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An exploration of detrimental pollutants causing air pollution in India

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Abstract

Air pollution is one of the most alarming environmental concerns for any developing countries as for example India where the quality of air is extremely poor and undefined. It has a significant role for human health and the environment. Poor air quality in India has resulted in the worst conditions in different cities such as New Delhi, Mumbai, Kolkata, Bengaluru etc. The American Environmental Protection Agency (EPA) has identified six pollutants which are known as “criteria'' pollutants. They include particle pollutants (PM), ground-level ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). However, the distribution and the intensity of these pollutants in terms of air quality classification are less known in India. My study investigated the temporal trends of these pollutants in different cities, and the most influential pollutants behind air quality prediction. A secondary dataset found on Kaggle, a data science platform, was used in this study. The study found that the particulate material (PM) was the most influential factors behind the air quality index. However, there was no clear pattern in air pollution concentration over the period from 2015 to 2020 but big cities were more polluted than the smaller. My study also shows the pre and post Covid effects on air pollution. The air pollution level has improved during the covid period because of the lockdown. During the lockdown period India’s government implemented many restrictions leading to an improved air quality.

Language: English
Key Words: Air pollution, Air quality index, Data processing, Statistical Analysis, Correlation

Contents

1 Introduction

Air pollution is the contamination of air due to the presence of substances in the atmosphere which are dangerous for the health of humans and other living organisms. It is also contributing to climate change and causes harm to ecosystems. (Daniel & Vallero,2014). There are many different types of air pollutants such as gases (carbon monoxide, sulphur dioxide, nitrous oxides, methane, carbon dioxide), particulates (organic and inorganic) and biological molecules. Air pollution causes health diseases, allergies, and even death to humans. It can also cause harm to many other living organisms such as animals and food crops. Air pollution also damage the natural environment causing climate change, ozone depletion and acid rain for example. Air pollution is caused by human activities and natural processes. (Lelieveld et al., 2019).

Air pollution occurs when dirt particles, smoke, gases, fumes, or odor are introduced into the atmosphere. Air pollution is another one of the main threatens to the health of humans and different living organisms on Earth. It creates smog and acid precipitation which causes cancer. In this industrial age, air pollution cannot be fully eliminated, however, steps can be taken to decrease the pollution. The government has improved, and continues to develop, guidelines for air quality and ordinances to limit emissions to regulate the air pollution. On an individual level, we can control the pollution by reducing our contribution to the pollution problem by using public transport or bicycle which are eco-friendly. Additionally, buying energy-efficient light bulbs and electrical device or otherwise reducing our electricity use may help to reduce the pollutants released in the production of electricity, which creates most of the industrial air pollution. (Rao & Rao, Tata McGraw-Hill, 2007).

Air pollution and climate change have a complex relationship because black carbon and ozone, increase warming by trapping heat in the atmosphere and on the other hand, light reflecting particles formed by sulphur dioxide have a cooling effect on the climate. (Kandlikar et al.,2010). By reducing air pollution, we can protect our climate. (Arneth et al.,2009)

2 Aims of the study

The main aim of my study is to examine the variation of air quality considering city-wise changes in concentration of pollutants by establishing the answers to three specific questions:

1. Is the air quality in small cities better than in larger cities?
2. Which are the principal pollutants behind the changes?
3. How do concentrations of air pollutants fluctuate over time (2015 to 2020)?

3 Background of my study

Air pollution is one of the major environmental problems for a developing country like India where the level of pollution is high and is causing an increasing number of premature mortalities. There is also steady increase in allergy and asthma because of air pollution (Ghosh et al., 2020). According to the clean air act of the environmental protection agency (EPA) in the USA, there are six air pollutants, also known as “criteria air pollutants”, which are commonly found in most countries. These pollutants are strong enough to destroy the environment and human health and cause property damage (EPA, 2021).

In India, a study estimated 695,000 premature deaths in 2010 due to the unceasing contact with outdoor particulate matter (PM) and ozone pollutants. In many cities, the increasing pollution from the projected growth of industries, residential areas, transport, energy generation, and construction will affect human health severely by 2030. Information on current air pollution trends and intensities, their sources, and different effective interventions to control and minimize pollution, will suggest a cleaner pathway to 2030 (Guttikunda, 2014). My study will present the air quality in different cities in India.

4 Air pollution

Air pollution is the introduction of chemicals, particulate matter, or many biological compounds into the atmosphere which cause discomfort, disease, or death to human. A substance in the air which will be averse to humans and the environment is known as an air pollutant. Pollutants are solid particles, liquid droplets, or gases. Additionally, they will be natural or manufactured. Pollutants are classified into two types as primary or secondary pollutants. Usually, primary pollutants are e.g., directly created either as ash from a volcanic eruption and the carbon monoxide gas from a motor vehicle exhaust or sulphur dioxide released from factories. Secondary pollutants are not issued directly. Rather, they form within the air once primary pollutants react or interact. A vital example of a secondary pollutant is ground level ozone that is one of the secondary pollutants which make up chemical smog. Some pollutants are known as both primary and secondary: they are emitted directly and are formed from other primary pollutants. Air pollution is also defined as any kind of atmospheric condition in which certain substances are present in such concentrations that they may produce undesirable effects on human and on environment. Any visible or invisible gas or particle found in air, which is not part of the original, normal composition. (Donald, 2009).

According to the World Health Organization (WHO), air pollution is contamination of the outdoor and indoor environment by a physical, biological, or chemical, agent which modifies the natural

characteristics of the atmosphere. Motor vehicles, industrial facilities, chemical industries, household combustion devices and forest fires are regular sources of air pollution. Pollutants that concern major public health include such as particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide. Outdoor and indoor air pollution cause respiratory and other diseases, and this is an important source of morbidity and mortality. Around 4.2 million people die every year because of air pollution.

4.1 Types of Air Pollution

Air pollution is classified into two parts: Indoor and outdoor air pollution.

Indoor air pollution is one of the most critical global environmental problems (**Error! Reference source not found.**). Air pollution exposes more people to important air pollutants worldwide than does pollution in outdoor air. Rural people in developing countries may receive as much as two thirds of the global exposure of particles. (Bruce et al., 2000).

Figure 1 Reasons behind indoor air pollution. (Tang et al, 2017)

According to WHO, around 3 billion people are still cooking by using solid fuels in open fires with leaky stoves and it creates smog inside the house, heating the houses. About 2.7 billion people burn biomass (animal dung, crop waste, wood), and another 0.4 billion people use coal. This type of

cooking system and heating produce an elevated level of air pollution with a range of health-disease. (Bulletin of the World Health Organization, 2000).

Urban outdoor air pollution is a vital environmental health problem influencing people in each developed and developing country (**Error! Reference source not found.**). It is estimated that 1.3 million people worldwide more than half of them in developing countries die every year from outdoor air pollution. (Seinfeld&Pandis, 2006).

Figure 2 Causes of outdoor air pollution (Seinfeld, 2006).

5 Air quality

Air quality measures how clean or polluted the air is. Monitoring the quality of air is especially important because good or clean air is required for optimum health for humans, animals, and vegetation. Air quality can be compromised in industries, such as shipping ports, where fossil fuels and diesel are readily used. If the quality of air is compromised, this poses a risk to human health. The poor air quality will limit people's ability to be physically active. When the air quality is good, the air is clear and contains only tiny amounts of solid particles and chemical pollutants. Air quality is measured by the Air Quality Index (AQI) which is based on the concentration of pollutants present in the air at a particular location. (USEPA,2006).

According to British Columbian (BC) report, the term "air quality" means in what state the air around us is. Good air quality refers to clean, clear, and unpolluted air which is essential to maintain

the delicate balance of life on this planet, not just for humans, but also wildlife, vegetation, water, and soil. Poor air quality is a result of many factors, including emissions from various sources, both natural and human induced.

5.1 Air quality index (AQI)

EPA developed AQI table to provide the regular citizen with accurate, up to date and easily understandable information about daily levels of air pollution. Air Quality Index is used by the government agencies to communicate to the public how polluted the air currently is or how polluted it is forecast to become. Public health risks increase as the AQI rises. Different countries have their own AQI, corresponding to different national air quality standards. These are the Air Quality Health Index (Canada), the Air Pollution Index (Malaysia), and the Pollutant Standards Index (Singapore). (CPCB,2021).

According to Johnson et al (2016). air quality index (AQI) is known for measuring the condition of air which is relative to the requirements of one or more biotic species or any human need. AQI is divided into six categories, which are numbered, and each category is defined with different color codes. It provides a number from healthy standard level of zero to a very hazardous level of above 300 to indicate the level of health risk associated with air quality. Principally, green color is defined as a good indicator for air quality, whereas yellow, orange, red, purple, and maroon colors indicate moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous air quality, respectively (Figure 3 Classification of air quality index (modified from Rama Lakshmi 2014)

).

5.2 AQI categories

The National AQI was launched in New Delhi on September 17, 2014. The AQI has six category which are used for classifying the quality of air. The categories are shortly described below in Figure 3:

- Good: Air quality is known as a satisfactory level and air pollution poses negligible risk or no risk at this level.
- Satisfactory: Air quality is acceptable. However, for some pollutants there might be moderate health concerns for a tiny number of people who are not usually sensitive to air pollution.
- Moderately polluted: Members of sensitive groups may experience health issues. The public are not likely to be affected.

- Poor: Everyone might begin to experience health problems. Members of sensitive groups may experience major health effects.
- Very poor: Health warnings of emergency situations. The whole group of population is more likely to be affected.
- Severe: Everyone may experience major health problems.

AQI Category (Range)	PM_{10}(24hr)	$PM_{2.5}$(24hr)	NO_2(24hr)	O_3(8hr)	CO(8hr)	SO_2(24hr)	NH_3(24hr)	Pb(24hr)
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
Moderately polluted (101-250)	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+

Figure 3 Classification of air quality index (modified from Rama Lakshmi 2014)

Table 1 Health impacts classified by Air quality index (modified from Rama Lakshmi 2014)

AQI	Associated Health Impacts
Good	Minimal impact
Satisfactory	May cause minor breathing problem to sensitive people
Moderately polluted	Lung disease, heart disease
Poor	Discomfort to people with heart disease
Very Poor	May cause respiratory illness to people on prolonged exposure
Severe	Serious health impacts on people

From the above (Table 1) shows that health impacts according to the AQI category which indicates the quality of air effects on human health that is briefly described on the above figure.

6 Air pollutants

Major primary pollutants that create air pollution and are produced by human activity are describe in the sub chapters below.

6.1 Sulphur oxides (SO_2)

SO_2 is a particulate matter created by volcanoes and in numerous industrial processes. Since coal and petroleum or rock oil which usually contain sulphur compounds and their combustion generates sulphur dioxide. Further the oxidation of SO_2 that, sometimes occurs within the presence of a catalyst like NO_2, forms H_2SO_4, and result in acid precipitation. This is usually one of the causes for concern over the environmental impact of the use of these fuels as power sources. (Owen et al., 1997).

6.2 Nitrogen oxides (NO_2)

NO_2 is particularly expelled from extreme temperature combustion and is also created naturally during thunderstorms by electric discharge. This reddish-brown toxic gas has a characteristic biting, sharp. NO_2 is one of the most salient air pollutants. (Seinfeld et al., 2016).

6.3 Carbon monoxide (CO)

CO is a colorless, odorless, non-irritating but poisonous gas. It is a product produced by incomplete combustion of fuel such as natural gas, coal, or wood. Transports exhaust is a major supply of carbon monoxide. (Khalil et al, 1999).

6.4 Volatile organic compounds (VOCs)

VOCs are usually divided into methane (CH_4) and nonmethane (NMVOCs). Methane is an extremely efficient greenhouse gas that causes increased global warming. Alternatively, hydrocarbon VOCs are also vital greenhouse gases via their role in producing ozone and in prolonging the life of methane within the atmosphere, though the impact varies depending on local air. (Abhishek, 2011).

6.5 Gaseous pollutants

These pollutants contribute to a great extent in variations of the atmosphere composition and are mainly due to combustion of fossil fuels. Nitrogen oxides are mainly emitted as NO which rapidly reacts with ozone or radicals in the atmosphere forming NO_2. The main anthropogenic sources are

mobile and stationary combustion sources. Ground-level ozone (that differs from ozone present in upper layers of the atmosphere) is not emitted directly into the air but is created by chemical reactions between NO_2 and VOCs in the presence of sunlight. While the anthropogenic SO_2 results from the combustion of sulphur-containing fossil fuels (principally coal and heavy oils), where volcanoes and oceans are its major natural sources. Many of the so-called classical pollutants belong to this category. They are: SO_2, NO_2, CO and O_3. These pollutants have been subject to in depth investigation on their health effect and many air quality guideline values and standards have been defined over time for them. (Beychok, 2005).

6.6 Persistent organic pollutants

These are a toxic group of chemicals. They persist in the environment for long periods of time and their effects are magnified as they move up through the food chain (biomagnification). Biomagnification or bioaccumulation is an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. (Ritter et al, 2007).

6.7 Heavy metals

They include basic metal elements such as lead, mercury Hg, cadmium Cd, nickel, vanadium, chromium, and manganese. They are natural components of the Earth's crust; they cannot be degraded or destroyed, and can be transported by air, and enter water and food chain. In addition, they enter the environment through a wide variety of sources, including combustion, wastewater discharges and manufacturing facilities. They can enter human bodies and at higher concentrations they can become toxic. Most heavy metals are dangerous because they tend to bio-accumulate in the human body and have adverse effects (mercury and its compounds). (Balasubramanian & Wang, 2009).

6.8 Particulate matter (PM)

PM is the generic term used for a complex mixture of extremely small particles and liquid droplets that are suspended in the air, which vary in size and composition and are produced by a wide variety of natural and anthropogenic sources. Major sources of particulate pollution are industries, power plants, incinerators, motor vehicles, construction activity, fires, and natural windblown dust. The size of the particles varies ($PM_{2.5}$ and PM_{10} have an aerodynamic diameter <2.5 and <10

respectively) and different categories have been defined: Ultrafine particles: <0.1 in aerodynamic diameter, fine particles: <1 mm, and coarse particles >1 mm. In common ways of speaking, the PM_{10} and $PM_{2.5}$ are respectively, referred to as coarse and fine PM. The size of the particles determines the respiratory tract where they will deposit: PM_{10} particles deposit mainly in the upper respiratory tract while fine and ultra-fine particles are able to flow deeper reaching lung alveoli. (Seinfeld &Pandis, 1998).

7 Sources of Air pollution

There are various sources of air pollution which are described in the bellow (**Error! Reference source not found.**).

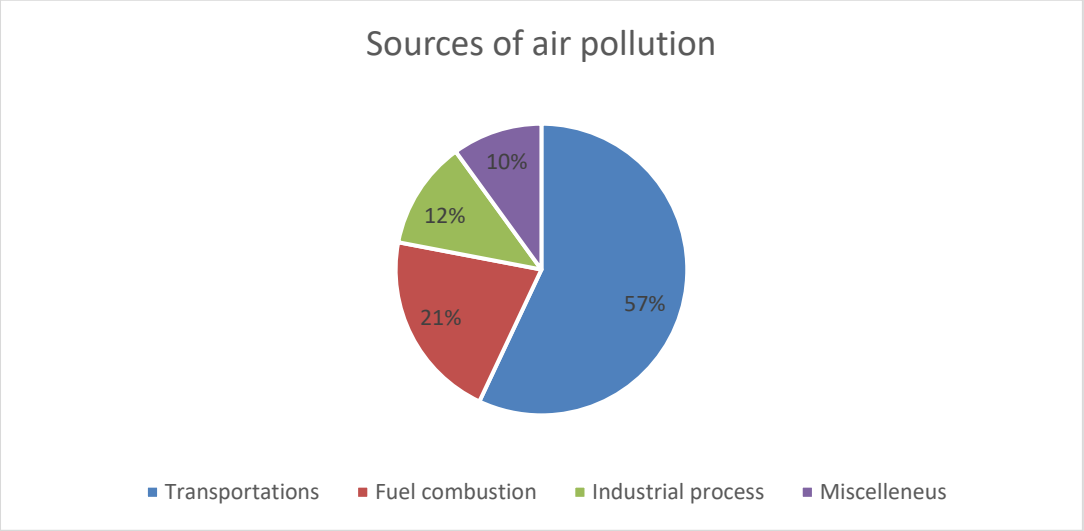

Figure 4 Contribution level of sources of primary pollutants (modified from Wikipedia)

7.1 The main sources of Air pollutions

7.1.1 Automobiles

Motor vehicles using fossil fuels are a major source of air pollution throughout the urban areas. They transmit various pm, lead, nitrogen, hydrocarbons, and carbon monoxide. In strong sunlight, certain of these hydrocarbons and oxides of nitrogen could also be converted into photochemical

pollutants of oxidizing nature within the atmosphere. Additionally, diesel engines when misused or badly adjusted can emit black smoke and malodorous, fumes.

7.1.2 Industrial pollution

Burning of fuel for heat production and power produces smoke, sulphur dioxide, nitrogen oxides and fly ash. Petrochemical industries produce organic halides, hydrochloric acid, and hydrogen fluoride. Many industries release carbon monoxide, carbon dioxide, ozone, hydrogen sulphide and sulphur dioxide. Industries also discharge their waste from high chimneys at high temperature and high speed.

7.1.3 Domestic source

Domestic combustion of coal, wood or oil is a major source of smoke, dust, sulphur dioxide and nitrogen oxides.

7.1.4 Tobacco smoke

The most direct and important source of pollution affecting the health of many people. Even people who do not smoke might inhale the smoke created by others (i.e., passive smoking).

8 Effects of air pollution

Air pollution is harmful to our health, and it impacts the environment reducing visibility and blocking sunlight, causing acid rain, and harming forests, wildlife, and agriculture. Along with decreasing human health, air pollution can cause a variety of environmental effects described in the sub-chapter below:

8.1 Acid rain

Acid rain is precipitation that contain harmful amounts of nitric and sulfuric acids. These acids fall to the Earth either as wet or dry precipitation. In the environment, acid rain harms forest and causes soils and water bodies to acidify, decreasing the water unsuitable for few fish and wildlife. It also speeds the decay of buildings, statues, and sculptures which are part of our national heritage. Acid rain has destroyed ponds, rivers, and soils, leading to damaged wildlife and forests. (Kjellstrom et al.,2006).

8.2 Eutrophication

This is a condition where high concentrations of nutrients stimulate mass occurrences of microalgae, that, in turn, can cause fish kills and loss of plant and animal diversity. Although eutrophication is a natural method within the ageing of lakes and estuaries, and coastal zones, human activities will greatly accelerate eutrophication by increasing the nutrients discharge to the aquatic ecosystems. Air emissions of nitrogen oxides from power plants, cars, trucks, and different sources contribute to the quantity of nitrogen getting into aquatic ecosystems. (Smith et.,1999).

8.3 Haze

Haze is caused when sunlight encounters small (about 0.1 micron with diameters) pollution particles in the air. Haze obscures the clarity, color, texture, and form of what we see. Some haze-causing pollutants are directly transmitted into the atmosphere by sources such as industrial facilities, trucks, automobiles and power plants, and construction activities. Many others are forming when gases transmitted into the air form particles as they are carried downwind.

8.4 Effects on wildlife

Poisonous pollutants in air, or deposited on soils or surface waters, will impact wildlife in a multiple of ways. As humans, animals will face health issues if they are exposed to sufficient concentrations of air toxicants over time. Air toxicants are contributing to birth defects, reproductive failure, and illness in animals. Persistent toxic air pollutants are of particular concern in aquatic ecosystems. These pollutants accumulate in sediments and might bio magnify in tissues of animals at the top of the food chain to concentrations many times higher than within the water or air. (David et al.,2010).

8.5 Ozone depletion

Ozone is a gas which occurs at ground-level and in Earth’s upper atmosphere, known as stratosphere. At the level of ground, ozone is a pollutant which can damage human health. In the stratosphere, however, ozone forms a layer which protects the life on earth from the sun's harmful ultraviolet (UV) rays. But this ’good’ ozone is slowly being destroyed by man-made chemicals which are referred to as ozone-depleting substances, as well as chlorofluorocarbons, hydrochlorofluorocarbons, and halons. These substances were formerly used and are sometimes still used in aerosol propellants, pesticides, solvents, fire extinguishers and coolants. Thinning of the protective ozone layer can cause increased amounts of UV radiation to reach the Earth, which may

lead to more cases of skin cancer, cataracts, and impaired immune systems. UV may also reduce crop yields sensitive crops, such as soybeans. (Abarca & Casiccia,2002).

8.6 Crop and forest damage

Air pollution harms crops and trees in a variety of ways. Ground-level ozone will lead to reductions in agricultural crop and commercial forest yields, decreased growth and survival of tree seedlings, and inflated plant susceptibility to illness, pests, and different environmental stresses (e.g., harsh weather). As represented above, crop and forest harms will also result from acid rain and increased UV radiation caused by ozone depletion. (Frouz et al., 2022)

8.7 Global climate change

The Earth's atmosphere holds a delicate balance of naturally occurring gases that trap some of the sun's heat close the Earth's surface. Most of the outgoing heat is absorbed by greenhouse gases (CO_2, methene) and is re- radiated back to earth to warm the planet. Since human started burning fossil fuels, created more greenhouse effect than are needed- causing the earth to become overheated, it is known as global warming. Global warming may have vital impacts on agriculture, water resources, human health, forests, wildlife, and coastal areas proved by science (Seinfeld et al.,1998).

8.8 Health effect

The health effects caused by pollution might embody problems in wheezing, coughing, bronchial asthma and worsening of existing metabolic processes and viscus conditions. These effects may result in inflated medication use, inflated doctor or emergency department visits, a lot of hospital admissions and premature death. The human health effects of poor air quality square measure way reaching, however chiefly influence the body's system and therefore the vascular system. Individual reactions to air wastes rely upon the kind of pollutant an individual is exposed to, the degree of exposure, and therefore the individual's health standing and biological science. (Epa.gov, 2006). All over the world, the children have high exposure to air pollution are at a high level of risk to improve health issues such as asthma, pneumonia, and other various respiratory infections. Because children are at the most times playing at outdoors, they are more vulnerable to harmful of air pollution. There are also increased risks of having low birth weights for children in such cities. World Health Organizations gave out reports which show that the highest concentrations of matter particles in the air are found in countries that have low economic power, high poverty and increasing rates of growth. However, in the U.S. despite passing the Clean Air Act in the year 2002,

almost 146 million citizens of Americans are living in areas where the concentration of some air pollutants are higher than the federal standards. Measure to protect children's health have been taken to in cities like India and New Delhi where vehicles use natural gas that is compressed so as to help in the elimination of pea soup smog. (Anderko et al., 2020).

8.9 Other effects

Artificial air pollution may be detectable on Earth from distant vantage points such as other planetary systems via atmospheric SETI – including NO_2 pollution levels and with technology to today. (Wright, 2021)

9 Material and methods

This chapter describes the research procedure that was used in the collection and analysis of the data. It includes the data source, research design, data collection and method of data analysis and presentation. In conducting my study, the following methodology was adopted in collecting data and information, for the preparation of my thesis.

9.1 Data

A dataset found on Kaggle (Air Pollution Dataset.xlsx), a data science platform, makes up the raw data for this study. These data are available as a comma separated values (.csv) format. In this dataset, 26 pollutants related features across 26 cities of India have been recorded from 2015 to 2020. This dataset is also known as 'Historical Daily Ambient Air Quality Data', which is released by the Indian Ministry of Environment and Forests and Central Pollution Control Board under the National Data Sharing and Accessibility Policy. (data.gov, 2021)

This dataset consists of the records of 16 features (Figure 5) brief information about the Air Quality data; city, date, $PM_{2.5}$, PM_{10}, NO, NO_2, NOx, NH_3, CO, SO_2, O_3, Benzene, Toluene, Xylene, AQI, and AQI_Bucket with 29,531 observations. It is a combination of both float and text (object) type data.

According to the Centers for Disease Control and Prevention (CDC, 2021), EPA has identified six pollutants which are known as "criteria'' pollutants. Criteria pollutants refer to the pollutants which are commonly found. It includes particle pollutants O_3, CO, SO_2, NO_2, and Pb. These pollutants harm human health and environment, and damage properties. EPA treated them as criteria pollutants because more than the permissible amount in the human body is highly detrimental. That is why a regulation is set on their emission from anthropogenic activities. Among these pollutants, PM and O_3 are the most widespread threats to health (DEC, 2021). This air quality dataset has the records

on five of the criteria pollutants along with other factors. At this project planning stage, this dataset satisfies the requirements of features and observations towards meeting the project objective.

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Date          29531 non-null object
Month         29531 non-null int64
Day           29531 non-null int64
Year          29531 non-null int64
PM2.5         24933 non-null float64
PM10          18391 non-null float64
NO            25949 non-null float64
NO2           25946 non-null float64
NOx           25346 non-null float64
CO            27472 non-null float64
SO2           25677 non-null float64
O3            25509 non-null float64
Benzene       23908 non-null float64
Toluene       21490 non-null float64
Xylene        11422 non-null float64
AQI           24850 non-null float64
AQI_Bucket    24850 non-null object
Longitude     29531 non-null float64
Latitude      29531 non-null float64
dtypes: float64(14), int64(3), object(3)
memory usage: 4.5+ MB
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Figure 5 Brief information about data set (NDSAP,data.gov,2021).

10 Result

10.1 Most polluted city

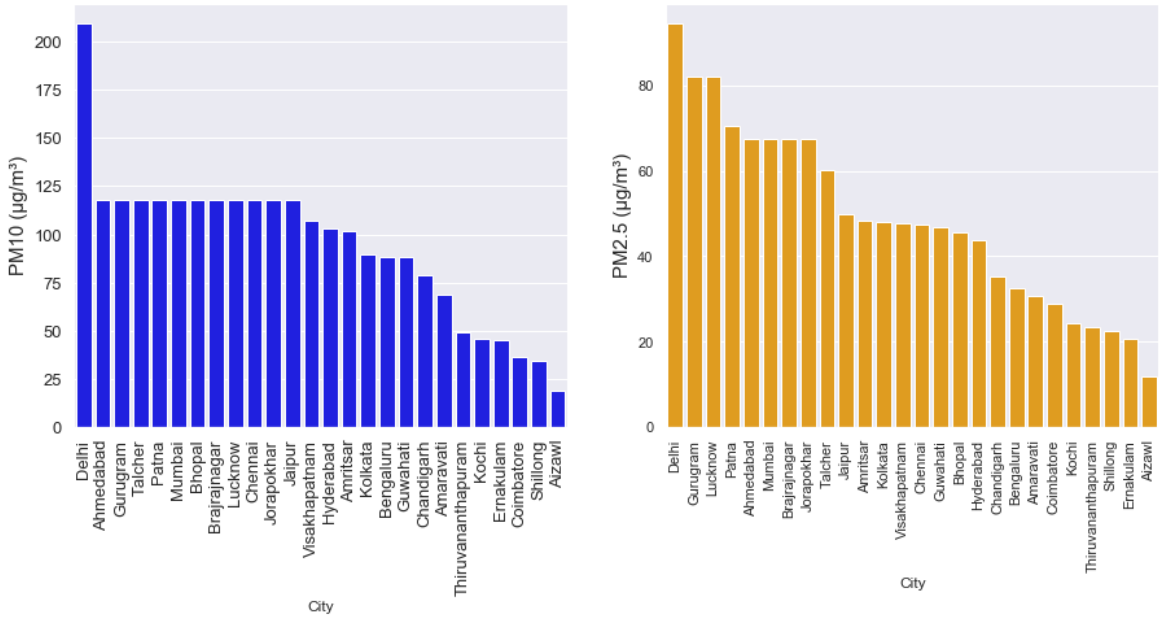

Figure 6 Average concentration of PM_{10} (ug / m3) and $PM_{2.5}$ in different cities

In Figure 6 I can see that Delhi has a high concentration of PM_{10} and $PM_{2.5}$ whereas Shillong and Aizawl have lowest levels. On the other side Aizawl is also a big city but the population level very low and here the economy is basically sustained by government services. Major reasons behind the rise of PM10, PM2.5 levels in Delhi are increasing traffic, dust, and smoke from fires.

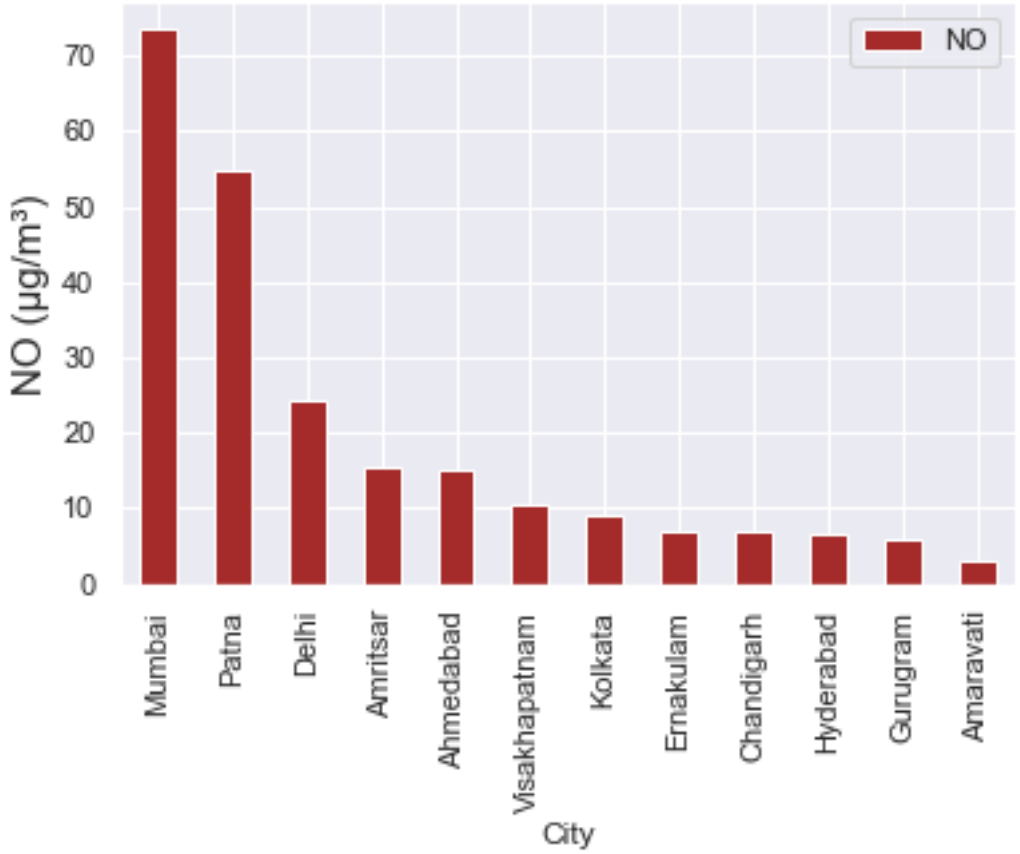

Figure 7 Concentration of Nitric Oxide (ug / m3) in different cities

Here I can see from Figure 7 that Mumbai has the highest levels of NO whereas Gurugram and Amaravati have quite less. Major spike of NO in the commercial capital of India are causing respiratory ailments, hematologic side effects, metabolic disorders, low blood pressure, nausea, vomiting and diarrhea.

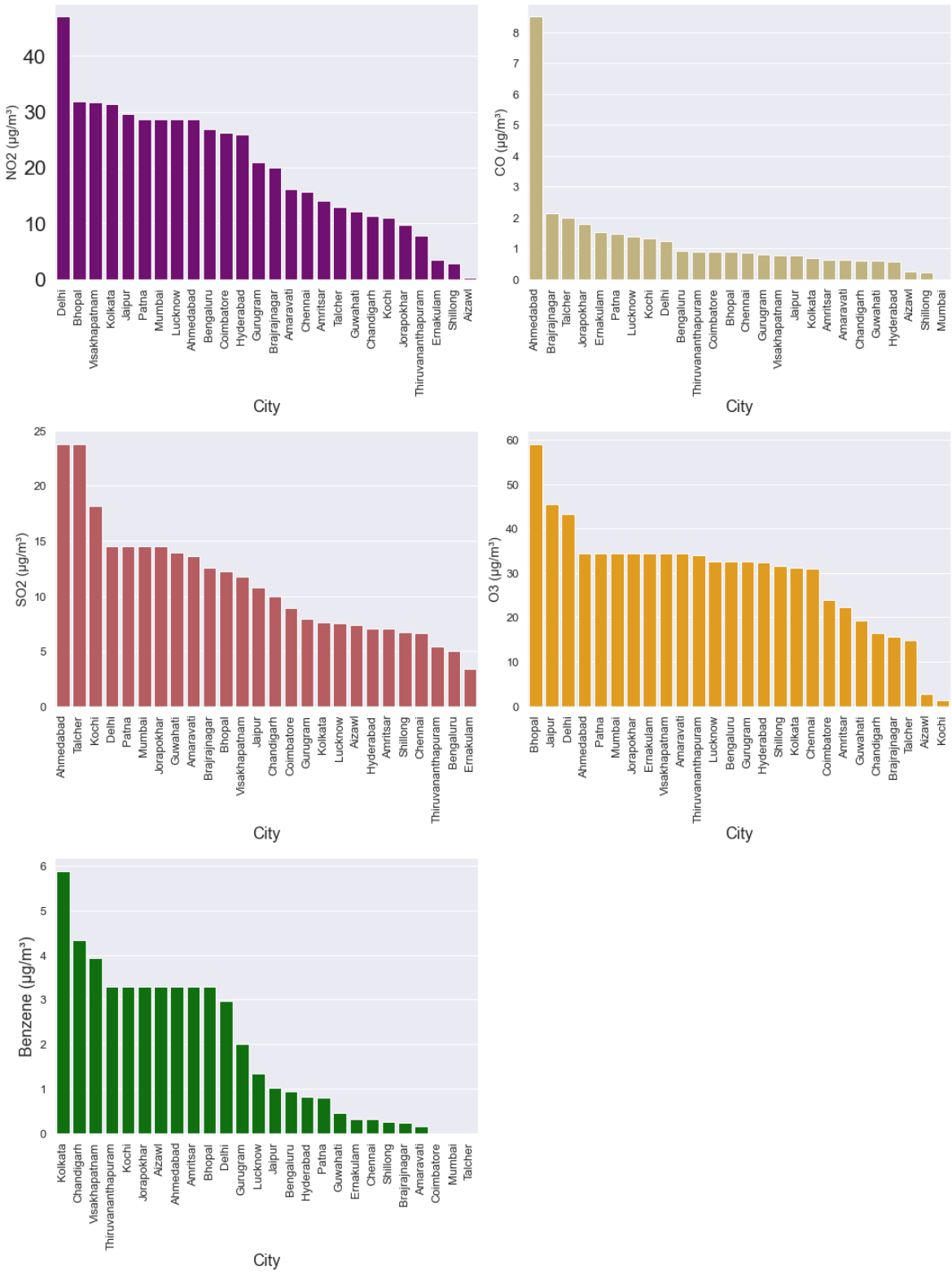

Figure 8 High concentration of NO_2 (ug / m3), CO, SO_2, O_3 and Benzene.

Ahmedabad has the highest pollution when sulphur dioxides and carbon monoxide is concerned, whereas Gurugram and Kolkata are the most polluted due to ozone and benzene respectively. On

a broader view, Ernakulam and Amaravati seem to be less hazardous compared to other cities Figure 8.

10.2 Distribution of air polluted (2015-2020)

10.2.1 Air pollution trends in Delhi

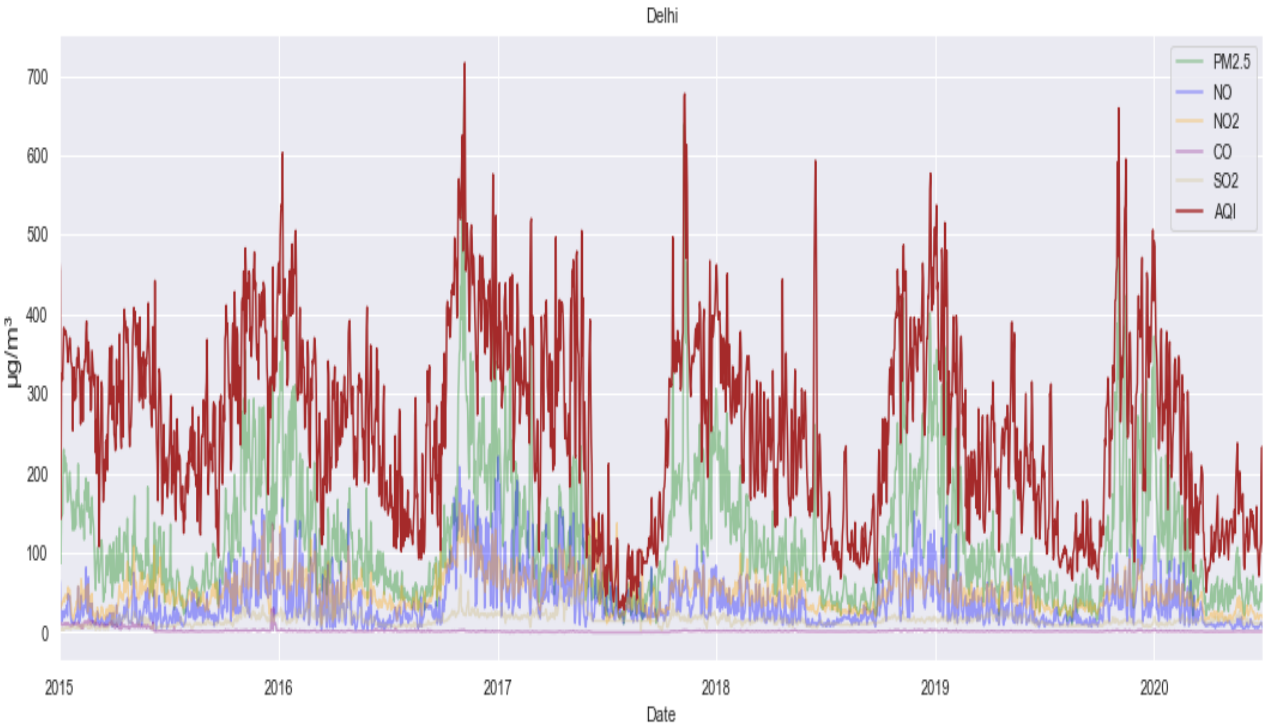

Figure 9 Concentration of pollutants (ug / m3) in air (2015-2020) in Delhi

The air quality basically depends on the present of the amount of individual pollutants. We can see in Figure 9 that pollution levels for NO_2 is moderately polluted, CO was "good" (very low) and SO_2 was "Satisfactory". However, $PM_{2.5}$ levels were rated as "Severe". Here the concentration of $PM_{2.5}$ is very high so that the overall period would be rated as "Severe".

10.2.2 Air pollution trends in Bengaluru

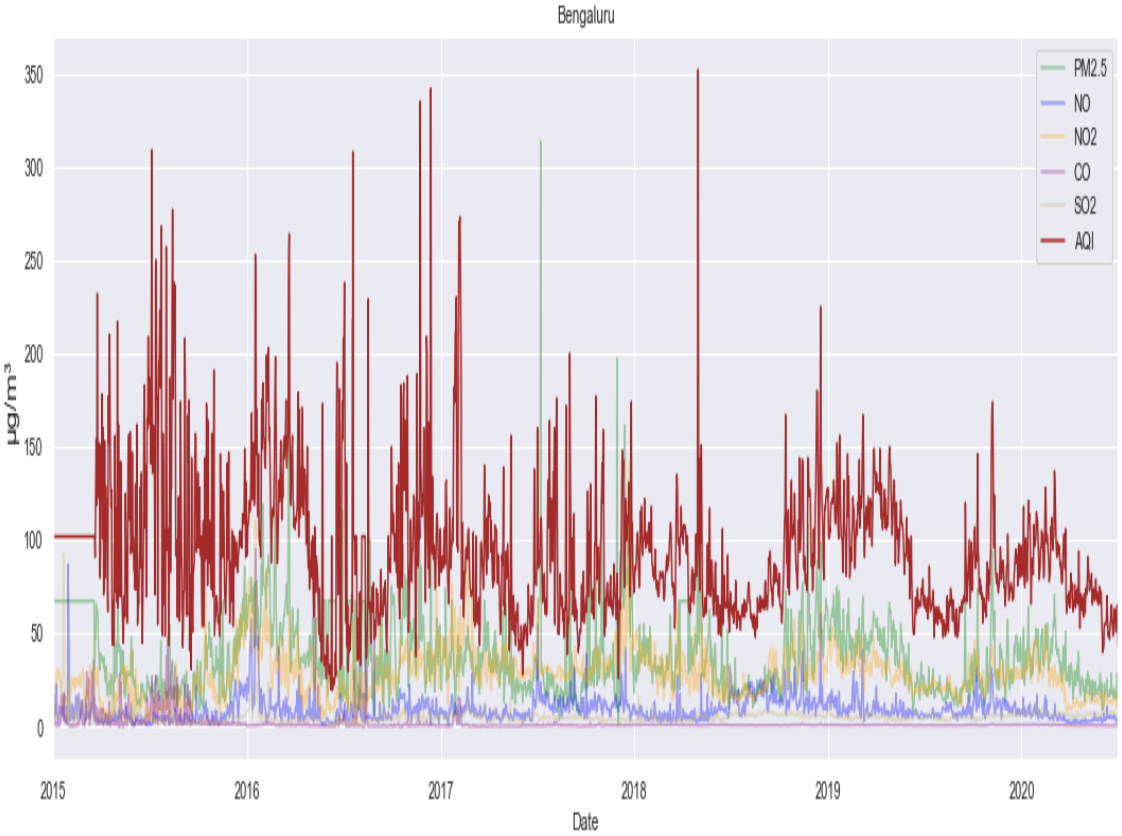

Figure 10 Concentration of pollutants (ug / m3) in air (2015-2020) in Bengaluru

The overall air quality bucket for a certain timeframe (2015-2020) is then based on the air quality index rating for the individual pollutants. In Figure 10 it can be seen that pollution level of NO and NO_2 are almost same and satisfactory but comparatively NO is more polluted, CO and SO_2 are "good" respectively. But $PM_{2.5}$ levels were visualized as "Very Poor" hence, the overall AQI is concentrated as "very poor.

10.2.3 Air pollution trends in Hyderabad

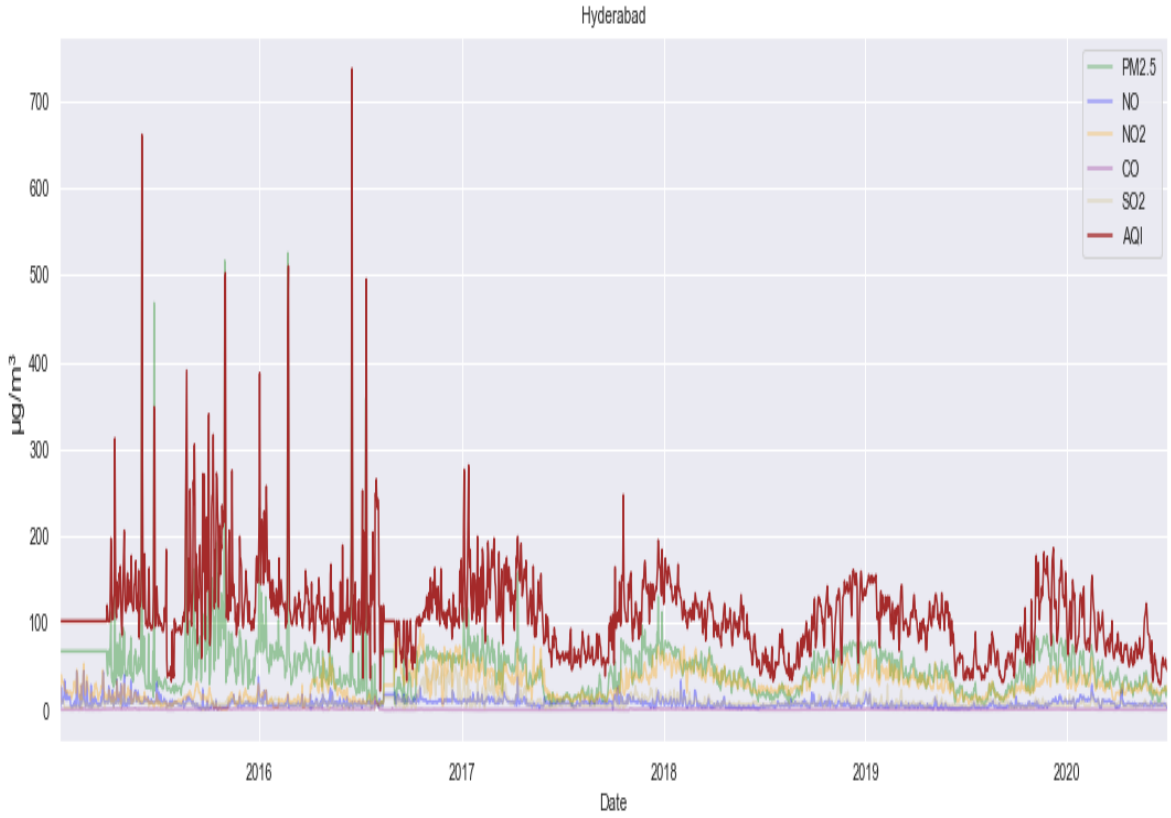

Figure 11 Concentration of pollutants (ug / m3) in air (2015-2020) in Hyderabad.

In Figure 11 it can be seen that pollution levels for NO and NO_2 are satisfactory, CO was “good” (very low) and SO_2 were “Good”. but $PM_{2.5}$ levels were rated as “Severe”. Then the overall period would be rated as ‘’ Severe”.

10.2.4 Air pollution trends in Mumbai

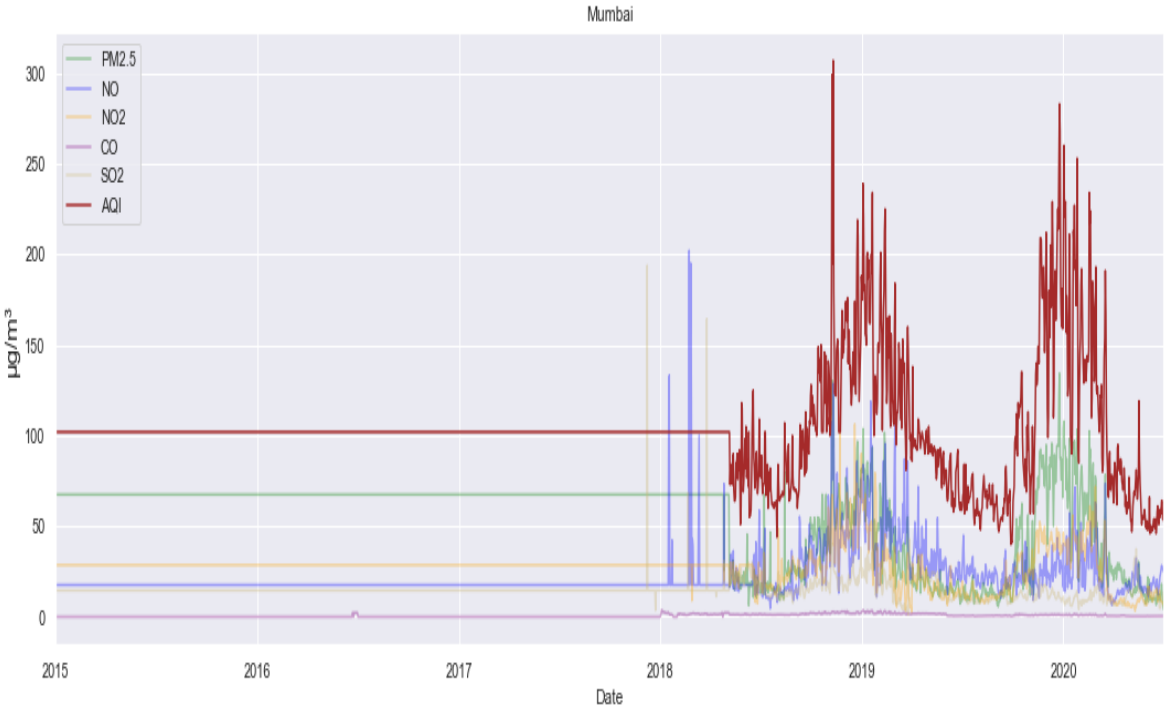

Figure 12 Concentration of pollutants (ug / m3) in air (2015-2020) in Mumbai

In Figure 12 it can be seen that pollution levels for NO and NO_2 are satisfactory, CO was “good” (very low) and SO_2 were “Satisfactory”. but $PM_{2.5}$ levels were rated as “very poor”. Then the overall period would be rated as ‘’ very poor” because AQI is very high according to the recommended level.

10.2.5 Air pollution trends in Bhopal

Figure 13 Concentration of pollutants (ug / m3) in air (2015-2020) in Bhopal

In Figure 13 it can be seen that pollution levels for NO and NO_2 are satisfactory, CO was "good" (very low) and SO_2 were "Good". but $PM_{2.5}$ levels were rated as "Poor". Then the overall period would be rated as '' Poor''.

10.2.6 Air pollution trends in Patna

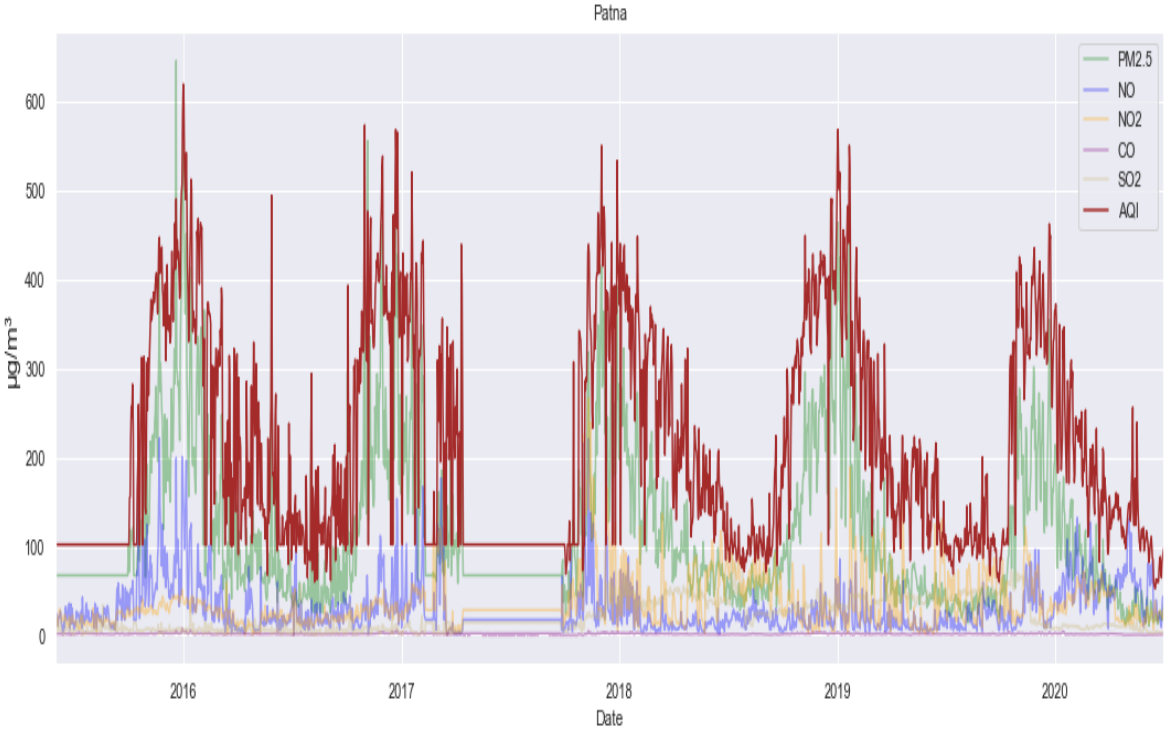

Figure 14 Concentration of pollutants (ug / m3) in air (2015-2020) in Patna

In Figure 14 it can be seen that pollution levels for NO and NO_2 are poor, CO was “good” (very low) and SO_2 were “Good”. but $PM_{2.5}$ levels were rated as “Severe”. Then the overall period would be rated as ‘’ Severe” because the air quality index crossed the level.

10.2.7 Air pollution trends in Coimbatore

Figure 15 Concentration of pollutants (ug / m3) in air (2015-2020) in Coimbatore

In Figure 15 it can be seen that pollution levels for NO and NO_2 are satisfactory, CO was "good" and SO_2 were "Good". but $PM_{2.5}$ levels were rated as "Moderate". Then the overall period would be rated as '' Moderately polluted" because the air quality index level is good according to the category.

10.2.8 Air pollution trends in Kolkata

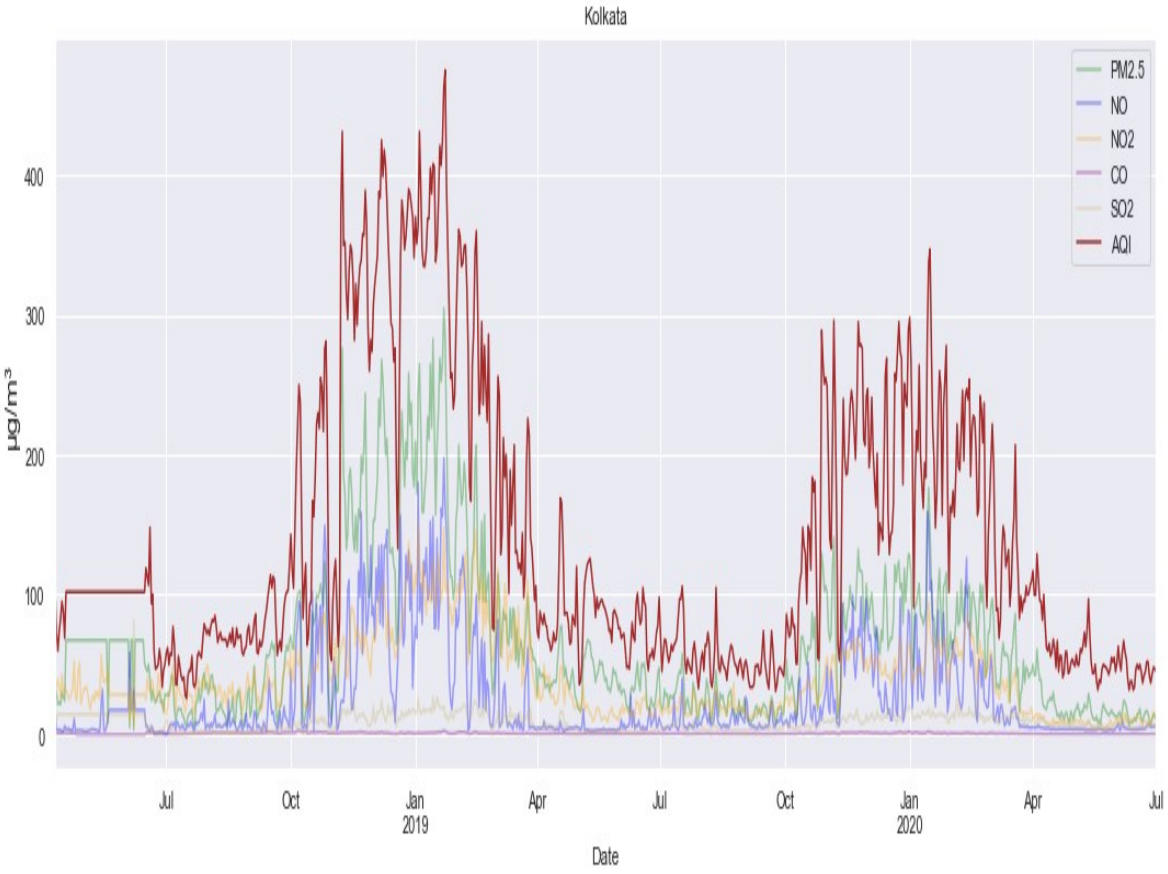

Figure 16 Concentration of pollutants (ug / m3) in air (2015-2020) in Kolkata

In Figure 16 it can be seen that pollution levels for NO and NO_2 are moderately polluted, CO was "good" (very low) and SO_2 were "Good". but $PM_{2.5}$ levels were rated as "very poor". Then the overall period would be rated as "very poor" because the air quality bucket level is very high.

10.2.9 Air pollution trends in Kochi

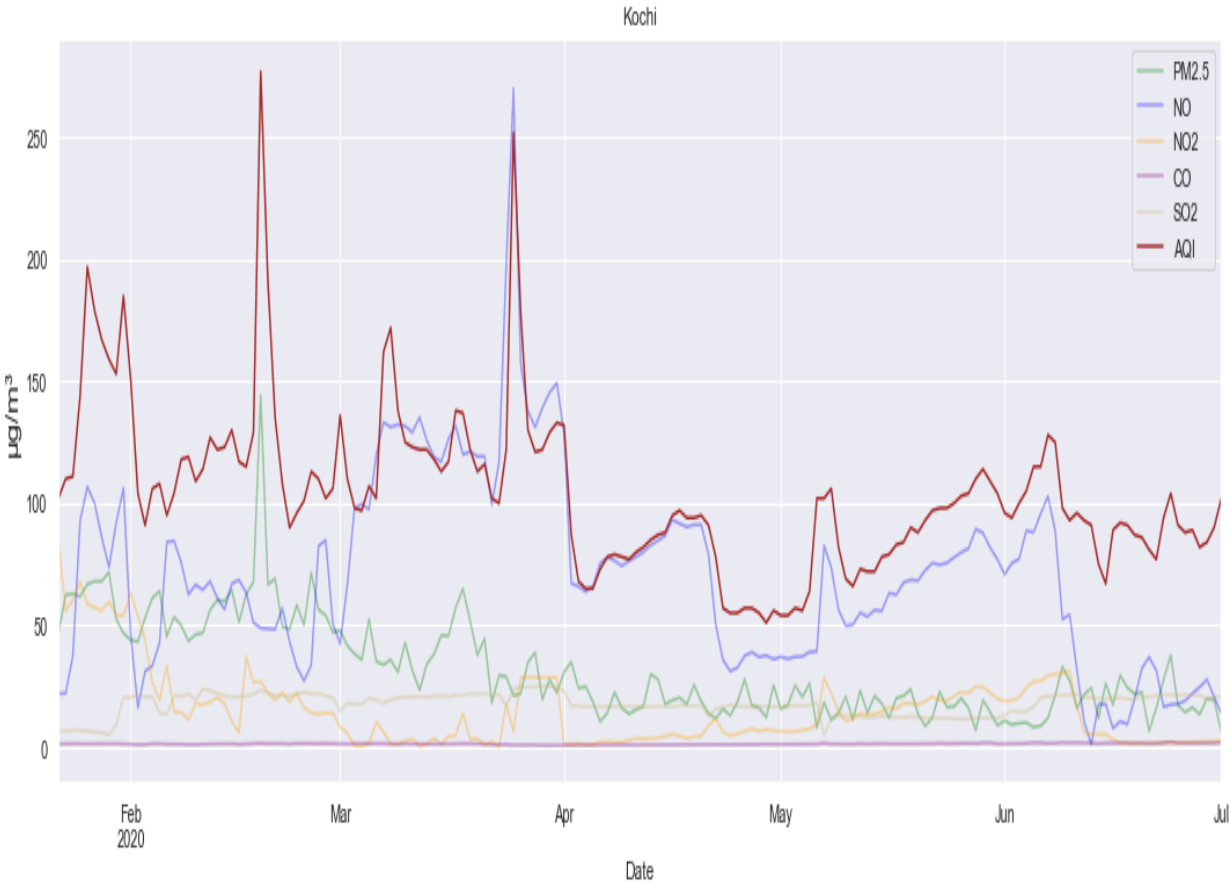

Figure 17 Concentration of pollutants (ug / m3) in air (2015-2020) in Kochi

In Figure 17 it can be seen that pollution levels for NO and NO_2 are satisfactory, CO was “good” (very low) and SO_2 were “Good”. but $PM_{2.5}$ levels were rated as “very poor”. Then the overall period would be rated as ‘’very poor” because the air quality bucket level is very high.

10.2.10 Air pollution trends in Ernakulum

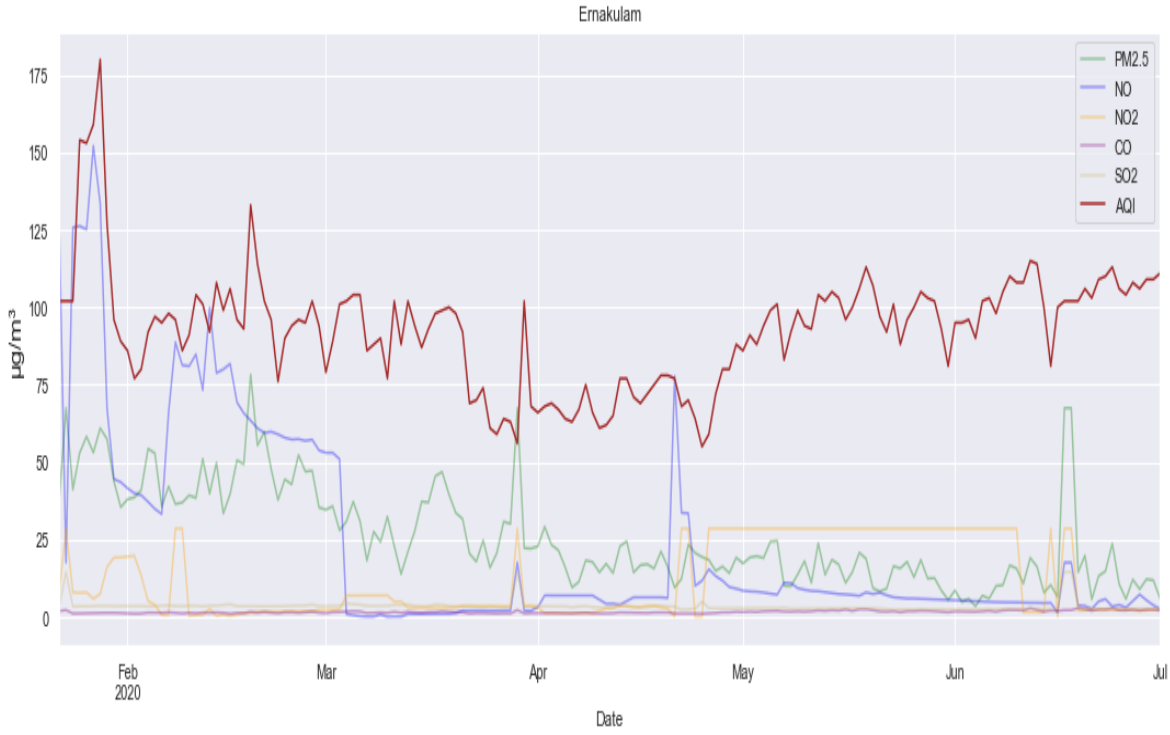

Figure 18 Concentration of pollutants (ug / m3) in air (2015-2020) in Ernakulum

The overall air quality bucket for a certain timeframe (2015-2020) is then based on the worst air quality index rating for the individual pollutants. In Figure 18 it can be seen that pollution levels for NO and nitrogen dioxide (NO_2) are good, CO was “good” (very low) and SO_2 were “Good”. but $PM_{2.5}$ levels were rated as “Moderately polluted”. Then the overall period would be rated as ‘’ moderately polluted” because the air quality bucket level is very high.

10.3 Patterns in pollutants concentration during covid time

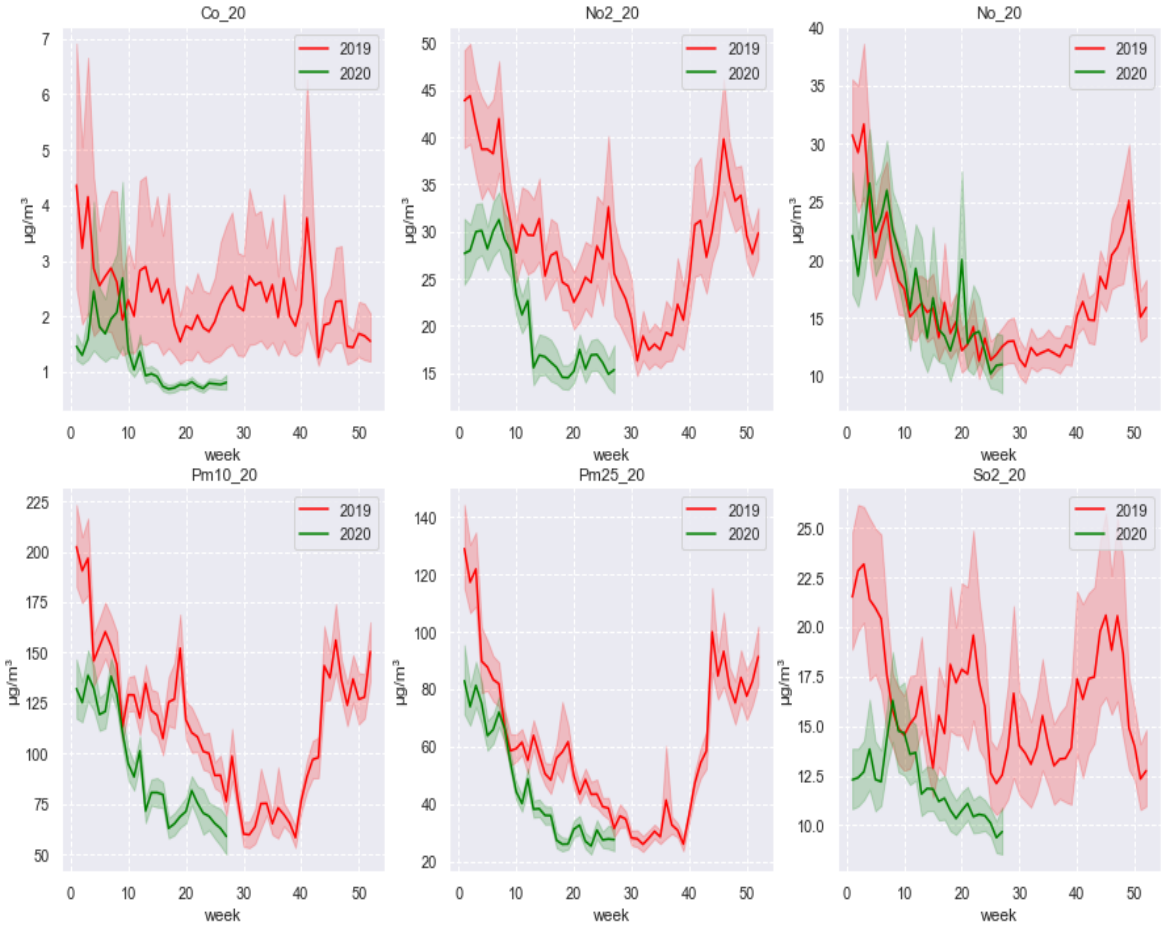

Figure 19 Trends in air pollution during covid time for Co, No_2, No,PM_{10},$PM_{2.5}$ and So_2 (ug / m3).

This graph Figure 19 shows the air pollution patterens between 2019 and 2020. It clearly shows that the quality of air in 2019 is very bad where the quality of air in 2020 is very good comparatively because of Covid situation. During covid situation, goverenment restricted the movement of the people also their activity. For this reason the air quality has changed.

10.4 Pre and post lockdown

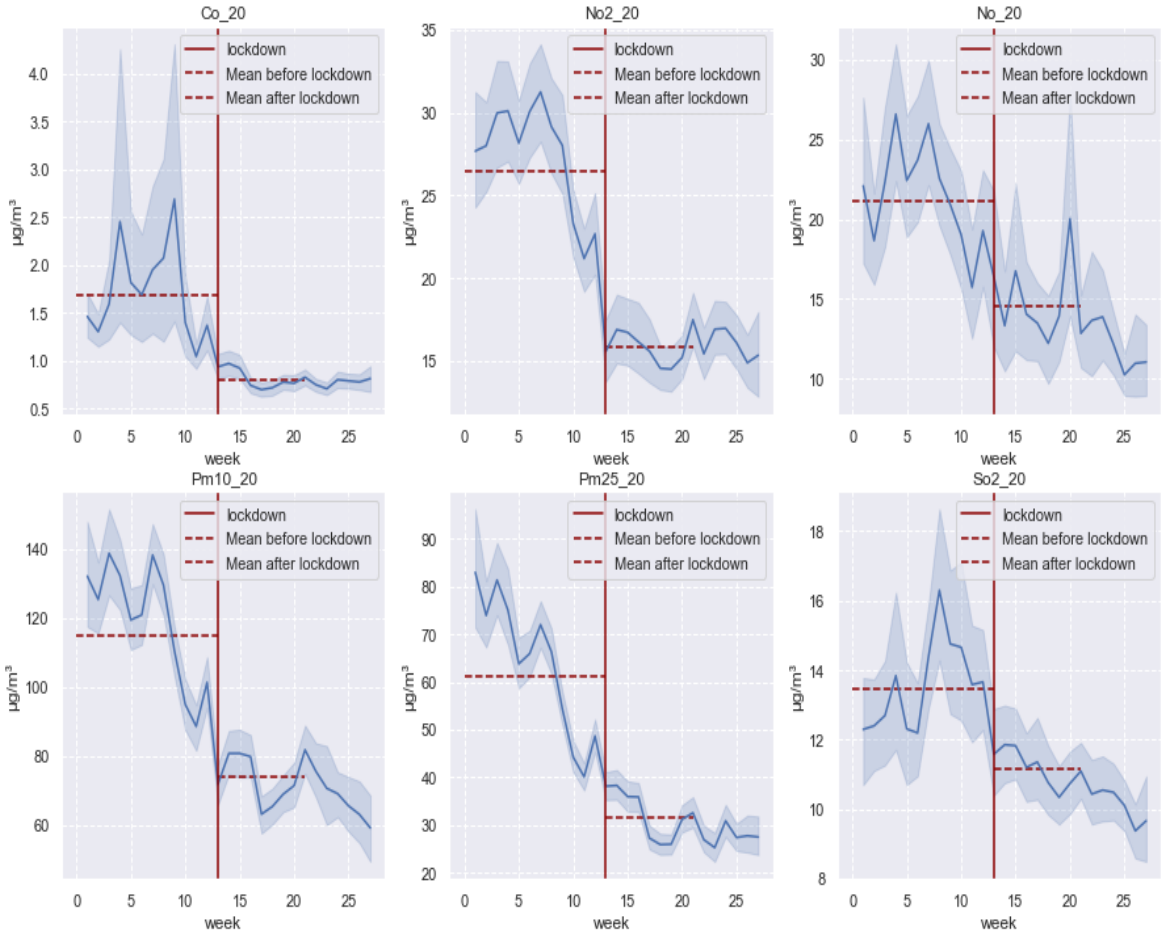

Figure 20 Changes in air pollution during lockdown in 2020 from 13-22 week for Co, No_2, No, PM_{10}, $PM_{2.5}$ and So_2 (ug / m3).

Air pollution before lockdown was much higher than after the lockdown during the covid pandemic. I analysis mainly week 13 to 22 in 2020 which was a lockdown period in India. From the above graph Figure 20 in 2020 the middle of the year, it has very low-level pollution. Because, during lockdown, all the industries were closed so that traffic, smog, foils in the road everything is going to decrease day by day. So, we can say Covid had a good impact on air pollution.

10.5 Correlation

Figure 21 Correlation between variables

My study Figure 21 shows that $PM_{2.5}$ and PM_{10} are highly correlated. CO and SO_2 are quite highly correlated. I can also observe that there is a correlation between PM_{10} and NO, NO_2 and NO. The rest are not directly correlated.

11 Discussion

My study focusses on population's exposure to $PM_{2.5}$ in ambient air, as associated health impacts have been found to dominate other negative consequences of air pollution in social, economic, and global terms.

I have found that the level pollutants in the air was not same for all cities. Air pollution occurs for many reasons such as large number of industries, chemical factories and over population. Based on Figure 6 I can say that because Delhi has the largest population it directly relates to the high pollution level. On the other side Aizawl is also a big city but the population level is very low and here the economy is basically sustained by government services. The city has many major hotels, banks but very few industries and therefore the population is not that high. Shillong has low level because of less industrialization. Here I can see from Figure 7 that NO level is highest in Mumbai city and Gurugram, Amaravati has a low level comparatively than others. When I was researching this city, I found that Mumbai city has a lot of chemical industries which together with the industrial process of making residential heating and traffic are the main reasons behind the increasing NO concentrations in the air. I can see that Gurugram is a bigger city than Mumbai but there the pollution is very low because the structure of this city is different. Amaravati is not a big city in terms of the industrial economy and population is low. From the above Figure 8 it can be see that the amount of NO_2 in the air is very high and in Shillong and Aizawl it is low. The reason behind this pollution are same as for $PM_{2.5}$ and PM_{10}. Ahmedabad is the fifth most populated city in the India State of Gujrat and the population is increasing day by day. Ahmedabad is known as an important economic and industrial sector in India. The air quality of Ahmedabad recorded the 4^{th} worst quality recently. There are many reasons behind the worst air quality and SO_2, CO, Pm_{10} are presented in the air that are responsible for air pollution. But According to the Central Pollution Board, they claimed PM_{10}, CO and SO_2 is the main pollutant because these particles are worse and responsible for air pollution. Bengaluru is a big city, but population and industries are less. Ernakulum is a small city. Bhopal is a highly polluted city due to the amount of traffic on its streets, the exponential rise in industrial output and the construction industry. The air has reached a high level of pollution. Higher than the maximum limit for 24 hours established by WHO. Ground Level Ozone (0_3) is produced from cars, industrial boilers, chemical plant etc. Aizawl and Kochi city has less pollution as Kochi is very small city. Kolkata has topped the charts in pollution across the country. Kolkata residents unwittingly smoked equivalent of 22 cigarette each per day just by breathing in the foil air. As cigarette contains benzene pollution in the air also this has a huge population. In large cities have a highest pollution and the worst air quality which is dangerous for human health and in small cities have a low level of air pollution comparison to the large cities. Overall, I can say that the large city has the highest pollution comparison to small cities.

I analysis the data from 2015 to 2020 and during these years the air quality fluctuated because of increase in population , driving on the road, or burning natural gases, but sometimes the pollution in the air is less. One of major reason behind this decrease is the Covid pandemic but also various reason because of less use of chemical population transfer from one place to another etc.

The air pollution level changes very much due to covid situation. When I compare the air quality before and after covid situation (in 2019 to 2020). From Figure 19 it can be seen there is a huge difference in the pollution level. Because of corona the whole world faced a lockdown and for this reason India's government restricted and also shut down many chemical industries and the road also became empty because schools, colleges, universities were closed so that the people also were less on the road. The effect of lockdown on air pollution can be seen in Figure 20. So, the overall corona situation had a positive impact on air pollution, it helped to improve the quality of air and if air quality is good then it will also be good for human health.

Many air pollution studies have mentioned that human-related activities, such as industrial production, traffic, and transport are major contributors to air pollution. Partial lockdown can bring these production and consumption activities almost to a standstill. Human-related activities are strongly associated with air quality and travel restrictions cannot apply to air pollution prevention and control. It is possible to improve air quality by reducing individual movements which is not essential and by highlighting the importance of green commuting. It will help to reduce the pollution. (Cole et al., 2005).

There are several types of pollution control technologies and strategies available to reduce or control the air pollution. In developed countries, land-use planning is a vital part of social policy and ensuring that the land is used efficiently for the profit of the broad economy and population, as well as to protect the environment. Therefore, interventions are always a better process for controlling the air pollution. These prevention process comes from government (laws) and some individual actions. In many big cities, monitoring equipment's have been installed at many points in the city so that the Authorities read them regularly to check the air quality. Governments throughout the world who have already taken the action and investing against the air pollution by introducing green energy, wind energy and solar energy, as well as other renewable energy, to minimize burning of fossil fuels. Companies who are also building more energy efficient cars, that pollute less than before. Encourage every family member to use the bus, train or bike when commuting. Use energy (light, water, boiler, kettle, and firewood's) wisely because lots of fossil fuels are burned to generate electricity, and so if we can cut down the use. Recycle and re-use of things will decrease the dependence of manufacturing new things. The manufacturing industries

create a lot of pollution, so if we can start to re-use things such as (shopping plastic bags) then it can help to reduce pollution. (Smil & Vaclav, 2010).

There are a various number of items that is commonly used as pollution control devices by industry or transportation devices. They can either destroy contaminants or remove them from an exhaust stream before it is emitted into the atmosphere. An electrostatic precipitator known as an air cleaner that is a particulate collection device removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge. Electrostatic precipitators are highly efficient filtration devices that minimally impede the flow of gases through the device and can easily remove fine particulates such as dust and smoke from the air stream. Particulate scrubbers or wet scrubber is a form of pollution control technology. The term describes a variety of devices that use pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, to remove the pollutants. (Fensterstock et al.,1971)

12 Uncertainties

When I started my analyses, I faced several limitations because my dataset has many missing values. For that reason, I could not investigate the impact of all elements of a city's emergency response and its long-term dynamic effects because of a lack of data. For example, Figure 8 shows that CO level in Mumbai city is very low. However, as I know Mumbai is a large city and it is an overpopulated city, due to lack of data, in this case, the results are not realistic.

The analysis and results would have been better if the dataset would not have missing data. A better data set would have resulted in a more exact analysis.

13 Recommendations and suggestions

The following recommendations were raised in my mind during the research. These have been recommended in respect to the reality what I have been experienced along with the opinions from the analysis.

- Firstly, to reduce pollution is to know the concept about Reduce, Reuse and Recycle properly. If people reduce the usage of air-conditioners, it would reduce harmful gases as instant ozone-depleting chlorofluorocarbons.

- If people would use cars, motorbikes and trucks less it would help to reduce air pollution on earth. The more the usage of vehicles, using fossil fuels, the more uses of dangerous gases which are released into the air such as nitrogen oxides, carbon monoxides, and sulphur dioxides that creates serious air pollution. However, these pollutants can be reduced when people start utilizing car-pools and the use of public transport such as bus, trains and monorails, for example. In addition, people can walk or use bicycle when commuting destinations instead of driving the cars which will lead to lesser air pollution. Therefore, reducing the usage of vehicles by no doubt can no doubt reduce air pollution.

- The government and non-governmental organizations (NGOs) play an important role by enforcing the laws about pollution in the country which is one of the best ways to reduce pollution on earth. If government increases fines and extending jail periods it will force them to think twice before they pollute the environment indirectly.

- The social and health workers need to make proper plans, education and training systems for the local people so that they are able to learn about air pollution, its sources, and effects.

- Another important way to decrease pollution in the world is to create awareness among citizens. Awareness about the importance on reducing pollution on Earth. Awareness can be implanted through education; for example, advertisements on televisions, and articles in newspapers, Meta (previously Facebook), different social networking sites, which are related to ‘How to reduce pollution’.

14 Conclusions

Air pollution is being treated as an alarming issue in India, but if this issue cannot be treated with sustainable mitigation efforts, then this phenomenon might spread out as an epidemic in the country. The presence of pollution in air was detected after a long period of time, so it is better to examine the air quality at a regular basis to ensure that there is no other PM and toxic element in the air. Although air pollution has been declared as a national disaster by the Indian government.

From the presented study it has been seen that India is suffering from one of the worst air pollutions. According to 2017 State of Global Air Report by Health Effects Institute, there was almost 150% increase the number of deaths caused by air pollution in India between 1990 and 2015. It has been declared as a public health emergency in the whole country. Air pollution is widely spread, and it continues to expand day by day. With the increasing population, a widespread air pollution is continually realized. This is a great challenge for both the citizens and the government because they are negatively affected by the consequences of air pollution. The whole country is affected by air pollution in almost all aspects but mostly the health effects are more adverse than the others. Air pollution is a threat not only to human life but also it affects animals, visibility, plants, and many other things. It is observed from the study that the crop yield was reduced drastically in areas affected by air pollution.

Notwithstanding, this study broadens the knowledge of air pollution in Indian cities and its most detrimental pollutants behind bad air quality. The findings of this study can help Indian environmental agencies to implement different strategies based on pollution during certain periods.

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