m3)	SO2 24-hr	NH3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5 –1.0
Moderate (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} * (C - C_{low}) + I_{low}$$

where, I: Air Quality Index

C: the pollutant concentration

C_{low}: the concentration breakpoint that is ≤ C

C_{high}: the concentration breakpoint that is ≥ C

I_{low}: the index breakpoint corresponding to C_{low}

I_{high}: the index breakpoint corresponding to C_{high}

Overall AQI is calculated only if data are available for minimum three pollutants out of which one should necessarily be either $PM_{2.5}$ or PM_{10}. Else, data are considered

insufficient for calculating AQI. Similarly, a minimum of 16 hours' data is considered necessary for calculating sub index. The sub-indices for monitored pollutants are calculated and disseminated, even if data are inadequate for determining AQI. The Individual pollutant-wise sub-index will provide air quality status for that pollutant. The worst sub-index is the AQI for that location.

Table 3.4: Indian Air Quality Index Category and Range

AQI Range	AQI Category
0 - 50	Good
51 - 100	Satisfactory
101 - 200	Moderate
201 - 300	Poor
301 - 400	Very Poor
401 - 500	Severe

3.7 Regression analysis

In statistical modelling, regression analysis is a set of statistical processes for estimating the relationships among variables. It includes many techniques for modelling and analysing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). More specifically, regression analysis helps one to understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed.

Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables – that is, the average value of the dependent variable when the independent variables are fixed. Less commonly, the focus is on a quantile, or other location parameter of the conditional distribution of the dependent variable given the independent variables. In all cases, a function of the independent variables called the regression function is to be estimated.

Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. In restricted circumstances, regression analysis can be used to infer causal relationships between the independent and dependent variables. However, this can lead to illusions or false relationships, so caution is advisable.

Many techniques for carrying out regression analysis have been developed. Familiar methods such as linear regression and ordinary least squares regression. The performance of regression analysis methods in practice depends on the form of the data generating process, and how it relates to the regression approach being used. Since the true form of the data-generating process is generally not known, regression analysis often depends to some extent on making assumptions about this process. Regression models for prediction are often useful even when the assumptions are moderately violated, although they may not perform optimally.

3.7.1 Linear Regression

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory (independent) variable, and the other is considered to be a dependent variable. Before attempting to fit a linear model to observed data, a modeler should first determine whether or not there is a relationship between the variables of interest. This does not necessarily imply that one variable causes the other, but that there is some significant association between the two variables.

A scatterplot can be a helpful tool in determining the strength of the relationship between two variables. If there appears to be no association between the proposed explanatory and dependent variables (i.e., the scatterplot does not indicate any increasing or decreasing trends), then fitting a linear regression model to the data probably will not provide a useful model.

A linear regression line has an equation of the form: **Y = a + bX,** where X is the explanatory variable and Y is the dependent variable. The slope of the line is b, and a is the intercept (the value of Y when X = 0).

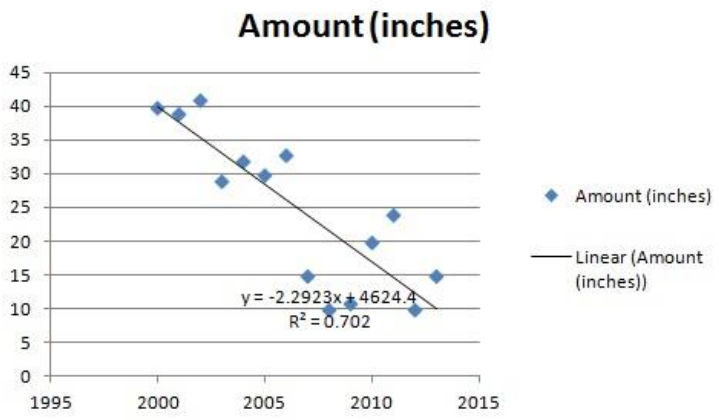


Figure 3.5 Sample Linear Regression Model

A valuable numerical measure of association between two variables is the correlation coefficient, which has a value between -1 and 1 indicating the strength of the association of the observed data for the two variables. Correlation coefficient formulas are used to find how strong a relationship is in between data. The formulas return a value between -1 and 1, where:

- r = 1 indicates a strong positive relationship.
- r = -1 indicates a strong negative relationship.
- A result of r = 0 indicates no relationship at all.

The absolute value of the correlation coefficient gives us the relationship strength. The larger the number, the stronger the relationship. A positive correlation of r = 1.0 would means the line's slope would is at 45 degrees upward, and a negative correlation of r = -1, is at 45 degrees downward. If correlation, r = 0 with a horizontal line, there is no correlation. The correlation approaching +1 is said to be positively correlated, as one variable increases, the other variable increases. A correlation approaching -1 is negatively correlated, and opposite of the positive correlation.

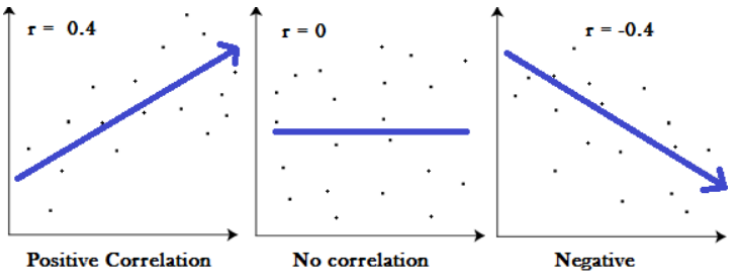


Figure 3.6 Correlation coefficient and relationship

Pearson's correlation coefficient: **Pearson's *r***

Correlation coefficients are used to measure how strong a relationship is between two variables. There are several types of correlation coefficient, but the most popular is Pearson's correlation coefficient is a correlation coefficient commonly used in linear regression. The full name is the Pearson Product Moment Correlation (PPMC). It shows the linear relationship between two sets of data. Manually, it can be calculated using the formula:

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[\, n\Sigma x^2 - (\Sigma x)^2 \,][\, n\Sigma y^2 - (\Sigma y)^2 \,]}}$$

3.7.2 Correlation between meteorological parameters and pollutants

Linear regression has been used to establish correlation between pollutant levels and prevailing meteorological conditions using Microsoft Excel. Meteorological data has been obtained from weather archives of Akola. The effects of increase in some meteorological parameters on pollutants and their concentrations can be explained as below:

- **Wind:**

  Wind is responsible for the dilution/dispersion of the pollutants. Horizontal dilution / dispersion is mainly due to horizontal wind movement, depends on speed and direction.

- **Atmospheric stability:**

  Atmospheric stability is the term applied to the condition of the atmosphere that affects the vertical motions of the air parcels. When the temperature decreases with height at the rate less than the adiabatic or when temperature increases with height (temperature inversion), vertical motions are damped and the atmosphere is called stable. Intensity of the turbulence and therefore the atmospheric diffusion of pollutants increases with instability of the atmosphere.

- **Precipitation:**

  Falling drops of precipitation (rain and snow) pick up particulate matter and soluble gases, vapours and mists in their path. This leads to depletion of pollutants from the atmosphere.

- **Humidity:**

  High humidity leads to fog formation and also it obstructs radiation from sun and reflects back to sky. Humidity accelerates some chemical reaction and corrosion rate. It also leads to cloud formation and ultimately to the rain.

- **Temperature:**

  It accelerates pollutants reaction with atmosphere (warmer the air, it contains more water, reacts with SO_2 to form H_2SO_4, hence acid rains). It affects wind movement in both directions (upward and downward). 50% increase in particulate matter causes 1^oC rise in temperature and more wind movement.

- **Solar radiation:**

  Sunlight is a portion of the electromagnetic radiation given off by the Sun, in particular infrared, visible, and ultraviolet light. The ultraviolet radiation in sunlight has both positive and negative health effects, as it is both a requisite for vitamin D3 synthesis and a mutagen. But it also plays an important role in formation of ozone and photochemical smog (secondary pollutants).

- **Atmospheric pressure:**

  High atmospheric pressure produces inversion condition (anticyclones). Lower atmospheric pressure (cyclones) is good for rapid mixing and dispersion of pollutants in the surrounding atmosphere. This condition of lower pressure results in unstable atmosphere.

3.8 Role of GIS in Air Quality Analysis

The employment of technological developments is found to be one of the most important remedial measures to deal with the increased risk to human health due to road transport. The invention of hybrid car technology and alternative sources of cleaner fuel appear to be boon in reducing the emissions level. However, strict exhaust emission legislation for all vehicles can be highly effective in reducing the road transport related hazardous air pollutants. Technological advancements alone cannot be adequate enough to reduce the effects of transport related health problems. Hence integrated planning is needed in the form of simulation or modelling using sophisticated computer technologies.

The sources of air pollution are generally multiple and depend not only upon the geography of the location under study but also changing meteorological conditions and climate. In urban areas, the major sources of air pollution are transportation, power

generation, commercial and residential activities and industry. With the rising number of vehicles on the roads, the situation is becoming serious for human health. Air pollution easily surpasses political or administrative boundaries. In the scenario of industrial air pollution, trans-boundary pollution is a common problem when the source is proximal to another state.

The application of Geographic Information System (GIS) technology is very powerful in decision support. It is a tool that can help reduce decision making time, for example, with transport related human health problems, by conducting spatial analysis for the evolution of a suitable methodology and modelling. In recent years, there has been an increasing amount of literature on awareness of health hazards caused by air pollution. There has been also an increasing demand for visualization of spatial data to identify the areas of greatest potential threat. According to Knowles and Hillier (2008), GIS functions go beyond what maps or databases alone can do; GIS is intrinsically capable of answering descriptive questions of What? Where? When? How big or how much? GIS can reveal patterns that would otherwise escape attention. In more advanced practice, GIS can resolve conditional queries such as “what if” and pose multivariate scenarios.

Geographic Information Systems (GIS) is an essential scientific tool for health data processing, analysis of geographical distribution and variation of diseases, mapping, monitoring and management of health epidemics (Johnson and Johnson, 2001). Medical geographical investigations are largely based on the following three complementary groups of models:

- environmental or ecological models of epidemiology that explain the occurrence or incidence of diseases on the basis of environmental associations and causations.
- spatio-temporal models that explain spatial processes, and the implications of space-distance-time involved in the spread and flow patterns of diseases.
- behavioural models of epidemiology that explain the behaviours involved in the vector-host-agent relations in the occurrence, persistence and spread of diseases.

The application of Geographical Information Systems (GIS) software in the mapping and visualisation of the results of the study is also a demonstration of the diffusion of the innovation of GIS technology. Geographic Information Systems (GIS) has the capability to link several databases such as demographic, clinical, and billing systems, and generate

a high-resolution display of the spatial distribution and behaviours of events. GIS generates a high-resolution display of the spatial distribution and behaviour of occurrences. Because of these capabilities, the use of GIS in health-related studies is emerging as an important tool for health care planning, quality assurance, and research (Facchinelli et al., 2001). GIS has been used frequently in studies to analyse various issues related to health. It has measured the spatial patterns of cancer mortality in China (Lam, 1986), identified high levels of lead exposure in children (Guthe et al., 1992), defined localities for the management of primary health care in England (Bullen et al., 1996).

A GIS is a system of hardware and software that is able to capture, store, analyze, display geographically referenced information, and flexibly retrieve information on demand (Tim, 1995; Dangermond, 1990). The capability to relate seemingly unrelated information using its spatial context and to reach a conclusion about multivariate relationships of that information, makes it quite powerful. Generally, the information given about a place contains a positional reference to some point or extent on the globe.

The use of GIS techniques for exposure modelling (e.g., pollutants, traffic accidents, and diseases) has a comparatively recent history and, in most of the cases and studies, the emphasis has mainly been on dispersion modelling. Some of the perceived second-generation models have been developed to prop up air pollution management. In most of the studies pertaining to health problems like epidemics, the concern has been on developing GIS based methods based on simple extraction of relatively distance-based metrics of exposure (based on proximity to source). But during last decade, attention has refocused on GIS-based pollution mapping using interpolation techniques such as inverse distance weighting, Kriging and land use regression modelling (Jerrett et al., 2005). GIS is a powerful tool that can help contribute to answers to all the questions and lead to possible amelioration of problems. The application of GIS will assist towards better understanding of the problem and its potential solution.

3.9 Use of IDW Interpolation

Interpolation is a commonly used GIS technique to create continuous surface from discrete points. A lot of real-world phenomena are continuous - elevations, soils, temperatures etc. If one wants to model these surfaces for analysis, it is impossible to take measurements throughout the surface. Hence, the field measurements are taken at various

points along the surface and the intermediate values are inferred by a process called ‘interpolation’.

Interpolation predicts values for cells in a raster from a limited number of sample data points. It can be used to predict unknown values for any geographic point data, such as elevation, rainfall, chemical concentrations, noise levels, and so on. The illustrations below show the distribution and values of sample points and the raster generated from them. The left illustration shows a point dataset of known rainfall-level values. The illustration on the right shows a raster interpolated from these points. Unknown values are predicted with a mathematical formula that uses the values of nearby known points.

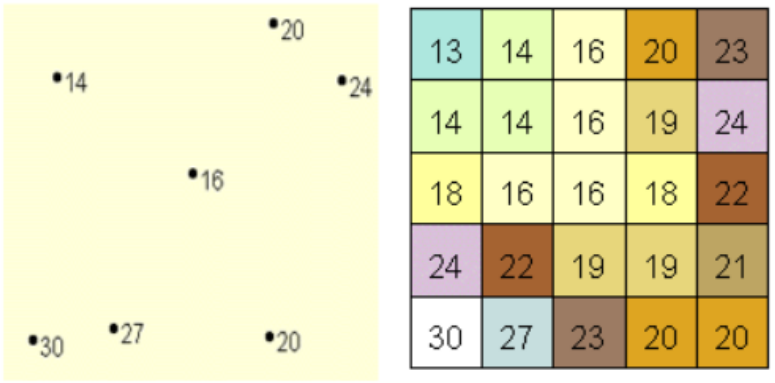


Figure 3.7 Schematic Diagram of Interpolation

There are many kinds of interpolation techniques inbuilt in GIS, and include IDW, Kriging, and spline. These techniques are mostly used in air pollution studies. Inverse Distance Weighted (IDW) is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell. This method assumes that the variable being mapped decreases in influence with distance from its sampled location. The closer a point is to the centre of the cell being estimated, the more influence, or weight, it has in the averaging process. When the set of points is dense enough to capture the extent of local surface variation needed for the analysis, IDW is used. It estimates grid values using a linear-weighted combination of a set of data and it is a function of two fields, namely, the distance between sampling sites and the site at which the interpolation has to be made (Gunnink and Burrough, 1996). Points will have higher weight if they are nearer to the point where the value is to be interpolated.

The IDW technique computes an average value for unsampled locations using values from nearby weighted locations. The weights are proportional to the proximity of the sampled points to the unsampled location and can be specified by the IDW power coefficient. The larger the power coefficient, the stronger the weight of nearby points as can be gleaned from the following equation that estimates the value z at an unsampled location j:

$$\hat{Z}_j = \frac{\sum_i Z_i / d_{ij}^n}{\sum_i 1 / d_{ij}^n}$$

The carat ^ above the variable *Z* reminds us that we are estimating the value at *j*. The parameter *n* is the weight parameter that is applied as an exponent to the distance thus amplifying the irrelevance of a point at location *i* as distance to *j* increases. So, a large *n* results in nearby points wielding a much greater influence on the unsampled location than a point further away resulting in an interpolated output looking like a Thiessen interpolation. On the other hand, a very small value of n will give all points within the search radius equal weight such that all unsampled locations will represent nothing more than the mean values of all sampled points within the search radius.

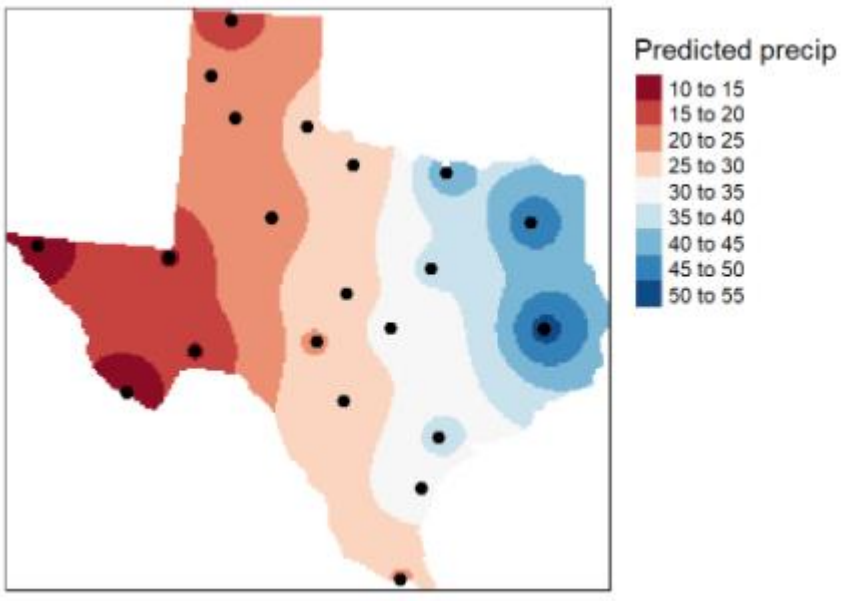


Figure 3.8 An IDW interpolation of the average yearly precipitation for several meteorological sites in Texas.

(An IDW power coefficient of 2 was used in this example)

3.9.1 Steps for IDW Interpolation in QGIS software

QGIS 3.16.5 version has been used to perform spatial IDW interpolation for variation of pollutants – SO_2, NOx, PM_{10} over the city. The process is explained in the following steps:

1. Import an existing shapefile or create a new shapefile layer of Akola city boundary into QGIS.
2. Mark the locations of monitoring stations as per their co-ordinates over the city shapefile using point feature under 'New Shapefile Layer' option and name it as 'Stations' layer.
3. Open the attribute table for the 'Stations' layer by right-clicking on it.
4. In this attribute table under editing mode, insert new columns (field) with decimal number type and one field for each pollutant data and one field for naming the station points.
5. Insert the pollutant concentration values (here, average annual values) for the pollutant whose spatial variation is to be created in each respective field for every station point and save it.
6. Go to the 'Processing' menu in the toolbar of QGIS and select 'Toolbox' option.
7. From the Processing Toolbox, click on Interpolation and select 'IDW Interpolation'.
8. In the IDW interpolation window, choose the vector layer as 'Stations'. Then, out of the list of pollutants, select the interpolation attribute as a particular pollutant to be interpolated and click on '+' symbol. Keep the distance coefficient as it is. Click on the 'extent' options and choose 'Calculate from layer' and select 'City' layer. Increase the number of rows and columns as per convenience (here, 100 rows and 404 columns). Lastly, save the Interpolated file to a specific location in the PC and 'Run' the process and close that window.
9. Go to 'Raster Extraction' and select 'Clip Raster by Mask layer'. Choose the Mask layer as 'City' and keep the Input layer as 'Interpolated' and click 'Run'. Delete the 'Interpolated' layer and rename the 'Clipped' layer as required.
10. Go to the properties of the newly formed 'Clipped' layer and change the render type to 'Singleband pseudocolor'. Keep the Interpolation option as 'Linear'. Select

'Reds' color ramp and invert it. Open the 'Mode' dropdown and choose 'Equal interval' and make the Classes to 5. Click OK.

11. Move the 'Stations' layer to the top so that the stations are visible.
12. Contours: Again, go to 'Raster Extraction' and choose 'Contour'. Select Input layer as 'Clipped' layer and vary the 'Interval between contour lines' as per requirement. Give attribute name and select 'Run' to execute.
13. Go to properties of 'Contour' layer and select 'Labels'. Choose 'Single Labels' and select the 'attribute name' from 'Value' dropdown. Edit as per requirements and click 'OK'.
14. Now, click on 'Project' in the menu bar and select 'New Print Layout', name the layout. Add the map to this layout and edit it as required by adding station names, captions, legend, scale, North direction, etc. Finally, save it and export it as a jpeg image into a desired folder on the PC drive.

Thus, a suitable interpolated map showing shaded spatial variation of the selected pollutant throughout the specified boundary along with labelled contours will be generated.

The entire process has been repeated to generate spatial variation maps of all the average annual pollutant concentrations of each pollutant over the years 2012-20 for Akola city.

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1 Wind Rose Diagram for Different Seasons:

4.1.1 Wind Rose for Summer season

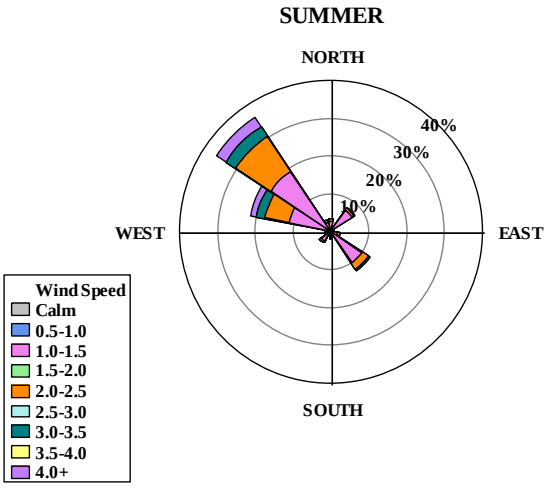


Fig. 4.1 Wind Rose Diagram for Summer Season

In the Summer season over the years 2012-2020 for Akola city, the prevailing wind blows from Northwest direction.

4.1.2 Wind Rose for Monsoon season

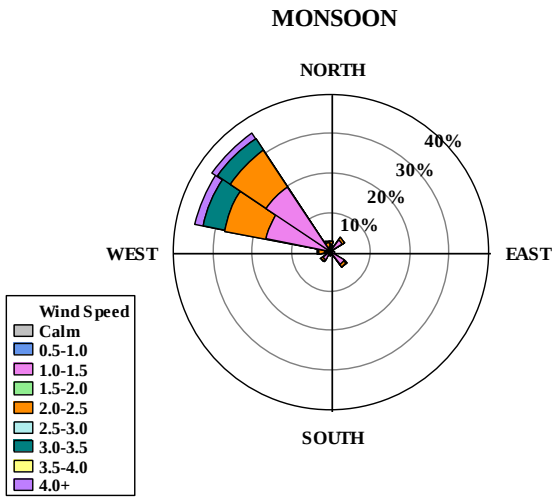


Fig. 4.2 Wind Rose Diagram for Monsoon Season

The prevailing wind blows prominently from Northwest and west of northwest direction in the Monsoon period over the years 2012-2020 for Akola city.

4.1.3 Wind Rose for Post Monsoon season

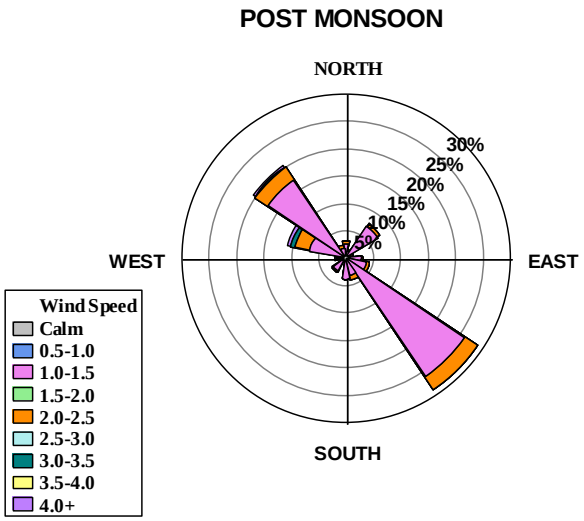


Fig. 4.3 Wind Rose Diagram for Post Monsoon Season

The prevailing wind direction for Post monsoon season over the years 2012-2020 is from southeast direction.

4.1.4 Wind Rose for Winter season

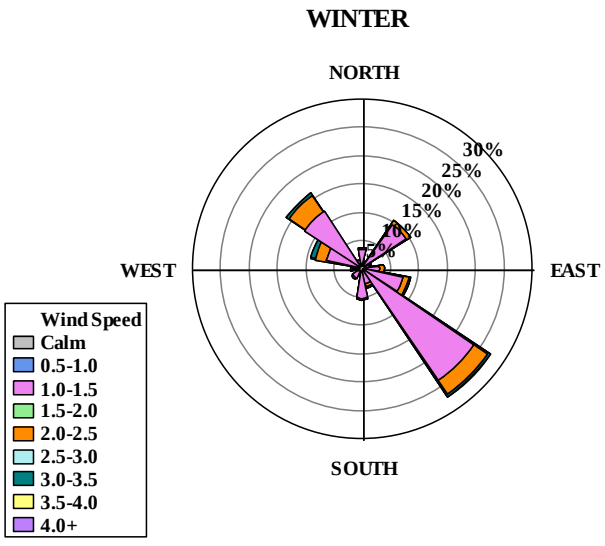


Fig. 4.4 Wind Rose Diagram for Winter Season

In the Winter season over the years 2012-2020 for Akola city, the prevailing wind blows from southeast direction.

4.2 Annual Variations of Pollutants in Akola City

4.2.1 Annual Variations in SO_2:

The annual average concentrations of SO_2 in $\mu g/m^3$ have been determined at the three monitoring stations over a period of nine years from the year 2012 to 2020. They are as follows:

Table 4.1 Annual average concentrations of SO_2

YEAR	MONITORING STATION		
	COE	LRC	MIDC
2012	8.529	7.624	9.930
2013	8.127	7.232	8.662
2014	8.715	7.637	9.429
2015	7.544	6.714	8.317
2016	8.793	7.853	9.027
2017	9.234	8.933	10.284
2018	12.019	11.53	13.607
2019	14.854	13.348	17.078
2020	13.344	12.33	14.648

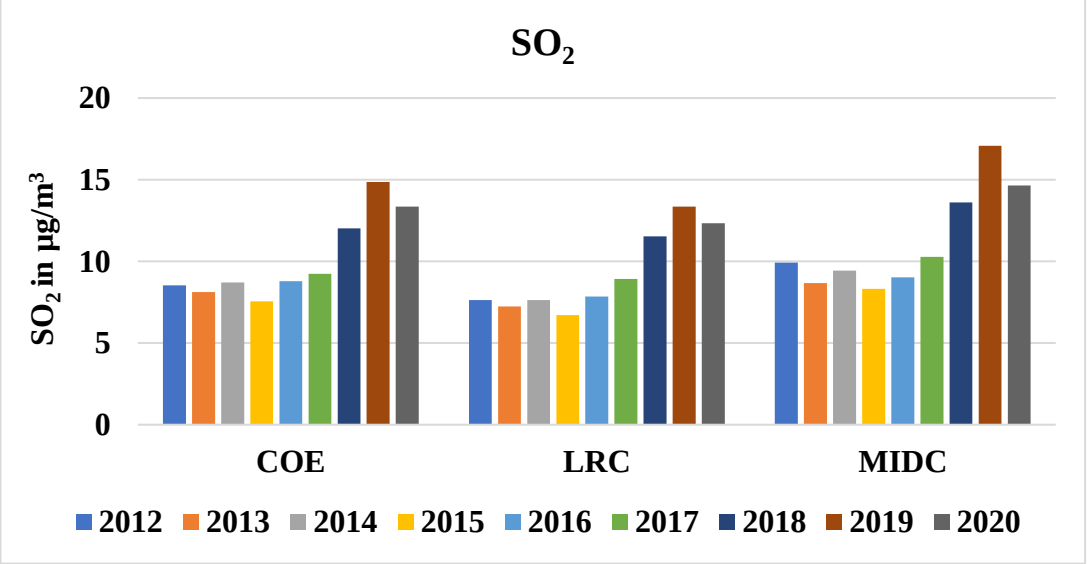


Fig. 4.5 Annual Variations in SO_2

- The above graphical representation shows that the SO_2 levels fluctuate in the early years from 2012 to 2017.
- The SO_2 level soared up in the years 2018 and 2019. The reason behind these increased levels might be growth of vehicular traffic and industries in the city of Akola.
- The SO_2 level dropped down in the year 2020 due to the lockdown restrictions imposed in entire country.
- SO_2 concentrations are higher in COE (commercial area) and MIDC (industrial area) as compared to LRC (residential area).

4.2.2 Annual Variations in NOx:

The annual average concentrations of NOx in $\mu g/m^3$ have been determined at the three monitoring stations over a period of nine years from the year 2012 to 2020. They are as shown below:

Table 4.2 Annual average concentrations of NOx

YEAR	MONITORING STATION		
	COE	**LRC**	**MIDC**
2012	9.906	9.139	11.49
2013	9.3	8.525	9.883
2014	9.94	8.78	10.846
2015	8.478	7.295	10.077
2016	9.543	8.598	9.947
2017	10.018	9.846	10.716
2018	12.273	11.948	14.427
2019	15.314	14.27	19.867
2020	13.828	13.096	14.966

- The below graphical representation shows fluctuations in NOx levels which soared up and dropped down alternately from the year 2012 to 2015.
- There is an increasing trend in NOx concentration from 2015 to 2019 with a significant rise in the year 2019. Increased use of automobiles can lead to such rise in NOx emission.

- There is a fall in NOx level in 2020 when compared with that in 2019 which might be an effect of the lockdown restrictions due to pandemic.
- MIDC (industrial area) and COE (commercial area) show higher NOx emissions than LRC (residential area).

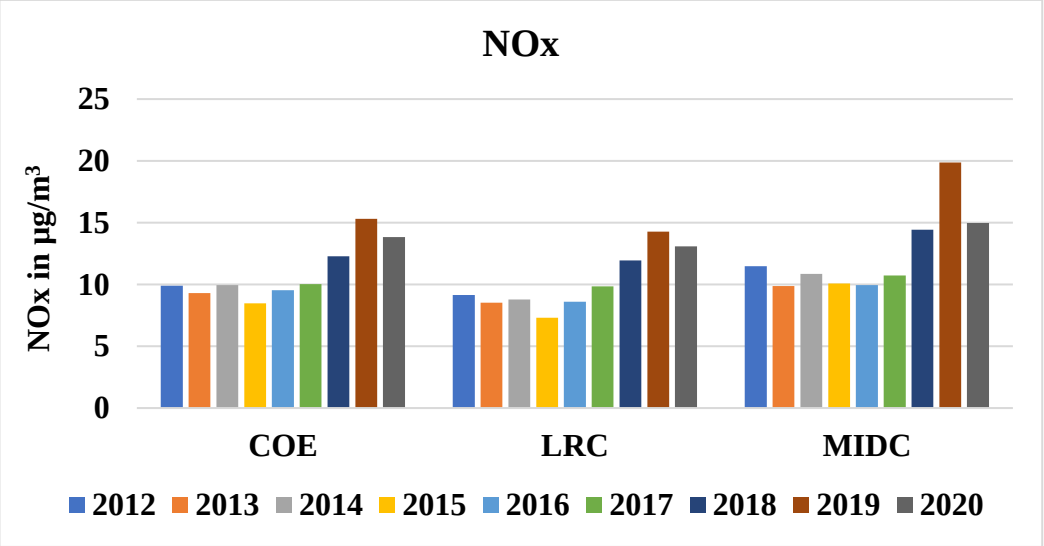


Fig. 4.6 Annual Variations in NOx

4.2.3 Annual Variations in PM_{10}:

The annual average concentrations of PM_{10} in $\mu g/m^3$ have been determined at the three monitoring stations over a period of nine years from the year 2012 to 2020. They are as given below:

Table 4.3 Annual average concentrations of PM_{10}

YEAR	MONITORING STATION		
	COE	LRC	MIDC
2012	149.352	126.277	139.32
2013	148.681	124.725	139.377
2014	152.08	120.857	135.417
2015	138.433	114.933	126.856
2016	140.739	106.99	125.248
2017	126.811	120.76	128.908
2018	72.104	68.617	77.53
2019	68.697	67.843	74.456
2020	54.634	53.542	56.682

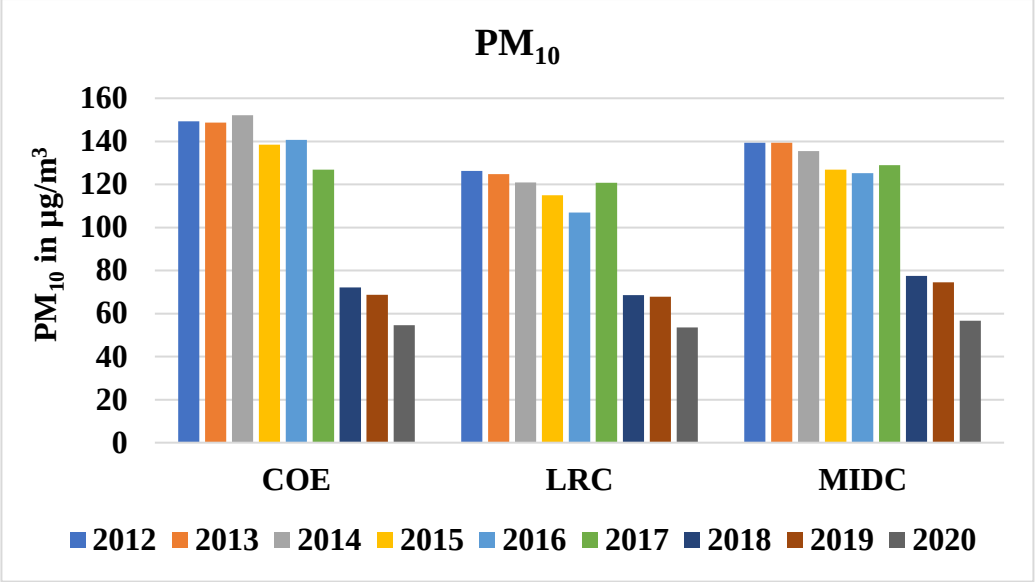


Fig. 4.7 Annual variations in PM_{10}

- The above graphical representation displays a minute fluctuation in PM_{10} levels from 2012 to 2017 and a sudden descent in the year 2018.
- PM_{10} levels decline continuously from 2018 to 2020. This drop might be due to reduction of sulphur in fuel and implementation of stringent standard of particulate emission from vehicles in the city.
- Highest levels of PM_{10} have been recorded at COE (commercial area) and lowest levels at LRC (residential area).

Table 4.4 Highest Daily Mean Concentration and Average Annual Concentration over years 2012 - 2020

	STATION	SO_2	NO_X	PM_{10}	AQI
Highest Daily Mean Concentration ($\mu g/m^3$)	**COE**	19	20	179	153
	LRC	18	19	179	153
	MIDC	22	174	166	194
Average Annual Concentration ($\mu g/m^3$)	**COE**	10.169	10.965	115.758	106.295
	LRC	9.278	10.158	99.839	95.346
	MIDC	11.183	12.589	111.523	104.323

The previous table displays the **highest recorded concentrations** of SO_2 and NOx as well as AQI at the **MIDC** monitoring station when compared with other stations.

4.3 Seasonal Variations of Pollutants in Akola City

- For understanding seasonal variations of pollutants, the duration of December to February is considered as Winter season, March to May as Summer season, June to September as Monsoon season and October and November as Post-monsoon season.
- Analysis of seasonal variation is done for the three monitoring stations for each pollutant – SO_2, NOx, and PM_{10} over the years 2012 to 2020.

4.3.1 Seasonal Variations in SO_2

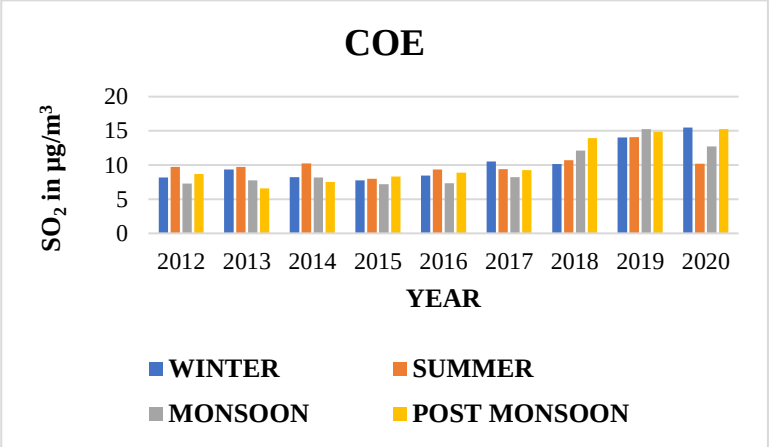


Fig. 4.8 Seasonal Variations in SO_2 at COE

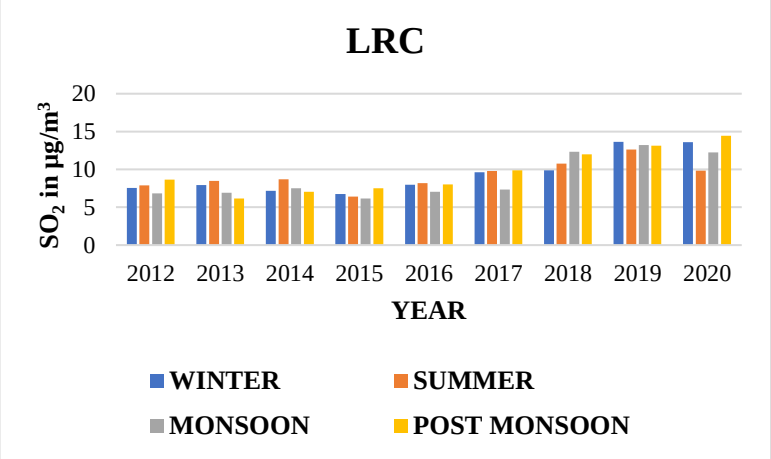


Fig. 4.9 Seasonal Variations in SO_2 at LRC

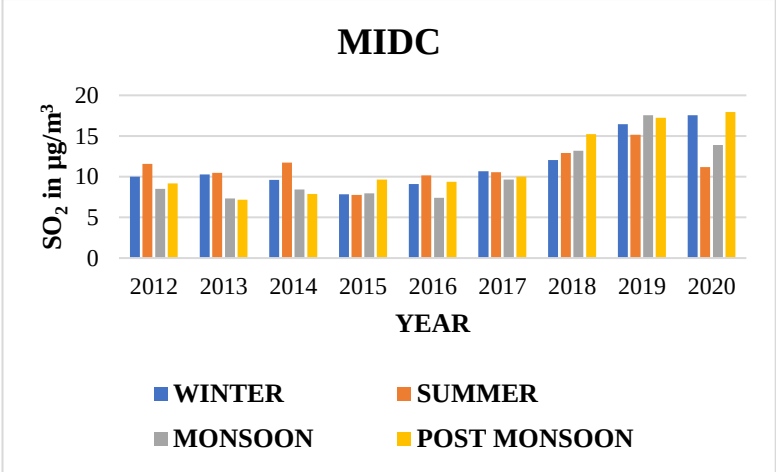


Fig. 4.10 Seasonal Variations in SO_2 at MIDC

4.3.2 Seasonal Variations in NOx:

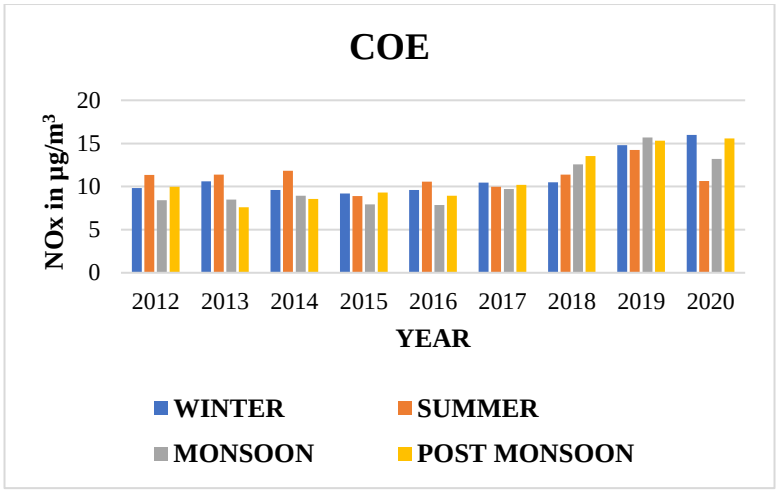


Fig. 4.11 Seasonal Variations in NOx at COE

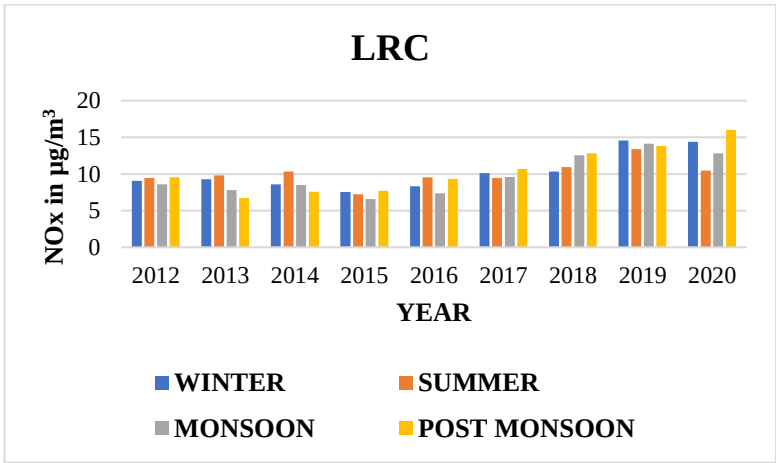


Fig. 4.12 Seasonal Variations in NOx at LRC

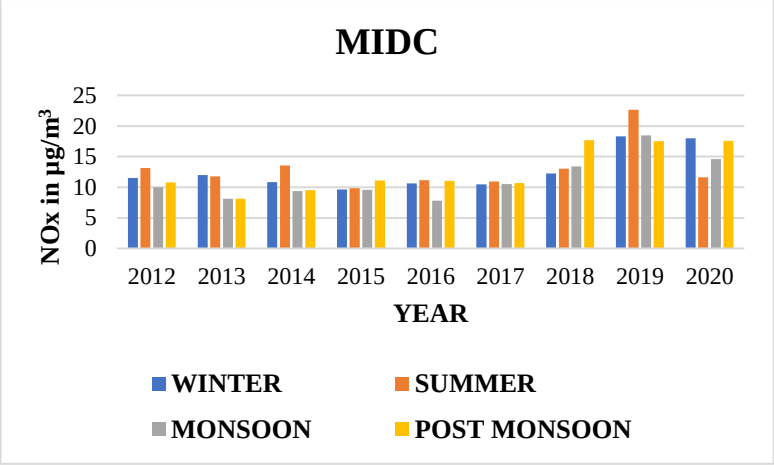


Fig. 4.13 Seasonal Variations in NOx at MIDC

4.3.3 Seasonal Variations in PM_{10}:

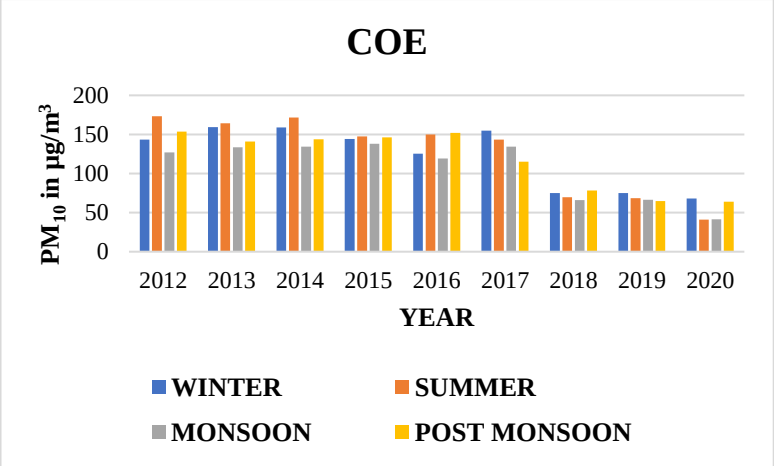


Fig. 4.14 Seasonal Variations in PM_{10} at COE

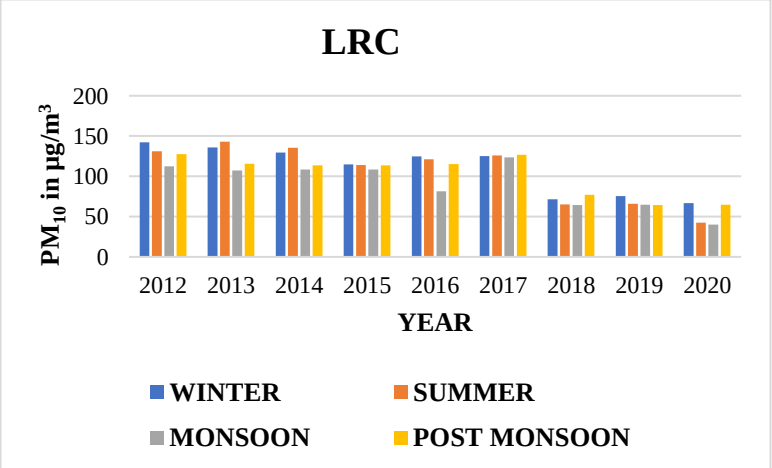


Fig. 4.15 Seasonal Variations in PM_{10} at LRC

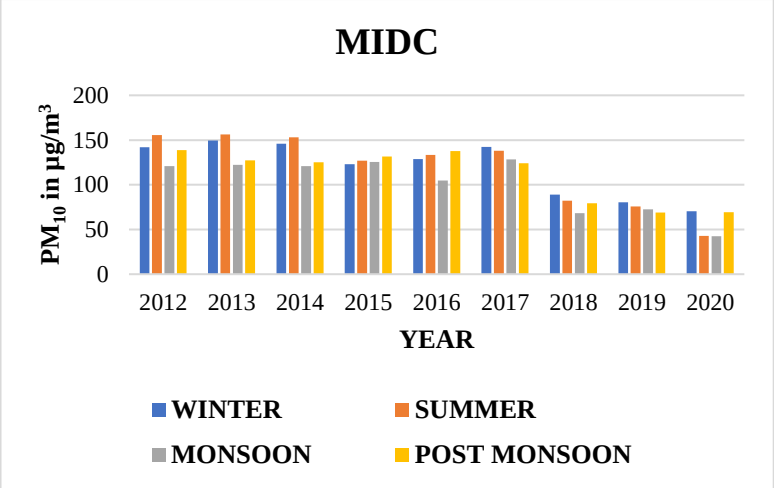


Fig. 4.16 Seasonal Variations in PM_{10} at MIDC

4.4 Common Trends in Seasonal Variations

- It is observed that in majority of the years, high-most concentration of the pollutants SO_2, NOx, and PM_{10} are recorded during Post Monsoon season of the year.
- These high concentrations of pollutants can be due to the inversion effect which is very commonly observed during the cold winter evenings.
- The inversion effect doesn't allow proper and even dispersion of pollutants and thus, ultimately leads to high pollutant concentrations over the earth's surface.
- Additionally, the least concentration of the pollutants is mostly seen during the Monsoon season. This is due to precipitation and winds which helps out to lower down the pollutant concentration in the atmosphere.
- However, as per data analysis of certain years, the concentrations of PM_{10} at all the three sites are found to be significant during Summer season.

4.5 Exceedance Factor (EF)

$$EF = \frac{\text{Observed Annual Mean of Criteria Pollutants}}{\text{Annual Standard for Respective Pollutant}}$$

4.5.1 Exceedance factor for PM_{10}

Annual Standard for PM_{10}: 60 $\mu g/m^3$

Table 4.5 Exceedance factor for PM_{10}

YEAR	MONITORING STATION		
	COE	LRC	MIDC
2012	2.489	2.105	2.322
2013	2.478	2.079	2.323
2014	2.535	2.014	2.257
2015	2.307	1.916	2.114
2016	2.346	1.783	2.087
2017	2.114	2.013	2.148
2018	1.202	1.144	1.292
2019	1.145	1.131	1.241
2020	0.911	0.892	0.945

4.5.2 Exceedance factor for SO_2

Annual Standard for SO_2: 50 $\mu g/m^3$

Table 4.6 Exceedance factor for SO_2

YEAR	MONITORING STATION		
	COE	LRC	MIDC
2012	0.171	0.152	0.199
2013	0.163	0.145	0.173
2014	0.174	0.153	0.189
2015	0.151	0.134	0.166
2016	0.176	0.157	0.181
2017	0.185	0.179	0.206
2018	0.24	0.231	0.272
2019	0.297	0.267	0.342
2020	0.267	0.247	0.293

4.5.3 Exceedance factor for NOx

Annual Standard for NOx: 40 μg/m^3

Table 4.7 Exceedance factor for NOx

YEAR	MONITORING STATION		
	COE	LRC	MIDC
2012	0.248	0.228	0.287
2013	0.233	0.213	0.247
2014	0.249	0.22	0.271
2015	0.212	0.182	0.252
2016	0.239	0.215	0.249
2017	0.25	0.246	0.268
2018	0.307	0.299	0.361
2019	0.383	0.357	0.500
2020	0.346	0.327	0.374

Table 4.8 Exceedance factor criteria and indicator

S. no.	Exceedance factor range	Pollution level
1	Greater than 1.5	Critical Pollution
2	1 to 1.5	High Pollution
3	0.5 to 1	Moderate Pollution
4	Less than 0.5	Low Pollution

- Darker regions with EF ≥ 1.5 show critical pollution due to PM_{10} during years 2012 to 2017 throughout the Akola city. However, the air quality improvised in 2018 and 2019 but still there was high pollution due to particulates. In 2020, pollution due to PM_{10} is observed to be low with EF < 0.5.

- Exceedance factor for SO_2 has always been lesser than 0.5 at all the three sites for all the years indicating low pollution. However, the EF value for SO_2 seems to be rising with the years.
- Exceedance factor for NOx is also mostly below 0.5 but are higher than those obtained for SO_2 and reached the highest of 0.5 for MIDC station showing signs of moderate pollution. The EF values are increasing over the year which is an alarming trend for the air quality status of the city.

4.6 Air Quality Index (AQI)

Average Air Quality Index has been calculated for every month of each year 2012 to 2020 at all the three monitoring stations and the results are tabulated below:

Table 4.9 Indicator for Air Quality

AQI	AIR QUALITY
0 - 50	GOOD
50 -100	SATISFACTORY
100 - 200	MODERATE

Table 4.10 Air Quality Index for COE

COE	YEAR								
MONTH	2012	2013	2014	2015	2016	2017	2018	2019	2020
JAN	114.3	142.75	139.778	130.1	131.444	127.4	79.333	77.25	67.5
FEB	143.75	129.875	143.875	130.25	131.5	130	73.25	75.25	68.25
MAR	149.5	140.222	146.6	131.625	132.75	126.5	70.625	67.375	50.625
APR	148.444	145.5	149	133	132.778	129.875	70.889	68.556	33.5
MAY	149	-	147.571	-	134.125	129.7	67.111	69.333	39.125
JUN	109.625	-	140.125	125.375	132	125	62	67.5	42.2
JUL	122.167	-	-	125.1	98.8	116.333	65.667	65	41.71
AUG	113.857	120.125	116.4	125.667	89	126	67.5	66	40.2
SEP	124.375	124.625	112.125	125.25	114.8	125.625	69	66	-
OCT	132.143	125.75	129.333	127.667	128.667	123.9	78.125	64.287	55.556
NOV	139.6	128.9	129.111	134.1	140.667	90.8	78.316	65.375	72.462
DEC	146.2	134.75	127.875	97.111	140.714	73.75	72	68.556	66.1

Table 4.11 Air Quality Index for LRC

LRC	YEAR								
MONTH	2012	2013	2014	2015	2016	2017	2018	2019	2020
JAN	139.25	124.778	120.125	109.875	109.75	116.875	69.889	78.444	65.75
FEB	117	126.125	122.625	110.875	109.556	115.25	67	77	66.375
MAR	124.875	127.75	124.167	111.4	112.375	114.4	65.556	66.625	51.1
APR	117.778	131.5	122.889	107.875	114.25	120.375	65.875	65.556	34.556
MAY	120.111	-	123.875	108.875	115.5	118	64.5	65.889	40.375
JUN	138.889	-	112.667	104.6	113.875	115.111	61.5	66.375	41.571
JUL	92.8	-	-	105.625	45.167	113.222	43.5	63	41.4
AUG	85	98.333	102.714	106.625	49.6	119.5	66.733	65.333	38
SEP	107.8	108.667	101.8	106.222	106	114.25	75.571	63.6	-
OCT	116.111	106.556	108.125	108.25	106.333	121.5	75.5	64.143	55.75
NOV	121.25	115	110.125	109.833	113.444	114.25	77.833	64.778	69.786
DEC	121.111	116.6	108.778	131.125	118	75.778	70.25	67.556	67.333

Table 4.12 Air Quality Index for MIDC

MIDC	YEAR								
MONTH	2012	2013	2014	2015	2016	2017	2018	2019	2020
JAN	125	131.111	131.8	117.889	123.25	128.625	89.444	82.556	69.333
FEB	131	130.75	132.5	108.25	116	125.917	86.625	81.375	70.889
MAR	138.875	137.5	131.8	118.75	119.7	122.778	82.4	89.222	51.875
APR	138.375	138	133.111	117	123.25	126	83.25	75	34.25
MAY	134.3	-	140.125	118.125	124.75	127.625	80.5	75.778	42.778
JUN	120.625	-	116	114.875	125	122.222	66.667	76.556	43.667
JUL	110.875	-	-	116.22	70.25	112.75	67.5	69.8	43
AUG	108.222	114.429	113.375	117	82.571	118.625	74.667	71	41
SEP	116.667	115.25	112.5	119.444	109	121	67.286	70	-
OCT	121.5	116.9	117.4	119.889	123	125.125	79.667	69.143	64.8
NOV	129.2	119.75	116.375	122.333	127.375	105.5	79.842	68.778	74.625
DEC	135.125	126.625	116.889	121.2	130.9	90.3	77.333	70.625	71.222

Above tables present that the ambient air in Akola city ranges from good to moderate in quality. Air quality was majorly moderate till 2017 and has improvised later on to be eventually good in 2020 as a probable impact of the lockdown imposed during global pandemic. However, the higher values of AQI during 2012-17 is due to larger PM_{10} levels in city. AQI values are also seen to be dipping down during monsoon season.

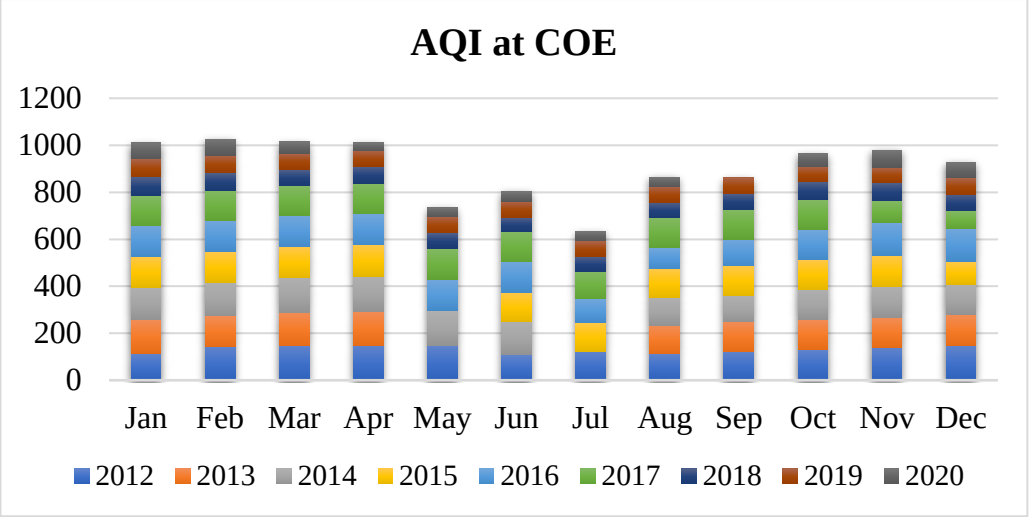


Fig. 4.17 AQI variation at COE

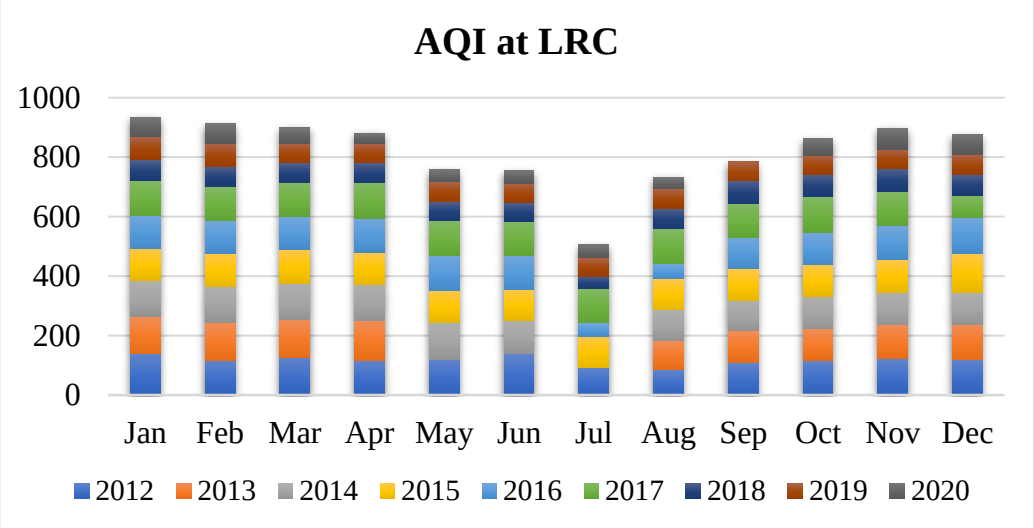


Fig. 4.18 AQI variation at LRC

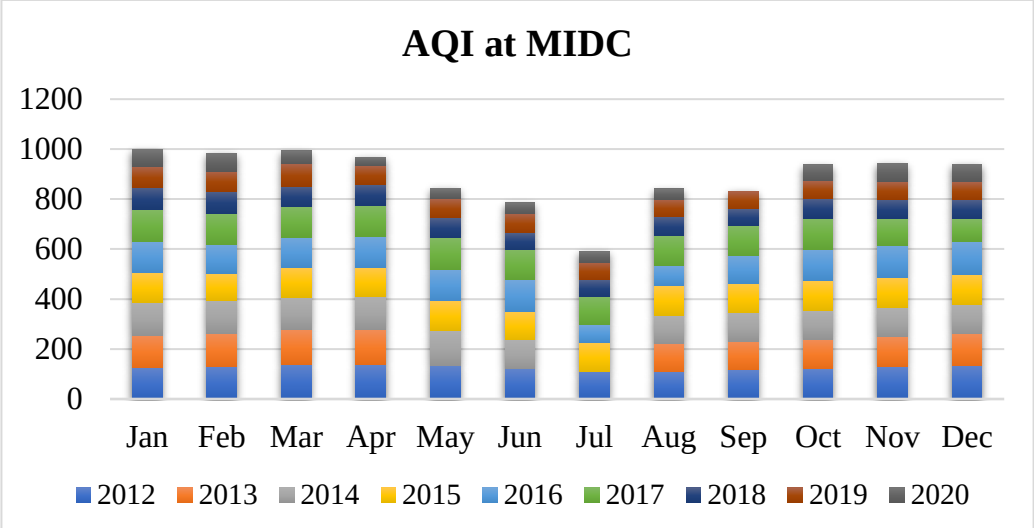


Fig. 4.19 AQI variation at MIDC

4.7 Correlation between Pollutants and Meteorological parameters:

Linear Regression analysis has been performed to establish correlation as follows:

4.7.1 Regression analysis for data from COE monitoring station:

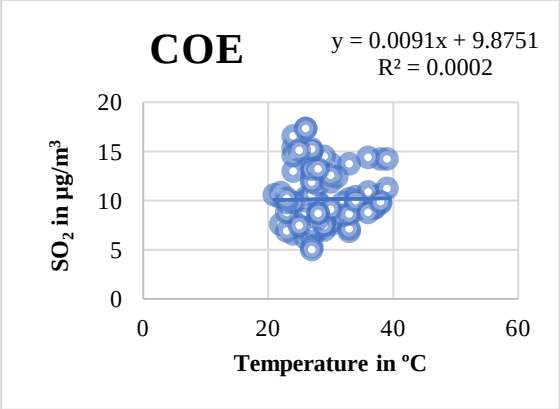


Fig. 4.20 SO_2 vs. Temperature at COE

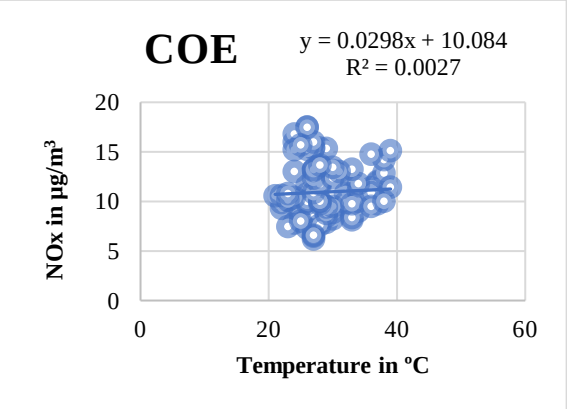


Fig. 4.21 NOx vs. Temperature at COE

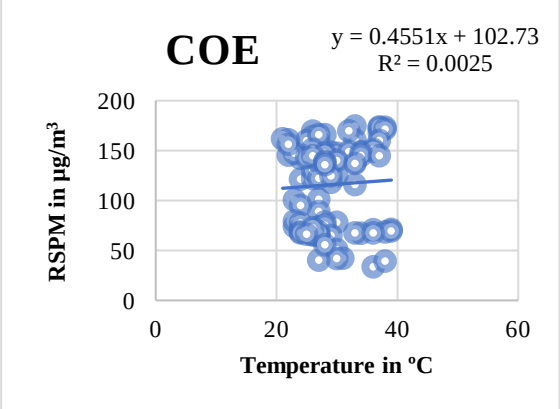


Fig. 4.22 RSPM vs. Temperature at COE

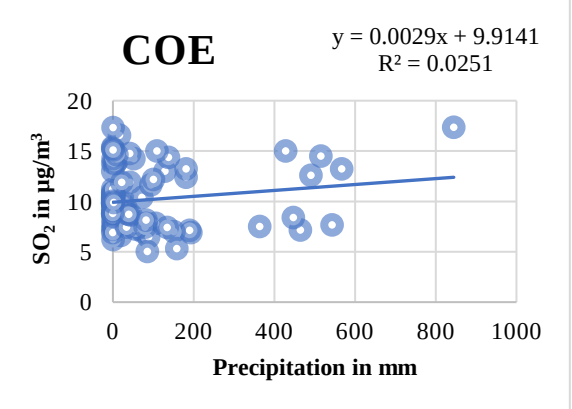


Fig. 4.23 SO_2 vs. Precipitation at COE

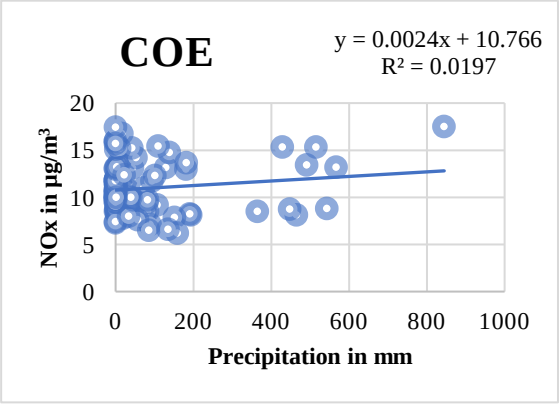


Fig. 4.24 NOx vs. Precipitation at COE

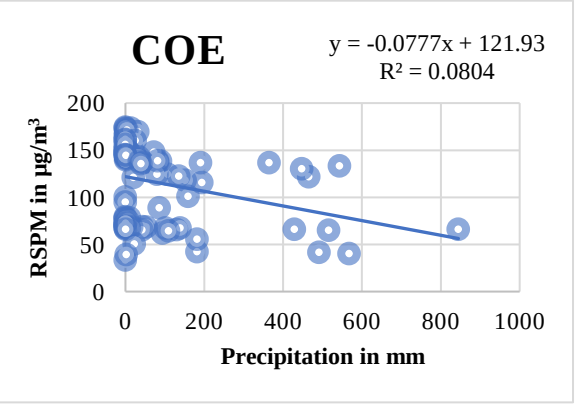


Fig. 4.25 RSPM vs. Precipitation at COE

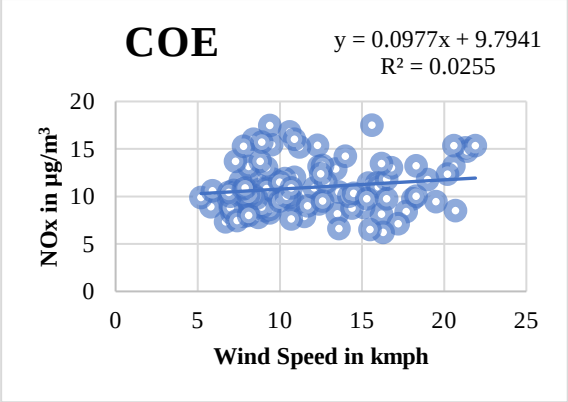


Fig. 4.26 SO_2 vs. Wind Speed at COE

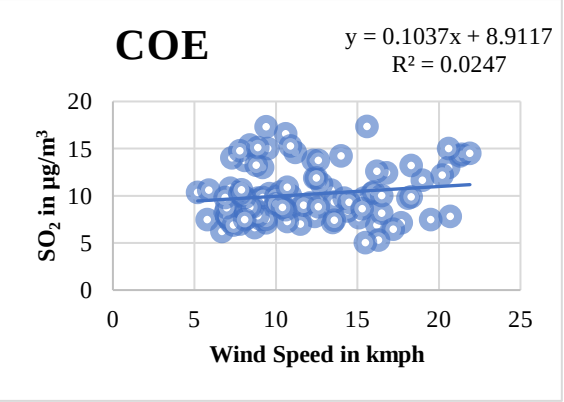


Fig. 4.27 NOx vs. Wind Speed at COE

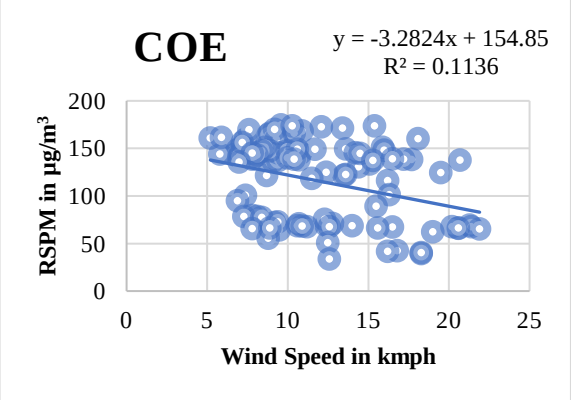


Fig. 4.28 RSPM vs. Wind Speed at COE

Table 4.13 Regression coefficient for COE

POLLUTANT	METEOROLOGICAL PARAMETER					
	TEMPERATURE		PRECIPITATION		WIND SPEED	
	R^2	R	R^2	R	R^2	R
SO_2	0.0002	+ 0.0141	0.0251	+ 0.1584	0.0247	+ 0.1572
NOx	0.0027	+ 0.0520	0.0197	+ 0.1404	0.0255	+ 0.1597
PM_{10}	0.0025	+ 0.0500	0.0804	- 0.2835	0.1136	- 0.3370

- From the above graphs, it can be observed that all the pollutants increase in concentration with the rise in temperature.

- However, the value of correlation coefficient R is very low which indicates that this relationship between pollutant levels and temperature is unreliable.
- After inferring the graph between pollutants and precipitation, it is understood that both SO_2 and NOx levels increased with precipitation which seems to be impractical. But, the level of PM_{10} declines with increase in precipitation which is a well-established fact.
- The pollutant versus wind speed graphs illustrate drop in PM_{10} levels with the increase in wind speed which is due to the adequate dispersion of particulates. The correlation coefficient of this relationship is highest among all and the relationship can be considered reliable.

4.7.2 Regression analysis for data from LRC monitoring station:

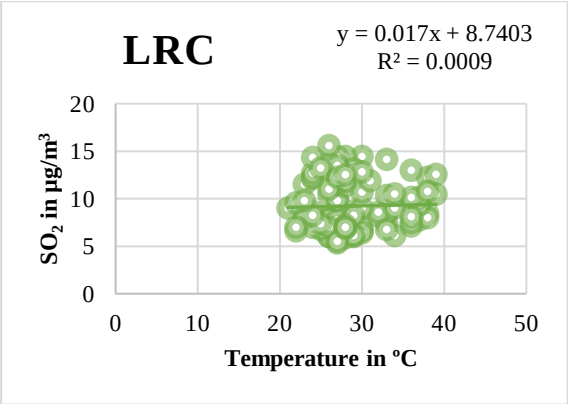


Fig. 4.29 SO_2 vs. Temperature at LRC

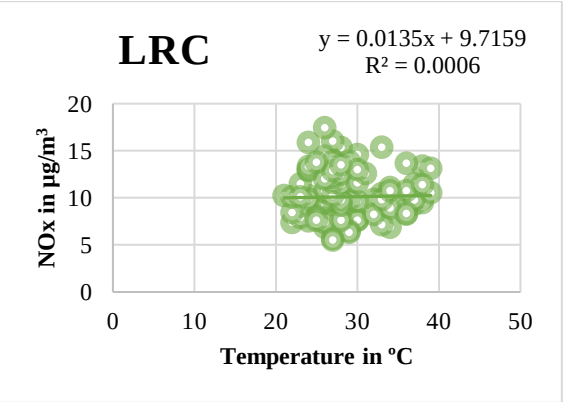


Fig. 4.30 NOx vs. Temperature at LRC

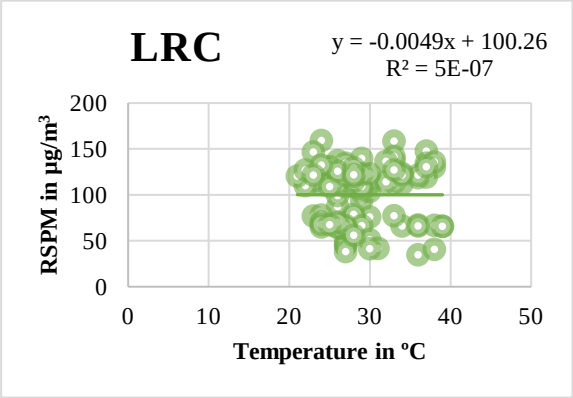


Fig. 4.31 RSPM vs. Temperature at LRC

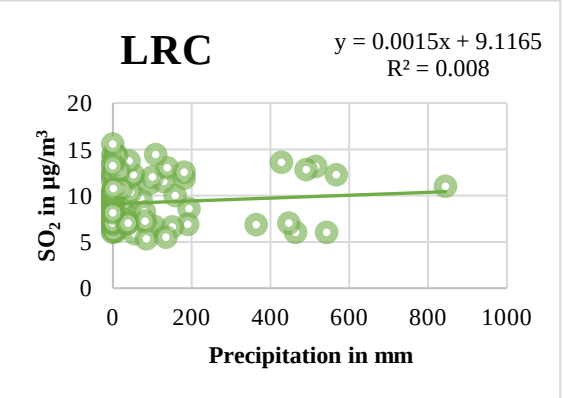


Fig. 4.32 SO_2 vs. Precipitation at LRC

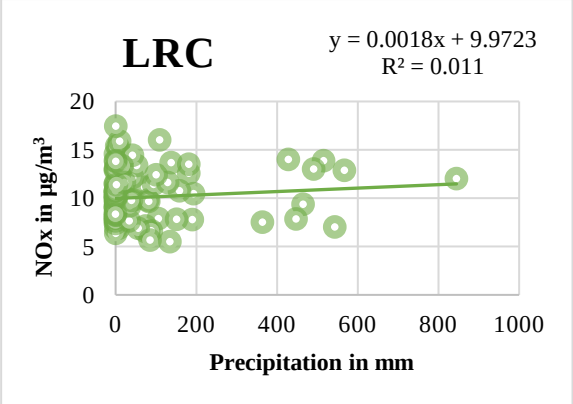


Fig. 4.33 NOx vs. Precipitation at LRC

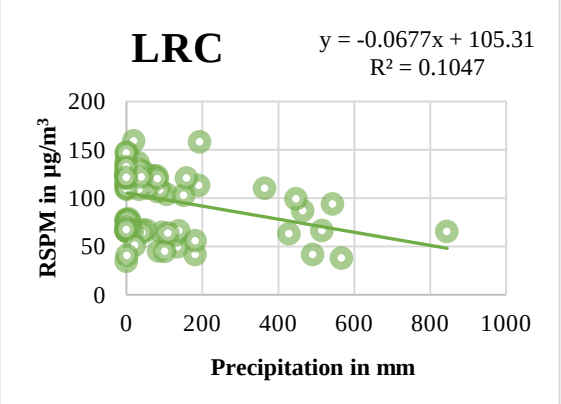


Fig. 4.34 RSPM vs. Precipitation at LRC

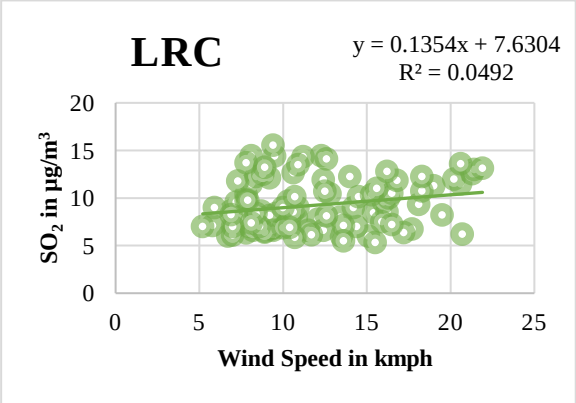


Fig. 4.35 SO_2 vs. Wind Speed at LRC

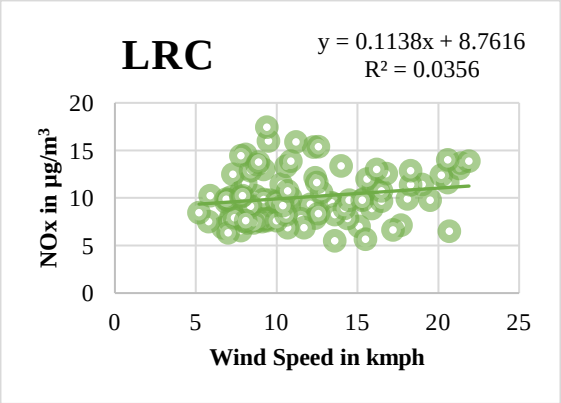


Fig. 4.36 NOx vs. Wind Speed at LRC

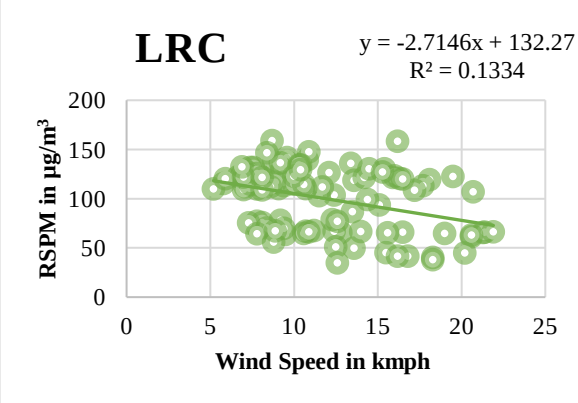


Fig. 4.37 RSPM vs. Wind Speed at LRC

- When considering relationship between each pollutant and temperature, the values of correlation coefficients are obtained to be extremely low and hence the resultant relationship cannot be considered true and reliable.

Table 4.14 Regression coefficient for LRC

POLLUTANT	METEOROLOGICAL PARAMETER					
	TEMPERATURE		PRECIPITATION		WIND SPEED	
	R^2	R	R^2	R	R^2	R
SO_2	0.0009	+ 0.0300	0.0080	+ 0.0894	0.0492	+ 0.2218
NOx	0.0006	+ 0.0245	0.0110	+ 0.1049	0.0356	+ 0.1887
PM_{10}	5.00E-07	- 0.0007	0.1047	- 0.3236	0.1334	- 0.3652

- When correlating PM_{10} with temperature at LRC, it is found that particulate concentrations reduce with increasing precipitation which is true as rains wash down particulates to earth surface.
- Similarly, PM_{10} also decreases with rising wind speeds which is established through above correlation coefficient of - 0.365.

4.7.3 Regression analysis for data from MIDC monitoring station:

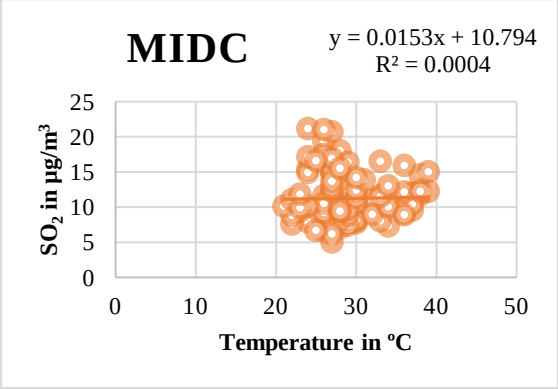


Fig. 4.38 SO_2 vs. Temperature at MIDC

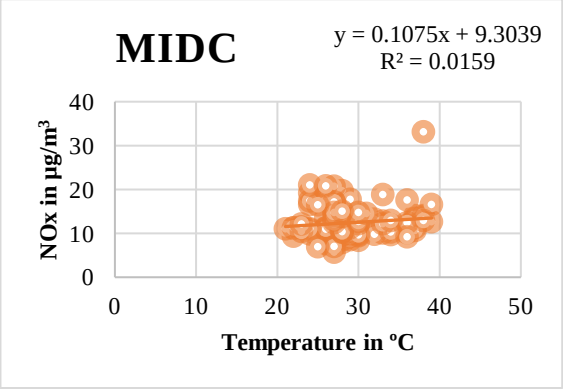


Fig. 4.39 NOx vs. Temperature at MIDC

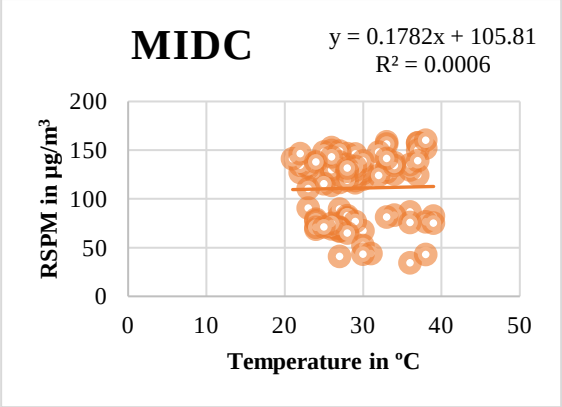


Fig. 4.40 RSPM vs. Temperature at MIDC

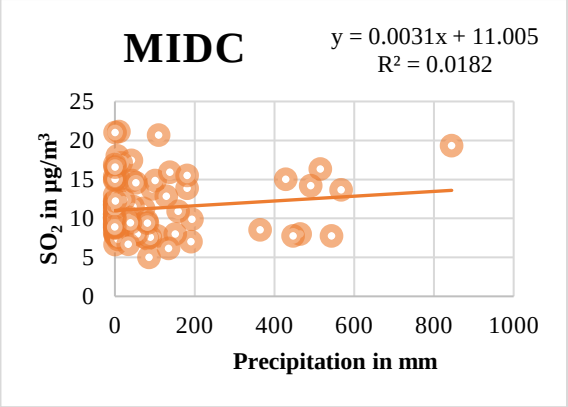


Fig. 4.41 SO_2 vs. Precipitation at MIDC

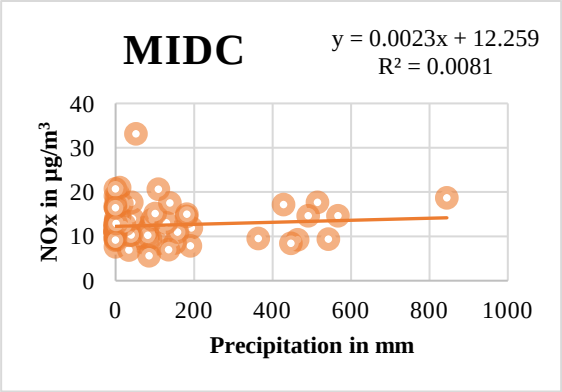


Fig. 4.42 NOx vs. Precipitation at MIDC

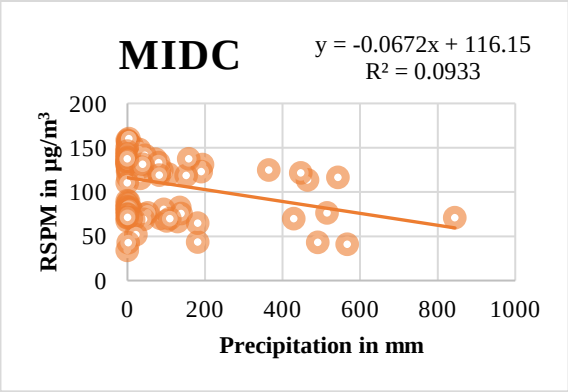


Fig. 4.43 RSPM vs. Precipitation at MIDC

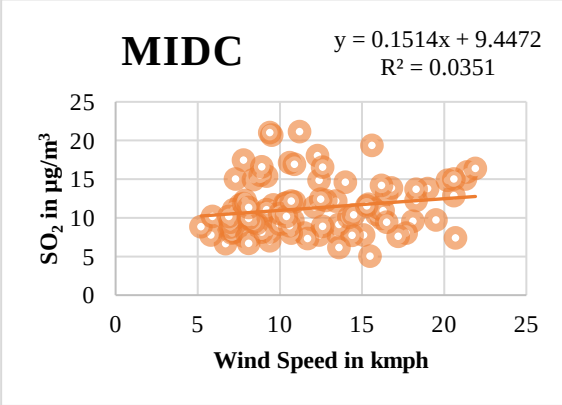


Fig. 4.44 SO_2 vs. Wind Speed at MIDC

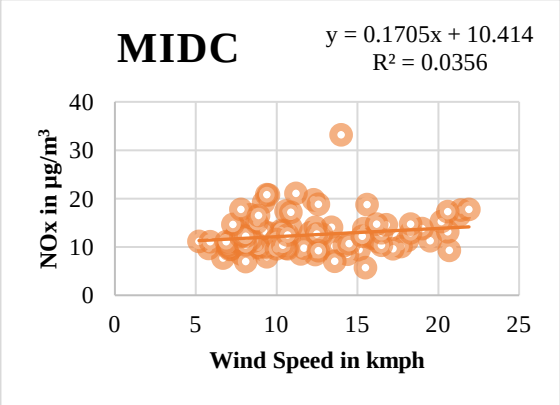


Fig. 4.45 NOx vs. Wind Speed at MIDC

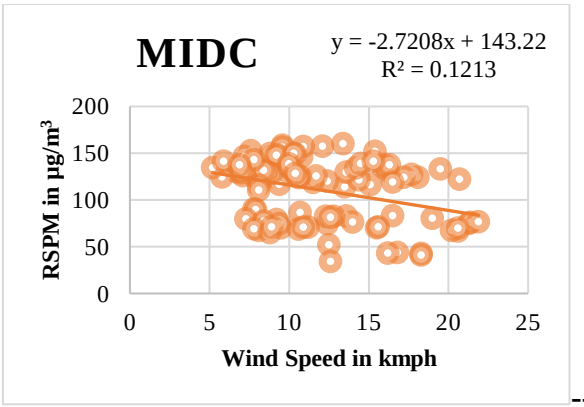


Fig. 4.46 RSPM vs. Wind Speed at MIDC

Table 4.15 Regression coefficient for MIDC

POLLUTANT	METEOROLOGICAL PARAMETER					
	TEMPERATURE		PRECIPITATION		WIND SPEED	
	R^2	R	R^2	R	R^2	R
SO_2	0.0004	+ 0.0200	0.0182	+ 0.1350	0.0351	+ 0.1873
NOx	0.0159	+ 0.1260	0.0081	+ 0.0900	0.0356	+ 0.1887
PM_{10}	0.0006	+ 0.0245	0.0933	- 0.3050	0.1213	- 0.3483

- At MIDC, trends in correlation between PM_{10} and precipitation are similar to that established at COE and LRC stations.
- Increase in NOx with rise in temperature with Correlation coefficient of + 0.12 can be referred from above table, which may or may not hold true.
- Increase in wind speeds lead to better dispersion of pollutants and this fact holds true at MIDC too with a significant correlation coefficient of - 0.348.
- Additionally, the correlation coefficients for relationship between SO_2 and PM_{10} with temperature are very low and insignificant to draw any conclusion.

4.8 Spatial Variation of Pollutants

IDW interpolation was performed to understand spatial variation of pollutants throughout the Akola city for each pollutant - SO_2, NOx and PM_{10}. The annual average values of pollutants are used in this process for every year. The outputs show contours of pollutants connecting points of equal concentration of respective pollutants. The darker zones indicate regions with higher pollutant levels whereas lighter zones are the regions with low pollutant concentrations. This helps one to understand area of influence of a particular pollutant and the variation in pollutant level in different zones over the entire region.

4.8.1 Spatial Variation of SO_2 over Akola city

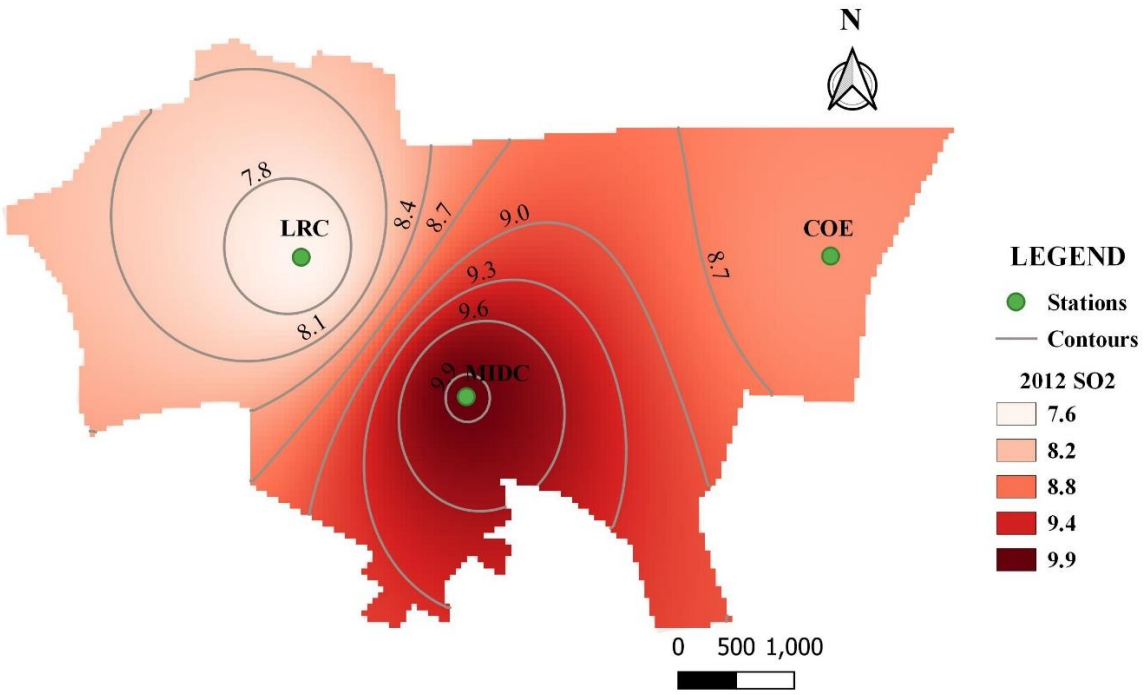


Fig. 4.47 Spatial Variation of SO_2 in 2012

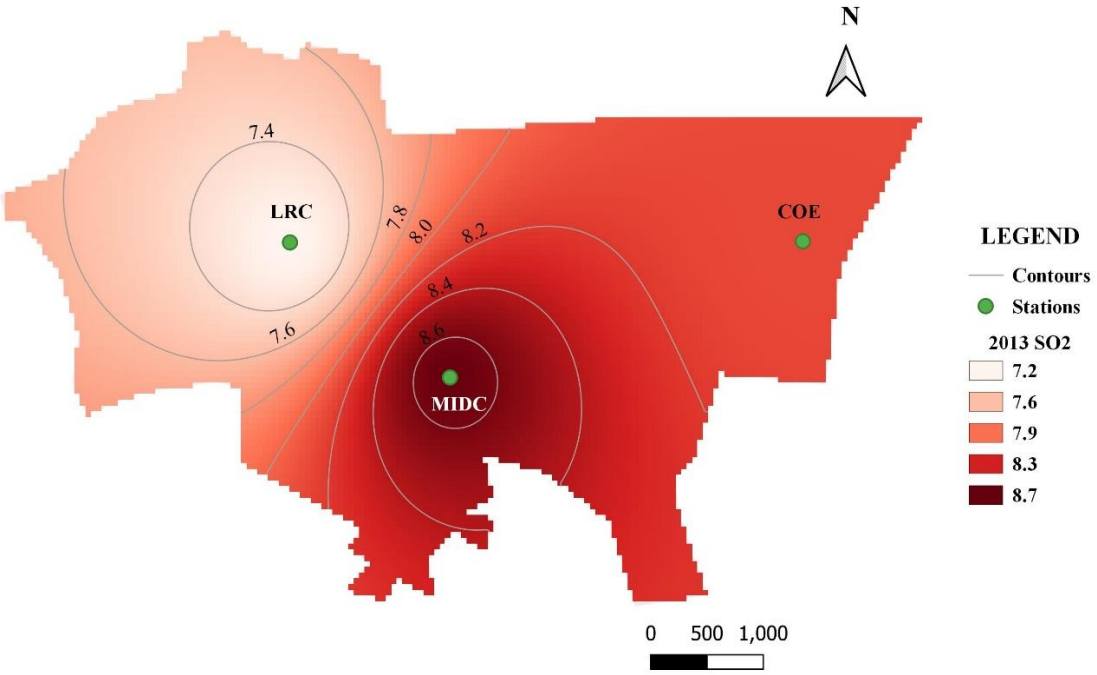


Fig. 4.48 Spatial Variation of SO_2 in 2013

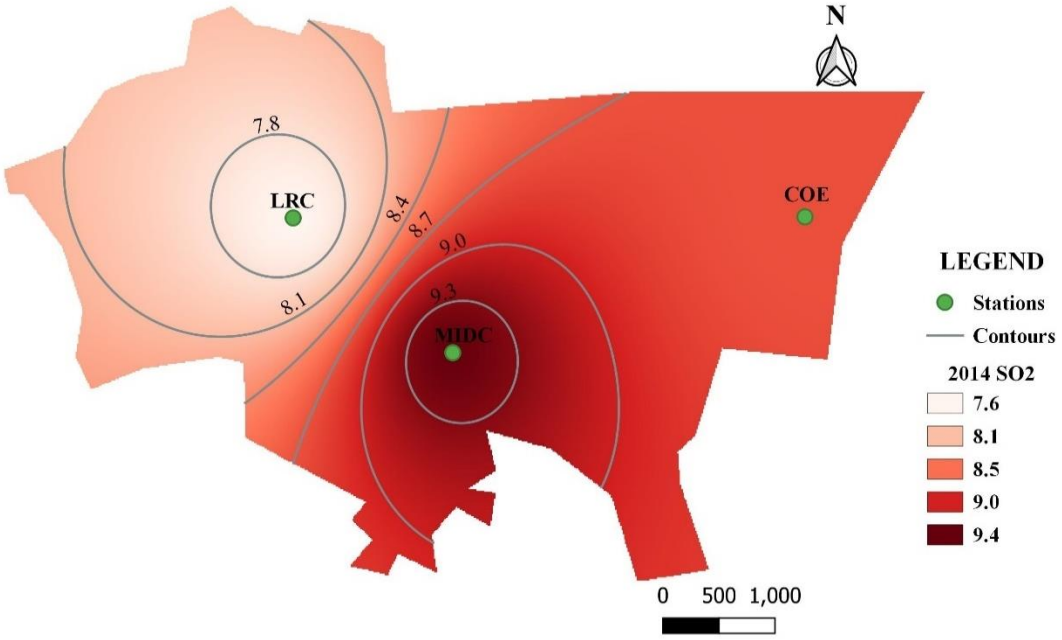


Fig. 4.49 Spatial Variation of SO_2 in 2014

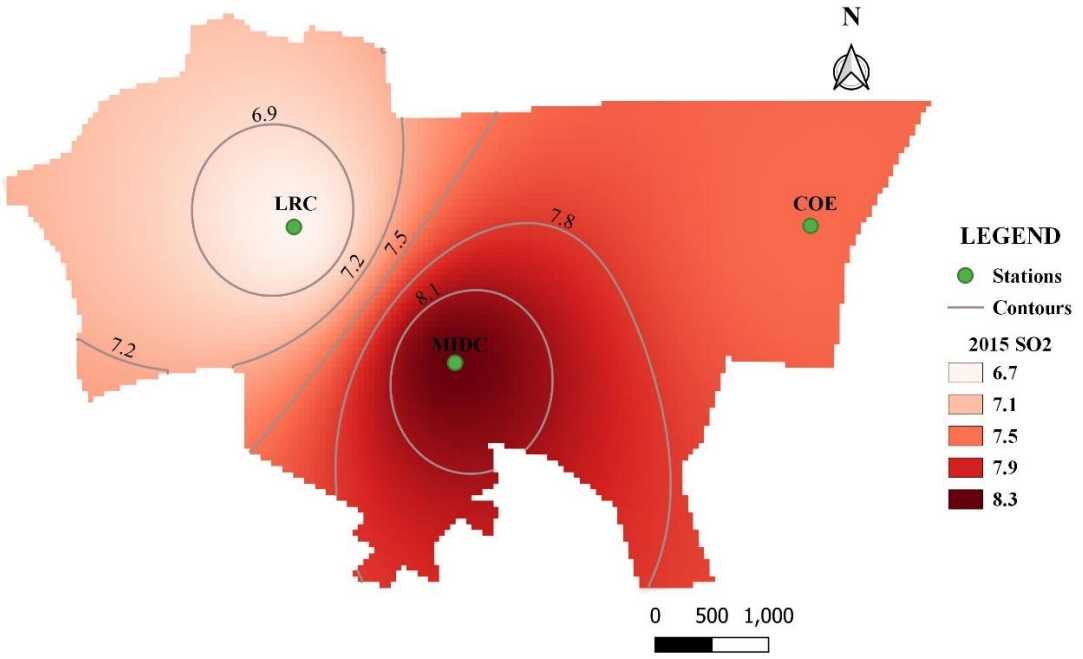


Fig. 4.50 Spatial Variation of SO_2 in 2015

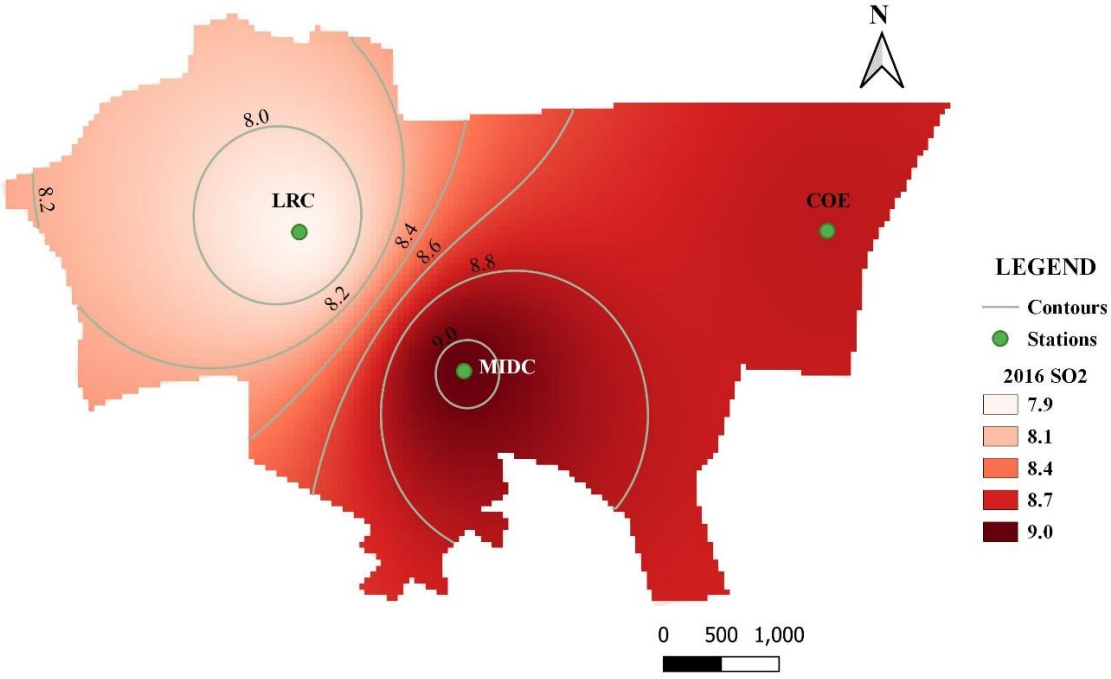


Fig. 4.51 Spatial Variation of SO_2 in 2016

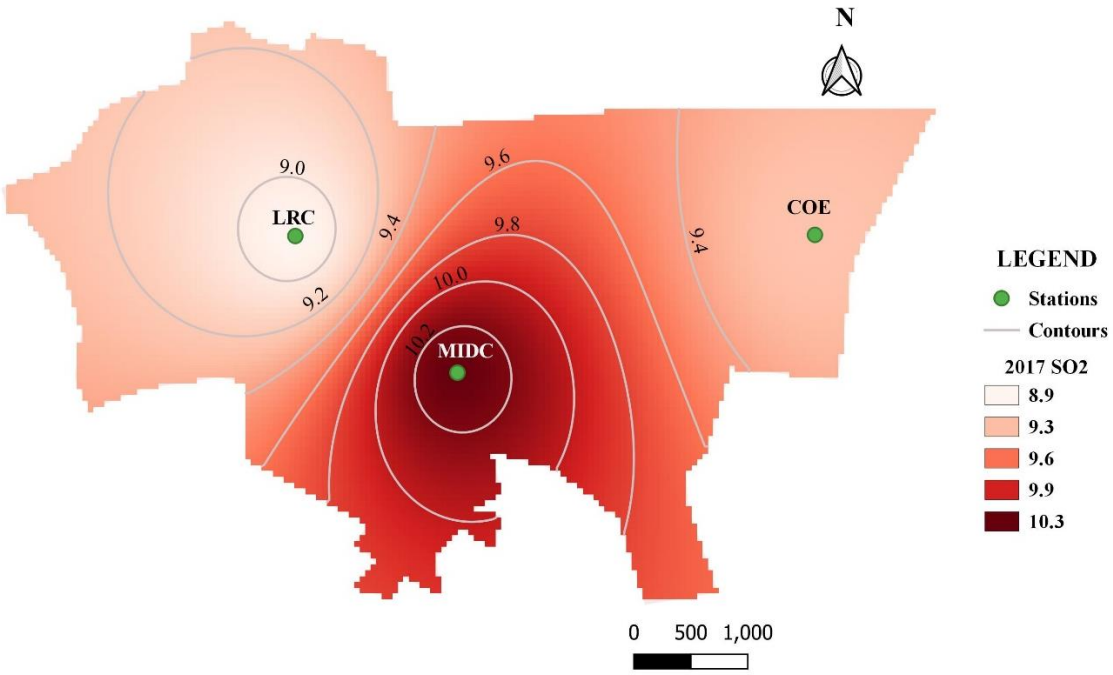


Fig. 4.52 Spatial Variation of SO_2 in 2017

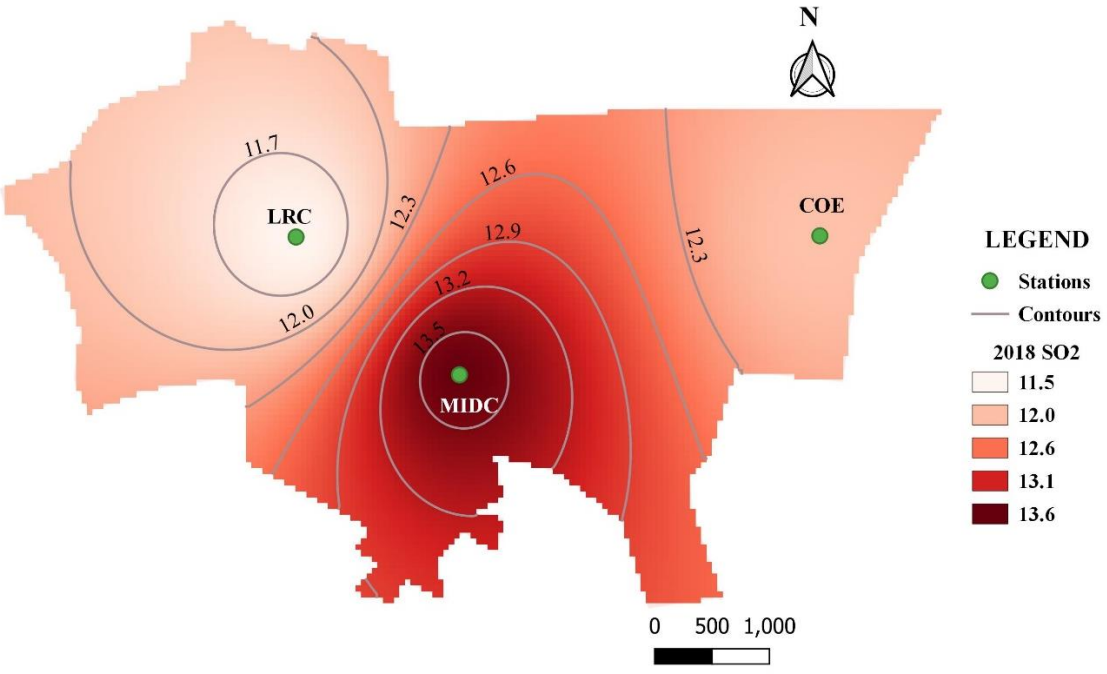


Fig. 4.53 Spatial Variation of SO_2 in 2018

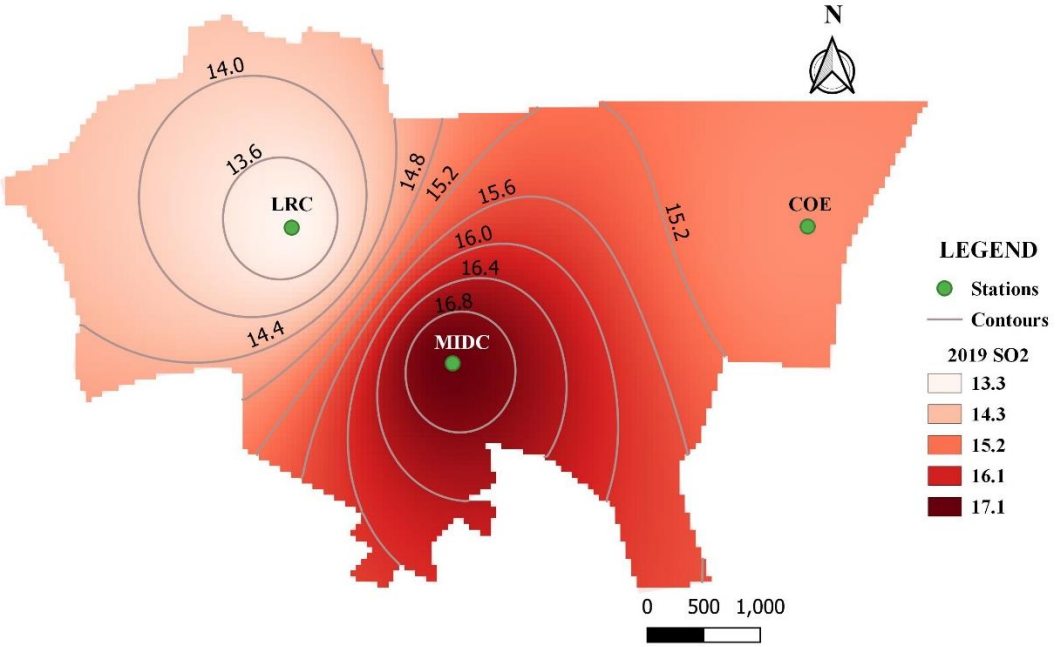


Fig. 4.54 Spatial Variation of SO_2 in 2019

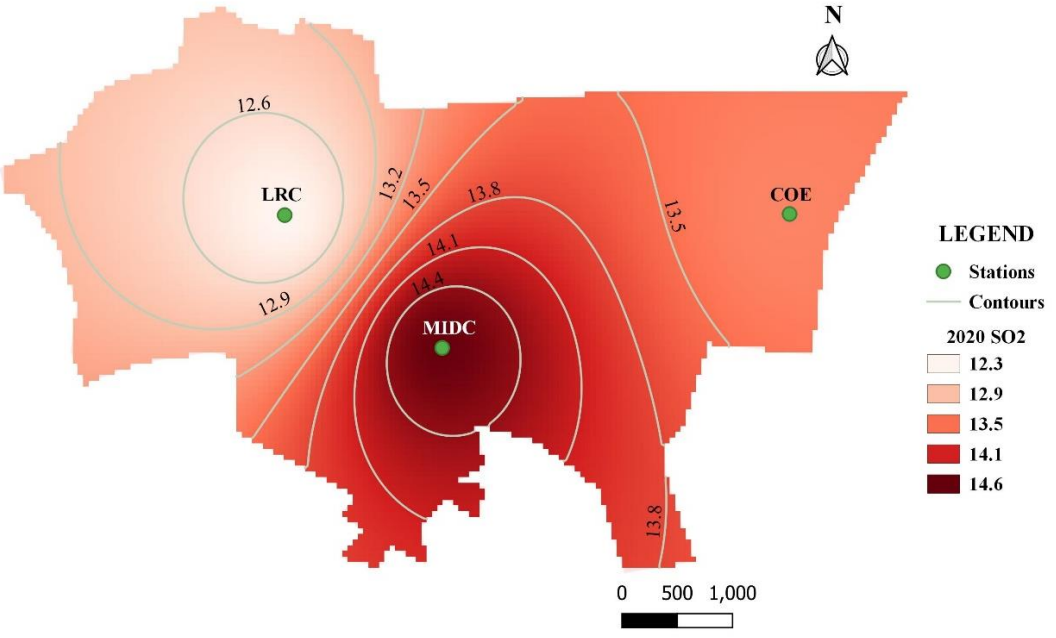


Fig. 4.55 Spatial Variation of SO_2 in 2020

Table 4.16: Comparison of SO_2 concentration in different zones

Year	SO_2 concentration in different zones
2012	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$
2013	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$
2014	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$
2015	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$
2016	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$
2017	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERICAL} \approx (SO_2)_{RESIDENTIAL}$
2018	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$
2019	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$
2020	$(SO_2)_{INDUSTRIAL} > (SO_2)_{COMMERCIAL} > (SO_2)_{RESIDENTIAL}$

***(**colour indication shows a result unusual from other results**)**

4.8.2 Spatial Variation of NOx over Akola city

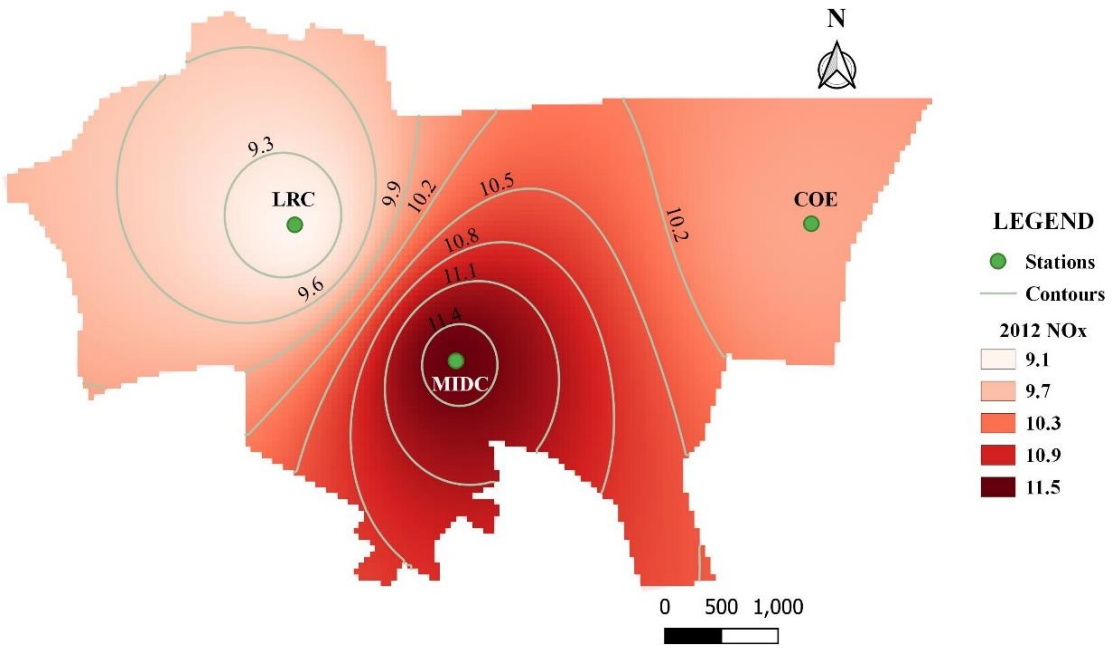


Fig. 4.56 Spatial Variation of NOx in 2012

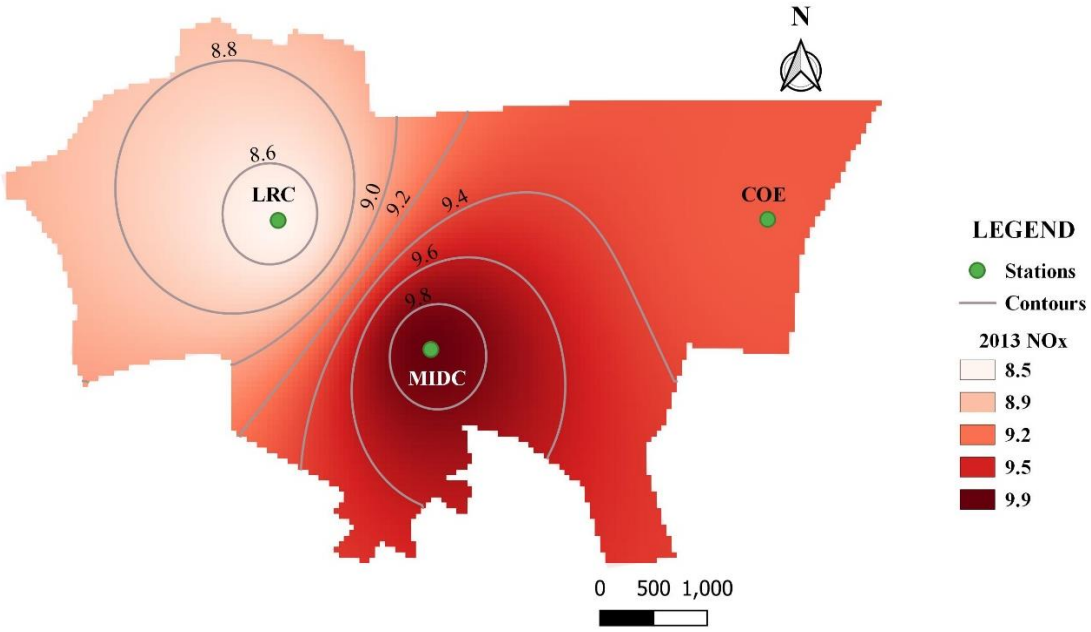


Fig. 4.57 Spatial Variation of NOx in 2013

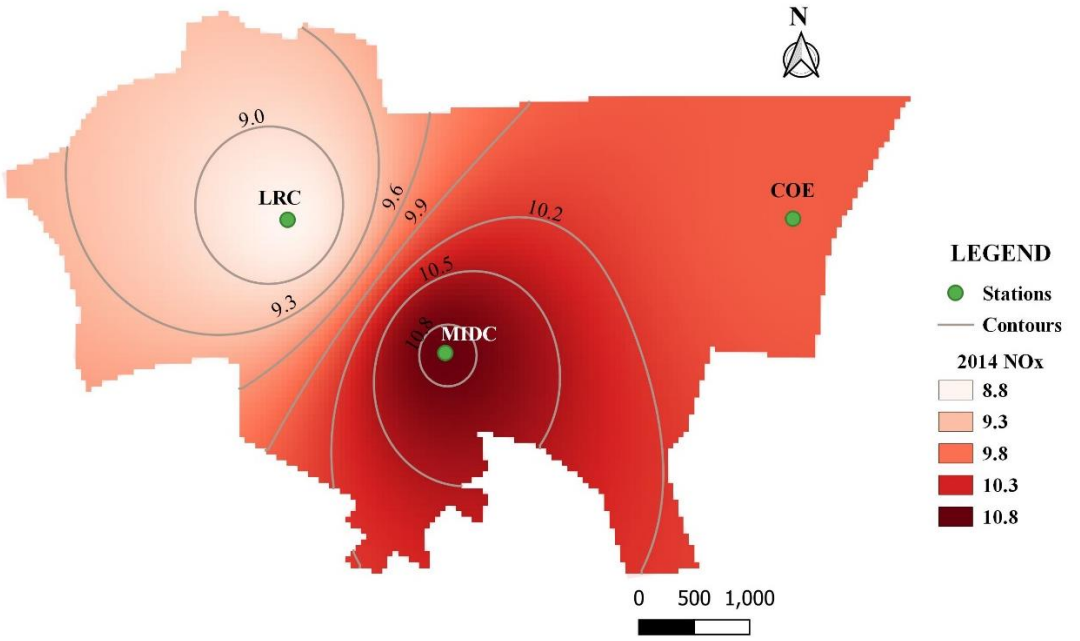


Fig. 4.58 Spatial Variation of NOx in 2014

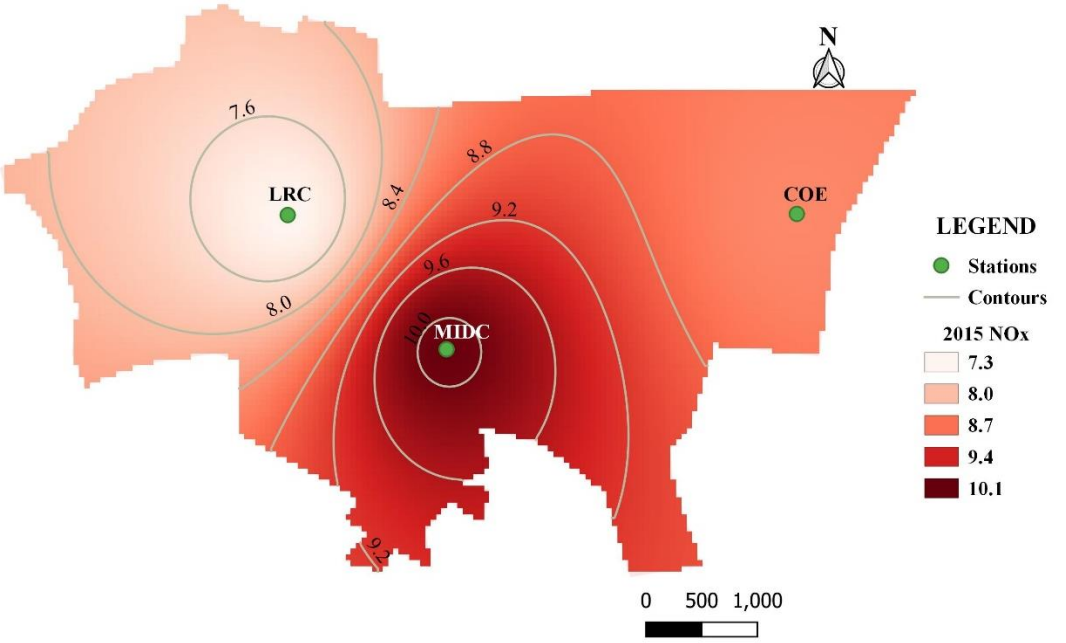


Fig. 4.59 Spatial Variation of NOx in 2015

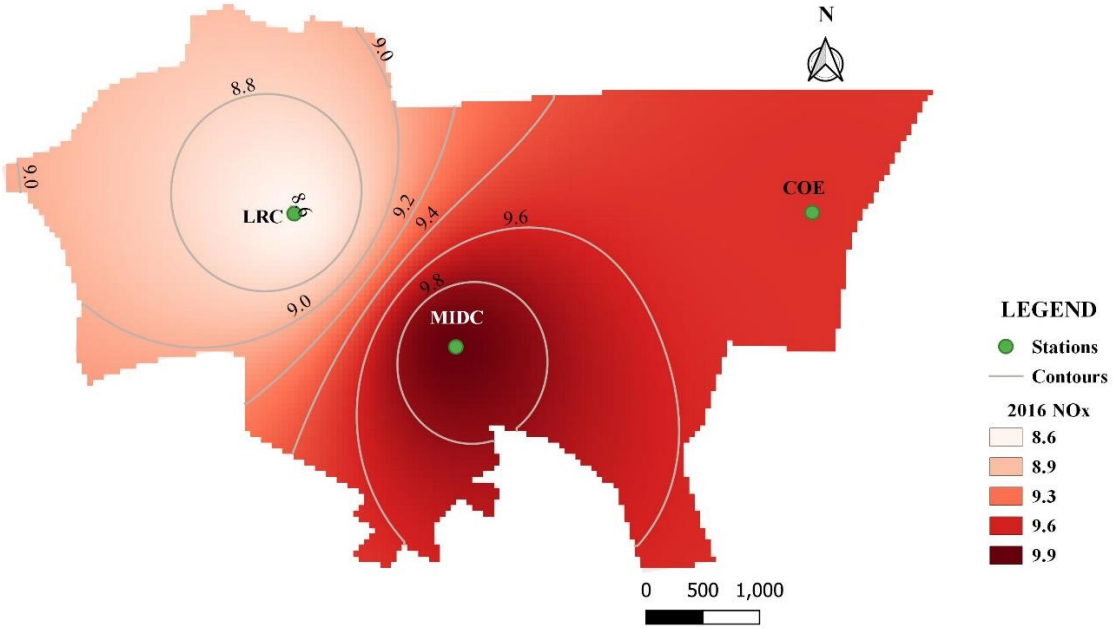


Fig. 4.60 Spatial Variation of NOx in 2016

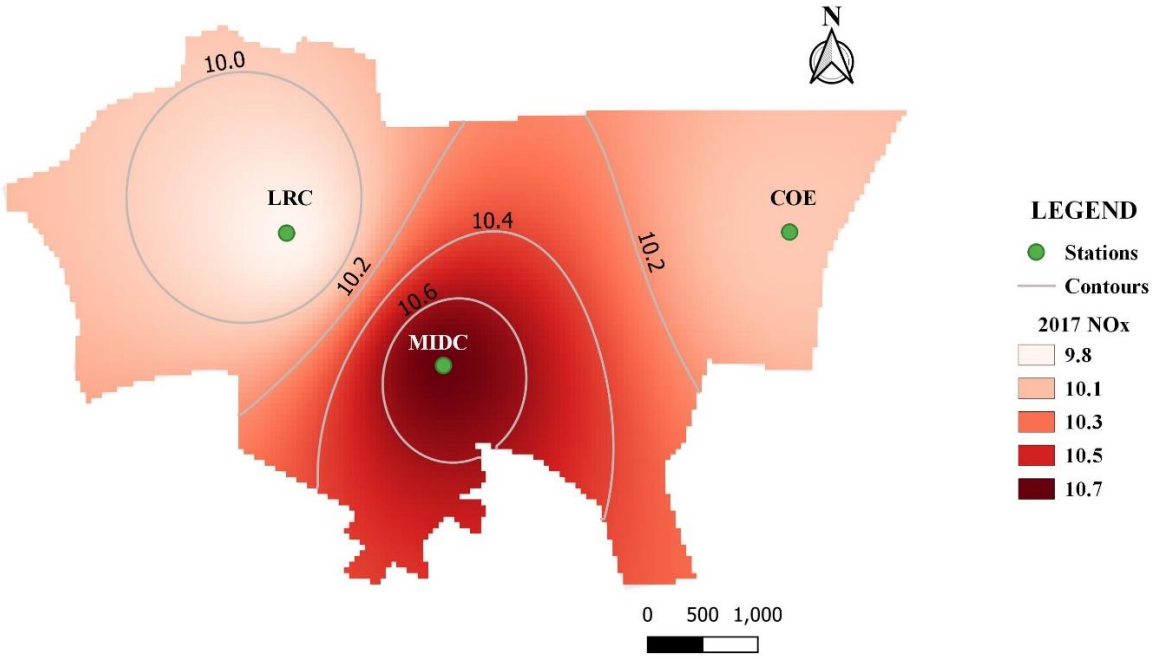


Fig. 4.61 Spatial Variation of NOx in 2017

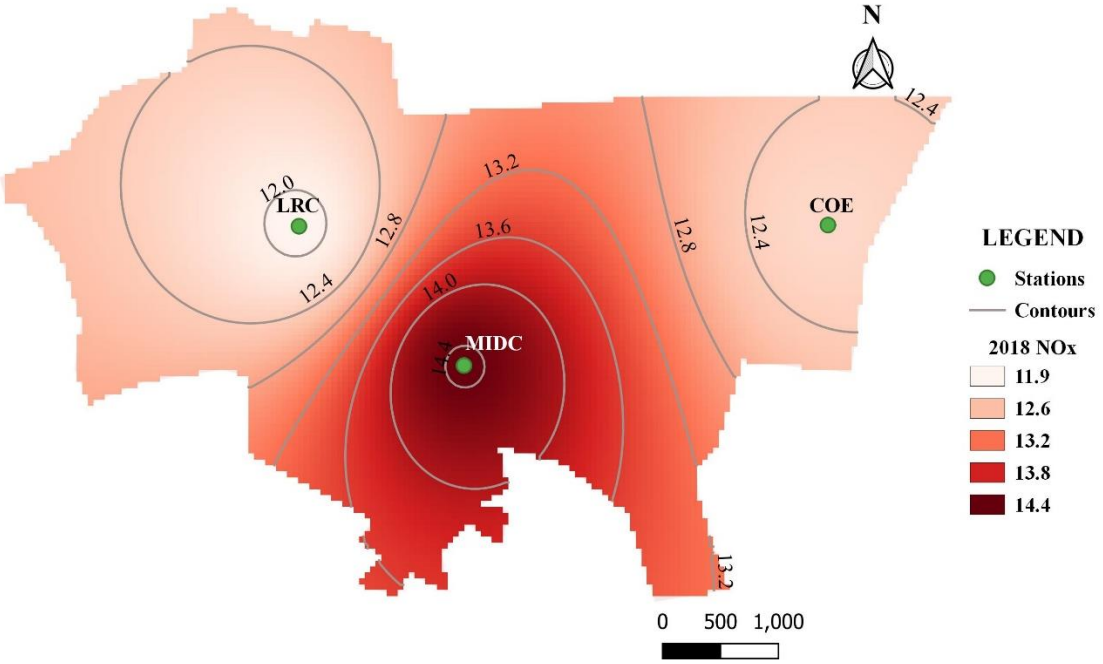


Fig. 4.62 Spatial Variation of NOx in 2018

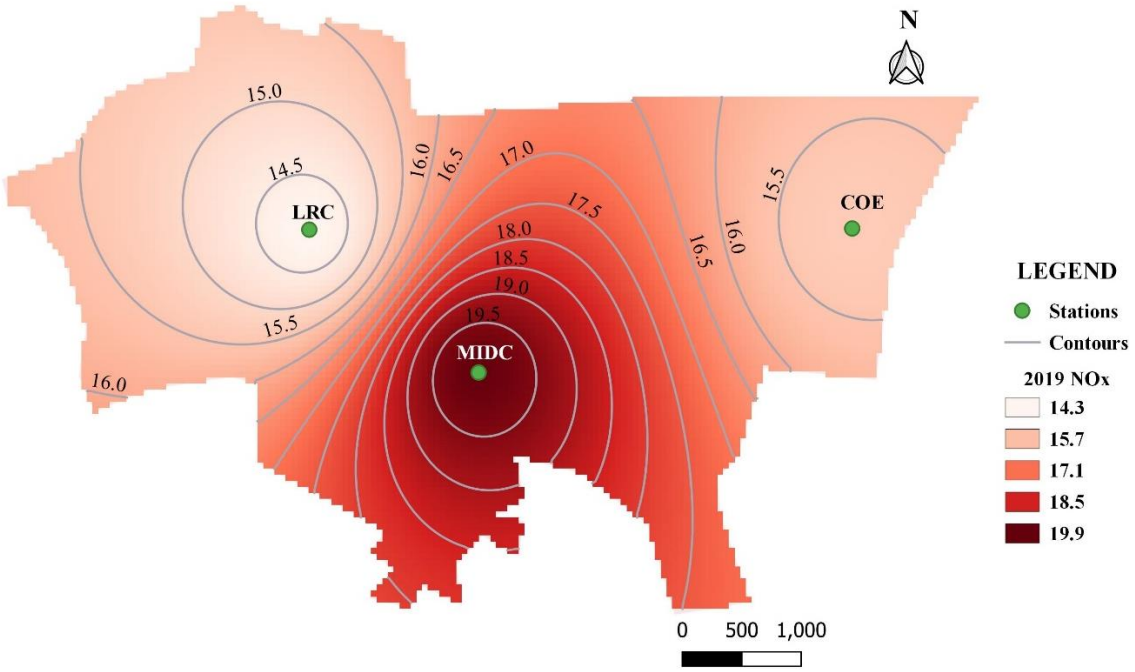


Fig. 4.63 Spatial Variation of NOx in 2019

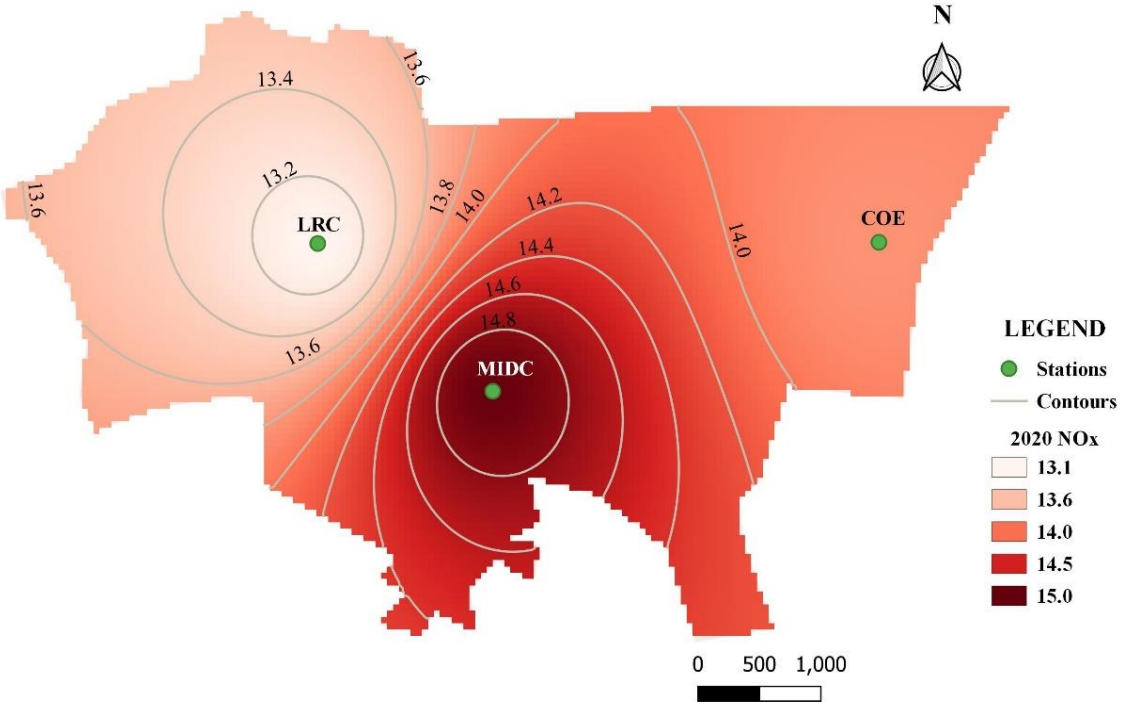


Fig. 4.64 Spatial Variation of NOx in 2020

Table 4.17: Comparison of NOx concentration in different zones

Year	NOx concentration in different zones
2012	$(NOx)_{INDUSTRIAL} > (NOx)_{COMMERCIAL} > (NOx)_{RESIDENTIAL}$
2013	$(NOx)_{INDUSTRIAL} \approx (NOx)_{COMMERCIAL} > (NOx)_{RESIDENTIAL}$
2014	$(NOx)_{INDUSTRIAL} > (NOx)_{COMMERCIAL} > (NOx)_{RESIDENTIAL}$
2015	$(NOx)_{INDUSTRIAL} > (NOx)_{COMMERCIAL} > (NOx)_{RESIDENTIAL}$
2016	$(NOx)_{INDUSTRIAL} \approx (NOx)_{COMMERCIAL} > (NOx)_{RESIDENTIAL}$
2017	$(NOx)_{INDUSTRIAL} > (NOx)_{COMMERCIAL} \approx (NOx)_{RESIDENTIAL}$
2018	$(NOx)_{INDUSTRIAL} > (NOx)_{COMMERCIAL} \approx (NOx)_{RESIDENTIAL}$
2019	$(NOx)_{INDUSTRIAL} > (NOx)_{COMMERCIAL} \approx (NOx)_{RESIDENTIAL}$
2020	$(NOx)_{INDUSTRIAL} > (NOx)_{COMMERCIAL} > (NOx)_{RESIDENTIAL}$

***(**colour indication shows a result unusual from other results**)**

4.8.3 Spatial Variation of PM_{10} over Akola city

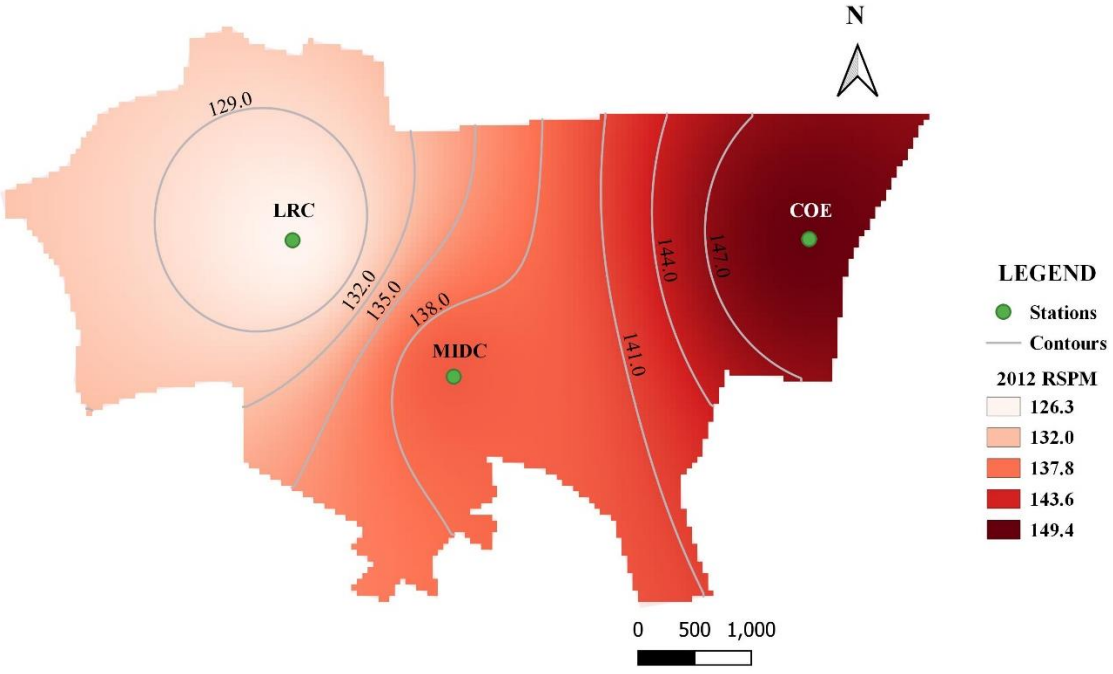


Fig. 4.65 Spatial Variation of PM_{10} in 2012

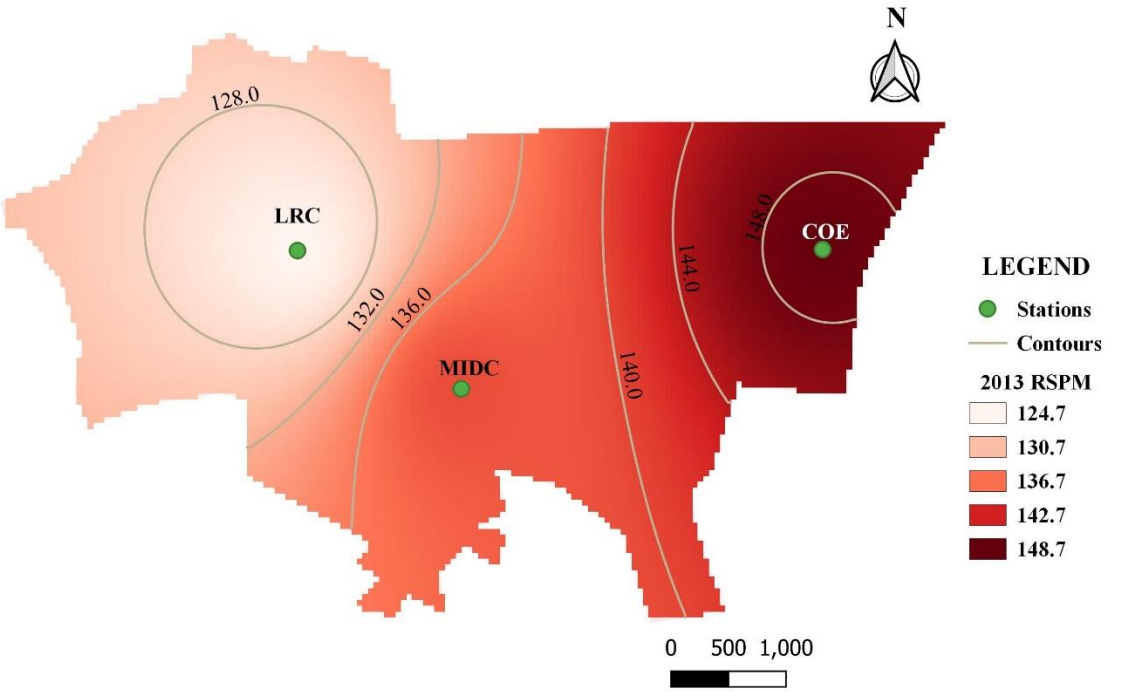


Fig. 4.66 Spatial Variation of PM_{10} in 2013

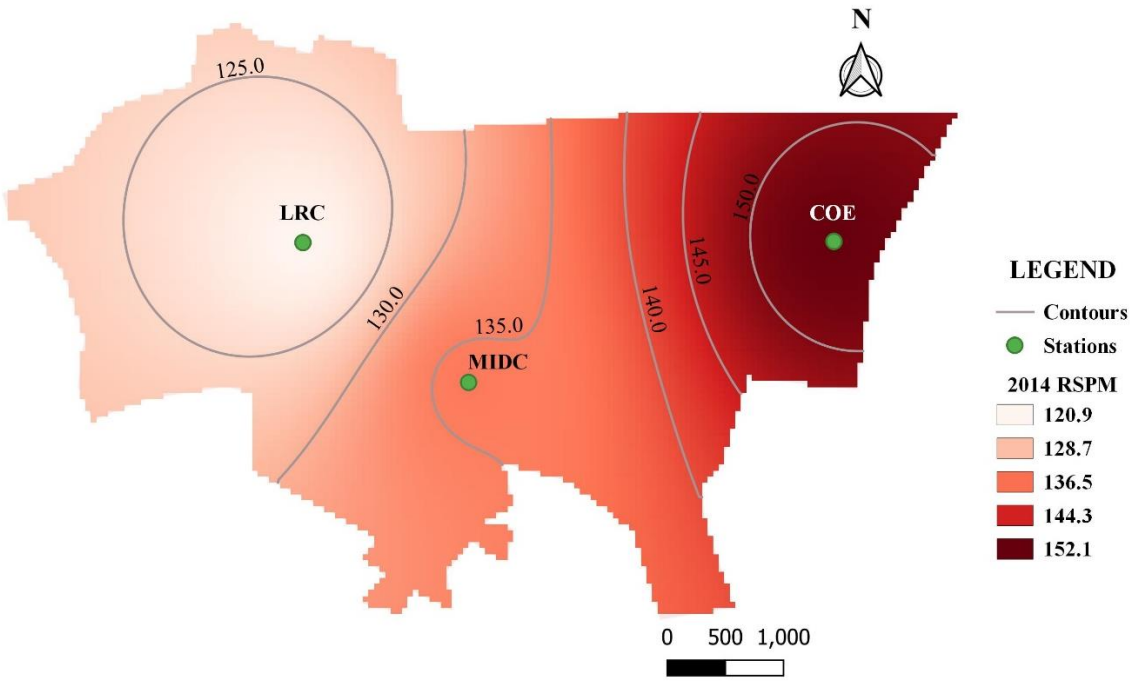


Fig. 4.67 Spatial Variation of PM_{10} in 2014

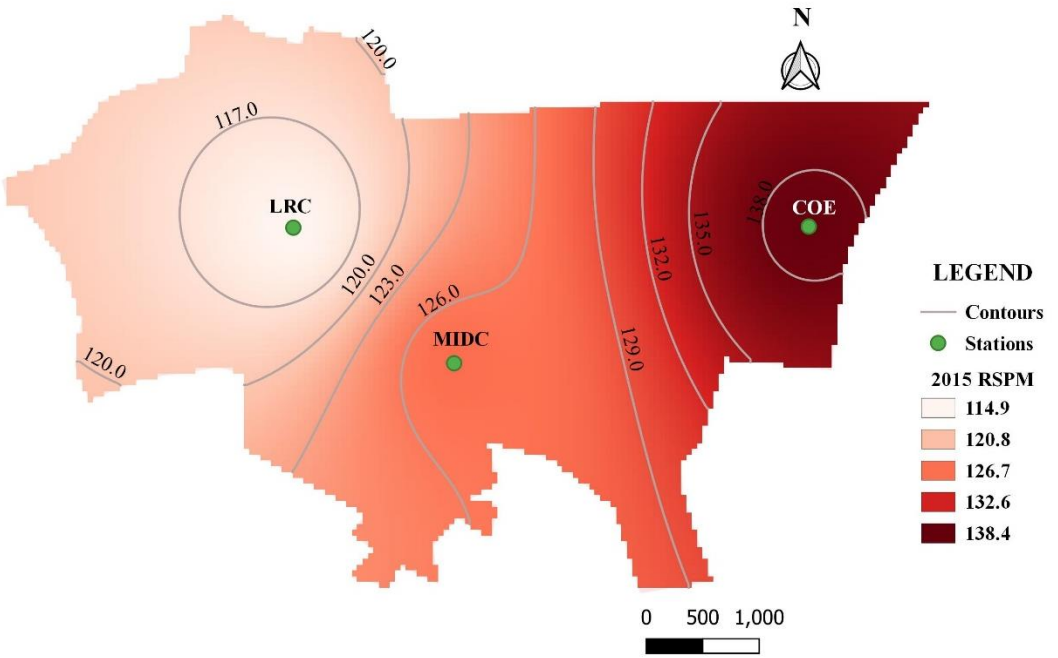


Fig. 4.68 Spatial Variation of PM_{10} in 2015

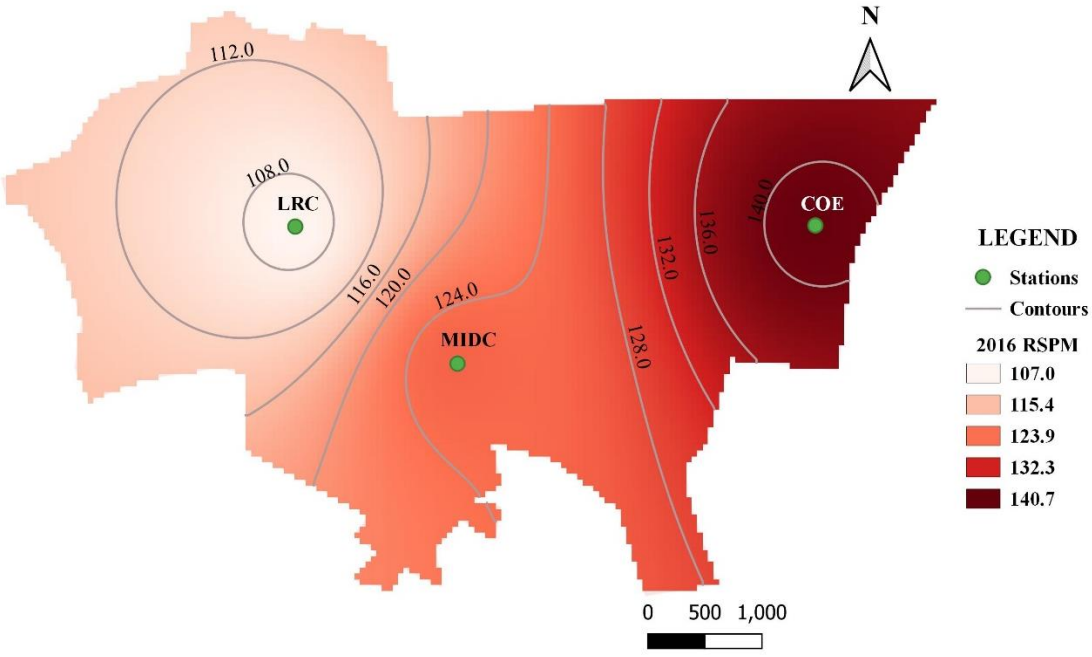


Fig. 4.69 Spatial Variation of PM_{10} in 2016

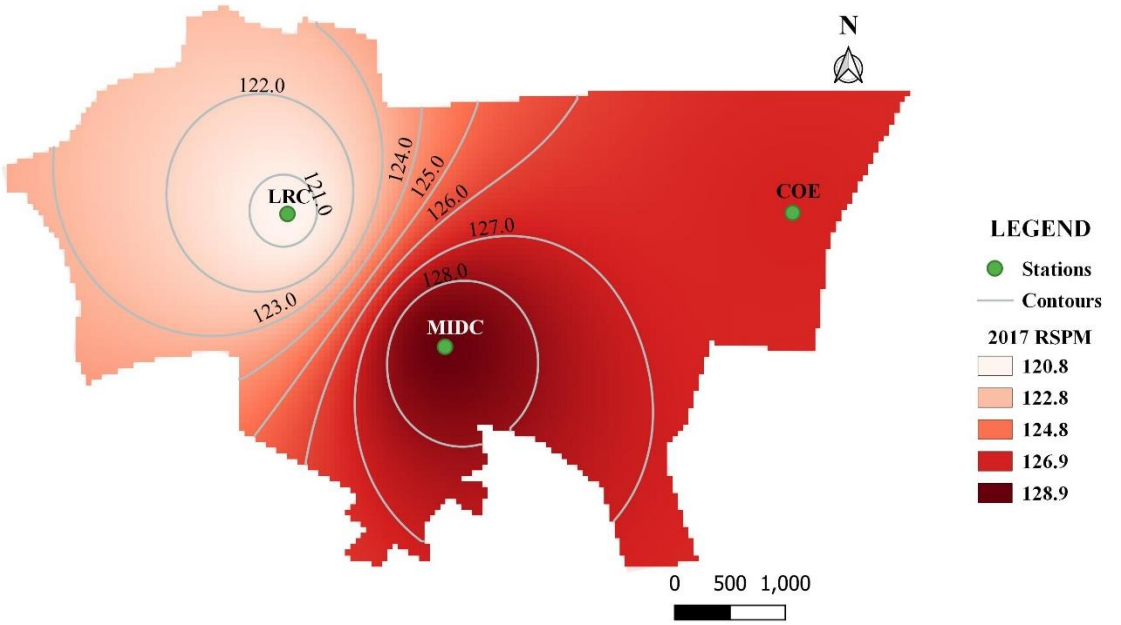


Fig. 4.70 Spatial Variation of PM_{10} in 2017

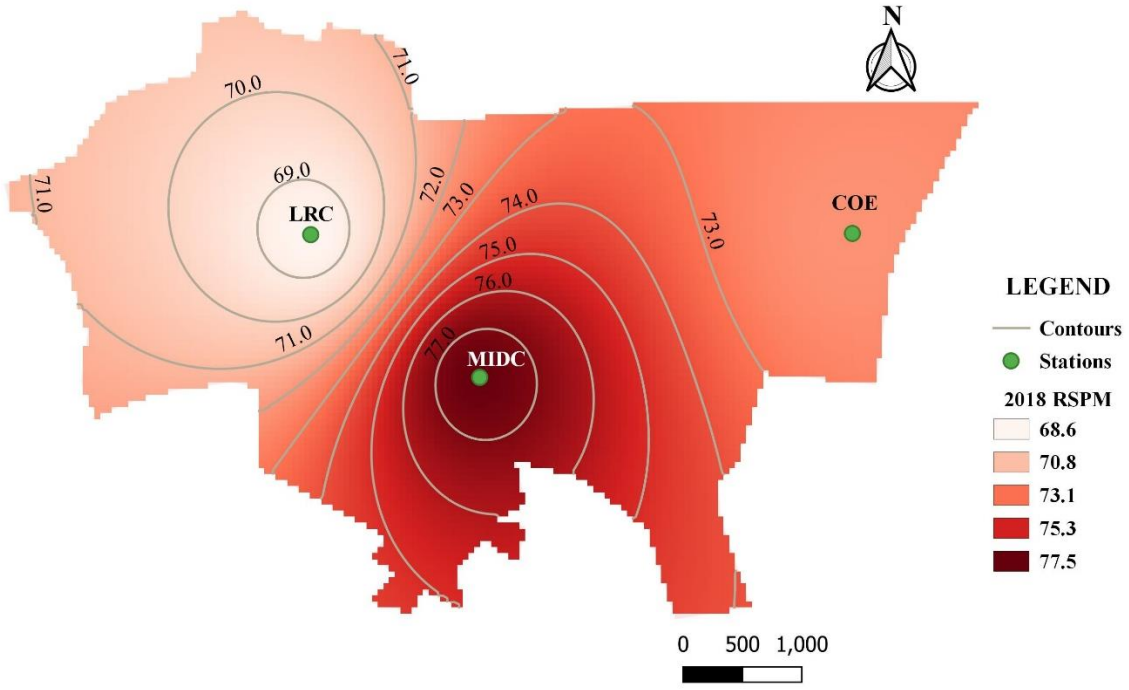


Fig. 4.71 Spatial Variation of PM_{10} in 2018

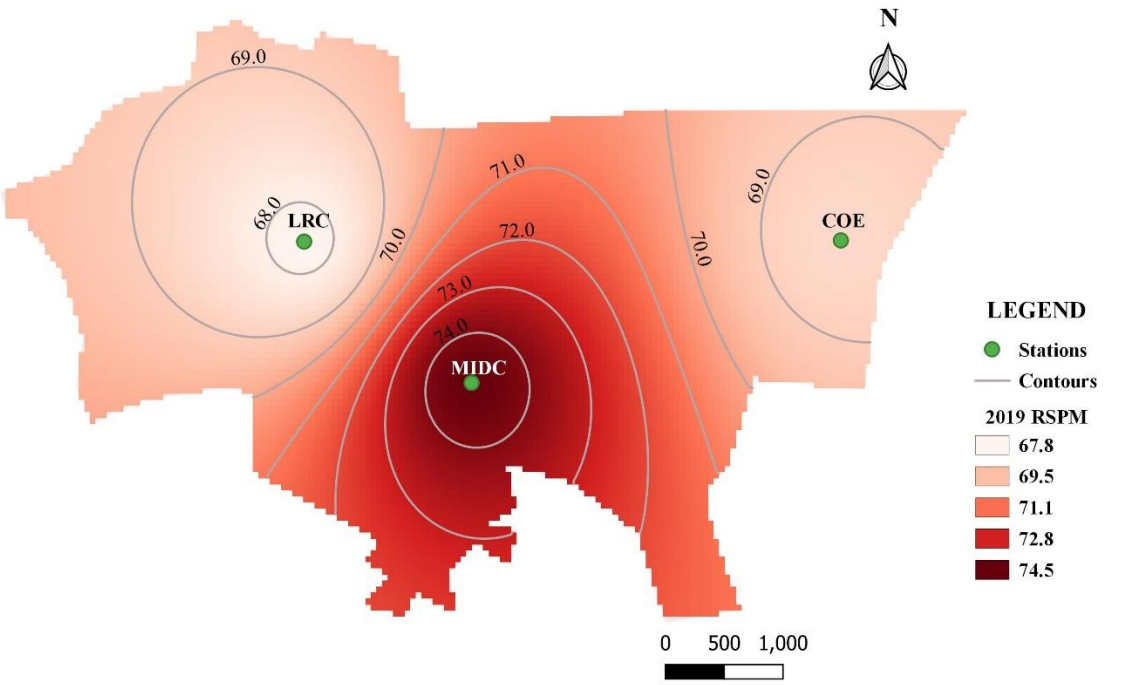


Fig. 4.72 Spatial Variation of PM_{10} in 2019

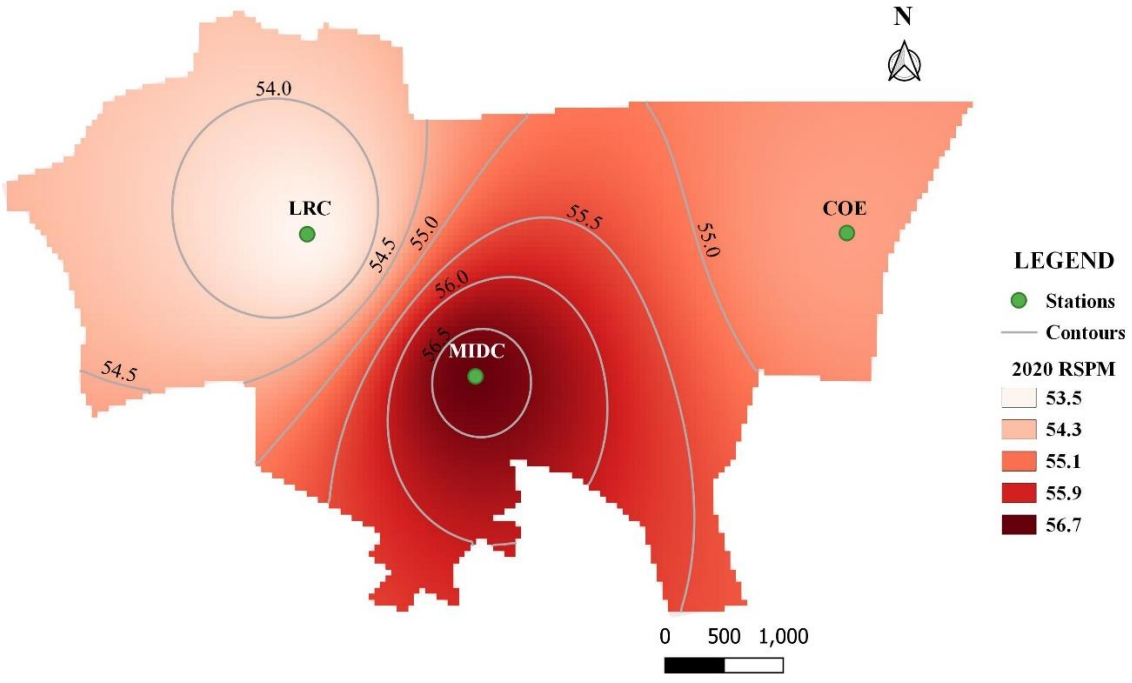


Fig. 4.73 Spatial Variation of PM_{10} in 2020

Table 4.18: Comparison of PM_{10} concentration in different zones

Year	PM_{10} concentration in different zones
2012	$(PM_{10})_{COMMERCIAL} > (PM_{10})_{INDUSTRIAL} > (PM_{10})_{RESIDENTIAL}$
2013	$(PM_{10})_{COMMERCIAL} > (PM_{10})_{INDUSTRIAL} > (PM_{10})_{RESIDENTIAL}$
2014	$(PM_{10})_{COMMERCIAL} > (PM_{10})_{INDUSTRIAL} > (PM_{10})_{RESIDENTIAL}$
2015	$(PM_{10})_{COMMERCIAL} > (PM_{10})_{INDUSTRIAL} > (PM_{10})_{RESIDENTIAL}$
2016	$(PM_{10})_{COMMERCIAL} > (PM_{10})_{INDUSTRIAL} > (PM_{10})_{RESIDENTIAL}$
2017	$(PM_{10})_{COMMERCIAL} \approx (PM_{10})_{INDUSTRIAL} > (PM_{10})_{RESIDENTIAL}$
2018	$(PM_{10})_{INDUSTRIAL} > (PM_{10})_{COMMERCIAL} > (PM_{10})_{RESIDENTIAL}$
2019	$(PM_{10})_{INDUSTRIAL} > (PM_{10})_{COMMERCIAL} \approx (PM_{10})_{RESIDENTIAL}$
2020	$(PM_{10})_{INDUSTRIAL} > (PM_{10})_{COMMERCIAL} \approx (PM_{10})_{RESIDENTIAL}$

***(**colour indication shows a result unusual from other results**)**

CHAPTER- 5

CONCLUSION

Analysis of annual variations in the concentrations of the three criteria pollutants namely, SO_2, NOx and PM_{10} in ambient air has been performed for the duration from year 2012 to 2020 in Akola city. It shows that SO_2 levels have soared up by nearly 75% over these years in the city. Similarly, NOx concentrations have also gone up by nearly 61%, slightly lesser than that of SO_2. This rise in SO_2 and NOx is probably due to increase usage of vehicles and industrial operations leading to higher emissions. However, PM_{10} levels in air have dropped down over the years in the city by nearly 50%. The reason behind this reduction in PM_{10} concentrations are probably due to stringent implementation of emission standards and increased usage of cleaner fuels with less sulphur content.

Determination of Exceedance Factor (EF) has shown that the pollution due to RSPM has been significant over these years in Akola city as high RSPM levels have been recorded. This scenario changed in 2018 when a sudden drop in RSPM concentration was observed and the air pollution due to RSPM changed from critical to moderate. Further, the EF values indicate that the air pollution due to SO_2 and NOx has been low over these years and still under control. However, this scenario might change over the next decade owing to the rapid industrialization and urbanization and if proper preventive and control measures aren't implemented to keep the air pollution in check.

Air Quality Index (AQI) values are obtained for each month of every year from 2012 to 2020 for all the monitoring stations in the city. After studying AQI variations throughout the year, it has come to notice that the air quality is much better during monsoon with lowest AQI values and worsens in post monsoon and winter season with highest AQI values while it seems to be improvising during summers. The good air quality observed in monsoons is because of the effect of precipitation (rainfall) which washes down pollutants to earth surface. Also, the air quality degrades in winter and post monsoon season due to lesser dispersion of pollutants, which is caused by inversion condition prevailing during these periods in the atmosphere. The AQI values represent that the air quality was moderate in the city from 2012 to 2017. The air quality is found to be satisfactory in 2018 and 2019 due to excess reduction in PM_{10} levels. Also, good air quality has been observed

in 2020 which can be credited to the strict lockdown imposed in India due to the global COVID-19 pandemic.

Spatial variation maps of these three pollutants in the city have been generated using IDW interpolation feature of QGIS software for every year from 2012 to 2020. The spatial variation maps of both SO_2 pollutant for the Akola city for the entire study period illustrate that MIDC station and its surrounding region (industrial area) have much higher concentrations, COE station and its commercial zone have intermediate pollutant concentrations while LRC station zone, which is surrounded by residential area has the lowest concentrations. Maps showing spatial variation of NOx represent that its concentrations are highest in the industrial zone of MIDC and lowest in the residential region of LRC station for all the years. However, in 2013 and 2016, these levels rose up in commercial zone of COE station to nearly those in MIDC zone. From 2017-19, NOx values lowered in the commercial zone of COE and are nearly equal to those in LRC zone.

The spatial variation maps of PM_{10} for years 2012 to 2016 show that the highest concentrations are found at COE station and the surrounding commercial area while least concentrations are at LRC station and its residential zone with moderate PM_{10} levels in the industrial zone around MIDC station. However, in 2017, both industrial MIDC station and commercial COE station zones reached nearly same concentrations of PM_{10} which are greater than that at LRC station (residential) zone. From 2018 onwards, PM_{10} concentration is seen at its highest level in MIDC station and its commercial region when compared to the lower levels in area of COE and LRC station. This can be further used to locate sources of the above pollutants in the city and to implement mitigation and control measures.

CHAPTER- 6

REFERENCES

- V. Prathipa, A. Sahaya Raja, International Journal of PharmTech Research, 'Air Quality Assessment and Air Quality Index of Dindigul Town (Tamil Nadu), India– A Case Study', ISSN: 0974-4304 Volume 8, No.6, pp 45-55, 2015.
- Joginder Singh Yadav, Amul Patwal, International Journal of Scientific & Engineering Research, 'Air Quality Assessment over years on Diwali Using GIS Approach', ISSN 2229-5518, Volume 6, Issue 3, March-2015.
- Shiva Chandra Vaddiraju, International Journal of Research in Advent Technology, 'Mapping of Air Pollution Using GIS: A Case Study of Hyderabad', E-ISSN: 2321-9637, Volume 7, No.5, May 2019.
- Awkash Kumar, Indrani Gupta, Jørgen Brandt, Rakesh Kumar, Anil Kumar Dikshit & Rashmi S. Patil, Journal of the Air & Waste Management Association, 'Air quality mapping using GIS and economic evaluation of health impact for Mumbai City', India, ISSN: 1096-2247, Volume 66, No. 5, 470-481, 2016.
- Aman Tyagi & Preetvanti Singh, International Journal of Environmental Engineering and Management, 'Applying Kriging Approach on Pollution Data using GIS Software', ISSN 2231-1319, Volume 4, Number 3, pp. 185-190, 2013.
- Sh. Rahmatizadeh, M. R. Delavar and S. Motesaddi, ISPRS Journal of Photogrammetry and Remote Sensing, 'Design and Development of a Customised GIS for Air Quality Management', Commission VII, WG VII/3, 2004.
- Amrita Thakur, Oriental Journal of Chemistry, 'Study of Ambient Air Quality Trends and Analysis of Contributing Factors in Bengaluru, India', ISSN: 0970-020X CODEN: OJCHEG, Vol. 33, No. (2): Pg. 1051-1056, 2017.
- Richa Rai, Madhu Rajput, Madhoolika Agrawal and S.B. Agrawal, Journal of Scientific Research, Banaras Hindu University, 'Gaseous Air Pollutants: A Review on Current and Future Trends of Emissions and Impact on Agriculture', ISSN: 0447-9483, Vol. 55, Pg.: 77-102, 2011.
- Kishore and Deswal, International Journal on Emerging Technologies, 'Analysis of Air Pollution in Indian Cities - A Literature Review', ISSN No.: 2249-3255, Volume 8, No. (1): Pg.191-195, 2017.

- Abhishek Raj Yadav, Har Amrit Singh Sandhu and Nitin Thakur, International Journal of Current Engineering and Scientific Research, 'Analysis of NO2, RSPM & SPM: a GIS approach', ISSN: 2394-0697, Volume 4, Issue 7, Pg. 63-70, 2017.
- F. Patania, A. Gagliano, F. Nocera & A. Galesi, WIT Transactions on Ecology and the Environment, 'The application of GIS to air quality analysis in Enna City (Italy)', ISSN: 1743-354, Air Pollution XVII, Volume 123, Pg. 75-86, 2009.
- Agarwal, A., Narain, S., Srabani, S., 'State of India's Environment: The Citizens Fifth Report Part I National Overviews', Centre for Science and Environment, New Delhi, 1999.
- Garg, A., Shukla, P.R., Bhattacharya, S., Dadhwal, V.K., 'Sub-region (district) and sector level SO_2 and NOx emissions for India: assessment of inventories and mitigation flexibility', Atmospheric Environment 35, 703–713, 2001.
- Borzacchiello, M. T., Casas, I., Ciuffo, B. and Nijkamp, P., 'Geo-ICT in transportation science'. Vrije Universiteit Amsterdam, Faculty of Economics and Business Administration, 2008.
- Chowdhury, M. A. and Sadek, A., 'Fundamentals of intelligent transportation systems planning'. Artech House, 2003.
- Ziliaskopoulos, A. K. and Waller, S. T., 'An Internet-based geographic information system that integrates data, models and users for transportation applications', Transportation Research Part C: Emerging Technologies, 8, (1-6), pp. 427-444, 2000.
- Knowles, A. K. and Hillier, A., 'Placing history: how maps, spatial data, and GIS are changing historical scholarship'. ESRI Press, Redlands, California, US, 2008.
- Johnson, C. P. and Johnson, J., 'GIS: a tool for monitoring and management of epidemics', Proceedings of Map India 2001 Conference, New Delhi, MIT Press, Cambridge, MA, USA, pp. 7–9, 2001.
- Facchinelli, A., Sacchi, E. and Mallen, L., 'Multivariate statistical and GIS- based approach to identify heavy metal sources in soils', Environmental Pollution 114, (3), pp. 313-324, 2001.
- Lam, N. S., 'Geographical patterns of cancer mortality in China', Social Science and Medicine, 23, (3), pp. 241-247, 1986.

- Guthe, W. G., Tucker, R. K., Murphy, E. A., England, R., Stevenson, E. and Luckhardt, J. C., 'Reassessment of lead exposure in New Jersey using GIS technology', Environmental research, 59, (2), pp. 318-325, 1992.
- Bullen, N., Moon, G. and Jones, K., 'Defining localities for health planning: A GIS approach', Social Science and Medicine, 42, (6), pp. 801-816, 1996.
- Tim, U. S., 'The application of GIS in environmental health sciences: opportunities and limitations', environmental Research, 71, (2), pp. 75-88, 1995.
- Dangermond, J., 'A classification of software components commonly used in geographic information systems', Taylor & Francis, UK, 1990.
- Jerrett, M., Burnett, R. T., Ma, R., pope, C. A., Krewski, D., Newbold, K. B., Thurston, G., Shi, Y., Finkelstein, N., Calle, E., Thun, M. J., 'Spatial Analysis of Air Pollution and Mortality in Los Angeles', Epidemiology, 16, (6), pp. 727-736, 2005.
- J.L. Gunnink, P.A. Burrough, Spatial Analytical Perspectives on GIS, 'Interactive spatial analysis of soil attribute patterns using exploratory data analysis (EDA) and GIS', 1996.
- IS 5182-2 (2001): Methods for Measurement of Air Pollution, Part 2: Sulphur Dioxide (SO_2)
- IS 5182-6 (2006): Methods for Measurement of Air Pollution, Part 6: Oxides of nitrogen (NOx)
- IS 5182-23 (2006): Methods for Measurement for Air Pollution, Part 23: Respirable suspended particulate matter (PM_{10})
- Guidelines for the Measurement of Ambient Air Pollutants Volume-I Guidelines for Manual Sampling & Analyses by CPCB
- http://www.cpcb.nic.in
- https://www.mpcb.gov.in
- https://www.worldweatheronline.com/
- https://www.mpcb.gov.in/air-quality/Akola
- https://windroseexcel.com/guides/how-to-interpret-a-wind-rose-diagram/