Smart IOT based Air Quality Monitoring systems for Smart Cities: Designs issues, Implementation, Analytics, and challenges

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Submitted by:

HIMANSHU NANDANWAR

2K20/ISY/010

Under the supervision of

Ms. Anamika Chauhan

ASSISTANT PROFESSOR

DEPARTMENT OF INFORMATION TECHNOLOGY

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi

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DEPARTMENT OF INFORMATION TECHNOLOGY

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi

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I, Himanshu Nandanwar, Roll No. 2K20/ISY/010 of M.Tech. (Information Systems), Hereby declare that the dissertation report titled "**Smart IOT based Air Quality Monitoring systems for Smart Cities: Designs issues, Implementation, Analytics, and challenges**" which is submitted by me to the Department of Information Technology, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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Date: **Himanshu Nandanwar**

DEPARTMENT OF INFORMATION TECHNOLOGY

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi

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I, hereby certify that the dissertation which is submitted by Himanshu Nandanwar, Roll No. 2K20/ISY/010 (Information Systems), Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Himanshu Nandanwar	**Ms. Anamika Chauhan**
(2K20/ISY/010)	**SUPERVISOR**

Place: Delhi

Date:

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Abstract

Air pollution has become a major global problem, with severe adverse effects on humans and their environment. Given this alarming situation, a system that allows both urban and rural populations to monitor air quality so that they can take the necessary precautions and measures. Such systems that maintain healthy environmental conditions must be designed and implemented. Toxic gas and fine dust that dissolve in the air greatly contribute to this pollution. With the availability of intelligent internet-based sensor systems that can record, analyze and predict air quality, we can develop them. Intelligent IoT-based air pollution monitoring systems(APMS) have proven to be a future solution. Many researchers have proposed several IoT-based solutions for air pollution monitoring systems. This paper focuses on understanding the various environment variables, pollutants, and components of existing intelligent IOT-based APMS. The study also has the vision of focusing on a comparative analysis of available systems and providing an overview of the relevance of pollution control systems in smart urban environments. This article also provides a comprehensive overview of the different classes of sensors, microcontrollers, and required communication technologies. This overview paper provides a general architecture for intelligent APMS and discusses various parameters in more detail. This article summarizes the challenges and open research areas. This review paper concludes with an analysis and recommendations to make Intelligent APMS reliable, efficient, and cost-effective.

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CHAPTER 1
INTRODUCTION

1.1 MOTIVATION

The prime purpose of the IoT Air & Sound Monitoring System is to resolve the growing problem of air and sound pollution nowadays. For a brighter life and safe living for everyone, air quality needs to be regulated and kept under control. Here, we introduce a monitoring system for air pollution as well as sound pollution that enables us to track and monitor live air pollution and sound pollution in a region via IoT. The project includes air sensors to detect the presence in the air of hazardous gasses/compounds and to communicate this data continuously. It is also examined by measuring and reporting the sound level. The sensors communicate with Arduino, which handles and transmits this data over the application. This helps authorities in multiple areas to control and act against air pollution. Regulators will also keep an eye on noise pollution near schools, university campuses, hospitals, and no-honking zones, and if the device senses air quality and noise problems is high, it warns authorities to take action to contain the problem. Some possible market applications proposed for IoT sound like science fiction, but some of the technology's more functional and plausible-sounding possibilities include: getting warnings on your phone or wearable device when IOT networks detect nearby physical hazards such as self-parking vehicles, automatic grocery ordering, automatic workout habits monitoring and other days. Network Components and Internet of Things(IoT) it is possible to change all sorts of ordinary household gadgets to operate on the IoT system. To allow them to operate on the Internet of Things, Wi-Fi network adapters, motion sensors, cameras, microphones, and other instrumentation can be installed in these devices. Primitive versions of this idea have already been introduced by home automation systems for items such as light bulbs, plus other devices such as wireless scales and wireless blood pressure monitors, each reflecting early examples of IoT gadgets[1].

The biggest problem in any country, whether it is developed or developed, is air pollution. Particularly in developed countries' metropolitan centers, where computerization and mechanization and the increasing figure of transportation lead to the release of a lot of hazardous gasses contaminants, health problems have increased more rapidly. Light hypersensitive responses like inflammation in the mouth, eyeball, and nose-cone, moreover create certain serious problems such as "bronchitis, heart diseases, pneumonia, lung, and exacerbated asthma", which are harmful outcomes of pollution. Because of pollution caused by air, "50,000 to 100,000 early loss of life each year occur in the U.S. alone", according to a study. Whereas the EU number approaches 300,000 and more than 3,000,000 worldwide IOT Based Air Pollution Monitoring System tracks the standard of the air over a central server using the Internet and activates an alert when the quality of air crosses some certain level when there is a sufficient quantity of harmful gasses present in the air, such as "CO2(carbon dioxide), smoke, alcohol, benzene, NH3, LPG, and NOX". In PPM, it will display the quality of air on the LCD & the website so that it can be tracked very easily. In this device, which is mostly used in houses, an LPG sensor is added. The temperature and relative humidity of the device will be revealed. The device can be mounted anywhere but mainly in factories and homes where most gasses are discovered and the system reaches the threshold limit with an alarm[2].

The cause of air pollution in all developed areas is the automobile and the other is the factory. The most common use of automobiles is to increase pollutants in the environment. This is the source of environmental pollution that threatens human health. This has also caused other breathing problems, such as chest infections and sore throats. The air quality monitoring system is mounted in a specific location and there is an air pollution monitor(tracking) system to track the component of air particle smell(hazardous gasses) which may have adverse effects on human health and other living beings. This device uses Arduino and dust sensors to evaluate the amount of unfavorable environmental vapors such as CO, NH3, particulate matter, and smoke. Carbon monoxide has the greatest preference since it is a greenhouse gas and a significant pollutant that heats the earth. The amount of pollution is shown on the LCD screen, which allows users to update their current air quality. Users can display the air quality status as numeric. In comparison, the Air Quality Index (AQD) for the current level of pollution is calculated and shown in the application along with the health consequences. Thus this program helps users to take appropriate precautions in advance to safeguard themselves from adverse effects[3].

As the quality of life continues to increase, in the twenty-first century, the respiratory condition has now become a key subject of contention for researchers. It has been verified by several researchers that the indoor environment is more lethal than outdoor air. Today, 90 percent of the rural population in the most industrialized nations and about 50 percent of the global population use open fire unpasteurized fuel, and indoor combust stoves that are not functioning properly. The indoor(internal) air pollution (TAP) and poor & ill health of children and pregnant women who are most vulnerable to such a polluted environment is responsible for these faulty cooking techniques. A broad range of toxic pollutants such as "particulate matter (PM), nitrogen dioxide (NO), carbon monoxide (CO), sulfur oxides, polycyclic organic matter, and formaldehyde", are generated by waste and coal smoke. A general source of many injurious & unfavorable diseases in economically-developing nations is prolonged exposure to IAP due to solid fuel combustion. Chronic pulmonary disease (COPD), bacterial infections, respiratory infections, pneumonia, influenza, cancer of the lung, larynx, and digestive nematodes, low birth rate, maternal and neonatal conditions, and severe eye disorders that may also contribute to blindness are included in the group.

In this, we proposed a system for monitoring the quality of air as well as a system for monitoring sound(noise) pollution that allows us to track and regulate via IoT both real-time air quality and sound pollution in the area. To confirm the existence of dangerous gasses/compounds in the air and to continuously transmit this information, the system uses air sensors. Also, the system continues to calculate and report the sound level, the sensors communicate with the Arduino that processes and communicates these data over the framework. It helps the authorities in various areas to monitor and counteract air pollution. In schools, hospitals, and no-honking zones, the systems can also detect noise pollution, and if the unit detects air quality and noise concerns, it alerts the regulators so that they can take action to address the issue.

1.2 INTERNET OF THINGS

The Internet of Things (IoT) symbolizes an Internet interlinked object device, capable, without human interference, of gathering and sharing data over a Wi-Fi Network. The Internet of Things (IoT), in simple terms, refers to a continuous movement towards connecting any form of a physical object, particularly those that could not be anticipated. This may involve daily household products including coolers and lightbulbs, company properties such as shipping labels and medical equipment, unimaginable wearables, mobile devices, and even smart cities that only exist because of the Internet of things. Another internet of things can be an implanted person, a farmer with a biochip transponder, a vehicle with integrated sensors, a tire pressure iv r Any man-made or normal object that can be attributed to a web protocol (IP) address and can communicate information over a network. IoT businesses increasingly use IoT to function more effectively, provide consumers with better understanding and improved customer support, enhance inference and resolution, and increase the profitability of their business- province and concern[4]. Figure 1.1 Architecture of Internet of things(IOT).

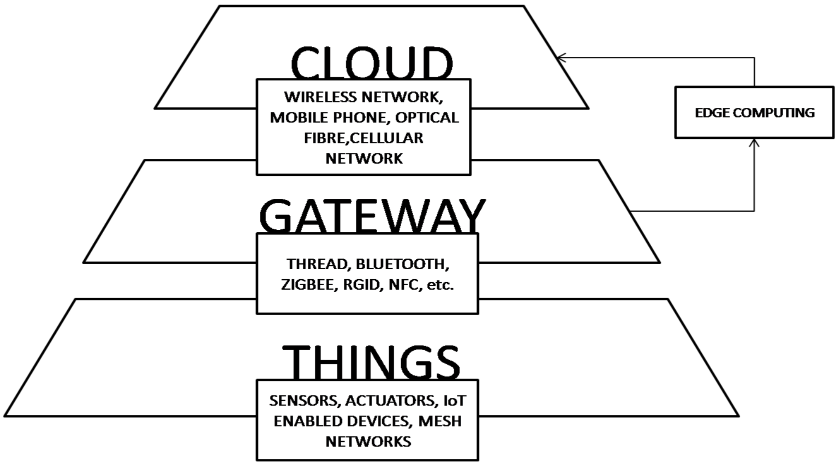


Figure 1.1 Architecture of Internet of things (IoT)

An IoT ecosystem provides web-based, intelligent systems that via integrated devices such as processors, sensors, and wireless communications, can collect, transmit, and act on information acquired from their environment. IoT systems share the sensor information they gather through a connection to an Embedded controller or another border system, where information is sent for quick analysis or analysis to the cloud. Sometimes, like other similar devices, they communicate and act on the knowledge they get from each other. For instance, the devices do many other functions beyond human interaction, while individuals may communicate with the devices to set them up, provide feedback, or access data. On these web-enabled computers, the networking, authentication, and communication protocols used to depend in large part on the specific IoT apps that are used. Artificial intelligence (AI) and machine training[5] can be used by IoT to enable and optimize data collection.

The IoT definition was by a member of the Radio Frequency Identification (RFID) development group in 1999 and has recently become more applicable to the real scenario, primarily because of the growth of mobile systems and ubiquitous networking, cloud computing, and big data. Imagine a society where millions of entities can sense, connect, and exchange knowledge, all interconnected through publicly or privately Internet Protocol (IP) networks. These accommodations have routinely obtained, processed, and used data to take initiatives, providing a lot of information for scheduling, analysis, and decision-making[6][7]. This is the Internet of Things (IoT) world.

The definition of the Internet of Common Things is described as a network of physical objects called the Internet of Things (IoT). The Internet is not just a network of machines, but also a network of devices of all levels and backgrounds, vehicles, phones, household items, gadgets, sensors, medical devices and industrial equipment, animals, people, structures, all connected devices, all wireless routers, all network devices, all mobile applications, all wearable technology, all wireless networks, all smart devices, all communication and exchange of information based on stipulated protocols, to achieve smart restructuring, tracking, monitoring.

IoT is defined in three classes as follows:

The IoT is 3 things:

(1) Persons to persons,

(2) Application to people/things,

(3) Things/Machines/Machines, Communicating on the Internet.

The IoT(internet of things), relates to the broader concept of things, In particular, everyday objects that can be readable, identifiable, located, addressed via an informational sensing system, and/or monitored through the Internet, irrespective of the means of communication (whether via RFID, wireless LAN, wide area networks, or other means)[8]. Daily day products include not only electronic devices that we experience or products of higher technological growth, such as vehicles and machinery, but also things that we do not generally considered to be electronic-such as food, clothes, chairs, animals, flowers, water, etc.

The IoT(internet of things) is a modern Internet movement. Things make themselves identifiable and gain knowledge by making or allowing context-related decisions by enabling them to transmit data about themselves. They may have permission to access data that has been consolidated by other complex actions. This development is correlated with the advent of cloud computing abilities and the transfer from the Internet to IPv6 with an almost infinite potential for addressing.

The aim of the Internet of Things(IoT) is to make it possible for things to be linked at any time, anywhere, with anything and anyone who preferably uses any direction and service.

1.3 APPLICATION OF IOT

Smart living:-

In smart living, it consists mainly of remotely control devices that are used to remotely switch on/off any device and save power. A smart forecast system is used to show whether parameters such as temperature, humidity, rainfall, wind speed. Smart Home Appliances used for the LCD screen on the microwave shall indicate the items that are present inside and the license number of the items, the products to be purchased in the future, and all the data given on the application. Washing machines allow monitoring systems of the laundry by trying to adjust the temperature monitoring and controlling the self-cleaning functionality. The safety tracking device is used to supervise cameras, alert systems at houses, and build a better life. A Network Security device is used to detect intruders by opening doors. It is used to monitor water and energy consumption at home to reduce costs and assets [9].

Smart farming:-

To increase fresh fruit and vegetable production, smart farming consists of nurseries and segments and sub controls. To avoid the occurrence of infectious and other toxins, fertilizer is used to control temperature and relative humidity levels. Animal Tracking is used to locate and identify grazing animals in open fields, as well as to study the quality of air and airflow in farms. In animal farms, Offspring Treatment is used to monitor the offspring's growing season and to protect the plant's lives and health. Via daily reporting of proper data collection and field planning, field management reduces waste and plant waste[9].

Smart parking lot:-

Smart Parking is used to track the available city parking spaces and to allow the user to find the nearest parking spaces or Usable parking spaces. Management of waste allows the identification of waste concentrations in containers so that they can improve waste disposal routes. Garbage Containers are equipped with RFID tags that warn the worker and signify that the waste has been decomposed successfully [9].Figure 1.2 shows the application of Internet of Things(IoT).

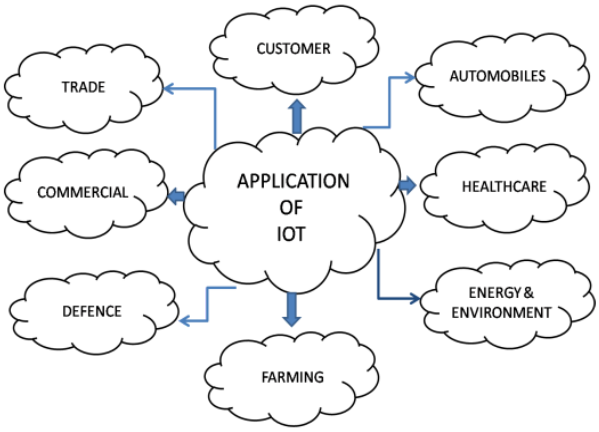


Figure 1.2 Application of Internet of things (IoT)

Smart City:-

In a smart city, systemic health is used for tracking Material conditions for houses and bridges. It also tracks whether there are any irregularities in the buildings. safety prevention consists of fire control, emergency alert systems, wireless video surveillance. For any unexpected incident, the transportation system consists of sensor roads and highways with warning signals and diversions[9].

Smart Industries:-

Smart Industries are composed of volatile and hazardous gasses, consisting of the identification of gas level and emission in industry, the control of toxic gas and oxygen levels in petrochemical industries, and the tracking of oil and gas levels in pumping stations and reservoirs. Repairs and Maintenance provide early identification of any fault units in the smart industry and service maintenance may be automatically allocated to a specific malfunction[9].

Smart Environments:-

In the smart world, monitoring of air pollution regulates the emission of CO2 from factories And emissions from vehicles. Forest Fire Monitoring is used to track the gas and to establish warning zones. Climate monitoring involves moisture, temperature, pressure, and early earthquake warning. The quality of water and the assessment of water adequacy in rivers are controlled by Water Quality. River floods are used often during the rainy season to regulate water levels in dams and reservoirs[9].

Smart Energy:-

In the case of smart energy, it is made up of a power system that determines the regulation and management of the industry's energy use. The Turbine Machinery is used to control and track the flow of energy from windmills and power plants. Bi-directional communication with clients is also provided. To evaluate usage trends, smart meters are then used. All Power Supply Controllers The AC-DC Power Supply Controllers are related to consumer, digital, and telecommunications applications.

1.4 Why do we need a real-time air pollution monitoring system?

Several factors have led to the recent global economic crisis. One of the most important factors is pollution, which has far-reaching consequences such as global warming, climate change, and ozone layer depletion. Pollution is caused by a variety of factors, each with its unique impact on the environment, harm scale, and remedy. Each pollutant must be understood and tracked simultaneously, which is not an easy or simple task. Because of modern trends and widespread pollution, the globe must develop a better method of monitoring pollution levels of various environmental elements. This may be easily accomplished with the quality monitoring system in place in numerous locations. Given the alarming rate of deterioration of air quality and the difficulty in cleaning it, air quality monitoring is critical.

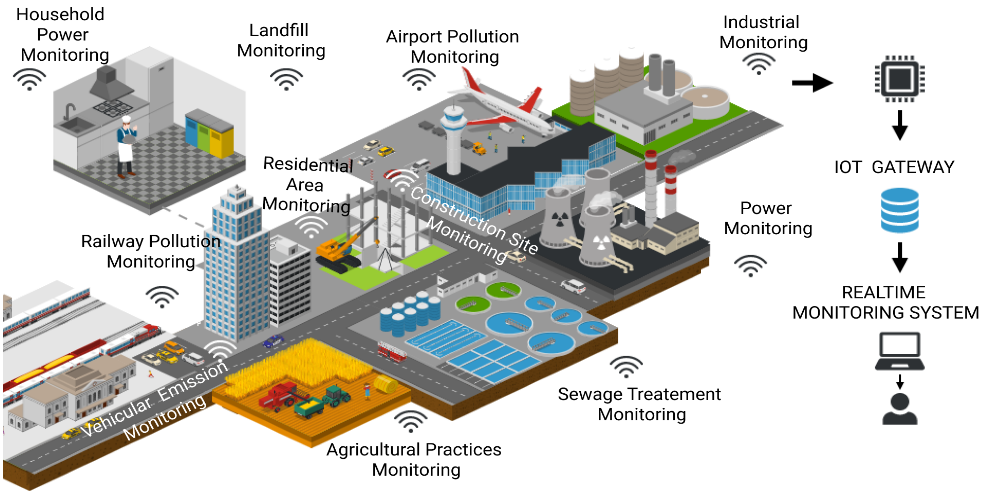
It is feasible to separate and clean soil and water without using solvents. The battle is a little harder when it comes to air quality, and prevention is better than cure when it comes to air quality regulation.

Environmental sensors are used to assess the quality of the air. Sensors are classified into three types: air, water, and soil. This requires us to first understand the many illnesses that affect and taint our environment. Air pollution is caused by a variety of sources, including emissions from laboratories, refineries, factories, and automobiles.

Individuals and society suffer from a wide range of health issues as a result of the poisons in the air we breathe. As a result, air quality monitoring is used in the workplace. We can also use it to determine current air quality and pollution levels, as well as create future predictions. In this procedure, an air sample is frequently collected through diffusion or biomonitoring, and the results are then examined. Because our natural resources are depleting at an alarming rate, environmental monitoring requires the Internet of Things (IoT). Samples are collected, examined, and analytical tools are used in standard environmental monitoring approaches. When we discuss the application of the Internet of Things, we usually associate it with waste management, air pollution, and weather forecasting. Sensors cannot be employed for regulatory reasons due to the complexity of the environmental monitoring system. If we have data on water and air, we can utilize AI and machine-learning techniques, among other things. Water quality, radiation, and hazardous substances, among other things, can be monitored with environmental sensors.

Last but not least, it is utilized to detect violations of standard air quality levels, also known as ambient air quality. This method can also be used to monitor changes in air quality over time, as well as the factors and activities that caused such changes. Similarly, statistics on air pollution are made available to the public in this manner to enlighten and inform them. As a result, the system in question must be extremely real-time and meet international air quality monitoring standards... The more advanced the analytics, the better they should be. Individuals and adolescents in the twenty-first century must understand and use air quality monitoring. Throughout the year, the Air Quality Monitoring System (AQMS) measures wind speed, direction, and other weather parameters, as well as an air pollutant and particulate matter concentrations (such as SO2, NOx, CO, O3, THC, and so on). Figure 1.3 shows how a single APMS can be configured to track multiple locations.

Figure 1.3 IOT-based Smart Air Pollution Monitoring System



1.5 Air Quality Management(AQM) in India:-

PM 2.5 concentrations are high in most Indian cities, and the country is home to 21 of the world's 30 most polluted cities. Cities have become more congested as a result of increased urbanization, vehicle population growth, and insufficient infrastructure to support municipal solid waste management, and biomass cooking. The Central Pollution Control Board's current air quality standards expose approximately 80% of urban residents to air quality that exceeds the ambient PM10 (60 g/m3) limit. The Indian state and federal governments have recently taken a number of steps to reduce air pollution. For example, they've discussed setting pollution reduction goals, determining air quality and the status of pollution sources, developing air quality control strategies, putting policies in place on the ground, and performing ongoing evaluations, among other things. Despite progress on various AQM components, Indian air quality, population, and geographic scope require additional attention.

The first aim of AQM is the National Clean Air Program (NCAP), which was launched in January 2019, aims to reduce PM concentrations by 20-30% in India's 122 non-attainment grounds. Every city or region has its own distinct characteristics in terms of air pollution sources and local administrative, social, and political. To achieve the NCAP goal, each source of air pollution must have a city-level goal, which is currently lacking in many urban areas. We'll need city-specific goals if we want to see results on the ground. Every city or region has its own distinct characteristics in terms of air pollution sources and local administrative, social, and political conditions. As a result, each area's goal must be defined separately, taking the source profile and other local characteristics into account**.**

The second aspect of AQM is the evaluation of air quality and the status of sources. To achieve the AQM goal, air quality managers employ tools such as emissions inventories, air quality monitoring, and air quality modeling. Before proposing an effective mitigation solution, it is necessary to determine the level of air pollution, the sources of air pollution, and the contribution of various types of air pollution sources to regional and local atmospheres. The National Air Monitoring Program in India operates 793 stations in 344 cities and towns across 28 states and seven union territories (NAMP). A total of 261 continuous Ambient Air Quality Monitoring Stations in 134 cities in 23 states and union territories are linked to the web-based system, which provides Real-Time Ambient Air Quality information. There are many of these monitoring stations in cities, particularly in megacities like Delhi. In smaller towns, there are few manual air quality stations and continuous monitoring stations. There are no air quality monitoring stations in rural areas. Emission inventories are a useful tool for determining pollution sources and modeling air quality. Data on emissions inventories are scarce in India, and those that are available are not accessible to the general public. The country lacks high-resolution emissions inventories to determine the local source contribution.

The third aspect of AQM is the development of control strategies. In this stage, politicians devise strategies for reducing air pollution emissions. Air pollution control strategies have been developed for a variety of sources. Providing LPG to solid fuel consumers, expanding public transportation, and improving MSW collection efficiency are just a few examples. In contrast, the majority of these policies are based on a basic analysis of the country's overall air pollution sources, which takes other priorities into account. To effectively manage air quality in the country, India must develop city and district-level strategies that include a thorough understanding of local air pollution sources. As a result, policymakers would be able to develop air pollution mitigation measures for previously unknown sectors with significant local and regional air quality effects.

Several significant policies for reducing air pollution have been developed and are currently in place in India. The associated source sector's air pollution emissions were significantly reduced as a result of these policies. This policy reduces outdoor and indoor air pollution while also providing other benefits to Indian families, such as Prime Minister Ujjwala Yojna. The Indian government is implementing several policies that have a direct impact on air pollution emissions from related industries such as transportation and municipal solid waste (MSW). Aside from industries and road dust, there are several unrecognized sources in the United States. Many policies are geared toward major cities, while smaller towns and rural areas are largely ignored. Lower-cost methods can be used to improve air quality. It is also critical to identify the steps that must be taken. We can only do this if we have up-to-date local data.

Last but not least, AQM necessitates ongoing assessments to determine how far the air quality goal has been met. Because air quality is influenced by so many factors, it is currently only assessed using ambient air quality, which yields an incorrect result. Smaller variations in air quality cannot be used to track progress toward goals. There is currently no formal mechanism in place to evaluate Indian air quality goals and progress in AQM.

Because AQM is a dynamic process, it is critical to evaluate each step of the cycle on a regular basis. The AQI requires contributions from researchers, city managers, policymakers, and politicians, as well as social scientists and community members. The AQM system in India has improved over time, but changing the status quo will require much more effort.

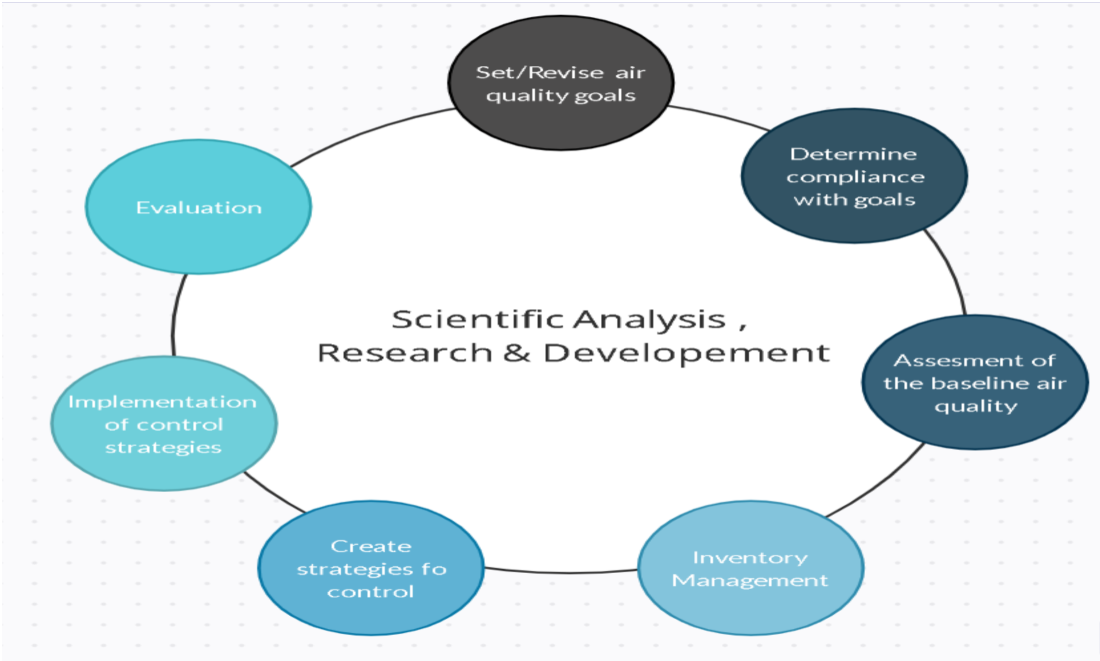


Figure 1.4 AQM process

1.6 Objectives:-

1. Design and implementation of a low-cost smart air pollution monitoring system (APMS) based on the Internet of things.

2. Comparative analysis of India's AQI parameters across 26 major urban cities during COVID-19 lockdown.

3. Implementation of ML and DL modeling of historical time series AQI dataset from 2015-2020 and comparative & analysis of the result.

CHAPTER 2

LITERATURE REVIEW

2.1 Air pollution:-

The release of air pollutants and contaminants into the air that is harmful to human health & the environment as a whole is referred to as air pollution. The term air pollution refers to a mixture of solid particles and gasses in the atmosphere. Many major pollutants cause air pollution as shown in fig 2.1:- major air pollutants.

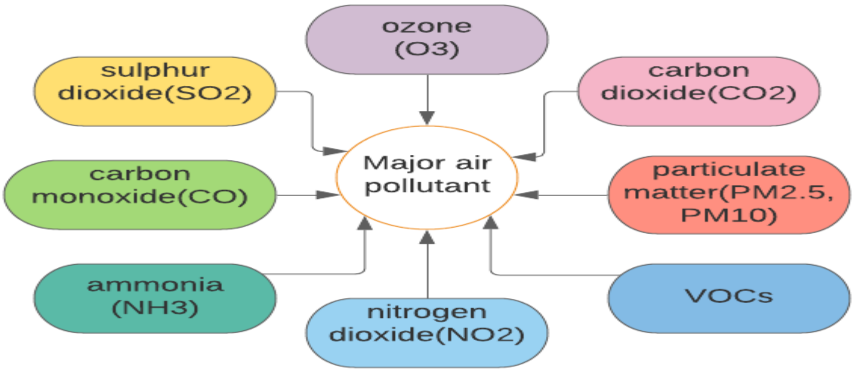


Figure 2.1 Major air pollution

2.1.1 AQI:-

Air quality index (AQI) is an air quality monitoring system used by the agency and the government to transmit information about the condition and quality of air to the public.

Air quality indices are by national air quality standards in different countries like the National air quality index(India), Air pollution index (Malaysia). AQI measures the quality of air, how the air is affected by pollution. AQI helps common people to get information about the quality of air, the impact on air due to pollution, and its effect on their health.

The air quality index (AQI) has 5 major pollutants, which have been set to national air quality standards for safeguarding public health, is calculated by Environmental Protection Agency (EPA):-

- Ozone level present at ground
- Particular matter (PM2.5/PM10)
- Carbon Monoxide (CO)
- Sulfur dioxide (SO2)
- Nitrogen dioxide (NO2)

As the air quality index is higher in value, the contamination is increased and health risks become higher. Different countries have their air quality standards concept, used widely for the past three decades. AQI rapidly spreads information about air quality in real-time. Table 1 " shows the AQI level with its associated health effects". AQI helps to compare the air quality at various places, locations in real-time.

Table1:- AQI value and its impact

AQI value (air quality index)	Color representing AQI	Level	Description
0-50	green	Good	The air quality is satisfactory: and pollution presents no hazard.
51-100	yellow	Moderate	While air quality is adequate, certain pollutants may pose a moderate health risk to a small no. of very sensitive people.
101-150	orange	Unhealthy for a few groups of people	The vulnerable group may suffer adverse health effects. The general population is unlikely to contract the infection and disorder.
151-200	red	Unhealthy	Everybody will start to recognize health effects, members of vulnerable groups may notice more serious health effects.
201-300	purple	Very poor	Everyone could suffer serious health consequences.
301-500 and above	maroon	Highly hazardous	An emergency health alert has been released. The entire population may suffer.

2.1.2 indoor air pollution:-

Indoor air pollution consists of smoke, dust, harmful gasses in the surrounding or inside a campus, house, buildings, or office which can harm and affect us in breathing. Indoor air pollution generally comes from burning woods, smoke, gas stoves, and burning crop waste. According to WHO, the world's largest source of health risk is indoor air pollution. In a low-income nation, 6% of premature deaths are due to indoor air pollution.

Indoor air pollution is more dangerous than outdoor air pollution as it causes more severe health problems. Most of the time we spend inside the closed square, it is important to minimize and control indoor air pollution. Ventilation plays a major role in controlling indoor pollution. Common indoor pollutants are:-

- Particular matter(PM2.5/PM10)
- Nitrogen dioxide(NO_2)
- Carbon monoxide(CO)
- Lead

2.1.3 outdoor air pollution:-

Outdoor air pollution consists of a mixture of various pollutants from natural and man-made sources like emission of fuel, combustion of motor vehicles, industries & mining solid fuel, burning off unwanted substances, etc. outdoor air pollution also known as ambient air. Common outdoor air pollutants are:-

- PM2.5/PM10
- Ozone(O_3)
- Nitrogen dioxide(NO_2)
- Carbon dioxide(CO_2)

- CARBON monoxide(CO)
- Sulfur dioxide(SO2)

Outdoor air pollution causes chronic diseases, asthma, cardiac failure, heart stroke. Table 2 shows the major indoor/outdoor pollutant & their effect on health.

Table2:- major indoor/outdoor pollutant and its adverse effects on health

Name of pollutant	**Effect on health**	**A significant source of pollution**
PM 2.5(particle having a size of 2.5 micrometers or less than)	Eyes, nose, throat irritation. Life expectancy can be reduced if exposed for a long time. Increase disease transformation.	Motor vehicles, mining factories, coal, wood-burning.
PM 10(particle having a size of 10 micrometers or less than)	It causes severe lung function asthma and lung conditions such as bronchitis are getting worse.	Forest fire, dust storm, mining, burning of fossil fuel, and wooden coal.
Nitrogen dioxide (NO2)	Asthma symptoms have worsened, resulting in more severe asthma attacks. Inflammation of the airways to healthy people.	Motor vehicles, factories, industries, gas heaters, gas stoves, smoke.
Carbon monoxide (CO)	People with coronary heart disease experience chest pain. When exposed to elevated levels, there is a risk of adverse health consequences for unborn diseases.	Found in cigarette smoke, burning of wood and plastic, emission of motor vehicles, gas heaters.
Ozone (O3)	Respiratory infections are more likely to occur. Coughing, sore and scratchy throat, or an unpleasant sensation in the chest. Reduced lung capacity means we can't breathe as deeply or as intensely as we used to.	Ozone generator, smoke, highly reactive gases. In
Sulfur dioxide (SO2)	Cardiovascular disease exacerbation. People with asthma have faced more asthma attacks.	Combustion of fossil fuel, industries, volcanic eruptions.
Carbon dioxide (CO2)	It increases pollution and it causes diseases, fever, headache, and lack of concentration power.	Cement manufacturing, deforestation, fossil fuel burning, oil, natural gasses.
VOCs	Irritation in the eyes, nose, throat for a short period but can cause cancer if exposed for a long period, fatigue, headache, vomiting.	Paints, varnishes, wax, smoke, wood preservatives, fuel, pesticides.

Lead	People can have kidney problems and in adults, they can face heart stroke or attack, leading to low IQ levels.	Industries, paints, old pipes, gasoline.

2.1.4 A major type of pollutants causing pollution and their source of emissions:-

One of the most serious environmental issues affecting people and the world is air pollution. According to the World Health Organization's data, one out of every nine persons who breathe filthy air dies from respiratory disease. The largest concentrations of air pollution are found in cities and surrounding industrial areas. Toxic gases and trash are released into the atmosphere as a result of human and industrial activities. These leftovers are hazardous to the environment as well as to the health of all living Creatures.

Types of Air pollutants:

1) **Carbon monoxide (CO):-** Carbon monoxide, a colorless, odorless, and poisonous air pollutant, is created when carbon-containing fuels such as fossil fuels, oils, charcoal, and firewood are burned inefficiently.

Harmful Effects:

CO harms people's health by impairing the blood's ability to deliver oxygen to bodily tissues. When carbon monoxide is inhaled, it quickly passes through the alveolar epithelium and into the bloodstream, where it binds to hemoglobin to create carboxyhemoglobin, a helpful marker for anticipating CO's health effects. CO has a 200-fold higher affinity for hemoglobin than O_2, hence its presence in the lungs will cause O_2 to be displaced from the hemoglobin. At very high levels CO can cause dizziness, unconsciousness, and death.

Sources:

In populated areas, motor vehicle emissions are the largest source of CO in outdoor air, and They are linked to the highest outdoor CO exposure in nonsmokers. CO concentrations outside are higher in metropolitan areas.

2) **Carbon dioxide (CO_2):-**

Carbon dioxide is a colorless, non-flammable, odorless gas that, depending on pressure and temperature can be solid or liquid.

Harmful Effects:

The amount of CO_2 in a building is usually proportional to the amount of fresh air coming in. In general, the lesser the amount of fresh air inside a structure, the greater the CO_2 level in the structure. Headaches, dizziness, restlessness, a tingling or pins-and-needles sensation, breathing problems, perspiration, hypoxia, and other negative effects of CO_2 exposure have been reported.

Sources:

CO_2 emissions are mostly caused by the combustion of organic natural resources such as coal, petroleum, gasoline, firewood, and sewage sludge.

3) **Sulphur dioxide (SO_2):-**

Sulfur dioxide is a colorless and highly toxic gas. It is a member of the sulfur oxide chemical family (Sox).

Harmful Effects:

Short-term SO_2 exposure, which makes breathing difficult, may harm human respiratory systems. Asthma populations, particularly youngsters, are vulnerable to gas damage. Acid rain, which can harm delicate ecosystems, can produce SO_2 and other sulfur oxides.

Sources:

The combustion of fossil fuels in power plants and other industrial operations is a major source of SO_2 in the atmosphere. Smaller SO_2 producers include mineral exploitation, natural resources such as volcanoes, other vehicles and heavy fuel vehicles, and heavy equipment. The combustion of fossil fuels in power plants and other industrial operations is a major source of SO_2 in the atmosphere. Smaller SO_2 producers include mineral exploitation, natural resources such as volcanoes, other vehicles and heavy fuel vehicles, and heavy equipment.

4) **Lead (Pb):-**

Lead (Pb) is a heavy metal element that occurs naturally and in manufactured goods. Lead can be discharged into the atmosphere as suspended particles.

Harmful Effects:

Lead enters the body through the lungs and circulates through the bloodstream before settling in the bones. Lead can harm the neurological system, kidney function, immunological system, reproductive and developmental systems, and cardiovascular system depending on the level of exposure. Lead exposure reduces the ability of the blood to carry oxygen.

Sources:

Lead is generated by the manufacturing industries.

5) Ammonia (NH_3)

Ammonia, a kind of nitrogen, is a colorless gas that is emitted when organic matter decomposes, and it can have serious consequences for human health and the environment.

Harmful Effects:

Ammonia can link to other gasses in the atmosphere to produce ammonium, which is particularly harmful to the cardiovascular and pulmonary systems. Because of nitrogen deposits, ammonia can have a direct harmful effect on plants or cause changes in species composition.

Sources:

Non-agricultural sources of ammonia include catalytic converters in gasoline cars, landfills, sewage treatment plants, organic material composting, combustion, industry, and wild creatures and birds.

6) Particulate matter:-

PM is a complicated mixture of solid particles and liquid airborne droplets in terms of size, composition, and concentration. The PM's size is a key grade.

PM10 particles have a diameter of 10 microns or less and can cause health problems in the lungs. Fine particulate matter is defined as particles with a diameter of 2.5 millimeters or less (PM2.5). As a result, PM2.5 contains some PM10.

PM10 and PM2.5 are derived from a variety of sources, and their chemical compositions vary. The combustion of fuel, oil, diesel, or wood fuel produces huge volumes of outdoor pollution of PM2,5 and significant amounts of PM10.

PM10 is made up of dust from buildings, deposits, fields, brush and waste fires, industrial sources, open-air wind dust, pollen, and bacterial fragments.

Harmful Effects:

Exposure to PM2.5 and PM10 has been linked to a range of adverse health effects. Shorter PM2.5 exposure (up to 24 hours) was associated with more hospitalizations for heart and lung disease, acute bronchitis and chronic asthma, asthma, respiratory symptoms, and fewer days of exercise. Many of these health issues have primarily affected neonates, toddlers, and senior citizens with previous heart or lung illnesses.

Sources:

PM can be emitted directly from atmospheric sources or formed as a result of chemical processes involving gasses such as SO2, NOX, and some organic molecules (secondary particles).

7) Nitrogen oxides (NOx):-

When nitrogen is liberated during the burning of fuel with oxygen atoms, nitric oxide (NO) is formed. Nitrogen dioxide is produced when this reacts with oxygen (NO2). Nitrogen oxide is not considered a health hazard at ordinary ambient amounts, but nitrogen dioxide is. Nitrogen dioxide is found in both nitrogen and oxides (NOx). NOx emissions contribute to the formation of smog and acid rain, as well as fine particles (PM) and soil-level ozone, both of which have negative health impacts.

Harmful Effects:

When NOx levels are high, it has a significant impact on breathing and causes airway inflammation. Long-term exposure may impair lung function and increase the risk of airborne infections, among other things. NOx also promotes the formation of fine particles (FP) and soil-level ozone, both of which are harmful to human health.

Sources:

When nitrogen and oxygen gas react in the air, NOx is produced, especially at high temperatures. In areas with substantial motor vehicle traffic, such as large cities, the number of nitrogen oxides discharged into the atmosphere as air pollution can be significant. NOx fumes are produced when nitrogen is combusted, such as in automobiles, and are also naturally produced by lightning.

2.1.5 Application of IOT based Air Monitoring System:-

As an interconnected gadget, the Internet of Things is an ideal medium for determining the quality of air in a specific organization. To determine the air quality index (AQI) or determine the concentration of a single dangerous gas, high relative equipment such as sensors and meters placed in strategic positions can be employed.

IoT applications are the greatest instruments for monitoring air quality since they have capabilities like real-time tracking, multi-channel warnings, and technical analysis. The information is transferred without delay to a centralized spot, allowing for remote monitoring of a location's AQI.

Applications of Internet of Things-based Air Quality Monitoring system:

1) Indoor Air Quality Monitoring System

It's astonishing to learn that indoor air pollution kills almost 3.8 million people each year. When particulate matter and dangerous gasses are present in the air, the quality of the air is lowered, which can lead to serious illnesses such as asthmatic, substantially reduced pulmonary function, and sometimes even cancer when inhaled.

Although the evidence relates to both the industrial and commercial sectors, the impact of air pollution on employees is greater due to higher toxins concentrations. As a result, the indoor air quality monitoring system assists businesses in promoting a healthy and clean working atmosphere and keeping the AQI in line. Companies can promote proper ventilation, regulate the generation of contaminants in their operation, and maintain temperature and relative humidity levels in a reasonable range by analyzing actual air quality data with ideal circumstances.

2) Outdoor Air Quality Monitoring System

For centuries, atmospheric hygiene has become a contentious issue. To maintain excellent air quality, several legislation and rules related to pollutant emissions in the air have been enforced. As a result, it is essential for enterprises to control the generation of dangerous gasses and be able to preserve the emission rate well within the established criteria.

Organizations must monitor the air quality index in their surroundings such as industrial units and, as a result, manage their exhaust emissions by using outdoor air quality monitoring systems. This aids them in adhering to rules and avoiding any legally enforced penalties from air quality management agencies when levels of pollution surpass specified limitations.

3) Particulate Matter Monitoring

Particulates (PM) or Particulate matter are microscopic particles floating in the atmosphere that are solid or liquid. These nanoparticles, also known as aerosols, are undetectable to the human eye and can be composed of a variety of materials such as acids, chemicals, dirt, silt, organic matter, and so on.

Because all these particles are so tiny, they can be readily swallowed and have a negative impact on health. The diameter of these nanoparticles has a direct relationship to the intensity of the health conditions. Coarse PM, which is commonly found near road networks or dust industries, has a diameter of 2.5 to 10 micrometers. Particle diameters of less than 2.5 micrometers, on the other hand, are more harmful though they can readily travel through nasal passages and reach the lungs.

Preventing the formation of these nanoparticles throughout production or any other activity is thus critical in organizations because their constant exposure might have an impact on employee health and productivity. Organizations can monitor the emissions of particulate matter contained in their operation by deploying a PM tracking sensor in conjunction with air quality monitoring equipment. When particulates pass across the sensor's laser, they are scattered. The concentration of PM in the air can be determined based on the scattering of the laser.

As a result, organizations can take action to lower aerosol concentrations in their premises and promote a healthy and clean working atmosphere for their staff.

4) Gas Detection System:

In industries like chemicals and oil & gas, where harmful gasses and toxins are either used or produced in or during manufacturing processes respectively, even a minor leakage can result in a catastrophe.

Working under the presence of $H2S$ or $SO2$ for long durations can affect the respiratory system of the workers. Prolonged exposure can even affect mental health and cause severe headaches, convulsions, nausea, or conjunctivitis. Also, leakage of combustible gasses such as LPG or methane can result in explosions, causing injury to nearby operators and equipment damage. Moreover, oxygen displacing gasses (also known as asphyxiants) such as methane or propane can reduce the concentration of oxygen levels which can cause severe mental health issues and also death.

By using gas detection systems, the leakage of toxic and combustible gasses can be detected and steps can be taken to roll out the evacuation process, minimize equipment damage, and prevent their spread.

Constituents such as particulate matter and gasses determine the quality of air. These pollutants depreciate the quality of air, which causes severe diseases when inhaled continuously. With air quality monitoring systems, industries can detect the presence of these toxics and monitor air quality to take intelligent measures to improve the quality of air for their workers. This leads to an increase in productivity, reduced equipment damage, and effective regulatory compliance.

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2.2. Microcontrollers:-

In an embedded device, a microcontroller is a small integrated chip that governs a particular operation in the system. It is a low-cost, compact in size chip that is designed in a particular way to perform a specific task[10]. It is also known as MCU or microcontroller unit. A microcontroller is a small chip that is integrated into each element that it requires to execute the required operations and can undertake a certain duty on a regular basis without the need for additional sources [11]. A microprocessor, memory units, and input-output interfaces, as well as analog-to-digital conversion (ADC), pulse width modulation (PWM), and numerous control and communication modules, are all included[12]. In IoT, there are different microcontrollers as shown in figure 2.2:-

1. Based on bits
2. Based on architecture

Two-third of IoT developers and manufacturers use the following architecture:-

A. ARM
B. MIPS
C. X86

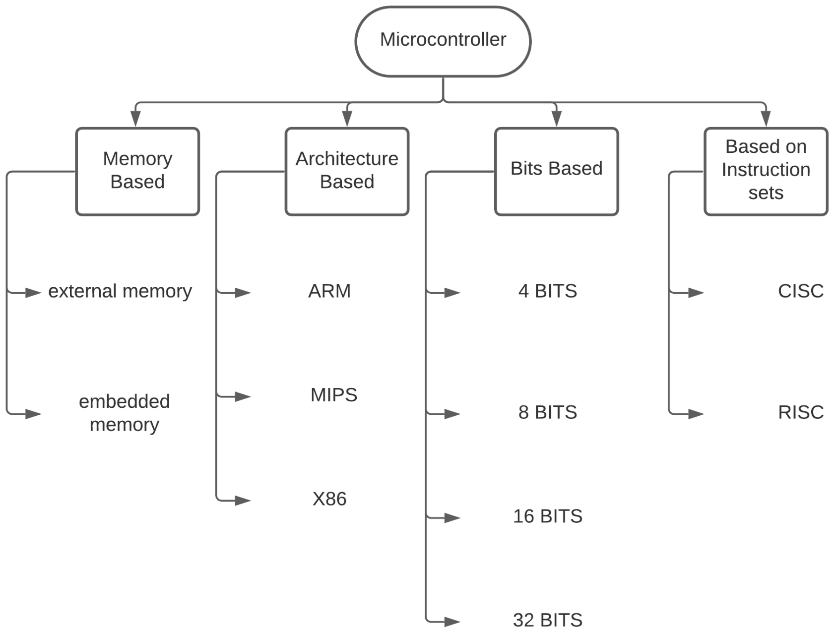

Figure 2.2 Different types of microcontrollers in the IoT environment.

A microcontroller can run at low speed or high speed depending upon the requirement and tasks. The overall performance of the microcontroller depends on its memory. Fig 2.3 shows the architecture of the microcontroller.

The chip contains the CPU, ROM, RAM, OSC, Timer, Serial interface, and other components. CPU is also supported. A wide range of systems and devices use microcontrollers. A microcontroller appears to be an effective electronic chip but is too profound as it can be programmed[13]. The microcontroller is made up of two words micro + controller where micro means small, compact in size, and controller means the ability to enhance control functional capability. The microcontroller's elements are the CPU, RAM(volatile memory), ROM(non-volatile memory), and peripheral[14]. In figure 5 we have demonstrated the generic architecture of the microcontroller.

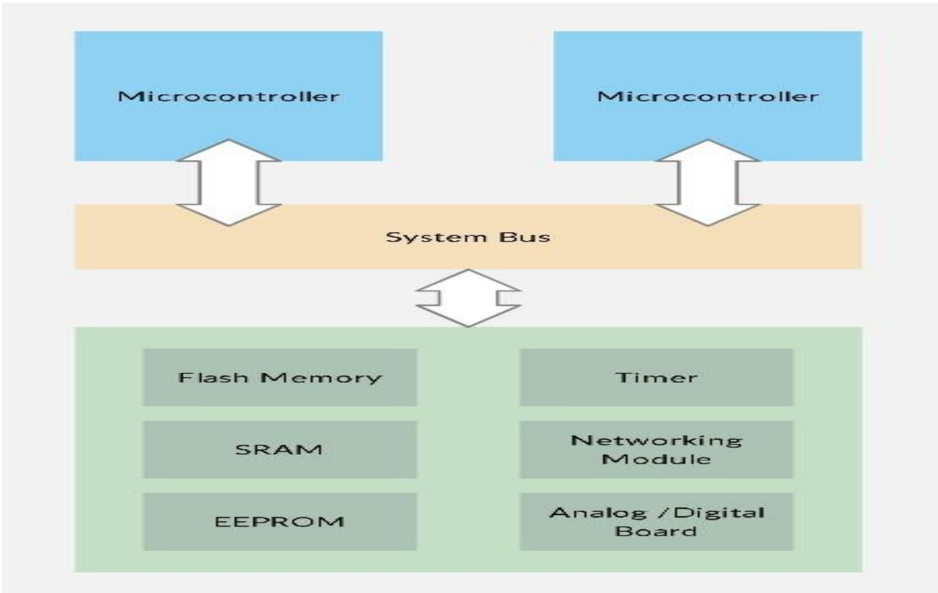

Figure 2.3 Architecture of generic microcontroller.

Type of microcontroller(based on bits):-

- **8 bit microcontroller:**-This kind of microcontroller is used to perform mathematical & logical operations such as addition, subtraction, division or multiplication, etc.
- **16 bit microcontroller:-**This kind of microcontroller is used when high precision and efficiency are required to perform arithmetical and logical operations.
- **32-bit microcontroller:**-In general, this kind of microcontroller is used in controlled devices, such as automatic operating machines, medical devices, etc

Type of microcontroller board:-

In figure 2.4 we have demonstrated the different types of microcontroller boards in the IoT environment

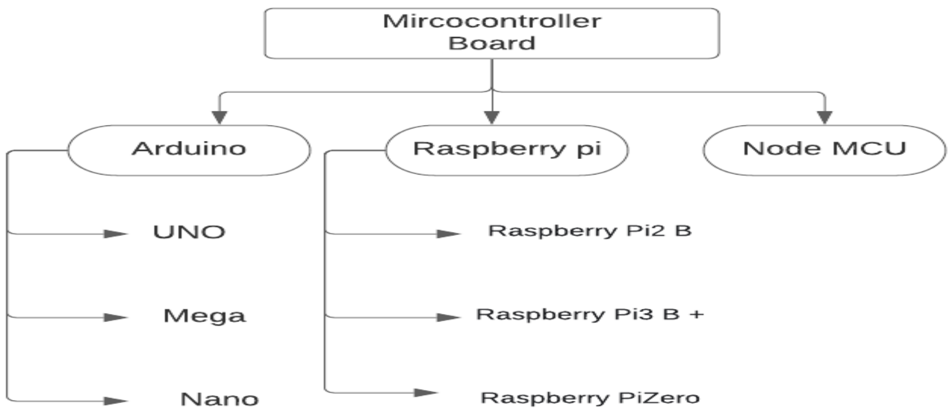

Figure 2.4 Different types of microcontroller boards.

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- **Arduino:-** the most common microcontroller board used in the IoT environment. Arduino consists of both a physically programmed circuit board & a software integrated development environment. It is an open-source platform[15]. Different Arduino boards are available in the industries[16,17]. The Arduino UNO is the most popular board in the Arduino family. Table 3 shows the comparative analysis of different Arduino boards.

Table 3:- comparative analysis of a different version of Arduino

Parameters	**ARDUINO UNO**	**ARDUINO NANO**	**ARDUINO MEGA**
Microcontroller processor	ATmega328p - 8 bit	ATmega328p - 8-bit	ATmega 2560
Voltage for input	6-20 v	7-12 v	7-12 v
Speed	16 MHz	16 MHz	16 MHz
Analog I/O pins	6(A0-A5)	8(A0-A7)	16
Digital I/O pins	14	14	54
Flash memory	32 KB	32 KB	256 KB
SRAM	2 KB	2 KB	8 KB
EEPROM	1 KB	1 KB	4 KB
USB	Regular	Mini	Regular

- **Raspberry pi:-** The raspberry pi is a small, low-cost device in the size of a credit card that connects to a computer, monitor, television and uses a regular desktop computer, touch screen devices, gamepad. It is also an open-source platform. It is a mini-computer board that runs on the Linux operating system. The first raspberry pi generation was the raspberry pi Model B[18].
- **Node MCU:-** Node microcontroller unit, is an open-source software and hardware development environment based on ESP8266. Node MCU is a Lua-based firmware for ESP8266 wifi. It is low-cost wifi with TCP/IP protocol[19].

Table 4 shows the comparative analysis of different microcontrollers boards.

Table 4:- comparative analysis of the different types of microcontroller boards

Parameters	Node MCU	Raspberry pi	Arduino Uno
Cost	Cheap as compared to others.	Expansive as compared to others.	Cheap as compared to a raspberry pi.
Size	Small in size	Large size	Small size as compared to a raspberry pi.
Wi-fi support	It has in-built features.	Support	Support
Analog I/O pins	1	28	6
Digital I/O pins	17	12	14
Computational power	Medium	High	Medium
Flash	4 MB	Depend on the SD card	32 MB
SRAM	Up to 128 KB	512 MB	2 KB
Voltage for operation	3.3 V	5 V	7-12 V
Speed	24-52 MHz	700 MHz	16 MHz

2.3 Sensors:-

By gathering external information or data for smarter decisions, sensors support the internet of things(IoT) sensor is a smart device that helps to collect information and can be replaced by a signal so that people and machines can differentiate between them.

A sensor is a system that detects changes in its surroundings. Sensors can also detect physical changes like temp, humidity, and pressure and they convert this into an electric signal. Sensors are an essential part of the internet of things. Smart sensors are IoT modules that transform the real-world function by evaluating it into an electronic information stream that can be transmitted to a terminal.

There must be 3 features in smart sensors:-

- It needs to be sensitive to the physical condition which it is observing and detecting.
- It shouldn't be affected by other physical factors.
- During the observing and detecting process, it does not change the physical phenomena being measured.

There is a wide range of sensors, which detect almost every physical parameter nearby us. For example:- temp sensor, gas sensor, light sensor, air quality sensor, noise sensor, motion sensor, etc … The sensor should have the following properties so that it can easily be used with IoT components:- low cost, reliability, accuracy, small size, and power consumption.

Various sensors that are used in IoT based air monitoring systems as shown in figure 2.5:-

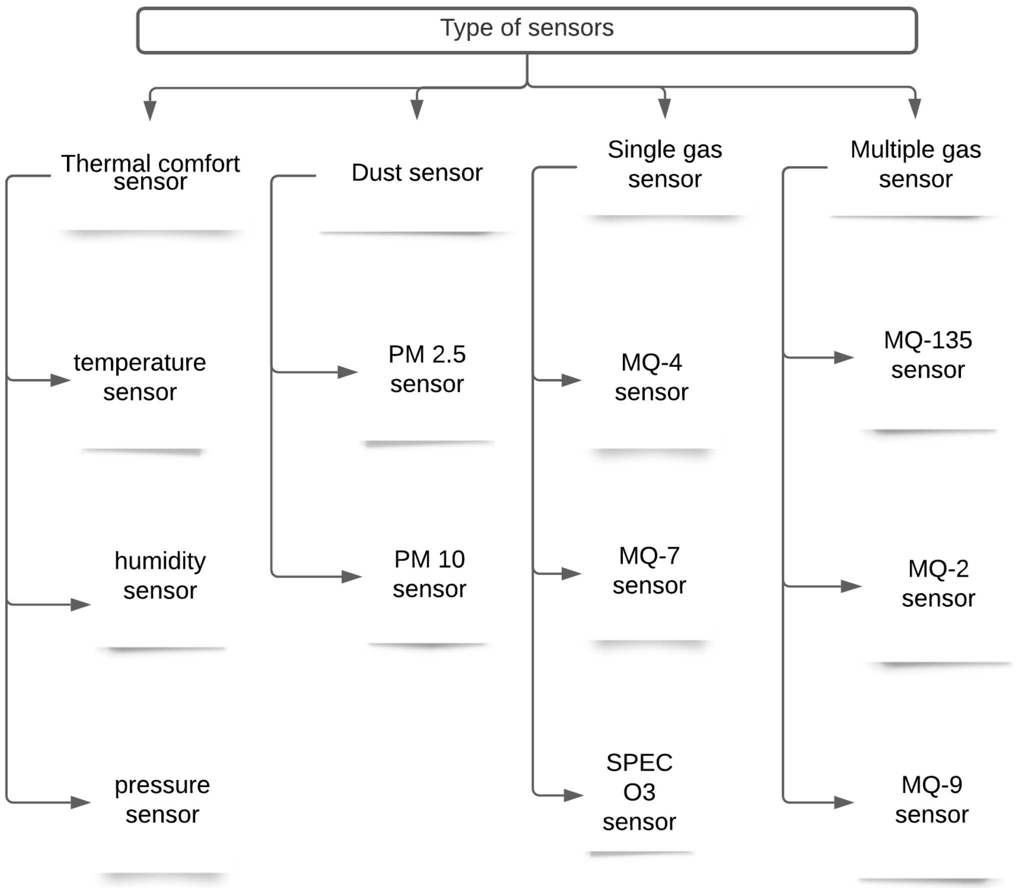


Figure 2.5 Different type of sensors in APMS

- Dust sensor:- it is a sensor used to sense the dust particles in the surrounding by using optical sensing technique. A smart dust sensor can sense minute particles such as smoke, dust, pollens. Dust sensors can sense air particles of large size also. It is suitable to measure PM2.5/PM10 concentration in air. Table 5 shows different types of dust sensors(PM2.5/PM10) with their working conditions.
- Thermal comfort sensor:- it is a sensor used to measure physical factors like temp, humidity, pressure, air velocity. It converts input data into electronic data to store and analyze changes in the temp, humidity. Table 6 shows different thermal comfort sensors with their working conditions.
- Gas sensor:- is a sensor used to measure various gasses present in the environment. It is generally used in detecting toxic and explosive gasses in the area. For example:-
  - I. MQ135:- it is a dynamic gas sensor, it can detect CO2, NH3, smoke, benzene.
  - II. MQ9:- is used to detect carbon monoxide and flammable gasses.
  - III. MQ4:- is used to detect methane and CNG gasses.
  - IV. MQ5:- is used to detect natural gas and LPG.
  - V. MQ7:- is used to detect carbon monoxide
  - VI. MQ136:- is used to detect hydrogen sulfide gas.
  - VII. MQ137:- is used to detect ammonia.
  - VIII. MQ214:- is used to detect methane and natural gas.
  - IX. MQ2:- is used to detect methane, butane, LPG, smoke concentration.
  - X. MQ3:- is used to detect alcohol, ethanol, and smoke concentration.

Table 7 shows different multiple parameters gas sensors and table 8 shows different sensors for determining different attributes of a specific range.

Table 5:- sensor's for pm2.5 and pm10

Name of sensor	Prediction attributes	Range of nominal value	Reliability and accuracy	Condition of working	Time of interval
DSM501A dust sensor	PM2.5, PM10	0 to 15000 pcs/283 ml or 1µm	-	For temp = -10°**c** to +65°**c** For hum = 0 to 95% RH	It can be between 10 seconds to 250 seconds which is adjustable.
PDD42NS dust sensor model	PM2.5, PM10	0 to 28 pcs/1 ml	Reliable to 1µm of diameter	For temp =0-45°**c** For hum = 0 to 95% RH	-
GP2Y1010-AUOF dust sensor	PM2.5, PM10	0 to 600 ug/m3	± 30% of ug/m3	For temp =-10°**c** to +65°**c**	0.3 second
SDS 011	PM2.5, PM10	0 to 999 ug/m3	±10 ug/m3	For temp = -10°**c** to +50°**c** For hum = 0 to 70% RH	1.2 seconds
PMS 5003	PM2.5	0 to 500 ug/m3	±10% @ 100-500 ug/m3 ±10% ug/m3 @ 0-100 ug/m3	For temp = -10°**c** to +60°**c** For hum = 0 to 90% RH	Less than 1 second

Table 6:- sensor's for determining thermal comfort

Name of sensor	Prediction attributes	Range of nominal value	Reliability and accuracy	Condition of working	Time of interval
DTH 11	temperature, humidity	For temp = 0-50°**c** For hum = 20-90%RH	For temp = ±1°**c** For hum = ±5%RH	For temp = 0-50°**c** For hum = 20-90%RH	6-7 seconds
DTH 12	temperature, humidity	For temp = -20°**c** to +60°**c** For hum =20-95 % RH Resolution for temp = 0.1°**c** Resolution for hum = 0.1% RH	For temp = precision 25°**c** @ ±0.5 For hum = precision 25°**c** @ ±5%RH	For temp = -20°**c** to +60°**c** For hum =20-95 % RH	Less than 20 seconds
DTH 22	temperature, humidity	For temp = -40°**c** to +80°**c** For hum =	For temp = ±0.5°**c** For hum = ±2-5%RH	For temp = -40°**c** to +80°**c** For hum =	2 seconds

		0-100%RH		0-100%RH	
STH10	temperature, humidity	For temp = -40°**c** to 124°**c** For hum = 0-100%RH	For temp = ±0.5-1°**c** For hum = ±4-4.5%RH	For temp = -40°**c** to 125.8°**c** For hum = 0-100%RH	5-8 seconds
STH 21	temperature, humidity	For temp = -40°**c** to 125°**c** For hum = 20-80%RH	For temp = ±3°**c** For hum = ±2%RH	For temp = -40°**c** to 125°**c** For hum = 20-100%RH	7-30 seconds
STH 30	temperature, humidity	For temp = 5-60°**c** For hum = 20-95%RH	For temp = ±3°**c** For hum = ±3%RH	For temp = 5-60°**c** For hum = 20-90%RH	5-8 seconds
STH 31	temperature, humidity	For temp = -5°**c** to 60°**c** For hum = 20-80%RH	For temp = ±0.3-0.5°**c** For hum = ±3%RH	For temp = -5°**c** to 60°**c** For hum = 20-80%RH	Greater than 2 seconds
TH 2	temperature, humidity	For temp = 0-70°**c** For hum = 0-100%RH	For temp = ±0.5°**c** For hum = ±4.5-5%RH	For temp = 0-70°**c** For hum = 0-100%RH	5-30 seconds
BME 280	temperature, Humidity, pressure	For temp = 0-60°**c** For hum = 0-100%RH	For temp = ±1°**c** For hum = ±1-3%RH	For temp = -40**c** to 85°**c** For hum = 0-100%RH	For temp = < 2 seconds For hum = < 1 second
BMP 180	Pressure	-	±0.5	-	>= 7.5ms

Table 7:- various air quality monitoring gas sensor's

Name of sensor	**Prediction attributes**	**Range of nominal value**	**Reliability and accuracy**	**Condition of working**	**Time of interval**
MQ 2	SnO2, methane, butane, LPG, smoke	300-10,000 PPM	-	For temp = 20 ± 2°**c** For hum = 65 ± 5% RH	-
MQ 3	Ethanol, benzene, smoke, alcohol	0.04mg/L to 4 mg/L	-	For temp = 20 ± 2°**c** For hum = 65 ± 5% RH	-
MQ 5	Natural gas, LPG	200-10,000 PPM	-	For temp = 20 ± 2°**c** For hum = 65 ± 5% RH	Less than 10 seconds
MQ 6	LPG, iso-butane,	200-10,000 PPM	-	For temp = 20 ±	Less than 10

	propane, LNG, smoke, alcohol			2°c For hum = 65 ± 5% RH	seconds
MQ 9	Carbon mono-oxide, flammable gas	10-10,000 PPM (flammable gas), 10-1000PPM (CO)	-	For temp = 20 ± 2°c For hum = 65 ± 5% RH	-
MQ 135	NH3, NOx, benzene, alcohol, smoke, CO2, ethanol	10-300PPM (NH3), 10-1000PPM (benzene), 10-300PPM (ethanol)	-	For temp = 20 ± 2°c For hum = 65 ± 5% RH	Less than or equal to 1 second
Misc-6841	NO2, carbon mono-oxide, ethanol, NH3, methane, butane, propane	0.05-10 PPM (NO2), 0-1000PPM (CO), 10-500PPM (ethanol), 1-500 PPM (NH3), >1000PPM (CH4), (C3H8), (C4H10)	± 15-25%	For temp = -30°c to 80°c For hum = 5 to 90% RH	-

Table 8:- various sensors for determining different attributes of a specific range

Name of sensor	Prediction attributes	Range of nominal value	Reliability and accuracy	Condition of working	Time of interval
MQ 4	Carbon monoxide (CO)	20-10,000 ppm	-	For temp = 20 ± 2°c For hum = 65 ± 5% RH	-
MQ 7	CH4	20-20,000 ppm	-	For temp = 20 ± 2°c For hum = 65 ± 5% RH	Greater or equal to 1 second
4-SO2-20	Sulfur dioxide	0-20 ppm	± 0.1	For temp = -20 to 40°c For hum =15% to 90% RH	Greater or equal to 45 seconds
4-NO2-20	Nitrogen dioxide	0-20 ppm	±0.1	For temp = -20 to 50°c For hum =15% to 90% RH	Greater or equal to 30 seconds
4-CL2-50	CL2	0-50 ppm	±0.1	For temp = -20 to 50°c For hum =15% to 90% RH	Greater or equal to 30 seconds
GSNT 11	Nitrogen dioxide	0-200 ppm	-	For temp = -10 to 70°c	Less than 5 seconds

SO2-AF	Sulfur dioxide	0-50 ppm	±0.3	For temp = -30 to 50°**c** For hum = 15% to 90% RH	Less than 25 seconds
Misc 2610-11	O3	10-1000 ppb	-	For temp = -40 to 70°**c** For hum = 5% to 90% RH	-
SPEC O3	O3	0-5 ppm	15%	For temp = -30 to 55°**c** For hum = 10% to 95% RH	Less than 30 seconds
KG-C62	C6H6	0-320 mg/	-	For temp = -20 to 50°**c** For hum =15% to 90% RH	-
KG-HO2	HOHO	0-7 mg/	0.01 ppm	For temp = -20 to 50°**c** For hum =15% to 90% RH	-

2.4 Communication tools:-

In the IoT environment, there are a variety of communication technologies, techniques, protocols like Bluetooth, WI-FI, cellular(2G/3G), NFC, RFID, GSM are the main IoT communication technologies. This internet of things communication protocol is tailored to & fulfills the functional requirements of an IoT framework. These technologies and protocols have their own sets of capabilities, data transmission rate, communication range, operating power, and storage memory. Each of them has certain advantages & disadvantages. Some are suitable in small-scale networks while others may be used in large-scale networks.

Bluetooth is a short-range wireless technology interface for sharing data using radio waves[20]. It is the most widely used technology in the IoT environment. RFID stands for Radio Frequency Identification, it is a wireless technology for short-range with high-frequency techniques[21]. Cellular consists of GSM/GPRS, 2G, 3G, 4G, and 5G standard. It has a communication range between 35kms to 200kms in HSPA[22]. It is almost the most popular choice due to its reliability, and capability of data transmission. WI-FI is the best communication protocol for many IoT designers due to its widespread accessibility in-home or on LANs. There is a large current model & architecture that allows for quick data transmission & handling of large amounts of data[23,24,25].

Table 9:- different existing technologies of communicating devices

Parameters	**NFC**	**RFID**	**Bluetooth**	**Wifi**	**GSM**
Description					
Range	10 cm in range.	12 meters in range.	Physical range up to 10m (33ft.) up	Min range is 50 m and the max depends	Depending on antennas (35kms)

			to 100m.	on frequency.	
Frequency	NFC operates at 13.56 MHz.	Low frequency runs at125 to 134 kHz. High frequency runs at 13.56 MHz. ultra-high frequency runs at 433 and 860-960 MHz.	2.402 GHz to 2.480 GHz	2.4 GHz device and 5 GHz device.	890-915 Hz.
Communication	2-way connection	2-way connection	2-way connection	2-way connection	2-way connection
Data rate	106,212 or 424 k bit/s	Can achieve data rate as high as 100mbps.	Max. the data rate is 2.1 mbit/s and depends on the version of Bluetooth.	Max data rate is 600 to 9608 mbit/s in wifi 6E.	270.833 KBIT/S
Network	Personal area network	Personal area network	Personal area network	Local area network	Wide area network
Topology	P2P	STAR	STAR	STAR	MESH
Power consumption	LOW	Very LOW	LOW	MODERATE	HIGH
cost	low-cost	low-cost	low-cost	Medium- cost	Highly-priced
Application	E-wallet, smart card.	Used in security, passport, identification.	Laptop, printer, wireless headset, transfer of images, files.	Home appliances, video conferencing, internet browsing	Email, remote monitoring, security system.

2.5 Literature review:-

People and the environment are both harmed by large-scale urban air pollution. In recent years, India's environmental problems have become much more serious. Automobiles and industries are the primary sources of air pollution, which causes a wide range of respiratory ailments such as asthma and sinusitis. Major cities such as Kolkata, Delhi, and Mumbai have poor air quality due to emissions from vehicles and industries such as CO2. Conventional monitoring systems rely on sophisticated statistical techniques and a slew of other instruments to produce trustworthy and accurate data. As a result, these pieces of equipment are often quite expensive, consume a lot of electricity, and are big in size and weight. To some extent, technological advancement presents solutions to these challenges, in that low-cost ambient sensors with compact size and quick reaction are easily accessible. They cannot, however, reach the same levels of data precision as standard monitoring systems.

According to the current study, there have been several approaches for air quality monitoring. They are divided into two types: uniform air monitoring systems and vehicular air monitoring systems. Figure 9 shows the monitoring system's categories in a hierarchical order, based on deployment methodologies.

According to research, air monitoring systems are moving toward a brand-new strategy that integrates low-cost sensors, including the wireless sensor network (WSN), in a single technique [26]. Low-cost sensor-based models enable researchers to control the spread of air contaminants much more successfully and accurately. Eventually, a group of members will assess their exposure to toxins based on the recommendations of wearable sensor nodes [27], [28], and [29].

Most Air Quality Monitoring systems are based on the generic architecture but, owing to the complex variety of features, scale, and applications, a variety of solutions have been offered by researchers over time. IoT systems design varies with changes in sensors availability and suitability, they are also impeded in terms of resources like battery, computational power, on-board memory, bandwidth etcetera. But on the positive side, this makes them very configurable and renders easy application of algorithms. Most recently the Smart aspect has been implemented using Machine learning particularly Deep learning techniques, and the results are quite promising. Concerning the hardware and software aspects, the solutions are enabled by technologies like Cloud Computing, Fog Computing.

The goal of this work[30] is to develop a low-cost, low-power solution for indoor air quality monitoring. Using XBee modules and ATTiny-85 microcontrollers, the system suggested in this study provides a low-cost design. To achieve the lowest possible power consumption, a sleep state algorithm and interface circuitry were created and implemented. To reduce the amount of electricity used by indoor air quality monitoring equipment, future research should use energy-efficient algorithms.

By merging wireless sensor technologies, ARIMA predictive models, and fuzzy theory, this work offers an intelligent air quality control system that monitors indoor air quality. The system analyzes and forecasts the working environment inside the building[31].

The author[32] proposed an air quality prediction system based on sensor data and machine learning in this article. They tested the performance of a composite model, assuming that the data (i.e. different sensor measures) interact with one another and that the model provided in this article has a better predictive ability than the single linear regression method. They also suggested an approach for determining the ideal time step size for deep learning models automatically. Through testing with a variety of parameter settings, this model confirmed its viability and remarkable performance and plans to incorporate additional sensor nodes and use more advanced machine learning algorithms are in the works.

Cost-effective wireless air pollution sensors are emerging in densely dispersed networks, with higher spatial resolution than standard ambient air quality monitoring systems. This study describes an air quality measuring system that consists of a wireless sensor network formed by a dispersed sensor network connected to a cloud system (WSN). Sensor nodes use low-power ZigBee notes and use a gateway to send field measurement data to the cloud. The data received from the sensor network was stored, monitored, processed, and visualized using an optimized cloud computing system. The cloud is used to handle and analyze data, and artificial intelligence techniques are used to improve compound and contaminant detection[33].

For wireless sensor networks to monitor air quality, a low-cost, low-power and the tiny node has been created. With these features, a huge number of nodes can be deployed to construct a ubiquitous sensor network. Pre-processing data before delivering it, lowering its dimensionality, and connecting the nodes directly to the cloud, where the data is stored, processed, and displayed, are all possible with the use of a gateway. The network's goal is to collect data on air contaminants on a broad scale. The identification and quantification of volatile organic molecules have demonstrated their effectiveness (BTEX). For this, pattern recognition algorithms were applied[34].

In this article, the author describes the network structure, the GUSTO sensing techniques, the mobile sensor grid design, and the distributed data mining technique used in the MoDisNet project's urban air pollution analysis. The device can produce excellent performance due to the high-quality mobile detection capabilities of the GUSTO sensor unit, which can monitor pollutants at very short timed periods. A well-designed e-science grid architecture and distributed data mining method are also required for this scenario due to the spread of sensors across a broad metropolitan region and the constraints of system aggregation during transmitting and processing [35].

Many projects have been described in the literature that make use of low-cost air pollution sensors that can be carried by people or mobile vehicles, as shown in table 10.

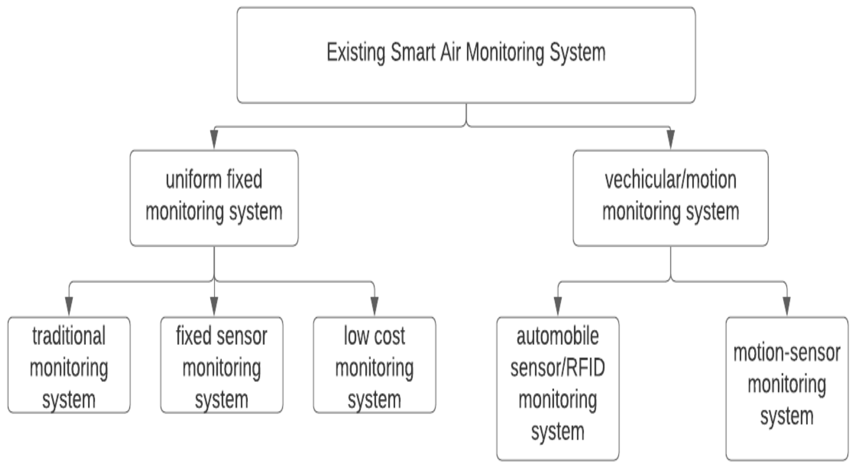


Figure 2.6 Existing smart air monitoring system

Table 10:- literature review of existing techniques

Reference	Network architecture	Environmental parameters	indoor/outdoor air quality monitoring system
[30]	Low-cost Zigbee sensor-based model	CO2, benzene, NOx, and ammonia	It can be used for both indoor and outdoor air quality monitoring. Zigbee communication protocol is used.
[36]	A cost-effective and portable PM monitoring system, model name- C air.	PM2.5, PM10	It can be used for both indoor and outdoor air quality monitoring. Mobile-based system.
[37]	Low-cost model based on electronic	NOx, CO, VOCs, relative humidity(RH)	It can be used for both indoor and outdoor air quality monitoring. HVAC system for quality is used.

	nose-based solid sensor		
[38]	Real-time monitoring system	CO2, VOCs, SO2, NOx, CO, PM, and ozone.	It is used only for indoor air quality monitoring.
[31]	Intelligent wireless sensing auto-regressive integrated moving average(ARIMA) system.	CO2, RH, temperature	It is used only for indoor air quality monitoring. IEEE 1451.4 standard and the Zigbee technology are used.
[39]	Sensor network for CAN(controller area network)	Air pollutant, gaseous content, PM concentration	Real-time based. Highly reliable for indoor air quality monitoring.
[34]	Cost-effective WSN system using low-cost sensors using Arduino microcontroller	CO, VOCs, CO2	Most suitable for indoor and outdoor air quality monitoring systems. The least mean square method and micro gas sensor are used.
[40]	Air cloud model system using a low-cost personal network	PM2.5, PM10 concentration level	Air quality monitoring systems can be used for indoor and outdoor air quality systems. Cloud-based engines are used.
[41]	Comprehensive air quality indicator system(CIAQI)	VOCs, PM10, CO, temp, humidity sensor	It is based on IoT and economical solutions. It can be used as an indoor air quality monitoring system.
[42]	Wireless based on real-time air quality monitoring system	Humidity, temp, gaseous pollutants, PM concentration	Real-time input HVAC system. It is a monitoring system designed especially for indoor air quality but can be also used as an outdoor air quality monitoring system,
[32]	Model is estimated using GRU and compared with LSTM and linear regression.	VOCs, light quantity, humidity, fine dust, temp, and CO2.	It is used for indoor air quality monitoring systems using deep learning.
[33]	A low-cost system using WSN	CO2, CO, humidity, luminosity, air temp	It is used for both indoor/outdoor wireless communication networks established with Zigbee and IEEE802.15.4 radio standard.
[35]	End to end system is designed using WSN	RH, ambient temp, CL2, O3, NO2, SO2, CO, and CO2.	The prime aim of the model is for indoor air monitoring systems. Communication is established using Zigbee pro.
[43]	Real-time monitoring system using WSN	RH, temp, PM, and gaseous pollutant	It can be used for indoor as well as outdoor air monitoring systems. A monitoring server is developed to analyze the sensor data.
[44]	Low-cost portable monitoring system	Sound level, illuminance, CO, CO2, VOCs, PM10, PM2.5, RH,	It is designed for both indoor as well as outdoor air quality monitoring systems. The overall performance of the model is calculated based on that IEQ(indoor environment quality).
[45]	Low-cost air quality system especially for the household.	PM2.5, CO2, VOCs, RH, and temp	It is designed only for indoor purposes. The system is designed using the FOOTBOT monitor-based percentage system.

[46]	Arduino based real-time air quality monitoring system	RH, temp, O3, SO2, NO2, CO, PM2.5, PM10	This model can be installed indoors as well outdoor for monitoring air quality, it uses the IBM Waston IoT platform
[47]	IoT-based air quality monitoring system using the raspberry pi module.	RH, temp, NO2, CO2, the concentration of smoke	It is designed for indoor air quality monitoring systems. It uses an MQ series sensor directly to interface with the raspberry pi module.
[48]	The model is based on a distributed sensor network and WSN based cloud.	VOCs, including xylene, ethylbenzene, toluene, benzene	It is designed for indoor as well as outdoor air quality for volatile gases. It is developed using the multilayer perceptron principle and it is compared with different ML algorithms like SVM, backpropagation.
[49]	IoT-based air and sound monitoring system that is built using Arduino and pi. It is an expansive model.	Sound level, temp, humidity, CO, PM concentration.	It is designed for outdoor air quality like hospitals, schools.
[50]	The monitoring system is developed using raspberry pi and STM32/8 arm controller.	CO2, CO, SO2, NO2	It is designed for outdoor air quality monitoring systems. Web server is built using pi.
[51]	An air monitoring system is developed using a wifi module on Arduino.	PM concentration, temp, humidity	It is built for outdoor air quality monitoring. Data communication is established using Modbus and transferred using GSM.
[52]	The Model is built using Arduino using an MQ series sensor for air quality monitoring system	LPG, PM concentration, natural gas	It is built for an outdoor air quality monitoring system. The data is stored on things spoken using a wifi module.
[53]	The model is built using Arduino UNO, it is a low-cost air monitoring system.	Smoke concentration, open burning pollutant	It is built for an outdoor air quality monitoring system using LAN. The local database is created using a local area network with Arduino.
[54]	Air quality monitoring system using request and response protocol having a mixture of data-centric IoT protocol.	CO2, CO, PM2.5/PM10, NH3	This system is specially built for indoor air monitoring.
[55]	IoT-based air pollution monitoring system using node MCU with the alarming system.	CO2, smoke, alcohol, benzene, NH3	This system is designed for outdoor air quality monitoring. Web server is created and it is easily accessible through mobile and computer.
[56]	Smart air quality monitoring system using Arduino and WSN.	CO, NO2, smoke	This system is designed for industrial and urban areas. It is a real-time monitoring system.

[57]	WSN based smart air monitoring system for vehicles using Zigbee.	Smoke, dust particles	It is a low-cost module for monitoring the quality of air in vehicles.
[58]	Arduino UNO-based air pollution monitoring system for vehicles based on RFID.	CO, SO2, NO2, methane	It is designed to monitor pollution emissions caused by vehicles.
[59]	Sensor grid air pollution monitoring system using Zigbee.	NO, NO2, O3, SO2	It is designed for measuring volatile gasses in the surrounding area using data mining techniques.
[60]	Air pollution monitoring system using SVM based on Hadoop distributed system.	CO, SO2, O3, NO2, PM10	It is designed for multiprocessing systems using parallel processing and map-reduce techniques.
[61]	Air pollution monitoring system for the urban area using random forest technique,	PM2.5/PM10, SO2, NO2, O3, CO	It is designed for urban areas using the RAQ algorithm and AQI is monitored every 30 minutes.
[62]	Air pollution monitoring system using multi-hop data aggregation algorithm.	NO2, temp, humidity, CO2, NO2, O2	It is a real-time air monitoring system that uses WASP libelium motors. It is deployed in the IIT Hyderabad campus.
[63]	Air quality monitoring system using low power wide area(LPWA) technique.	PM2.5/PM10, smoke	It is a three-layer module based on a radio prototype.

CHAPTER 3

PROPOSED METHODOLOGY

3.1 Generic Architecture of smart air pollution monitoring system:-

We have designed a generic prototype of a smart air pollution monitoring system in fig. A smart air pollution monitoring system consists of a microcontroller, LCD, various gas sensors, and communication tool & protocol. As demonstrated in fig 10 a layered IOT based architecture is shown with five different phases. Sensors are the base of the whole prototype and microcontrollers act as the heart of the system. The microcontroller is the main component in the system through which all the sensors and communication tools & protocols are connected[64]. Various sensors detect the air quality level like MQ-135 sensing the amount of CO_2, NH_3, smoke, and benzene, so it is also known as a dynamic sensor. Dust sensor senses the concentration of PM2.5/PM10[2]. MQ-135 detects the quality of air in PPM(parts per million). The output from the MQ-135 gas sensor will be in the form of a voltage level which is translated to PPM[3]. After collecting the information about the quality of air, AQI is calculated. If the value of AQI is below the threshold value, no health risk, it shows the quality of air is good[4]. If the value of AQI is above the threshold value, it shows the quality of air is poor & dangerous to health and an emergency alert message will be displayed[5]. Based on that people are advised to take suitable measures. When the level of PPM limit exceeds 1000 PPM, it will cause various health issues like headache, vomiting, asthma problems, etc[6].

The main objective of IoT based monitoring system is[1]:-

- Sensor module:- The goal of this module is to use various sensors, sensing the quality of air like MQ-135, MQ4, MQ6, MQ9, etc. For measuring dust particles and the concentration of particulate matter in the air, a dust sensor is used. Temperature and humidity sensors are used to measure physical factors like temp, humidity, pressure, air velocity. Sensors are deployed in different locations to collect information in different parts/areas.
- Processing module:- Measured value and data are analyzed in this module. Calculation of Air quality index and concentration of other gasses take place and data is stored & uploaded in a cloud database. The prediction system is developed using different algorithms.
- Communication module:- Different communication technologies and protocols are used to communicate & retrieve data from cloud databases. It acts as an interface between the user & the cloud platform. Various technologies and protocols that are used are GSM, WiFi, ZigBee, MQTT Protocol, ESP8266 module, etc.

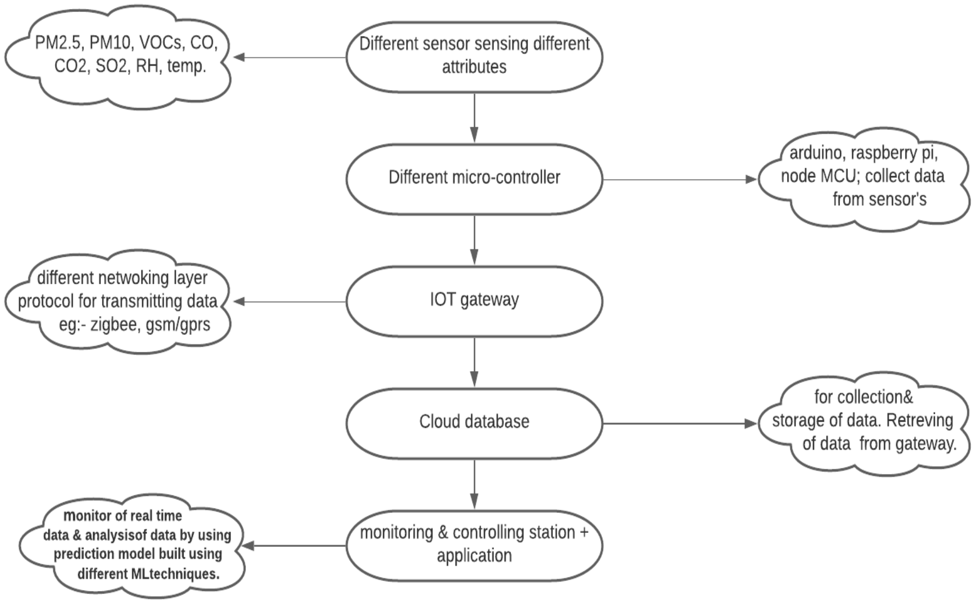


Figure 3.1 An adaptive Framework of IoT based smart APMS.

In figure 11 we have demonstrated the generic architecture of a smart air pollution monitoring system.

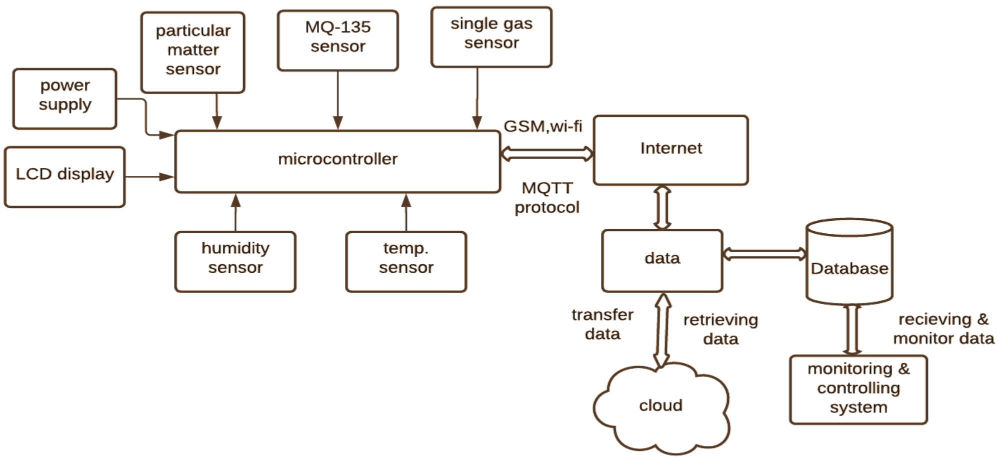


Figure 3.2 Generic architecture of Air Quality Monitoring System(AQMS).

3.2 COMPONENT USED

A. Microcontroller
B. Sensors
C. Communication tool

A. Microcontroller

A microcontroller is a small compact and economical micro-controller designed in such a fashion it performs a set of tasks such as displaying the information of microwaves, receiving remote signals, etc The micro-controller consists of the following parts, the CPU or processor, the memory (RAM, ROM), serial ports, counters, timers. It is used for different analog functions(performance) and is breadboard-friendly. The automatic air & noise monitoring system used various sensor's communication tools and a microcontroller(Arduino /Raspberry Pi)

Arduino is an open-source platform, consisting of an IDE(integrated development environment) & a physically Programmable Board of Circuits that can run on our device & practice for Computer Code Writing & Uploading to the physical computer board.

The Raspberry Pi is a very low-cost computer that uses regular keyboards and a mouse to plug the computer or TV. It is a small-scale tool that permits a person of all ages to survey programming in languages like Scratch and Python and to learn how to program. You can do everything you would imagine a desktop computer to do from internet browsers and video streaming to smartphones, word-processing, and games.

B. Sensor

I. **DS3231 Sensor:-** It is a Real-time Clock(RTC) Sensor. It is used for time and date, which have a battery configuration that keeps the module running in the absence of eternal electricity. It updates all time and data continuously. We can therefore have precise RTC modules time and date anywhere, whenever we want.

Figure 3.3 DS3231 Sensor

II. DTH 11:- It measures both humidities as well as temperature. It is a low-cost, easy-to-use digital sensor. Any microcontroller like Arduino / Raspberry Pi can be easily interfaced with to quickly calculate moisture and temperature in the air.

DTH 11 has 2-degree precision in temperatures between 0-50 degrees celsius. This sensor has a humidity range between 20% and 80% with 5% precision. The sampling rate of DTH 11 is 1Hz i.e. for each second, it gives one reading. DTH 11 is small and runs voltage between 3-5 votes for calculating the map. Current is 2.5 ma.

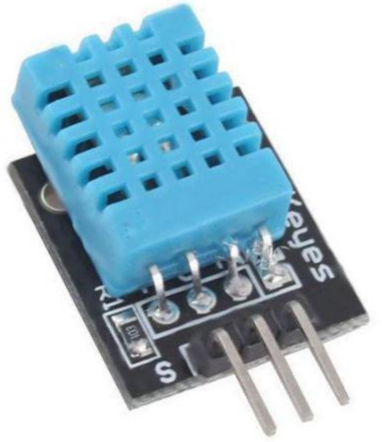


Figure 3.4 DTH 11 Sensor

III. **MQ-7 Sensor:-** It is a sensor used for sensing carbon monoxide concentration in the air. It can measure carbon monoxide concentration between 10 to 500 ppm.MQ7 sensor is highly responsive and easily reacts having a very fast response time.

IV. **MQ-135 Sensor:-** The MQ-135 Gas sensors are applied to measure/control the quality of air and are also capable of detecting & measuring NH_3, NOx, alcohol, beneze, smoke, CO_2.

The module of sensor MQ-135 comes with a digital pin that allows the sensor to operate even without a microcontroller & is useful if we only try to detect a specific gas. The analog pin must be employed if you have quantified the gas in PPM. The TTC pin works with 5V, so it can be used with any microcontroller.

Features of MQ135 Sensor:-

- Wide scope for detection
- Highly sensitive and quick response time
- Long-lasting and reliable
- The voltage of operation is +5V
- Analog performance voltage:- 0V to 5V.
- Digital performance voltage:- 0V to5V.
- 20 seconds of preheat time

V. **DSM501A Dust Sensor:-** It is used to measure PM2.5/PM10. The DSM501A is a low-cost small-size sensor for particle density. It is used for measuring particles in a quantitative (>1 micron), way using smoke & pollen, dust controller principle. It is made up of a light-emitting diode lamp, detector, signal amplifier & heater and can easily be used by users with PWM sensor output in applications such as air cleaners or air purifiers.

VI. **MG811 sensor:-** It is used to detect carbon dioxide concentration in the air. It is a metal oxide sensor that must heat the tank to the required level of amount. The heated vapor & the separation of CO_2 from the air are produced by the power supply.
This module has a sensor part MG811 on board. The MG811 is an extremely CO_2 sensitive & less alcohol & CO sensitive signal device for a heating sensor.

VII. **MQ4 sensor:-** It is used to detect the methane, CNG gas levels in the air. It can track down the concentration of natural gas between 300-1000 ppm. It is highly sensitive & has a quick response time. MQ4 sensor has Sno2 as a sensitive material which can clean air conductive power. The conductivity of the sensor increases with the rise of gas concentration when the target glasses.

VIII. **Sound module by REES52:-** It is used to measure the sound level. The sound level sensor module offers a simple Way to sound monitoring and is commonly used for the detection of sound intensity. The sound sensor module is preferable for various programs and functions like security, switching & tracking. Its precision can easily be modified for usability. The input to an amplifier, peak detector, and buffer is provided by a microphone. It uses when the sound sensor senses a tone, the signal strength is sent to the microcontroller & is interpreted.

C. Communication tool

1. GSM:-

GSM offers advanced multimedia and universal Mobile technology for voice and data services delivery. GSM operates about 900mhz - 1800mhz on mobile communication frequency. It is a highly powerful and mobile network technology that integrates. GSM has an enhanced spectrum, low-cost mobile collection, high standard voice. GSM helps to reduce time by controlling the soil moisture level to remove human inaccuracy and to exaggerate its net production. Some features of GSM include international roaming, improved spectrum capacity, integration with the digital network integrated services (ISDN) (FDN).

2. Bluetooth:-

Bluetooth is a wireless technology designed to link computers and portable devices. It needs low power and is very easy to run. In theory, Bluetooth links devices over a short period using low-power radio. It is about 10 meters high (30 feet). The frequency band of 2.45GHz is sponsored.

3. Wifi module(ESP8266):-

Esp8266 is an affordable Wi-Fi module for adding wireless internet access, functionality via UART serial connection to an existing microcontroller project. The module can also be rewritten to operate as an individual Wi-Fi computer.

<u>Features of ESP8266:-</u>

- 802.11 b/g/h protocol
- TCP/IP optimized stack
- Direct WiFi (P2P)
- Output power +19.5 dBm in mode 802.11
- Encourage diversity of antenna
- Integrated sensor for temperature
- Leak current of less than 10 uA.
- As an application processor, an integrated low-power CPU of 32 bits can be used.

3.3 Proposed model

Air and sound pollution is increasingly growing. To have it under oversight. We are proposing a method to solve this problem that can be observed in the surroundings, sound level, and presence of dangerous gasses. Creating problems for living individuals, whether it is high-decibel or Pollutant gasses that propagate in the atmosphere, has started to create rising pollution at such an alarming pace which hurts human health and hence a required more vigilance and alertness.

IoT- based Air & Sound control system's primary aim is to ensure air and sound pollution increases day by day. Air quality must be identified and preserved for a prosperous and healthier future. For this reason, we proposed an air & sound pollution monitoring(tracking) device that recognizes us via the internet of things(IoT) to get the measure of and to interpret the quality of the living air as well as noise pollution in an environment. The model uses various types of gas sensors to identify and relay the data on a variety of occasions to noxious gasses found in the atmosphere. The system also tracks and records sound levels. Figure 3.5 shows the generic APMS block diagram.

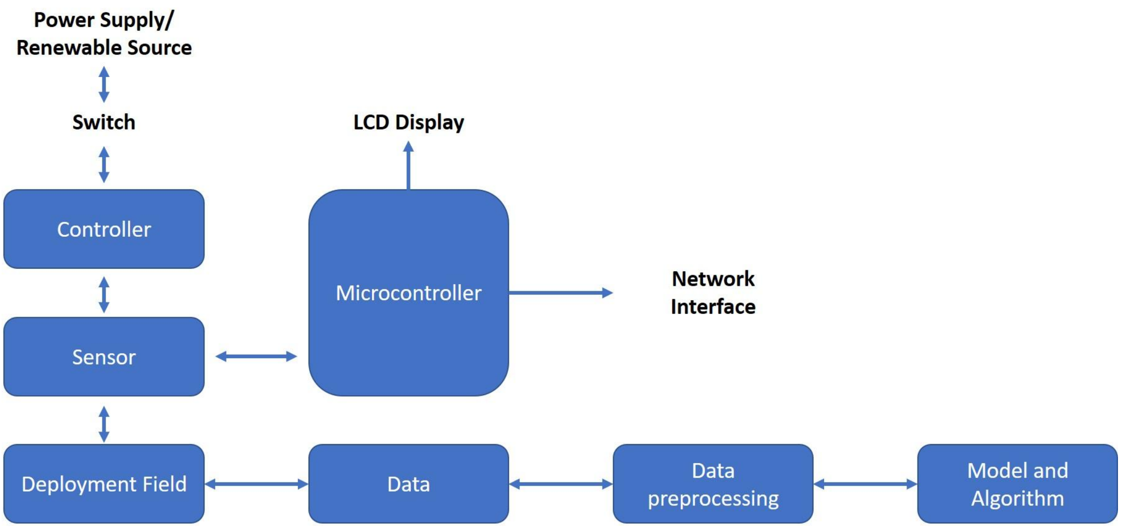
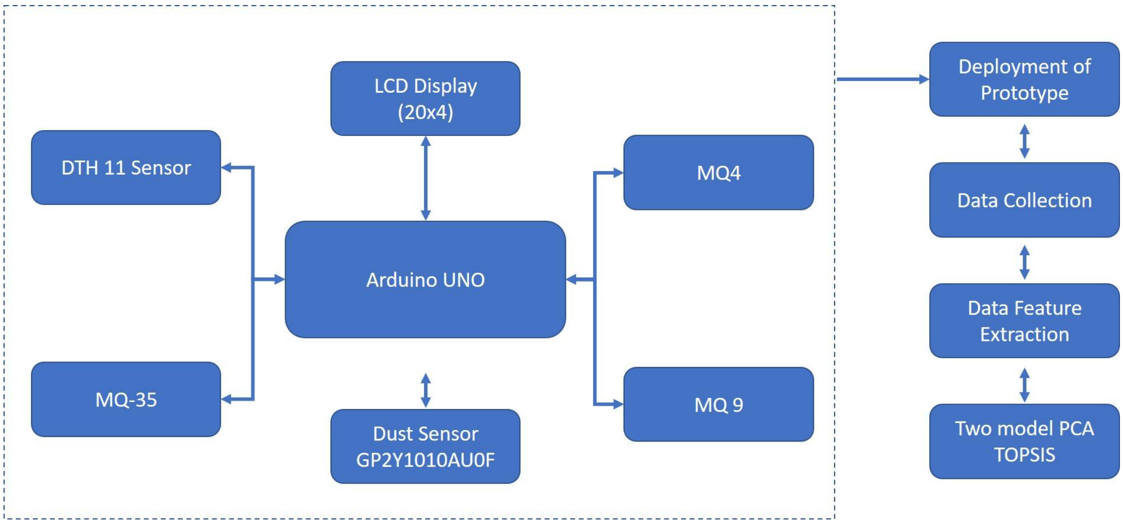


Figure 3.5 Generic APMS block diagram

3.4 Working Of prototype:-

In our proposed prototype, we have used Arduino Uno, 3 MQ- series sensors, and one dust sensor for measuring and detecting the particulate matter concentration and air quality index & quality of air in the environment. All these sensors detect different types of pollutants in the environment and fed them to the Arduino Uno. The Arduino Uno is connected to the LCD screen, it displays all the concentration of pollution values. As this system is based on the Internet of things. MQ-4, MQ-9, and MQ-135 collect the data of different pollutants in PPM and it will result in the form of the phase of voltage which is converted into PPM using different libraries of respective sensors. The data collected using the different sensors is sent to the Thingspeak platform through a microcontroller using a network interface. In our proposed system we have used ESP 8266 to provide internet/WIFI connectivity. To collect the data and test the prototype, the author installed the prototype at Dilshad garden situated in Delhi, India, and collected the daily data at 5:00 PM using Arduino Uno from 1-06-2021 to 31- 12-2021. figure 3.6 shows the real time monitoring of the designed prototype.

Figure 3.6 Working of proposed APMS framework.



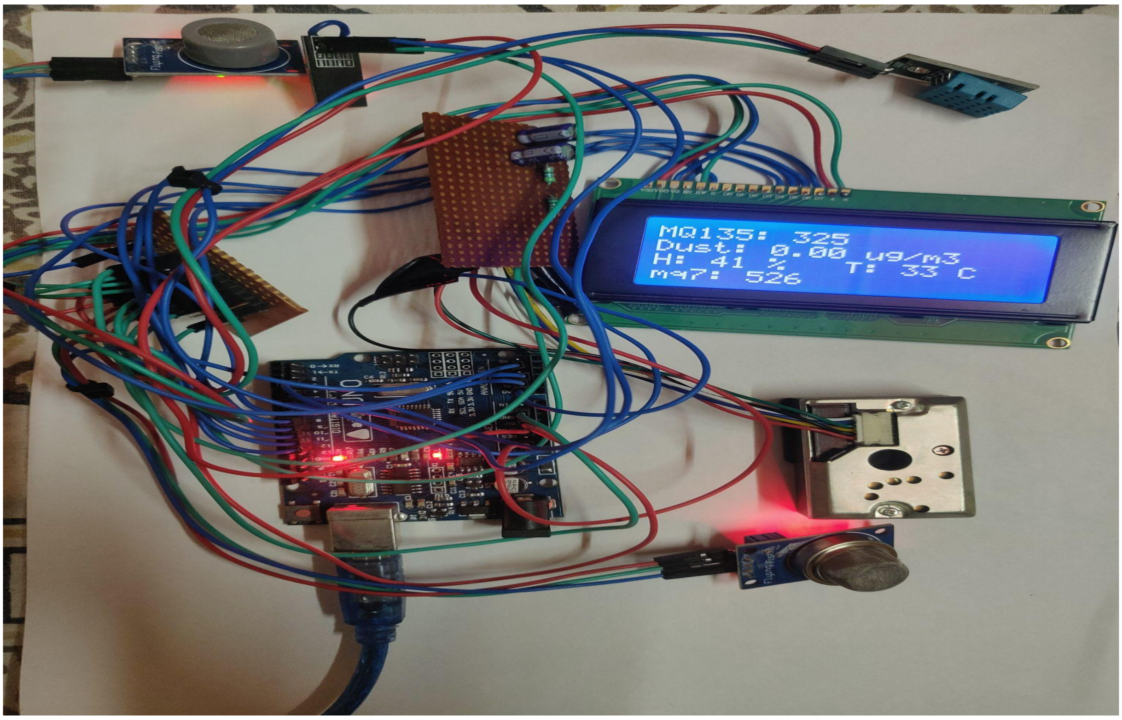


Figure 3.7 Connectivity of real time low cost on APMS using sensor, arduino uno and ESP8266 wifi.

CHAPTER 4

Comparative Study Of Impact Of COVID-19 Lockdown On AQI Parameters Across Urban India

4.1 INTRODUCTION

The Indian government, led by Prime Minister Narendra Modi, imposed a 21-day statewide lockdown on March 23, 2020, as a preventive step against the COVID-19 sickness in India, prohibiting mobility for the whole Indian population of 1.38 billion, or 138 crores. And so our lives as Indians would begin in the midst of the epidemic{66}.

People began to notice that the environment, particularly the air quality, had improved considerably almost immediately after the curfew was implemented. So much so that the picturesque Dhauladhar Mountains in Himachal Pradesh may be seen from its bordering states.

Coronaviruses are a wide range of viruses that both animals and humans can be infected with. Many coronavirus diseases in humans have been connected from the ordinary cold to more serious disorders such as Middle East Respiratory Syndrome and Severe Acute Respiratory Syndrome (SARS) with respiratory infections[67]. The newly found coronavirus is the cause of coronavirus disease. COVID-19 was recognized as a public health emergency by the World Health Organization (WHO)[68].

The number of cases worldwide is expanding daily. This dataset covers statistics from India and union territories on a universal scale. Air is a necessary component of life. The better our health and well-being, the cleaner the air[69]. However, artificial sources, in particular, pose a considerable risk to air quality.

Air pollution is the release of chemicals into the atmosphere that are harmful to human and world health[4]. It has the potential to be one of humanity's most dangerous threats ever. All of them are affected by animals, agriculture, forest, and water. It also increases the depletion of the ozone layer, protecting the Earth from sunlight. Haze, eutrophication, and global temperature changes are some of the additional effects of air pollution[70].

Fuel utilization and industry are the primary sources of air pollution. When fossil fuels are burned, they release gasses and compounds into the atmosphere. Furthermore, air pollution not only contributes to climate change but is exacerbated by a particularly damaging feedback mechanism[71]. The planet’s temperature rises due to air pollution from carbon dioxide and methane. Smog occurs when the temperature is hotter and there is more UV radiation, and the heat increases this kind of air pollution.

Climate change is boosting mold and pollen production (due to severe weather conditions and increased flooding) (due to a longer pollen season and more pollen production).

"Air pollution" is one of the most significant challenges of our era, not only because of the impact on climate change but as a result of increased mortality in both public and individual health. Pollution is described as the development [72] of chemicals which are dangerous to the environment for humans and other living things. Pollutants are hazardous, more than usual, solids, liquids, or gasses that harm the quality of our environment. The psychological effects of air pollution are enormous. Even in times of minimal air pollution, the health of individuals is vulnerable and delicate. Short-term exposure to air pollutants is all associated with COPD, cough, shortness of breath, wheezing, asthma, respiratory disease, and a significant risk of hospitalization[73]. The long-term effects of air pollution include chronic disease, asthma, pulmonary insufficiency, and heart disease. In addition, air pollution seems to have several detrimental health repercussions, including psychiatric, respiratory, and chronic problems, for early human development[74].

Analysis of the air quality index as criteria ranging from 0 to 500. The higher the AQI value, the higher the levels of air pollution and the greater the risk of poor air quality. For example, air with an AQI of 50 or less is considered excellent quality, whereas air with an AQI of more than 300 is considered dangerous. Pollution is the biggest threat to human life, and it is worse in India than in any other country. The Air Quality Index (AQI) is a numeric scale used to measure and report air quality in a specific location on a particular day. PM10, PM2.5, NO2, SO2, CO, O3, NH3, and Pb are the eight major pollutants used to calculate the local AQI. As the AQI grows, so do the risks to public health.

4.2 Problem statement:-

- To examine the relationships amongst toxic pollutants.
- The purpose of this research is to look at the impact of various environmental conditions on air quality.
- To determine the impact of altitude variations on air quality.
- To determine the impact of air quality on various regions.
- To determine the impact of various pollutants on air quality.
- Recognize different trends in the degree of air pollution throughout the course of a day.
- The purpose of this study is to see how the Covid-19 lockdown has affected air pollution levels in India, particularly in North India.

4.3 How does the AQI function?

In India, AQI calculations include eight contaminants for which National Environmental Quality Standards (NAAQS) have been established. These pollutants are- PM2.5, PM10, N02, CO, SO2, O3, NH3, and lead.

- Individual pollutant sub-indices are derived from a monitoring station's 24-hour mean concentration value (8-hourly for CO and O3) and a set of health breakpoints. For this location, the AQI is the worst sub-index.

- Not all of the eight contaminants can be tested in every location. It is conceivable. Only AQI can be calculated if data for at least three pollutants, including PM2.5 or PM10, are available. In the absence of this information, the AQI estimate is deemed insufficient. A minimum of 16 hours of data is also required for the sub-index to be calculated.
- While there isn't enough data to calculate AQI, subsets of contaminants observed are calculated and distributed. The air quality status for each pollutant will be provided by the individual pollutant-wise sub-index.
- The AQI is provided in real-time through web-based technology. Without human intervention, the system collects data from continuous control stations and displays the Air Quality Index (AQI) based on average running values (e.g. AQI at 6 am on a day will incorporate data from 6 am on the previous day to the current day).
- An AQI calculator was created for manual stations, where data can be manually inputted to obtain an AQI value.

The overall AQI can only be calculated if data for at least three pollutants, either PM2.5 or PM10, are available. Similarly, a minimum of 16 hours of data is required for the calculation of the sub-index.

4.4 Study area and Methodology:-

Our study is based on 26 cities of India which includes "Ahmedabad, Hyderabad, Patna, Gurugram, Amritsar, Mumbai, Chennai, Delhi, Bengaluru, Lucknow, Jorapokhar, Jaipur, Thiruvananthapuram, Amaravati, Brajrajnagar, talcher, Kolkata, Guwahati, Shillong, Chandigarh, Bhopal, Ernakulam, Kochi, Aizawl, Visakhapatnam, Coimbatore". The air quality index of 26 cities is studied from 01-01-2015 to 01-07-2020. The pollutant on which our studies are focused is PM2.5, PM10, N02, CO, SO2, O3, BTX.

India is officially known as the “Republic of India” is a country situated in South Asia. It is the second most populated country in the world, the seventh-biggest by geographic area, and the largest democracy.

The study was divided into two parts:

- Analysis during the years - 2015-2020 of India's pollution levels:- It provides an outline of India's rising pollution levels and present situation.
- the consequences of the lockdown on India's pollution levels:- We'll look at pollution levels in India before and after the initial shutdown in this study. We'll compare pollution levels in the same months of 2019 to see whether there's a difference. We might also compare the levels of pollution in Northern India between now and the winter months of 2019. (The months of October and November)

The analysis of data in all these sections should provide us with a realistic picture of Lockdown's impacts on pollution levels in India.

4.5 Dataset used:-

For our study, we have used "Air Quality Data in India (2015-2020). It is an Air Quality Index (AQI). & hourly data across the stations & Cities in India. In this dataset, the total number of Cities is 26. Cities are "Ahmedabad, Hyderabad, Patna, Gurugram, Amritsar, Mumbai, Chennai, Delhi, Bengaluru, Lucknow, Jorapokhar, Jaipur, Thiruvananthapuram, Amaravati, Brajrajnagar, talcher, Kolkata, Guwahati, Shillong, Chandigarh, Bhopal, Ernakulam, Kochi, Aizawl, Visakhapatnam, Coimbatore".

This dataset has:- City-data, City hour data, Station data, Station hour data, Station. In this, Station is controlled and monitored by the Central & State agency which is the central pollution control board and state pollution control board respectively.
This dataset consists of 15 parameters which are Date, PM2.5, PM10, NO, NO_2, NOX, NH3, CO, CO2, SO_2, O3, Benzene, Toluene, Xylene, AQI & AQI Bucket.

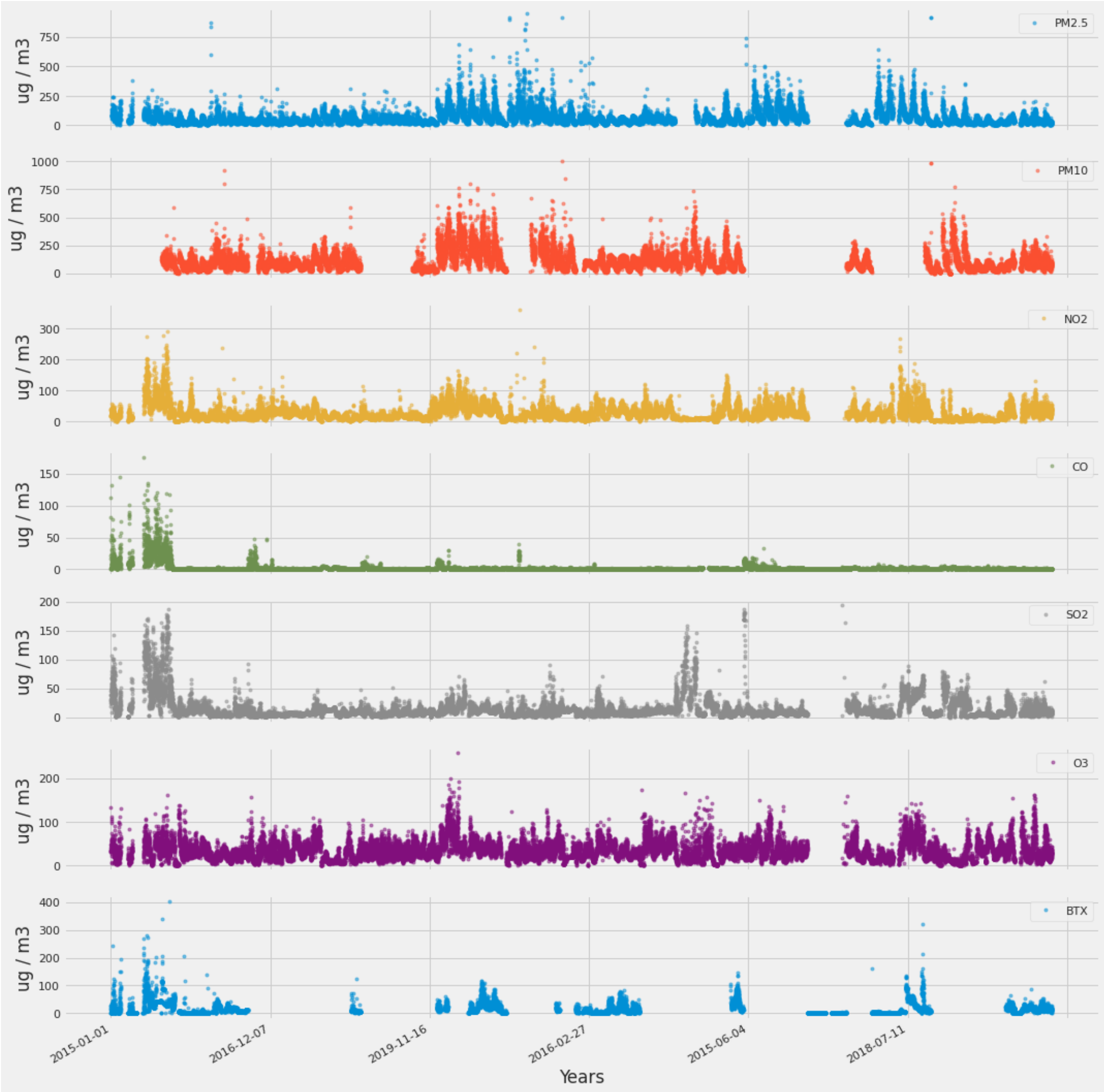
4.5.1 Data pre-processing:-

- In this dataset, the date Column parameter is converted into the date-Time format.
- In this dataset, data is available between 01-01-2015 to 01-07-2020.
- After analyzing all the parameters of the dataset we have Combined Benzene, Toluene & xylene Columns into one Column & named at BTX.
- Similarly, we have combined PM2.5 & PM10 columns into one as particulate matter.

4.6 Simulation and Results:-

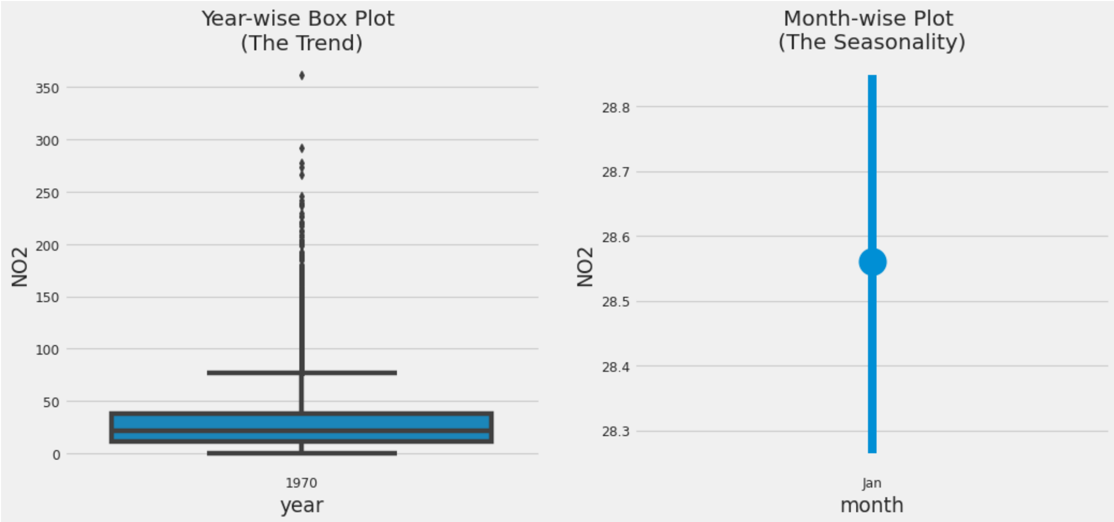
In our data, we have different types of pollutants. We have selected some eminent and distinguished pollutants, ones which are PM2.5, PM10, N02, CO, SO2, O3, BTX.

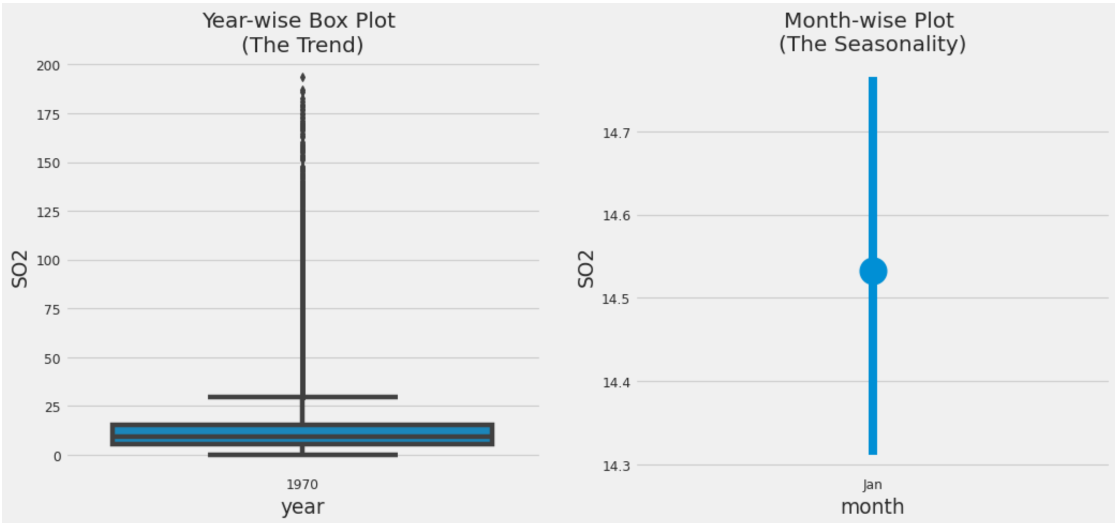
Firstly, we have visualized and analyzed the data yearly between 2015-2020 for PM2.5, PM10, N02, CO, SO2, O3, BTX and plotted a graph as shown in fig 4.1.

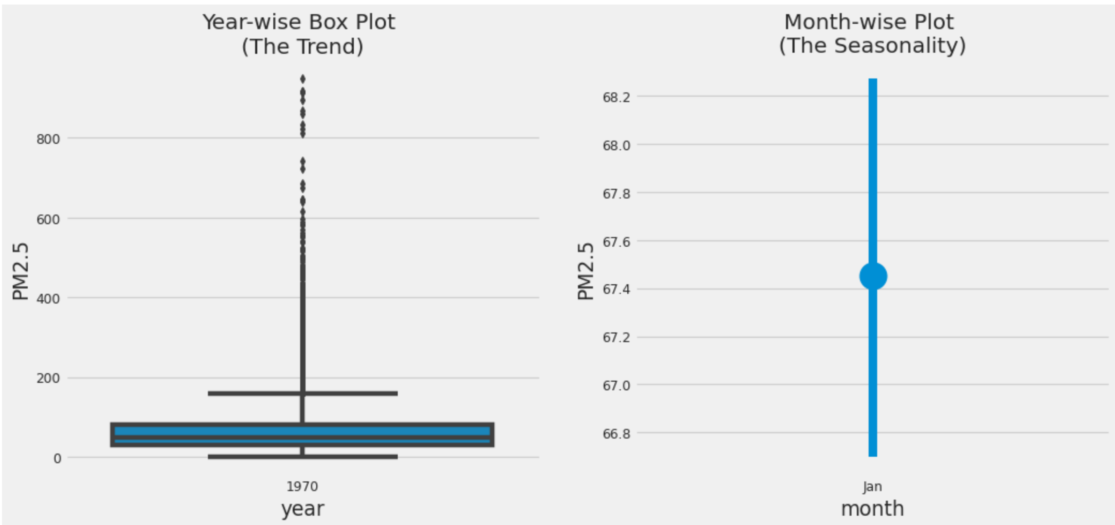


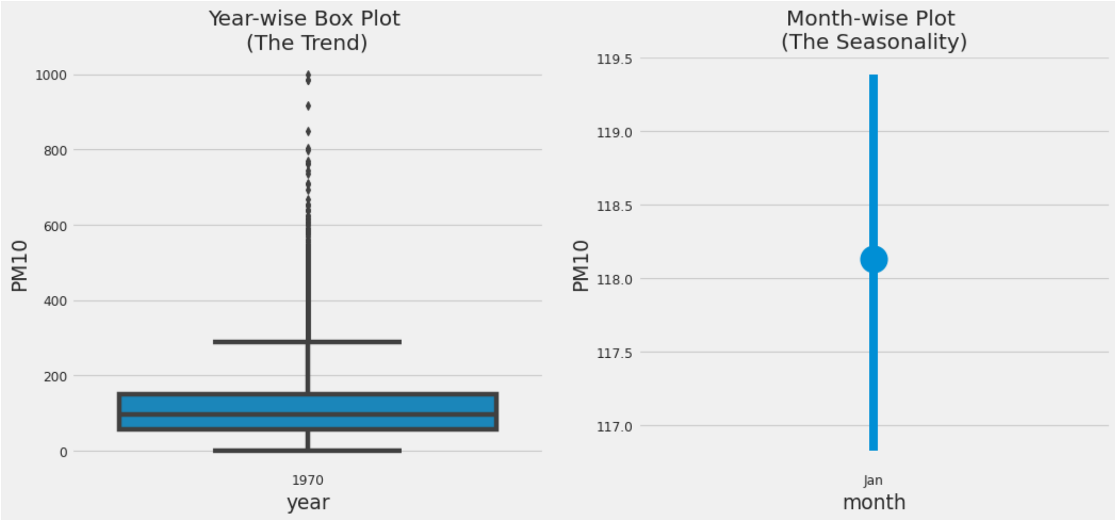
As we can see in fig 4.1, PM2.5 and PM10 decrease in 2020 as compared to 2019. Pollution concentration for PM2.5 and PM10 has a periodic influence, with pollution concentration being greater in the winter months, particularly in comparison to the summer months. The level of SO2 began to climb after 2017, but there was a brief spike in 2015. The same trend may be seen at the BTX level as well. The O3 concentration is high between 2017-2019.

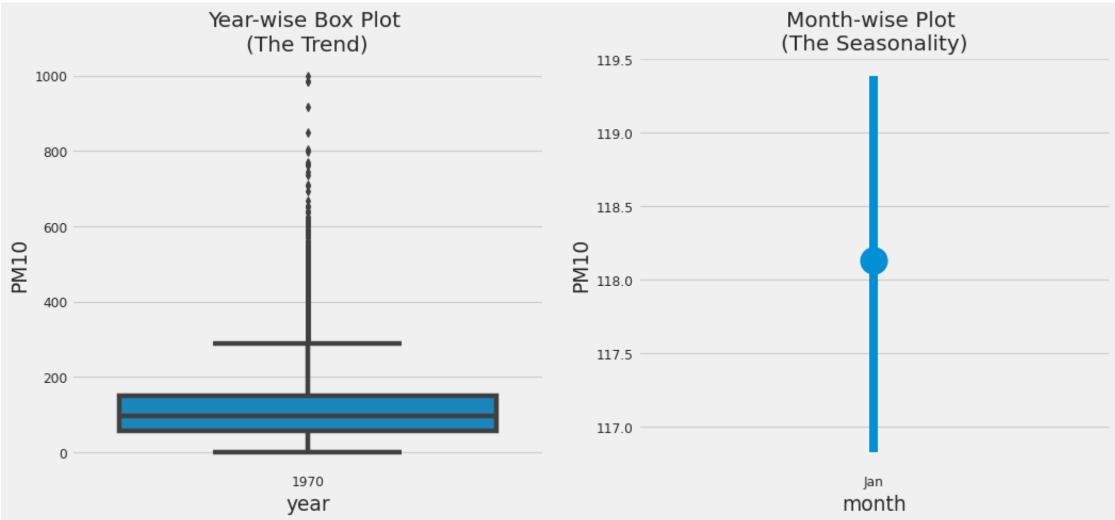
To analyze the level of pollution deeply and to understand the pattern, we have visualized and analyzed the data monthly and yearly between 2015-2020 for PM2.5, PM10, N02, CO, SO2, O3, BTX and plotted a graph year-wise to understand the trend of pollutants and month-wise to understand the concentration of pollutants seasonally.

- 
Year-wise Box Plot
(The Trend)
NO2
350
300
250
200
150
100
50
0
1970
year
Month-wise Plot
(The Seasonality)
NO2
28.8
28.7
28.6
28.5
28.4
28.3
Jan
month


Year-wise Box Plot
(The Trend)
SO2
200
175
150
125
100
75
50
25
0
1970
year
Month-wise Plot
(The Seasonality)
SO2
14.7
14.6
14.5
14.4
14.3
Jan
month


Year-wise Box Plot
(The Trend)
PM2.5
800
600
400
200
0
1970
year
Month-wise Plot
(The Seasonality)
PM2.5
68.2
68.0
67.8
67.6
67.4
67.2
67.0
66.8
Jan
month





In fig4. 2,3,4,5,6, we can see, in the month of July and August, there is a noticeable downward trend in India's pollution level. It might be due to the fact that the monsoon season arrived during these months. Interestingly, in April, the BTX levels indicate a significant drop. After this, the environmental pollution concentration begins to rise, peaking during the winter months due to the burning of crop residuals, particularly in the northern parts, which is common throughout this season.
After 2017, the amount of SO2 began to grow, albeit it had also risen suddenly in 2015. The same trends may be seen at the BTX level as well. The median reading for 2020 is usually lower than for previous years, indicating that pollution may have decreased recently.

After analyzing the trend of pollution year-wise and month-wise, now we have a look into the top 10 most polluted cities from our dataset in each pollutant category: PM2.5, PM10, N02, CO, SO2, O3, BTX.

City	PM2.5	City	PM10	City	NO2	City	SO2	City	CO	City	BTX
0 Patna	123.500000	0 Delhi	232.810000	0 Ahmedabad	59.030000	0 Ahmedabad	55.250000	0 Ahmedabad	22.190000	0 Kolkata	38.230000
1 Delhi	117.200000	1 Gurugram	191.500000	1 Delhi	50.790000	1 Jorapokhar	33.650000	1 Lucknow	2.130000	1 Ahmedabad	37.110000
2 Gurugram	117.100000	2 Talcher	165.770000	2 Kolkata	40.400000	2 Talcher	28.490000	2 Delhi	1.980000	2 Delhi	26.860000
3 Lucknow	109.710000	3 Jorapokhar	149.660000	3 Patna	37.490000	3 Patna	22.130000	3 Talcher	1.850000	3 Patna	17.430000
4 Ahmedabad	67.850000	4 Patna	126.750000	4 Visakhapatnam	37.190000	4 Kochi	17.600000	4 Bengaluru	1.840000	4 Visakhapatnam	15.030000
5 Kolkata	64.360000	5 Brajrajnagar	124.220000	5 Lucknow	33.240000	5 Delhi	15.900000	5 Brajrajnagar	1.800000	5 Gurugram	14.600000
6 Jorapokhar	64.230000	6 Jaipur	123.480000	6 Jaipur	32.420000	6 Mumbai	15.200000	6 Ernakulam	1.630000	6 Amritsar	14.580000
7 Brajrajnagar	64.060000	7 Bhopal	119.320000	7 Bhopal	31.350000	7 Guwahati	14.660000	7 Patna	1.530000	7 Hyderabad	10.730000
8 Guwahati	63.690000	8 Guwahati	116.600000	8 Coimbatore	28.780000	8 Amaravati	14.260000	8 Kochi	1.300000	8 Chandigarh	9.090000
9 Talcher	61.410000	9 Kolkata	115.630000	9 Hyderabad	28.390000	9 Bhopal	13.060000	9 Gurugram	1.260000	9 Amaravati	3.680000

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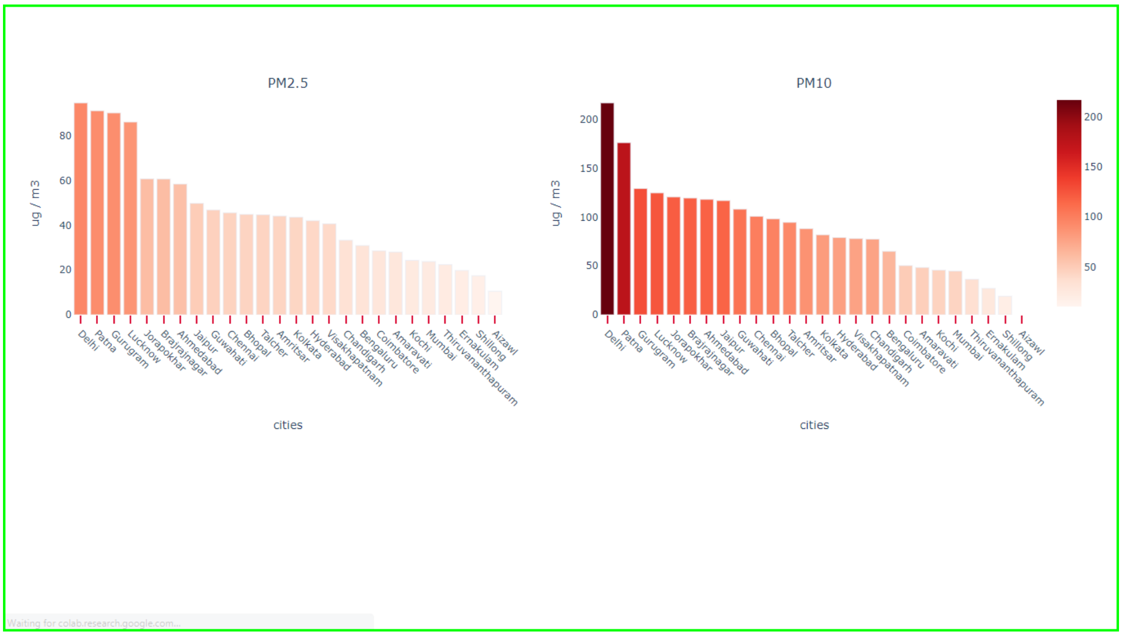
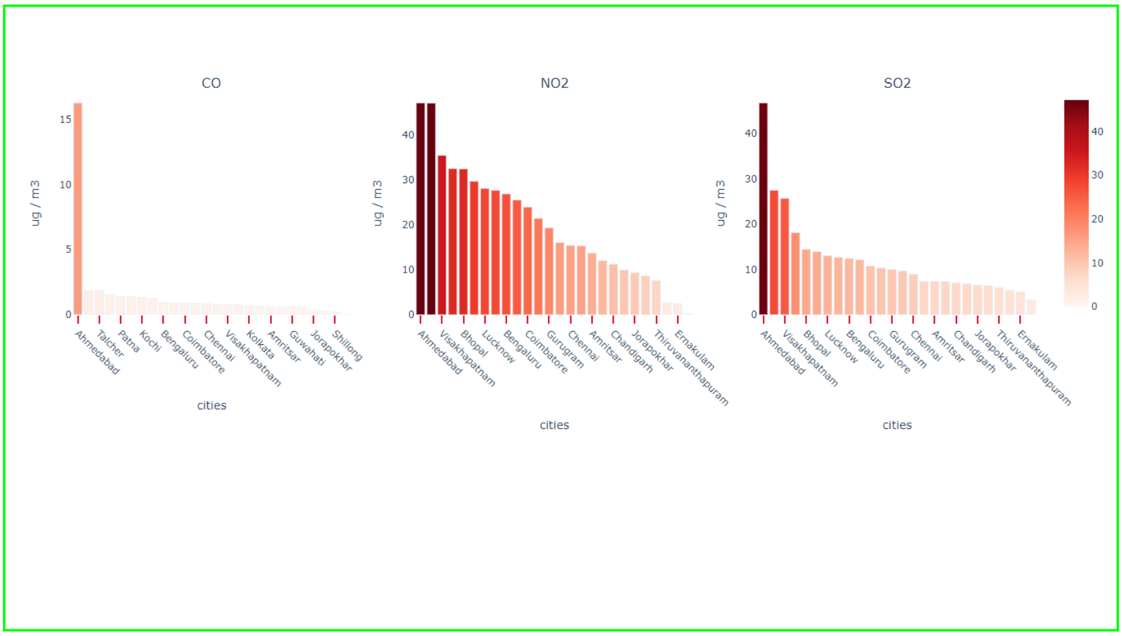
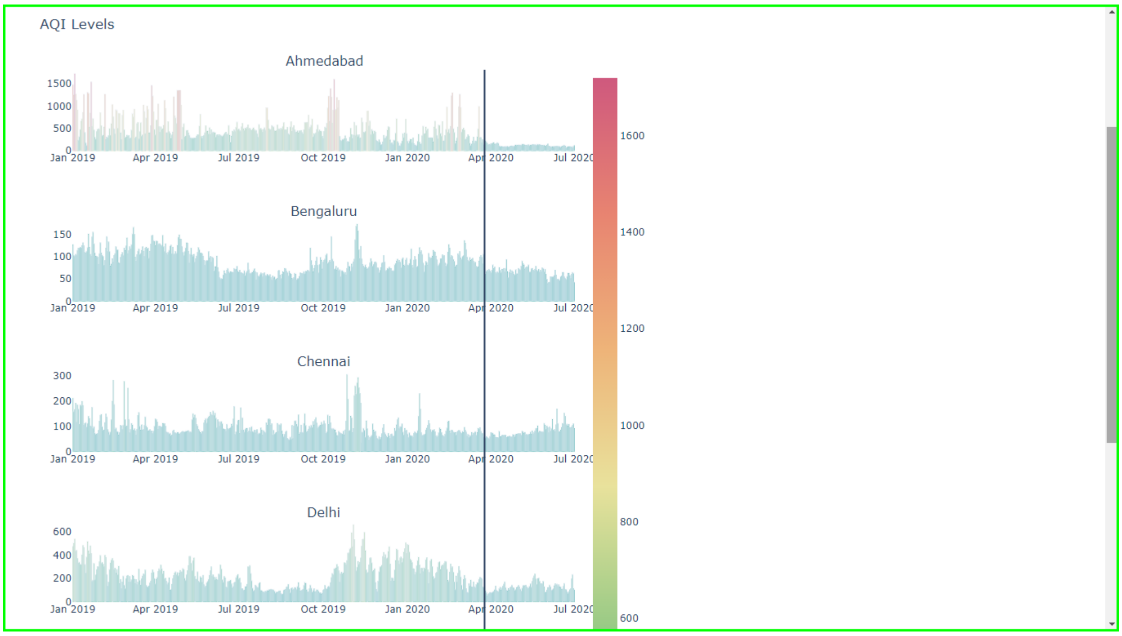
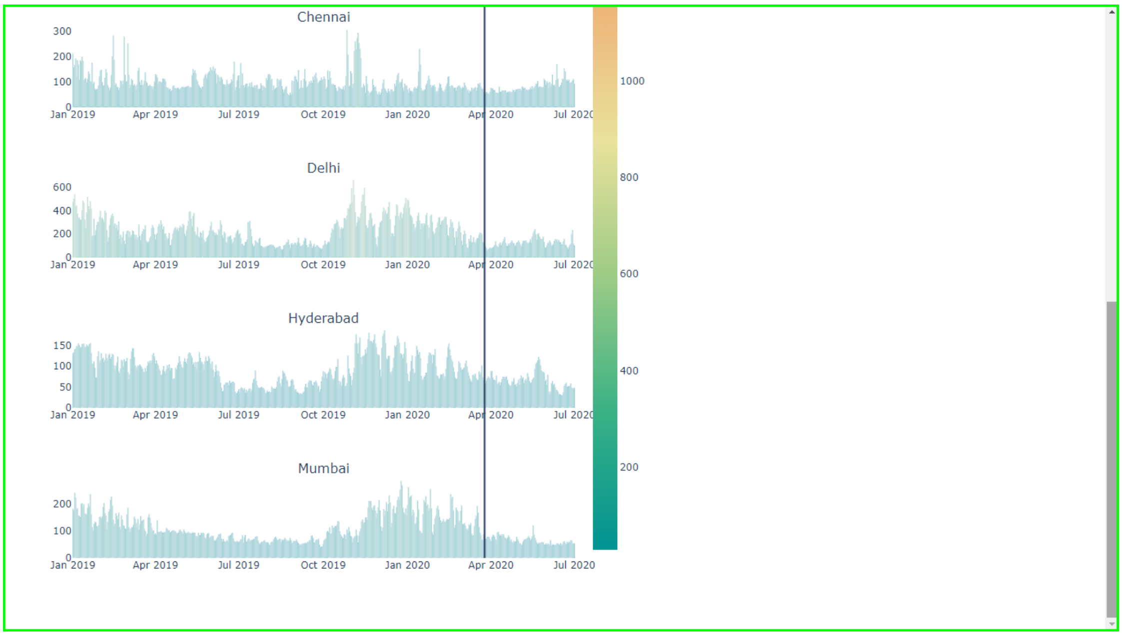
As we can see in fig 4.7, Patna has the highest concentration of PM2.5, Delhi has the highest concentration of PM10. Ahmedabad has the highest concentration of SO2 & CO and Kolkata has the highest level of BTX(benzene, toluene, and xylene) concentration.
To look at these values and understand them clearly, we have plotted a histogram as shown in fig4. 8&4.9.





Thirdly, we have understood the effect of lockdown on AQI in 6 cities:- Ahmedabad, Delhi, Mumbai, Chennai, Bengaluru, and Hyderabad. We will only look at data from 2019 onwards for this.

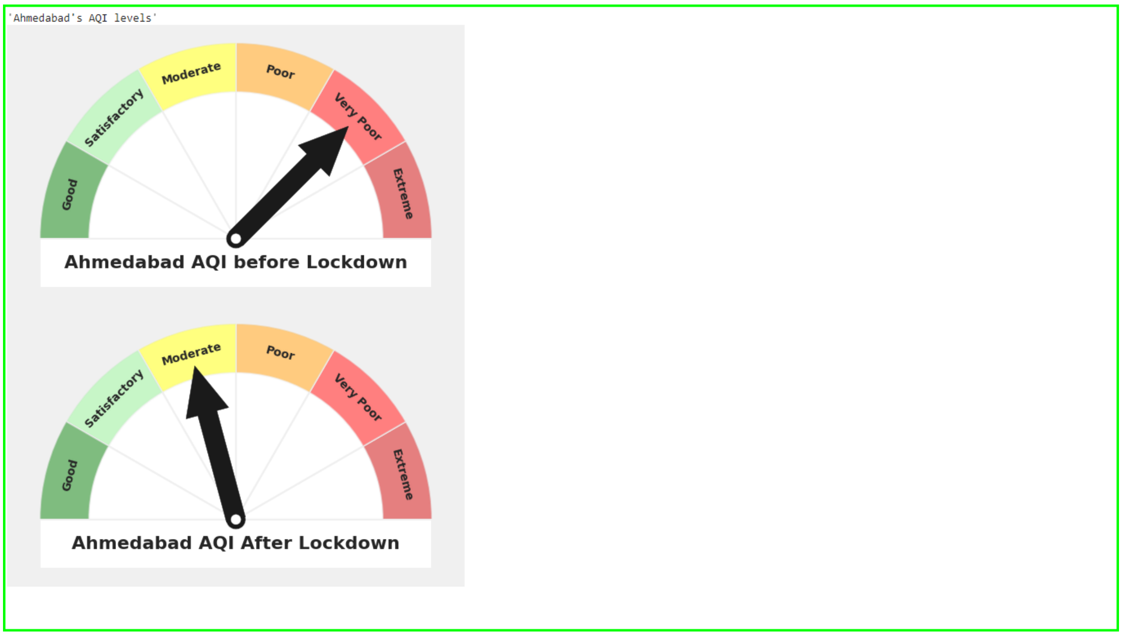


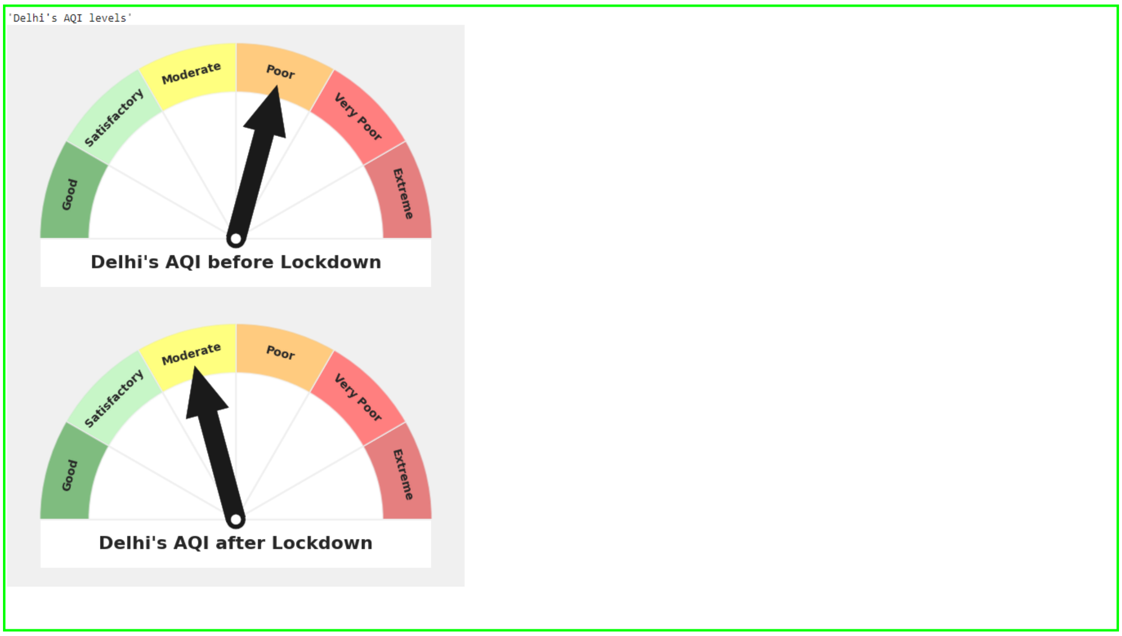


In fig 4.10,4.11 we can see the data on which India's first phase of lockdown went into force is indicated by black vertical lines. From January 2019 until the present, the graph above depicts the variance in various pollutant levels.

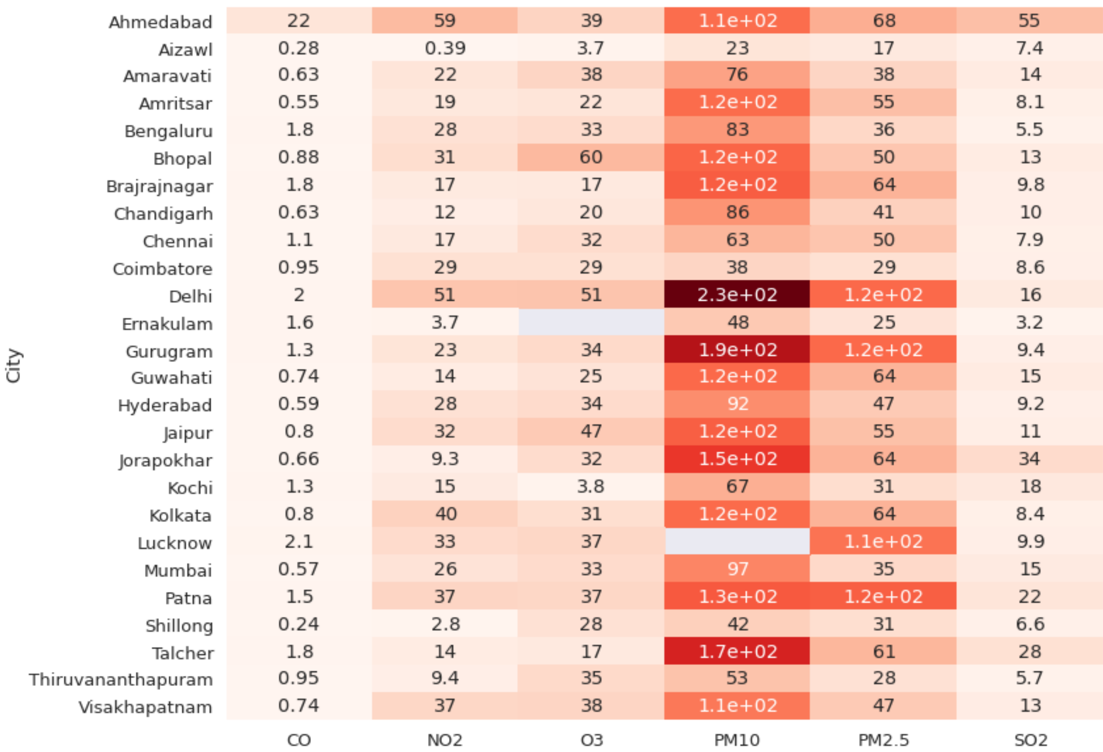
Unfortunately, all of the Indian cities listed above appear to have an extremely high level of pollution concentration. Undoubtedly, all of the cities under consideration look to be seeing a fast decrease after March 2020.

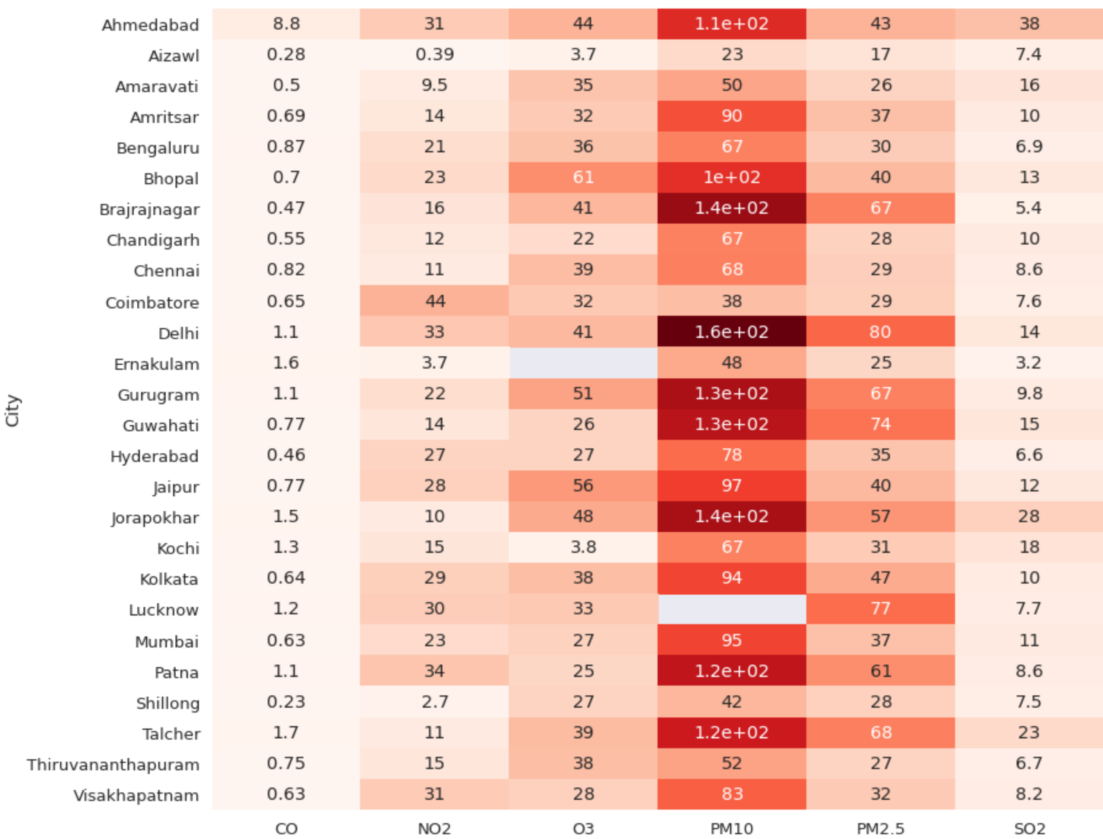
For better understanding, we have plotted gauge meters having labels:- Good, Satisfactory, Moderate, Poor, Very Poor, and Extreme representing AQI levels. For all the 3 cities mentioned above gauge-meter is shown in fig 4.12,4.13,414.





Lastly, to show the relationship between cities and type of pollutants(PM2.5, PM10, N02, CO, SO2, O3, BTX) for the 2015-2020 year and for the 2020 year is plotted in fig 4.15 & 4.16 respectively.


City
CO
NO2
O3
PM10
PM2.5
SO2
Ahmedabad 22 59 39 1.1e+02 68 55
Aizawl 0.28 0.39 3.7 23 17 7.4
Amaravati 0.63 22 38 76 38 14
Amritsar 0.55 19 22 1.2e+02 55 8.1
Bengaluru 1.8 28 33 83 36 5.5
Bhopal 0.88 31 60 1.2e+02 50 13
Brajrajnagar 1.8 17 17 1.2e+02 64 9.8
Chandigarh 0.63 12 20 86 41 10
Chennai 1.1 17 32 63 50 7.9
Coimbatore 0.95 29 29 38 29 8.6
Delhi 2 51 51 2.3e+02 1.2e+02 16
Ernakulam 1.6 3.7 48 25 3.2
Gurugram 1.3 23 34 1.9e+02 1.2e+02 9.4
Guwahati 0.74 14 25 1.2e+02 64 15
Hyderabad 0.59 28 34 92 47 9.2
Jaipur 0.8 32 47 1.2e+02 55 11
Jorapokhar 0.66 9.3 32 1.5e+02 64 34
Kochi 1.3 15 3.8 67 31 18
Kolkata 0.8 40 31 1.2e+02 64 8.4
Lucknow 2.1 33 37 1.1e+02 9.9
Mumbai 0.57 26 33 97 35 15
Patna 1.5 37 37 1.3e+02 1.2e+02 22
Shillong 0.24 2.8 28 42 31 6.6
Talcher 1.8 14 17 1.7e+02 61 28
Thiruvananthapuram 0.95 9.4 35 53 28 5.7
Visakhapatnam 0.74 37 38 1.1e+02 47 13


City
CO
NO2
O3
PM10
PM2.5
SO2
Ahmedabad 8.8 31 44 1.1e+02 43 38
Aizawl 0.28 0.39 3.7 23 17 7.4
Amaravati 0.5 9.5 35 50 26 16
Amritsar 0.69 14 32 90 37 10
Bengaluru 0.87 21 36 67 30 6.9
Bhopal 0.7 23 61 1e+02 40 13
Brajrajnagar 0.47 16 41 1.4e+02 67 5.4
Chandigarh 0.55 12 22 67 28 10
Chennai 0.82 11 39 68 29 8.6
Coimbatore 0.65 44 32 38 29 7.6
Delhi 1.1 33 41 1.6e+02 80 14
Ernakulam 1.6 3.7 48 25 3.2
Gurugram 1.1 22 51 1.3e+02 67 9.8
Guwahati 0.77 14 26 1.3e+02 74 15
Hyderabad 0.46 27 27 78 35 6.6
Jaipur 0.77 28 56 97 40 12
Jorapokhar 1.5 10 48 1.4e+02 57 28
Kochi 1.3 15 3.8 67 31 18
Kolkata 0.64 29 38 94 47 10
Lucknow 1.2 30 33 77 7.7
Mumbai 0.63 23 27 95 37 11
Patna 1.1 34 25 1.2e+02 61 8.6
Shillong 0.23 2.7 27 42 28 7.5
Talcher 1.7 11 39 1.2e+02 68 23
Thiruvananthapuram 0.75 15 38 52 27 6.7
Visakhapatnam 0.63 31 28 83 32 8.2

4.7 Conclusion:-

The Air Quality Index (AQI) has declined substantially throughout the country since the Janta Curfew on 22 March to date. Summer pollution levels in India are lower than winter levels. Nonetheless, the present drop in pollution levels in the country is owing to the country's lockdown. As a result, all plants and other enterprises have been closed since the last week of March. The AQI scores in Indo-Gangetic cities improved dramatically, going from the higher to the lower end of the scale, with seven cities moving to the satisfactory category and three cities going to the 'good' category, respectively. Concentrations of PM10 and PM2,5 reduced by nearly half compared to the pre-lockdown period. Air quality was improved by more than 60 percent in transport and industrial regions. Air quality has improNO2 and CO levels were also dramatically decreased during the lockdown. ved considerably in central and eastern Delhi. On the second and fourth days of lock-down, the air quality improved by 40 to 50 percent.

Concentrations of PM10 and PM2,5 diminished by almost half contrasted with the pre-lockdown time frame. NO2 and CO levels were likewise significantly diminished during the lockdown. Air quality was improved by in excess of 60% in transport and mechanical districts. Air quality has improved significantly in focal and eastern Delhi. On the second and fourth long stretches of lock-down, the air quality improved by 40 to 50 percent.

During the lock-out period in 2020, Delhi, Mumbai, Hyderabad, Kolkata, and Chennai showed a considerable decrease in PM2.5 and AQI (Air Quality Index) as well as a downturn in the tropospheric NO2 level over the year. The air quality for the entire lock-up period has improved considerably, providing the municipal governments with critical information in drafting regulations and legislation to improve air quality. Delhi has also seen significant improvements, with high pollution levels being dealt with virtually all year. A good AQI is between 0 and 50, a decent AQI is between 51 and 100, a moderate AQI is between 101 and 200, a bad AQI is between 201 and 300, and an AQI of 401-500 is extremely poor. The Air Quality Index is a method of measuring air quality that takes several factors into consideration. Clean air is represented in the AQI. The lower the AQI, the better. Patna in Bihar and Delhi were the most polluted cities with a PM2.5 concentration of 123 and 117µg/m3 respectively. Delhi and Gurugram were the most polluted cities with a PM10 concentration of 232 and 191µg/m3 respectively. Ahmedabad has the highest level of NO2, SO2, and CO concentration of 59,55.2, and 22.1µg/m3 respectively. Nitrogen dioxide (NO2) is a greenhouse gas released by fossil-fuel burning and has been substantially decreased, averaging 13% in India and 31.5% in six towns. The national capital fell by 40 percent.

CHAPTER 5

Challenges and Discussion

5.1Challenges:-

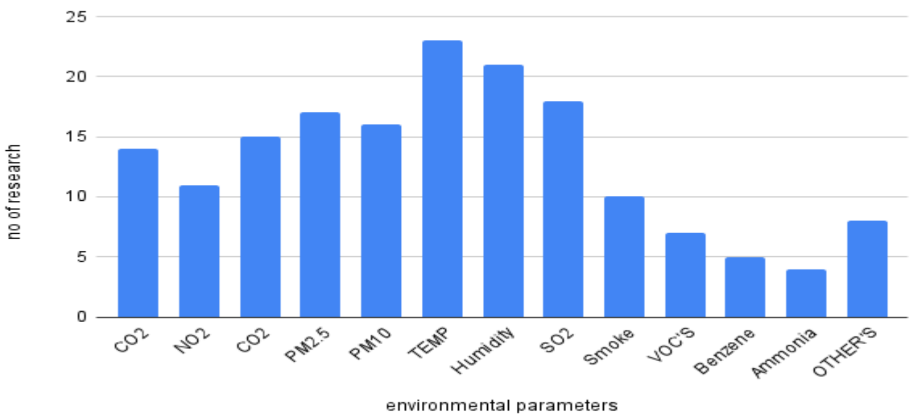
- Large-scale IoT-based smart air quality/pollution monitoring systems are difficult to deploy and maintain.
- Air quality monitoring systems based on the Internet of Things use communication technologies and protocols, but they are not reliable or standardized.
- Smart city implementation on a large scale.
- IoT necessitates cloud and backend services.
- There is a lot of power being used.
- Availability of network coverage.
- Scalability is essential if we need to connect multiple devices at the same time.
- Inadequate security and privacy standards, as well as a lack of end-to-end protection solutions.
- We needed to implement more energy-saving measures.
- the use of renewable energy in a device is required.
- a standard for the handling of unstructured data.
- Newer aggregation tools require technical skills, which can be learned.
- machines can communicate with each other, or "machine interoperability."
- The adoption of new technologies is sluggish.

5.2 Results and Discussion:-

Our research and studies include the different types of air pollution for indoor and outdoor environments. We have analyzed the different types of major air pollutants, their effects on health and its significant sources of emissions. In table 1 we have studied AQI levels, AQI values, color, and its effect. Using the Air quality index(AQI), we can compare real-time air quality at various locations. In this study, environmental parameters were monitored using a variety of models, methodologies, and sensors.

Figure 5.1 depicts the pollutants that were determined to be the most important in the study. All of these pollutants have long piqued the curiosity of researchers. Measuring and monitoring these pollutants have been the only significant advances in the last decade or so.

Figure 5.1 Histogram of environmental parameter by the reviewed system.

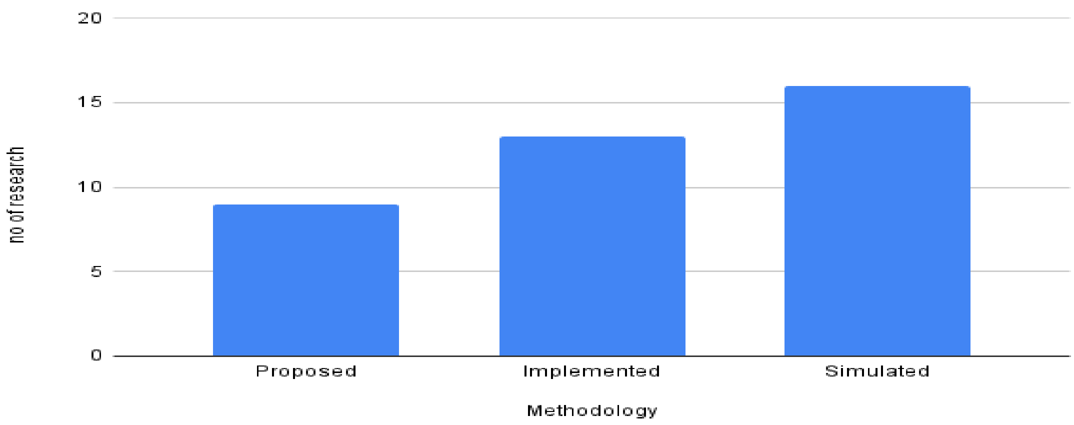


In table 10, it presents the summary of existing techniques, models, network architectures of air pollution monitoring systems on various environmental parameters such as CO2, CO, PM 2.5/10, NO2, benzene, etc.. the review was carried out based on several factors including:-

- Low-cost monitoring system
- Fixed sensor-based monitoring system
- Traditional air monitoring system
- Automobile sensor/ RFID based monitoring system

An air quality monitoring system for smart cities has been included in the majority of reviews, therefore nine systems have presented a proposed framework, thirteen systems have presented implemented models, and sixteen systems have presented simulation models, as shown in figure 5.2

Figure 5.2 Histogram of APMS model..



The effectiveness of smart air pollution monitoring systems is assessed using a variety of criteria, including reliability, techniques, and models used, low cost, low power consumption, and accuracy. Sensors that analyze different pollution in the environment play an important role in an air pollution monitoring system. The most important evaluation parameters of air pollution monitoring systems are PPM concentration and air quality index (AQI) value.

In table 4, it shows the different types of microcontroller boards used in the existing systems. The most common microcontroller board used by the researchers is Arduino because it is user-friendly. In addition, it has a large amount of memory (RAM) as well as a hard drive (ROM). It is also very simple to program on the Arduino due to the availability of pre-made functions whereas Raspberry pi is more powerful than Arduino as it can easily handle multitasking and run more complex advanced functions.

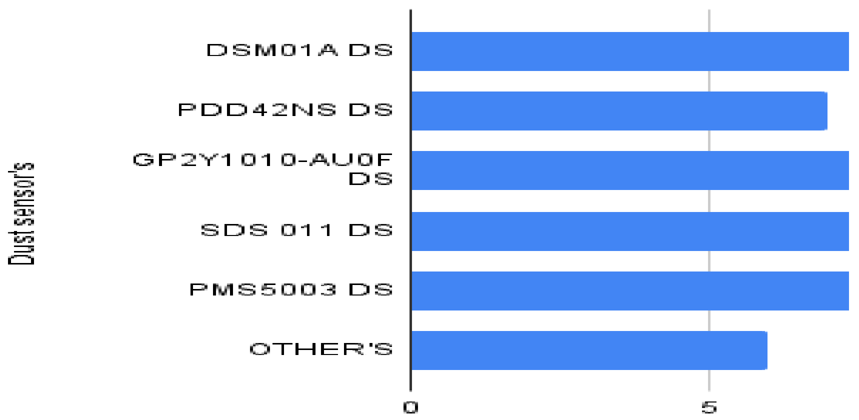
In table 3, it shows the different versions of Arduino. Arduino UNO is the most common microcontroller amongst researchers. A 16 MHz Atmega328 processor, 32kb of program memory, 1kb of EEPROM, and 2kb of RAM are included. The Arduino Mega is faster than Arduino nano and has more I/O chips. The Arduino UNO has a larger footprint. For applications using the Arduino mega, I/O pins and a variety of communication protocols are typical requirements to be met. In terms of size and weight, the Arduino Nano is the smallest and lightest device. UNO is a small microcontroller board that can be connected to several tasks such as remote-controlled robots or cars. It's difficult to use the Arduino Mega because of its size. When it comes to more computational power, the Arduino Mega is best with more GPIO.

Because of IoT innovations, every object can now be connected to the internet. Most entities including homes, offices, and factories are now connected to the internet to collect and use data for a variety of purposes. According to many experts, "data is the new oil".

Sensors are essential when it comes to developing IoT solutions. A sensor is a device that detects external data and converts it into a signal that humans and machines can interpret. As a result, sensors are now widely used in a wide range of applications, including medical care, nursing, industries, and logistical logistics and transportation, agricultural, disaster prevention, tourism, and regional business. Because of the expansion of fields in which sensors play an important role, the market for a variety of sensors continues to grow. Sensor networks are widely acknowledged to be a critical technology in the Internet of Things (IoT). This technology has the potential to shape the world through the measurement, inference, and comprehension of environmental indicators. In recent years, technological advancements have made it possible to use remote sensing applications on a large scale with devices that are both efficient and low-cost. Smartphones are connected to a variety of sensors, enabling a variety of mobile applications in a variety of IoT domains. Processing large-scale sensor data is the most difficult task due to energy and network limitations, as well as other unknowns.

In table 5, we have discussed the different PM 2.5/10 concentrations (Dust Sensor). Optical dust sensor-GPY2Y1010AU0F is the most common dust sensor designed to predict dust particles. As a result, because it is particularly good at detecting very small particles such as cigarette smoke, it is widely used in air purifiers too. It is a small and compact package of (46*30*17.6mm). It has minimal power consumption (Icc: Max- 20 mA). It can easily detect airborne dust particles having single pulse photometry. It can recognize the difference between smoke and dust in the surrounding area. Figure 5.3 shows the most common Dust Sensors. GP2Y1010-AUF and DSM501A are the most frequent dust sensors because of their operating conditions and reaction time interval.

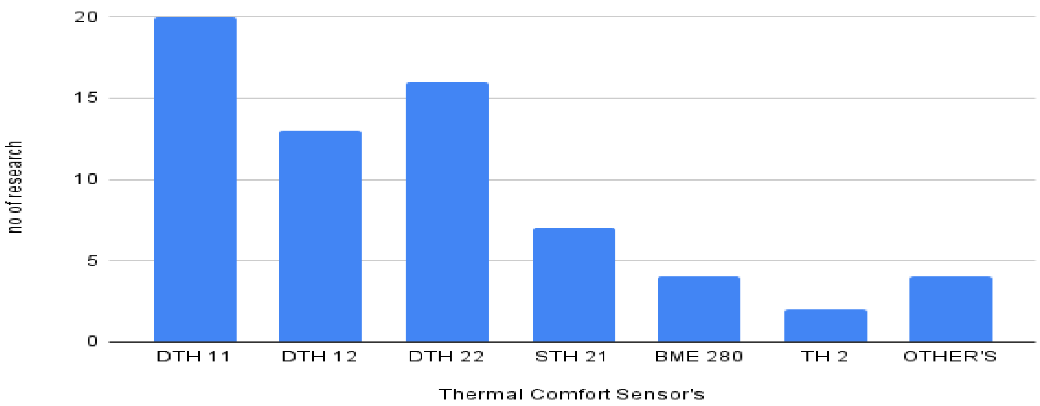
Figure 5.3 Histogram of dust sensor(reviewed in the study).



Based on the analysis of table 6, different types of thermal comfort sensors are discussed. DTH11 is the most commonly used sensor amongst the researchers. DTH11 is a low-cost, small-size temperature and humidity sensor. DTH11 has some disadvantages including a smaller form factor and a narrower temp/humidity range from 20 to 80% with 5% accuracy. For the big project and research that requires accuracy, the DTH22 is the way to go, having a range from 0 to 100% with 2-5% accuracy. DTH22 is expensive as compared to DTH11. STH 21 is 6 DFN pin temperature and humidity sensor IC. Regarding size & intelligence, it has become a standard in the field of computing. Because of its proven reliability & long-term stability, the STH21 has an excellent performance-to-price ratio.

Figure 5.4 depicts the most common thermal comfort sensors. Because of its inexpensive cost, the DHT11 digital temperature and humidity sensor is the most commonly used sensor. The DTH 11 sensor has low power consumption and exceptional long-term stability.

Figure 5.4 Histogram of Thermal comfort sensor(reviewed in the study).



Tables 7 and 8 represent the various gas sensors which are classified as dynamic attribute gas sensors respectively.
For example, the MQ series of gas sensors includes an electrochemical sensor as well as a small heater because of their broad range of gas detection, they are ideal for indoor use at room temperature.
They can be calibrated to some extent, but only if the measured gas or gasses are of known concentration. Many sensors in the MQ series have a 1-watt absorption rate because the heating element consumes so much energy (5U here means less than 200 milliamperes). With the MQ series of gas sensors, measuring or detecting a specific gas has never been easier or less expensive.
MQ 135 is the most common gas sensor used for air pollution monitoring. MQ 135 is an air quality sensor that can detect a wide range of gasses like NH3, NOX, and alcohol as well as smoke and carbon dioxide. This sensor is best suited for use in a factory or office. The MQ 135 gas sensor can detect smoke and other harmful gasses. Because of its low cost and ease of use, it is ideal for air quality monitoring applications. MQ 2 is suitable for Methane, Butane, smoke, and LPG whereas MQ 4 is suitable for Methane and CNG gasses. MQ 9 is used to detect carbon monoxide, flammable gasses, MQ 7 is used to detect carbon monoxide only. MQ 137 is used to detect the ammonia level in the air whereas MQ 136 is used to detect the Hydrogen Sulphide gas concentration in the environment. SPEC-03 is used to measure ozone concentration with a range of 0-5 ppm. Figure 5.5 depicts dynamic and single attribute gas sensors. The most prevalent dynamic sensor, the MQ-135, is the most widely used dynamic sensor. The MQ-135 can detect gasses such as ammonia, sulfur, and benzene. MQ-135 which operates on 2.5 to 5.0 volts, also generates digital and analog outputs.

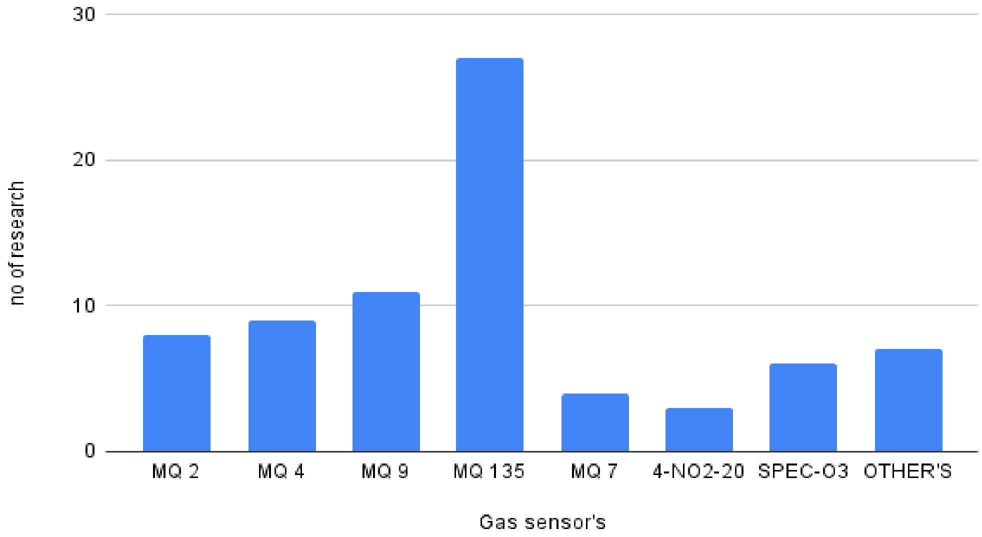


Figure 5.5 Histogram of Gas sensor(reviewed in the study).

Table 9 represents the different communication technologies that are classified on various parameters like range, frequency, data transmission rate. Bluetooth wireless technology eliminates the need for proprietary cabling between devices such as laptop computers, handheld computers, PDAs, digital cameras, and laser printers. Has a range of 10 to 100 meters and communicates at less than 1 Mbps. Bluetooth adheres to the IEEE 802.15.1 standard. ZigBee is one of the most widely used protocols for improving the capabilities of wireless sensor networks. ZigBee has a low data rate, a relatively short transmission range, and a flexible protocol design in addition to its low cost. IEEE 802.15.4 defines it as a low-power wireless network protocol. The ZigBee protocol has a range of approximately 100 meters and a bandwidth of 250 kbps for home use. This is due to the energy-efficient design of IEEE 802.15.4-based protocols such as ZigBee and IEEE 802.15.4-based protocols. This is due to the recent development of more efficient Wi-Fi components and an appropriate system design. Bluetooth, ZigBee, and RFID are a few examples of technologies with limited transmission ranges. Radio waves are used in RFID to wirelessly transmit the identity of an object or person in the form of a serial number. RFID technology is essential for identifying objects in the Internet of Things. Wi-Fi is comparable to ZigBee and RF Link, but they cannot broadcast data because they only communicate between two devices. It is simple to integrate into existing infrastructure because IP network compatibility is built into the technology. Wi-Fi (Wireless Fidelity) is a networking protocol that allows computers and other devices to communicate wirelessly. Figure 5.6 depicts the most common communication technology used in an air pollution monitoring system. Bluetooth and wi-fi are the most widely used technologies, followed by GSM. NFC, RFID, ZIGBEE, and Sigfox are uncommon technologies because they are difficult to install due to their limited range in Air quality monitoring systems.

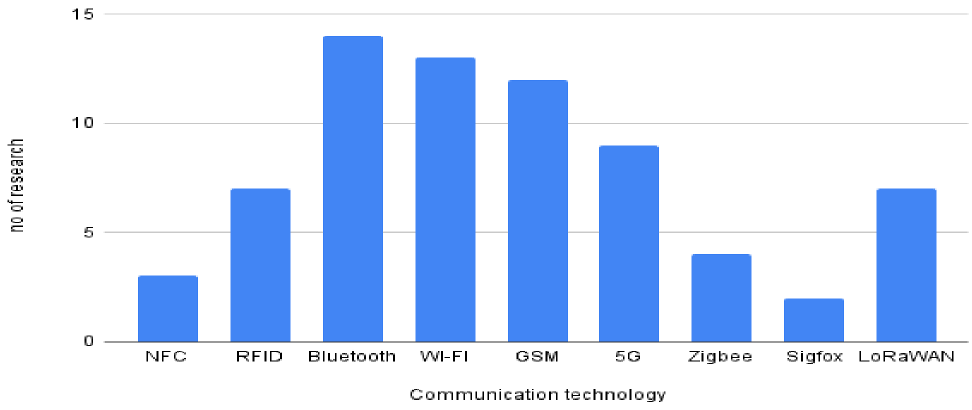


Figure 5.6 Histogram of Communication technology (reviewed in the study).

5.3 Analysis

Based on a thorough review of the literature on various smart air quality monitoring systems and architecture, this section includes an analysis and a few key recommendations.

The smart air quality monitoring system was thoroughly examined in addition to providing information on air pollution, types of air pollution, various types of air pollutants, and their health effects. Sensors, microcontrollers, communication technology, and protocols used over the last two decades were also discussed and thoroughly reviewed.

According to a comprehensive study on smart environmental monitoring systems, the following major findings are-

1. Smart air pollution monitoring systems, as well as the design of innovative urban living environments, are areas of research focus that would also contribute to long-term economic growth.
2. The research model/methods studied in the literature review section are classified based on sensor data, the algorithm used, the protocol used, cost, IoT device used, and different types of sensors used to sense various environmental parameters.
3. A review was done on four different types of sensors: thermal comfort and PM2.5/10 dust sensors as well as dynamic and single-attribute gas sensors.
4. The accuracy of each sensor is critical when it comes to error rates and overall system performance. The sensors must comply with a set of operating conditions. The sensor ranges are critical in the selection of Gas Sensors.
5. From sensor cost to working conditions to sensor response time, all of these factors play a role in the decision-making process. In extreme cold or extreme heat, neither all sensors nor all high-temperature sensors can function properly. However, some sensors must be calibrated regularly, whereas others are already set up.
6. To collect data for a real-time monitoring system, various communication technologies/protocols are used. Data rates and bandwidths differ depending on the communication technology. It is unusual to see the use of new communication technologies, methods, and models in smart air pollution monitoring systems.

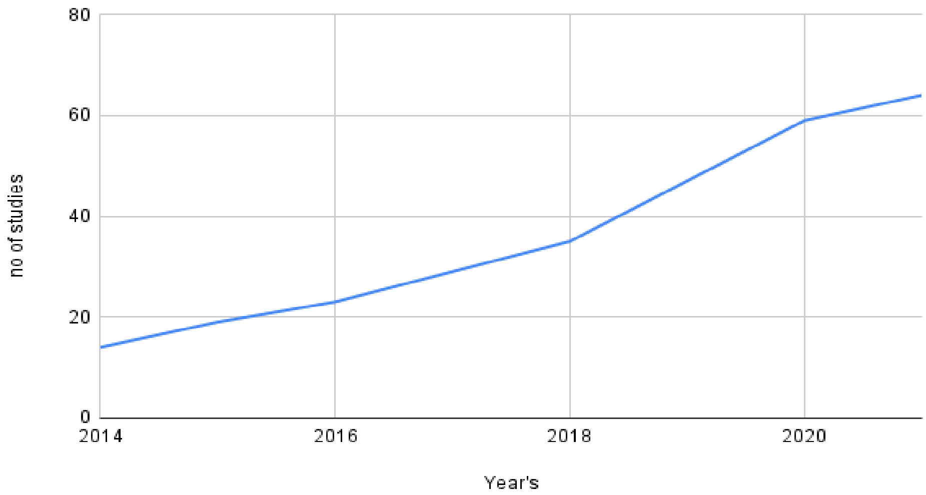
We recommend the following to make environmental monitoring systems more reliable, intelligent, and cost-effective:

1. It is critical to developing a framework for machine learning methods.

2. Regardless of the purpose of using the Smart air pollution monitoring system, a robust set of characterization, prognostication, and modeling techniques that can operate on any data must be developed.
3. Smart air pollution monitoring systems and smart environments are essential for long-term development. It is still difficult to install loT, WSN, and other sensors in rural areas, as well as in the majority of low and middle-income countries. As a result, both local and global governments must become involved.
4. A variety of standards and protocols are available to address interface problems and technical challenges in the implementation of various types of sensors.

CHAPTER 6
CONCLUSION

The massive problem of air pollution endangers human health. Because of recent advances in IoT and embedded systems (low-cost smart sensors), we have conducted extensive research on Air Quality Monitoring. Figure 18 depicts the number of research studies conducted from 2014 to 2021. Without a doubt, the number of studies has increased in recent years.



With the help of this study, we will examine air pollution monitoring systems and determine the best solution for today and tomorrow so that the consequences of air pollution can be avoided. This paper provides a detailed comparison of air pollution monitoring systems from around the world. In addition to calculating the air quality index, the researchers investigated gas detection methods, communication modes, and sensor calibration. This paper conducted an in-depth investigation of air pollution monitoring in order to develop a reliable air pollution monitor.

This paper presents the low-cost and low-power consumption air quality monitoring system using different MQ-series sensors and Dust sensors. This paper also represents the literature review of the existing models, and techniques used to design and analyze the prototype and its data. *The prototype was deployed in a particular region of Delhi, and has collected sensor data over some time, consisting of different levels of pollutants. Several prominent Data-driven modeling and analysis techniques, namely PCA, TOPSIS, and CCA, were used for analyzing features and predictions. The PCA algorithm to analyze helps in the identification of decision thresholds as the output consists of extremely negative and extreme positive components.* From the PCA graph, we understood how AQI values are aligned towards the above points on a particular day. According to PCA most of the values are aligned towards an extremely negative point which indicates that AQI values on that particular day are very high making air quality levels hazardous. Whereas from the TOPSIS algorithm we can conclude how day-to-day urban activities like vehicular traffic, industrial gasses, burning of crops, and crackers at festivals are affecting the AQI values. TOPSIS score indicates the level of pollution in AQI values on a particular day when compared to another day.

In the future, several prototypes can be deployed for better coverage in different areas to collect the different values for analysis in a better way. In the future, the application of fog computing layered architecture for data preprocessing shall enable better analysis. Cloud platforms can be used to store the collected data from the real-time monitoring system. *Thus enabling a healthier environment for smart urban living spaces

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