DECADAL CHANGE OF AIR POLLUTION OF TWO SELECTED LOCATIONS OF KOLKATA, WEST BENGAL

JADAVPUR UNIVERSITY

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Decadal Change of Air Pollution and Analysis of Air Quality using Statistical Method

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A thesis Submitted in partial fulfillment of the requirements for the award of the degree of M.TECH in Environmental Biotechnology in Jadavpur University by

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DECLARATION

I hereby declare that the work presented in this thesis report title **"**Decadal change of Air Pollution on Behala, Ultodanga and Analysis of air quality using Statistical Method**"** submitted to Jadavpur University, Kolkata in partial fulfillment of the requirements for the award of the degree of Master of Technology in Environmental Biotechnology course of Jadavpur University for the session 2022-2024 under the supervision of Prof. Subarna Bhattacharyya. It is declared that no part of this thesis report, have been submitted elsewhere for the award of any degree or diploma.

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CERTIFICATE

This is to certify that the Thesis Report titled “The Decadal Change of Air Pollution in Kolkata and Analysis of Air Quality using Statistical Method**.**” Submitted by Adrita Mohonta (102130904010) to Jadavpur University, Kolkata for the award of the degree of Master of Technology in Environmental Biotechnology is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the constituents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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Final examination for evaluation of thesis

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Signature of the Examiner

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ABSTACT

Data on the concentration of air pollutants in a recently constructed industrial park in Kolkata, India's rapidly expanding metropolis, is presented in this study. Kolkata is a part of the State of West Bengal. By gathering records of monthly secondary data of air pollutants from the West Bengal Pollution Control Board (WBPCB) website, the ambient air quality assessment was conducted at two different locations, namely Behala Chowrasta and Ultodanga, with respect to SOx, NOx, suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM), as well as the Air Quality Index (AQI). It is shown that even the average concentrations of SPM, NOx, Sox, and AQI were at their maximum levels in the winter, summer, and rainy season, respectively, at the two location sites.

Following data collection, a graph was used to statistically analyse the decadal change in air pollution. Standard division was used to add or subtract error from the monthly average value of air pollutants for the years 2009 to 2019. Ultimately, statistical tools such as the Box Plot and Regression technique were employed to conduct trend analysis in order to determine the nature of the air pollution trend at the two Kolkata locations that were mentioned between 2009 and 2019. Up until 2030, the future trend in air pollution was also computed using the preceding pattern as a guide. Precautions and solutions for improving air quality were also covered.

The second section examined the state of the air quality during the COVID-19 pandemic in 2020–2021, examining the air quality throughout the three distinct phases of pre-, lockdown, and post-lockdown of the two same locations of Kolkata.

Keywords: Air Quality, Monitoring Air pollutants, RDS, SOx, NOx, SPM, RSPM

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CHAPTER 1

INTRODUCTION

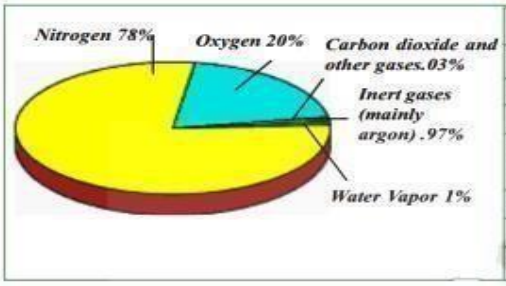
Air pollution refers to the presence of hazardous substances or contaminants in the planet's atmosphere. These contaminants may be harmful to people's general well-being, the environment, and their health. These pollutants, which can be either gaseous or particulate, are mostly released into the atmosphere by industrial processes, transportation, and the burning of fossil fuels. Common air pollutants include carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), particulate matter (PM), and other hazardous materials. A few of the sources of these pollutants are household heating and cooking, power plants, industrial facilities, and vehicle emissions.

When these pollutants accumulate in the atmosphere, they may have a variety of detrimental effects. Air pollution can aggravate respiratory conditions such as asthma, bronchitis, and other chronic obstructive lung illnesses. It can aggravate lung cancer, allergies, and cardiovascular issues. Furthermore, air pollution damages ecosystems, reduces crop yields, speeds up climate change, and alters the equilibrium of greenhouse gases in the atmosphere. Efforts to combat air pollution include promoting cleaner technology, improving transportation infrastructure, and raising public awareness of the importance of reducing pollution. Air pollution reduction is a goal of international agreements and initiatives, such as the Paris Agreement on climate change, as part of larger environmental protection measures (Daly et al, 2007). These days One of the biggest issues and well-known environmental health risk is air pollution. These days, it's easy to observe smoke rising from a smoke stack, exhaust below rushing across a highway, or a brown cloud settling over a metropolis. While not all forms of air pollution are visible to us, strong odors can warn us. It poses the greatest threat to life and the health of the entire world. throughout 6.5 million fatalities worldwide are attributed to it each year; throughout the previous few decades, this number has climbed. Air pollution affects many delicate ecosystems and has an impact on crops and the chemistry of the atmosphere (Daly et al, 2007).

The phrase "air quality" refers to the ability of the air to support various processes, yet the planet's air quality is deteriorating daily. While air pollution initially caused problems in urban areas, during the past 20 years, it has also increased in rural areas. Pollutants come in two varieties.1. Gaseous 2. Particulate matter.

Due to humankind's diverse activities and the advancement of technology across multiple industries, air pollution has become a major global concern. Fossil fuel combustion releases a variety of air pollutants, including particles, sulphur dioxide, nitrogen dioxide, carbon dioxide, carbon monoxide, unburned hydrocarbon, and hydrogen fluoride.
The planetary system of the earth is altered by air pollution. Climate change is caused by global warming.

Depletion of the ozone layer and greenhouse consequences. Ocean water levels rising and polar ice melting are contributing factors to the long-term, steady process of global warming. For everyone who perished on the river's banks, global warming is thus directly to blame. Temperature rises are mostly driven by carbon emissions, which trap harmful radiation like UV and IR in different forms of gases including carbon dioxide, CFC, and NOx. This phenomena raises the temperature of the earth's atmosphere. It consequently has an impact on seasonal and weather variations. The ozone layer shields humans from the sun's UV radiation and its fatal effects, but it is currently being destroyed by global warming, resulting in an ozone hole or depletion (Dameris, 2010).
As a result of air oxidation, sulfuric and nitric acids are generated as oxides of sulphur and nitrogen. This acid combined with the precipitation in the form of rain to create acid rain. It is known as "Marble cancer" and affects monuments and buildings composed of marble materials. Additionally, both terrestrial and marine aquatic ecosystems are impacted by this acid rain.



Componet	Symbol	Volume
Nitroten	N2	78.084%
Oxygen	O2	20.947%
Argon	Ar	0.934%
Carbon Dioxide	CO2	0.033%
Water Vapor	H2O	0-2%
Argon	Ar	0.1%
Other Traces		

Source: Ballentine, C. J & Barfod , 2000

- **Types of air pollutants**

Primary air pollutants:

Primary air pollutants are substances that are released into the atmosphere right away as a result of human activity or natural processes. These contaminants might be dangerous for human health, the environment, and the quality of the air in general. Among the main air pollutants are the following: Burning fossil fuels, particularly coal and oil, releases sulphur dioxide (SO_2). Apart from its substantial contribution to acid rain, SO_2 can cause respiratory problems and damage to the lungs. Examples of nitrogen oxides (NO_x) include nitric oxide (NO) and nitrogen dioxide (NO_2). They are primarily released from fossil fuel combustion in automobiles and power plants.

The development of smog and respiratory issues may be influenced by NO_x. Nitrogen oxides (NO_x) include, for example, nitric oxide (NO) and nitrogen dioxide (NO_2).
The primary sources of their discharge are vehicle exhaust and the burning of fossil fuels in power plants. The development of smog and respiratory issues may be influenced by NO_x.

Fossil fuels partially burn to produce carbon monoxide (CO), a colourless and odourless petrol that is mostly produced in automobiles and industrial processes. High concentrations of CO can be lethal because they reduce the blood's ability to carry oxygen. Volatile Organic Compounds (VOCs): These are organic substances that easily evaporate at normal temperature. Paints, solvents, burning fuel, and industrial operations are some of the sources of them. VOCs react with other pollutants to generate ground-level ozone, a major cause of smog.

Even though lead (Pb) emissions have significantly dropped over time, it is still considered a significant air contaminant. It is released by lead-acid batteries, industrial processes, and leaded petrol, among other sources. Exposure to lead can have serious health effects, with the nervous system being particularly affected.
The impacts of air pollution can be exacerbated by secondary pollutants like ground-level ozone, acid rain, and fine particulate matter that are created when these main air pollutants react chemically with one another in the environment (Sonwari & Saxena, 2016).

Secondary air pollutants:

Secondary air pollutants are produced when main pollutants interact with other substances or undergo chemical changes in the environment. These reactions are often fueled by photochemical reactions as well as other atmospheric processes. Unlike primary pollutants, which are released into the atmosphere right once, secondary pollutants are produced within the environment.

Here are a few examples of common secondary air pollutants:

- Ozone (O_3): When sunlight is present, nitrogen oxides (NO_x) and volatile organic compounds (VOCs) combine to produce ozone, a secondary pollutant. It is a major contributor to smog and can harm plants in addition to respiratory issues. (White et al , 1976).

- Nitrogen Dioxide (NO_2): The main source of nitrogen dioxide emissions is combustion processes. However, it can also oxidise nitric oxide (NO) in the atmosphere, forming a secondary pollutant. In addition to being a respiratory irritant, NO_2 is a factor in the development of photochemical smog and acid rain.

- Oxidation of sulphur dioxide (SO_2), a major pollutant released by power stations, industrial processes, and volcanic eruptions, produces sulfuric acid (H_2SO_4). One of the main causes of acid rain, which can be harmful to buildings, ecosystems, and people's health, is sulfuric acid.

- Particulate Matter (PM): Tiny, soaring particles comprise particulate matter. While some particles, like soot from combustion processes, are directly released into the atmosphere as primary pollutants, other particles, like ammonia, organic compounds, and other gases, are produced when gases like sulphur dioxide and nitrogen oxides interact with other elements in the atmosphere. These processes produce fine particulate matter ($PM_{2.5}$), which can be hazardous to human health when ingested (Mysliwiec et al, 2002).

- Formaldehyde (HCHO): Formaldehyde is a secondary air pollutant that is produced when volatile organic compounds (VOCs) oxidise in the presence of sunshine. It is frequently released by industrial processes, motor vehicle emissions, and building materials. Formaldehyde is a known human carcinogen and respiratory irritant.

It is important to keep in mind that the production and persistence of secondary pollutants in the atmosphere are influenced by a number of factors, including primary pollutant emissions, meteorological conditions, and geographic location. The reduction of primary pollution emissions and the enforcement of air quality standards are necessary to minimise the production of secondary air pollutants.

- **Sources of air pollutants:**

- Air pollution is caused by a wide range of natural and man-made elements, as well as one another. The following is a list of some of the primary causes of air pollution:

- Transportation: When fossil fuels are burned to power cars, trucks, buses, aero planes andships, air pollutants like nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO) and particulate matter (PM) are released into the atmosphere. Industrial Emissions: Particulate matter, NO_x, sulphur dioxide (SO_2), and other hazardous compounds are among the pollutants that factories and other industrial facilities release into the atmosphere as a result of their manufacturing processes (Colvile et al, 2001).

- Power generation: Coal, oil, and natural gas are burned in power plants to produce electricity. Numerous pollutants, including mercury, SO_x, NO_x, and greenhouse gases like CO_2 and methane, are released by these facilities.

- Agricultural practices, including animal husbandry and the use of chemical pesticides and fertilizers, are a significant contributor to the emissions of ammonia (NH_3) and other pollutants.

- The improper disposal of waste, including open burning of trash and emissions from landfills, leads to the release of hazardous substances and exacerbates air pollution. When solid fuels like wood, charcoal, coal, and others are used in houses for cooking and heating, harmful pollutants can be released, particularly in areas with inadequate ventilation (Holman, C. (1999).

- Natural Sources: When dust storms, volcanic eruptions, and wildfires occur naturally, particulate matter and other pollutants can contaminate the atmosphere. (Guttikunda,2014).

❖ Building and demolition: The dust and fumes released during these processes have the potential to pollute the nearby air.

❖ Chemical and oil refineries release hazardous and volatile organic compounds (VOCs) into the environment throughout the refining process.

❖ Smoking: When people smoke cigarettes and emit other emissions associated to tobacco use, they release a range of harmful chemicals and particles into the air.

❖ Paints: When utilized, specific paints, solvents, and other volatile substances can leak volatile organic compounds (VOCs) into the atmosphere.

❖ Air Conditioning and Refrigeration: Antiquated air conditioning and refrigeration systems have the potential to produce hydro- and chlorofluorocarbons (HCFCs) and CFCs, which are linked to climate change and the thinning of the ozone layer.

❖ Indoor sources of air pollution include construction materials, cleaning supplies, fossil fuel-powered cooking and heating appliances, tobacco smoke, and other household chemicals. Contaminants may build up within due to inadequate ventilation, which will lower the quality of the air (Tichenor et al, 1990).

Effective pollution management techniques must be used in order to address these sources, protect the environment, and enhance air quality. Governments, corporations, and citizens all working together for lowering the emissions and implement greener procedures and technology.

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects
Hazardous	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

Source: Bhawan , p, & Nagar, 2020

- ## Air pollution criteria

Air pollution criteria are a collection of accepted rules or guidelines that are used to assess and manage air quality. The purpose of these regulations is to protect the general public's health and the environment from harmful air pollutants. Usually, after carrying out extensive scientific research and health assessments, governmental or environmental organisations make their decisions and establish the criteria. The following are some of the main causes of air pollution:

Particulate matter (PM_{10} and $PM_{2.5}$) is made up of tiny solid particles and liquid droplets that are suspended in the atmosphere. $PM_{2.5}$ refers to particles that have a diameter of 2.5 µm or less, whilst PM_{10} refers to particles that have a diameter of 10 µm or fewer. Due to their deep respiratory system penetration, both types of particles have the potential to be harmful to health.

Ground Level Ozone (O_3): When sunlight interacts with volatile organic compounds (VOCs) and nitrogen oxides (NO_x), ground level ozone (O_3) is produced. This is a secondary pollutant. High levels of ozone can cause respiratory issues for vulnerable populations, including children, the elderly, and those with respiratory conditions (Suh, H. H.,2000).

Nitrogen Dioxide (NO_2) is a reddish-brown petrol that is mostly created from the combustion of fossil fuels in automobiles and industrial processes. It might aggravate respiratory conditions that already present and agitate the respiratory system.

Sulphur Dioxide (SO_2): When fossil fuels containing sulphur, such as coal and oil, are burned, sulphur dioxide, a gas, is produced. It can aggravate respiratory conditions and promote the growth of particulate matter.

A colourless and odourless gas called **carbon monoxide (CO)** is produced when fossil fuels burn partially. It can make it more difficult for the body to transmit oxygen, and it can be especially dangerous in confined spaces.

Lead (Pb) is a toxic heavy metal that can be released into the atmosphere by several means, such as industrial and petrol use. Exposure to lead can impact neurological development, particularly in early infancy.

Usually, the standards for the exposure or concentration of each pollutant are established for certain time periods (e.g., hourly, daily, or annual averages). These regulations vary from country to country and are periodically updated to reflect new discoveries in science and medicine. putting in place programmers to regulate air quality and emission restrictions, and other actions to protect public health and reduce pollution levels are frequently required in order to comply with these requirements(Snyder, W. H. (1972).

Air quality index as per WHO :

Pollutants	Standard Value
$PM_{2.5}$(µg/m³)	25µg/m³
PM_{10}(µg/m³)	50µg/m³)
CO_2(ppm)	1000ppm
HCHO(ppm)	0.1ppm

Source-WHO, World Health Organization(WHO),2010

- **Air pollutants characteristics:**

Physical characteristics:

Compounds in the atmosphere known as air pollutants have the potential to endanger human health, the environment, and other living things. These pollutants could be created by human activities or they could be present naturally. The physical characteristics of air pollutants can vary significantly depending on their source and content. The following are some physical characteristics of air pollution that are typical:

- ✓ Particle size: The size of airborne particles can vary, ranging from less than 2.5 µm to less than 0.1 µm, with coarse particles being larger than 10 µm. The size of the particles affects how far they can go through the air and how deeply they can get into the respiratory system when inhaled.
- ✓ State of Matter: Air pollutants exist in three different phases: solid, liquid, and gaseous. In contrast to gases such as CO, SO_2, NOx, Ozone, and Sulfur Dioxide, particulate matter (PM) and some volatile organic compounds (VOCs) are frequently present in either solid or liquid forms.
- ✓ Density: The concentrations of various air contaminants influence their movement and dispersion within the atmosphere. Lighter pollutants may spread over greater distances, but larger pollutants tend to settle closer to the ground.

- ✓ Volatility: Volatile organic compounds (VOCs) are substances that easily evaporate into the atmosphere at ambient temperature. Their unpredictable activity affects their ability to contribute to smog and create ozone at ground level.
- ✓ Solubility: When specific pollutants, such sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), combine with atmospheric moisture and dissolve in water vapor, acid rain is produced.
- ✓ Reactivity: Air pollutants possess the capability to undergo chemical reactions with other constituents in the atmosphere, hence generating secondary pollutants. For example, sunlight combines with nitrogen oxides (NO_x) and volatile organic compounds (VOCs) to form ozone, a secondary pollutant.
- ✓ Colour and Odour: Certain pollutants could have distinct colors and smells that make them easier to find. For example, nitrogen dioxide (NO_2) can give the air a brownish color, and hydrogen sulfide (H_2S) has a strong stench similar to rotten eggs.
- ✓ Persistence: Certain air contaminant has the capacity to persist in the atmosphere for an extended period, potentially leading to long-range transportation and worldwide consequences. Carbon dioxide is one type of persistent greenhouse gas (CO_2).

It is imperative to bear in mind that the detrimental consequences of air pollutants on both human health and the ecosystem depend on multiple parameters, such as concentration, duration of exposure, and individual sensitivity. Regulatory agencies and environmental specialists regularly monitor air quality to ascertain and manage the consequences of air pollution on ecosystems and public health (Wang, 2015).

Chemical characteristics:

Air pollutants are substances found in the atmosphere that have the potential to harm humans, the environment, and other living things. They could be released due to either natural or human activity. Here are a few common chemical characteristics of fair pollutants (Garofalide et al, 2020)

- ✓ Particulate matter, or PM, is the term used to describe tiny solid or liquid particles hanging in the air. PM comes in a variety of forms and formulations. Common sources include vehicle exhaust, dust from construction and agriculture, and industrial pollutants.
- ✓ Nitrogen oxides (NOx) include both nitrogen dioxide (NO2) and nitric oxide (NO). They are produced by combustion processes, which are present in car engines, power plants, and industrial facilities.

- ✓ Burning fossil fuels that include sulfur, such as coal and oil, releases sulfur dioxide (SO_2).
- ✓ Ozone (O_3): Although ozone in the stratosphere, the upper atmosphere that protects humans from harmful UV radiation, is advantageous, ozone at ground level is a hazardous air pollutant. It is produced by the chemical reactions of NOx and volatile organic compounds (VOCs) in the presence of sunlight. Gasoline fumes and other industrial byproducts are sources of volatile organic compounds (VOCs).
- ✓ The colorless and odorless gas known as carbon monoxide (CO) is produced when fuels containing carbon, such as coal, wood, and gasoline, burn incompletely. Vehicle emissions and residential heating systems are common sources.
- ✓ A family of substances called volatile organic compounds (VOCs) is composed of carbon and readily evaporates into the atmosphere. They originate from a number of things, including paints, solvents, industrial processes, and vehicle emissions.
- ✓ Ammonia (NH_3): A gas produced by agriculture, ammonia.
- ✓ Lead(Pb): Due to regulatory measures, lead emissions, which were formerly a significant air pollutant from sources including leaded gasoline and industrial operations, have drastically diminished.
- ✓ Mercury (Hg): Mercury emissions can come from various industrial processes and coal-fired power plants. It is a heavy metal that can accumulate in the food chain and is quite harmful.
- ✓ Radon (Rn): Radon is a radioactive gas that is able to enter buildings from the ground. It is a natural pollutant and a serious health issue (Suh, H. H.,2011).

Biological Characteristics:

Air pollutants can interact with living things in a variety of ways and negatively affect health because they can have a wide range of biological qualities. The typical air pollutants and their biological properties are as follows:

- ✓ Particulate matter is the term used to describe tiny solid or liquid particles that are suspended in the atmosphere (PM). Two examples of the different sizes of these particles are PM10 particles, which have a diameter of 10 µm or less, and PM2.5 particles, which have a diameter of 2.5 µm or less. When PM is breathed into the respiratory system, it can lead to breathing and cardiovascular problems. Particles too small to be seen in the blood can damage several organs.

- ✓ Ozone (O_3) is a highly reactive gas composed of three oxygen atoms. when stratospheric ozone, or ozone at high altitudes, is present.
- ✓ Gases such as nitrogen dioxide (NO_2), which is reddish-brown in color, are released into the atmosphere by vehicles, power plants, and industrial processes. It may cause respiratory problems, especially in people with pre-existing respiratory conditions like asthma.
- ✓ Burning fossil fuels releases sulfur dioxide (SO_2), a potent gas that is mostly produced in power plants and industrial activities. It may cause respiratory irritation and contribute to the development of particulate matter.
- ✓ Carbon monoxide (CO) is a colorless, odorless gas that is produced when fuels containing carbon burn partially. It reduces the ability of red blood cells to carry oxygen when it attaches to hemoglobin in those cells. Elevated CO levels can cause headaches, dizziness, and in severe cases, even death.
- ✓ Volatile organic compounds, or VOCs, are a group of organic molecules that have the ability to evaporate and spread throughout the atmosphere. They come from a range of sources, such as consumer products, automotive pollutants, and solvents. In addition to irritating the eyes, nose, and throat, volatile organic compounds (VOCs) can also damage the liver, kidneys, and central nervous system. Additionally, they may aid in the production of ground-level ozone.

- ✓ Lead (Pb), a heavy metal pollutant that can enter the air, can come from two sources: industrial processes and leaded gasoline, though its use has significantly decreased. Inhaling lead dust can harm the nervous system, particularly in young children, which can lead to behavioral and developmental issues (Sørensen et al, 2003).

▪ **Sources of air pollution in Kolkata**:

The main cause of pollution in Kolkata is the transportation sector. These days, there are a lot of historic gasoline and diesel cars on the road. These vehicles emit a lot of harmful emissions and are not subject to regulations. It is estimated that over 95% of the population is affected by diesel- powered cars and trucks. There are also many alternative, albeit dilapidated, public transportation options, such as open buses, trams, and automobiles. Furthermore, the abundance of private and business automobiles adds to traffic and congestion, which lengthens commutes and wastes more fuel (Haque et al,2017).

The city's surrounding thermal power plants contaminate the city's water and air. Numerous small businesses may be found in the metropolitan area, which adds to the pollution and makes it harder for people to breathe. Despite multiple attempts by the government to outlaw it, the use of plastic remains one of the other issues in Kolkata. In Kolkata, the same has been more subtly applied. Every day, a large number of people use plastic bags, which they either burn or dispose of in the water. Toxic vapors and an unpleasant stench are released into the air when plastic is burned. It's standard procedure to burn rubbish. Huge landfills exist where vast volumes of trash are regularly burned, contaminating the air. Due to urbanization and population increase, new buildings are created, which results in the production of construction dust, which includes waste wood, cement, and other building materials. In order to create way for new construction, trees are being chopped down, depriving the environment of fresh air. Close stoves and open flames are the primary domestic combustion sources of $PM_{2.5}$ and PM_{10}, accounting for 38% of $PM_{2.5}$. Fine particle matter such as nitrate, sulfates, ammonia, elemental carbon, and organic carbon accounted for 70% to 80% of $PM_{2.5}$. With a diameter of 10µm>2.5µm, aluminum, sulfur, potassium, calcium, and iron make up 40–50% of the course particulate matter. While inhaling, human nostrils can filter out particles up to 10 µm in diameter, although some particles smaller than that may still pass through. The particle matter's composition has an aesthetic influence and might make yellow less visible. It results in asthma, lung cancer, and early death. The WHO states that the ambient $PM_{2.5}$ level should be less than 25 ug/m³. According to the CPCB, the annual average of $PM_{2.5}$ levels in India is 40 ug/m³, while the daily average is 60 ug/m³. High levels of air pollutants like SPM, RSPM, NOx, and other organic and inorganic matter that can harm human health and the ecosystem are caused by vehicle emissions. Ambient particulate matter may contain heavy metals, acids, and carcinogens. Organic compounds may also have detrimental effects on human health and the ecosystem (Spiroska et al,2011).

- ## Health Effects:

Cardiovascular Disease: A 10 ug/m³ rise in $PM_{2.5}$ was linked to an increased risk of heart failure. Fine particulate matter can block blood vessels, and postmenopausal women who are exposed to NO_x on a regular basis run the risk of experiencing a hemorrhagic stroke. Pregnant women are particularly at risk of dangerously high blood pressure. Fine particulates from the outdoors are responsible for 22% of deaths in India from ischemic heart disease (Lee et al, 2014).

Respiratory Disease: Lung development can be impacted by air pollution. When pollutants reach the respiratory system in large enough quantities, they can cause inflammation. Some pollutants enter through the nose. Inflammation can worsen pulmonary system damage and even cause cell death. In addition to reducing lung function, air pollution also increases airway reactivity and inflammation. Additionally, it may result in respiratory infections and COPD (Kim, D.et al, 2018).

Effects on Children: The primary cause of the increased number of school absences was the elevated level of air pollution, which resulted in acute respiratory infections. Premature births and low birth weight babies are the expected outcomes of pregnant women being exposed to air pollution (Braga et al, 2001).

CHAPTER 2: STUDY OF BACKGROUND

2.1. International scenario

Chaloulakou *et al., (*2002) conducted a field research to look at the carbon monoxide (CO) concentrations inside and outside of a public school in Athens, Greece. We simultaneously measured the CO concentrations outside and indoors using a non-dispersive infrared analyzer. The mean hourly CO concentrations inside and outside the sampling chamber were measured every 24 hours in May and June 1999. They were made every fourteen hours in December 1999. Examining the building' sattenuation pattern of outside pollution levels was the aim of the investigation. Inside CO concentrations are generally lower than corresponding outdoor levels, according to diurnal concentration fluctuations recorded for multiple days of the week. The morning peaks of indoor concentrations show a delay of one hour or less when compared to the morning peaks of outdoor concentrations. The concentration ratios of measurements taken both indoors and outdoors show seasonal fluctuations. In order to evaluate an indoor air quality model for the prediction of indoor concentration levels developed by Hayes, a program is constructed and tested using experimental data. Overall, there is high agreement between the model outputs and indoor concentration data, while there are few cases when the model cannot account for sudden variations in outdoor concentration. There is a range of 0.88 to 1.23 between the expected and measured daily maximum indoor concentration. There is a strong internet link between model forecasts and hourly measurements. Over a continuous 96-hour period, indoor concentrations have a slope of 0.64 and a coefficient of determination (R^2) of 0.69.

A study (Missia *et al.,* 2010**)** was carried out as part of the BUMA (Prioritization of Building Materials Emissions as Indoor Pollution Sources) initiative, which is sponsored by Europe and aims to measure exposure to substances released into indoor air. Five separate European cities—Milan, Copenhagen, Dublin, Athens, and Nicosia—saw the conduct of field campaigns. Among these efforts were weekly concentration measurements in the two public and two private buildings in each city. BTEX, terrenes, and carbonyls were measured at two places inside the structure and one outside using passive sampling. The VOC emissions from various building materials have also been measured using the Field and Laboratory Emission Cell (FLEC). The results pertaining to the amounts of compounds such as acetaldehyde (0.7-41.6 g/m^3) and formaldehyde (1.2-62.6 g/m^3) indoors Indoor sources of xylenes (0.2-177.5 g/m^3), acetone (2.8-308.8 g/m^3), and toluene (0.9-163.5 g/m^3) have varied and been quite significant depending on the building style, age, etc.

Branis *et al (*2011) looked at the mass concentration, mineral makeup, and shape of particles that kids in Prague, Czech Republic's, urban, suburban, and rural elementary school gyms re-suspended during class-time physical instruction. Cascade impactors were used to sample the particle matter. $PM_{2.5}$ and PM_{10} coarse particulate matter fractions were measured using scanning electron microscopy, gravimetric, and energy dispersive X-ray spectroscopy. As indicators of human activity, the amount of time students spent in physical education classes and the number of students who exercised were also counted. 4.1-7.4 g/m³ and 2.0-3.3 g/m³, respectively, were the average PM2.5 2.5 concentration and PM1 1.0 mass concentration outside compared to 13.6-26.7 g/m³ and 3.7-7.4 g/m³, indoors. When physical activity was scheduled, there was a higher concentration of coarse aerosol indoors. In the early years of the twenty-first century, there was substantial evidence from earlier studies indicating fine particulate matter pollution was harmful to the health of both adults and children.

The objectives of the study (Elbayoumietal.,2013) was to track the mass concentrations of fine particulate matter ($PM_{2.5}$, PM10) indoors and outdoors in 12 naturally ventilated schools (36 classrooms) in the Gaza Strip and evaluate the impact of outdoor pollutant concentrations on the indoor concentrations using to calculate the probability of fine particulate inhalation during student activities. Measurements of fine particles, specifically $PM_{2.5}$ and PM10, were conducted during the first 1.5 months of 2012 winter between the hours of 7:00 am and 12:00 am in each classroom and outdoors. Meanwhile, details regarding the students' after-hours activities were gathered. The results showed that the concentrations of $PM_{2.5}$ and PM10 inside the building were 197.4 and 34.6 g/m³, respectively, while those outside the building were 134.7 and 32.3 g/m³. Furthermore, the data show that although the I/O ratios were almost equal across the school, there were statistically significant variations in the mean I/O values for PM2.5 and PM10 between different buildings.

The main goal of this study (Sarbu *et al.,* 2015) was to evaluate thermal comfort using subjective and experimental measurements in two air-conditioned classrooms at a university, where the air-exchange rate is guaranteed by natural ventilation, based on the predicted mean vote (PMV) and predicted percent dissatisfied (PPD) indices. The indoor environment was pleasant, and all of the circumstances were comfortable. The mean PPD index values range from 11.66 to 15.04%, while the mean PMV index values vary from 0.55 to 0.69 in both seasons. The effects of the air conditioner and manually operated windows on CO_2 concentration and thermal comfort metrics throughout the cooling season are also investigated using in situ measurements. Because of the ventilation system and rates, the air temperature is greater than the 27°C comfort criterion when there is no cooling. The PMV and PPD indices have values of 0.87 and 21%, respectively, and the CO_2 content climbs above the allowed limit to 2400 ppm. The CO_2 level dramatically decreases when the windows are opened manually.

Mandin *et al (*2017) showed that the European project OFFICAIR sought to increase knowledge about indoor air quality (IAQ) in modern office buildings, that is, buildings that had recently been constructed or renovated. Targeted pollutants included particulate matter with an aerodynamic diameter of less than 2.5 m ($PM_{2.5}$), ozone, nitrogen dioxide, seven aldehydes, and twelve volatile organic compounds. While the concentrations of - and d-limonene were higher and the concentrations of aldehyde, nitrogen dioxide, and $PM_{2.5}$ were of the same magnitude, the concentrations of benzene, toluene, ethyl-benzene, and xylene were lower in OFFICAIR buildings than in previous studies of office buildings. It was discovered that the quantities of formaldehyde, ozone, and benzene, d-limonene, and nitrogen dioxide were significantly higher in the summer than they were in the winter. The levels of 2-ethylhexanol and terpene in the structures varied depending on the season. Acetaldehyde and hexanes concentrations tended to increase by 4-5%.

Shi *et al(*2018) examined mechanical ventilation systems which were not present in buildings with split air conditioners, or SAC buildings. The two main ways that these buildings get fresh air are through natural ventilation and air infiltration, both of which have the ability to introduce particulate matter (PM)-contaminated indoor environments from the outside. To concurrently meet the criteria for fresh air and indoor PM concentration, two indoor air purification systems can be used: air purifiers (APs) combined with open-window ventilation (AP-Mode) and fresh air units (FAUs) combined with positive pressure control (FAU-Mode). Research is required to determine which of the two alternatives is more appropriate for different kinds of SAC buildings. First, it is advised to use a novel method to calculate the mechanical fresh air supply rate needed to maintain a positive room pressure for SAC constructions. If the mechanical fresh air delivery rate is more than 3.2, it is found that positive room pressure can be maintained by multiplying the natural air infiltration rate, which is the air infiltration rate in a room without mechanical fresh air supply. Next, the clean air delivery rates (CADRs) for APs used in the AP-Mode and FAUs used in the FAU-Mode are calculated for different $PM_{2.5}$ I/O ratios and fresh air supply rates. Next, the two methods' yearly energy usage is contrasted. The mass balance theory of indoor particle matter is the basis for this. It is therefore demonstrated that the implementation of the FAU-Mode in SAC buildings in Beijing, Shanghai, and other cities generally leads to a reduction in the annual energy consumption. Lastly, rooms with fresh air requirements less than one hour should use the AP-Mode, while When applying the FAU-Mode in different scenarios, it is important to consider the $35g/m^3$ indoor $PM_{2.5}$ concentration upper limit and the room air tightness requirement for positive pressure control. Given that people spend the majority of their lives indoors, indoor air quality, or IAQ, is a major concern for human health.

Bennett *et al (*2019) conducted a study on the school children exposure to air pollution in school environment. Children are particularly vulnerable to the negative effects of air pollution on their health. Understanding the variables influencing the interior air quality in schools is crucial for the measurement and management of indoor air pollution. This study looked at the concentration and sources of air pollution at a primary urban school in Wellington, the capital of the country, serving students aged 5 to 11. Over the course of three weeks in the spring, indoor measurements of temperature, humidity, carbon dioxide (CO_2), nitrogen dioxide (NO_2), and particulate matter (PM2.5, PM10) were made. For elemental speciation analysis, hourly air particulate matter samples (PM2.5, PM10-2.5) were also gathered both indoors and outdoors. During the school day, indoor PM10 levels were significantly (p 0.001) higher than outdoor levels. in contrast to 8.9 (1.0-35.0, SD 6.8) g m3, 30.1 g m^3 (SD = 1.9, range 10.0-75.0). Based on elemental analysis and receptor modeling of PM samples, the bulk of the components in indoor PM10 were identified as

being from crustal matter (soil), which was likely brought within by children wearing shoes. Mitigation techniques, like better cleaning practices, less carpets in classrooms, and better ventilation, are required to lower exposure to indoor air pollution at schools. The primary cause of indoor PM2.5 was the entry of outside pollutants, with motor vehicle emissions' byproducts being the biggest source of indoor PM2.5. The results of this study about high foot traffic will be helpful to many other public buildings, including schools. are more vulnerable to the negative effects of air pollution on health. Regarding the Understanding the elements influencing the interior air quality in schools is crucial for the measurement and control of indoor air pollution. This study looked at the concentration and sources of air pollution at a primary urban school in Wellington, the capital of the country, serving students aged 5 to 11. Over the course of three weeks in the spring, indoor measurements of temperature, humidity, carbon dioxide (CO_2), nitrogen dioxide (NO_2), and particulate matter ($PM_{2.5}$, PM_{10}) were made. For elemental speciation analysis, hourly air particulate matter samples (PM2.5, PM10-2.5) were also gathered both indoors and outdoors. During the school day, indoor PM10 levels were significantly (p 0.001) higher than outdoor levels. in contrast to 30.1 (range 10.0-75.0, SD 1.9) g m^3 and 8.9 (1.0-35.0, SD 6.8) g m^3. Most of the Elemental analysis and receptor modeling of PM samples revealed that the components of indoor PM_{10} were those found in crustal matter (soil), which was likely brought indoors on children's shoes. Mitigation techniques, like better cleaning practices, less carpets in classrooms, and better ventilation, are required to lower exposure to indoor air pollution at schools. The primary cause of indoor $PM_{2.5}$ was the entry of outside pollutants, with motor vehicle emissions' byproducts being the biggest source of indoor $PM_{2.5}$. The results of this study about high foot traffic will be helpful to many other public buildings, including schools.

Scriber *et al., (*2019**)** examined the association between particulate matter ($PM_{10}$and $PM_{2.5}$) concentrations outdoors and indoors and assesses the impact of several variables that may affect particle pollution levels in homes. 24-hour measurements of the PM_{10} and $PM_{2.5}$ concentrations were taken simultaneously indoors and outdoors in 179 different places across Krakow with the use of personal aerosol monitors. Information on the properties where the measurements were taken was gathered using a questionnaire. Significant, statistically significant correlations were found between outside and indoor PM_{10} and $PM_{2.5}$ concentrations ($r = 0.78$, $p=0.001$) and between outside and indoor $PM_{2.5}$ ($r = 0.82$, p0.001), even though the daily average outside PM_{10} and $PM_{2.5}$ levels were higher than inside levels ($p= 0.001$). the most significant predictors of interior readings following correction for outdoor measurements. Because indoor concentrations of PM_{10} and $PM_{2.5}$ rise in tandem with outdoor concentrations, improving urban air quality will also enhance interior air quality.

Stamate lopouloset al., (2019**)** showed a good correlation between numerous harmful health effects in respect to indoor air pollution. Babies and young children spend most of their time indoors, but it's unclear how much of an exposure to indoor pollutants they may have. In order to define comfort parameters for living rooms and children's bedrooms, as well as to identify the factors that influence indoor PM and HCHO concentrations, the objectives of this study were to characterize the particulate matter (PM) and total volatile organic compound (HCHO) concentrations that young children are exposed to. Additionally, the study sought to determine how residents' daily activities and socioeconomic status affected the diurnal variations in these indoor pollutants. In this context, a research of PM, HCHOs, and comfort factors was conducted in Athens, Greece, in homes containing young children under the age of three. During the six-to seven-day sampling period, real-time monitoring was used.

Kim et a (2020) examined the psycho-physiological impact of interior heat conditions on the academic performance of college students. To do this, twenty volunteers in an experiment were conducted in a climate chamber. Five different heat conditions were created with the climate room. The indoor environment's standard was noted. In order to examine the subjects' learning performance, four cognitive tests were administered to evaluate their executive, working memory, attention, and perceptual skills simultaneously. The subject's psycho-physiological responses, such as their mental workload, mental stress, attentiveness, and mental fatigue, were also assessed using an electroencephalogram. The study employed one-way repeated-measures ANOVA to investigate the statistical significance of the different components.

Alves *et al,(*2020) conducted a study in an unstudied work environment, a university cafeteria where a thorough air monitoring campaign was carried out. The collection of volatile organic compounds and carbonyls was made possible by the use of passive diffusion samplers. Temperature, relative humidity, CO_2, CO, and particulate matter were continuously monitored both inside and outside. Both during the day and at night, simultaneous PM_{10} sampling was conducted using high- and low-volume equipment fitted with Teflon and quartz filters, respectively. The carbonaceous content of the quartz filters was determined using thermo-optical analysis, and the organic components were determined using GC-MS analysis. Both PIXE and ion chromatography were utilized to examine the elements and ions that were soluble in water in the Teflon filters. Low air change rates (0.31–1.5 h1) and infiltration coefficients of 0.14 for $PM_{2.5}$ and PM_{10} particles are signs of poor ventilation. Compared to the surrounding region, the cafeteria had much higher levels of gaseous pollutants and particulate matter, with strong daily variations according to occupancy and activity levels. The average amount of PM_{10} generated inside was determined to be 32 g/m^3.Among the organic substances identified in PM_{10} were alkanes, polycyclic aromatic hydrocarbons (PAHs), saccharides, phenolic alcohols, acids, alkyl esters, triterpenoids, and sterols. The complex particle composition indicates a diversity of sources, production reactions, and removal processes, all of which are still poorly understood. These comprised kitchen emissions, tobacco smoke, ulster suspension, abrasion and off-gassing from building materials, and several consumer goods. Various compounds are present in personal care products, flame retardants, plasticizers, pesticides, and psychiatric medications. The cancer risks associated with metal and PAH inhalation were found to be substantial.

2.2. National Scenario:

K Ghose et al(2004) stated that the status of air pollution in the area had been evaluated and a questionnaire survey was conducted to estimate the allergic symptoms and exposure to assess the respiratory disorders. The information is analyzed to determine the severity of the air pollution crisis and the activity-wise impact of respiratory diseases (RDs) on the health of the middle class subpopulation in the area. There is a suggested strategy plan for managing air quality. It has been discussed what steps should be taken to maintain the balance between environmental management and sustainable growth in order to mitigate the city's air pollution problems.

In Delhi City, a study (Goyal *et al.,* 2009) on indoor-outdoor RSPM mass concentration monitoring was conducted in a classroom of a naturally ventilated school building next to an urban street. Monitoring is planned to run for a year, starting in August 2006 and concluding in August 2007, to account for hourly, daily, weekly, monthly, and seasonal fluctuations in pollutant concentrations. The monitoring schedule is for the following days: Saturday and Sunday from 8:00 a.m.to 2:00 p.m. on the weekends, and Monday, Wednesday, and Friday on weekdays. The concentrations of indoor and outdoor RSPM have been simultaneously recorded with meteorological parameters, including temperature, relative humidity, pressure, wind direction and speed, and traffic parameters, including kind and volume. to ascertain the connection between indoor particle concentration and ventilation rate. The results of the study demonstrate that, during all monitoring periods, including weekends and holidays, RSPM concentrations in classrooms routinely above permissible values and adding that, should students be exposed, this could pose a health risk to them. When the I/O ratio is greater than 1, it means that not all particle sizes are protected from outside pollutants by the building envelope. Furthermore, a significant influence of traffic volume, ventilation rate, and weather on I/O has been observed. Higher I/O for PM10 suggests the presence of indoor sources in the classroom and the major influence of daily activities on indoor concentrations of these sources.

Gurjar et al (2016) studied that the emissions and concentration trends of criteria and other air pollutants (polycyclic aromatic hydrocarbons, carbon monoxide and greenhouse gases) were examined in the three Indian megacities. Further, various policies and control strategies adopted by Indian Government were also discussed to improve air quality. Because the sulfur content of coal and diesel has decreased, declining trends in SO2 have been seen in all three megacities.Nonetheless, a growing trend in NOx emissions was seen in these megacities, which might be attributed to the rise in the number of registered vehicles and the high flash point of CNG engines. The largest emissions of SPM and PM10 were discovered in Kolkata, while the highest ambient concentrations were noted in Delhi. SPM concentrations showed variable trends in Mumbai and Kolkata between 1991 and 1998, then stabilised until 2005; in Delhi, however, there remained a fluctuating trend throughout the study period. Nonetheless, India has implemented a number of measures to reduce air pollution, but control must be the main priority.

B Paul et al (2018) objectified that the presence of IAP (Indoor air pollution) , its associated factors and impact on health of women residing in an urban slum of Kolkata, West Bengal, India. A cross-sectional study involving 120 slum homes was conducted between January and March of 2017. A pre-planned, pre-tested timetable was used to gather data from the housewife in each family. R: A Language and Environment for Statistical Computing was used for all studies. Kerosene was primarily used as cooking fuel in almost 60% of households. Of the respondents, 57.5% were concerned by smoke coming from nearby houses. Over 60% of the homes were overcrowded, and over 70% had inadequate ventilation. The presence of IAP sources and its contributing components was substantially connected with IAP-related symptoms such dry cough, suffocation, and eye discomfort. Out of the 120, 78 (65%) said they thought they had IAP in their homes.

Biswas et al(2020) portrayed the current air pollution situation with seasonal variation in three zones (two from Kolkata and one from Siliguri) as it evaluates the present level of different air pollutants like particulate matter (PM), carbon monoxide, nitrogen dioxide, and sulfur dioxide. Following the seasonal analysis, monthly characteristics of the most variable seasonal pollutants were examined in the studied areas. The results indicated that the critical level of air pollutants, particularly PM2.5 and PM10, had reached its highest concentration during the post-monsoon season in the Rabindra Bharati University zone in Kolkata (363.5 and 295.4 μg/m3 during the day, respectively). Because various pollutants were contributing to rising temperatures, these seasonal variations in pollution levels also represented the effects of weather. Thus, this study also attempted to support the environmental contamination scenario by comparing the average daily temperature (°C) with the concentration of air pollutants (μg/m3), such as CO and PM2.5, individually, using the Spearman's rank correlation coefficient approach.

The main **(**Saraga *et al.*, 2023) objectives of the study was to pinpoint the primary causes of indoor air pollution in three diversely used interior environments: a museum, a printing factory, and an office. For this reason, other pollutants were also monitored: particulate matter (TSP, PM10, and PM2.5), organic pollutants (BTX and formaldehyde), and inorganic pollutants (NOx, SOx, and O3). The types of indoor activities, the emissions from the existing equipment, the number of residents, the ventilation pattern, and the outside background were among the characteristics that varied significantly between the three sites. The printing industry had the highest average levels of PM2.5 (151 g/m^3), benzene (69.4 g/m^3), toluene (147 g/m^3), SO2 (47 g/m3), and NO2 (96.6 g/m^3), despite the fact that all of them were evaluated during the experimental campaigns. Formaldehyde had the greatest quantity in the museum (50.5 g/m^3). The workplace of nonsmokers was found to have the highest concentration of O3 (238 g/m^3), whilst the industry of printer presses (11.0 g/m^3) had the lowest and possessed the least.It seems that the sites' geographical location has a significant influence as well. The ratio of benzene to toluene indicated that traffic was a major factor. Moreover, the print refectory and the museum, which are located in urban areas, had moderate levels of ozone, while the offices in suburban regions had much higher levels, suggesting that the substance came from outside.

CHAPTER 3: AIMS AND OBJECTIVES

The environment and human health are both greatly impacted by air pollution. Pollutant emissions into the atmosphere have an impact on the environment, including harm to ecosystems, changes in the climate, and the spread of infectious illnesses. These air pollutants, which can cause respiratory and cardiovascular conditions, are found in ambient air and include ozone, nitrogen dioxide, sulfur dioxide, and particle matter. Strict emission control policies and teamwork are essential to lowering these pollutants' levels and safeguarding public health and the environment. Through the first part of the study we aim at

- Gathering monthly secondary data on air pollutants from the West Bengal Pollution Control Board (WBPCB) website in order to compile the ambient air quality at two different locations, such as Behala Chowrasta and Ultodanga, with regard to SOx, NOx, suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM), and the Air Quality Index (AQI).Observing decadal change of air pollution and analyzing trend statistically with graph after collecting data from the year 2009 to 2019 at the following location .
- Projecting future air pollution trends up to 2030 while using previous trends as a guide and talking about preventative measures and solutions for improved air quality .
- The second section examines the state of the air quality during the COVID-19 pandemic in 2020–2021 by examining the air quality during the three distinct periods of lockdown are pre, lockdown, and post in same locations of Kolkata.

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CHAPTER 4: MATERIALS AND METHODOLOGY

Description of study area :

Founded around 1690 on the eastern bank of the Hoogly River, Kolkata is one of the oldest cities in India. It was originally composed of the three villages of Govindpor, Sutanutee, and Kalikata. The city expanded to the right bank of the Hoogly River after 1793, having previously developed in a linear fashion along the left bank. England had a significant impact on Kolkata's development and architecture, particularly in the domains of politics, society, business, and culture. Due to urban industrial expansion, migration, and economic opportunities, Kolkata experienced significant changes in both shape and function throughout time, which exacerbated environmental degradation.

My current work is structured around two different location named **Ultodanga** and **Behala Chowrasta.**

Ultadanga is one of the most crowded junctions in Kolkata. The location delineates the boundary of the Kolkata district and is situated on the northeastern edge of the city.In 1717, the Mughal emperor Farrukhsiya granted the East India Company the right to rent 38 adjacent villages for their settlement. Of these, five were located in the Howrah district, across the Hooghly. On the Calcutta side were the remaining thirty-three settlements. When Siraj-ud-daulah, Bengal's final independent Nawab, fell, it bought these villages from Mir Jafar in 1758 and reorganized them. Ultadanga was one of these villages named Dihi Panchannagram, collectively known as en bloc. Ulta Danga, which derives from the area's previous name, Ulta Dingi, was once thought to be a suburb outside the Maratha Ditch. It was a ghat region, and it's likely that at one point in history, before the Ganges changed its path, this was also on the banks of the river. The Kolkata Municipal Corporation designated Maniktala, Ultadanga, and Beliaghata as "fringe area wards" in 1889. Ultadanga, Kolkata, West Bengal, India is situated in the Districts location category of the India country, with GPS coordinates of 88° 23' 9.4416" E and 22° 35' 38.5584" N (Fig. 1)

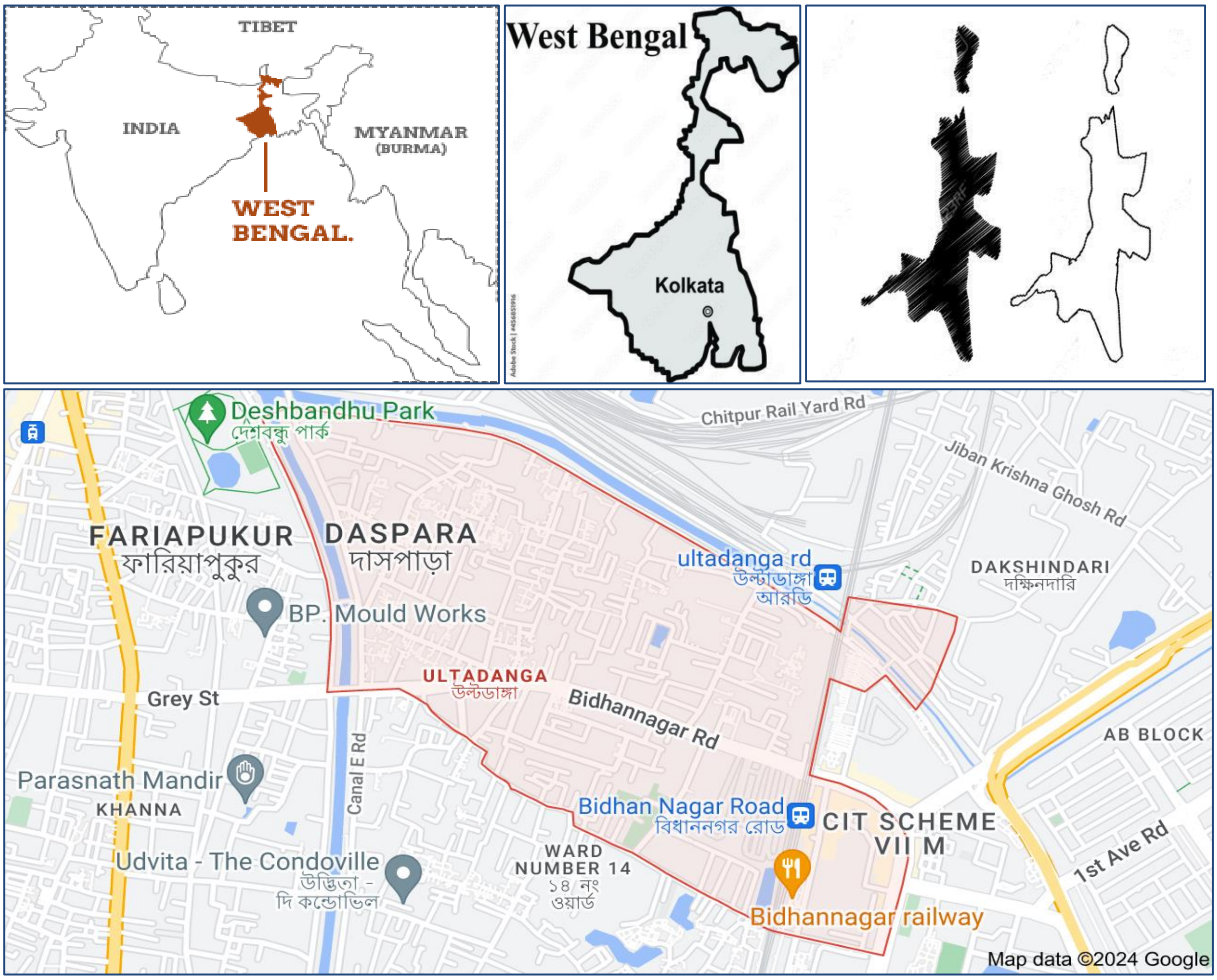


Fig 1. Study area location: Ultodanga

In the Indian state of West Bengal, Behala Chowraata is a neighborhood in the Kolkata district of Kolkata city. The region covered by Kolkata Municipal Corporation includes Behala. Spread out over the Kolkata Municipal Corporation's Ward Nos. 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, and 132, it is separated into two Vidhan Sabha constituencies, namely Behala Paschim and Behala Purba. This region is covered by the Behala Division, also known as the South West Division of the Kolkata Police, which is made up of the police stations at Behala, Parnasree, Thakurpukur, Haridevpur, and Sarsuna. Taratola is also included in this division.

Behala is among the city's oldest neighborhoods. One of the oldest zamindar families in Western India is the Sabarna Roy Choudhury family. This is the home of Bengal and the Kalighat Kali Temple trustee. In addition, Sovan Chatterjee, a former Kolkata mayor, and Sourav Gangul, a former captain of the Indian cricket team, call it home. Launched by Laksmikanta Majumdar in 1610, the Durga Puja festival of the Sabarna Roy Choudhury family in Barisha is the second oldest family Durga Puja in western Bengal. Sarbojanin pujas with an unusual theme commemorate Durga Puja in Behala today. Since 1792, the 10-day Barisha Chandi Mela has taken place in November or December of each year.

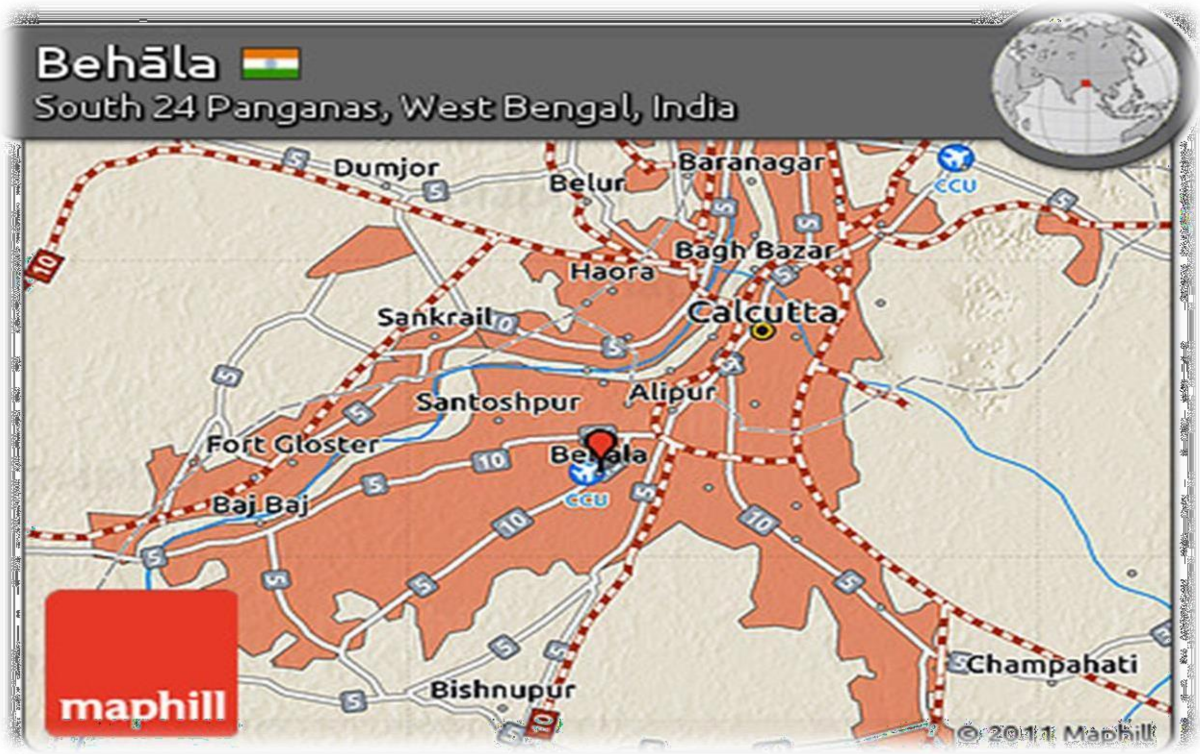


Fig 2. Study area location: Behala Chowrasta

Latitude and longitude coordinates of Behala Chowrasta are: 22.498140N, 88.310837E(Fig 2).

Statistical Analysis and Software used

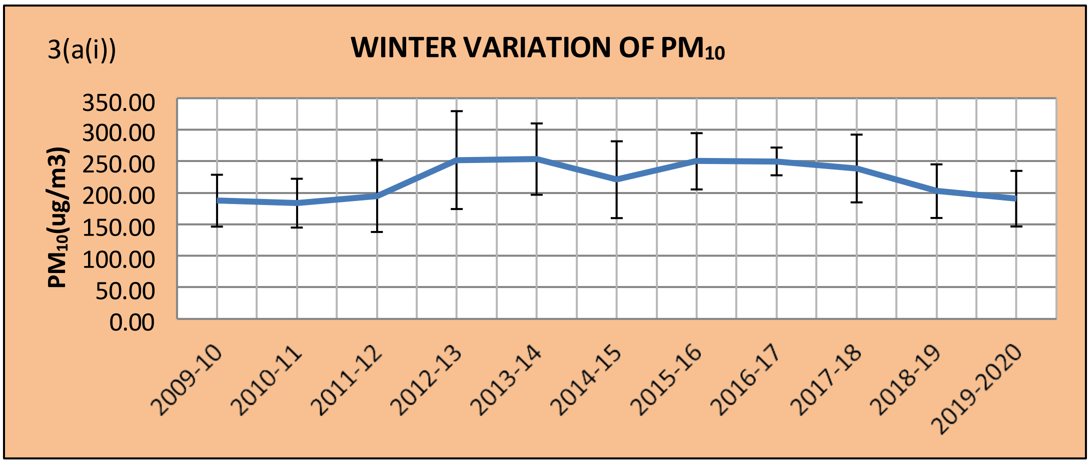
By gathering records of monthly secondary data of air pollutants from the West Bengal Pollution Control Board (WBPCB) website, the ambient air quality assessment was conducted at two different locations in Kolkata with respect to SOx, NOx, suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM), as well as the Air Quality Index (AQI). Following data collection, a graph was used to statistically assess the decadal change in air pollution. Standard division was used to add or subtract error from the monthly average value of air pollutants for the years 2009 to 2019. Ultimately, trend analysis techniques such as the Box Plot and Linear Regression method were employed as statistical tools to determine the kind of air pollution trend at the two Kolkata locations that were mentioned between 2009 and 2019. Other than I used a linear regression model (formula $Y = mX + c$) for trend analysis of concentration levels of air quality parameters with time (where Y is the air pollutant, X is the time, m is the slope, and c is the intercept) in order to perform basic statistical analysis (e.g., average, standard deviation, etc.) of the air quality parameters. Here, I utilized the Linear Regression approach with XLSTAT 2018.5, a statistical software, to determine the trend of air pollution from 2009 to 2019. In scientific investigations, the linear regression model is frequently employed to comprehend the relationship between two variables, including trend analysis. Trend analysis shows how the concentration levels of air pollutants have changed over time, indicating whether the installation of air pollution controls has been effective or not. Trend analysis shows how air pollution concentration levels have changed over time (i.e., increased, decreased, or remained unchanged), suggesting that the efficacy of mitigating air pollution with policies and technologies has been studied (Mishra et al,2016). Apart from conducting trend analysis, we also computed the net change in air pollution concentration levels between 2009 and 2019. The parts that follow have covered the in-depth trend analysis and a net change in the concentration levels of air pollutants.

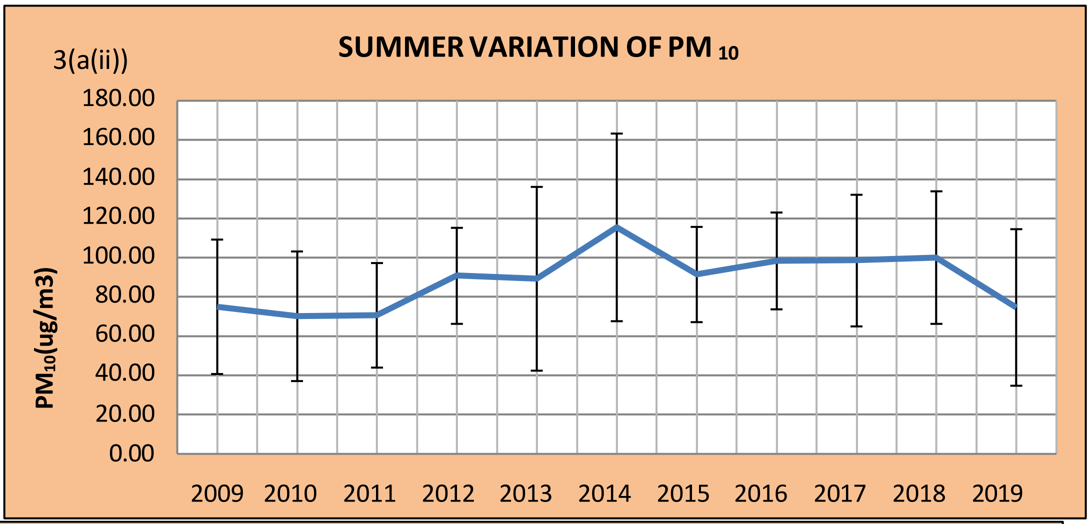
CHAPTER 5. RESULT AND DISCUSSION

PART I : Decadal change of Air Pollutants with seasonal variation

5.1) Particulate Matter: Changes in the intensity of air pollution emissions and fluctuations in climatic conditions over time affect the concentration of air pollutants, particularly PM (such as PM10), in ambient air. Numerous studies have been conducted in a variety of locations across the globe, including Beijing and Nanjing (Zhou et al., 2020), Guangzhou (Verma et al., 2010), Hedo (Verma et al., 2011; Kondo et al., 2011), Seoul (Seoet al., 2018), Bangkok (Sangkham et al., 2021), and others, to examine the relationship between the concentration levels of air pollutants in ambient air and meteorological conditions and emission intensity. Figures 3(a) and 3(b) showed the temporal seasonal fluctuations in the monthly average concentration of PM_{10} in Kolkata's Behala, Chowrasta, and Ultodanga locations from January 2009 to December 2019. The standard deviation was used as an error measure. Tables 1 and 2 offer statistics on PM_{10}. The PM_{10} statistics displayed in Table 1, 2, and Fig. 3 represent the average of all WBPCB and CPCB data collected in the corresponding cities. Figures 3(c) and (d) show the trend analysis, which shows how PM_{10} concentration levels in Ultodanga and Behala have changed over time, as well as the government-mandated PM_{10} NAAQS. Seasonal fluctuations were clearly seen in the PM_{10} concentration levels. Their levels demonstrated their reliance on meteorological circumstances, being higher in the winter and lower in the summer or during wet seasons.

Location 1. Behala Chowrasta (Kolkata)





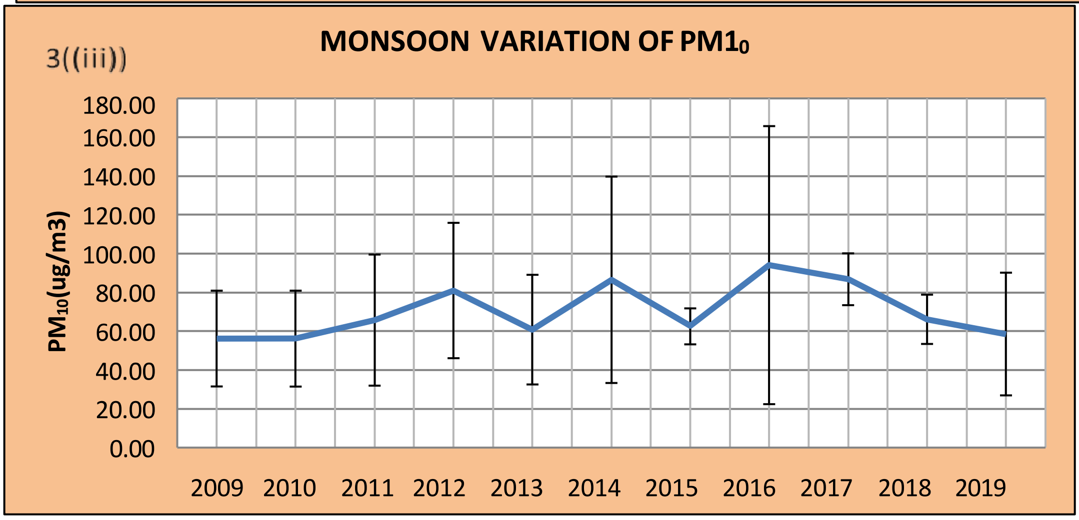
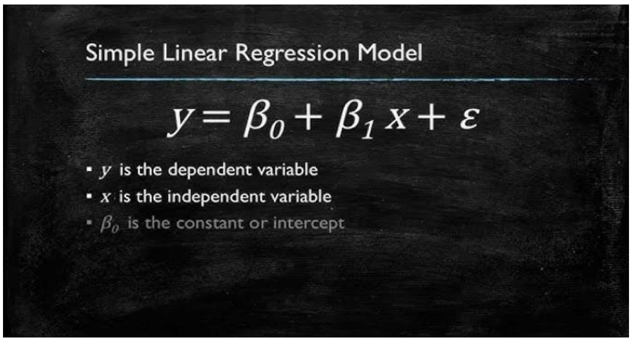
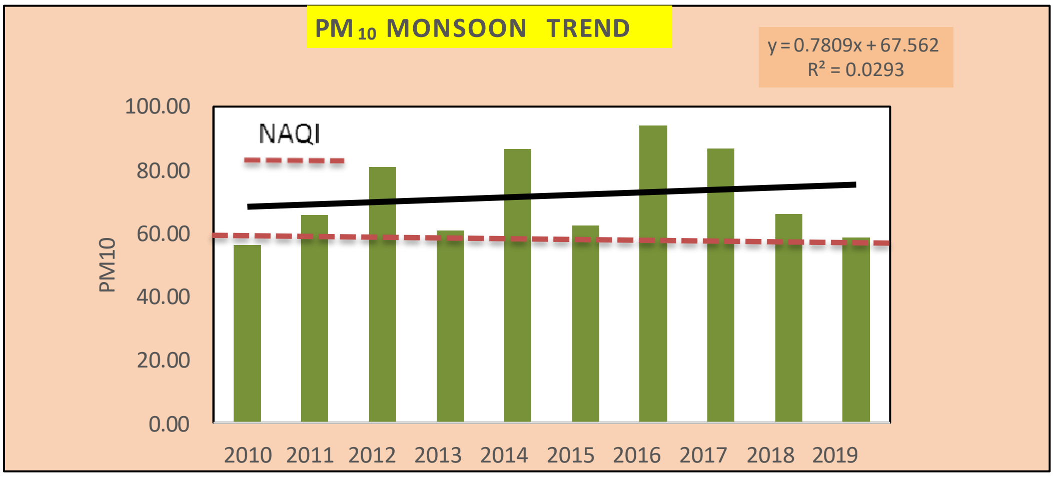


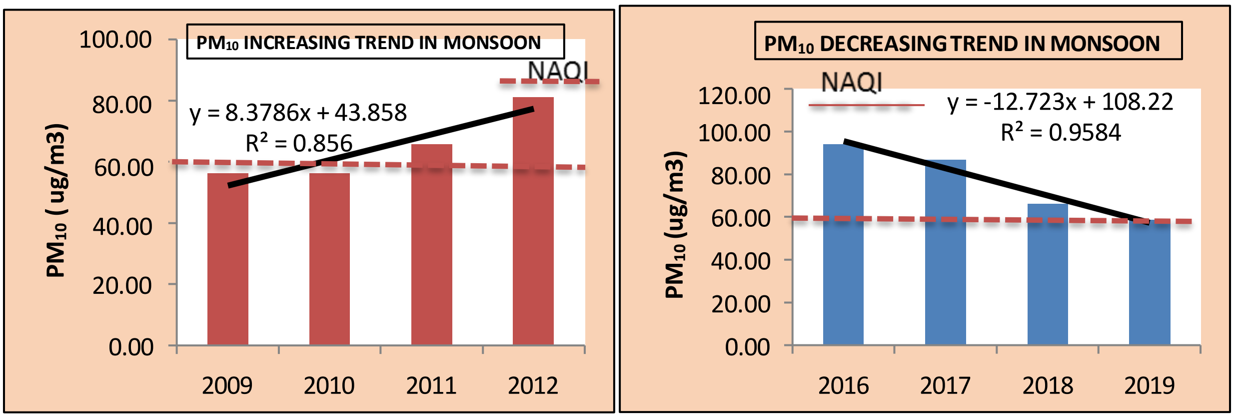
Fig 3(a). PM_{10} (ug/m3) Concentration Seasonal variation in Behala Chowrasta from 2009-2019

An essential method for analyzing how pollutant concentrations vary over time is trend analysis. A variable's value can be predicted using linear regression analysis based on the value of another variable. The dependent variable is the one that needs to be predicted. The independent variable is the one that is being used to predict the value of the other variable. To determine the association between two quantitative variables, simple linear regression is utilized. Y = mX + b is the formula for simple linear regression, in which X is the predictor (independent) variable, b is the estimated intercept, m is the estimated slope, and Y is the response (dependent) variable.

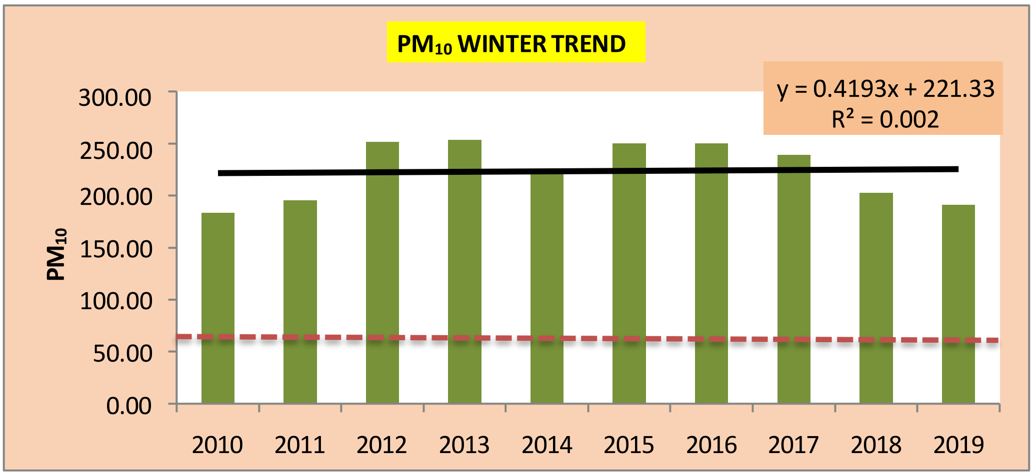




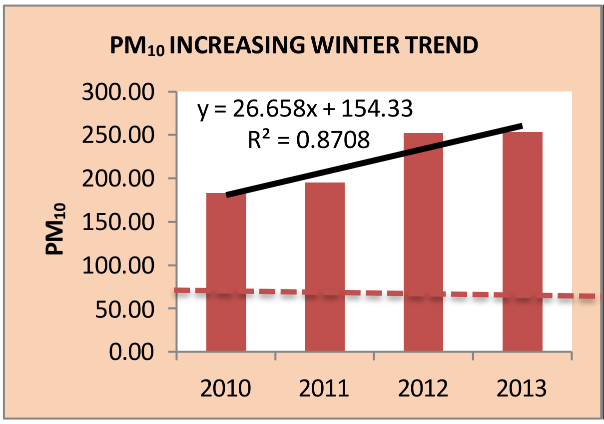
Since the PM10 monsoon data in Behala from 2010 to 2019 exhibits a poor trend (r^2 = 0.0293), no conclusions can be drawn because it is unclear how the concentration of this pollutant will change between 2009 and 2019.

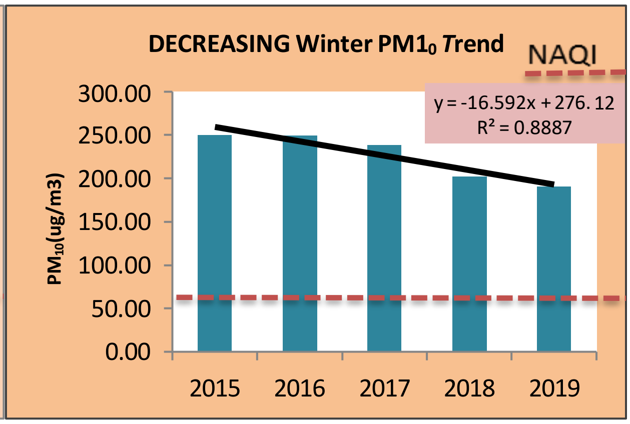


The monsoon graph is displayed here in two divisions in Fig. 3(c (i)). With the NAQI value chosen as standard, the decade is separated into two parts: the former part shows a rising trend from 2009 to 2012 (r^2 = 0.856), while the later part shows a falling trend (r^2 = 0.95) from 2016 to 2019.

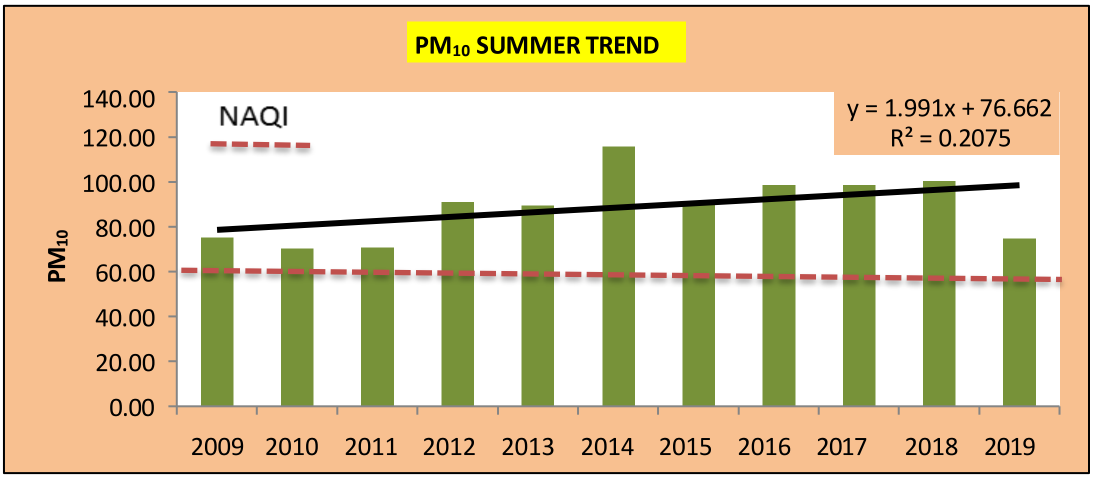


With the NAQI value (for PM_{10} 60 ug/m3) taken as standard, the winter PM_{10} data for Behala from 2010 to 2019 indicates a poor trend (r^2 = 0.002), making it unable to make any statements due to the unknown change in this pollutant concentration between 2009 and 2019.

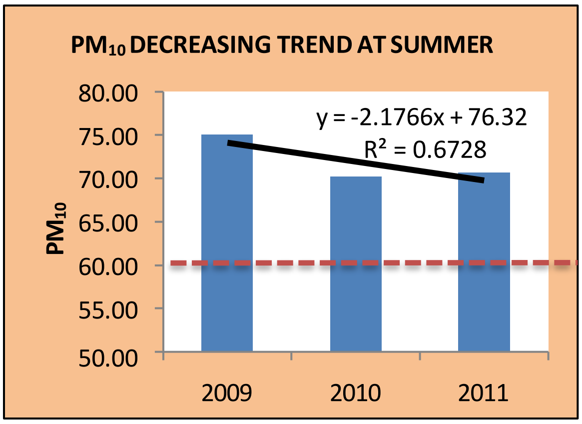


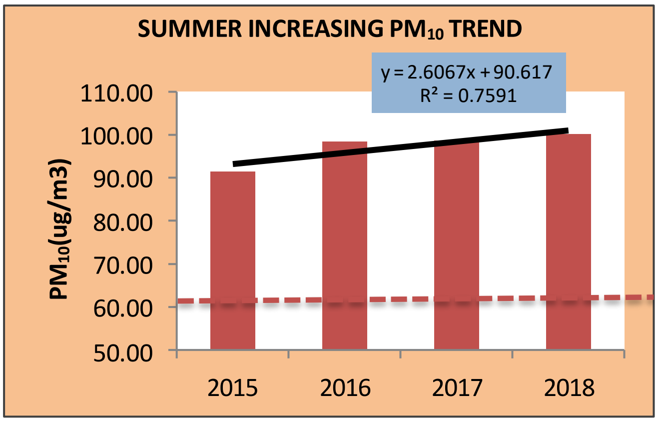


The winter graph is displayed in two divisions in Fig. 3(c(ii)). With the NAQI value (for PM_{10} 60 ug/m3) taken as standard, the decade is divided into two parts: the first portion shows a rising trend from 2010 to 2013 (r^2 = 0.87), while the later part shows a decreasing trend (r^2 = 0.88) from 2015 to 2019.



With the NAQI value (for PM_{10} 60 ug/m3) taken as standard, the summer PM_{10} data for Behala from 2009 to 2019 indicates a poor trend (r^2 = 0.2075), making it unable to make any conclusions due to the unknown change in this pollutant concentration between 2009 and 2019.





The summer graph is displayed in two divisions in Fig. 3(c(iii)). With the NAQI value (for PM_{10} 60 ug/m3) taken as standard, the decade is divided into two parts. The first portion shows a decreasing trend from 2009 to 2011 (r^2 = 0.67), while the second part shows a decreasing trend (r^2 = 0.75) from 2015 to 2018.

The seasonal fluctuation of PM10 in Behala Chowrasta from 2009 to 2019 is trend analyzed in Fig. 3(c), coupled with the government-mandated National Ambient Air Quality Standards (NAAQS).

- **.Location 2. Ultodanga (Kolkata)**

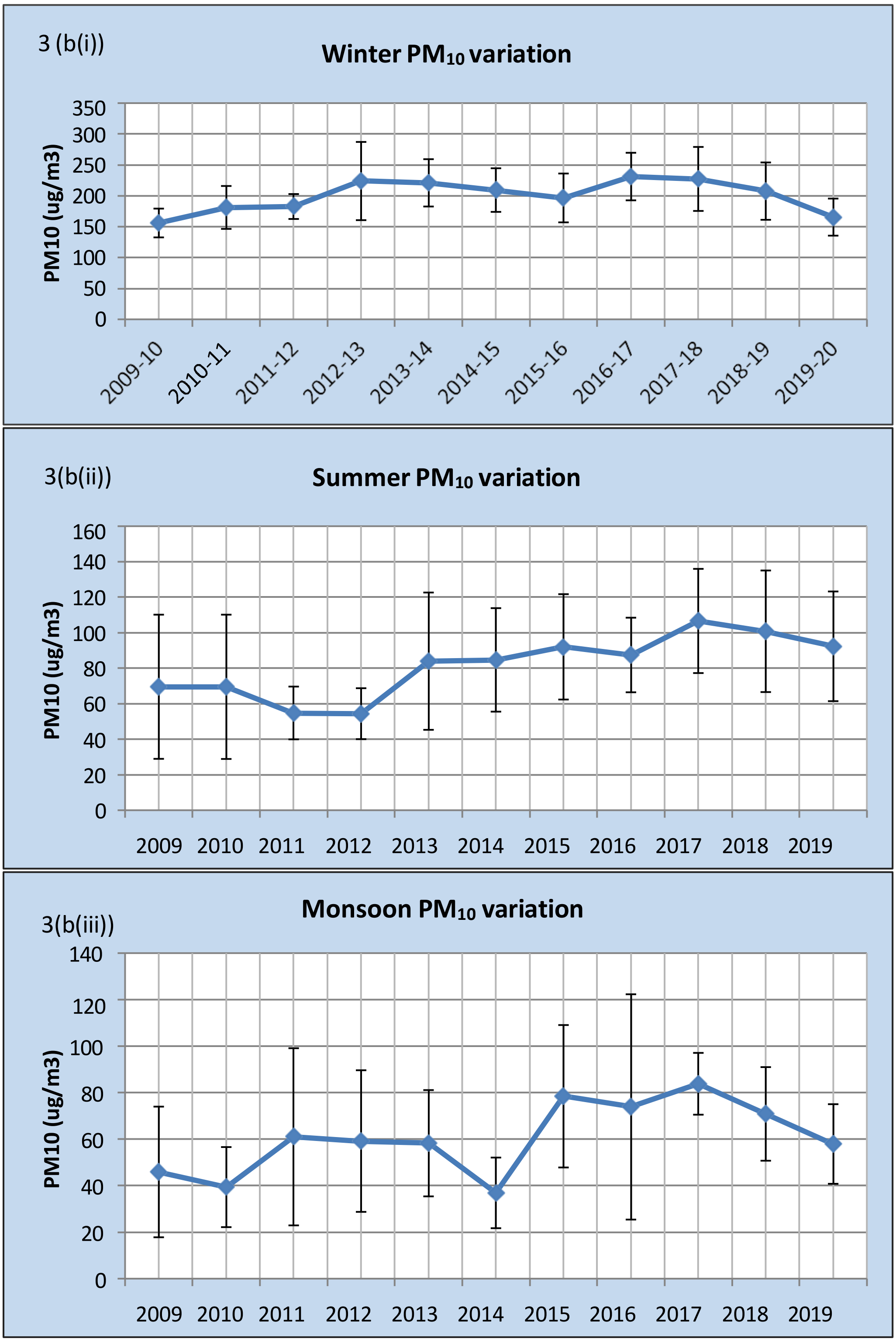
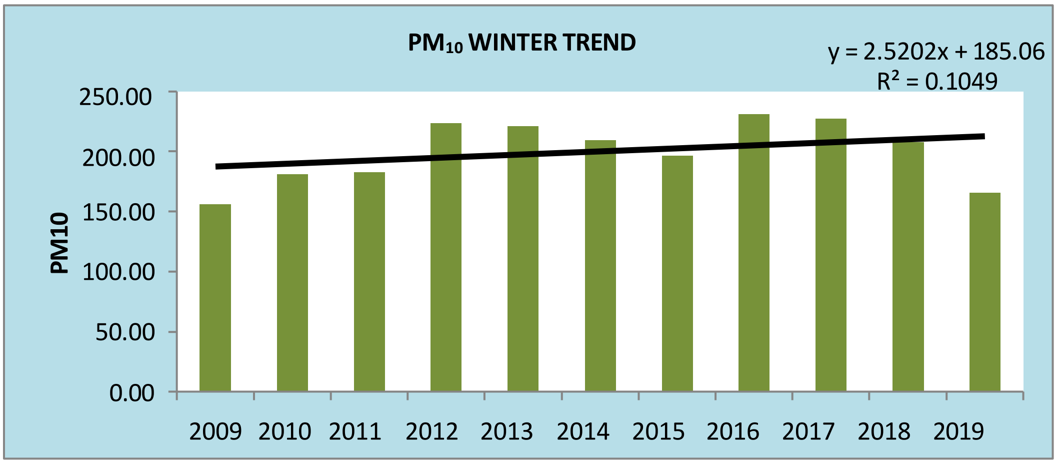
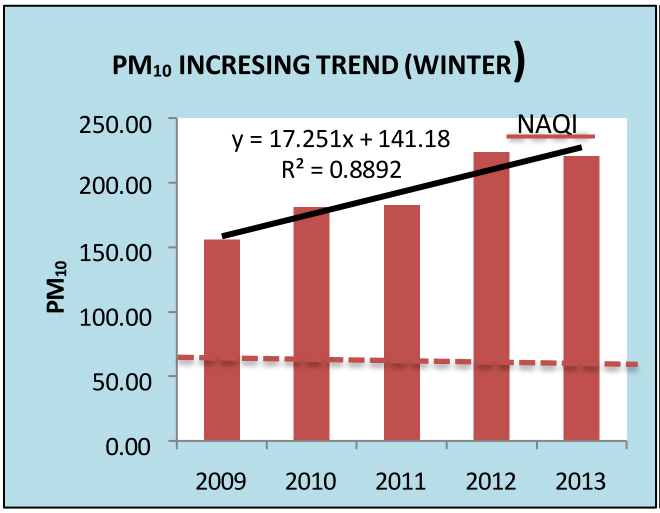
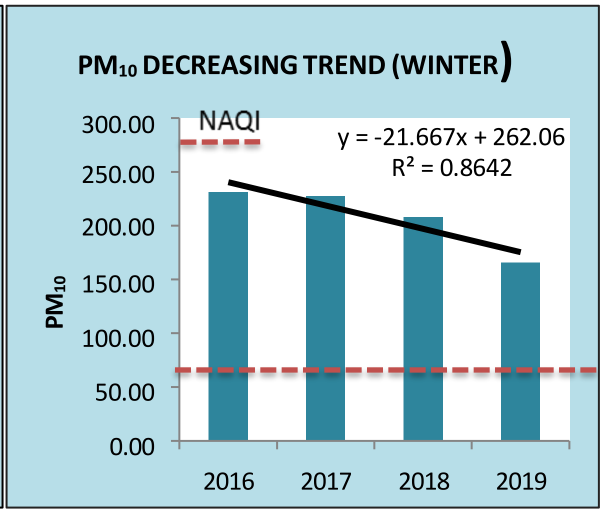


Fig 3(b). PM10 (ug/m3) Concentration Seasonal variation in Ultodanga from 2009-2019

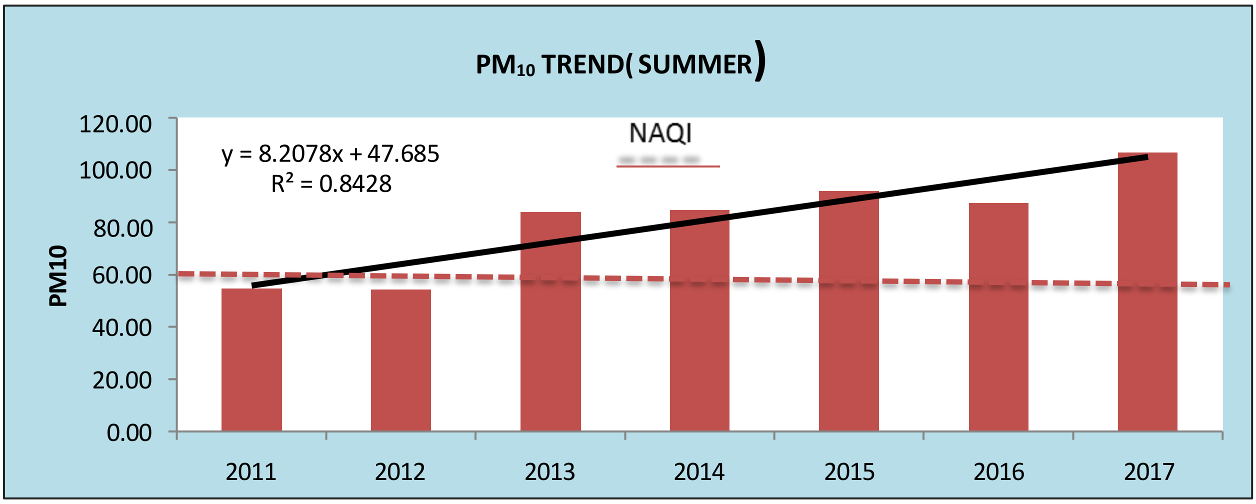


The winter data of PM_{10} from 2009 to 2019 in Ultodanga shows poor trend ($r^2 = 0.105$) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019 with NAQI value (for PM_{10} 60 ug/m3) taken as standard.

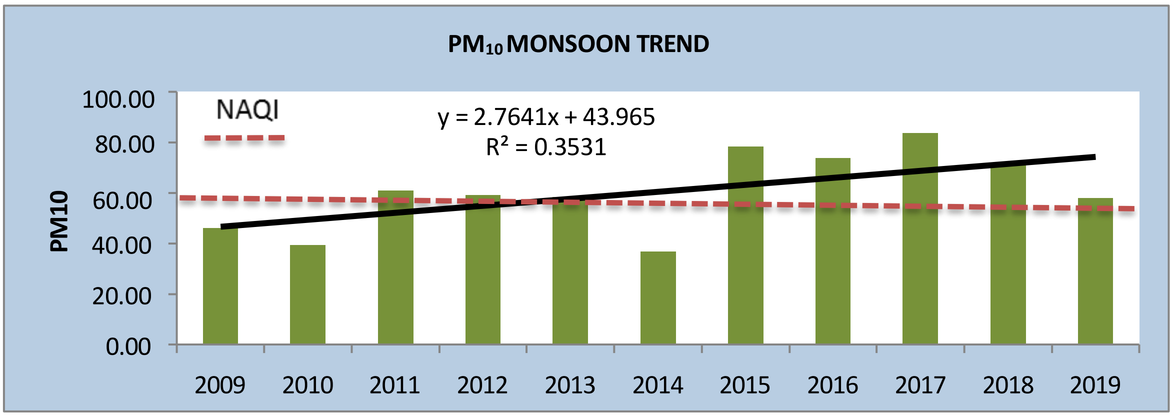




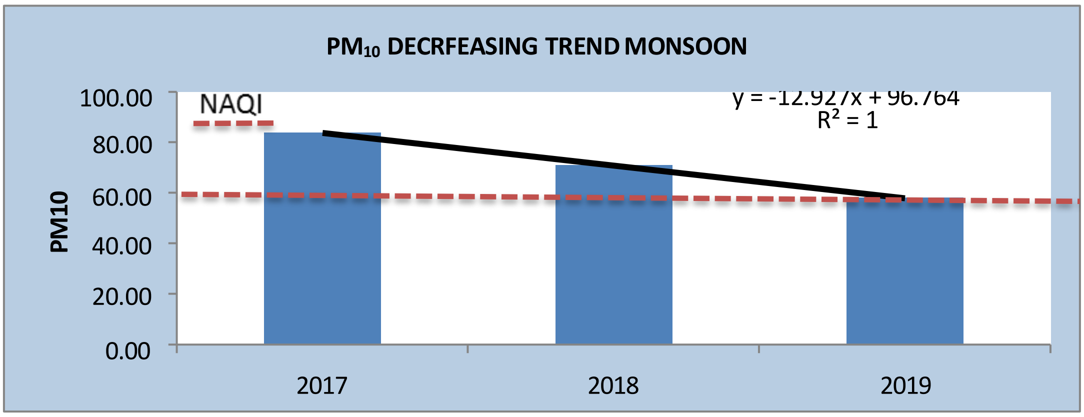
Here in Fig. 3(d(i)) winter graph is shown in two division. The decade is divided into two parts and former part shows increasing trend from 2009 to 2013 ($r^2 = 0.8892$) and later part shows decreasing trend ($r^2 = 0.86$) from 2016 to 2019 with NAQI value (for PM_{10} 60 ug/m3) taken as standard.



Here Fig (3 (d(ii))) shows the summer data of PM_{10} from 2011 to 2017 in Ultodanga shows increasing trend ($r^2 = 0.85$) in between 2009 to 2019 with NAQI value (for PM10 60 ug/m3) taken as standard.



The monsoon data of PM_{10} from 2009 to 2019 in Ultodanga shows poor trend ($r^2 = 0.351$) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019 with NAQI value (for PM_{10} 60 ug/m3) taken as standard.



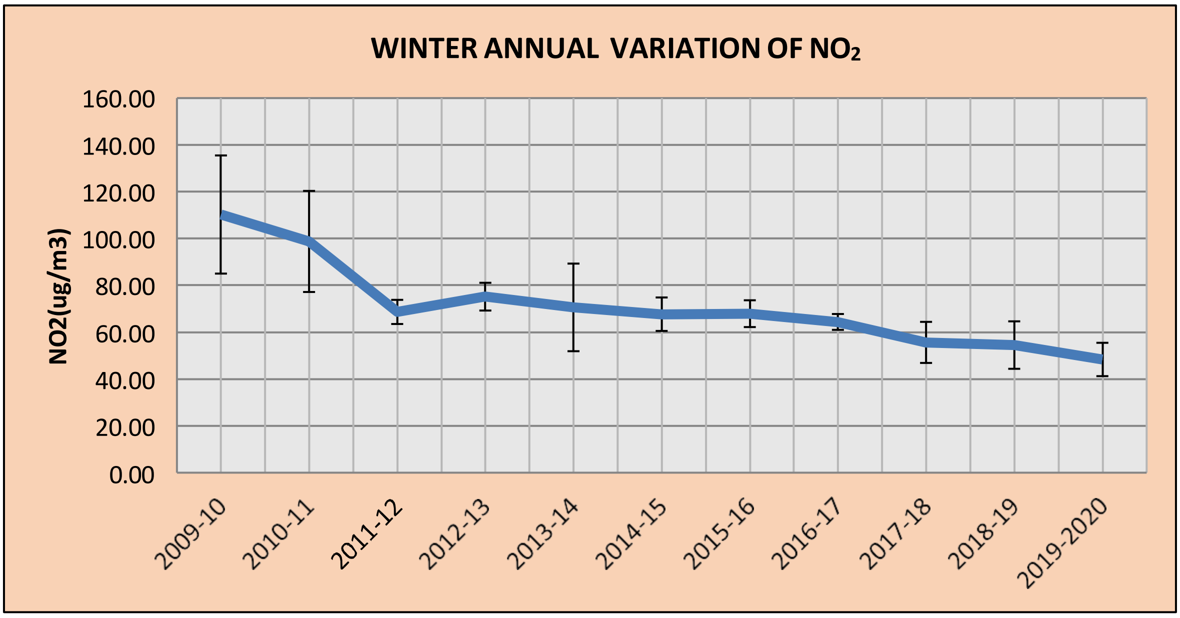
Here Fig (3 (d(iii))) shows the monsoon decreasing trend ($r^2 =1$) of PM_{10} from 2017 to 2019 in Ultodanga with NAQI value (for PM_{10} 60 ug/m3) taken as standard

Fig 3(d). includes trend analysis between 2009 to 2019 for seasonal variation of PM_{10} in Ultodanga along with the Government-prescribed National Ambient Air Quality Standards (NAAQS) for PM_{10}

Seasonal fluctuations were clearly seen in the PM10 concentration levels. Their levels demonstrated their reliance on meteorological circumstances, being higher in the winter and lower in the summer or during wet seasons, presuming that there was little variation in PM10 emissions in these sites throughout the year. The concentration levels of PM10 in Kolkata have continuously demonstrated significant seasonal fluctuations, with greater levels in the winter and slightly lower levels in the summer or during the monsoon. As a conduit for air pollution outflow from the Indo-Gangetic Plan (IGP) to the Bay of Bengal, Kolkata and the surrounding eastern region of India are frequently affected by biomass burning during the winter (Srinivas et al., 2015; Sasmita et al., 2022). The PM10 concentration values found in this investigation were comparable to those found in Kolkata by Karar et al.(2006). The yearly average concentrations of PM10 measured in Kolkata from 2009 to 2019 are represented in Tables 1.a, 1.b, 1.c, and 2.a, 2.b, 2.c. Figs. 3.c and 3.d illustrate the net change in concentration levels as well as a trend analysis of PM10 over time in these locations. The trend analysis showed that the Behala PM10 trend is in growing order during the monsoon season from 2016 to 2019 (r2 = 0.9285) and decreasing order during the winter season (r2 = 0.8887) from 2015 to 2019 and increasing trend from 2010–13 (r2 = 0.87). As presented in Fig. 3(c), summertime trends vary depending on climatic conditions, with an increasing trend (r2= 0.7591) from 2015 to 2018 and a decreasing trend (r2= 0.7) from 2009 to 2011. The government-mandated National Ambient Air Quality Standard (NAAQS) for PM10 is set at 60 ug/m3. The government's efforts to reduce air pollution may be the cause of these declining trends in PM10 concentration levels over the winter and monsoon seasons. According to Fig. 3(d), the trend analysis for Ultodanga PM10 showed that, depending on the meteorological conditions, the trend is in increasing order in winter (r2 = 0.8892) from 2009 to 2013, decreasing order in winter (r2 = 0.8642) from 2016 to 2019, and increasing order in summer (r2 = 0.8428) from 2011 to 2017. The National Ambient Air Quality Standard (NAAQS) for PM10 set by the government is 60 ug/m3. While there was no pattern at the start of this decade, 2009-2019, due to an unknown shift in the PM10 value, as shown in Table 2, from year to year, the monsoon trend was determined to be decreasing (r2=1) in Ultodanga from 2017 to 2019. It is outside the purview of this study to assess the specifics of the government's air pollution control initiatives. Moreover, the mean yearly concentrations of PM10 recorded in Ultodanga between 2011 and 2017 and in Behala between 2015 and 2019 were consistently greater than the recommended NAAQS PM10 threshold of 60 ug/m3 (Fig. 3c & d).

5.2) NO_2 : From January 2009 to December 2019, the monthly average concentration levels of NO2 in Kolkata (Behala & Ultodanga) varied throughout time, as shown in Fig. 4(a & b). The trend in the annual average concentrations of NO_2 recorded in the designated areas of Kolkata is shown in Fig. 4(c & d). Tables 1 and 2 include the equivalent figures for the annual average concentration levels of NO_2. A net change in the NO_2 concentration levels from 2009 to 2019 and a trend analysis of the NO_2 levels in these cities were also included in Tables 1 and 2 and Fig. 4(a, b, c, d). These findings shed light on how the concentration levels of NO_2 vary throughout time. The NO_2 concentrations shown in Table (1, 2) and Fig. 4(a & b) represent the average values found across all WBPCB and CPCB sites that were operational in these areas. Similar to PM_{10}, NO_2 concentration levels in Kolkata have shown greater seasonal changes over time, with wintertime seeing higher levels and summer or monsoon seasons seeing lower levels. The study's seasonal changes in NO_2 concentration levels matched those noted by Chatterjee (2022) in Kolkata.

Location 1 : Behala Chowrasta



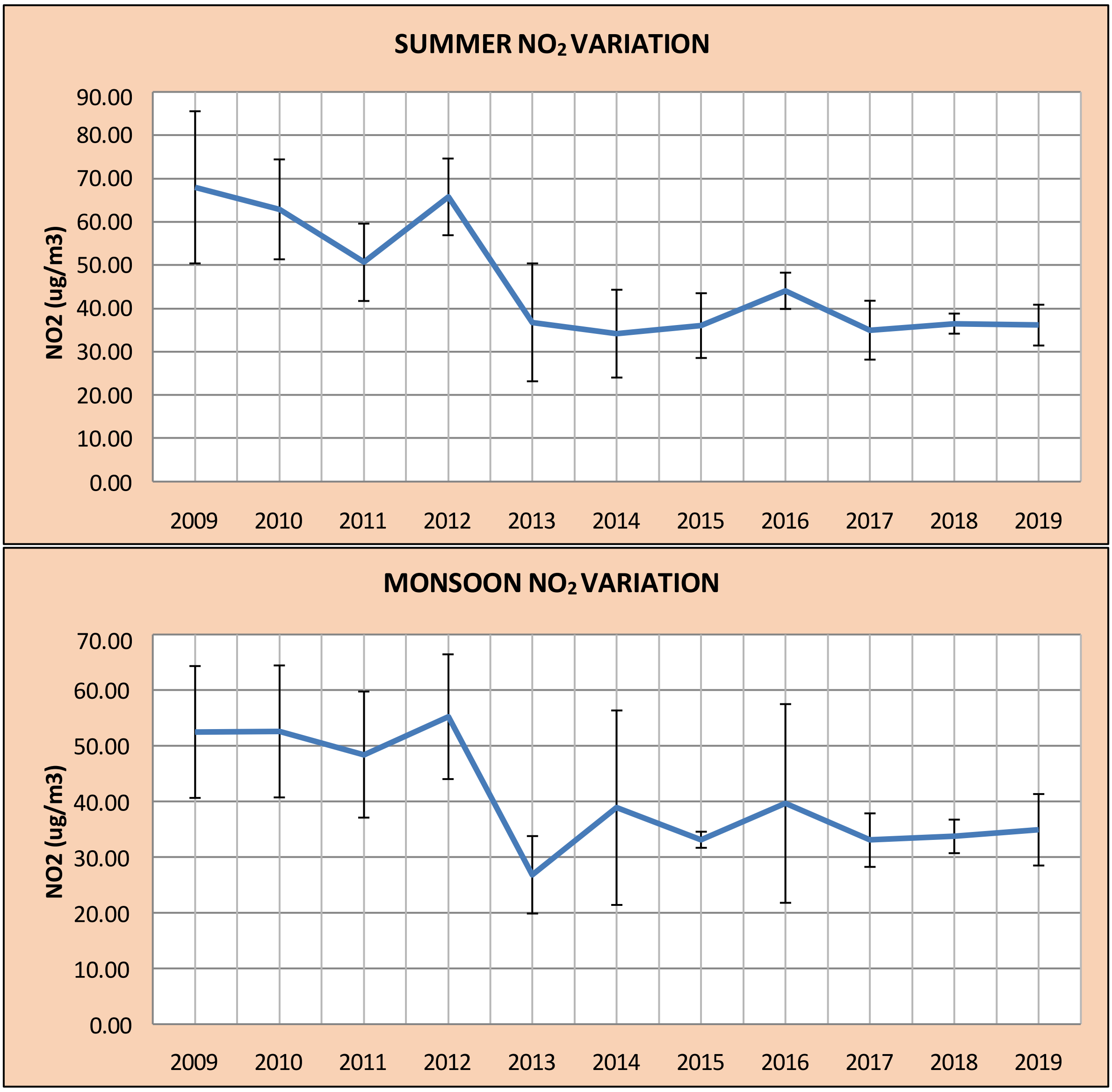
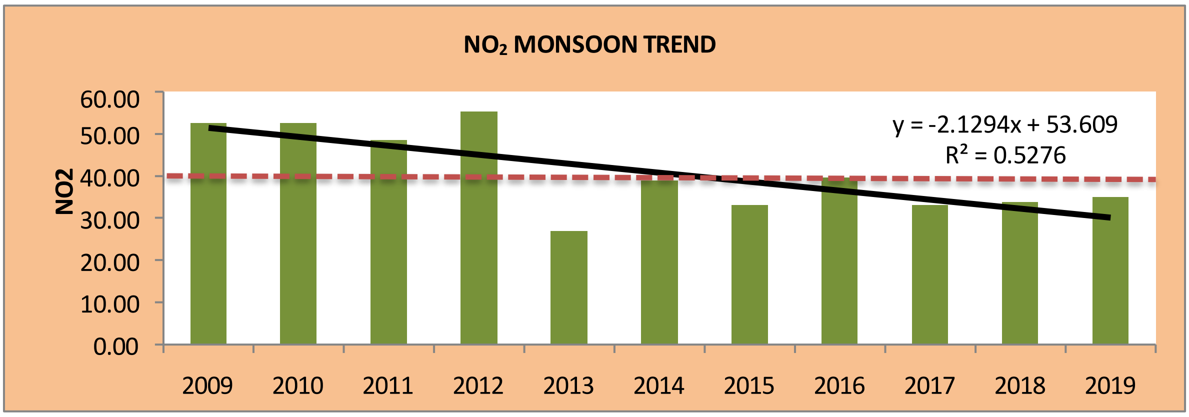
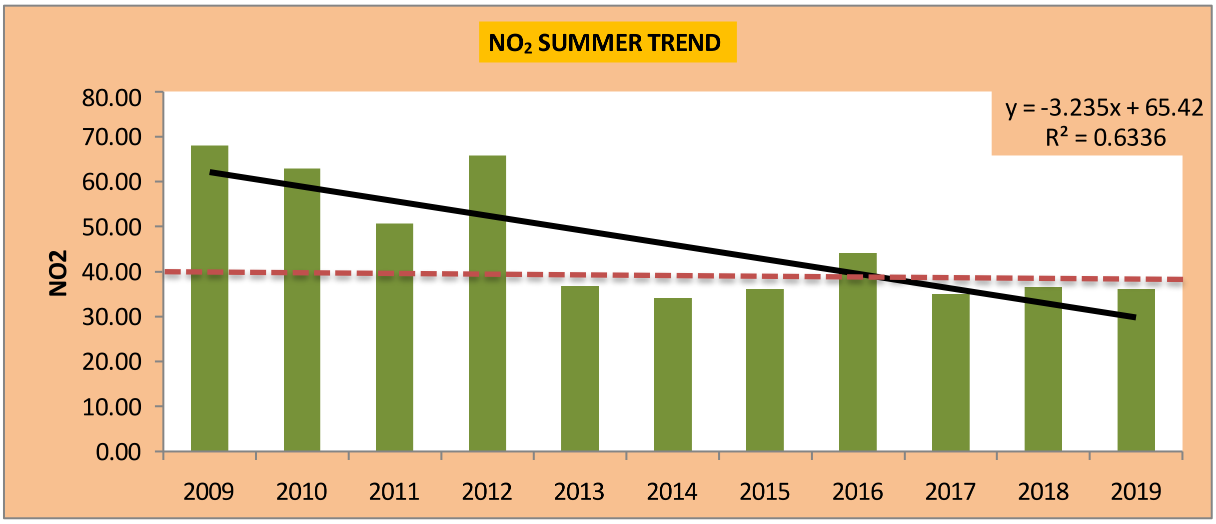


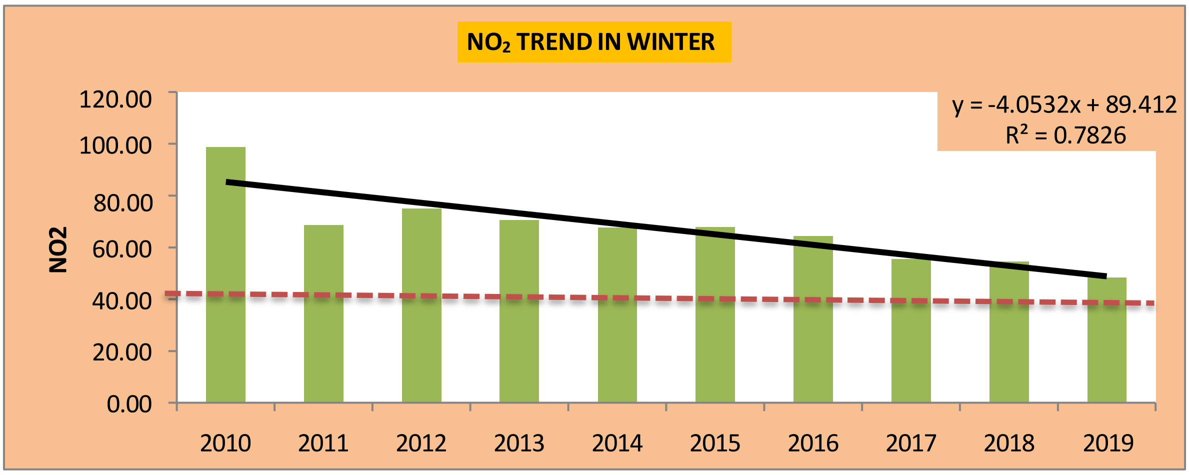
Fig 4(a). NO2 (ug/m3) Concentration Seasonal variation in Behala Chowrasta from 2009-2019



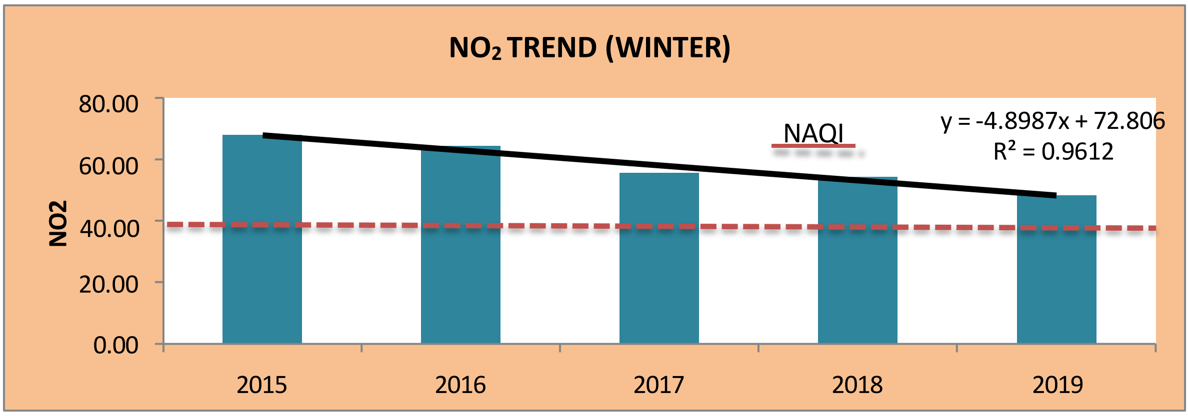
In Fig. 4 (c(i)) the monsoon data of NO_2 from 2009 to 2019 in Behala shows poor trend (r2 = 0.5276) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.



In Fig. 4 (c(ii)) the summer data of NO_2 from 2009 to 2019 in Behala shows poor trend (r2 = 0.6336) and so no statement can be made due to uncertain change of this pollutant concentration. .



The winter data of NO_2 from 2009 to 2019 in Behala shows not so good but decreasing trend (r2 = 0.79)



In Fig. 4 (c(iii)) the winter data of NO_2 from 2015 to 2019 in Behala shows decreasing trend(r2 = 0.96) . So NO_2 is in decreasing order in last few years of the decade 2009 to 2019 range.

Fig 4(c). includes trend analysis between 2009 to 2019 for seasonal variation of NO2 in Behala Chowrasta along with the Government-prescribed National Ambient Air Quality Standards (NAAQS) for NO_2.

Location 2. Ultodanga (Kolkata)

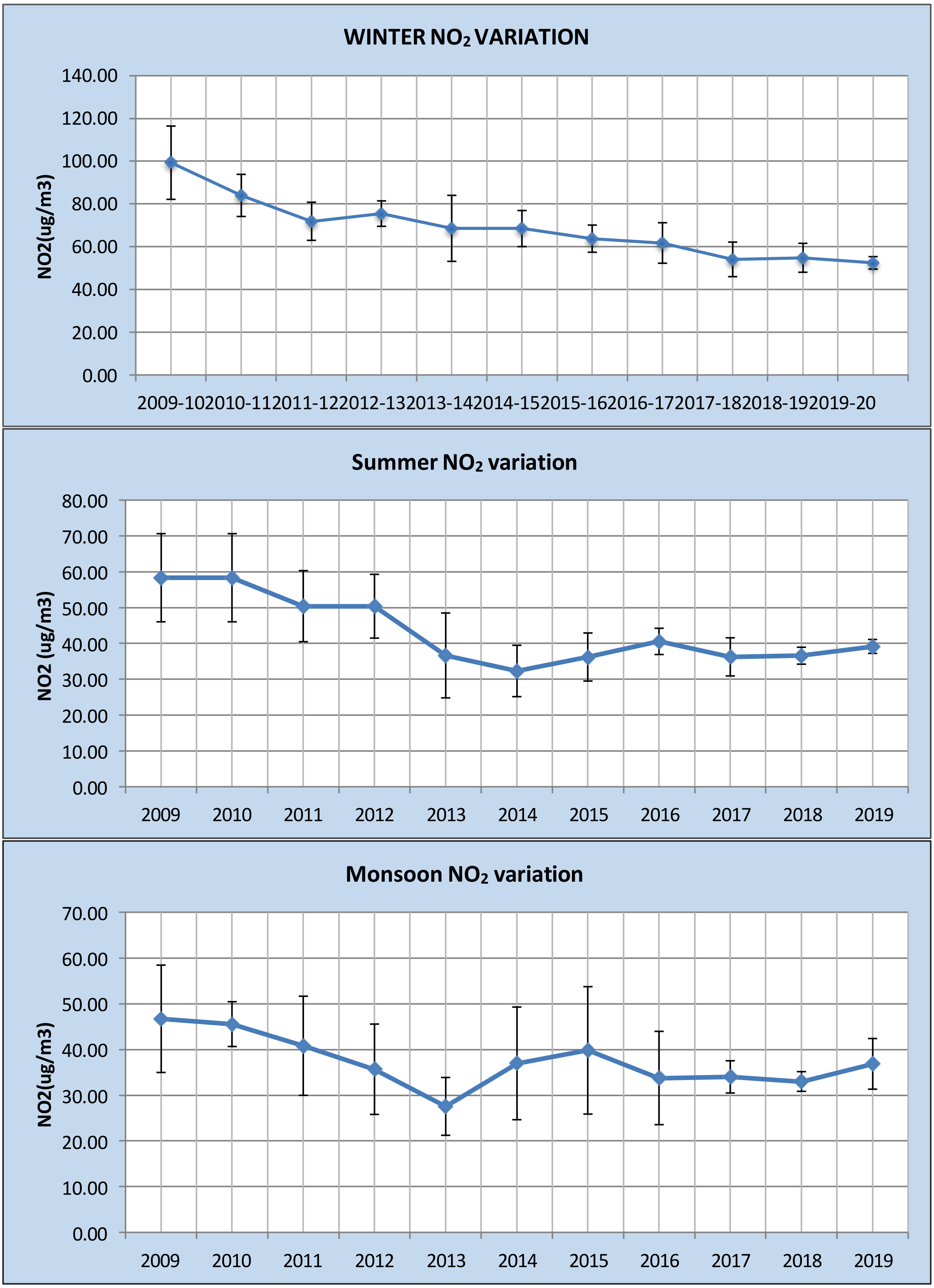
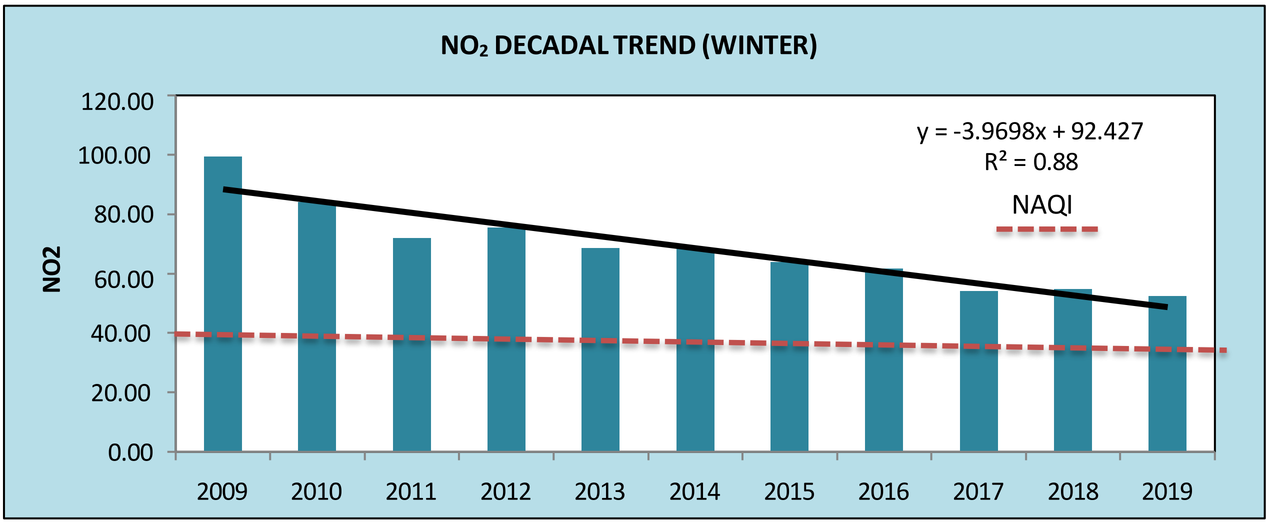
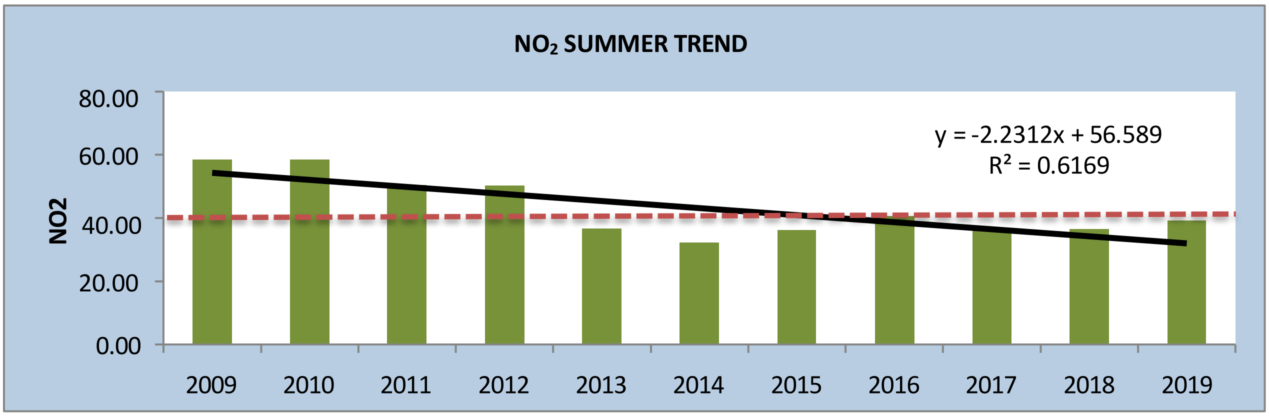


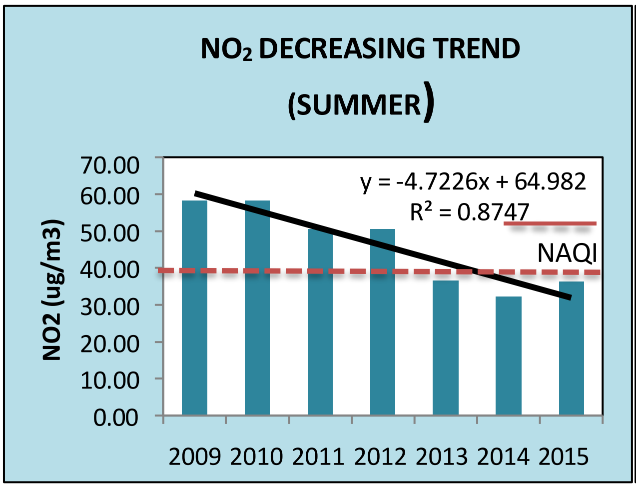
Fig 4(b). NO2 (ug/m3) Concentration Seasonal variation in Ultodanga from 2009-2019

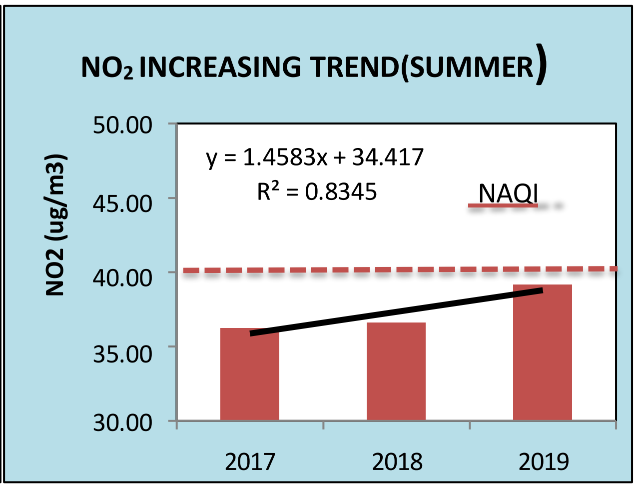


In Fig. 4 (d(i)) the winter data of NO2 from 2015 to 2019 in Ultodanga shows decreasing trend (r2 = 0.89) . So NO2 is in decreasing order in the decade 2009 to 2019 range.

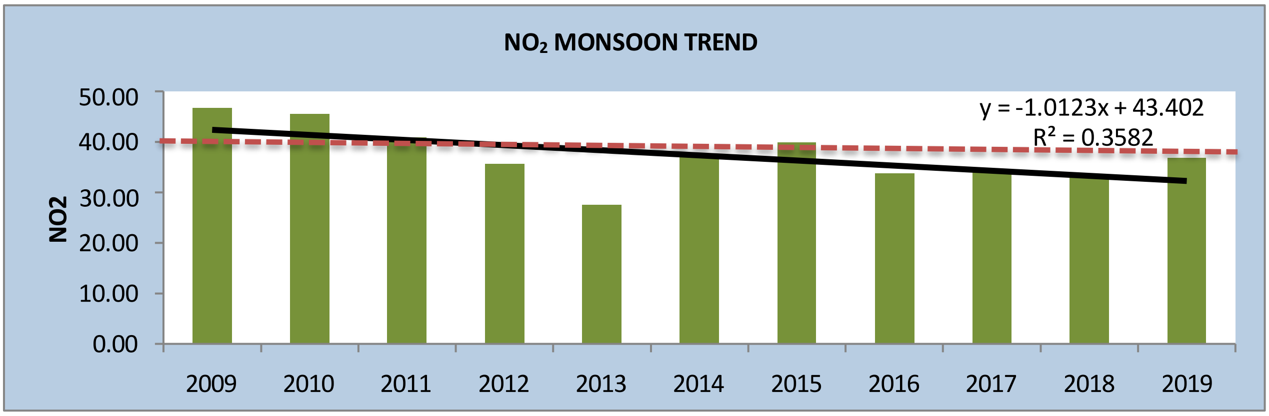


The summer data of NO2 from 2009 to 2019 in Ultodanga shows poor trend (r2 = 0.6169) and so no statement can be made due to uncertain change of this pollutant concentration.





Here in Fig. 4(d(ii)) summer graph is shown in two division. The decade is divided into two parts and former part shows decreasing trend from 2009 to 2015 (r2 = 0.87) and later part shows increasing trend (r2= 0.8345) from 2017 to 2019 with NAQI value (for NO_2 40 ug/m3) taken as standard

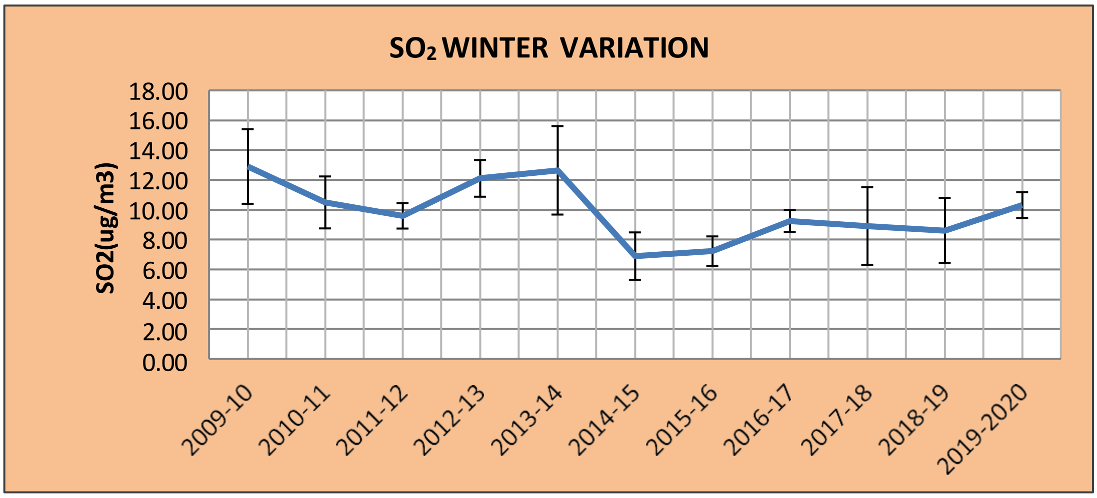


In Fig. 4 (d(iii)) the monsoon data of NO_2 from 2009 to 2019 in Ultodanga shows poor trend (r2 = 0.35) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.

The seasonal variation of NO_2 in Ultodanga between 2009 and 2019 is trend analyzed in Fig. 4(d), coupled with the government-mandated 40 ug/m3 NO_2 National Ambient Air Quality Standards (NAAQS). The observed yearly average concentration values of NO_2 at the two designated locations in Kolkata are displayed in Tables 1 and 2, with standard deviation taken into account as an error. Seasonal fluctuations were evident in the concentration levels of NO_2. Assuming that there were no major variations in the NO_2 emissions in these areas throughout the year, their levels were higher in the winter and lower in the summer or during wet seasons, demonstrating their dependence on meteorological circumstances. Kolkata has continuously demonstrated significant seasonal fluctuations in NO_2 concentration levels, with greater levels in the winter and somewhat lower in the summer or in monsoon. According to Chatterjee et al. (2022), Kolkata and the neighboring eastern region of India serve as a doorway for air pollution outflow from the Indo-Gangetic Plan (IGP) into the Bay of Bengal. This outflow is most noticeable in the winter and is largely caused by biomass burning in the area. The study's observations of seasonal fluctuations in NO_2 concentration levels were in line with those made in Kolkata by Chatterjee et al. (2022). The yearly average concentrations of NO_2 measured in Kolkata from 2009 to 2019 are represented in Tables 1.a, 1.b, 1.c, and 2.a, 2.b, 2.c. Figs. 4.c and 4.d show a net change in the concentration levels and a trend analysis of NO_2 over the years in these locations. The results of the trend analysis showed that, from 2015 to 2019, the Behala NO_2 trend is in decreasing order in the winter (r2 = 0.9612), depending on the weather and the government-mandated 40 ug/m3 National Ambient Air Quality Standard (NAAQS). The authorities' actions to reduce air pollution may be the cause of these declining patterns in the concentration levels of NO_2 over the winter. Due to the uncertain shift in the NO_2 value displayed in Table 1 from year to year, no trend was identified in the monsoon and summer season (r2=0) in Behala Chowrasta between 2009 and 2019. The trend study from 2009 to 2019 showed that the Ultodanga NO_2 trend is in decreasing order during the winter (r2 = 0.88). In the same way, it disclosed The summertime trend in Fig. 4(d) is decreasing from 2009 to 2015 (r2 = 0.87) and increasing from 2017 to 2019 (r2 = 0.84), respectively, depending on the meteorological circumstances and the government-mandated 40 ug/m3 annual NO_2 National Ambient Air Quality Standard (NAAQS). Because of the erratic annual variation in the NO2 value displayed in Table 2, no trend was seen in Ultodanga's monsoon season (r2 = 0) from 2009 to 2019. It is outside the purview of this study to assess the specifics of the government's air pollution control initiatives. Moreover, the yearly mean concentrations of NO_2 recorded in Ultodanga between 2009 and 2019 and in Behala between 2015 and 2019 were consistently greater than the 40 ug/m3 annual NAAQS level for NO_2 (Fig. 4c & d).

5.3) SO_2 : Temporal fluctuations in the monthly averaged SO_2 concentration levels found in Kolkata were displayed in Fig. 5(a & b). Variations in the annual average concentrations of SO_2 measured at two localities in Kolkata, namely Ultodanga and Behala, were displayed in Figure 5(a & b). The yearly average concentration values of SO_2 measured in these locations were presented in Fig. 5(c & d) and Table1,2, together with a trend analysis and a net change in the SO_2 concentration values over time. The average of all the CPCB & WBPCB data operated in the city is represented by the SO_2 concentrations displayed in Fig. 5 and Table 1, 2. The concentration levels of SO_2 in these places have showed higher seasonal changesthroughout the year, with higher levels in winter and similar to the levels of PM and NO_2 in Kolkata. lower in the monsoon or summer. Due to the excessive usage of coal, oil, and gas in the city, Kolkata had higher SO_2 concentrations throughout the majority of the time. The yearly average concentrations of SO_2 detected in Kolkata from 2009 to 2019 are represented in Tables 1.a, 1.b, 1.c, and 2.a, 2.b, 2.c. Figs. 5.c and 5.d illustrate the net change in the concentration levels and trend analysis of SO2 over the years in these locations.

Location 1 : Behala Chowrasta



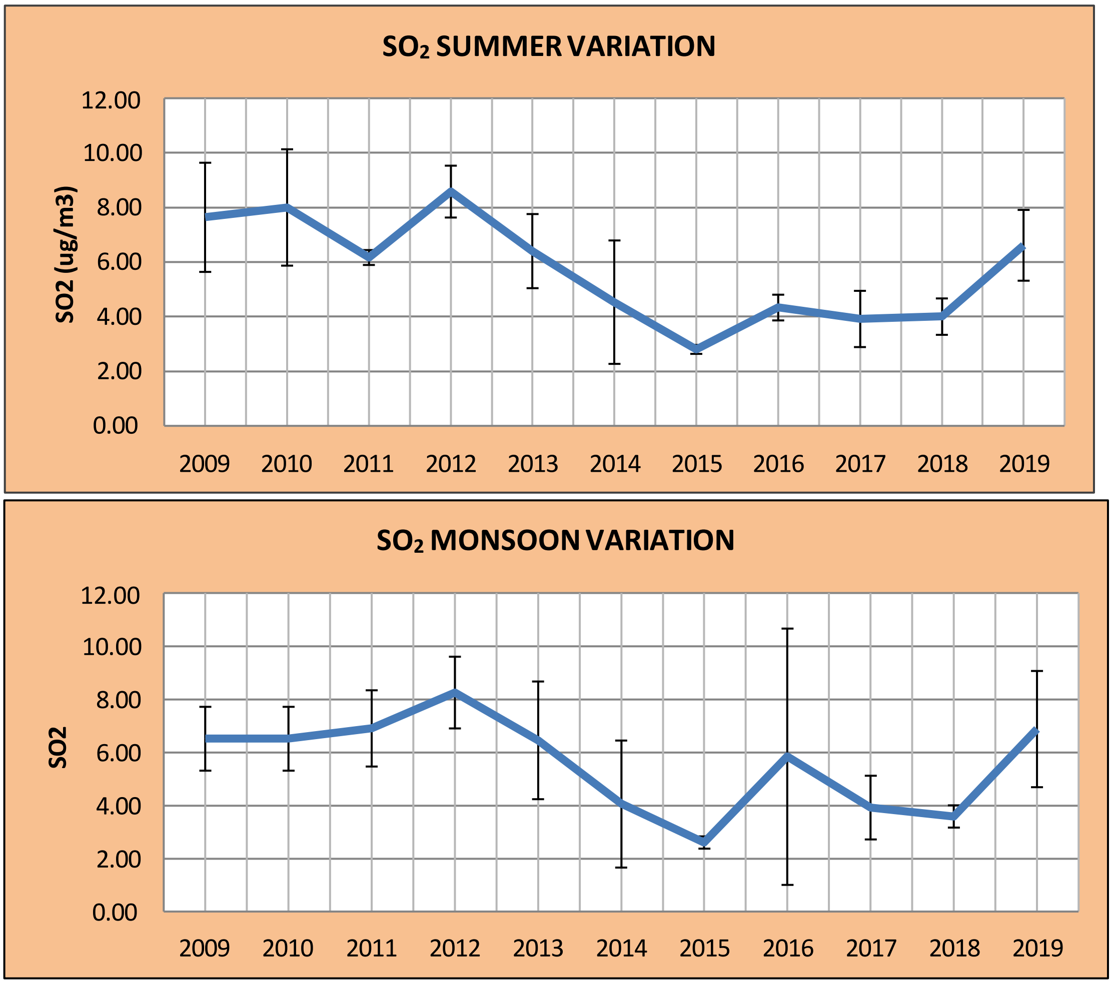
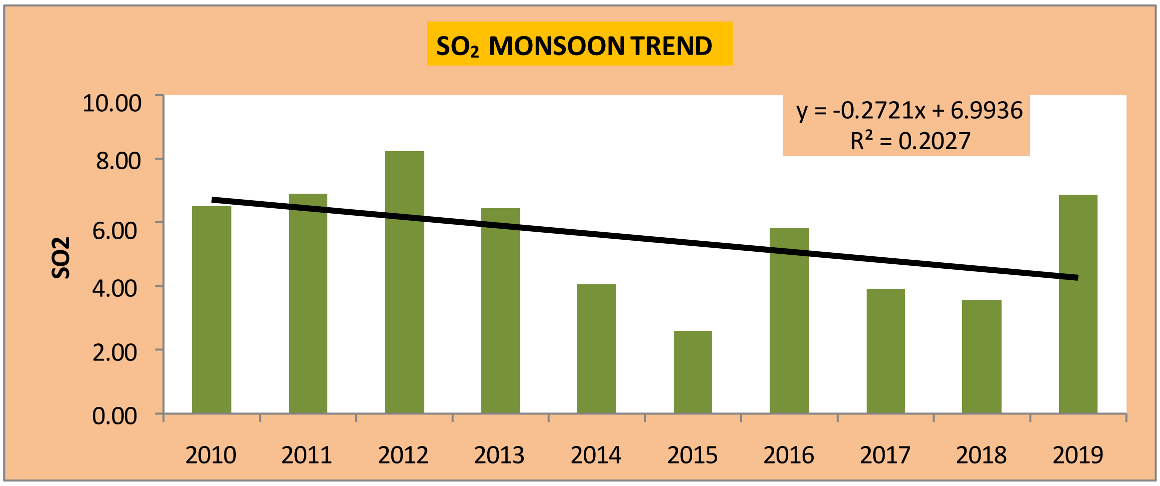
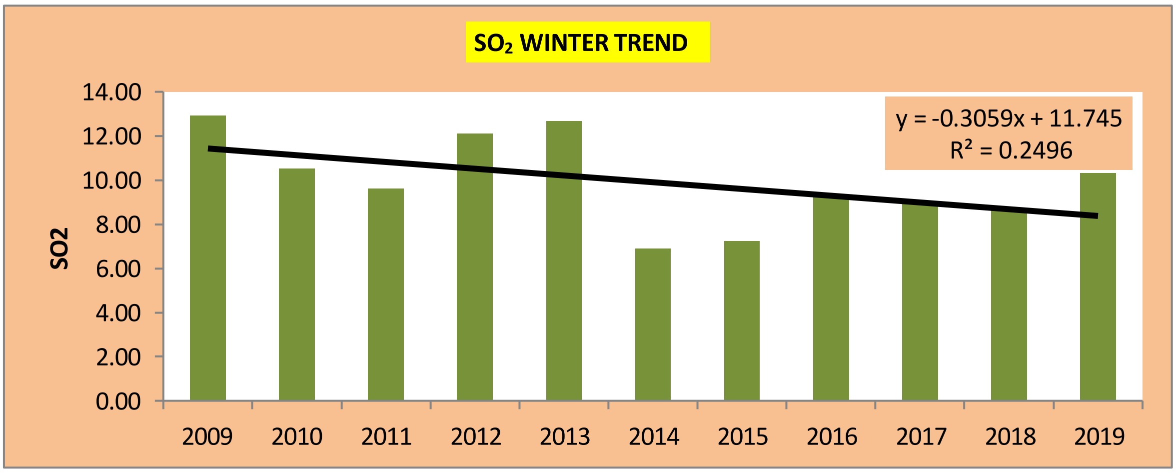


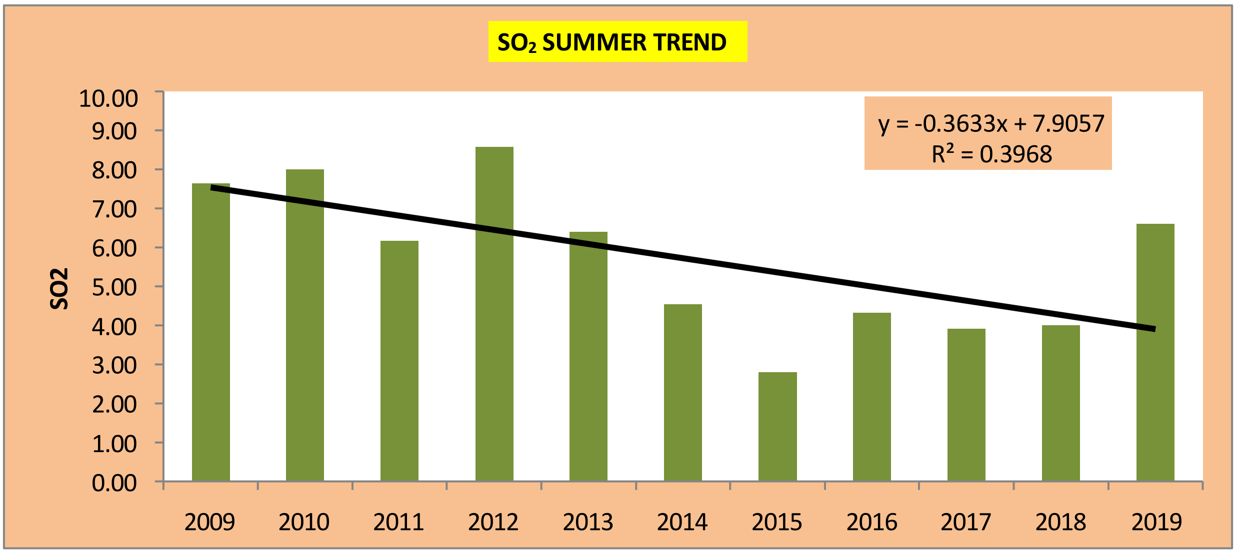
Fig 5(a). SO_2 (ug/m3) Concentration Seasonal variation in Behala Chowrasta from 2009-2019



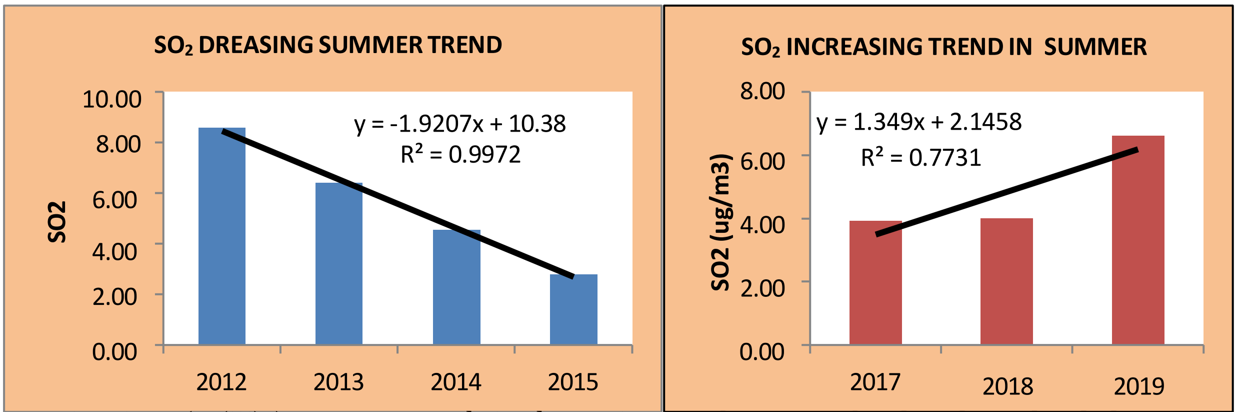
In Fig. 5 (c(i)) the monsoon data of SO_2 from 2009 to 2019 in Behala shows poor trend (r2 = 0.2027) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.



In Fig. 5 (c(ii)) the winter data of SO2 from 2009 to 2019 in Behala shows poor trend (r2 = 0.2496) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.



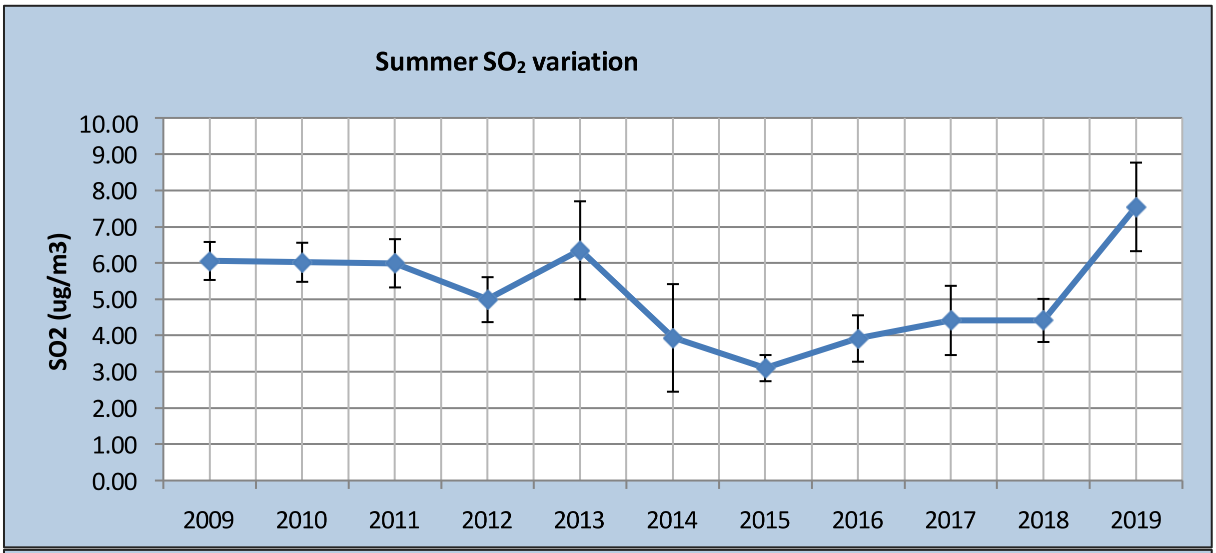
The Summer data of SO_2 from 2009 to 2019 in Behala shows poor trend (r2 = 0.3968) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.

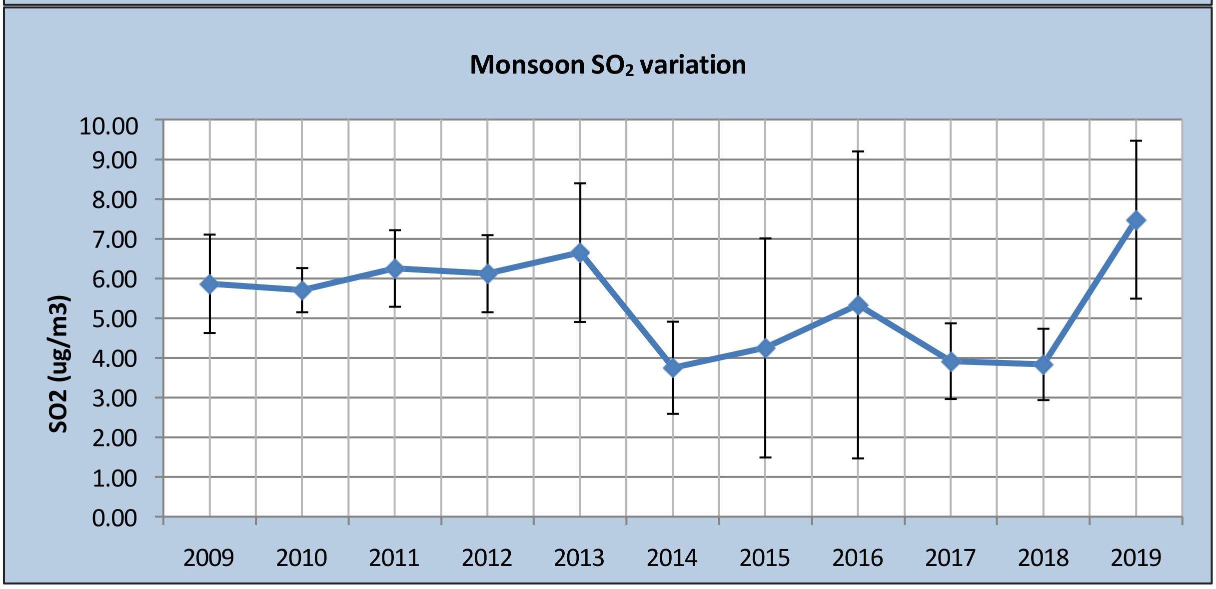


Here in Fig. 5(c(iii)) summer graph is shown in two division. The decade is divided into two parts and former part shows decreasing trend from 2012 to 2015 (r2 = 0.9972) and later part shows increasing trend (r2= 0.7731) from 2017 to 2019 with NAQI value (for SO_2 50 ug/m3) taken as standard

Fig 5(c). includes trend analysis between 2009 to 2019 for seasonal variation of SO_2 in Behala Chowrasta along with the Government-prescribed National Ambient Air Quality Standards (NAAQS) for SO_2.

- **Location 2 : Ultodanga :**





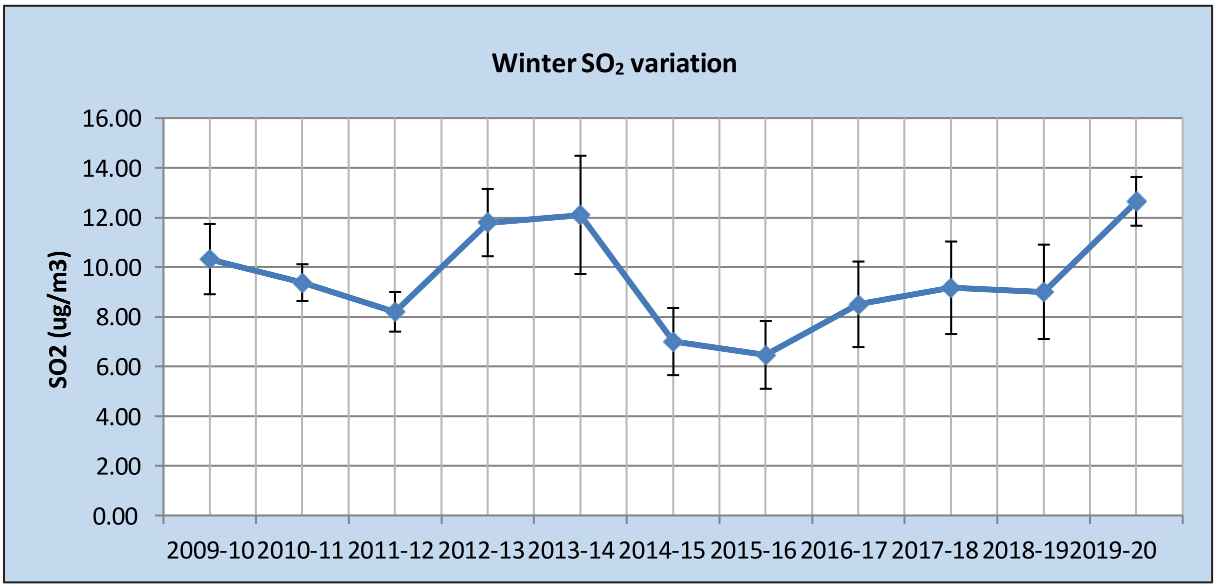
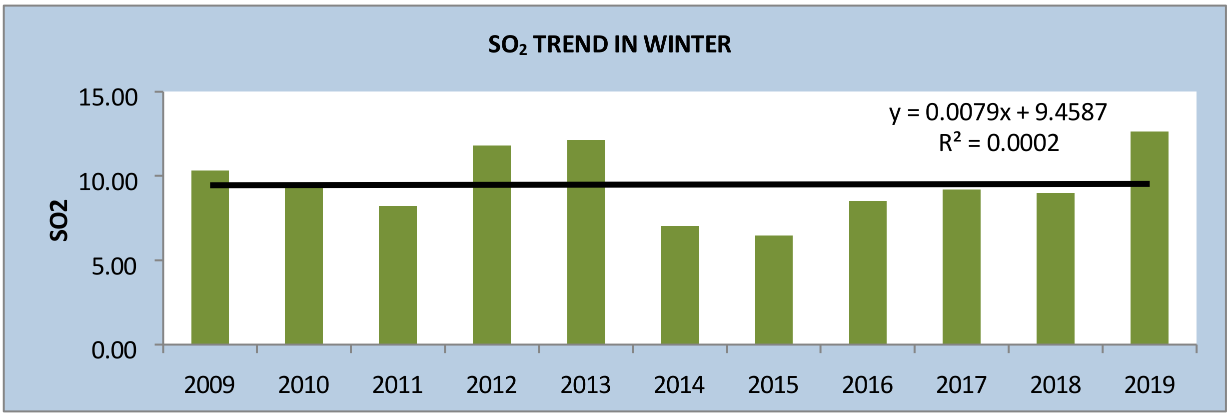
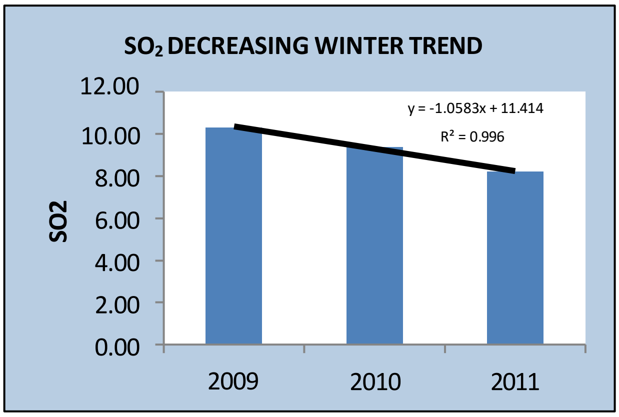
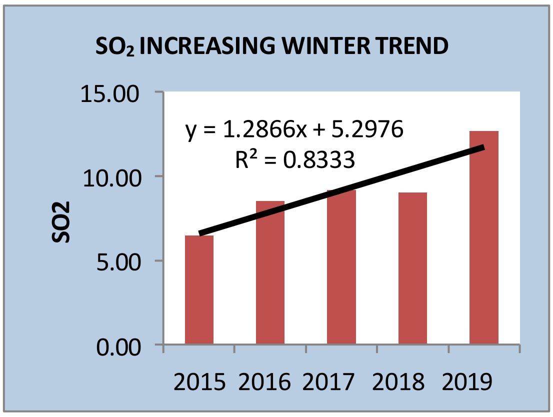


Fig 5(b). SO_2 (ug/m3) Concentration Seasonal variation in Ultodanga from 2009-2019

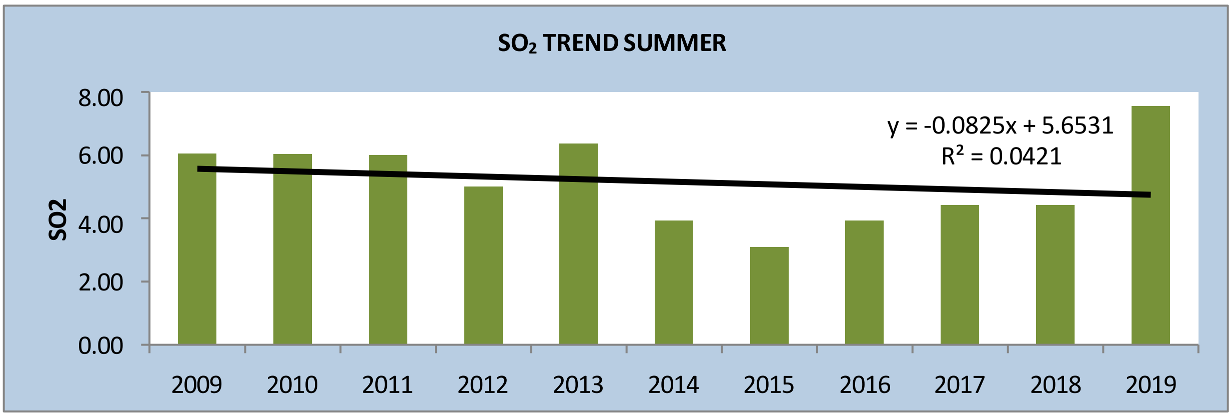


The winter data of SO_2 from 2009 to 2019 in Ultodanga shows very poor trend (r2 = 0.0002) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019

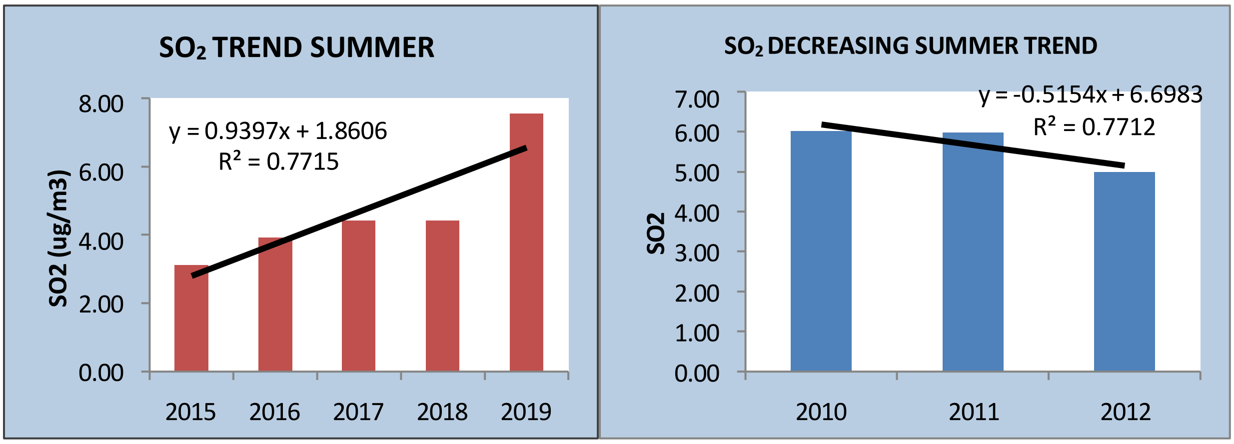




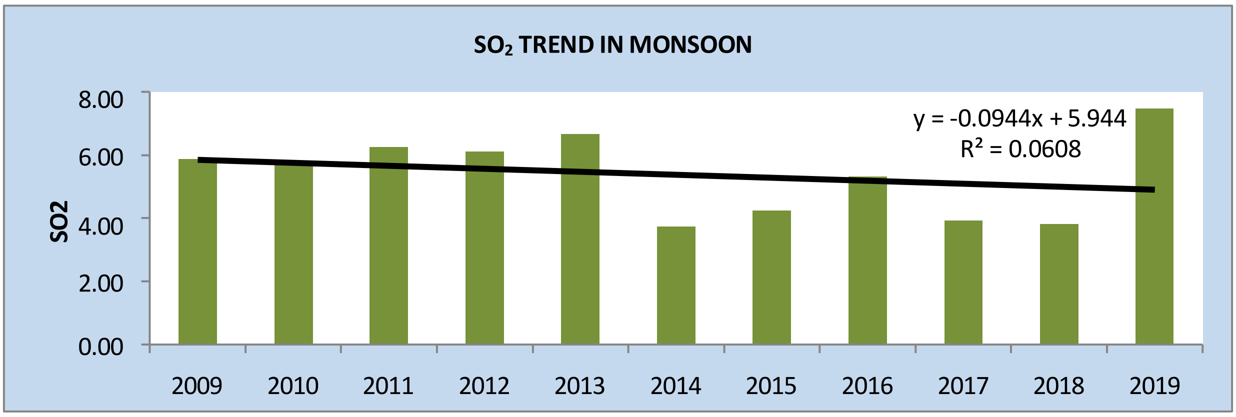
Here in Fig. 5(d(i)) winter graph is shown in two division. The decade is divided into two parts and former part shows decreasing trend from 2009 to 2011 (r2 = 0.996) and later part shows increasing trend (r2= 0.84) from 2015 to 2019 with NAQI value (for SO_2 50 ug/m3) taken as standard.



The summer data of SO2 from 2009 to 2019 in Ultodanga shows very poor trend (r2 = 0.0421) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019



Here in Fig. 5(d(ii)) summer graph is shown in two division. The decade is divided into two parts and former part shows decreasing trend from 2010 to 2012 (r2 = 0.7712) and later part shows increasing trend (r2= 0.7715) from 2015 to 2019 with NAQI value (for SO_2 50 ug/m3) taken as standard



In Fig 5 (d (iii))The monsoon data of SO_2 from 2009 to 2019 in Ultodanga shows very poor trend (r2 = 0.068) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019

Fig 5(d). includes trend analysis between 2009 to 2019 for seasonal variation of SO2 in Ultodanga along with the Government-prescribed National Ambient Air Quality Standards (NAAQS).

According to the trend analysis, the Behala SO_2 trend is falling in order from summer 2012 to 2015 (r2 = 0.99), and increasing in order from 2017 to 2019 (r^2 = 0.77), as shown in Fig. 5(c) based on the weather and using the 50 ug/m3 National Ambient Air Quality Standard (NAAQS) for SO2 that the government has set. These rising trends in summertime SO2 concentration levels may be related to an increase in air pollution brought on by heavy vehicle use and massive SOX production from industrial activity. The winter and monsoon seasons (r^2=0) at Behala Chowrasta did not exhibit any trend from 2009 to 2019. This can be attributed to the unclear year-to-year variation in the SO2 value, as indicated in Table 1. According to Fig. 5(d), the ultra-deep summertime SO2 trend is increasing (r^2 = 0.78) from 2015 to 2019 and decreasing (r^2 = 0.7715) from 2010 to 2012, depending on the meteorological conditions and the government-mandated 50 ug/m3 annual National Ambient Air Quality Standard (NAAQS) for SO2. Similar to Ultodanga, it showed no trend in the monsoon (r^2 = 0) between 2009 and 2019 because of erratic year-to-year variance. It is outside the purview of this study to assess the specifics of the government's air pollution control initiatives. Comparably, Ultodanga's winter trend is rising orderly from 2015 to 2019 (r^2=0.84) and falling from 2009 to 2011 (r^2= 0.996). These growing Trends in the summertime concentration levels of SO2 may be related to an increase in air pollution brought on by a high vehicle usage rate and the massive amounts of SOX produced by industrial activity. Therefore, the government should implement special measures to reduce the production of SOX. Moreover, the mean annual SO2 concentrations measured in Ultodanga from 2015 to 2019 and in Behala from 2016 to 2019 were continuously below the 50 ug/m3 annual SO2 level set by the NAAQS(Fig.5c&d).

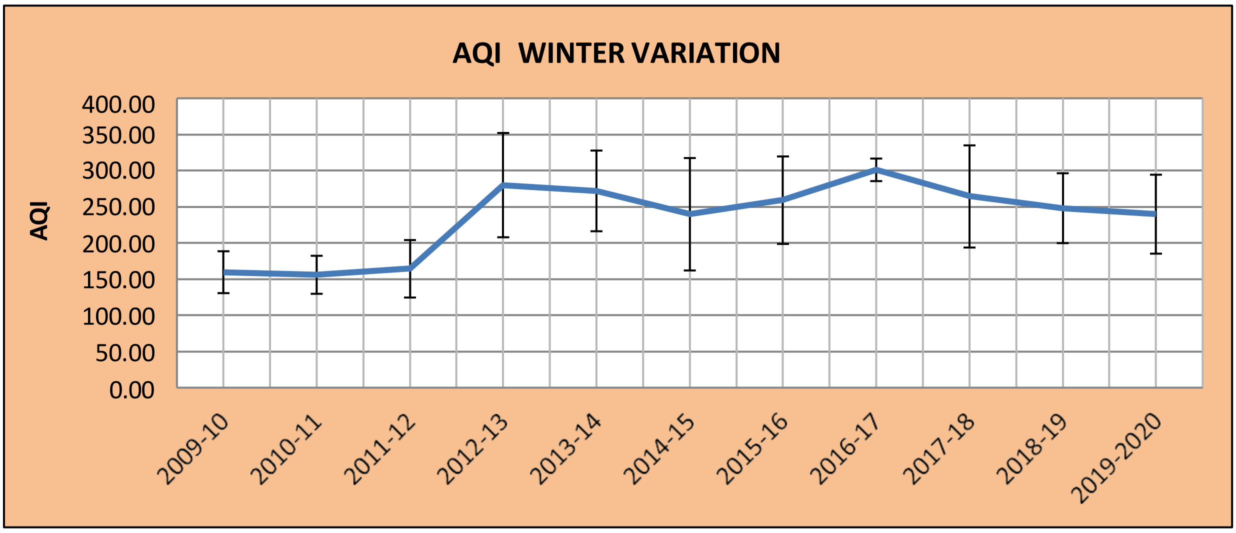
5.4) NAQI : Over 450 CAAQMS were included in the real-time NAQI released by CPCB in India. The NAQI is determined by calculating the weighted average of eight criterion pollutants in a single value matrix: PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, NH_3, and Pb. Verma and Kamyotra (2021) and the Report on National Air Quality Index (CPCB, 2014) both go into detail about the formulas used to calculate the NAQI. Figure. 6 displayed the temporal changes in the NAQI values at two places in Kolkata, Behala and Ultodanga, from 2009 to 2019. Figure. 6(a) showed how the monthly mean NAQI in Behala Chowrasta varied over time, whereas Fig. Ultodanga's annual average NAQI is displayed in Fig 6(b) and Table (1 & 2)which also includes trend analysis and the net change in NAQI values over time. There have been noticeable seasonal fluctuations in Kolkata's NAQI ratings between 2009 and 2019.

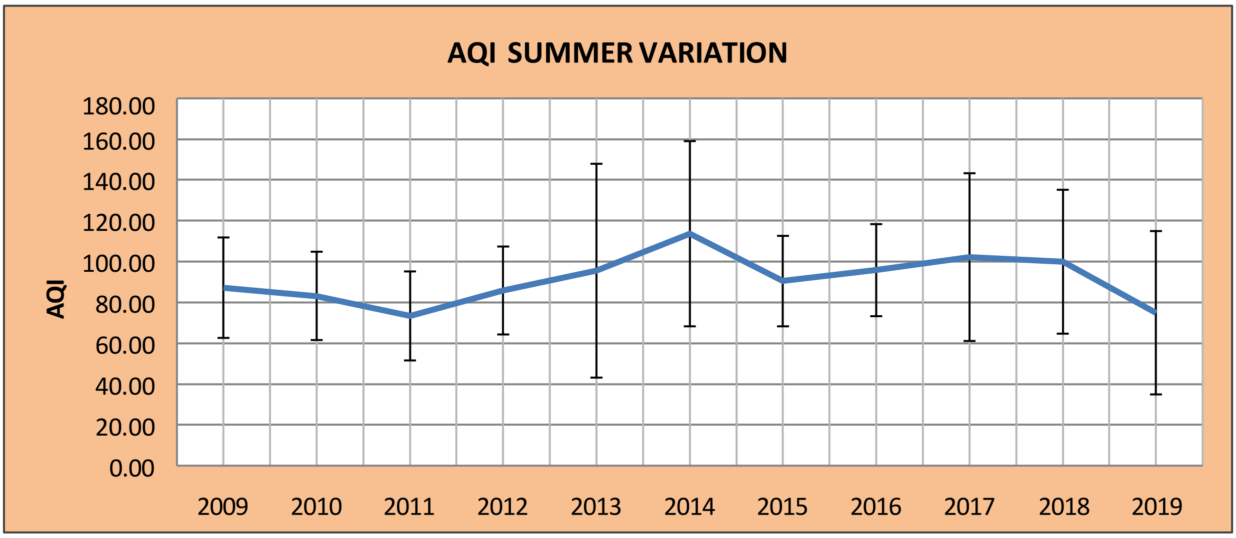
As seen in Figs. 6a & 6b, Kolkata's monthly average NAQI fluctuates often between 200 and 300 throughout the winter, although it is lower at 200 during the monsoon and summer seasons. That suggests that the air quality in these two Kolkata places is unhealthy.

NAQI categories and color code:

GOOD	SATISFACTORY	MODERATE	POOR	VERY POOR	SEVERE
(0 – 50)	(50 – 100)	(101 – 200)	(201 – 300)	(301 – 400)	(> 400)

Location 1 : Behala Chowrasta





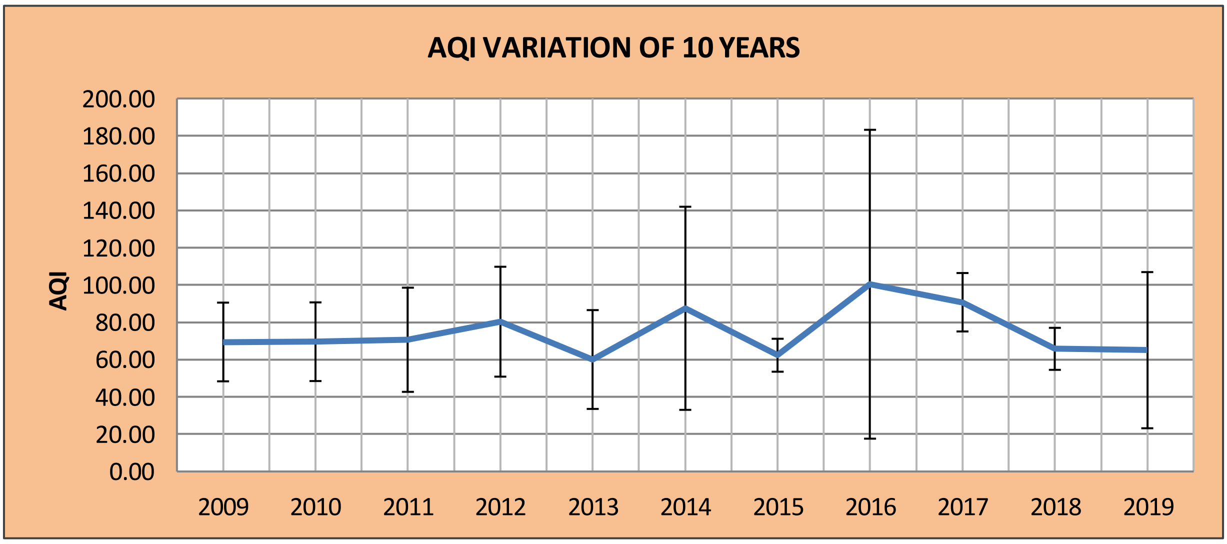
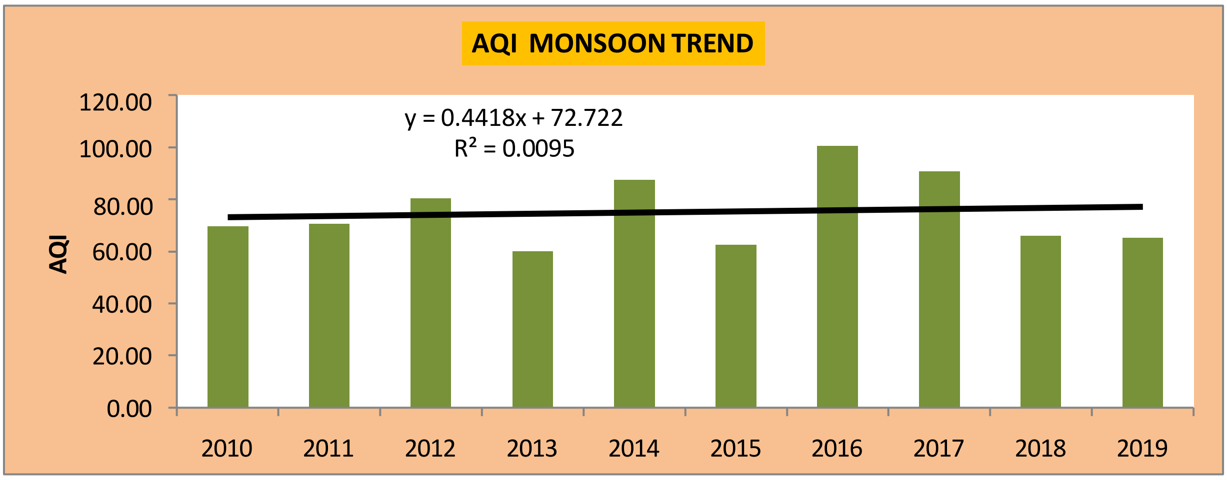
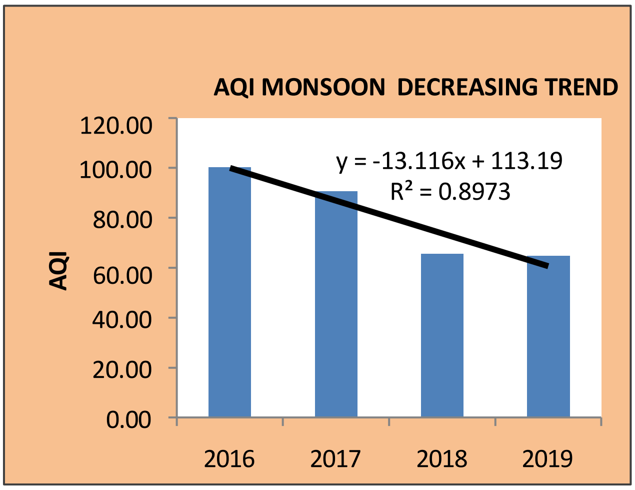
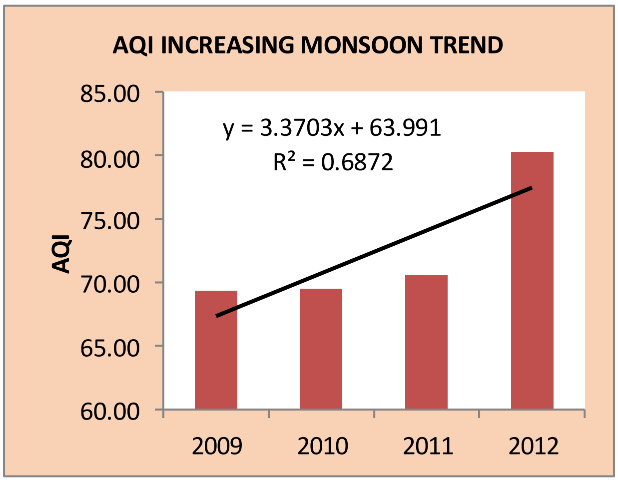


Fig 6(a). AQI Seasonal variation in Behala Chowrasta from 2009-2019

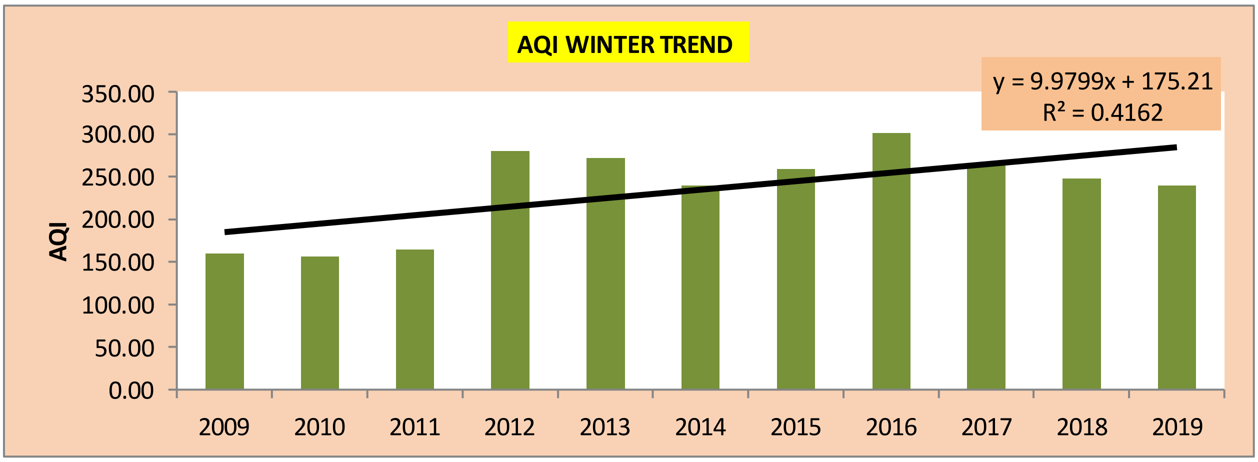


The monsoon data of AQI from 2009 to 2019 in Behala shows poor trend (r2 = 0.00 95) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.

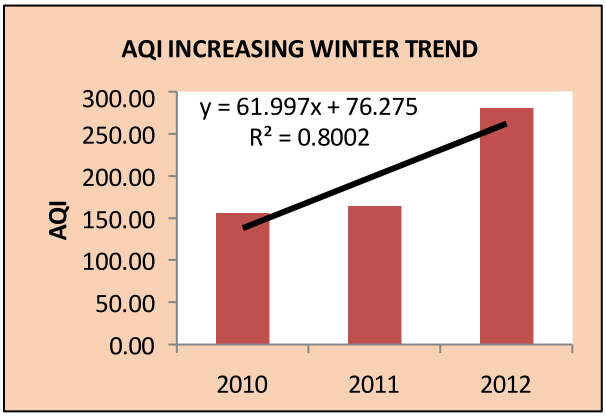


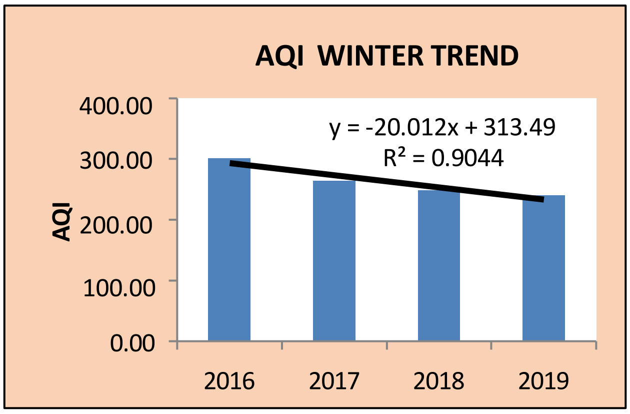


Here in Fig. 6(c(i)) monsoon graph is shown in two division. The decade is divided into two parts and former part shows decreasing trend from 2009 to 2012 (r2 = 0.7) and later part shows increasing trend (r2= 0.89) from 2016 to 2019 with NAQI value taken as standard.

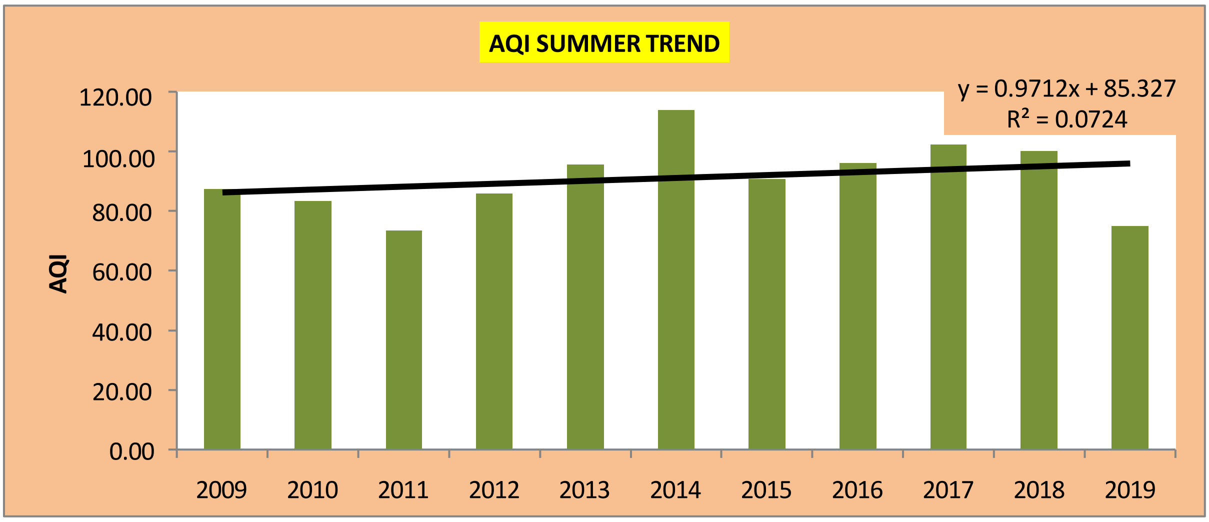


The winter data of AQI from 2009 to 2019 in Behala shows poor trend (r2 = 0.41 and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.

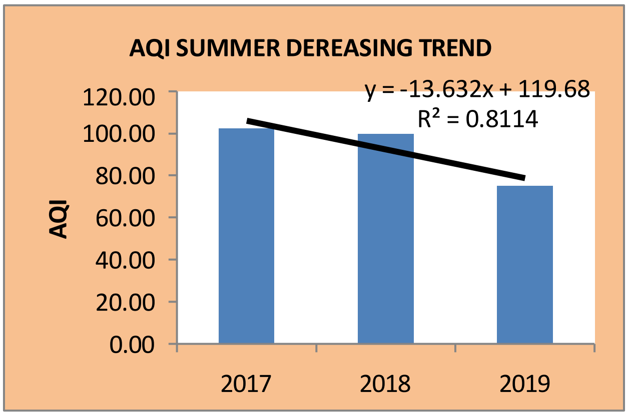


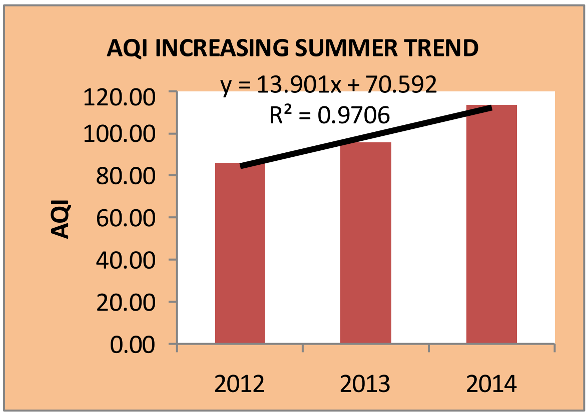


Here in Fig. 6(c(ii)) winter graph is shown in two division. The decade is divided into two parts and former part shows increasing trend from 2010 to 2012 (r^2 = 0.8) and later part shows increasing trend (r^2= 0.9) from 2016 to 2019 with NAQI value taken as standard.



The Summer data of AQI from 2009 to 2019 in Behala shows poor trend (r^2 = 0.074) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019.

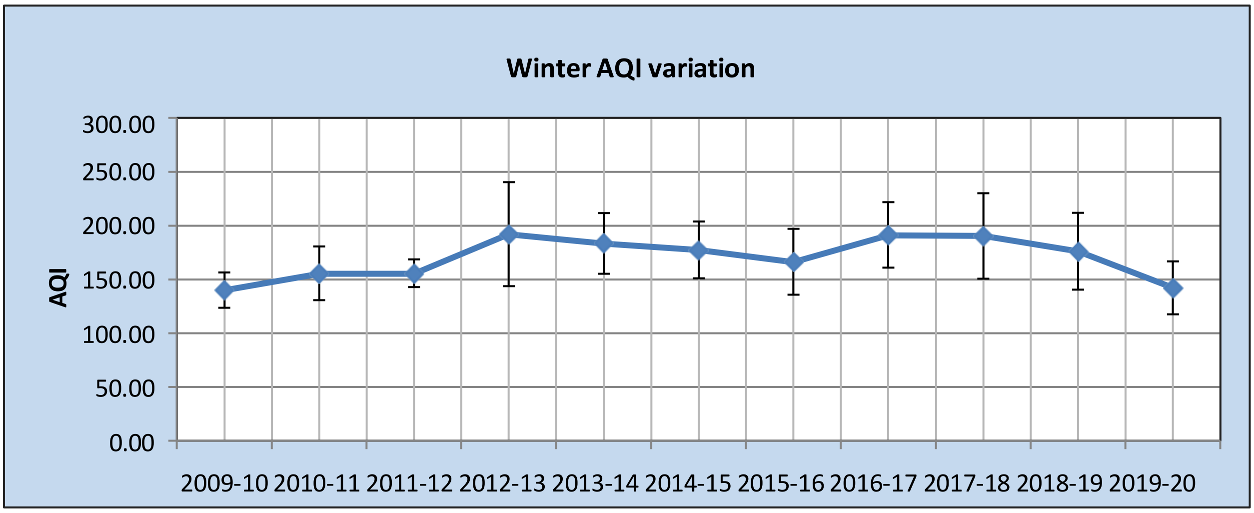


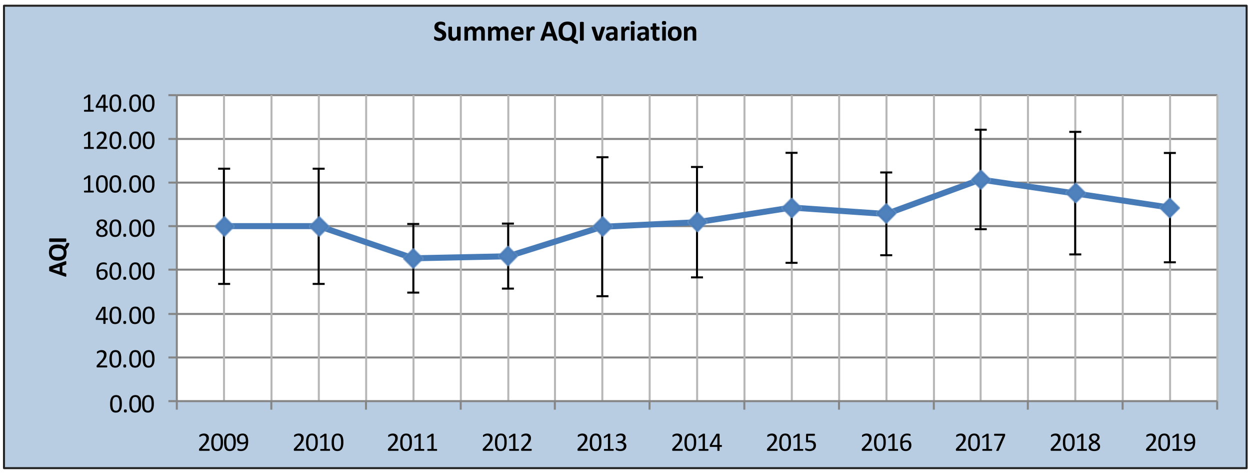


Here in Fig. 6(c(iii)) summer graph is shown in two division. The decade is divided into two parts and former part shows increasing trend from 2012 to 2014 (r^2 = 0.9) and later part shows decreasing trend (r^2= 0.8) from 2017 to 2019 with NAQI value taken as standard.

Fig 6(c). includes trend analysis between 2009 to 2019 for seasonal variation of AQI in Behala Chowrasta along with the Government-prescribed National Ambient Air Quality Standards (NAAQS) for AQI

- **Location 2 : Ultodanga**





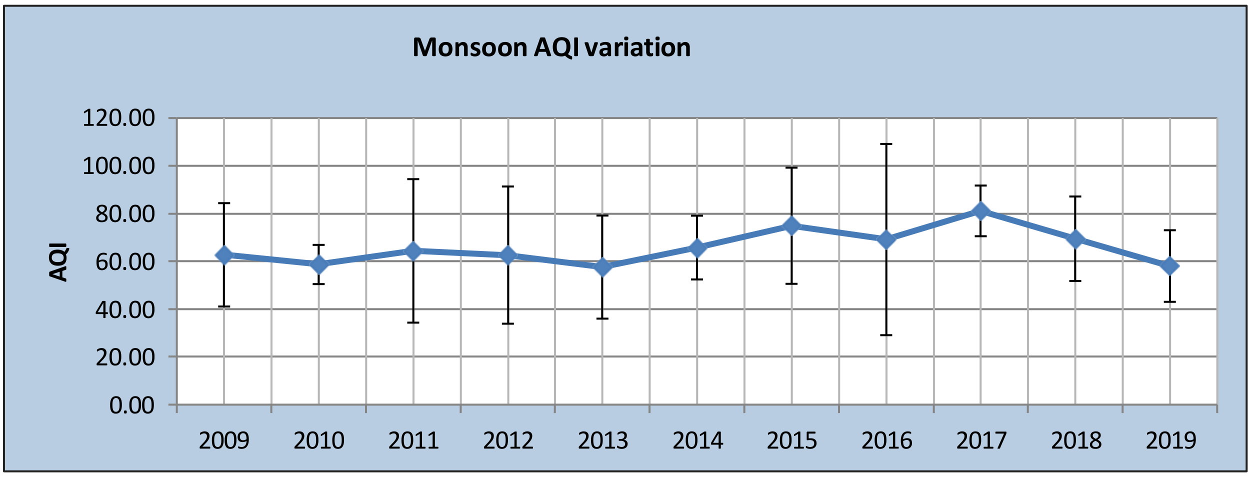
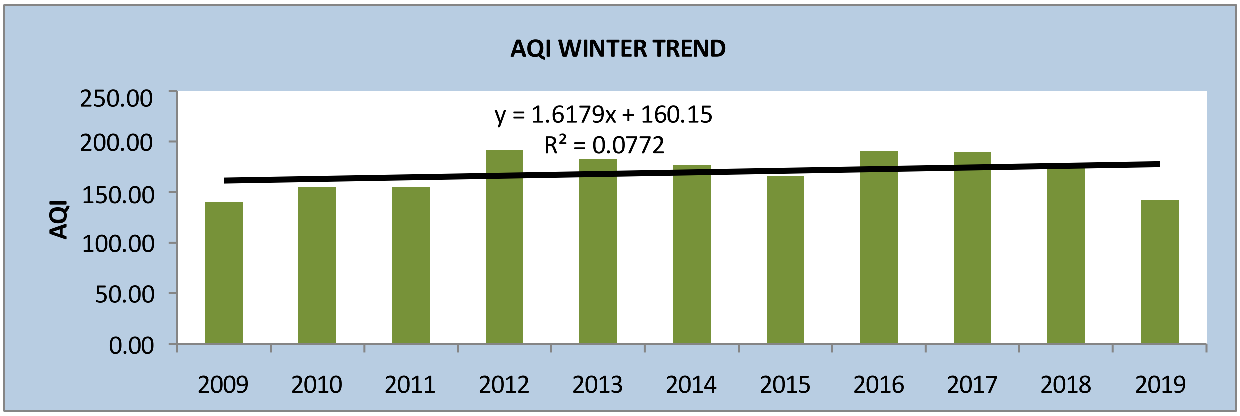
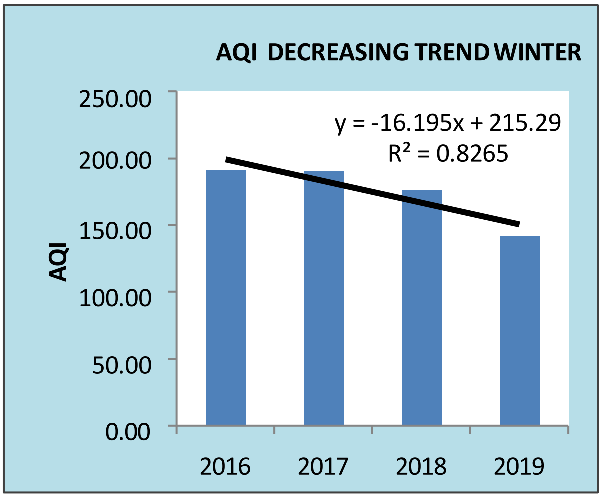
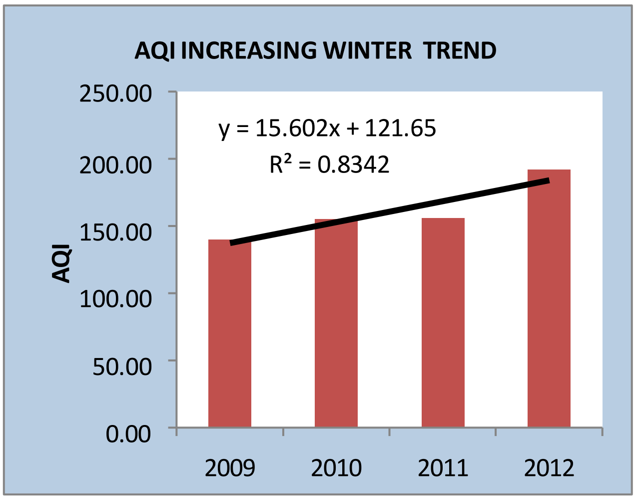


Fig 6(b). AQI Seasonal variation in Ultodanga from 2009-2019

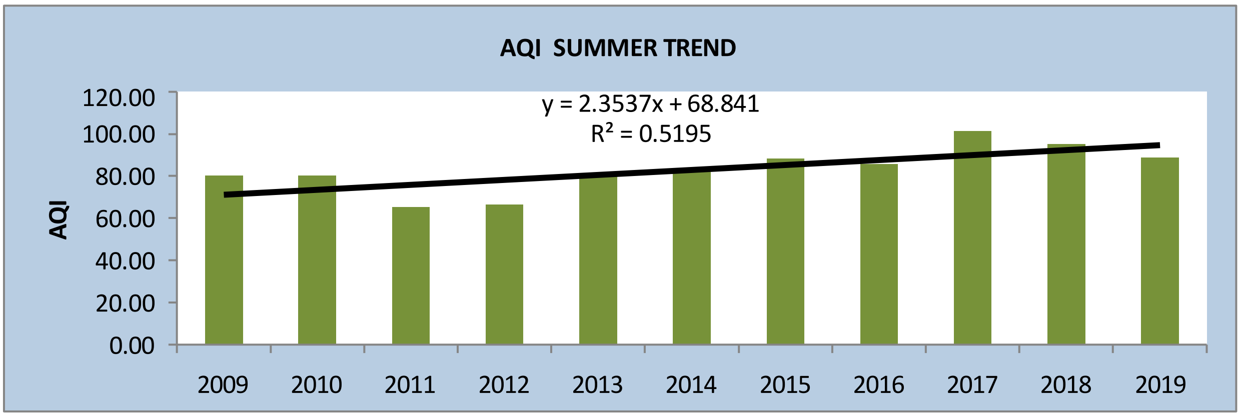


The winter data of AQI from 2009 to 2019 in Ultodanga shows very poor trend (r^2 = 0.077) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019





Here in Fig. 6(d(i)) winter graph is shown in two division. The decade is divided into two parts and former part shows increasing trend from 2009 to 2012 (r^2 = 0.832) and later part shows decreasing trend (r^2= 0.82) from 2016 to 2019 with NAQI value taken as standard



The Summer data of AQI from 2009 to 2019 in Ultodanga shows very poor trend (r2 = 0.5) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019

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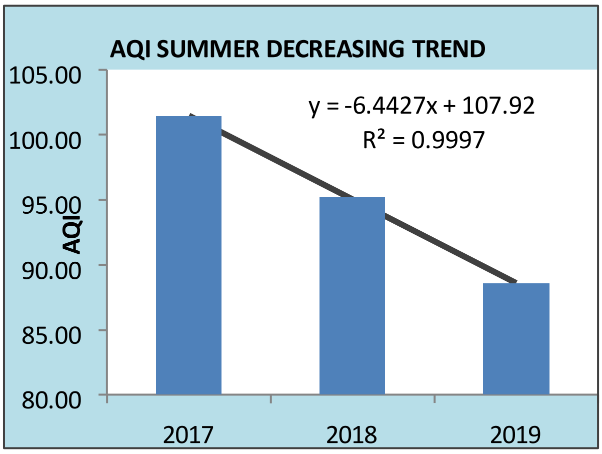
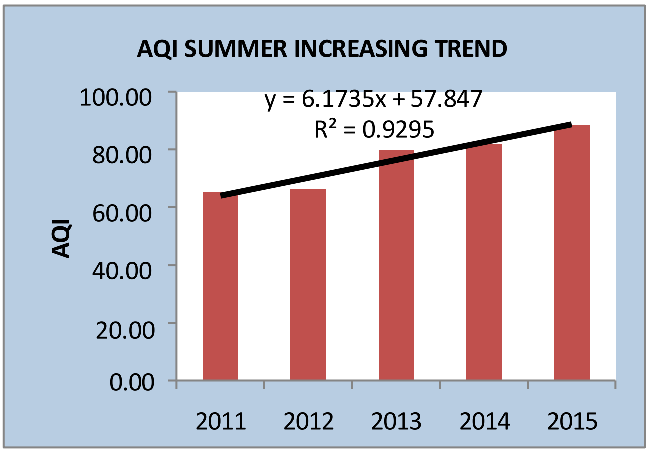
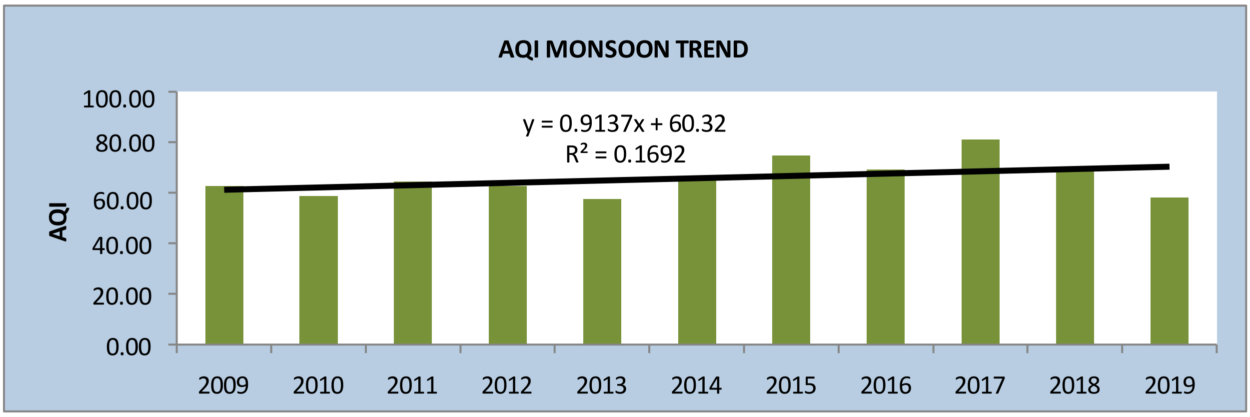
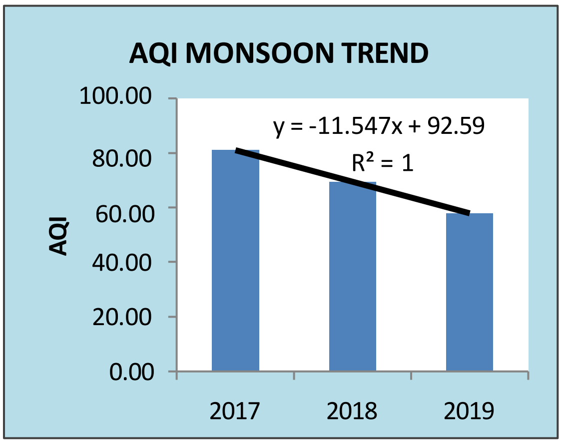


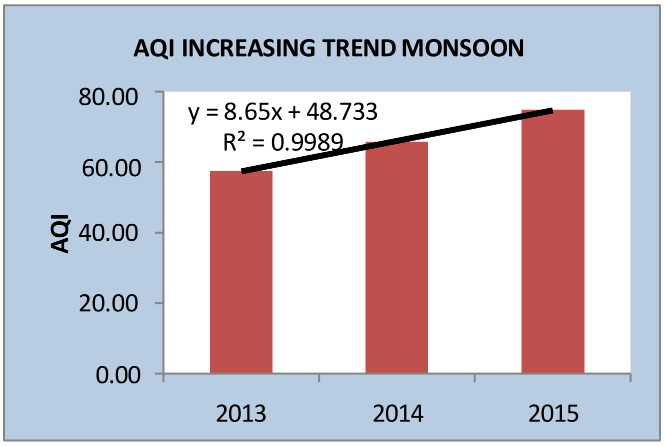


Here in Fig. 6(d(ii)) summer graph is shown in two division. The decade is divided into two parts and former part shows increasing trend from 2011 to 2015 (r^2 = 0.92) and later part shows decreasing trend (r^2= 0.99) from 2017 to 2019 with NAQI value taken as standard



The monsoon data of AQI from 2009 to 2019 in Ultodanga shows very poor trend (r^2 = 0.169) and so no statement can be made due to uncertain change of this pollutant concentration in between 2009 to 2019





Here in Fig. 6(d(iii)) monsoon graph is shown in two division. The decade is divided into two parts and former part shows increasing trend from 2013 to 2015 (r^2 = 0.99) and later part shows decreasing trend (r^2= 1) from 2017 to 2019 with NAQI value taken as standard

Fig 6(d). includes trend analysis between 2009 to 2019 for seasonal variation of AQI in Ultodanga along with the Government-prescribed National Ambient Air Quality Standards (NAAQS) for AQI.

Behala's annual average NAQI readings were between 200 and 300 in the winter and above 100 in the summer and monsoon, as indicated in Fig. 6(a) and Table 1. As illustrated in Fig. 6b and Table 2, Ultodanga's yearly average NAQI readings were below 100 throughout the summer and monsoon and between 150 and 200 in the winter. The NAQI ratings of Ultodanga fall into the moderate air quality category. However, Behala Chowrasta's summertime NAQI levels fluctuated, making it impossible to see a pattern (r^2 = 0) over time. On the other hand, the NAQI displays a declining trend (r^2= 0.9044) from 2016 to 2019 and an increasing trend (r^2= 0.8) in the winter, as well as an increasing trend (r^2= 0.68) from 2009 to 2012. As seen in Fig. 6 c. at Behala Chowrasta, there was a rising tendency from 2012 to 2014 (r^2 = 0.9) and a declining trend from 2017 to 2019 (r^2 = 0.8) in the summer seasons. The monsoon season ran from 2016 to 2019 (r2 = 0.89). It should be noted that while Behala's yearly average NAQI levels have been declining since 2016, which is encouraging for the city's air quality, NAQI values varied from 185 to 250 in the winter of 2015 to 2019, with 185–250 being classified as moderate to poor (Fig. 6a & b).Therefore, additional work must be done in Behala to further reduce air pollution emissions from various sectors in order to enhance the NAQI values. Similarly, Ultodanga's average yearly NAQI readings ranged between 80 to 100 in from 2009 to 2019, the summer and monsoon seasons were deemed good. The NAQI readings in winter, as seen in Fig. 6b and Table 2, ranged from 150 to 200, and were categorized as moderate to bad or unacceptable air quality. The NAQI levels, as displayed in Fig. 6d, indicated that Ultodanga's air quality is improving. They showed a decreasing trend from 2016 to 2019 (r^2= 0.8265) and an increasing trend from 2009 to 2012 (r^2 = 0.8) in the winter, an increasing trend from 2011 to 2015

(r^2 = 0.9), a decreasing trend from 2017 to 2019 (r^2 = 0.9) in the summer, and a decreasing trend in the monsoon from 2017 to 2019 (r^2 = 1). In addition to air pollution emissions, persistently stagnant weather, especially during the winter, is a major factor in the elevation of air quality in Kolkata. Figure 6(d) presents a trend study of Ultodanga's AQI seasonal variance from 2009 to 2019 in conjunction with the government-mandated National Ambient Air Quality Standards (NAAQS).

Additionally, Fig. 6 used the NAQI values to display the number of days in Kolkata at two designated places throughout the course of a year with the status of the air quality (good, satisfactory, moderate, poor, very bad, and severe). India began releasing real-time NAQI readings for Kolkata starting in July 2016.

CHAPTER 6 : METEROLOGICAL OBSERVATION

In an urban setting, meteorological factors have a big impact on the ambient air quality. Although Kolkata, the capital of West Bengal, is one of the world's megacities with the highest air pollution, little is known about the possible effects of weather on the megacity's air pollution standards. This study looked at the correlations between the concentrations of specific air pollutants (SO_2, NO_2, PM_{10}, and AQI) and meteorological characteristics such seasonal mean temperature (o F), relative humidity (%), and wind speed (mph) from January 2009 to December 2019. The temporal fluctuations of important meteorological data, such as temperature, relative humidity, and wind speed, are shown in Fig. 7 and Table 3 and were recorded at the Behala and Ultodanga from the West Bengal weather station at two places in Kolkata. There is a negative correlation between PM10 concentrations and temperature and wind speed, but a positive correlation with relative humidity and wind direction. Temperature and relative humidity were found to have correlation values of -0.15 and 0.01 respectively. Temperature and NO_2 concentration have a negative correlation ($R = -0.59$, $p < 0.001$). In all seasons, high NO_2 concentrations are seen with low wind speeds. Elevated relative humidity promotes NO_2 adsorption. Colder temperatures, slower wind speeds, higher pressure systems, somewhat less precipitation, and higher relative humidity are all positively correlated with higher SO_2 concentrations. Air pollution's generation and dispersal are influenced by humidity. Pollutants are trapped in the humid air around the ground for stopping them from escaping into the atmosphere through the earth. As a result, there are more contaminants in the air, particularly in cities. Lower average wind speeds are often associated with higher AQI scores, and higher average wind speeds are generally associated with lower AQI scores. High temperatures are generally correlated with high sun radiation. The AQI ratings are often high when ozone forms and the concentrations are high enough. The Air Quality Index (AQI) values indicate the relative quality of the air in a given area; higher scores correspond to higher concentration levels (Chen,Z. et al,2020).

Location 1 : Behala Chowrasta :

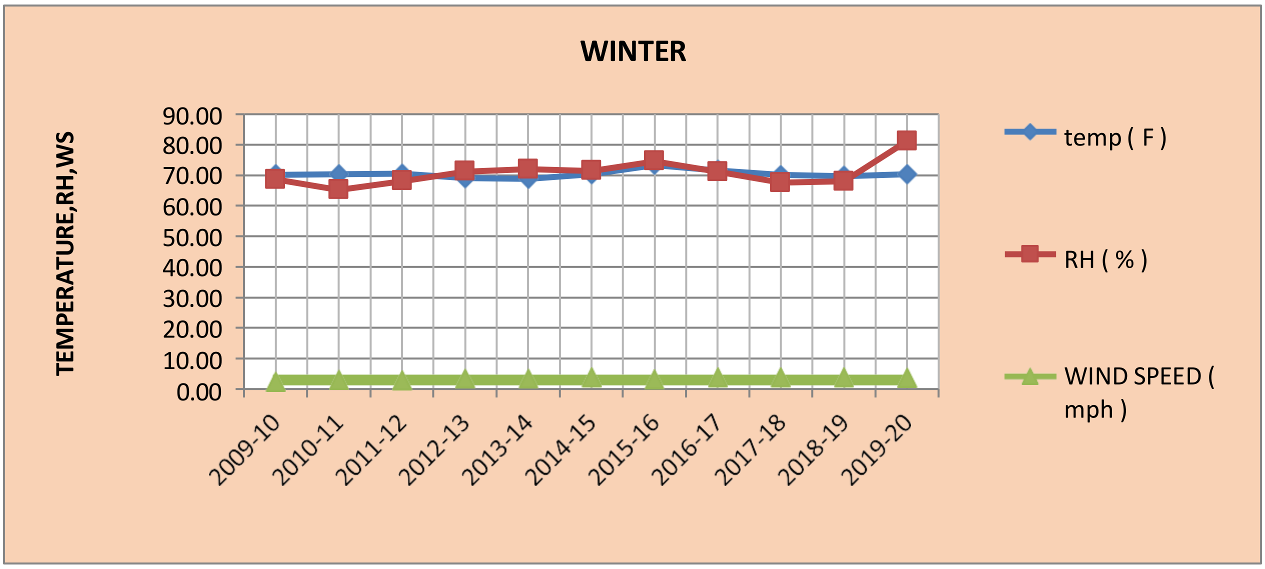


Fig 7 (a) shows the winter variation of temperature, relative humidity and wind speed of Behala from 2009 to 2019

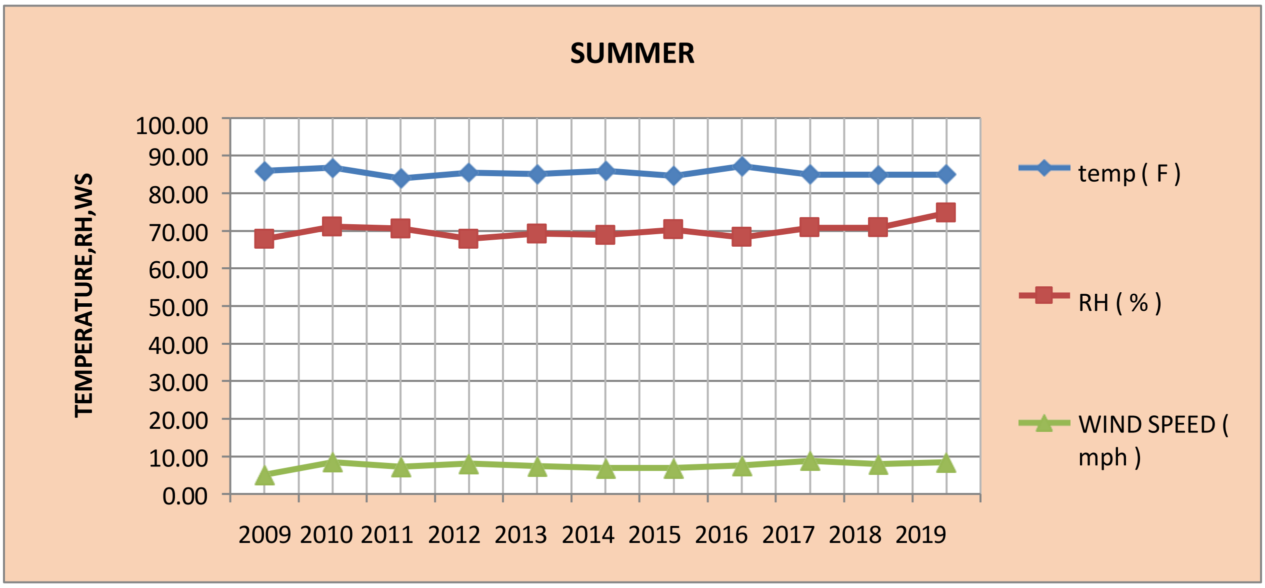


Fig 7 (b) shows the summer variation of temperature, relative humidity and wind speed of Behala from 2009 to 2019

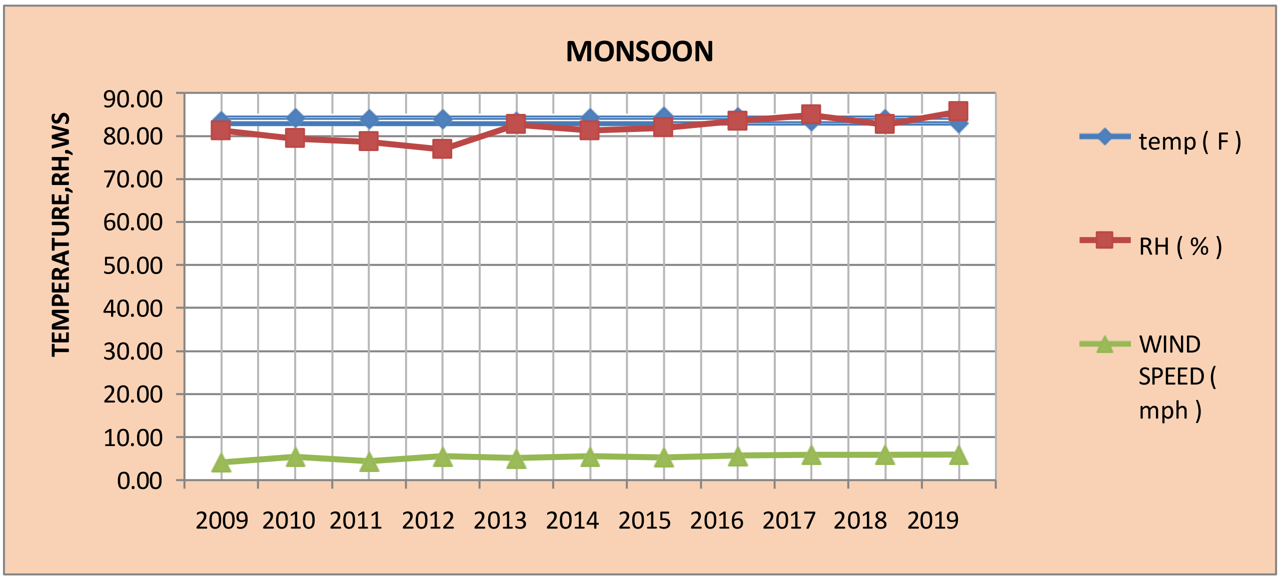


Fig 7 (c) shows the monsoon variation of temperature, relative humidity and wind speed of Behala from 2009 to 2019

:Location 2 : Ultodanga :

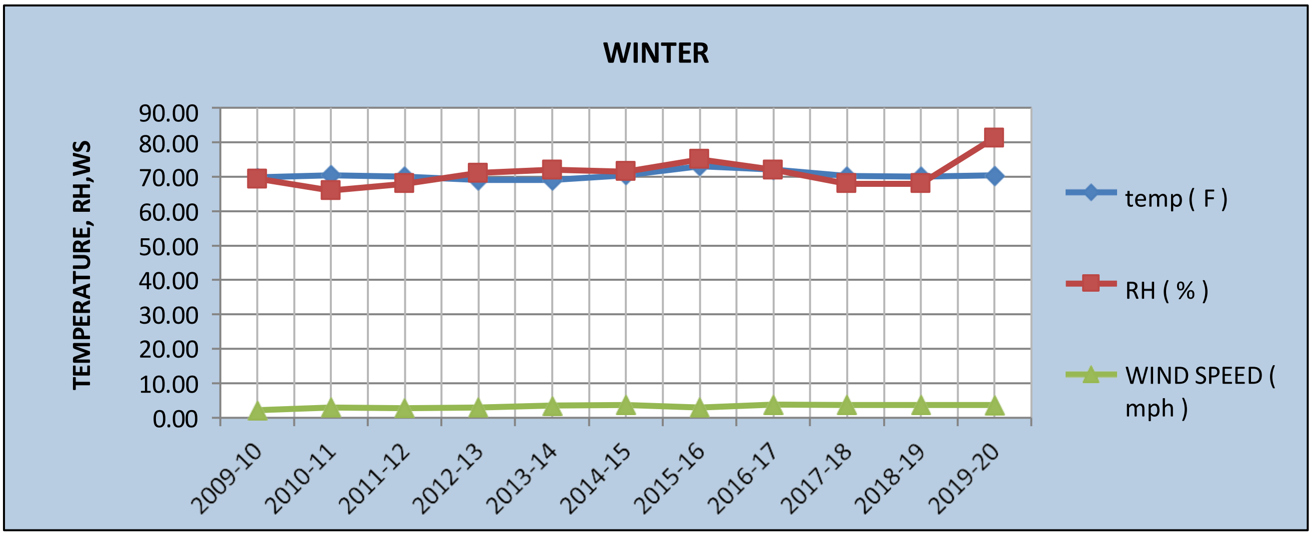


Fig 7 (d) shows the winter variation of temperature, relative humidity and wind speed of Ultodanga from 2009 to 2019

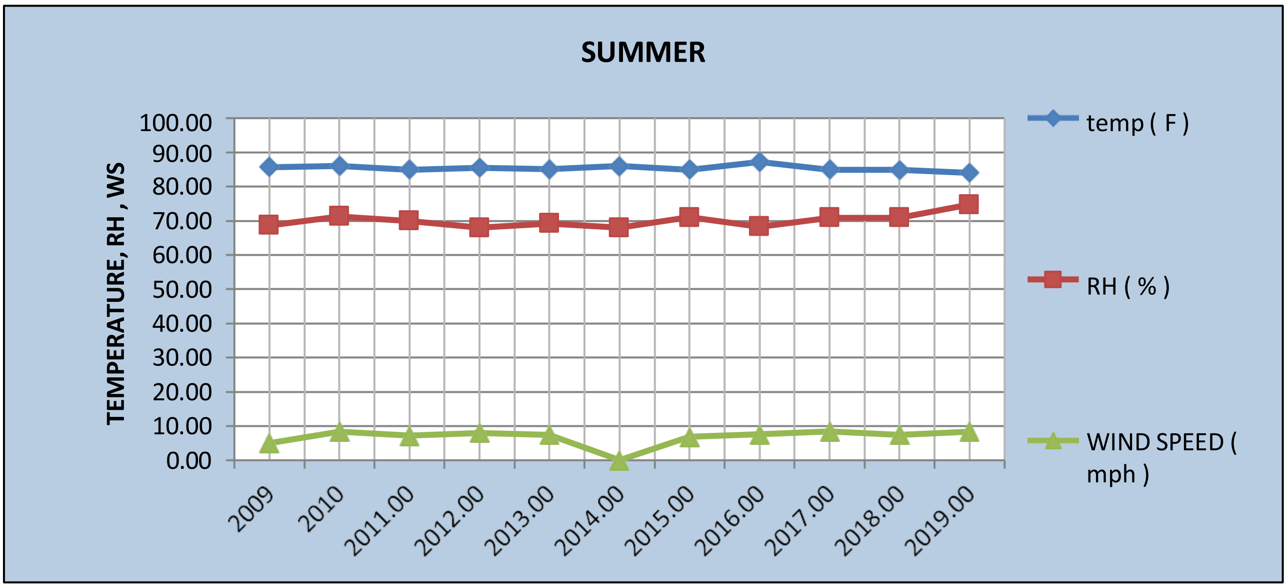


Fig 7 (e) shows the summer variation of temperature, relative humidity and wind speed of Ultodanga from 2009 to 2019

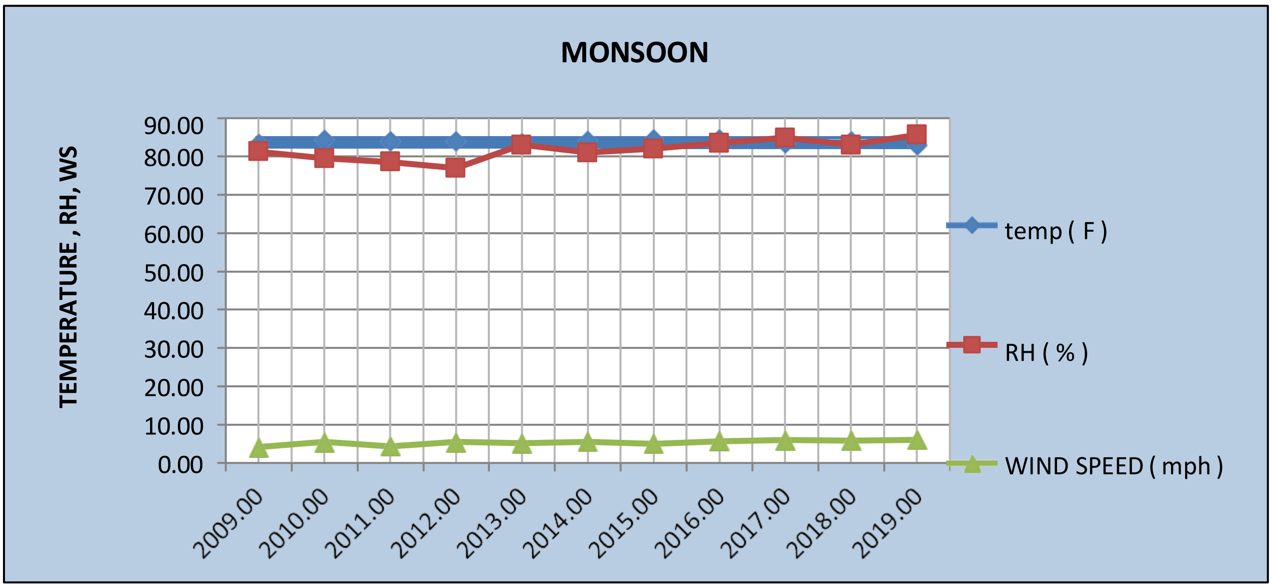


Fig 7 (f) shows the monsoon variation of temperature, relative humidity and wind speed of Ultodanga from 2009 to 2019

- **CORRELATION BETWEEN TEMPERATURE AND AIR POLLUTANT :**

Air quality is negatively impacted by temperatures that are either too high or too low. Both the chemistry and emissions of pollutants are impacted by temperature. Certain gases become less volatile in colder temperatures, although automotive emissions rise as a result of less efficient combustion. Indirectly, cold weather can produce peaks of fine particles since it will cause fine particles to be released from chimneys that are in operation (Roy, A. D.,2020).

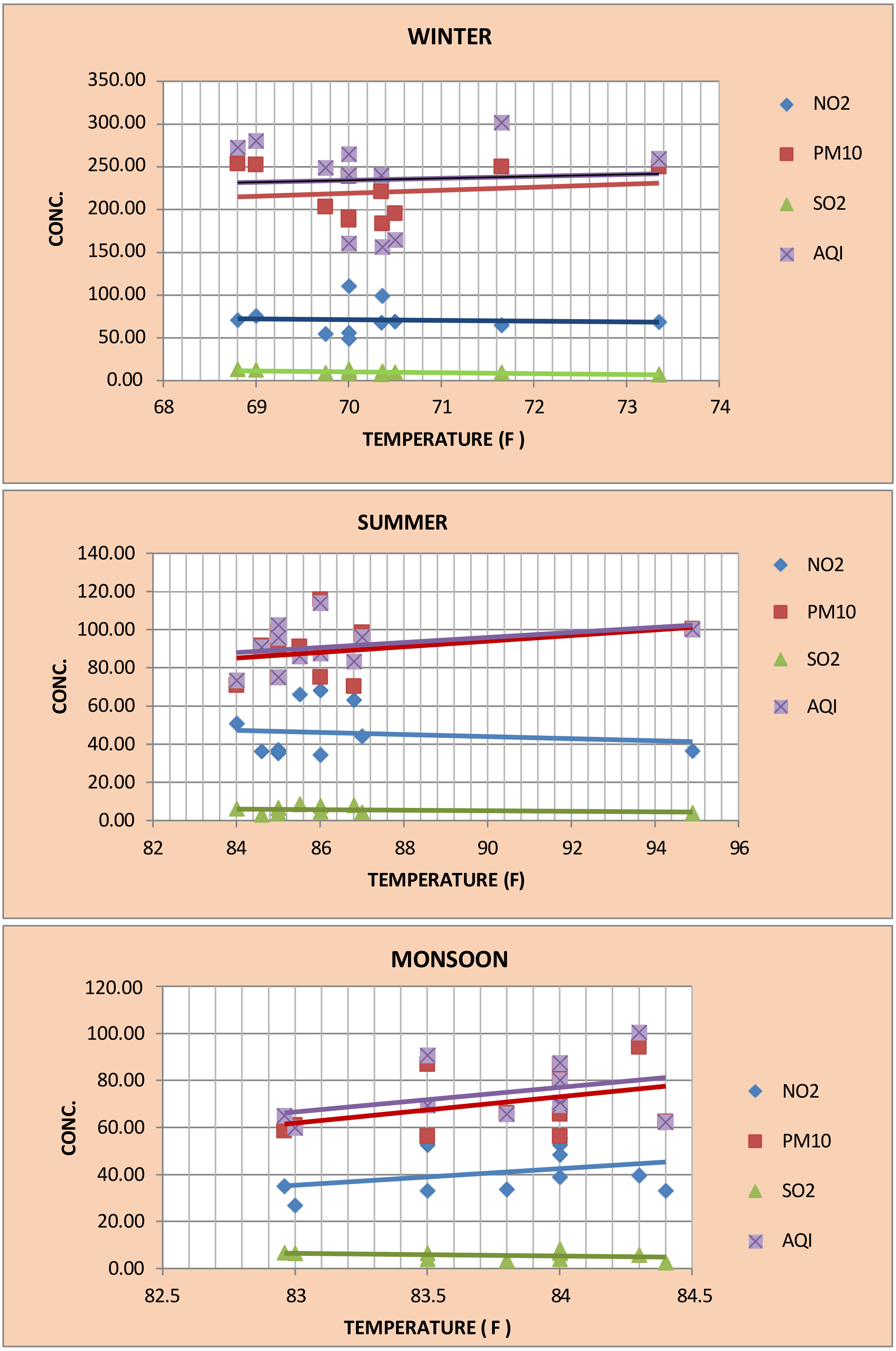


Fig 8 (a) shows the seasonal variation of air pollutant with temperature in two prescribed locations of kolkata from 2009 to 2019

Using spearman correlation analysis at a 5% significant level, the relationship between seasonal fluctuations in the amounts of air contaminants and temperature was ascertained. The correlation coefficient values are displayed in Table 4. A graphical representation of the correlation may be found in Fig. 8(a). Figure 8(a): Seasonal temperature and air pollution concentration correlation Winter (November–February), monsoon (July–October), and summer (March–June) are the three seasons. Table 4 clearly shows that NO2 had a positive association (r = 0.3472) with air temperature during the monsoon and a negative correlation (r = -0.058) with temperature throughout the winter and summer (r = -0.119). In a similar vein, PM10 showed positive correlations with air temperature during winter, summer, and monsoon (r = 0.1525), (r = 0.3035), and (r = 0.3851), respectively. They contended that water vapour is absorbed by particulate matter composed primarily of soil or road dust and so readily settles on the ground. During winter, summer, and monsoon, respectively, SO2 showed negative correlations (r = -0.638), (r = -0.225), and (r = -0.301) with atmospheric temperature. The air quality index (AQI) showed a positive connection with the atmospheric temperature in the winter, summer, and monsoon, respectively, (r = 0.055), (r = 0.327), and (r = 0.380).

MONSOON			SUMMER			WINTER		
	TEMPERATURE		TEMPERATURE			TEMPERATURE		
R	NO_2	0.347278	R	NO_2	-0.11971	r (coff)	NO_2	-0.05833
	PM_{10}	0.385123		PM_{10}	0.303573		PM_{10}	0.152552
	SO_2	-0.30191		SO_2	-0.22595		SO_2	-0.63831
	AQI	0.380634		AQI	0.327089		AQI	0.055615

Table 4 (a). Correlation coefficient of each pollutant with Temperature in three different season

- **CORRELATION BETWEEN RELATIVE HUMIDITY (RH%) AND AIR POLLUTANT :**

Air pollution's generation and dispersal are influenced by humidity. Pollutants are kept close to the ground in humid air, which stops them from spreading into the atmosphere. As a result, there are more contaminants in the air, particularly in cities. In the monsoon, relative humidity varied from 79 to 96%, in the summer, from 44 to 89%, and in the winter, from 54 to 88%. During the summer, the relative humidity was as low as 44% and as high as 98% during the monsoon season. Figure 8(b) and Table 4 visually represent the seasonal change of air pollution with relative humidity in the research area from January 2009 to December 2019 (Gupta,2008).

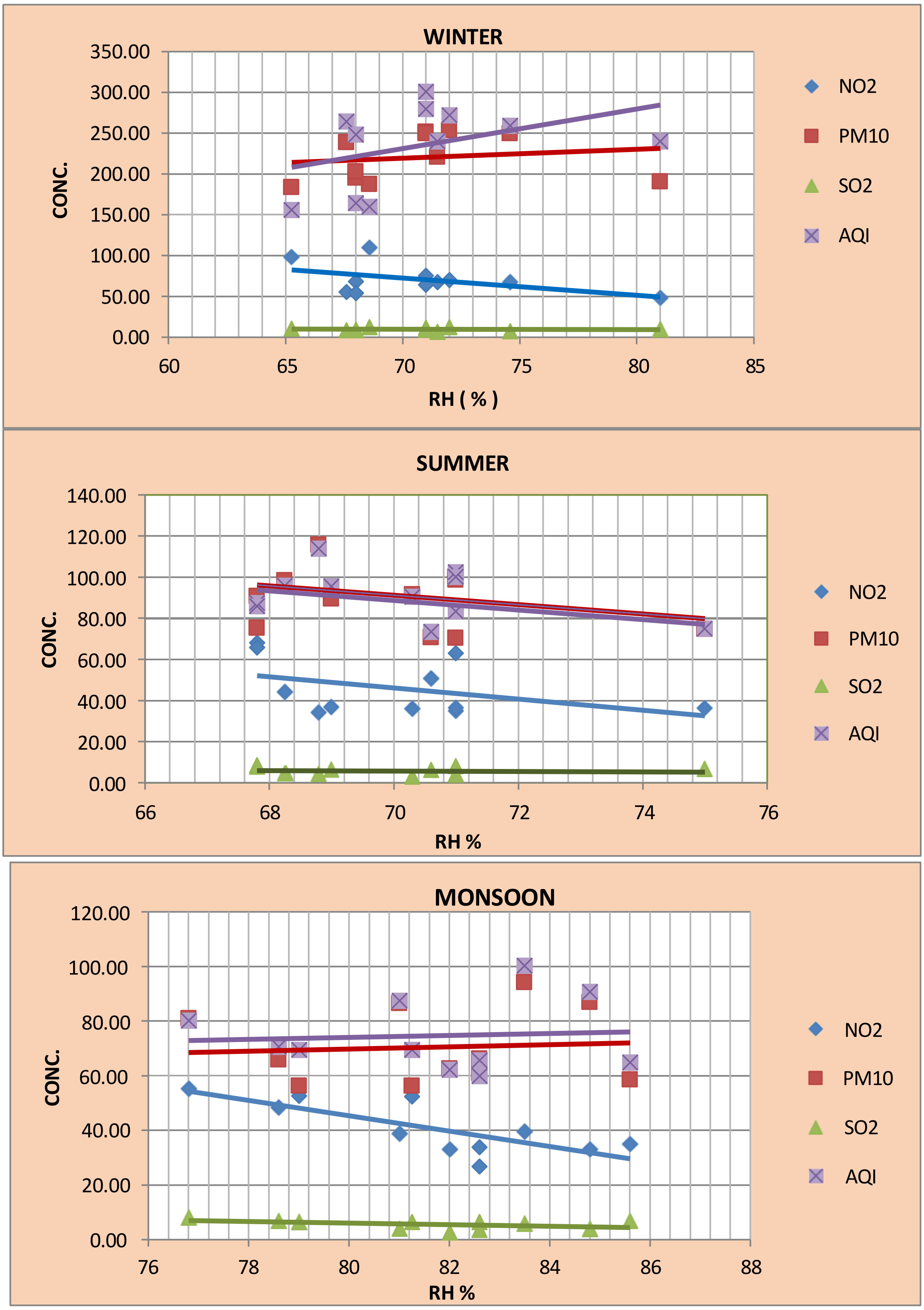


Fig 8 (b) shows the seasonal variation of air pollutant with Relative Humidity at two prescribed locations of kolkata from 2009 to 2019

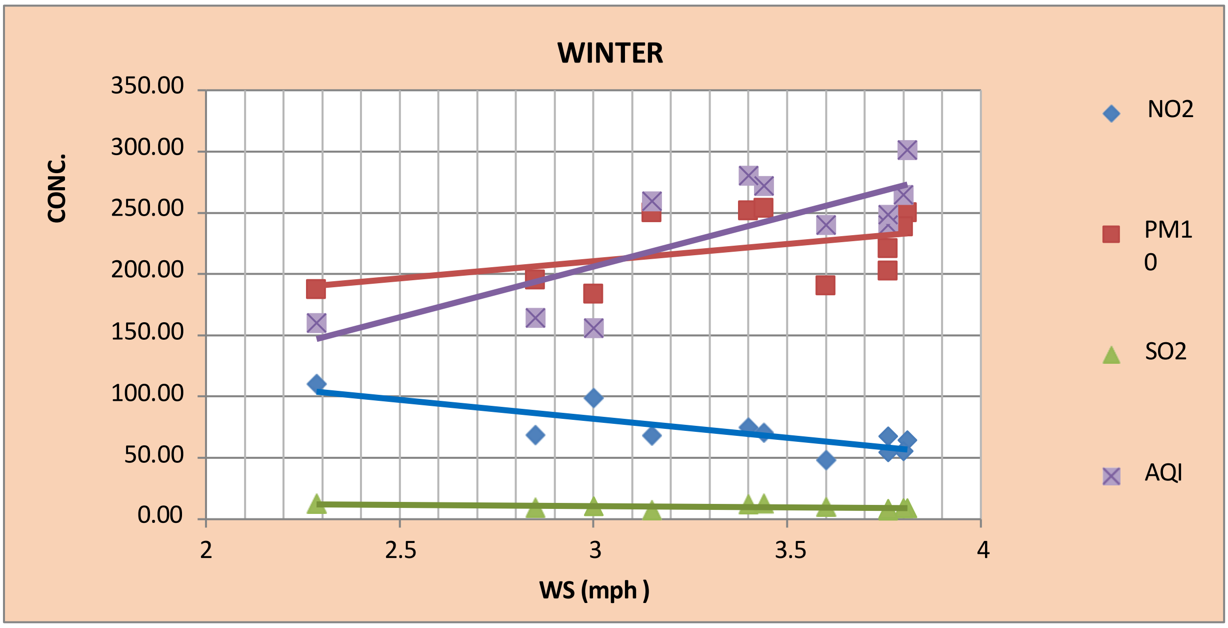
Using spearman correlation analysis at a 5% significant level, the relationship between seasonal fluctuations in the amounts of air contaminants and relative humidity was ascertained. The correlation coefficient values are displayed in Table 4. A graphical representation of the correlation can be found in Fig. 8(b). Figure 8(b): Relationship between seasonal relative humidity and the concentration of air pollutants Winter (November–February), monsoon (July–October), and summer (March–June) are the three seasons. Table 4 makes it clear that NO2 exhibited a negative association (r = -0.4868) with relative humidity in the summer and winter (r = -0.419), as well as a negative correlation (r = -0.77) with relative humidity during the monsoon. Similar to this, PM10 and relative humidity showed positive correlations in the winter (r = 0.16144), negative correlations in the summer (r = -0.335), and positive correlations (r = 0.0766) in the monsoon. They contended that particulate matter , primarily composed of soil or road dusts absorbs water vapors from atmosphere and thereby deposits to the ground easily. When it came to relative humidity in the winter, summer, and monsoon, SO2 showed a negative connection (r = - 0.078), (r = -0.118), and (r = -0.4373). The relationship between relative humidity and the AQI (air quality index) was positive (r = 0.402) in the winter, negative (r = -0.39) in the summer, and positive (r = 0.07) in the monsoon.

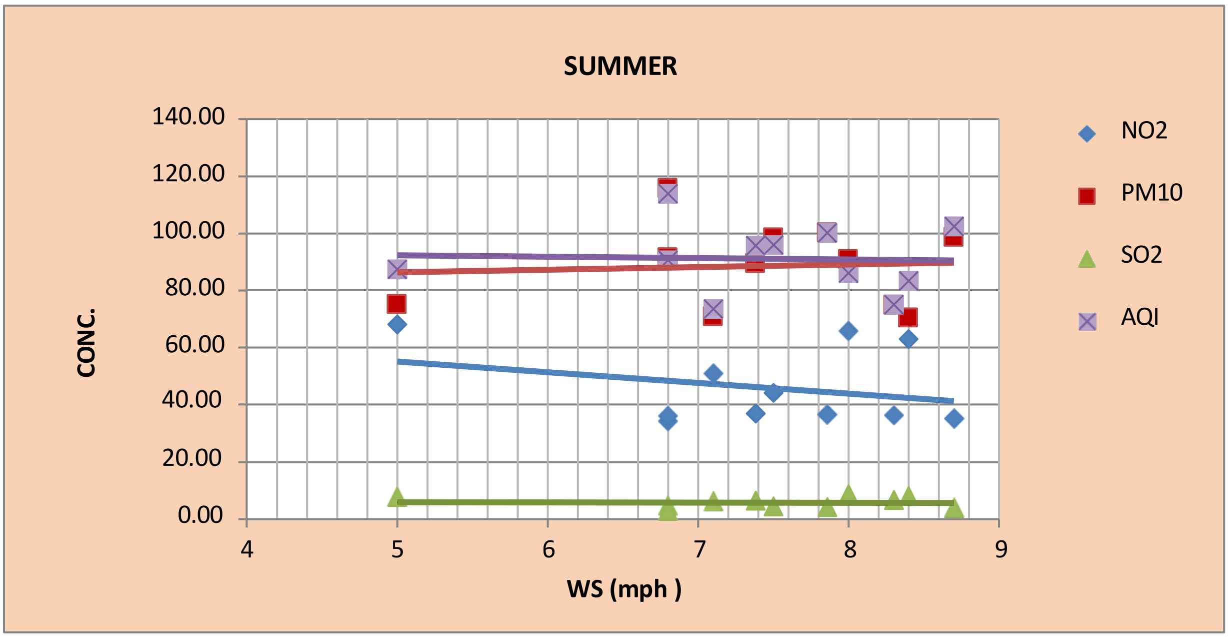
MONSOON			SUMMER			WINTER		
RH			RH			RH		
R	NO_2	-0.77162	R	NO_2	-0.41965	R	NO_2	-0.48683
	PM_{10}	0.076681		PM_{10}	-0.33508		PM_{10}	0.161447
	SO_2	-0.43733		SO_2	-0.11828		SO_2	-0.07853
	AQI	0.072993		AQI	-0.39709		AQI	0.402866

Table 4 (b). Correlation coefficient of each pollutant with Relative Humidity in three different season

- **CORRELATION BETWEEN WIND SPEED(mph) AND AIR POLLUTANT :**

Air pollutants disperse when wind takes them away from their source. Generally speaking, pollutants are more widely distributed and have lower concentrations with greater wind speeds. High winds, however, can also produce dust, which is an issue in arid, windy rural locations. Figure 8(c) and Table 4 visually represent the seasonal variation of air pollution with wind speed in the research area from January 2009 to December 2019 (Ganguly,A.,2008).


WINTER
CONC.
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
2
2.5
3
3.5
4
WS (mph)
NO2
PM1
0
SO2
AQI


SUMMER
CONC.
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
4
5
6
7
8
9
WS (mph)
NO2
PM10
SO2
AQI

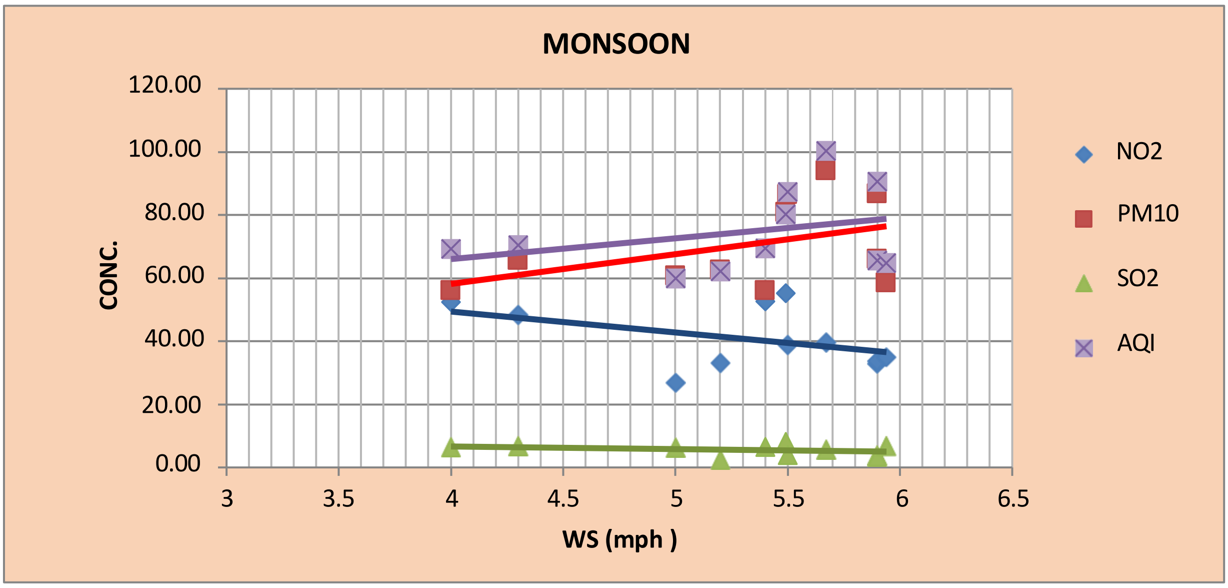

MONSOON
CONC.
120.00
100.00
80.00
60.00
40.00
20.00
0.00
3
3.5
4
4.5
5
5.5
6
6.5
WS (mph)
NO2
PM10
SO2
AQI

Fig 8 (c) shows the seasonal variation of air pollutant with Wind Speed (mph) at two prescribed locations of kolkata from 2009 to 2019.

With a 5% significant threshold of significance, spearman correlation analysis was used to determine the relationship between seasonal variations in the concentrations of air contaminants and wind speed. The correlation coefficient values are displayed in Table 4. A graphical representation of the correlation can be found in Fig. 8(c). Figure 8(c): Relationship between seasonal wind speed and the concentration of air pollutants Winter (November–February), monsoon (July–October), and summer (March–June) are the three seasons. Table 4 clearly shows that NO_2 had a negative correlation (r = -0.81) with wind speed in the summer and winter (r = -0.2868) as well as a negative correlation (r = -0.4378) with wind speed during the monsoon. Similarly, PM_{10} and wind speed showed positive correlations (r = 0.4696) in the winter, r = 0.065 in the summer, and r = 0.435 in the monsoon. They contended that particulate matter was mostly composed of dust from roads or dirt and absorbs water vapors from atmosphere and thereby deposits to the ground easily. In winter, summer, and monsoon, respectively, SO_2 showed a negative connection (r = -0.481), (r = -0.038), and (r = -0.305) with wind speed. The air quality index, or AQI, had a positive association (r = 0.7845) with wind speed during the winter, a negative correlation (r = - 0. 0.04286) during the summer, and a positive correlation (r = 0.322) during the monsoon.

MONSOON			SUMMER			WINTER		
WS			WS			WS		
R	NO_2	-0.43782	R	NO_2	-0.2868	R	NO_2	-0.81422
	PM_{10}	0.435624		PM_{10}	0.065296		PM_{10}	0.469646
	SO_2	-0.30598		SO_2	-0.03876		SO_2	-0.48151
	AQI	0.322072		AQI	-0.04286		AQI	0.784549

Table 4 (c). Correlation coefficient of each pollutant with wind Speed in three different season

Therefore, it is clear that there is little relationship between temperature, relative humidity, and wind speed and the seasonal change of air pollutants' correlation and Pearson coefficient. Therefore, nothing can be inferred from the graphs and computation above.

This study further calculates the association between temperature, relative humidity, wind speed, and the decadal change in air pollutants for each year between 2009 and 2019. In two places, the Pearson coefficient is also computed.

Location : Behala

	NO2	*PM10*	*SO2*	*AQI*	*Temperature*	*RH*	*WS*
NO2	1						
PM10	0.67033	1					
SO2	0.82057	0.70014	1				
AQI	0.56882	0.97447	0.65620533				
Temperature	**-0.69952**	**-0.87468**	**-0.73139025**		1		
RH (%)	**-0.43321**	**-0.43956**	**-0.32730130**		0.265415	1	
WS (mph)							

Table 4(d). Correlation coefficient of each pollutant with temperature , relative humidity and wind speed over the decade (2009-2019) in Behala Chowrasta

Location : Ultodanga

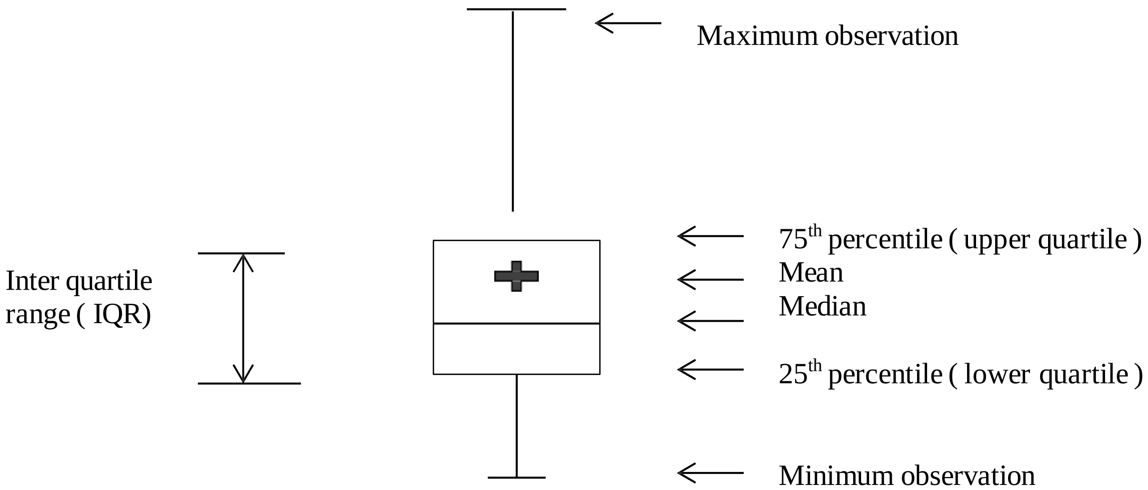
	NO2	*PM10*	*SO2*	*AQI*	*temperature (F)*	*RH (%)*	*WIND SPEED (mph)*
NO2	1						
PM10	0.696495	1					
SO2	0.718167	0.717701	1				
AQI	0.723567	0.994935	0.729211	1			
Temperature(F)	**-0.76125**	**-0.892**	**-0.75743**	**-0.888012**	1		
RH (%)	**-0.46564**	**-0.44413**	**-0.26909**	**-0.478602**	0.2654155	1	
WIND SPEED (mph)	**-0.63229**	**-0.60573**	**-0.57788**	**-0.603195**	0.7105326	0.129556	1

Table 4(e). Correlation coefficient of each pollutant with temperature , relative humidity and wind speed over the decade (2009-2019) in Ultodanga

In this instance, my results outperformed seasonal variation; the Ultodanga correlation coefficient of NO_2 with temperature, relative humidity, and wind speed, respectively, is -0.76, -0.5, and -0.63. Temperature, relative humidity, and wind speed have the following correlation coefficients: -0.89, -0.5, and -0.6 for PM10, respectively. Temperature, relative humidity, and wind speed all have a negative association coefficient (-0.75, -0.3, and -0.58) with SO_2. The AQI has a correlation coefficient of -0.88, -0.5, and -0.6 with temperature, relative humidity, and wind speed, respectively. Similarly, the correlation coefficients of NO2 with temperature, relative humidity, and wind speed at Behala Chowrasta are -0.7, -0.43, and -0.61 correspondingly. The relationship between temperature, relative humidity, and wind speed and PM10 correlation coefficient is -0.87, -0.43 , - 0.62 respectively. Temperature, relative humidity, and wind speed have correlation coefficients of - 0.73, - 0.32, and - 0.6 for SO_2. The AQI has a correlation coefficient of -0.83, -0.4, and -0.57 with temperature, relative humidity, and wind speed, respectively. It follows that at both of Kolkata's sites, temperature, relative humidity, and wind speed have a negative correlation with all of the contaminants included in the air quality index. The coefficient values for decadal variation are more significant than those for seasonal fluctuation.

CHAPTER 7 : BOX - WHISKER PLOT USING DESCRIPTIVE STATISTICS

The distributions of each air pollutant were compared, and outliers were found using descriptive statistics. The statistical analysis was carried by with the software XLSTAT 2018.5. The band next to the center boxes represented the median, while the top and bottom of the boxes reflect the 75th and 25th percentiles (quartile). At Behala and Ultodanga, each air pollutant (PM10, SO2, AQI, and NO2) will be examined based on its class. This graphic is significant because it provides a quick overview of the other significant distribution values. The features of this Boxplot The descriptive analysis was carried out using the XLSTAT 2018.5 software technique, which produced the plot location results for the plots that were included in the box (within the range) and those that were not (out of range) (Das, N,2021). The graphic that displays the highest or lowest values in relation to other data values among boxes known as outliers.



Box plot Characteristics

LOCATION 1 : BEHALA CHOWRASTA

Table 5 (a) .min, max, and quartile data of Box plot of Behala Chowrasta

MONSOON

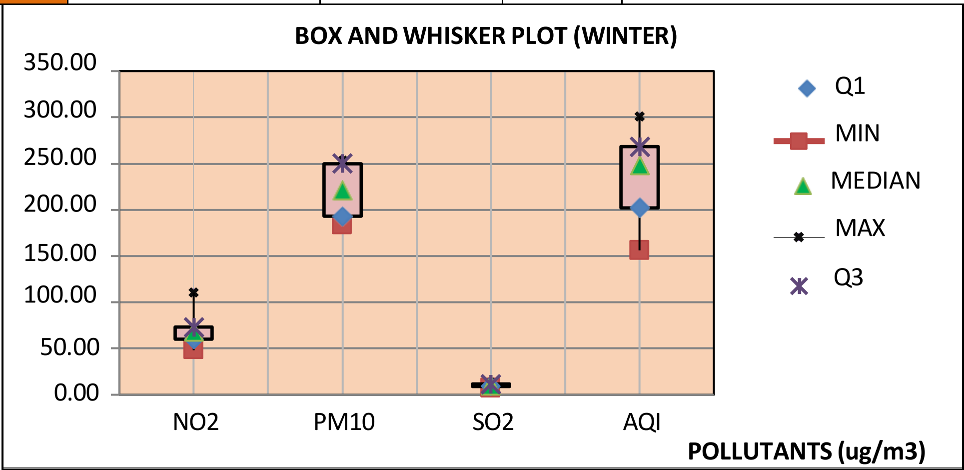
	NO_2	PM_{10}	SO_2	AQI
Q1	33.45	59.71	3.98	65.31
MIN	26.85	56.22	2.60	59.95
MEDIAN	38.90	65.75	6.45	69.50
MAX	55.25	94.08	8.25	100.33
Q3	50.48	83.78	6.69	83.83

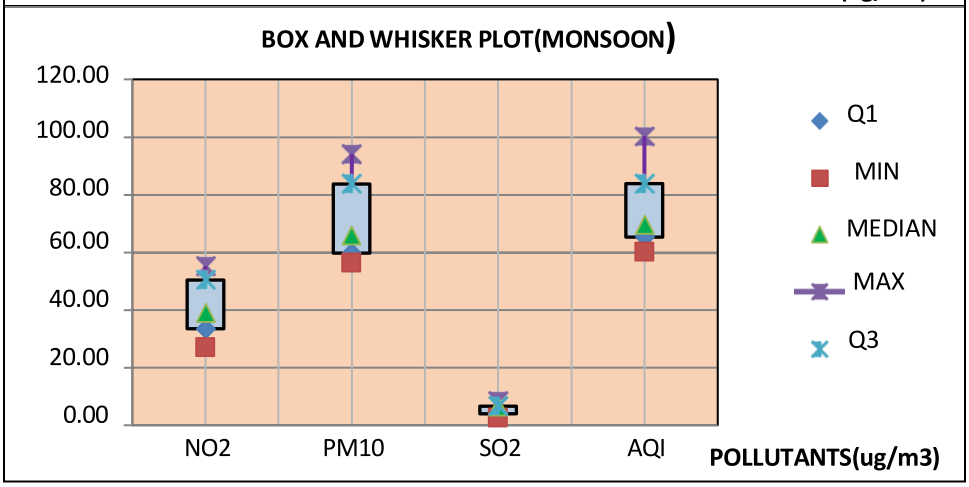
WINTER

	NO_2	PM_{10}	SO_2	AQI
Q1	59.96	192.86	8.77	202.20
MIN	48.31	183.50	6.90	156.16
MEDIAN	67.87	220.80	9.60	248.20
MAX	110.24	253.45	12.91	301.12
Q3	72.84	249.92	11.31	268.28

SUMMER

	NO_2	PM_{10}	SO_2	AQI
Q1	36.11	74.86	4.17	84.56
MIN	34.18	70.21	2.80	73.42
MEDIAN	36.80	90.78	6.17	90.50
MAX	67.98	115.48	8.58	113.69
Q3	56.78	98.50	7.13	97.92





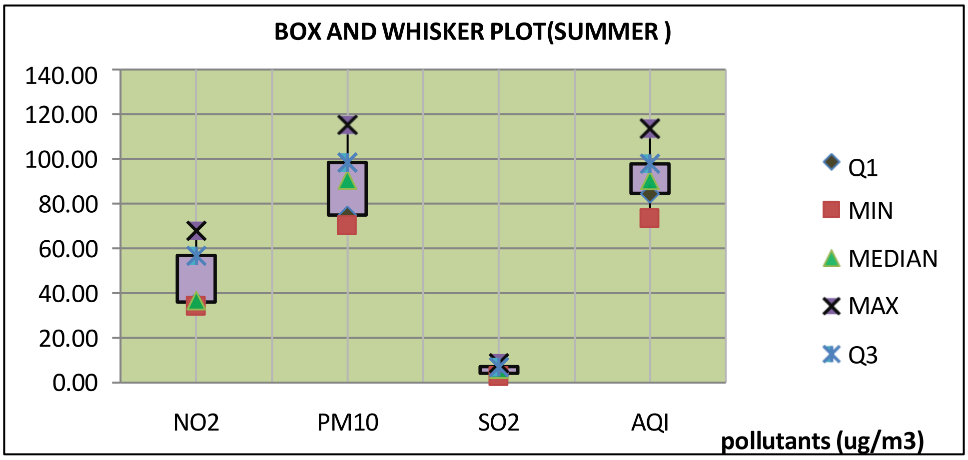


Fig 9 (a). shows the Box and Whisker plot of seasonal variation of air pollutant at Behala Chowrasta

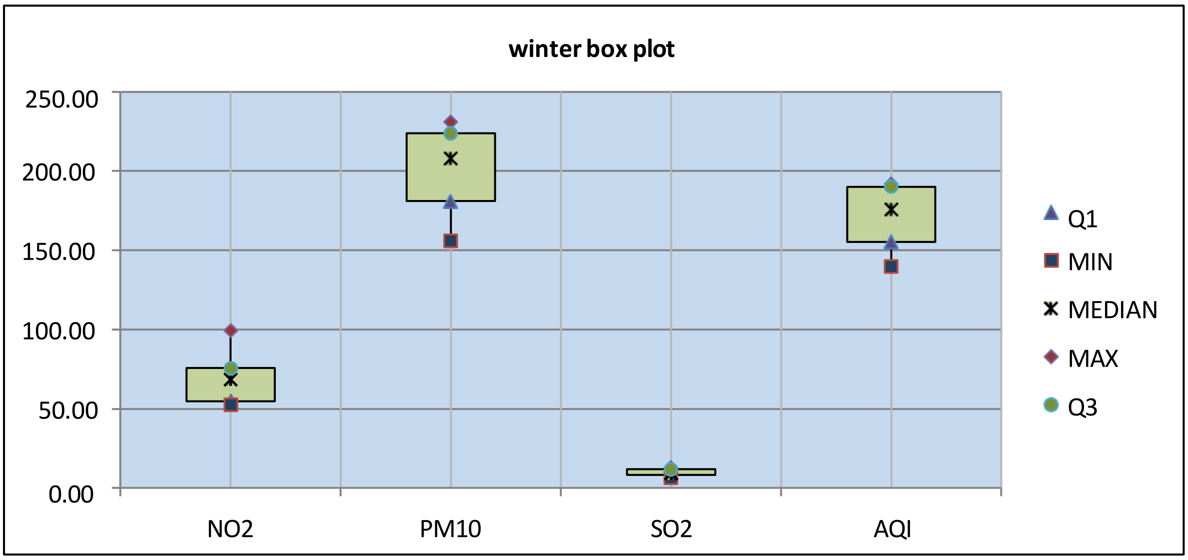
Figure 9(a) illustrates how boxplots are used to calculate each reading of air pollutant concentration that is included in a box and any outliers. The data values in the boxes include the 25th percentile, median, 75th percentile, and less or more than what is outside of the boxes. Every data set is displayed as a plot. The lowest and greatest data readings for each air pollutant concentration will be plotted for each set of air monitoring data that has undergone descriptive analysis. For example, the lowest or minimum value for each cluster class was consistently 56.22, 183.50, and 70.21 µg/m3 for PM10 throughout the monsoon, winter, and summer, respectively, and 26.85, 48.31, and 34.18 µg/m3 for NO2 concentration during the monsoon, winter and summer respectively. Each air pollutant concentration's highest or maximum value can be distinguished and thoroughly interpreted. The highest plots of PM10 concentration for Behala were 253.94, 115.48, and 253.08 µg/m3 during the monsoon, winter, and summer, respectively. At monsoon, winter, and summer, respectively, the maximum plots of NO2 concentration for Behala were 55.25, 110.24, and 67.98 µg/m3. In conclusion, the data for SO2 concentration indicate that the highest plots for Behala were 8.25, 12.91, and 8.58 µg/m3 during the monsoon, winter, and summer seasons, respectively. The boxplots contained data on air pollutants that fell between the recommended values found under the air quality and breathing environment standards.

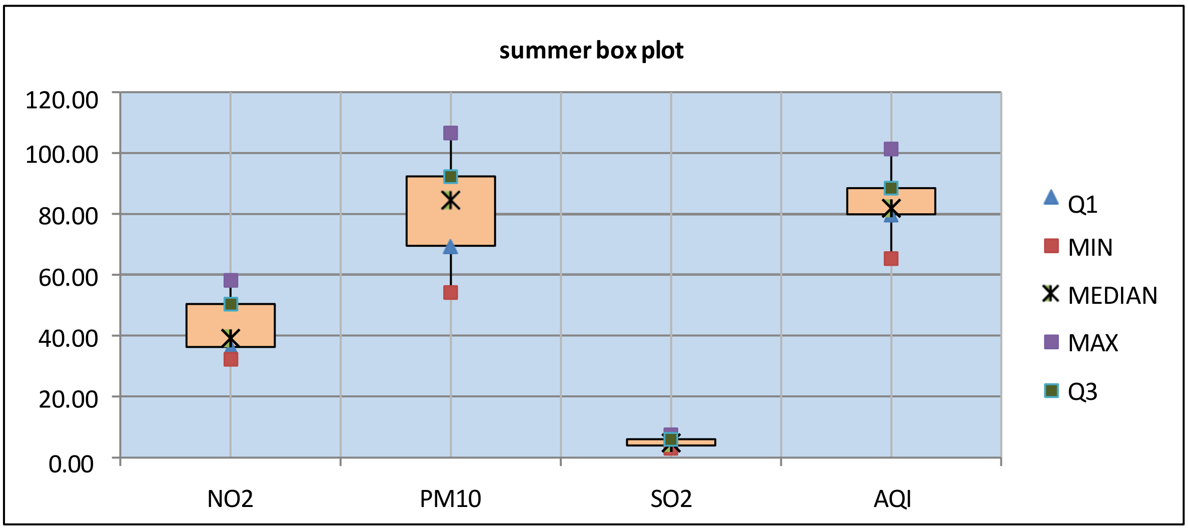
LOCATION 2 : ULTODANGA

		WINTER		
	NO_2	PM_{10}	SO_2	AQI
Q1	54.82	181.14	8.20	155.46
MIN	52.47	156.02	6.47	139.84
MEDIAN	68.50	207.67	9.17	175.97
MAX	99.32	231.17	12.65	191.84
Q3	75.48	223.89	11.79	190.17

		SUMMER		
	NO_2	PM_{10}	SO_2	AQI
Q1	36.25	69.49	3.93	79.80
MIN	32.32	54.32	3.10	65.36
MEDIAN	39.17	84.65	4.99	81.89
MAX	58.34	106.58	7.55	101.42
Q3	50.41	92.32	6.06	88.53
		MONSOON		
	NO_2	PM_{10}	SO_2	AQI
Q1	33.75	45.93	3.92	58.61
MIN	27.55	36.95	3.75	57.55
MEDIAN	36.85	59.23	5.70	64.30
MAX	46.70	83.83	7.48	81.08
Q3	40.80	73.92	6.25	69.42

Table 5 (b) .min, max, and quartile data of Box plot of Ultodanga





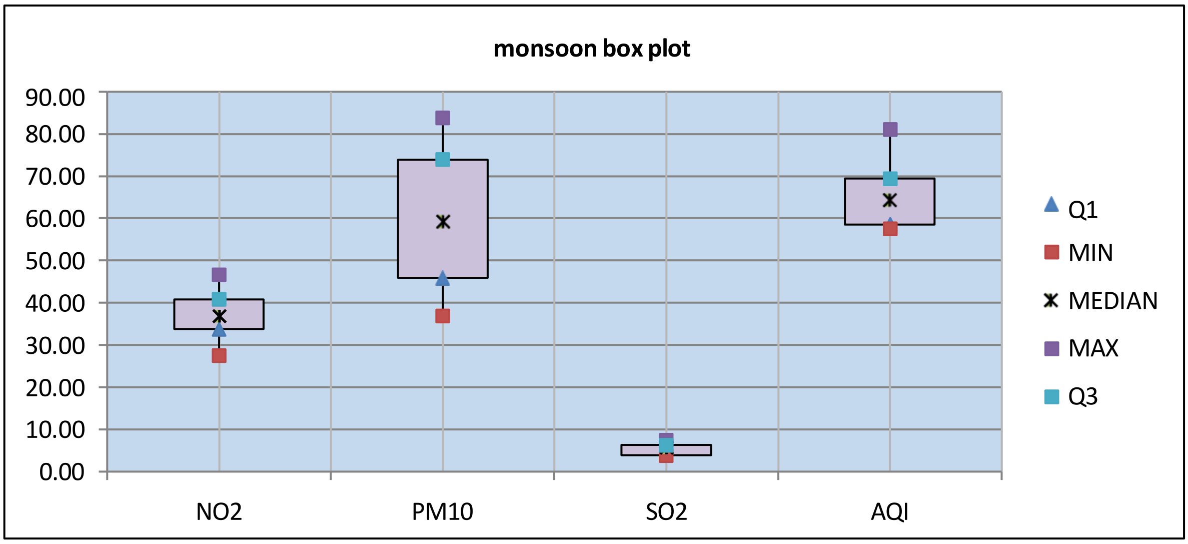


Fig 9 (b). shows the Box and Whisker plot of seasonal variation of air pollutant at Ultodanga in kolkata from 2009 to 2019

Figure 9(b) illustrates how boxplots are used to calculate each reading of air pollutant concentration that is contained in a box and any outliers. The data values in the boxes include the 25th percentile, median, 75th percentile, and less or more than what is outside of the boxes. Every data set is displayed as a plot. The lowest and greatest data readings for each air pollutant concentration will be plotted for each set of air monitoring data that has undergone descriptive analysis. For example, the values for PM10 at winter, summer, and monsoon were 156, 54, and 37µg/m3, while the NO2 concentration at winter, summer, and monsoon was 52, 32, and 27µg/m3, respectively. These values were consistent across all cluster classes in each lowest or minimum value plot. It is possible to identify and interpret in detail the largest or greatest variation in each air pollutant concentration. Ultodanga's highest PM_{10} concentration plots were 231, 106.5, and 83 µg/m3 during the winter, summer, and monsoon seasons, respectively. In the meantime, Ultodanga's highest NO_2 plots throughout the winter, summer, and monsoon seasons were 99, 58, and 47 µg/m3, respectively. In conclusion, Ultodanga's maximum plots for SO2 concentration measurements throughout winter, summer, and monsoon are 12.65, 7.55, and 7.48 µg/m3, respectively. The boxplots included data on air pollutants that fell between the recommended values found under the air quality and breathing environment standards.

CHAPTER 8 : FUTURE TREND OF AIR POLLUTION

Air pollution emissions have a number of negative effects, such as crop losses, early death and illness, biodiversity threats, and acidification of soils and surface waters. Scientific communities and policy organizations have typically addressed the past and future evolution of such emissions at the local, national, or regional scale because these effects are local and short-term. The theoretical foundation of trend analysis is the notion that previous events can be used to forecast future events. Analyzing data over a predetermined timeframe allows one to identify trends and forecast future occurrences.

To create a linear trend line through a given set of dependent y-values, utilize the Excel TREND function. An independent set of x-values and return values along the trend line is optional.

In order to project dependent y-values for a set of fresh x-values, the TREND function can also project the trendline further into the future.

The Excel TREND function has the following syntax:

TREND([new_x's], [const], [known_y's], [known_x's])

Where:

A list of the dependent y-values that you already know is called "Known_y's" (mandatory).

One or more sets of the independent x-values are known as "known_x's" (optional).

Sulfur Dioxide :

In Kolkata, the primary human source of sulfur dioxide (SO_2) emissions is power generation from coal and oil, with industrial energy combustion coming in second Figure 10 (a). Kolkata's SO_2 emissions have decreased by more than two-thirds over the last 20 years as a result of increased energy efficiency, changes in fuel blends, and the extensive use of end-of-pipe desulfurization in the power industry.

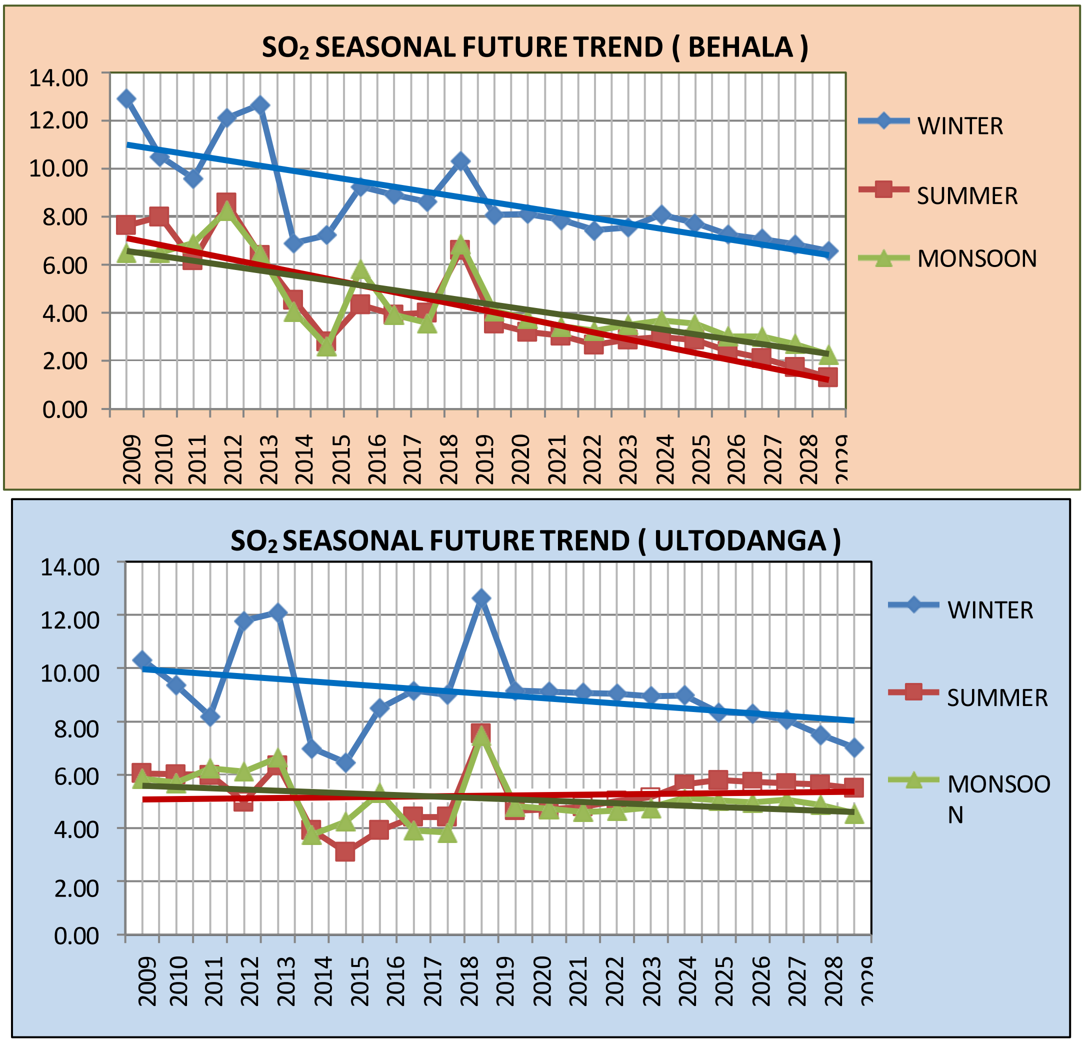
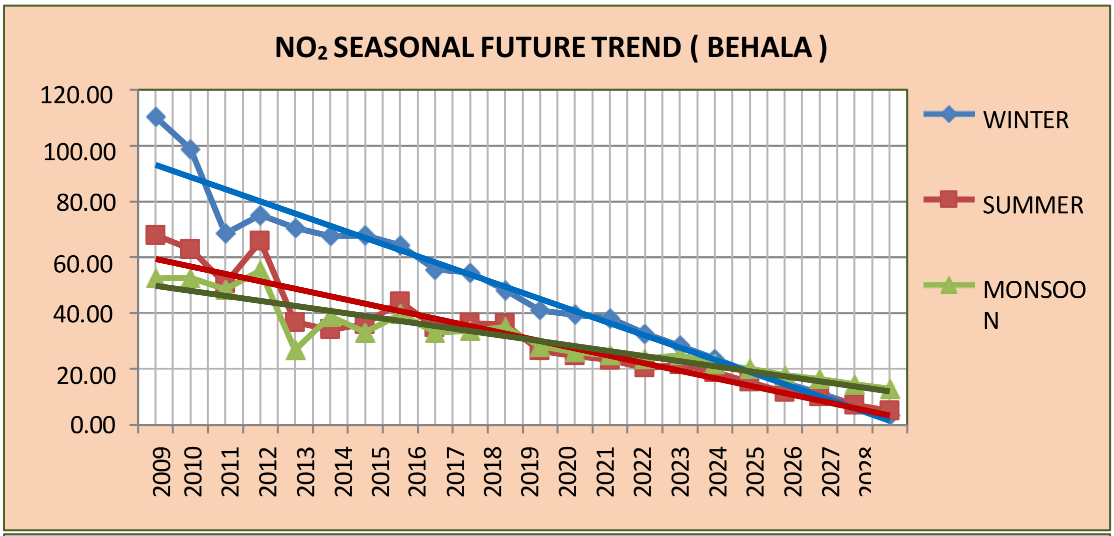


Fig 10 (a) represents seasonal future trend of SO_2 in two prescribed location of Kolkata Here, the seasonal pattern of SO_2 was projected for the years 2030 at two designated Kolkata locations. Figure 10(a) shows two graphs that show a declining trend of SO2 over the winter, summer, and monsoon seasons in the future. This is a benefit of the environment that can be further decreased by consistently and truly adopting safeguards.

Nitrogen Oxides :

The majority of global anthropogenic NOx emissions are caused by mobile sources. Following the widespread use of pollution control devices, the share of vehicle emissions declined in previous years despite the fleet's rapid rise Figure 10 (b). Experience indicates that emissions from diesel light-duty vehicles have barely decreased under real-world driving conditions, despite the fact that European legislation has established progressively strict limit values on NOx emissions from vehicles, which are typically fulfilled by new cars under test cycle conditions. There have recently been reports of similar incidents in

Kolkata. Power generation emissions kept rising and made for roughly 40% of all emissions worldwide. The development of NOx emissions in industrialized and emerging cities also differed significantly. The rise in NOx in emerging cities s was mainly caused by the growth of the power sector, which currently lacks emission control legislation. Because effective emission controls have been widely implemented, road transport emissions in emerging nations have only slightly increased despite the growth in the number of vehicles.



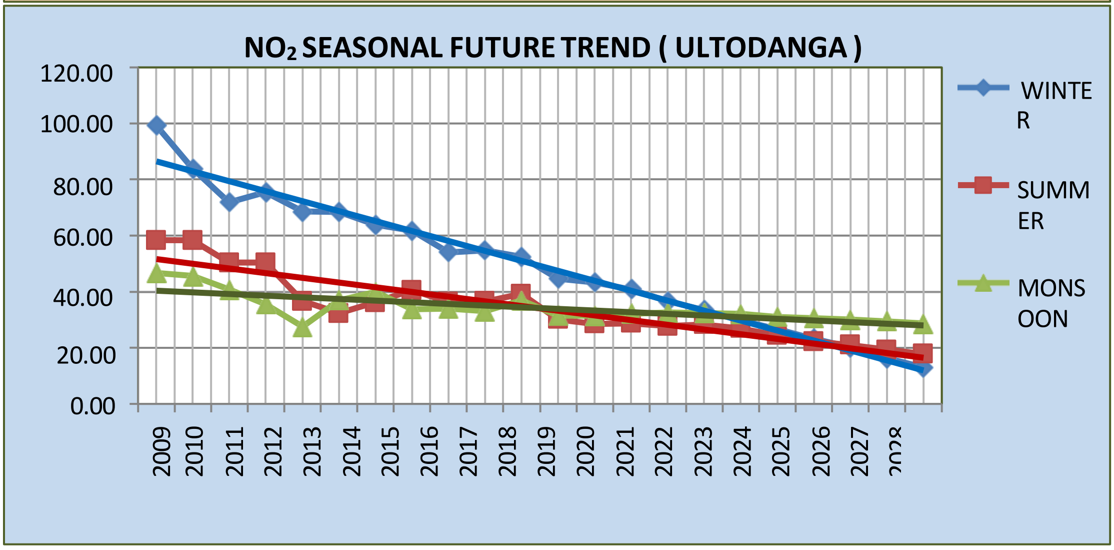
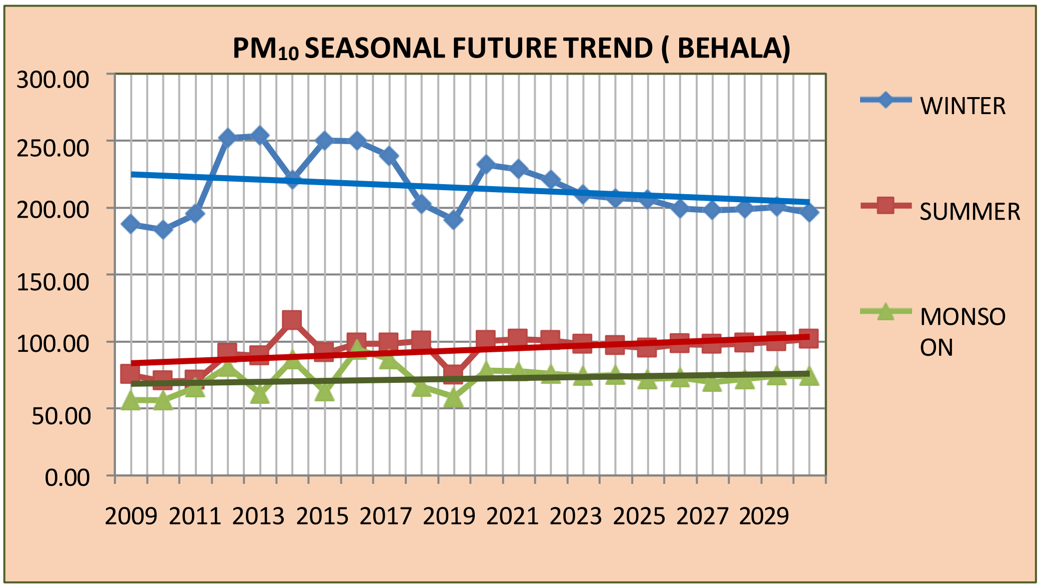


Fig 10 (b) represents seasonal future trend of NO_2 in two prescribed location of Kolkata

Here, the seasonal pattern of NO_2 was projected for the years 2030 at two designated Kolkata locations. Figure 10(b) shows two graphs that show a declining trend in NO_2 levels during the winter, summer, and monsoon seasons in the future. This is a benefit of the environment that can be further decreased by consistently and truly adopting safeguards.

➢ **Particulate Matter :**

The national data portal and the reports on the CPCB website were the sources of the yearly average PM10 statistics for the Behala and Ultodanga stations in Kolkata, which span the years 2009 through 2019. There are many years when the annual PM10 standard (60 µg/m3) is exceeded, with concentrations up to six times greater. Only a small percentage of the time do annual average PM10 measurements match the WHO Air Quality Guideline of 20 µg/m3. PM10 consists of dust from industrial sources, wind-blown dust from open areas, pollen, pieces of bacteria, dust from building sites, landfills, and farmland. It also includes wildfires and brush/waste burning. Animals may be impacted by PM_{10} in a similar manner to humans. The general presence of particles, not just PM_{10} or $PM2_{.5}$, has an impact on an area's use and appearance through visibility reduction and may affect buildings and vegetation. Pollens, dust storms, bushfires, and sea spray are examples of natural sources of PM_{10} and $PM_{2.5}$ pollution. Numerous industrial operations, including bulk material handling, combustion, and mineral processing, result in the production of PM_{10} and $PM_{2.5}$. These processes are employed by the following industries: iron and steel production, quarrying, cement production, bricklaying, refineries, and fossil fuel power plants.



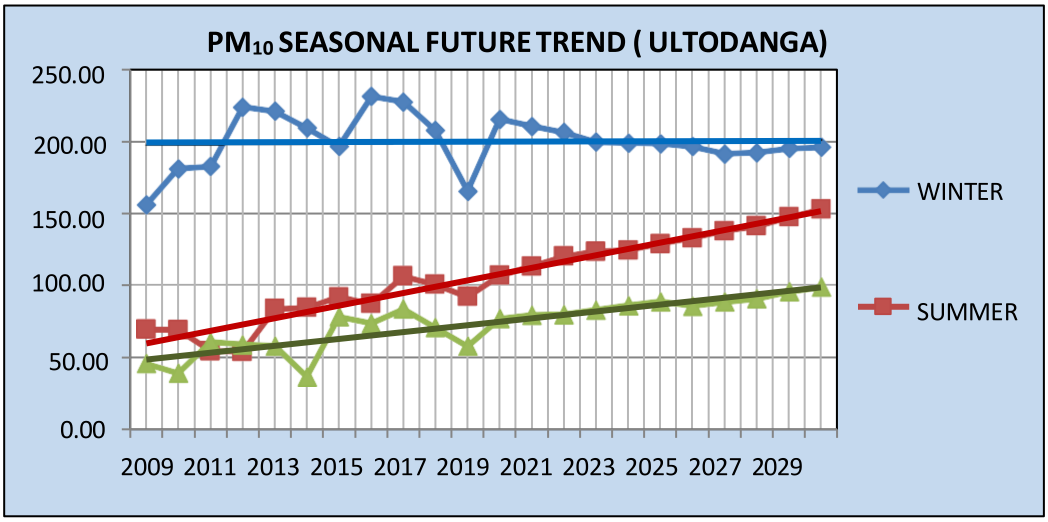


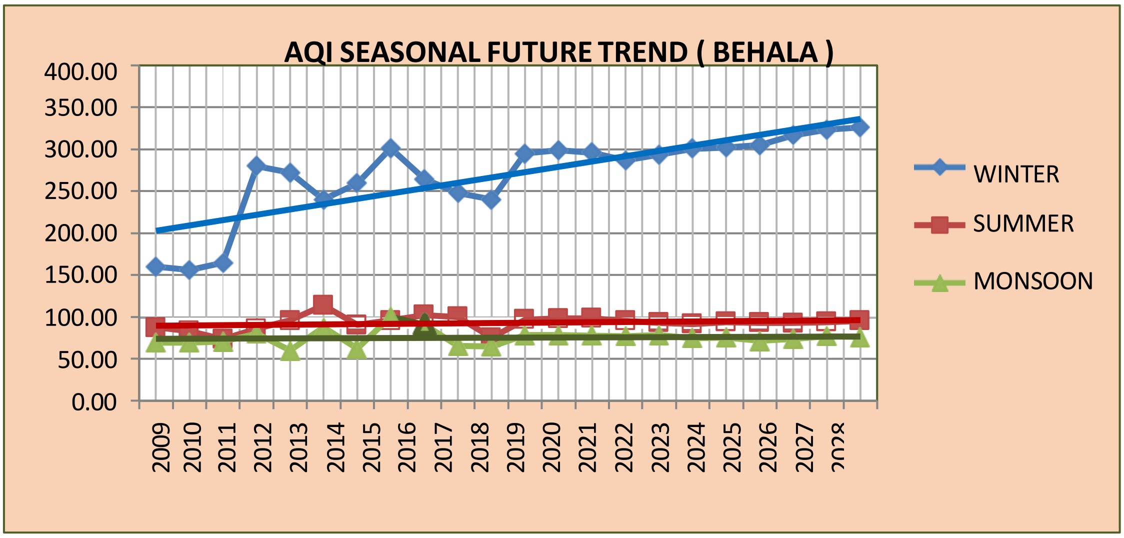
Fig 10 (c) represents seasonal future trend of PM_{10} in two prescribed location of Kolkata

Here, two designated locations in Kolkata were used to track the seasonal pattern of PM_{10} into 2030. According to the graph in Figure 10(c), PM_{10} is expected to continue rising in Ultodanga through 2030 throughout the summer and monsoon seasons, while in Behala, no discernible future trend is seen for any of the three seasons. This is an adverse effect of the environment that needs to be lessened by consistently and truly taking safeguards. Effective ventilation, frequent cleaning and dusting, the use of air purifiers with HEPA filters, reducing the use of harsh chemicals, and implementing practices that reduce particle generation—such as proper cooking ventilation and quitting smoking—are all important ways to reduce indoor particulate matter. The usage of air purifiers in offices and improved ventilation (by routine maintenance HVAC systems) can help reduce the presence of coarse particles. These gadgets lower the concentration of pollutants like PM10 in the office air by filtering and sanitizing the air.

Air Quality Index :

For the past 20 years, Kolkata has had dangerously high levels of air pollution (Ghose et al., 2005; Das et al., 2006; Chatterjee et al., 2013; Lelieveld et al., 2015). The annual average was regularly out of compliance with the national standard, particularly with regard to NOx and respirable suspended particulate matter, or RSPM (~PM_{10}). Solid wastes, road dust, soil dust, and coal combustion were shown to be the main causes. The VOC/NOx ratio indicates that the urban air shed in Kolkata is NOx-sensitive. But throughout the past 20 years, Kolkata's SO2 levels have consistently been considerably below the NAAQS. However, it has been observed in recent years that the yearly average PM_{10} and NOx level frequently exceeds the NAAQS, while the PM2.5 level far exceeds the standard in the winter months. While PM_{10} and $PM_{2.5}$ exceeded the

NAAQS on more than 60% and less than 40% of days, respectively, in Kolkata during 2013 to 2015, NOx concentrations above the NAAQS on multiple occasions at all monitoring locations. Due to meteorological considerations, Kolkata exhibits regular seasonal variation with respect to important air pollutants, with a notably high level during the winter months (November to February).



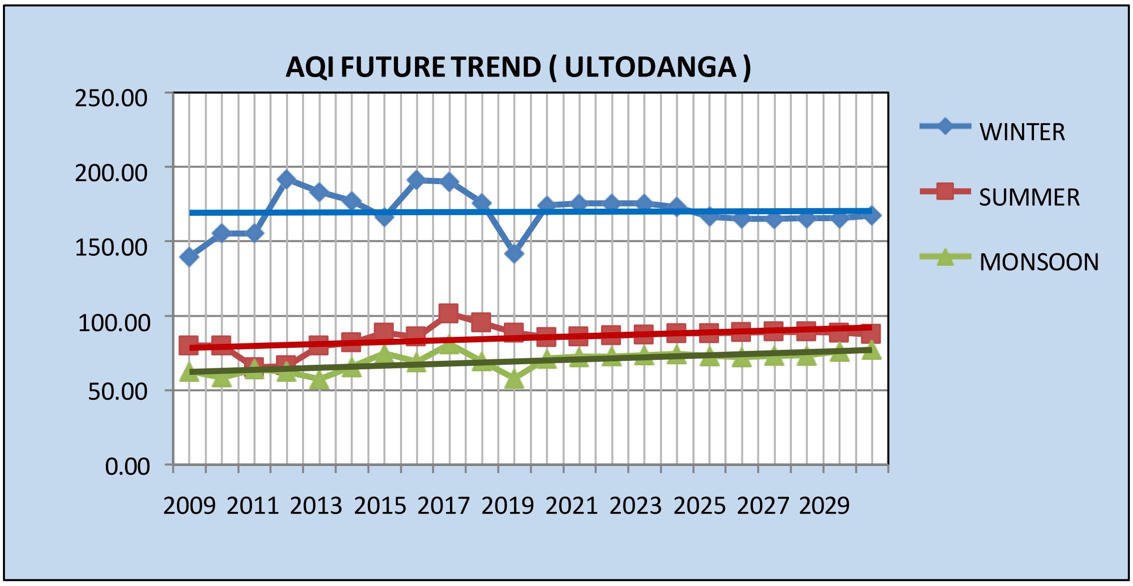


Fig 10 (d) represents seasonal future trend of AQI in two prescribed location of Kolkata

Here, the AQI's predicted seasonal pattern was measured in two designated Kolkata locations through 2030. Figure 10(d)'s graph depicts the AQI's increasing trend in Behala through 2030 for the winter seasons, while Ultodanga exhibits no discernible future trend in any of the three seasons. This is an adverse effect of the environment that needs to be lessened by consistently and truly taking safeguards.

CHAPTER 9 :PRECAUTIONS TO BE TAKEN

The WBPCB determined that in order to lower the amount of particle emissions from their operations, these industries needed to switch to clean fuel, such as gas or oil. In Kolkata, open burning of wood and coal needs to end. The following list contains some significant actions that people can take to help prevent air pollution:

- **Use Air filters-**
  Improved indoor air quality is achieved by using air filters and purifiers, which can be portable or installed as part of a home system to lessen exposure to allergens and particulate matter. When pollution levels are high, portable air monitors may help alert people who are at danger.

- **Use public transportation** –

  Increasing the number of car-free days is a fantastic method to lower air pollution. Using public transit is not only more affordable but also more convenient.

- **Recycle** –
  Greenhouse gas emissions can be decreased by recycling and reusing materials rather than disposing of them in a landfill.

- **Compost -** Recycling organic waste into compost rather than disposing of it in a landfill lowers methane emissions.

- **Buy organic** – Organic agricultural methods reduce the use of hazardous chemicals, which can enhance air quality.

- **Telecommute** – Try working remotely a couple of days a week if your job permits it rather than driving to the office every day.

- **Avoid idling** – Pollutants are released when an automobile's engine is operating but it is not moving. This is known as idling. Thus, attempt to avoid stopping in traffic, at a red light, or in the driveway when you're in your automobile.

- **Enhance Industrial Emission Controls-**

  Large volumes of pollutants are frequently released into the environment by industries. The impact of these emissions can be lessened by enacting stronger emission control laws and standards for industrial operations. Promoting the usage of greener technologies, including filters and scrubbers, can greatly lower the amount of dangerous pollutants released into the environment. To maintain compliance and safeguard the quality of the air in urban areas, regular environmental monitoring and the enforcement of emission rules are essential.

- **Promote Sustainable Construction Practices-**
  Encourage the use of eco-friendly building practices throughout construction projects to cut down on emissions and dust. Put techniques like covering work sites, using water sprays, and handling construction trash properly into practice to prevent construction dust.

- **Promote Energy Efficiency-**

  The production and consumption of energy are the main causes of air pollution. Promoting energy-efficient behaviors can help reduce emissions from houses and power plants. Enforcing energy-efficient construction regulations, promoting the use of energy-efficient appliances, and bolstering renewable energy sources can all help reduce urban air pollution. By implementing sustainable energy practices, we can reduce greenhouse gas emissions, combat climate change, and enhance air quality.

- **Implement Green Spaces and Urban Planning-**
  Parks and other green areas are essential for reducing air pollution in urban areas. As organic air filters, plants and trees take up toxins and release oxygen into the atmosphere. An urban environment that is healthier can be achieved by incorporating green spaces into urban planning initiatives.

- **Improve Vehicle Efficiency –**

  Enforce more stringent car emission regulations and encourage the use of greener technology. Encourage the use of hybrid and electric vehicles and the construction of infrastructure for charging them. To guarantee optimum performance and lower emissions, promote routine vehicle maintenance.

- **Improve Vehicle Efficiency –**

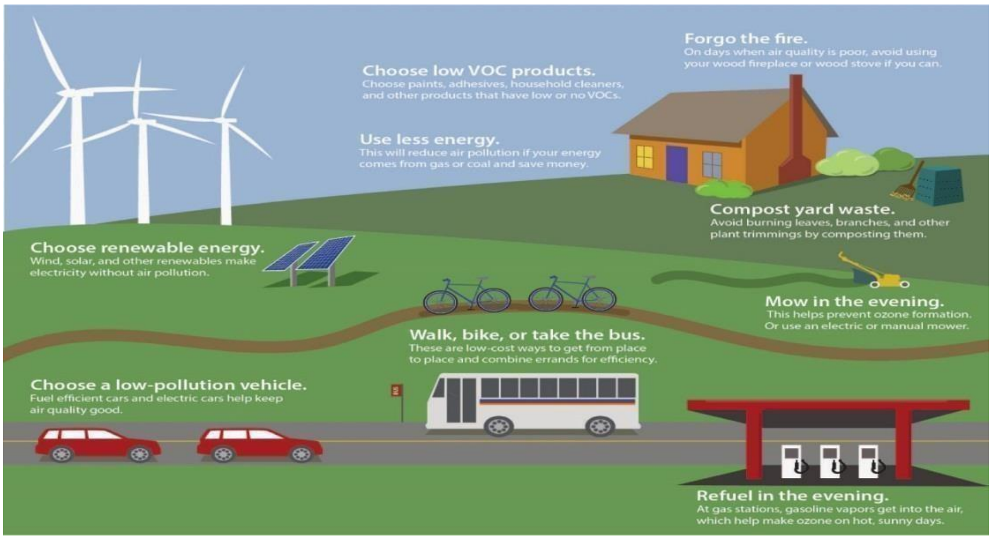
  Enforce more stringent car emission regulations and encourage the use of greener technology. Encourage the use of hybrid and electric vehicles and the construction of infrastructure for charging them. To guarantee optimum performance and lower emissions, promote routine vehicle maintenance. Campaigns for education, seminars, and initiatives involving the community can help spread knowledge about sustainable living and motivate people to adopt decisions that will not harm the environment. By providing residents with information, we can encourage a sense of shared accountability for lowering air pollution.

- **Strengthen Waste Management Practices-**

Because improper waste management releases harmful gasses into the atmosphere and burns garbage, it pollutes the air. Pollution from solid waste can be reduced by putting in place efficient waste management systems, such as recycling initiatives, waste segregation, and controlled waste disposal facilities. Reducing single-use plastics and promoting composting are two more ways to cut waste and, consequently, air pollution.

- **Collaborate and Advocate for Change-**

Collaboration amongst a range of stakeholders, including governmental agencies, businesses, organizations, and individuals, is necessary to address air pollution. When it comes to advancing sustainable practices and influencing governmental changes, advocacy groups can be quite important. We can all contribute to lowering air pollution in cities by cooperating, exchanging information and resources, and pushing for stronger laws.



Source : UCAR Centre for Science and Education (2016)

- **Implement Air Quality Monitoring-**
  Create extensive networks for monitoring air quality in order to track pollution levels in real time. Place monitoring stations all across the city to collect information on different types of pollution. Decision-making can be aided by this data, which can also be used to locate pollution hotspots and assess how well pollution management strategies are working.

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- **No Use of plastic bags-**
  Because plastic products are composed of oil, they take a very long time to degrade, which makes them potentially very damaging to the environment. Instead, using paper bags is a preferable option because they are recyclable and easily degrade.

- **Use of fans instead of Air Conditioner-**

  Using air conditioners is not good for the environment because it uses a lot of energy and produces a lot of heat. In comparison to fans, air conditioners require a lot more energy and power to operate.

- **Use filters for chimneys-**
  The gas released by factories' and residences' fireplaces seriously degrades the quality of the air and poses a serious risk for air pollution. If reducing consumption is not possible, filters should be employed since this will limit the effect of dangerous gasses absorbed in the air.

- **Avoid usage of crackers-**
  Unfortunately, one of the main causes of air pollution at festivals and weddings is the usage of crackers, which results in a layer of haze that is quite dangerous to human health. So, it is best to adopt the practice of not using crackers.

- **Avoid using of products with chemicals-**
  Paints and fragrances, among other products with strong scents or high chemical content, should be used sparingly or outside of the home. Using goods with organic qualities and minimal chemical content is another option.

- **Implement Afforestation-**
  Finally, but just as importantly, plant and raise as many trees as you can. Planting trees is a great way to aid the environment by releasing oxygen into the atmosphere.

- **Reduction of forest fires and smoking-**
  Smoking also contributes significantly to air pollution, deteriorating air quality, and harming people's health. Other major causes of air pollution include gathering trash and setting it on fire during dry seasons or dry leaves catching fire.

- **Switching off the lights when they're not in use –**
  Fossil fuels are used to generate the majority of our electricity, and they are a major source of air pollution. Thus, reducing electricity use is a practical means of avoiding air pollution. These are the methods for lowering air pollution, and we can all alter things for the better by doing small actions. Even while it might seem like one person won't have much of an impact, communities are made up of individuals who can greatly enhance the air quality.

PART II : CHAPTER 10 : Assessment of air quality in Kolkata before and after COVID-19 lockdown

- **Introduction:** Urbanized areas are afflicted by air pollution, which makes people more susceptible to the COVID-19 virus. Out of 1100 cities worldwide, Kolkata, India, comes up at number 25 according to W.H.O. During the COVID-19 shutdown, traffic mobility restrictions decreased this pollution. Activities were resumed, negating this. The trend of air pollutants, their interactions with PM2.5 and PM10, and the resulting National Air Quality Indices (NAQIs) are examined in this study both before and after the COVID-19 lockdowns in Kolkata. Unplanned, densely populated urban areas with a wide range of infrastructure, commercial activity, and functions have put undue pressure on the environment, leading to the creation of unsustainable urban enclaves all over the world. Widespread ambient air pollution is the result of these built-up landscapes and excessively high levels of anthropogenic activity, which have produced massive volumes of air pollutants (Mayer 1999). Issues such as population growth and the ongoing requirement for commercial enrichment, have led to an utter disregard for the environment, thereby increasing the vulnerability of human life to disease and deterioration, an example of which is the spread of the SARS-COV2 virus or COVID-19 virus, causing the global pandemic of today. Despite the risk that particulate matter shortens life spans, the COVID-19 virus has worsened human vulnerability to this illness, taking the lives of both healthy and immune-compromised people worldwide. However, at the same time, the Novel Corona Virus, also known as SARS-COV2 virus, was introduced in December 2019 and quickly spread throughout the world, forcing nations to impose lockdowns and quarantines, close borders, and limit manufacturing activities in order to reduce the amount of pollutants being released into the atmosphere for the first time. Following nearly two to three months of lockdowns, nations such as Brazil, India, the United States of America, Russia, and many more started to progressively lift restrictions, causing the disease to spread rapidly through active anthropogenic transmission. Nevertheless, Despite evidence to the contrary in the literature, the World Health Organization (WHO) has not established that the virus can spread by airborne particulate matter (Contini and Costabile 2020). The virus locates itself on particulate matter micelle, which travels far, often beyond 1.83m depending upon the wind speed and reduced humidity conditions, as non-mask wearing infected patients cough or sneeze, releasing the deadly virus through moisture droplets (Suhaimi et al. 2020). To make matters worse, once the virus uses these as a means of transmission, protective gear like the two or three layered masks that the WHO has recommended cannot stop these ultrafine particulate matter from entering airways (Zoran et al. 2020). China, Malaysia, Italy, and Spain have all reported similar incidents demonstrating the reality that rising National Air Quality Index (NAQI) and spread of this infection is directly related. The goal of the current experiment is to assess the decline in NAQI before, during, and after the lockdown periods at two designated locations—Behala and Ultodanga—in the megacity of Kolkata, the capital of the Indian state of West Bengal.

➢ COVID-19 and its Consequence

COVID-19 lockdowns were implemented gradually starting on March 25 to block the virus's transmission, and the city was placed on hold. Except for necessities like medicine distribution, food stores, and commodity delivery services, no one was permitted to leave their homes; offices, workplaces, amusement parks, theaters, schools, and colleges were closed. Public buses as well as privately owned and operated autos came to a stop. Gatherings could be controlled because factories, industries, and commercial buildings were fully closed throughout the nation and the city. Pollutant levels in the surrounding air quickly decreased as a result of the total cessation of industry and vehicle traffic. On April 15, however, limitations were loosened and certain additional industries were allowed to reopen in order to support the nation's economy while upholding COVID-19 standards for social distance, sanitization, and mask use. More limitations were loosened by the third and fourth stages, which fell on May 4 and May 18, respectively, in accordance with the guidelines provided by the government at the state and federal levels. However, during these stages, the number of cases kept increasing as a result of inadequate contact tracing, inadequate isolation tactics, and disregard for local social distancing customs. Furthermore, in their attempts to survive, less cognizant members of low-income groups, small company owners, and daily wage workers unintentionally spread the sickness that was first brought in by travelers. Additionally, asymptomatic carriers contributed significantly to the disease's spread and increased complexity. As a result, the number of affected instances has continued to rise, slowly at first during the lockdown and then suddenly during the "Unlock 1.0 and 2.0" phases when rules were relaxed. These numbers are currently skyrocketing as a result of more unintentional virus releases into the polluted air, and air pollution levels are rising at the same time, making the problem worse by accelerating the infection's spread. Because of this, the current study has been started to revisit the city's pollution levels, their trends, increases, and declines, and to recommend appropriate actions to maintain the level of air pollution in the most vulnerable regions through stricter regulations.

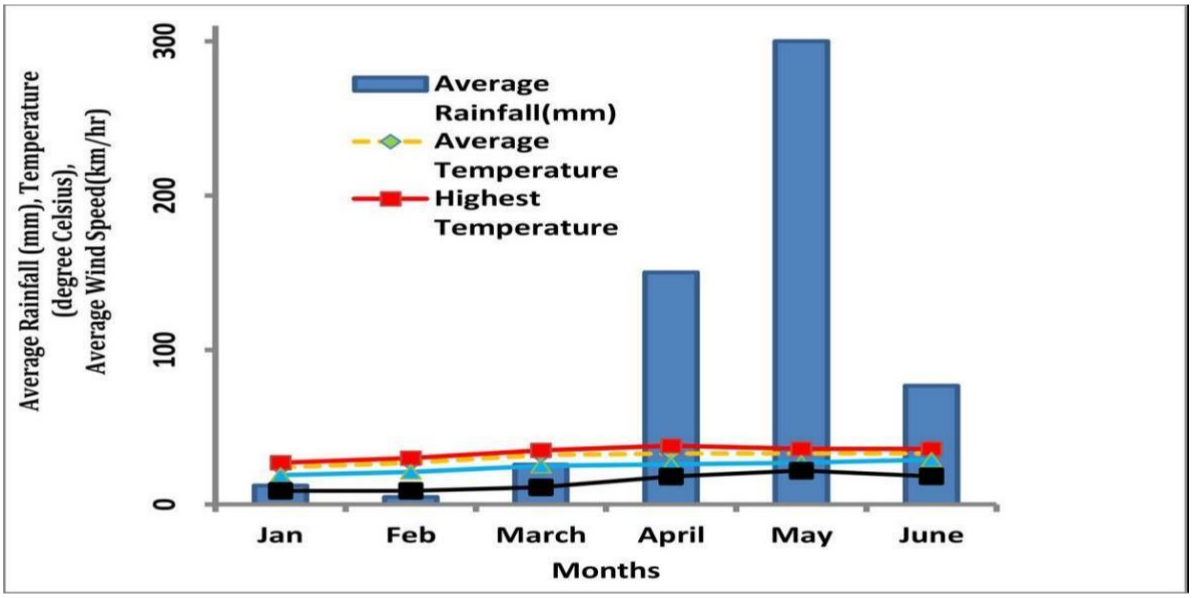
➢ Conceptual framework of the Air Quality Index (AQI)

The Air Quality Index (AQI) assesses whether humans could be harmed by the cumulative effect of contaminants in ambient air. These indices include nationally recognized allowable limits for specific contaminants in ambient air, which led to the creation of the Indian National Air Quality Index (NAQI) by the Central Pollution Control Board (CPCB). Data was gathered from manual and automatic stations via the WBCPCB website for the current study conducted in Kolkata. The West Bengal Pollution Control Board (WBPCB) website was consulted to determine the four most often used parameters—SO2, NO2, PM10, and PM2.5—that are used to measure the amount of air pollution in Kolkata. In order to evaluate Kolkata's NAQI (equation as mentioned in the supplementary section) for the first 6 months of 2020), this data and the prescribed air quality requirements were gathered. Due to COVID-19-related lockdowns, this data was gathered in three stages throughout the chosen timeline: the pre-lockdown phase (January 1–24), the lockdown phase (March 25–30), and the post-lockdown phase (June 1–30).

➢ National Air Quality Index (NAQI) at Behala and Ultodanga in Kolkata prior to and during lockdown and unlock phases :

In Behala and Ultodanga, the NAQIs vary from 76–290 in January, 80–171 in February, and 88–94 in March. PM10 and PM2.5 were the main pollutants causing these high NAQI values on each of these days. The range of recorded high temperatures during this period was approximately 27–38 C, while the range of recorded low temperatures was approximately 19–29 C. In a similar vein, the average temperatures varied from 24 to 33 C. During the entire time period under study (January to June 2020), the average rainfall varied from about 4.8 mm to 300.1 mm, while the average wind speed varied from 8.8 to 21.9 km/hr. The NAQI percentage change from the pre-lockdown to the lockdown period has decreased of around 57.53 % while the next phase, i.e. the lockdown to post lockdown/' Unlock-1 phase' saw a increase of around 9.6 %. In Behala and Ultodanga, the NAQIs vary from 76–290 in January, 80–171 in February, and 88–94 in March. PM10 and PM2.5 were the main pollutants causing these high NAQI values on each of these days. The range of recorded high temperatures during this period was approximately 27–38 C, while the range of recorded low temperatures was approximately 19–29 C. In a similar vein, the average temperatures varied from 24 to 33 C. During the entire time period under study (January to June 2020), the average rainfall varied from about 4.8 mm to 300.1 mm, while the average wind speed

varied from 8.8 to 21.9 km/hr. The NAQI percentage change from the pre-lockdown to the lockdown period has decreased. the state's and the nation's capital had a notable decline in NAQIs on March 25. The NAQI readings decreased in April, falling into ranges such as 49–73. In contrast to the preceding phase, the NAQIs during the lockdown significantly decreased and posed a far lower risk because the air quality could be categorized as acceptable or satisfactory. NAQI readings in May ranged from 42 to 50, with PM10 being the most prevalent pollutant. The NAQI values increased when services started to reopen by the end of May and the start of Unlock 1.0 in June. For instance, on June 5th, they were 55–62, on June 11th, they were 58–62, and so on.



Meteorological data of Kolkata (January to June 2020); Source: World Weather Online (2021).

➢ Air quality data source and analysis :

With 24,252 people per square kilo metre with expanding huge urban and industrial zones, Kolkata is a highly populated city. Its urbanized communication zones experience high levels of pollution emissions, with an approximate vehicle density of 8,831.52 vehicles/sq.km. However, the COVID- 19 crisis caused a swift change in the situation. The city's changing Air Quality has been identified for the pre-lockdown, lockdown, and post-lockdown phases, as chosen for this study, when previous NAQIs have consistently documented peaks. Since COVID-19-related air pollution has a completely new meaning, this study focuses on how national air quality changed during the pre- lockdown and "unlock" periods. There are about 12 air quality monitoring stations in Kolkata, which are positioned along some of the main thoroughfares in the city. Just two of them, Ultodanga and Behala Chowrasta, have weather monitoring. Each of them monitors the concentrations of distinct factors, such as SO_2, NO_2, PM_{10}, and $PM_{2.5}$; the trends of these have also been illustrated and juxtaposed with the Central Pollution Control Board's (CPCB) National Air Quality Standards. Particular attention has been paid to PM2.5 and PM10, which are suspended particulates. This increases human susceptibilities and promotes the virus's spread; literature from China, Spain, Italy, and Malaysia has documented this, however the WHO has not substantiated it. Thus, it is essential to monitor NAQIs and the predominant pollutants associated with them in order to prevent the virus from spreading quickly throughout the general populace. To this end, the current investigation makes use of the West Bengal Central Pollution Control Board's (WBCPCB) comprehensive pollution report, after which the sub indices approach was used to calculate the NAQI. In addition, as an increase in traffic results in a higher National Air Quality Index (NAQI), they have been compared to pollutant emissions in order to analyze the city's performance this year in terms of the NAQI during the chosen time period. The range between the values has then been assessed by using error bars to represent the standard deviation of each individual parameter. To repeatedly show how these values tend to raise the NAQI, conditional formatting was used to represent the daily change in pollutant levels during the chosen phases. The underlying gaseous properties of ambient air have shown substantial correlations, leading to an evaluation of the same for the chosen time-line using a Multiple Regression Analysis. Pre-lockdown conditions in both of the designated city locations in Kolkata, which has some of the worst air quality in the nation, were among the worst. The whole picture of the state of the air had changed by March 23. With a few exceptions where lockdown restrictions were partially removed, this reduction continued steadily in the same zones. However, following "Unlock1.00," June saw a progressive rise in the NAQI in the same areas of Kolkata. High PM10 levels are concurrently present in each of these zones with high NAQI values.

➢ Changes in air quality parameters at different monitoring sites, before lockdown, during lockdowns and unlock phases

The three chosen phases have seen a significant change in the amount of air pollutants (measured in ug/m3) that are still present in Kolkata's air, including NO2, SO2, PM10, and PM2.5. With the use of regression analysis and line graphs, it is clear that while the parameters had impressive pre-lockdown values, during the lockdown period they significantly decreased below the WHO-mandated standard limits. During the first phase, NO2 emissions were mainly within the allowed levels (80 mg/m3), with a few exceptions. After the first lockdown phase, this pollutant abruptly decreases, but it then starts to rise again during the Unlock 1.0 phase. The research period has not seen SO2 pollution levels beyond the recommended thresholds of 80 mg/m3 but its emission decreased during the lockdown phase and increased from the post-lockdown or Unlock 1.0 phase.

Particulate matter followed suit in a similar manner, albeit with significantly lower trends than any other contaminant. It is clear that the recommended limits for PM10 and PM2.5 are 100 and 60 ug/m3, respectively. The WBPCB's daily data on the selected parameters shows how quickly lockdowns and reduced mobility have impacted the city's air quality indexes. Retail stores, pharmacies, and workplaces all saw an abrupt decline in mobility rates; nevertheless, it is clear that residential areas saw an increase in the amount of time spent at homes over time. There has been a decrease in the amount of regular people visiting stores and entertainment venues, supermarkets and pharmacies, transit hubs, and job sites, as well as lockout phases. employing intensity-differentiated color hues in Tables 7 and 8. The lowest values in Tables 7 and 8 are highlighted in green using conditional formatting, while greater values shift from ochre to peach, with the latter displaying the greatest value. On the other hand, all values that surpass the national air quality criteria are indicated by the red boxes. Because of this, SO2 levels in January do not surpass allowed levels, despite the fact that suspended particle matter levels are believed to be skyrocketing. From the lockdown period (highlighted in yellow in the table) until April, the same essentially continues. Consequently, Tables show that, initially, NAQI values were recorded during the pre-lockdown phases, well over the standard limits. This dramatically gets better very quickly as mobilities decrease from the lockdown 1.0 phase as vehicular pollution, factory emissions reduced. The most intriguing aspect of this situation is that, in the case of the study region, educational facilities were closed before the nationwide lockdown program. As a result, a significant shift is apparent as of March 20 (Table), demonstrating that the majority of harmful gases and suspended particulate matter are produced by the frequent travel of school buses, private automobiles, and public and private transportation for the population's academic segment. Movement restrictions were loosened starting in the second lockdown phase, and pollution levels increased in every one of them. Tables 7 and 8 display the initial unlock stage, whereas the tables mostly display the remaining lockdown phases. While this work has employed three phases, the underlying lockdown break-ups have also been addressed in varying different colour. Based on the data obtained here, two high values that were beyond the recommended limits were only observed in April. After that, all parameters showed unthinkably low values compared to pre-lockdown readings until June 2020. This stays within the bounds observed during the pre-lockdown periods, mostly because fewer people are traveling by car and because social distancing rules prohibit people from engaging in large groups.

➢ Results and discussion :

Kolkata, the capital of West Bengal, is India's fourth-worst COVID-19 affected area. While this region's NAQIs and air pollution levels were successfully decreased during lockdown, the state's and its capital's NAQIs increased when lockdown limitations were loosened and the amounts of all observed pollutants suddenly surged. Consequently, the NAQIs for Kolkata, the fate of pollutants in relation to mobility rates over the designated time period, the predominance of parameters raising NAQIs, and their noteworthy interdependencies will all be evaluated in this section. The alterations that the pollutants go through prior to, during, and following lockdown will also be examined in this section.

Location 1 : Behala Chowrasta –

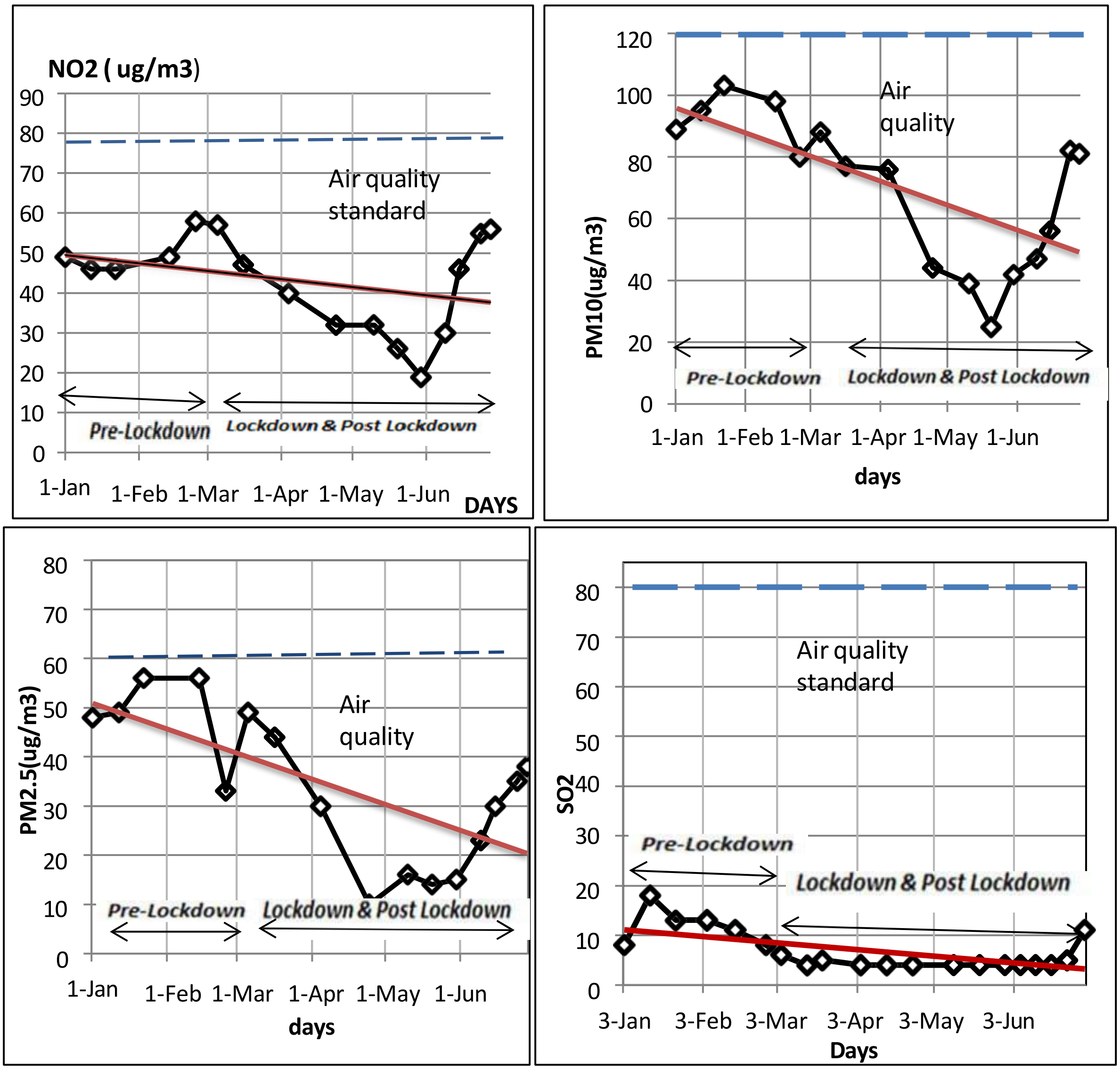


Fig.11 Trend of air pollutants during the phases of pre-lockdown, lockdown and post-lockdown in Behala

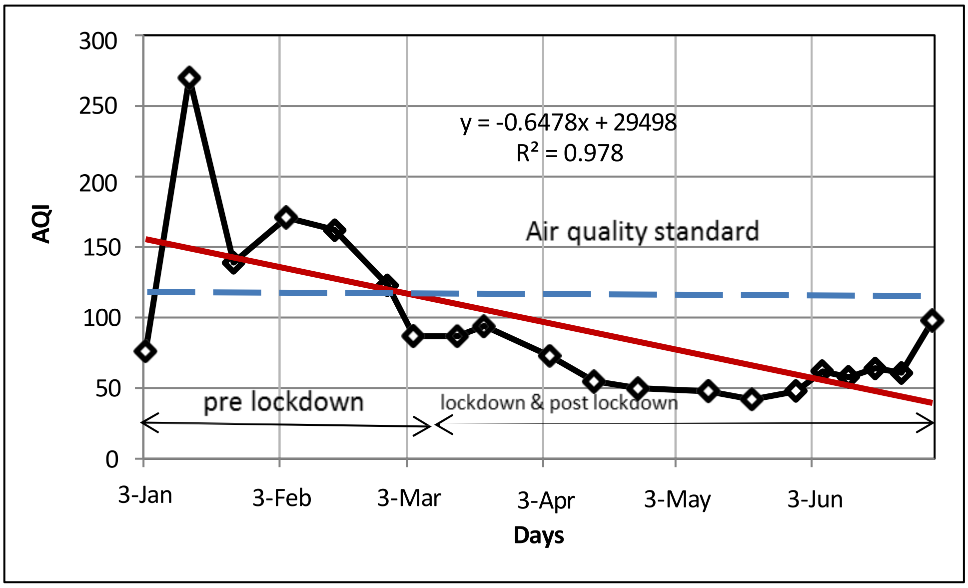


Figure 12. NAQI of Behala in the pre-lockdown, lockdown and post-lockdown phases

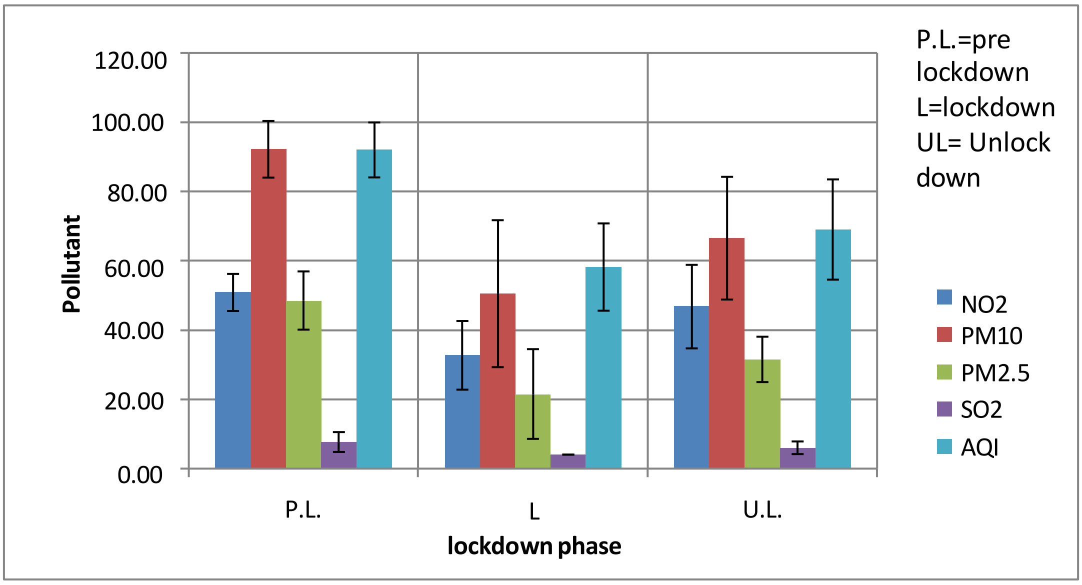


Fig. 13 Mean and Standard Deviation of individual air pollution parameters;

Behala's NAQIs vary from 76–102 in January, 80–100 in February, and 77–88 in March. PM10 and PM2.5 were the main pollutants causing this high NAQI readings on each of these days. The percentage change in NAQIs from the pre-lockdown to lockdown period was approximately 57.53%, but the lockdown to post-lockdown phase, also known as the "Unlock-1 phase," witnessed a rise of approximately 9.6%. Considering the daily pollution levels in the city, the pre-lockdown to unlock period showed a stunning 53.42% decrease in daily NAQIs. Nearly 70% of the data provided in January fall under the category of moderate danger to severe hazard to human life, according to the NAQI graphic. In a similar vein, According to the data, in February, NAQI readings ranged from 80 to 100, indicating a moderate to extremely poor health risk. PM10 was the most common pollutant for nearly all stations that were collected in March, with NAQI values ranging from 77 to 88. If this was the situation prior to the lockdown, as the COVID issue initially materialized, then the lockdown phases by the end of March, that is, on March 25th, resulted in a notable decrease in NAQIs for the state and its capital. The NAQI scores decreased in April, falling into ranges such as 49 to 70. In contrast to the earlier phase, there was a significant decrease in NAQIs during the lockout, resulting in significantly lower risk. NAQI readings in May ranged from 46 to 57, with PM10 being the most common pollutant. The NAQI numbers increased as services started to resume by the end of May and Unlock 1.0 in June. For instance, on June 9 it was 55, on June 15 it was 58, and on June 24 and 28, respectively, it was 81 and 82, 81.

Location : Behala Chowrasta

	Jan-20			Feb-20		Mar-20	
	1-Jan	12-Jan	22-Jan	14-Feb	25-Feb	5-Mar	16-Mar
NO_2	49	46	46	49	58	57	47
PM_{10}	89	95	103	98	80	88	77
$PM_{2.5}$	48	49	56	56	33	49	44
SO_2	9	10	10	9	4	4	4
AQI	89	95	102	98	80	88	77

Table 7 (a) Status of air quality parameters in pre-lockdown, 2020

	Apr-20		May-20		
	4-Apr	24-Apr	10-May	20-May	30-May
NO_2	40	32	32	26	19
PM_{10}	76	44	39	25	42
$PM_{2.5}$	30	10	16	14	15
SO_2	4	4	4	4	4
AQI	70	49	50	46	57

Table 7 (b) Status of air quality parameters in lockdown , 2020

	Jun-20			
	9-Jun	15-Jun	24-Jun	28-Jun
NO_2	30	46	55	56
PM_{10}	47	56	82	81
$PM_{2.5}$	23	30	35	38
SO_2	4	5	8	7
AQI	55	58	82	81

Table 7(c) Status of air quality parameters in Unlock phase 1, 2020

	P.L.(pre lockdown)	L (lockdown)	U.L. (Unlock phase 1)
NO_2	50.83 ±5.34	32.67±9.91	46.75±12.04
PM_{10}	92.17±8.18	50.50 ±21.21	66.50 ± 17.71
$PM_{2.5}$	48.50 ±8.4	21.50 ±12.96	31.50 ±6.6
SO_2	7.67 ± 2.9	4.00	6.00 ± 1.9
AQI	92±8	58.17±12.61	69.00 ± 14.5

Table 7(d) Mean and Standard Deviation of individual air pollution parameters;

Location 2 : Ultodanga –

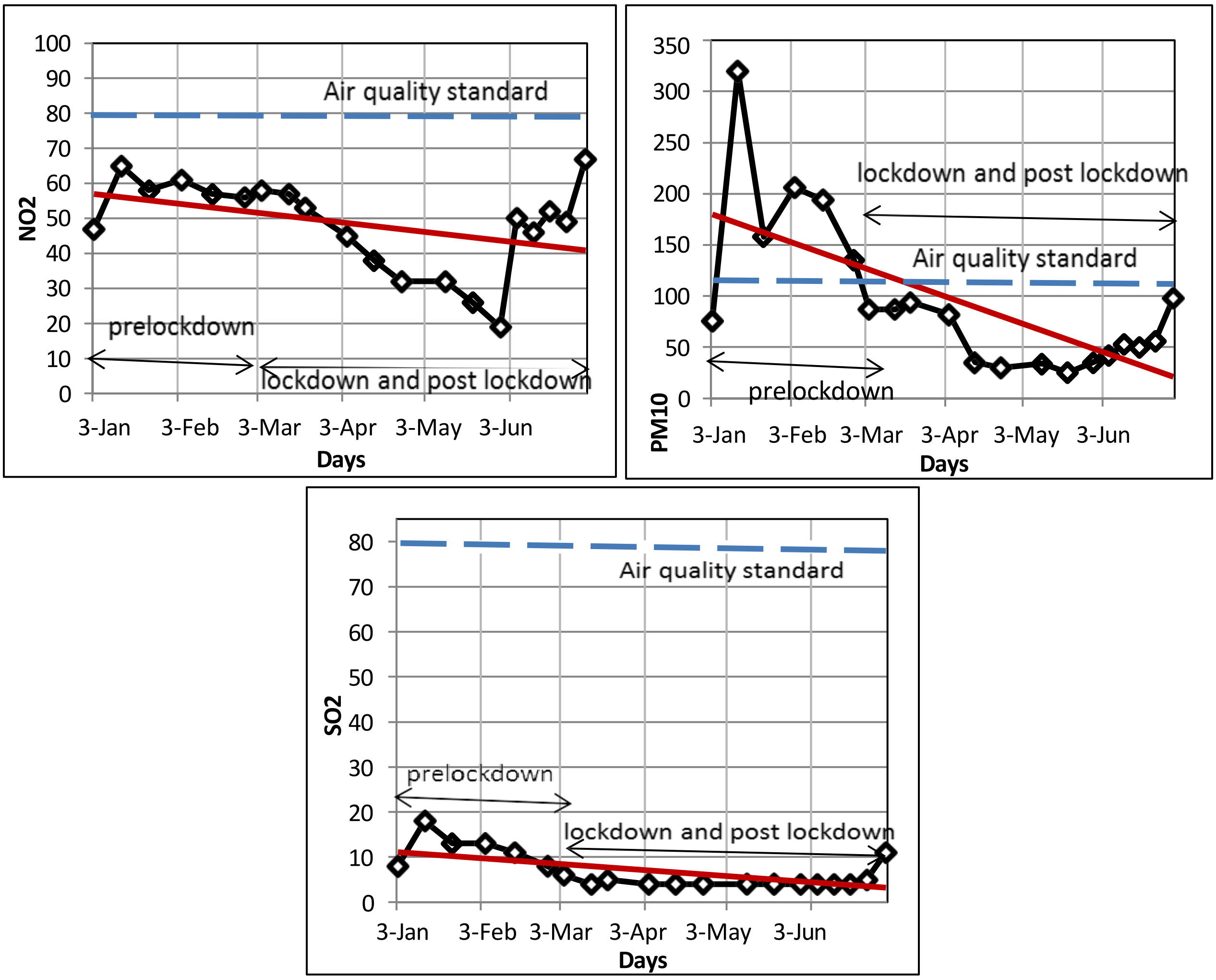


Fig.14 Trend of air pollutants during the phases of pre-lockdown, lockdown and post-lockdown in Ultodanga

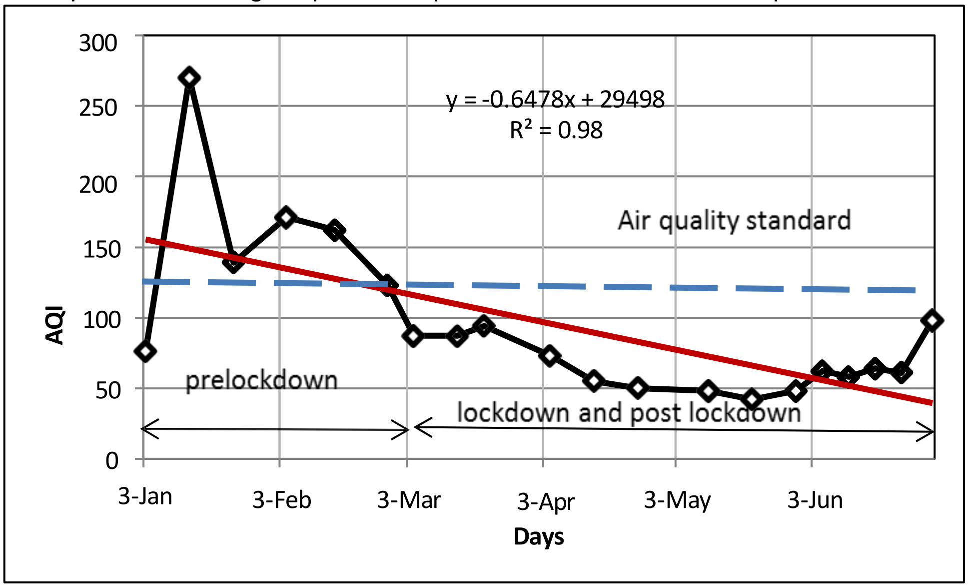


Figure 15. NAQI of Ultodanga in the pre-lockdown, lockdown and post-lockdown phases

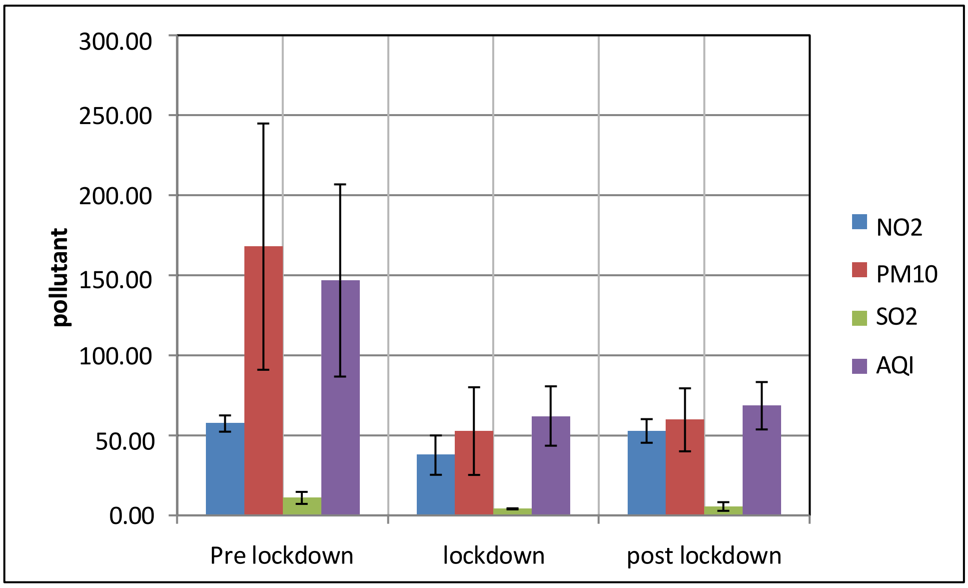


Fig. 16 Mean and Standard Deviation of individual air pollution parameters

The Ultodanga NAQIs vary from 76–270 in January, 123–171 in February, and 87–94 in March. PM10 and PM2.5 were the main pollutants causing the high NAQI readings on each of these days. The percentage change in NAQIs from the pre-lockdown to lockdown period was approximately 57.53%, but the lockdown to post-lockdown phase, also known as the "Unlock-1 phase," witnessed a rise of approximately 9.6%. Considering the daily pollution levels in the city, the pre-lockdown to unlock period showed a stunning 53.42% decrease in daily NAQIs. Nearly 70% of the data provided in January fall under the category of moderate danger to severe hazard to human life, according to the NAQI graphic. In a similar vein, According to the data, NAQI scores in February ranged from 123 to 171, indicating an extremely low risk to health. PM10 was once again the most common pollutant in March, with NAQI readings ranging from 87 to 94. If this was the situation prior to the lockdown, as the COVID issue initially materialized, then the lockdown phases by the end of March, that is, on March 25th, resulted in a notable decrease in NAQIs for the state and its capital. The NAQI readings decreased in April, falling into ranges between 50 and 73. In contrast to the earlier phase, the NAQIs during the lockdown significantly decreased and posed significantly less risk because they could be categorized as either good or satisfactory. NAQI readings in May ranged from 42 to 48, with PM10 being the most common pollutant. The NAQI numbers increased as services started to resume by the end of May and Unlock 1.0 in June. For instance, on June 5, it was 62; on June 11, it was 58; and on June 17, June 23, and June 30, it was 61, 64, and 98, respectively.

Location : Ultodanga

PRE LOCKDOWN							
	20-Jan			20-Feb			
	3-Jan	13-Jan	23-Jan	4-Feb	15-Feb	27-Feb	4-Mar
NO_2	47	65	58	61	57	56	58
PM_{10}	76	320	158	206	194	135	87
SO_2	8	18	13	13	11	8	6
AQI	76	270	139	171	162	123	87

LOCKDOWN								
	20-Mar		20-Apr			20-May		
	20-Mar	25-Mar	4-Apr	14-Apr	24-Apr	10-May	20-May	30-May
NO_2	57	53	45	38	32	32	26	19
PM_{10}	87	94	82	35	30	34	25	35
SO_2	4	5	4	4	4	4	4	4
AQI	87	94	73	55	50	48	42	48

POST LOCKDOWN					
	20-Jun				
	5-Jun	11-Jun	17-Jun	23-Jun	30-Jun
NO_2	50	46	52	49	67
PM_{10}	42	53	50	56	98
SO_2	4	4	4	5	11
AQI	62	58	64	61	98

Table 8(a) Status of air quality parameters in pre lockdown, lockdown and Unlock phase 1, 2020 in Ultodanga

	Pre lockdown	lockdown	post lockdown
NO_2	57.43 ±5.10	37.75±12.31	52.80±7.36
PM_{10}	168.00±77	52.75±27.38	59.80±19.7
SO_2	11.00±3.8	4.13±0.33	5.60±2.7
AQI	146.86±60	62.13±18.56	68.60±14.83

Table 8(b) Mean and Standard Deviation of individual air pollution parameters;

GOOD **MODERATE** **MODERATE TO POOR** **VERY POOR**

Colour wise air condition in Table 7 & 8

In order to prevent such tragedies, the government should put in place appropriate measures and policies for monitoring and controlling the release of the toxic elements. Lockdown phases have already demonstrated that industrial activities and vehicular movements are the two main sources of air pollution. Installing air pollution monitoring equipment at predetermined distances within a location to track the quantity and kind of pollutants being produced in metropolitan areas may make this feasible. Since car exhaust is primarily responsible for PM10 and PM2.5 emissions, it is necessary to reduce vehicle emissions through improved engines or internal filtration systems. Bio filters at locations where harmful gases are generated, battery- or electric-powered transportation services, enforcing the use of CNG instead of LPG, moisturizing parched or barren soils, and prohibiting aerosol releasing sprays, perfumes paints varnish etc. Which are some of the actions that must be taken soon in order to improve the quality of the air both now and in the future, ensuring that neither viruses nor ambient air pollutants harm people's ability to live healthy lives.

CHAPTER 11 : CONCLUSION

In this study, we examined changes in air quality in two areas of Kolkata, West Bengal: Behala Chowrasta and Ultodanga, from 2009 to 2019. According to our research, there was a noticeable shift in the quality of the air between 2009 and 2019 as a result of rising pollution from industrial activities, increased car emissions, etc. In Kolkata, the effect of the seasons on the quality of the air was also noted. Rapid urbanization and development are causing the air quality to deteriorate. Additionally, it was noted that winter pollution levels are significantly higher than summer and monsoon levels. From 2009 to 2019, there was an increase in the concentration levels of important air quality measures, such as PM2.5 and PM10, in both of the designated locations. This may have an impact on the air quality, or the air quality index, which is steadily declining from moderate to poor. Although necessary precautions have already been taken to prevent air pollution, this study found that most important air quality parameters, such as SO2 and NO2, have shown a declining trend over time. Nevertheless, air pollutant concentrations are still much higher than the limiting value. Therefore, in order to enhance and reach a decent level of air quality, people should be more concerned about the environment and should do everything in their power to uphold relevant laws and regulations. In a similar vein, this study also notes that air quality improved during the COVID-19 pandemic (2020).In urban society, air pollution is a persistent issue that endangers people's lives. This time of global lockdown was noticeable enough to demonstrate how stopping human activity can contribute to air purification in the shortest amount of time. This has proven true not only for the current study of Kolkata, the capital of West Bengal, but also for locations all over the world. The West Bengal Pollution Control Board's monitoring stations have provided data proof that shows a considerable decrease in air pollution occurred during the shutdown. During the same timeframe, there was a decrease in the contaminants that made up the substance. The previous 20 years have seen a significant rise in mortality rates and illnesses brought on by acute bronchitis, COPD, cardiovascular issues, and even lung cancer in India and the city of Kolkata. Lockdown phases have already demonstrated that industrial activities and vehicular movements are the two main sources of air pollution, even though the WHO has not yet confirmed a direct link between the virus and air pollution. As a result, the government should put in place appropriate policies and measures for monitoring and controlling the release of the toxic elements to prevent such tragedies. Installing air pollution monitoring equipment at predetermined distances within a location to track the quantity and kind of pollutants being produced in metropolitan areas may make this feasible. Since car exhaust is primarily responsible for PM10 and PM2.5 emissions, it is necessary to reduce vehicle emissions through improved engines or internal filtration systems. Biofilters that run on electricity or batteries are located at the sources of poisonous gas. Bio filters at toxic gas generation points, electric or battery-operated transport services, enforcing the use of CNG instead of LPG, humidifying dry or barren soils, and prohibiting aerosol-releasing sprays, paints, varnishes, and other aerosol-releasing products are just a few of the actions that must be taken soon to improve the quality of the air both now and in the future, ensuring that neither viruses nor ambient air pollutants harm people's ability to live healthy lives. The government's efforts to reduce air pollution may be to blame for the improvement in air quality. Policymakers and scientists may find the study's findings useful in developing air pollution management strategies that are particularly directed at industrial clusters.

APPENDICS:

- **BEHALA CHOWRASTA**:-

YEAR	NO_2	PM_{10}	SO_2	AQI
2009-10	110.24± 25.24	187.48± 41.15	12.91 ±2.50	159.88± 28.94
2010-11	98.71±21.59	183.50± 38.74	10.50± 1.74	156.16± 26.23
2011-12	68.60 ±5.14	195.10± 57.28	9.60± 0.85	164.50± 39.74
2012-13	75.14 ±5.93	251.83± 77.68	12.11± 1.23	280.15± 71.99
2013-14	70.55 ±18.70	253.45± 56.56	12.65± 2.96	272.15± 55.77
2014-15	67.65 ± 7.17	220.80± 60.87	6.90± 1.59	239.90± 77.72
2015-16	67.87 ±5.75	250.00± 44.67	7.23± 0.99	259.38± 60.46
2016-17	64.33±3.38	249.83± 22.01	9.25± 0.74	301.25± 15.52
2017-18	55.58±8.77	238.58± 53.78	8.92± 2.60	264.4± 70.60
2018-19	54.45±10.13	202.6± 42.55	8.63± 2.18	248.24± 48.25
2019-2020	48.31±10.13	190.63± 44.14	10.31± 0.87	239.94± 54.52

Table 1.a) Winter data of all pollutants in Behala Chowrasta

YEAR	NO_2	PM_{10}	SO_2	AQI
2009	67.98 ± 17.56	75.02± 34.24	7.64± 2.00	87.29± 24.61
2010	62.90± 11.55	70.21± 33.05	8.00± 2.13	83.23± 21
2011	50.67± 8.92	70.67± 26.63	6.17± 0.27	73.42± 21.83
2012	65.78± 8.85	90.78± 24.45	8.58± 0.95	85.89± 21.56
2013	36.80± 13.62	89.30± 46.83	6.40± 1.36	95.60± 52.39
2014	34.18 10.14	115.48± 47.82	4.53+± 2.26	113.69± 45.39
2015	36.05± 7.48	91.45± 24.27	2.80± 0.16	90.50± 22.18

2016	44.08± 4.19	98.42± 24.68	4.33± 0.47	95.83± 22.57
2017	35.00± 6.79	98.58± 33.54	3.92± 1.03	102.25± 41.12
2018	36.50± 2.32	100.08± 33.79	4.00± 0.67	100.00± 35.26
2019	36.16± 4.71	74.69± 39.90	6.61± 1.30	74.99± 40.02

Table 1.b) Summer data of all pollutants in Behala Chowrasta

YEAR	NO_2	PM_{10}	SO_2	AQI
2009	52.51 ± 11.84	56.25± 24.72	6.51± 1.20	69.36± 21.10
2010	52.6± 11.85	56.22± 24.73	6.51± 1.20	69.50± 21.08
2011	48.45± 11.32	65.75± 33.81	6.90± 1.44	70.55± 27.94
2012	55.25± 11.20	81.00± 34.89	8.25± 1.35	80.25± 29.45
2013	26.85± 6.95	60.85± 28.24	6.45± 2.22	59.95± 26.48
2014	38.90± 17.47	86.55± 53.19	4.05± 2.39	87.40± 54.45
2015	33.15± 1.45	62.5± 59.29	2.60± 0.23	62.25± 8.85
2016	39.67± 17.84	94.08± 71.67	5.83± 4.83	100.33± 82.83
2017	33.08± 4.80	86.83± 13.37	3.92± 1.20	90.67± 15.64
2018	33.75± 3.01	66.17± 12.73	3.58± 0.42	65.67± 11.26
2019	34.94± 6.42	58.56± 31.62	6.88± 2.19	64.95± 41.86

Table 1.c) Monsoon data of all pollutants in Behala Chowrasta

- **Location 2 : Ultodanga**

YEAR	NO_2	PM_{10}	SO_2	AQI
2009-10	99.32± 17.14	156.02± 23.34	10.32± 1.41	139.84± 16.47
2010-11	83.99± 9.84	181.14± 34.67	9.38± 0.74	155.46± 25.01
2011-12	71.90± 8.90	182.70± 20.12	8.20± 0.80	155.50± 12.90
2012-13	75.48± 5.95	223.89± 63.32	11.79± 1.35	191.84± 48.39
2013-14	68.60± 15.44	220.90± 38.28	12.10± 2.39	183.25± 28.21
2014-15	68.50± 8.43	209.30± 35.29	7.00± 1.36	177.20± 26.43
2015-16	63.78± 6.36	196.53± 39.52	6.47± 1.36	166.17± 30.58
2016-17	61.75± 9.46	231.17± 38.54	8.50± 1.72	191.17± 30.48
2017-18	54.08± 8.08	227.25± 51.77	9.17± 1.86	190.17± 39.76
2018-19	54.82± 6.76	207.67± 46.40	9.01± 1.90	175.97± 38.59
2019-20	52.47± 2.91	165.47± 30.03	12.65± 0.98	141.92± 24.58

Table 2.a) Winter data of all pollutants in Ultodanga (2009-2019)

NO_2	PM_{10}	SO_2	AQI	YEAR
58.34± 12.30	69.51± 40.62	6.06± 0.52	79.99± 26.35	**2009**
58.34± 12.29	69.49± 40.63	6.02± 0.54	79.99± 26.36	**2010**
50.41± 9.91	54.74± 14.88	5.99± 0.67	65.36± 15.71	**2011**
50.38± 8.90	54.32±14. 34	4.99± 0.62	66.34± 14.87	**2012**
36.65± 11.85	83.90± 38.67	6.35± 1.35	79.80± 31.78	**2013**
32.32± 7.16	84.65± 29.17	3.93± 1.49	81.89± 25.26	**2014**

36.20± 6.71	92.00± 29.69	3.10± 0.36	88.45± 25.15	**2015**
40.58± 3.66	87.42± 21.01	3.92± 0.64	85.67± 18.93	**2016**
36.25± 5.33	106.58± 29.35	4.42± 0.95	101.42± 22.77	**2017**
36.58± 2.35	100.75± 34.24	4.42± 0.60	95.17± 28.04	**2018**
39.17± 1.94	92.32± 30.89	7.55± 1.22	88.53± 25.01	**2019**

Table 2.b) Summer data of all pollutants in Ultodanga(2009-2019)

YEAR	NO_2	PM_{10}	SO_2	AQI
2009	46.70± 11.73	45.93± 28.09	5.86± 1.24	62.67± 21.65
2010	45.53± 4.89	39.44± 17.22	5.70± 0.56	58.61± 8.20
2011	40.80± 10.83	61.05± 38.09	6.25± 0.96	64.30± 30.05
2012	35.67± 9.87	59.23± 30.43	6.12± 0.97	62.56± 28.75
2013	27.55± 6.33	58.30± 22.83	6.65± 1.75	57.5± 21.59
2014	36.95± 12.32	36.95± 15.17	3.75± 1.16	65.70± 13.34
2015	39.80± 13.93	78.50± 30.61	4.25± 2.76	74.85± 24.30
2016	33.75± 10.20	73.92± 48.42	5.33± 3.87	69.08± 40.06
2017	34.00± 3.52	83.83± 13.28	3.92± 0.95	81.08± 10.63
2018	33.00± 2.15	70.92± 20.11	3.83± 0.90	69.4± 17.69
2019	36.85± 5.54	57.98± 17.10	7.48± 1.99	57.99± 14.98

Table 2.c) Monsoon data of all pollutants in Ultodanga (2009-2019)

METEROLOGICAL OBSERVATION:

LOCATION : BEHALA CHOWRASTA

YEAR	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED
2009-10	70	68.6	3
2010-11	70.36	65.26	3
2011-12	70.5	68	2.85
2012-13	69	71	3.4
2013-14	68.8	72	3.44
2014-15	70.35	71.5	3.76
2015-16	73.35	74.6	3.15
2016-17	71.65	71	3.81
2017-18	70	67.6	3.8
2018-19	69.75	68	3.76
2019-20	70	81	3.6

Table (3 (a)) shows the winter variation of temperature, relative humidity and wind speed of Behala from 2009 to 2019

YEAR	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED
2009	86	67.8	5
2010	86.81	71	8.4
2011	84	70.6	7.1
2012	85.5	67.8	8
2013	85	69	7.38
2014	86	68.8	6.8
2015	84.6	70.3	6.8
2016	87	68.25	7.5
2017	85	71	8.7
2018	94.9	71	7.86
2019	85	75	8.3

Table 3 (b) shows the summer variation of temperature, relative humidity and wind speed of Behala from 2009 to 2019

Table 3(c) shows the monsoon variation of temperature, relative humidity and wind speed of Behala from 2009 to 2019

YEAR	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED
2009	83.5	81.25	4
2010	84	79	5.4
2011	84	78.6	4.3
2012	84	76.8	5.49
2013	83	82.6	5
2014	84	81	5.5
2015	84.4	82	5.2
2016	84.3	83.5	5.67
2017	83.5	84.8	5.9
2018	83.8	82.6	5.9
2019	82.96	85.6	5.94

LOCATION 2 : ULTODANGA

YEAR	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED
2009-10	69.95	69.38	2.18
2010-11	70.36	66	3
2011-12	70	68	2.8
2012-13	69	71	3
2013-14	69	72	3.44
2014-15	70.36	71.5	3.77
2015-16	73	75	3
2016-17	72	72	3.8
2017-18	70	68	3.76
2018-19	70	68	3.76
2019-20	70	81	3.84

Table (3 (d)) shows the winter variation of temperature, relative humidity and wind speed of Ultodanga from 2009 to 2019

YEAR	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED
2009	85.72	68.63	5
2010	86.13	71.25	8.32
2011	85	70	7.16
2012	85.51	68	8
2013	85.07	69	7.38
2014	86	68	6.9
2015	85	71	6.75
2016	87.2	68.25	7.51
2017	85	71	8.4
2018	85	71	7.45
2019	84	74.75	8.38

Table 3 (e) shows the summer variation of temperature, relative humidity and wind speed of Ultodanga from 2009 to 2019

Table 3 (f) shows the Monsoon variation of temperature, relative humidity and wind speed of Ultodanga from 2009 to 2019

YEAR	TEMPERATURE (F)	RELATIVE HUMIDITY(%)	WINDSPEED(mph)
2009	83	81	4.11
2010	84	79.5	5.44
2011	84	78.63	4.30
2012	84	77	5.4
2013	83.5	83	5.11
2014	84	81	5,53
2015	84.5	82	5
2016	84.5	83.5	5.67
2017	83.5	85	5.93
2018	84	83	5.8
2019	83	85.6	6

NO$_2$				PM$_{10}$			
YEAR	WINTER	SUMMER	MONSOON	YEAR	WINTER	SUMMER	MONSOON
2009	110.24	67.98	52.51	2009	187.48	75.02	56.25
2010	98.71	62.90	52.61	2010	183.50	70.21	56.22
2011	68.60	50.67	48.45	2011	195.10	70.67	65.75
2012	75.14	65.78	55.25	2012	251.83	90.78	81.00
2013	70.55	36.80	26.85	2013	253.45	89.30	60.85
2014	67.65	34.18	38.90	2014	220.80	115.48	86.55
2015	67.87	36.05	33.15	2015	250.00	91.45	62.55
2016	64.33	44.08	39.67	2016	249.83	98.42	94.08
2017	55.58	35.00	33.08	2017	238.58	98.58	86.83
2018	54.45	36.50	33.75	2018	202.66	100.08	66.17
2019	48.31	36.16	34.94	2019	190.63	74.69	58.56
2020	41.04	26.60	28.06	2020	232.10	100.55	78.21
2021	39.40	24.74	26.17	2021	228.60	101.69	77.68
2022	38.20	23.25	24.95	2022	220.46	100.70	75.76
2023	32.70	20.41	23.76	2023	209.63	97.75	74.21
2024	28.39	21.61	25.01	2024	206.90	96.84	75.17
2025	23.75	18.87	21.73	2025	205.86	94.87	72.08
2026	19.03	15.34	20.20	2026	199.26	97.96	73.16
2027	15.05	11.81	17.70	2027	197.97	97.61	69.75
2028	11.44	10.02	16.53	2028	198.95	98.44	71.98
2029	7.15	7.20	14.58	2029	200.45	99.64	74.62
2030	3.43	5.06	12.97	2030	196.17	101.65	74.16

SO$_2$				AQI			
YEAR	WINTER	SUMMER	MONSOON	YEAR	WINTER	SUMMER	MONSOON
2009	12.91	7.64	6.51	2009	159.88	87.29	69.36
2010	10.50	8.00	6.51	2010	156.16	83.23	69.50
2011	9.60	6.17	6.90	2011	164.50	73.42	70.55
2012	12.11	8.58	8.25	2012	280.15	85.89	80.25
2013	12.65	6.40	6.45	2013	272.15	95.60	59.95
2014	6.90	4.53	4.05	2014	239.90	113.69	87.40
2015	7.23	2.80	2.60	2015	259.38	90.50	62.25
2016	9.25	4.33	5.83	2016	301.25	95.83	100.33
2017	8.92	3.92	3.92	2017	264.42	102.25	90.67
2018	8.63	4.00	3.58	2018	248.24	100.00	65.67
2019	10.31	6.61	6.88	2019	239.94	74.99	64.95
2020	8.07	3.55	4.09	2020	294.97	96.98	78.19
2021	8.12	3.21	3.76	2021	298.96	98.19	78.25

2022	7.87	3.05	3.44	**2022**	296.17	98.34	77.87
2023	7.44	2.67	3.26	**2023**	286.54	95.42	77.13
2024	7.55	2.88	3.51	**2024**	293.56	93.03	78.01
2025	8.09	2.98	3.70	**2025**	300.89	91.53	74.58
2026	7.74	2.88	3.55	**2026**	302.10	93.91	75.42

Table 6 (a) . Future trend of air pollution in Behala Chowrasta

PM_{10}				NO_2			
YEAR	WINTE R	SUMME R	MONSO ON	**YEA R**	**WINTE R**	SUMME R	MONSOON
2009	156.02	69.51	45.93	**2009**	99.32	58.34	46.70
2010	181.14	69.49	39.44	**2010**	83.99	58.34	45.53
2011	182.70	54.74	61.05	**2011**	71.90	50.41	40.80
2012	223.89	54.32	59.23	**2012**	75.48	50.38	35.67
2013	220.90	83.90	58.30	**2013**	68.60	36.65	27.55
2014	209.30	84.65	36.95	**2014**	68.50	32.32	36.95
2015	196.53	92.00	78.50	**2015**	63.78	36.20	39.80
2016	231.17	87.42	73.92	**2016**	61.75	40.58	33.75
2017	227.25	106.58	83.83	**2017**	54.08	36.25	34.00
2018	207.67	100.75	70.92	**2018**	54.82	36.58	33.00
2019	165.47	92.32	57.98	**2019**	52.47	39.17	36.85
2020	215.31	107.00	77.13	**2020**	44.79	30.13	31.54
2021	210.36	113.48	79.71	**2021**	43.39	28.58	31.36
2022	206.33	120.28	79.99	**2022**	40.83	28.74	32.21
2023	199.61	123.65	83.27	**2023**	36.69	27.70	32.53
2024	198.88	124.58	86.30	**2024**	33.59	28.26	32.42
2025	198.51	129.06	88.88	**2025**	29.86	26.93	32.11
2026	196.46	133.12	85.84	**2026**	26.65	24.38	30.99
2027	191.25	137.98	88.67	**2027**	23.27	22.23	30.58
2028	192.32	141.28	91.05	**2028**	20.20	20.98	29.98
2029	195.03	147.54	95.84	**2029**	16.31	19.23	29.44
2030	196.01	152.82	98.93	**2030**	13.02	17.76	28.70

SO_2				AQI			
YEAR	WINTE R	SUMMER	MONSOON	**YEAR**	WINTE R	SUMME R	MONSOON
2009	10.32	6.06	5.86	**2009**	139.84	79.99	62.67
2010	9.38	6.02	5.70	**2010**	155.46	79.99	58.61
2011	8.20	5.99	6.25	**2011**	155.50	65.36	64.30
2012	11.79	4.99	6.12	**2012**	191.84	66.34	62.56
2013	12.10	6.35	6.65	**2013**	183.25	79.80	57.55
2014	7.00	3.93	3.75	**2014**	177.20	81.89	65.70
2015	6.47	3.10	4.25	**2015**	166.17	88.45	74.85
2016	8.50	3.92	5.33	**2016**	191.17	85.67	69.08
2017	9.17	4.42	3.92	**2017**	190.17	101.42	81.08
2018	9.01	4.42	3.83	**2018**	175.97	95.17	69.42
2019	12.65	7.55	7.48	**2019**	141.92	88.53	57.99

2020	9.17	4.66	4.81	**2020**	174.13	85.52	71.28
2021	9.13	4.70	4.72	**2021**	175.43	85.99	72.54
2022	9.08	4.81	4.62	**2022**	175.48	86.57	72.82
2023	9.06	5.02	4.66	**2023**	175.37	87.23	73.78
2024	8.96	5.15	4.77	**2024**	173.13	88.11	74.23
2025	8.98	5.64	5.13	**2025**	166.60	88.17	73.03
2026	8.35	5.80	5.04	**2026**	165.36	88.82	72.43
2027	8.30	5.73	4.96	**2027**	165.05	89.16	73.36
2028	8.07	5.68	5.06	**2028**	165.61	89.21	73.40
2029	7.50	5.63	4.88	**2029**	165.68	88.49	76.05
2030	7.03	5.50	4.56	**2030**	167.49	87.52	77.34

Table 6 (b) . Future trend of air pollution in Ultodanga

CHAPTER 12 :REFERENCE

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