REAL TIME ENVIRONMENTAL PARAMETER ANALYSIS USING IOT BASED PLATFORM

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Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Abstract

Environmental pollution is a global issue and air pollution is its silent killer for every country in the world whether it is developed or developing. The largest amount of environment pollution is happening due to toxicity of air which endangers the whole planet lives. Health issues of these airborne pollution are wide ranged. It affects plants, living animals, most importantly human bodies with short or long-term diseases and in hazardous situation it brings death for man lives. In order to detect the presence of pollutant gases in air, this research was proposed. The environmental parameters are detected in a proper way and uploaded to IoT server. The data are real-time and accessible from anywhere as long as the device is connected to internet. The data were collected from Dhaka city and using the collected data, a comparative analysis is done between the fully lockdown period of COVID-19 and the no lockdown condition of recent time. The finding of this research suggest, air pollution must be reduced for a better and healthy environment for human being.

Keywords: Environment; pollution; Air Quality; Real-time; Data; IoT; Health Issue.

Dedication

This study is wholeheartedly dedicated to our belove parents who were our source of inspiration, support and strength when we were in thought of giving up.

Also, most importantly all thanks to The Almighty ALLAH for whom we are still breathing.

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List of Acronyms

AQI	Air Quality Index
PM	Particulate Matter
PPM	Parts Per Million
PPB	Parts Per Billion
CO	Carbon Monoxide
CO2	Carbon Dioxide
NH4	Ammonia
CH4	Methane
NOx	Nitrogen Oxide
NO2	Nitrogen Dioxide
O3	Ozone
LPG	Liquified Petroleum Gas
µg/m3	Micrograms per Cubic Meter
EPA	Environmental Protection Agency (US)
NAAQS	National Ambient Air Quality Standards
IDE	Integrated Development Environment
IoT	Internet of Things
API	Application Programming Interface
VCC	Voltage Common Collector
GND	Ground

Chapter 1

Introduction

1.1 Introduction

Air is one of the most basic elements we all living species need to live by. We literally have to breathe air every second in order to function normally. But it is a matter of sadness that the air has been polluted in many ways over the years. The pollution has been on its peek since the starting of industrialization era and it's getting worse day by day. In Bangladesh the situation is not so different. Specially in Dhaka, the pollution is at its best. The air quality in Dhaka is on verge of being labeled as toxic for its contamination. It has an effect on all living creatures including us humans as well as on the natural harmony of the environment. The pollution is caused for some specific reasons such as particular matter, harmful materials and some biological molecules in the atmosphere [1]. According to a news report, Bangladesh has the worst air quality and Dhaka was the 21st most polluted city in the world [2]. This actually shows the alarming situation of our environment which might affect in our existence in future world. The project is all about the quality of air we're breathing constantly in Dhaka city and its effects on us.

1.2 Background

Air is mainly consisting of various types of gases like nitrogen, oxygen, carbon dioxide etc. and some particulate matters. Some of these gases are harmful for human health and the atmosphere around us. All the particles stay together in certain concentration in the air. When this concentration somehow changes it is being considered as a polluted one. Air Pollution is increasing heavily these days due to the many important factors like Vehicle Emissions, Deforestation and Industrialization [3]. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

(IPCC), nearly all climate-altering pollutants either directly or indirectly (by contributing to secondary pollutants in the atmosphere) are responsible for health problems [4]. Almost every citizen spends 90% of their time in indoor air [5]. Outdoor air quality of the cities of developed countries improved considerably in recent decades. In contrast to this, indoor air quality degraded during this same period because of many factors like reduced ventilation, energy conservation and the introduction to new sources and new materials that cause indoor pollution [6].

Carbon Di Oxide is the most dangerous gas for human health. The increasing of this particle threatens the future of this planet. [7] Planet earth is getting warmer and specific places are warming faster because of CO2. The signs of early spring are all around us, and not just this year.[8] Carbon Mono Oxide in the atmosphere affects the greenhouse gases. Carbon monoxide intoxication continues to be one of the most common causes of morbidity due to poisoning in the United States [9]. These gases are linked to the global change and climate warning which is the most concerning for our environment.

Some air pollutants such as ozone, sulfates, and methane also cause changes in climate [10]. If methane leaks into the air before being employed from a leaky pipe, as an example it absorbs the sun's heat, warming the atmosphere [11]. Ozone damages tree leaves and negatively affects scenic vistas in protected natural areas. Heavy metal compounds that are emitted into the air from fuel combustion and deposited ashore and in water accumulates in plants and animals, a number of which are consumed by people.

Particulate matter is a liquid or solid matter which is microscopic and suspended in Earth's atmosphere. Particulate matter has the most significant contribution to the increase in air pollution [2]. In Dhaka, Bangladesh, particular matter (PM) is the air pollutant that is most harmful to public health and the environment when compared to other measured criteria pollutants. During recent years, the Government of Bangladesh has tried to control PM emissions coming from anthropogenic sources. About 30–50% of the PM_{10} mass in Dhaka (depending on location) is in fine particles with aerodynamic diameter less than 2.2 µm [12]. These particles are mainly of anthropogenic origin and predominately from transport–related sources [13]. However, the studies that we usually see in terms of air quality, most of them don't have information regarding particular matter. It is very important to know the concentration of particular matter in the atmosphere to get the actual result of Air quality.

To address this problem, a system consisting of SDS0111 which is a PM sensor is being used for monitoring the particulate matter along with the sensors employed for sensing carbon monoxide, carbon dioxide, methane, ozone, Temperature, Humidity and barometric air pressure using raspberry pi. We have used Raspberry pi to process all the data we got from Arduino Mega where all the sensors were integrated. Raspberry pi is a low power, less expensive, highly flexible minicomputer [14]. We also know that air quality varies from time to time because of the weather. By measuring the concentration of different air particles from time to time we can analyze the changes of the air quality. By comparing the measurement with National Ambient Air Quality Standards (NAAQS) we can know in which seasons we face the most air pollution.

Internet of Things (IoT) and cloud computing are the most emerging technologies that have been invented in recent years. IoT is a concept or in which without human interruption devices detects, identify, process and communicate with each other on their own [15]. The user can access the data that are being attained from the system later and then use them in research purposes. With added sensors, IoT based devices are able to collect a large amount of data on many different areas. As the devices of IoT interact and communicate with each other and do lot of task for us, then they minimize the human effort. A greater flow of information means that people behind the device can analyze large trends in the data to improve the features of the device [16].

1.3 Literature Review

There has been a significant amount of work have been done and there are many projects going on air quality all around the world. Because of the geographical diversity, the quality is not same in every place on the earth. But the standard is pretty much same everywhere. According to United States Environmental Protection Agency, there is a standard chart of the ideal concentration of all the elements in the air [17]. Now a days, home based air quality system has been an attraction to the researchers and science enthusiasts. Like [18] built a system where the system sends signals and protocols to the user continuously about the detailed concentration of elements of the air. There was a project [19] where an Unmanned Aerial Vehicle (UAV) based system was prepared in order to monitor the air pollution in rural areas. It was run by an autopilot for UAV control and a Raspberry Pi for sensing and collaborating the air pollution data.

There has been some work like [20] regarding industrial air pollution and its impacts on human bodies which is very severe in some cases. Marinov, Marin B. et al [21] worked on environmental parameters with atmospheric sensors and gas sensors (infrared) using the PIC18F87K22 microcontroller as system base. Sensors were set up in different areas for real time monitoring of environment and the results were displayed in a city map. Shete, Rohini and Agrawal S. [22] did their project which shows the framework for monitoring the city environment. A low-cost Raspberry pi was used to implanting the system. Parameters like carbon monoxide, carbon dioxide, temperature were measured in their project. In some cases, machine learning has been used in order to observe the air quality, like Chiwewe, Tapiwa M., and Jeofrey Ditsela [23] collected air quality data from different cities of South Africa. Machine learning technique was applied to the data and prediction models were generated for ground level ozone.

Recursive Converging Quartiles (RCQ) algorithm was imposed in [24] to improve the efficiency of wireless air pollution monitoring system. RCQ algorithm aggregates and eliminates data duplicates by removing invalid readings which saves storage space and makes the system more efficient. The system consisted of sensor nodes and wireless communication links to a server. The sensors collected data automatically get passed it on through the network to the server. The authors in [25] proposed a model where the concentration was measured and showed in a website in real time basis. An optimal Wireless Sensor Network (WSN) was proposed in [26] for monitoring the level of pollutants in the air. The system was enhanced by utilizing a flow concept that gave a combined result of the concentrations in the air.

An ambient real-time air quality monitoring system that constructed with some distributed monitoring stations which were connected wirelessly using machine-to-machine communication to a server station where all of the data were collected and analyzed [27]. The server reproduced the data as information that can be delivered to users through web portals and mobile applications. The use of Supervisory Control and Data Acquisition (SCADA) for air pollution monitoring was used in a project [28]. It enabled the acquisition and statistical processing of measured data in real time. The SCADA shows the results of different parameters to users instantly in websites. There is a project based on IoT where the authors used raspberry pi as their minicomputer to assemble and calculate all the data from various sensors of their device [29]. They've observed the environment for air pollution and noise for two months in order to come to a conclusion.

Metamorphic changes in the air were the main subject of a project [30]. Raspberry pi was used in the system as the main platform to collaborate different sensors in order to observe fluctuation of two or three parameters of Carbon Monoxide (CO) and other gases from the ideal level. The results were consisting of real-time air pollution data can be monitored on a website within the network's coverage. However, the parameters considered are not sufficient to give an accurate prediction of air pollution over a long time. In [31], another IoT based project was formulated regarding air pollution using Single Board Computers (SBC) which integrates IoT with wireless sensor network (WSN). Because of SBC, the data processing got efficient and less time consuming which made the alerting process smart and in real-time. Results showed that the proposed system offered a low-cost implementation that was very flexible and scalable. The only limitation of the project was its coverage which was not quite wide in terms of area.

In the paper [32] authors implement a system based on machine learning on the real time dataset collected from the 'Thingspeak' website and tried to convey the information about the effects on humans' health to the people and government if the same pollution continues [33,34]. Even though they were not clear about the consequences specifically according to the effects of the parameters. There have been some projects based on Arduino like in [35], .MQ135 gas sensor was used to sense different type of dangerous gases. Arduino collected the data from the server the uploaded the data to a server using external wifi module and because of this module, the system was not really efficient as it was an extra cost and power consuming. Authors have used a Local Host which is limited where they are able to see the output only on the laptop within the area where experimental setup is connected [36]. They've also worked on IoT to monitor the data from any places around the world, but it wasn't efficient in the end for low quality processor. Image processing and machine learning were used in [37] to monitor some parameters of air and big data techniques was used to analyze sensor values for the prediction of future values. The system was very stable and effective. There was an effort to make the system auto-communicative in order to be more efficient. The system was also automated for real- time monitoring which will helped to monitor industrial output [38-42].

In order to measure the real time concentration of some particular parameters, the project has been done in an indoor environment. By using IoT the collected data can be accessible to everyone around the whole world which is useful in terms of comparing the situation to an ideal environment.

1.4 Objective

This project is done to monitor the quality of air we're breathing in Dhaka city by measuring some essential parameters and their concentration. The results are prepared for comparison studies with the ideal situation of an environment. The project is also aimed to monitor the data live from a cloud server which will be accessible to everyone all around the world.

1.5 Scope of the project

A device has been made along with all the sensors integrated altogether in order to measure the concentration of various elements of the air and constantly comparing them with the ideal concentration. All the data have been collected in an indoor environment which is pretty much close to the outdoor as far as the air quality is concerned. There are three sets of data which represents the situation of the Dhaka's air quality in before, in between and at the last stage of Covid-19 outbreak in Bangladesh. With the analysis of these data we can come up with a statement about the change of air quality in this specific time.

1.6 Outline of the Thesis

The book has been organized in such a way that; **Chapter 1** represents the introduction with literature review. In **Chapter 2** theoretical background has been discussed. **Chapter 3** shows the experimental setup and its methodology and in **Chapter 4** the experiment data has been analyzed and discussed. Lastly, **Chapter 5** has the Conclusion and future plan of this thesis project.

Chapter 2

Theoretical Background

2.1 Environment and Toxicity in Air

Environmental issues are now a days the most alarming factor for the whole world. Every single day the environment pollution is making a new record for many places and Bangladesh is one top among them. From the beginning of last year, the environmental condition of Bangladesh was noticeably getting worse day by day. Due to large number of vehicles in road, construction and implementation of new giant projects Dhaka city was leaving its livability. In the meantime, on Wednesday April 24th of 2019, Dhaka city ranked worlds' second most polluted city in the world in terms of polluted air.[43] The issue became a burning question but the massive acknowledgement all over the country could not do any better to the environment. As a result, again in November, 2019 Dhaka ranked top in terms of AQI among all other countries in the world. Then arisen the question that how the environment is getting polluted increasingly every day. To find its answer, we had to look forward to the major causes of environmental pollution in Bangladesh. With some research on that topic we got to know that, the environmental pollution of Bangladesh is mainly from pollutant air particles and gases. [44][45] So, we tried to find how the toxicity of gases are spreading in air, what are the sources what are the effects on lives.

2.2 Air Pollution Measurement

Air is polluted in many ways which we have been learning from each of our childhood but the sources of air pollutions and the amount of it from those sources are unknown and scary. Transports both public and privates are one of the major reasons of pollution. Over the last ten years, the percentage of private car and motorcycles has risen more than double in numbers and due to the rapid increase of all types of public and private transport, air elements like NOx, CO, PM 2.5 are getting higher in concentration day by day which is causing air pollution. [45] Then from Industries, Garments Sectors which are increasing in Bangladesh, the chemical discharges are not the same as before now. The pollutant gases from there are also working as dangerous and threatening object for air quality. Not only them, there are also many more reasons why our environment is polluting every day. Therefore, to find the detailed idea about what are the gases that are being polluted, what are their measurement, we met AQI which is the Air Quality Index, introduced by EPA, United States. Initially the name was PSI which stands for Pollutant Standard Index but in 1999, it was renamed as AQI and all over the world the AQI is measured in EPA Standard.

2.3 Air Quality Index (AQI)

The AQI is a numerical scale to determine daily air quality regarding to the environment and human health. Government uses this AQI number to show its people that how the air quality changes time to time. Every government uses their own scale to determine AQI according to its own air quality standards. The initial ambient air quality standards for Bangladesh are contained within the Environmental Conservation Rules, 1997[46].

We can know how polluted our surrounding air is and how much it can affect our health by AQI. The higher the AQI index is means the more dangerous our air is. The AQI focuses on health effects you'll experience within some hours or days after breathing polluted air. It helps to warn sensitive populations that they must take appropriate measures to scale back their exposure to the ambient air and to tell the final public that there are serious problems with air quality that require to be addressed as a societal responsibility to the full population.

2.4 Safety Measurements of AQI

Local air quality means how safe the air we breathe is. AQI may vary time to time or place to place. It is based on the exposure to all of the criteria pollutants (PM, CO, O_3, SO_2, and NO_2) with the AQI based on the worst exposure concentration for any of these pollutants. So, we have to know the toxicity level of the air particles.

For our better understandings AQI are divided into 6 different categories. They are:

- Good: If the AQI value is between 0-50 that means the air of the area is of no risk to the people. And the air is not polluted much.
- Moderate: AQI value of 50-100 means that the air is a little polluted and this much of pollution is acceptable.
- Unhealthy (for some): When AQI values are between 101 and 150, members of sensitive groups may experience health effects. This means they are likely to be affected at lower levels than the general public. For example, people with lung disease are at greater risk from exposure to ozone, while people with either lung disease or heart disease are at greater risk from exposure to particle pollution. The general public is not likely to be affected when the AQI is in this range [47].

- Unhealthy: The AQI value of 150-200 means that it reaches the unhealthy stage. In this kind of air everyone faces a great danger. Any normal human might experience severe problems. People who are sensitive will face more serious health effects. Government or agencies have to acknowledge its people when AQI reaches this line.
- Very Unhealthy: When the AQI value is between 200 to 300, it brings danger to all kind of people. This means everyone who is breathing Oxygen from this air will have health problems.
- Hazardous: If the AQI value goes more than 300, everyone around the area is in high danger. The whole habitants are going to be contrived.

Carbon Dioxide

As atmospheric levels of carbonic acid gas still escalate and drive temperature change, we have seen that the difficulty of CO_2 toxicity is not taken as a risk globally. The toxicity of CO_2 for breathing has been well defined for high concentrations but it remains effectively unknown what level will compromise human health when individuals are perpetually exposed for his or her lifetime.

PPM	AQI Level	Health Issues
250-400 ppm	Good	Background (normal) outdoor air level.
350-1,000 ppm	Moderate	Typical level found in occupied spaces with good air exchange
1,000-2,000 ppm	Unhealthy for some	Level associated with complaints of drowsiness and poor air

2,000-5,000 ppm	Unhealthy	Level associated with headaches, sleepiness, and stagnant, stale, stuffy air; poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
>5,000 ppm	Very Unhealthy	His indicates unusual air conditions where high levels of other gases also could be present. Toxicity or oxygen deprivation could occur. This is the permissible exposure limit for daily workplace exposures.
>5,000 ppm	Hazardous	This level is immediately harmful due to oxygen deprivation.

Table 2.1: Carbon Dioxide levels and potential health problem [48]

As we see indoor levels of CO_2 are relatively high and affecting health more, it is generally possible to obtain relief by going outdoors. We can also understand that if the CO_2 is more than 1000 PPM in the air it has already become harmful for our body. However, if the concentration becomes more it might lead to serious diseases to our body.

Carbon Monoxide

Carbon monoxide is a colorless, odorless, tasteless gas produced by burning gasoline, wood, propane, charcoal or other fuel. Improperly ventilated appliances and engines, particularly in a tightly sealed or enclosed space, may allow carbon monoxide to accumulate to dangerous levels.

Concentration	Health Concerns
50 PPM	None for healthy adults. According to the Occupational Safety & Health Administration (OSHA), this is the maximum allowable concentration for continuous exposure for healthy adults in any eight-hour period.
200 PPM	Slight headache, fatigue, dizziness, and nausea after two to three hours.
400 PPM	Frontal headaches with one to two hours. Life threatening after three hours.
800 PPM	Frontal headaches with one to two hours. Life threatening after three hours.
1600 PPM	Headache, dizziness and nausea within 20 minutes. Death within one hour.

Table 2.2: Carbon Monoxide Levels and Their Symptoms [49].

Carbon monoxide poisoning occurs when carbon monoxide builds up in your bloodstream. When too much carbon monoxide is in the air, your body replaces the oxygen in your red blood cells with carbon monoxide. This can lead to serious tissue damage, or even death [50]. From the chart we are shown the toxicity level of CO. Even a little amount of Carbon Monoxide is harmful for our body. If the quantity reaches 400 PPM, it might even threaten our lives.

Ozone

In the Earth's lower atmosphere, near ground level, ozone is formed when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources react chemically in the presence of sunlight. Ozone at ground level is a harmful air pollutant.

The OSHA website [48] cites several guidelines for ozone in the workplace:

- 0.2 ppm for no more than 2 hours exposure
- 0.1 ppm for 8 hours per day exposure doing light work
- 0.08 ppm for 8 hours per day exposure doing moderate work
- 0.05 ppm for 8 hours per day exposure doing heavy work
- OSHA guidelines for O_3 in the workplace are based on time-weighted averages. Ozone levels should never exceed the following average: 0.10 ppm (parts per million) for 8 hours per day exposure. For more detailed information on safe ozone levels, see the bullet points below [51]. Ozone in the air we breathe can harm our health. Children, older adults, people with asthma, outdoor workers are most at risk from breathing air containing ozone.

Methane (CH4)

Methane (CH4) is a major greenhouse gas. It is produced during anaerobic decomposition of manure and accumulates around manure storage areas.

Exposure Level (ppm)	Effect or Symptom
1000	NIOSH 8-hours TLV
50000-150000	Potentially Explosive
500000	Asphyxiation

Table 2.3: Methane exposure levels and effects [52]

The National Institute for Occupational Safety and Health's (NIOSH) maximum recommended safe methane concentration for workers during an 8-hour period is 1,000 ppm (0.1 percent). Methane is considered an asphyxiant at extremely high concentrations and can displace oxygen in the blood.[52]

PM 2.5

PM 2.5 is the particulate matters floating in the air which has the diameter less than 2.5 micrometers. These types of particles are so small that we can see those only by microscope. PM 2.5 might also harm us if it increases by a significant amount [53].

PM2.5	AQI Level	Health Effects
0-12	Good	Little to no risks
12-35.4	Moderate	Unusually sensitive individuals may experience respiratory system.
35.5-55.4	Unhealthy for sensitive	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.
55.4-150.4	Unhealthy	Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in general population.
150.4-250.4	Very Unhealthy	Significant aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; significant increase in respiratory effects in general population.
250.4-500	Hazardous	Serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; serious risk of respiratory effects in general population.

Table 2.4: levels of PM2.5 are harmful [54]

Fine particulate matter ($PM_{2.5}$) is an air pollutant that is a concern for people's health when levels in air are high. $PM_{2.5}$ are tiny particles in the air that reduce visibility and cause the air to appear hazy when levels are elevated. There are outdoor and indoor sources of fine particles. Outside, fine particles primarily come from car, truck, bus and off-road vehicle (e.g., construction equipment, snowmobile, locomotive) exhausts, other operations that involve the burning of fuels such as wood, heating oil or coal and natural sources such as forest and grass fires. Fine particles also form from the reaction of gases or droplets in the atmosphere from sources such as power plants. These chemical reactions can occur miles from the original source of the emissions. [55]

PM 10

PM10 is the particles with a diameter of 10 micrometers and they are also called fine particles. An environmental expert says that PM10 is also known as respirable particulate matter [56]. The particles are so small that they effectively act as a gas. When breathed in they penetrate deep into the lungs [57]. The level of PM10 in the air is increasing which is causing air pollution and on the other hand risk of diseases is also emerging day by day.

In the table below, the health impact due to PM 10 particulate matter is addressed with AQI level condition:

PM10 [ppm for 24 Hours]	AQI Level	Health Impacts
0-54	Good	The air is not much polluted so this a living air for human being.
55-154	Moderate	None for healthy adults.
155-254	Unhealthy for Sensitive people	Elder people or people with past health issues might have some concerns.
255-354	Unhealthy	All type of people will face health impacts like coughing and wheezing.
355-424	Very Unhealthy	This number of concentrations will make the place harder to live if someone is sensitive to air pollution. General people will also feel unbearable environment.
425-604	Hazardous	Exposure to this concentration of PM10 can result to asthma attacks and bronchitis to high blood pressure, heart attack, strokes and premature death.[57]

Table 2.5: Corresponding AQI Categories for PM10 Concentrations [58].

NO_2 and SO_2 are the other parameters of AQI but as per unavailability of sensor and data we decided to exclude those two from our research. However, the parameter PM2.5 is the superior of all air quality parameters which we took in count and CO and Ozone also are two most impacting gases. NO_2 and SO_2 are on that case comparatively less impacting in term of detecting pollutants.

2.5 AQI Calculation

Air Quality Index is measured differently in different regions. Canada, Hong Kong, UK and some other countries use their own way of calculating AQI. However, in this research USA oriented AQI is used and here is the calculation theory for AQI according to EPA:

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

where,

I = Air Quality Index

C = Pollutant concentration

C_{high} = Concentration breakpoint that is higher than C

C_{low} = Concentration breakpoint that is lower than C

I_{high} = Index breakpoint corresponding to C_{high}

I_{low} = Index breakpoint corresponding to C_{low}

The equation here is to calculate the AQI level but here are some unknown terms. Those are used by EPA for evaluating the AQI from the concentrations of specific gases. To get the values of those unknown terms C_{high}, C_{low}, I_{high} and I_{low}, the following chart is a must to use which indicates a constant value for individual specific gases per time in the environment.

O_3 (ppb)	PM 2.5 (µg/m^3)	PM 10 (µg/m^3)	CO (ppm)	SO_2 (ppb)	NO_2 (ppb)	AQI	AQI
C_{low} - C_{high}	C_{low} - C_{high}	C_{low} - C_{high}	C_{low} - C_{high}	C_{low} - C_{high}	C_{low} - C_{high}	I_{low} - I_{high}	Category
0-54 (8-hr)	0.0-12.0 (24-hr)	0-54 (24-hr)	0.0-4.4 (8-hr)	0-35 (1-hr)	0-53 (1-hr)	0-50	Good
55-70 (8-hr)	12.1-35.4 (24-hr)	55-154 (24-hr)	4.5-9.4 (8-hr)	36-75 (1-hr)	54-100 (1-hr)	51-100	Moderate
71-85 (8-hr)	35.5-55.4 (24-hr)	155-254 (24-hr)	9.5-12.4 (8-hr)	76-185 (1-hr)	101-360 (1-hr)	101-150	Unhealthy for Sensitive Groups
86-105 (8-hr)	55.5-150.4 (24-hr)	255-354 (24-hr)	12.5-15.4 (8-hr)	186-304 (1-hr)	361-649 (1-hr)	151-200	Unhealthy
106–200 (8-hr)	150.5-250.4 (24-hr)	355–424 (24-hr)	15.5-30.4 (8-hr)	305–604 (24-hr)	650-1249 (1-hr)	201-300	Very Unhealthy
405-504 (1-hr)	250.5-350.4 (24-hr)	425-504 (24-hr)	30.5-40.4 (8-hr)	605-804 (24-hr)	1250-1649 (1-hr)	301-400	Hazardous
505-604 (1-hr)	350.5-500.4 (24-hr)	505-604 (24-hr)	40.5-50.4 (8-hr)	805-1004 (24-hr)	1650-2049 (1-hr)	401-500	

Table 2.6: EPA Standard Air Quality Calculation Chart [59][60]

2.6 Sensor Theory

Since the research is based on AQI measurement, we had chosen all the available sensors that are capable of detecting AQI gases from the environment. The sensors that we had chosen for air quality index, were:

i) SDS-011 sensor for detecting PM 2.5 and PM 10 (dust)

ii) MQ-131 sensor for detecting Ozone

iii) MQ-7 sensor for detecting Carbon Monoxide

Besides those primary gas sensors, we also had some additional gas sensors to detect other elements in the air. Those were:

i) MQ-135 as Carbon Dioxide and Ammonia sensor

ii) MQ-4 as CH_4 sensor

iii) BMP280 as pressure sensor

iv) DHT11

In this research, most of the parameters were measured by MQ gas sensors. All the sensors work in a same way with micro controller and all of their integrations are same but, understanding the MQ sensors is a big and complex thing.

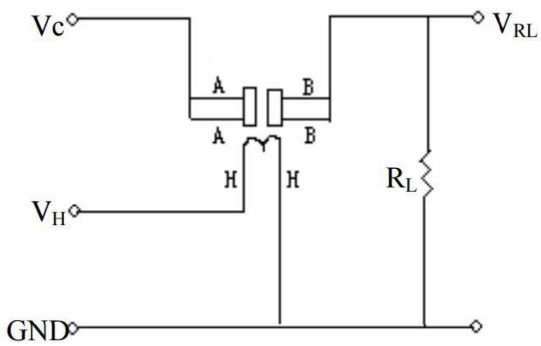

Figure 2.1: Basic MQ sensor Circuit (i) [61]

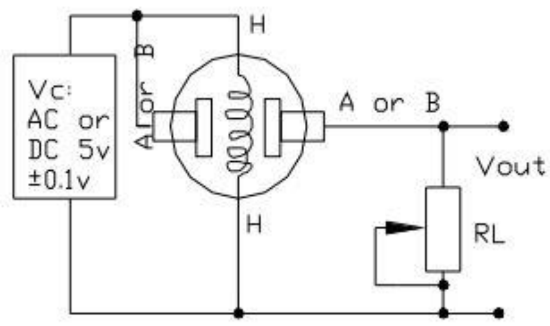

Figure 2.2: Basic MQ sensor Circuit (ii) [61]

Every MQ sensors contain a built-in resistor (R_s) [Fig 2.1] and that changes its value according to the concentration of gas. When the concentration is high, resistor decreases and if the concentration is low, the resistor increases. However, another load resistor (R_L) is required to be included in MQ sensors to serve better sensitivity and accuracy. The resistance value of the sensor is usually from 2k ohms to 47k ohms as the higher the value the sensor works the more sensitively. This resistance value depends on how high concentration the user wants to use. If the concertation if high enough and the resistance as well, then the result will not be accurate. Therefore, it is very important to choose resistance value wisely otherwise accuracy would not be possibly maintained.

Another essential thing is the pre heat. MQ sensors are required to be pre heated so that accuracy can be maintained. The heater is used with another built-in resistor shown in [Fig 2.2] is found in the MQ sensors which provides temperature that the sensor requires to work perfectly.

Each of MQ sensors data sheet provides a specific sensitivity graph, from which it is understandable that for what value of resistor ratio, what would be the parts per million (ppm) concentration for a specific gas.

The resistor ratio is $(\frac{Rs}{Ro})$

Where, R_s is the resistor that changes according to the concentration of gas

and R_o is the resistance of the sensor at a known concentration in fresh air without the presence of other gases.

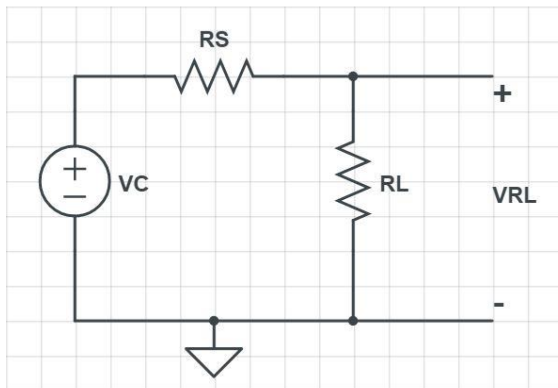

Figure 2.3: Simplified MQ sensor circuit [61]

Now, from Fig. 2.3 using ohms law, $V = IR$

$$\text{Or, } I = \frac{V}{R}$$

Combining sensor resistor R_S and load resistor R_L we find,

$$I = \frac{VC}{(Rs+Rl)}$$

Again from Fig. 2.3,

$$V = I \times R$$

$$V_{RL} = [\frac{Vc}{(Rs+Rl)}] \times Rl]$$

So, for Rs,

$V_{RL} \times (Rs + R_L) = V_C \times R_L$

$(V_{RL} \times Rs) + (V_{RL} \times R_L) = V_C \times R_L$

$(V_{RL} \times Rs) = (V_C \times R_L) - (V_{RL} \times R_L)$

$$Rs = \frac{Vc \times RL}{VRL} - RL$$

Using this formula resistance from different graphs for different MQ sensors can be found.

The data from Dust sensor SDS-011, Pressure sensor BMP-280 and Temperature and Humidity sensor DHT11 do not require any additional calculation. Those sensors simply provide an output that is of standard form with digital value.

2.7 IoT for Real Time Data

IoT stands for Internet of Things which is one of the most significant achievement of modern science and technology. The first example of IoT was during early 1980s. A Coca Cola machine located at the Carnegie Melon University was connected by internet by the local programmers to check how many drinks available in the machine or if they were cold or not. However, by the changing of era, the concept developed and in number of places IoT started being used in the name of "embedded internet".[62] Though the concept of first IoT came long ago in late 1970s, it was named "Internet of Things" by Kevin Ashton in 1999. Even though he could grab interest of some P&G executives, the term Internet of Things did not get widespread attention for the next 10 years.

IoT started to be popular from 2010 after a rumor against Google and the Chinese government’s announcement on priority of IoT in their “Five Year Plan” at the same year.[63] Gradually IoT became more and more advanced and as a result today IoT is available for anyone with a device having internet connectivity. Connected Industries, Smart Cities, Smart Energy, Smart Agriculture, Connected Cars and many more applications of IoT are in use nowadays. So, the applications of IoT are very widespread all over the world.

In this research, IoT was proposed to be implemented to track the data from anywhere. The plan of this research was to collect data from different places of Dhaka city and compare them. To do this, using IoT was a good idea because when someone is not near to the device while collecting data, there will be no track whether the data is correctly being found or not. Also, whether the data being collected is normal or not that can be confirmed from any place with using IoT. By connecting to internet, the whole device setup is accessible. This is a very attractive feature for any researcher to get data accessible from anywhere. Therefore, IoT was implemented here for collecting weather data even if the user is not present at the location where data being taken.

Chapter - 3

Experimental Setup and Methodology

3.1 Air Quality Detection Device

In order to work with real time air quality data, a detecting device was implemented with the help of a Raspberry Pi and an Arduino. For detection, there were an accurate dust sensor along with number of MQ sensors and power supply and all. Though PCB was designed but as per situation demand the setup was fully implemented in breadboard.

3.2 Model and Diagrams

- Block Diagram of the Model:

Now that we have already chosen our components and all, we can start implementing them. Here, we did not implement them at the beginning. Th e sensors were individually tested and then after successful result we implemented the whole setup. An Arduino was used to read the analog sensor data and send to the Raspberry Pi which is the main working medium in this project. The Raspberry Pi receives the digital data from the Arduino and send it to the Cloud Server. A 5V 4000mAh battery works as the power supply for each sensor and another 5V 4000mAh charging power supply (through adopter) works as the principle power supply of the whole system. The following block diagram shows the whole setup in a nutshell:

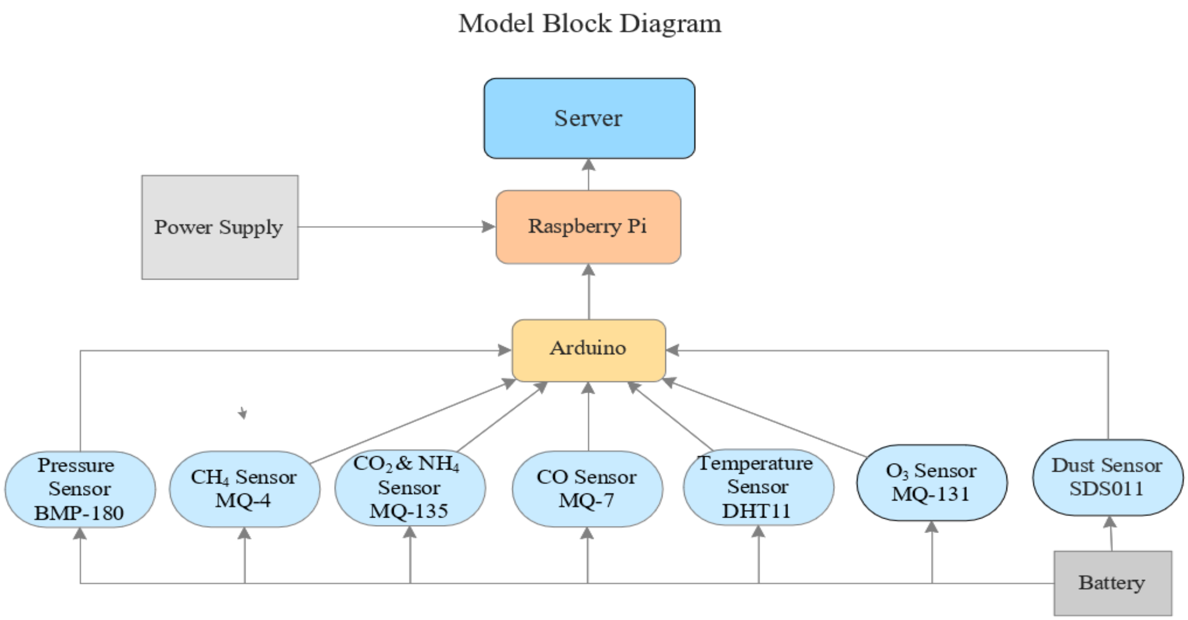

Figure 3.1: Block Diagram of Air Quality Monitoring Device

- Pinout Diagram:

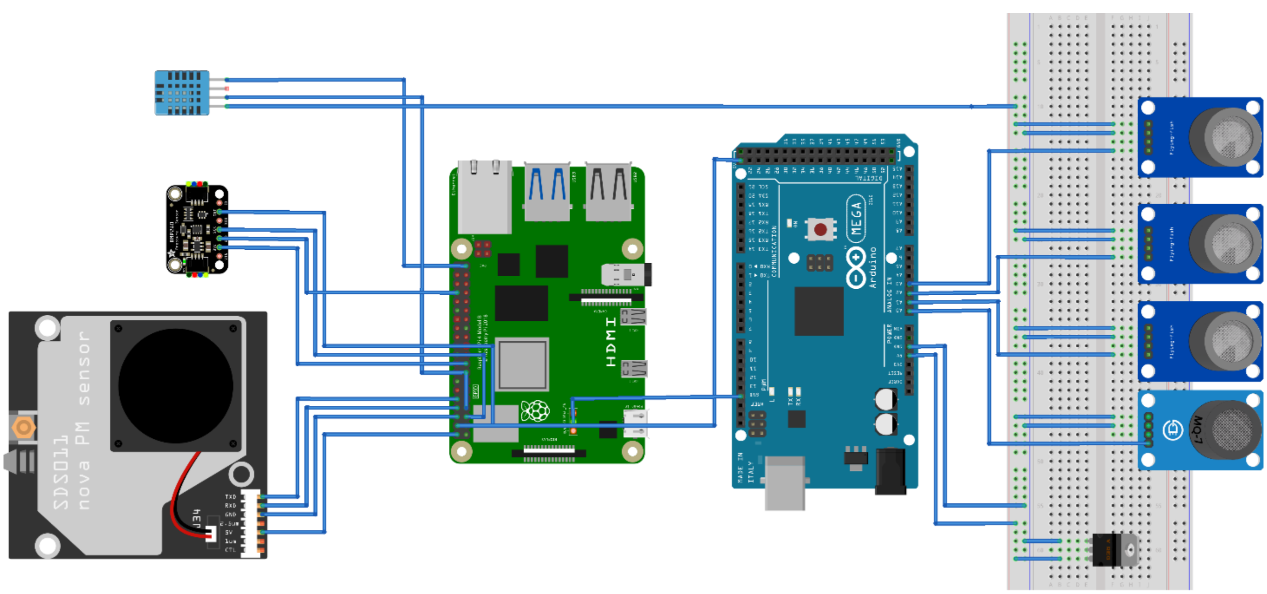

Figure 3.2: Pinout Diagram of the Model

- **Real Life Model Picture:**

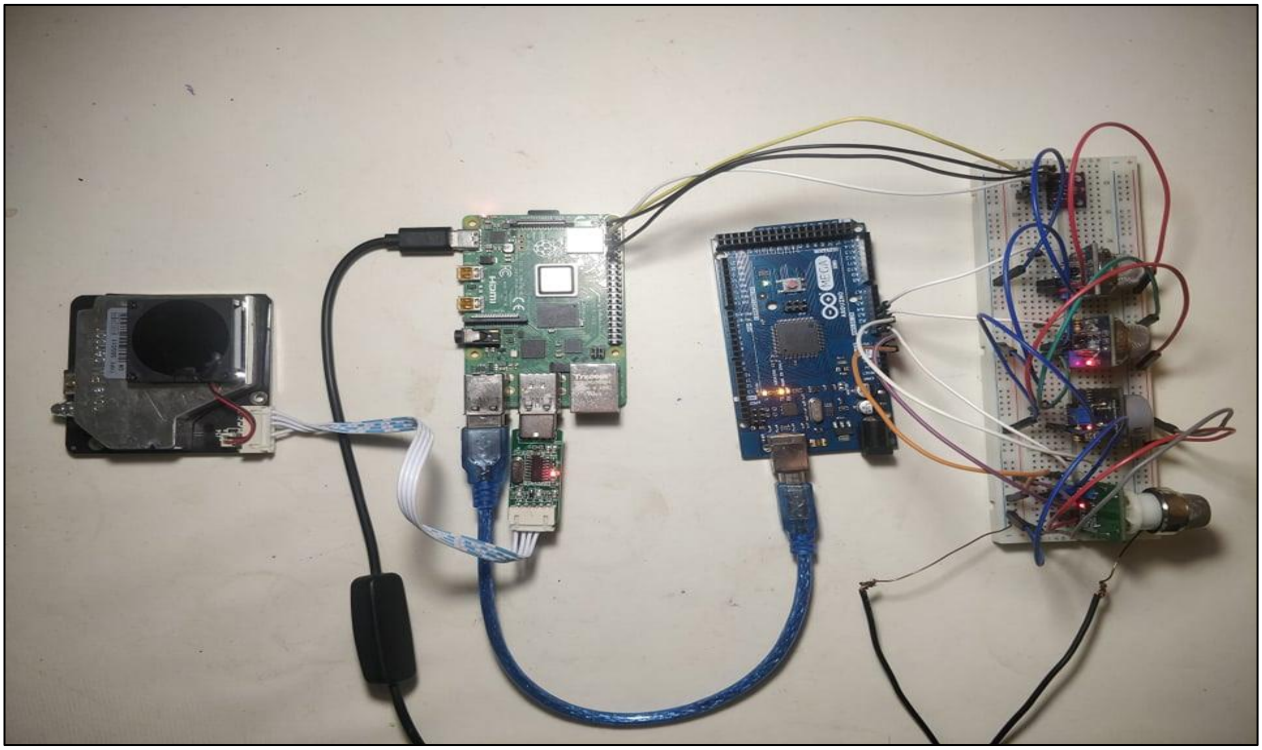

Figure 3.3: Real-life picture of the device (1)

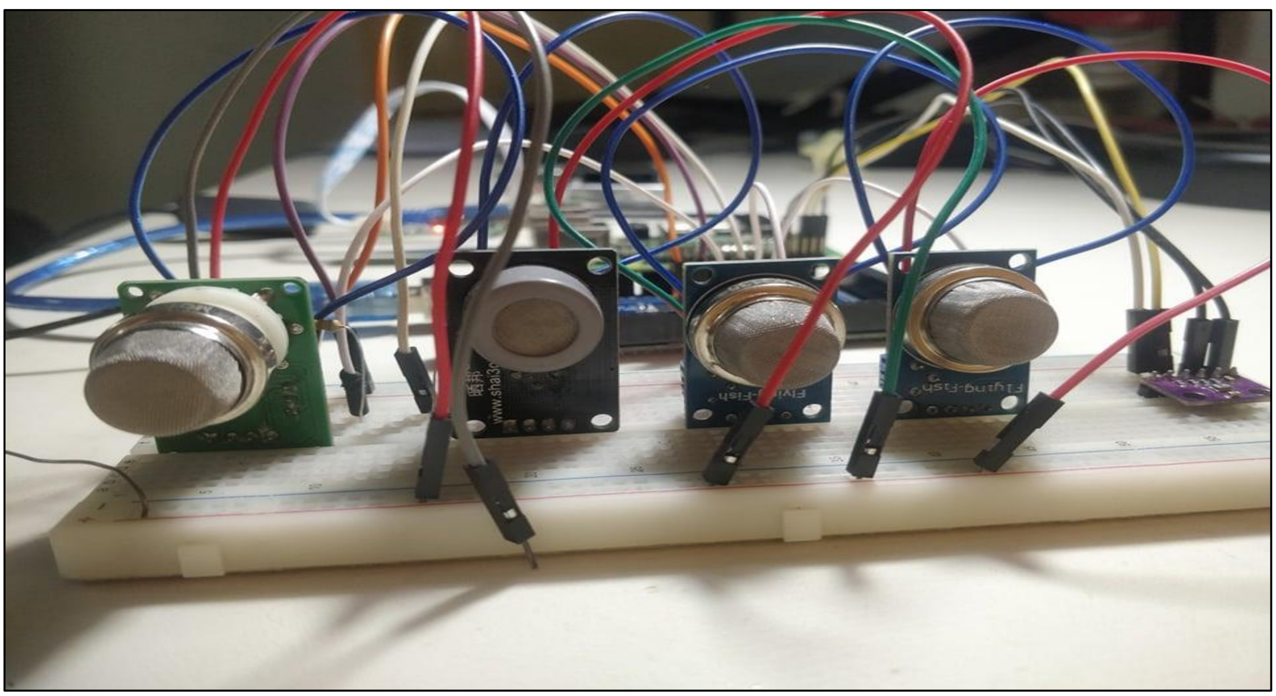

Figure 3.4: Real-life picture of the device (2)

3.3 Components

For the total hardware part, these following components were taken in use:

1. Raspberry Pi 4B
2. Arduino Mega
3. Sensors-
    i) SDS011 – Dust Sensor
    ii) MQ-135 – CO_2 & NH_4 Sensor
    iii) MQ-131 – O_3 Sensor
    iv) MQ-7 – CO Sensor
    v) MQ-4 – CH_4 Sensor
    vi) BMP280 – Pressure Sensor
    vii) DHT11 – Temperature and Humidity Sensor
4. Power Supply – 5V 4000mAh
5. Battery – 5V 4000mAh
6. Raspberry Pi Power Adopter
7. Wire
8. Breadboard
9. Potentiometer
10. LED
11. Voltage regulator

3.4 Medium and Sensor Description

Raspberry Pi

Raspberry Pi is a mini sized and low-cost computer that was developed by Raspberry Foundation in United Kingdom. It is a single board processor which can be connected to external monitor, mouse and keyboard and so on.

In our project, we used multiple Raspberry Pi 4B (latest model - 2019) with a random-access memory (RAM) of 4GB. The reason behind our choosing Raspberry Pi is because we are working with a IoT based project. As the Raspberry Pi 4B contains wifi feature, we can store our experimental data in cloud. So, that was the main idea behind using Raspberry pi as our main device for the project.

Figure 3.5: Raspberry Pi 4B Model [64]

Hardware Features [64]:

- 4GB of LPDDR4 SDRAM
- Quad core 64-bit ARM-Cortex A72 running at 1.5GHz
- H.265 (HEVC) hardware decode (up to 4Kp60)

- H.264 hardware decodes (up to 1080p60)
- Video Core VI 3D Graphics
- Dual HDMI display output support (up to 4Kp60)

Software Features [64]:

- ARMv8 Instruction Set
- Mature Linux software stack
- Actively developed and maintained
    – Recent Linux kernel support
    – Many drivers unstreamed
    – Stable and well supported userland
    – Availability of GPU functions using standard APIs

Power Supply and Electrical Specifications [64]:

Raspberry Pi 4B requires a good quality of USB-C power supply capable of delivering 5V at 3A. If attached downstream USB devices consume less than 500mA, a 5V, 2.5A supply may be used.

Absolute Maximum Rating:

Symbol	Perimeter	Minimum	Maximum
VIN	5V Input	-0.5V	6V

Table 3.1: Raspberry Pi absolute maximum rating [64]

Pinout and Interference:

- 802.11 b/g/n/ac Wireless LAN
- Bluetooth 5.0 with BLE
- 1x SD Card
- 2x micro-HDMI ports
- 2x USB2 ports
- 2x USB3 ports
- 1x Gigabit Ethernet port
- 1x Raspberry Pi camera port
- 1x Raspberry Pi display port

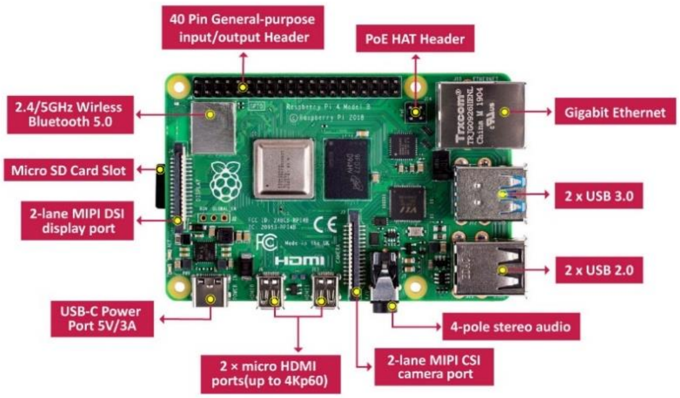

Figure 3.6: Interference of Raspberry Pi [64]

GPIO Pinout Diagram:

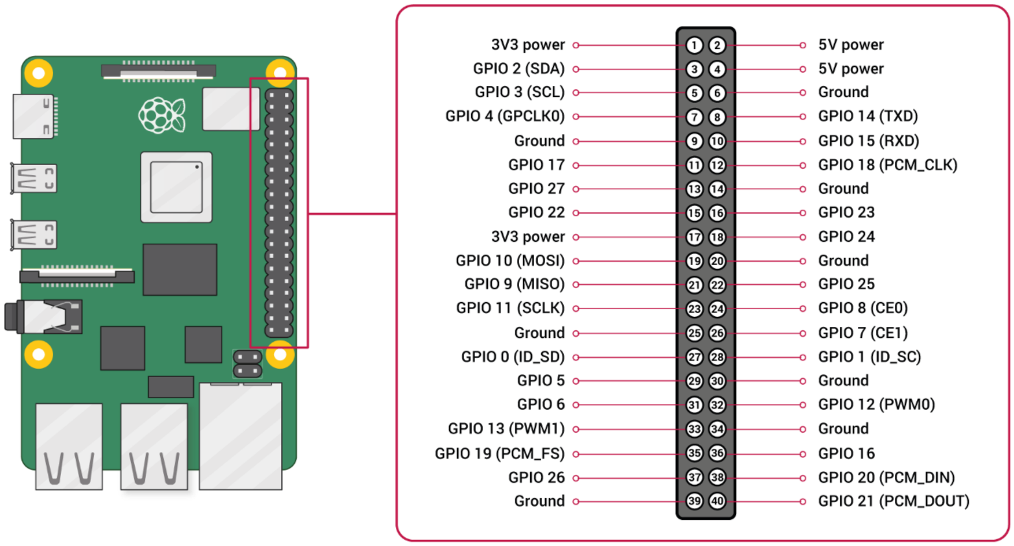

Figure 3.7: Pinout of Raspberry Pi [64]

Arduino Mega

Arduino is now a very widely used open source electronic board developed by Arduino LLC. It is an easy-to-use electronic based software and hardware. The hardware of Arduino board contains pin to read input from sensors and give output on operating systems and the software Arduino which is known Arduino IDE is used to write programs and get outputs according to them. Arduino's basic language is similar to C programming language. The Arduino Mega is an open-source microcontroller board based on the Microchip ATmega2560 microcontroller. Reason behind using this for our project is to take data from our analog sensors and get digital readings in the raspberry pi. As there is no heating issue like raspberry pi in this device, it was decided to bring in work.

Figure 3.8: Arduino Mega [65]

Specifications [65]:

- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Input Voltage (limit): 6-20V
- Digital I/O Pins: 54 (of which 15 provide PWM output)
- Analog Input Pins: 16

- DC Current per I/O Pin: 20 mA
- DC Current for 3.3V Pin: 50 mA+
- Flash Memory: 256 KB of which 8 KB used by bootloader
- SRAM: 8 KB
- EEPROM: 4 KB
- Clock Speed: 16 MHz

Pinout Diagram:

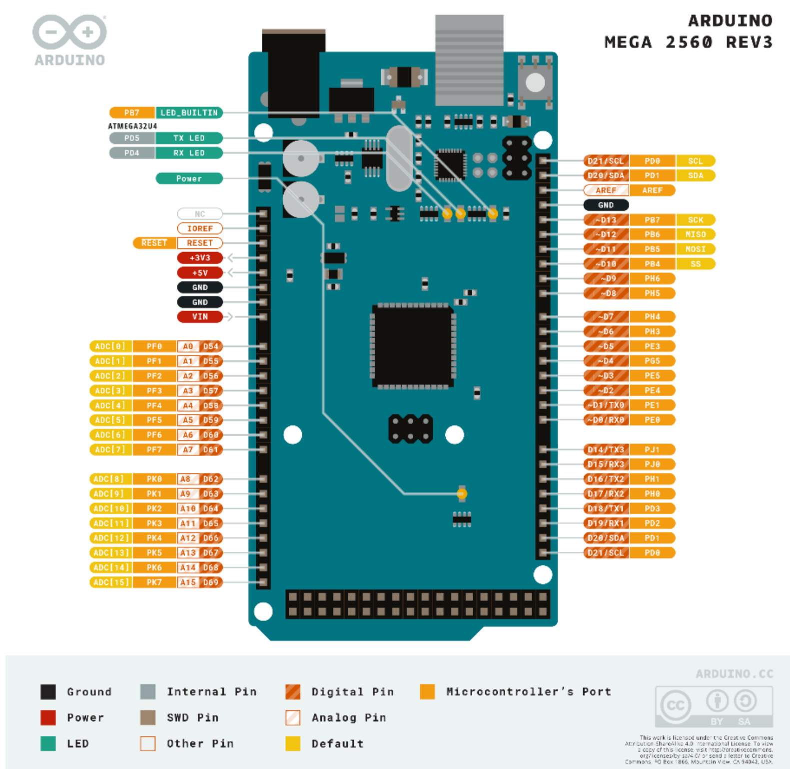

Figure 3.9: Arduino Mega Pinout [65]

Sensors

In order to detect air quality of the environment, we had to choose different sensors available in the market and specifically which were applicable for student projects. Because, many sensors available in the market are for industrial uses and those are highly expensive as well. For this, we chosen the sensors that will give us most accurate value within a lower expense. The sensors that we used are:

- Temperature and Humidity Sensor: DHT-11
- Pressure Sensor: BMP-280
- Dust Sensor: SDS-011
- MQ Gas Sensors:
    - MQ-4: Methane (CH_4) Sensor
    - MQ-7: Carbon Monoxide (CO) Sensor
    - MQ-131: Ozone (O_3) Sensor
    - MQ-135: Nitrogen Oxide (NOx) and Smoke (CO_2) Sensor

DHT-11 (Temperature Sensor)

One of the sensors we utilized in our work is temperature and humidity sensor DHT-11. The DHT-11 may be a basic, ultra-low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to live the encompassing air, and spits out a digital signal on the info pin (no analog input pins needed). It’s fairly simple to use, but requires full concentration [69].

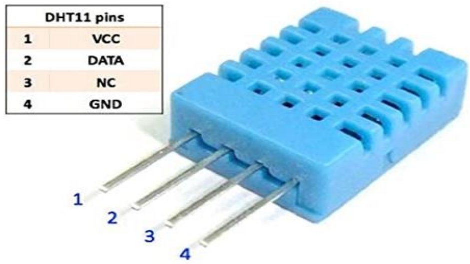

Figure 3.10: DHT-11 Sensor [69]

Characteristics**:**

Small Size

Lower Power Consumption

Quick Responses

Technical Specification [69]:

Power Supply： 3.3~5.5V DC

Output： 4 pin single row

Measurement Range： Humidity: 20-90%RH, Temperature: 0~50℃

Accuracy： Humidity +-5%RH, Temperature +-2℃

Resolution： Humidity 1%RH, Temperature 1℃

Interchangeability： Fully Interchangeable

Long-Term Stability： <±1%RH/year

SDS-011 Dust Sensor:

SDS-011 is a recently invented air quality sensor. It detects the amount of particulate matter available in the atmosphere. The sensor detects two types of particulate matter: PM_{10} and $PM_{2.5}$. PM_{10} is particulate matter of 10 micrometers or less in diameter and $PM_{2.5}$ is particulate matter of 2.5 micrometers or less in diameter.

The reason behind we are using this sensor instead of others is accuracy. SDS-011 gives the most accurate dust readings up to $PM_{2.5}$ in this lower cost. The other laser sensors available are likely used for professional uses and those are highly expensive as well. Therefore, in our project we decided to use SDS-011 for the best accuracy in this price range.

Figure 3.11: SDS-011 sensor [70]

Specifications [70]:

- Input Voltage: 5V
- Maximum Current: 100mA
- Sleep Current: 2mA
- Relative Error:10%
- Temperature Range: -20~50°C
- Physical Size: 71mm*70mm*23mm

Features [70]:

- Accurate and reliable in terms of detection, stability and consistency
- Detects polluting particles of concentration between 0.3 to 10μm in the air
- Response is very fast which is much less than 10 seconds when scene changes
- High regulation of 0.3μ g/m3 and built in fan for cooling

Pinout and Interference [70]:

Pin No.	Symbol	Description	Raspberry Pi Connection
1	NC	Not Connected	5V
2	1μm	PWM Output	-
3	5V	Input Voltage	5V
4	2.5μm	PWM Output	-
5	GND	Ground	GND
6	R	Rx of UART	Tx (14)
7	T	Tx of UART	Rx (15)

Table 3.2: Pinout and Connection of SDS-011

BMP-280 Sensor

BMP280 is an ultralow power, a high precision barometric pressure sensor with I2C serial interface. It has a pressure range of 300hPa to 1100hPa and a resolution of 0.01hPA. It also integrates a temperature sensor. The pressure data is of 16-19 bits, and the temperature data is of 16 bits.

BMP280 operates on a supply in the range of 1.71 to 3.6V. It is optimized for use in applications such as mobile phones, PDAs, GPS navigation devices and outdoor equipment. It can also be used for weather forecasting, leisure and sports wearables, vertical velocity indication etc [68].

Figure 3.12: BMP-280 Sensor Module [68]

BMP280 Module Features [68]

- Can measure temperature and barometric pressure.
- Pressure range: 300 to 1100hPa
- High relative accuracy of ±1hPa
- Can work on low voltages
- 3.4Mhz I2C interface
- Low power consumption (2.7uA)
- Pressure
- conversion time: 5msec

BMP280 Module Specifications [68]

- Operating voltage: 1.3V – 3.6V
- Input voltage : 3.3V to 5.5V
- Peak current: 1.12mA
- Consumes 2.7uA standby
- Operating temperature: -40ºC to +85ºC

MQ Sensors:

In Chinese, 'sensitive' means 'Mĭngăn' and 'Gas to' means 'Qĭ lai'. So, it is thought that more or less, MQ stands for the sensors having sensitivity towards gas. MQ sensors are very popular and useful for detecting polluting gases in the atmosphere. There are numbers of MQ sensors available in the market which measures different perimeters but all of them have some common characteristics and using methods. That's why here are some common overviews of MQ sensors that does not vary among different sensors [67]:

- Requires Preheating: Each of the MQ sensor is recommended to pre heat for 48 hours before taking values and at some reference paper 24 hours of pre heat is also mentioned.
- Sensitivity is adjustable and can be chosen which reading to find out by defining in the program
- Signal indicator available while taking data so that it can be assured that sensor is taking data at that moment
- Output voltage boosts along with increase of gas concentration in each of the sensors
- Fast Recovery and Response are with every MQ sensor

Pin name	Parameter	Functionality
V_{cc}	4 -5 Volts	Provides required voltage
A_{out}	~5 Volts	Feeds analog reading
D_{out}	0 or V_{cc}	Used to set alarm
GND	Provides ground	Connects to Ground

Table 3.3: Names and functionality the pins of MQ sensors

MQ-4 Methane Gas Sensor

MQ4 Methane Gas Sensor detects the concentration of methane gas in the air and outputs its reading as an analog voltage. The concentration sensing range of 300 ppm to 10,000 ppm is suitable for leak detection. For example, the sensor could detect if someone left a gas stove on but not lit. The sensor can operate at temperatures from -10 to 50°C and consumes less than 150 mA at 5 V [73].

Connecting five volts across the heating (H) pins keeps the sensor hot enough to function correctly. Connecting five volts at either the A or B pins causes the sensor to emit an analog voltage on the other pins. A resistive load between the output pins and ground sets the sensitivity of the detector.

Figure 3.13: MQ-4 Sensor [73]

General Specifications [73]:

- Good sensitivity to combustible gas in wide range
- High sensitivity to natural gas
- Long life and low cost
- Simple drive Circuit

MQ-7 Sensor

MQ-7 is a basic gas sensor and it detects the available Carbon Monoxide (CO) gas in the atmosphere. It can measure the concentration of gas from 10 to 10,000 ppm. The sensor can operate at a temperature of minimum -10 degree centigrade to maximum 50 degree centigrade and at 5V it consumes less than around 150mA [72].

Structure:

The sensor is composed by micro AL2O3 ceramic tube, Tin Dioxide (SnO2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless-steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-7 have 6 pins, where 4 of them are used to fetch signals, and other 2 are used for providing heating current [72].

Figure 3.14: MQ-7 Sensor [72]

Pinout and Interference:

Pin No.	Symbol	Description	Arduino Connection
1	DOUT	Digital signal	D2
2	AOUT	Analog signal	A0
3	GND	Ground	GND
4	VCC	Positive voltage supply (2.5V~5V)	5V

Table 3.4: MQ-7 Pinout

MQ-135 as Nitrogen Oxide (NOx) and Smoke (CO_2) sensor

MQ-135 is named as Air Quality monitoring sensor. It basically is a gas sensor which applies Sn02 which has a lower conductivity in the clear air. In atmosphere including polluting gas, this sensor's conductivity rises along with the concentration of harmful gas or smoke. MQ-135 is a low-cost sensor in order to detect gases. The MQ-135 is capable of sensing ammonia (10ppm-300ppm), benzene (10ppm-1,000ppm), and alcohol (10ppm-300ppm) air concentration levels. The ideal sensing condition for the MQ135 is 20°C ±2°C at 65% ±5% humidity [66].

Figure 3.15: MQ-135 Sensor [66]

Pinout and Interference [66]:

Pin No.	Symbol	Description	Arduino Connection
1	DOUT	Digital signal	D2
2	AOUT	Analog signal	A0
3	GND	Ground	GND
4	VCC	Positive voltage supply (2.5V~5V)	5V

Table 3.5: MQ-135 Pinout

MQ-131 as Ozone (O_3) Sensor

MQ-131 is a low conductivity carrying basic Ozone gas sensor. Though it is highly sensitive to Ozone gas, it can also detect strong oxides such as Cl_2, NO_2 etc. The sensor requires two voltage inputs heater voltage (VH) and circuit voltage (VC). VH is used to supply standard working temperature to the sensor and it can adopt DC or AC power, while VRL is the voltage of load resistance RL which is in series with sensor. On the other side, VC supplies the detect voltage to load resistance RL and it should adopt DC power.

Figure 3.16: MQ-131 Sensor [71].

Pinout and Interference [71]:

Pin No.	Symbol	Description	Arduino Connection
1	DOUT	Digital signal	D2
2	AOUT	Analog signal	A1
3	GND	Ground	GND
4	VCC	Positive voltage supply (2.5V~5V)	5V

Table 3.6: MQ-131 Pinout

3.5 Methodology

The main objective of our device is to read both analog and digital data of different air pollutant parameters from the air using different sensors, and storing data locally as well as in an IoT platform in order to present real-time values of the parameters over the internet on any mobile platform.

For us to implement the whole setup, we must integrate and interconnect all the analog MQ gas sensors to the Arduino Mega. After that, we connect the Arduino mega, DHT11, BMP280 and Nova PM sensors to the Raspberry Pi 4 B+. The Raspberry Pi 4 B+ will analyze and compute all the value and store the values locally. Moreover, the values will be sent and stored in an IoT platform. The IoT platform will provide user with quantitative and graphical presentation of the data in the web browser and on smartphones for us to view in real time. We will power the analog MQ sensors from an external source and supply power to the Raspberry Pi B+ from another source using its adapter. Below is the schematics of the whole.

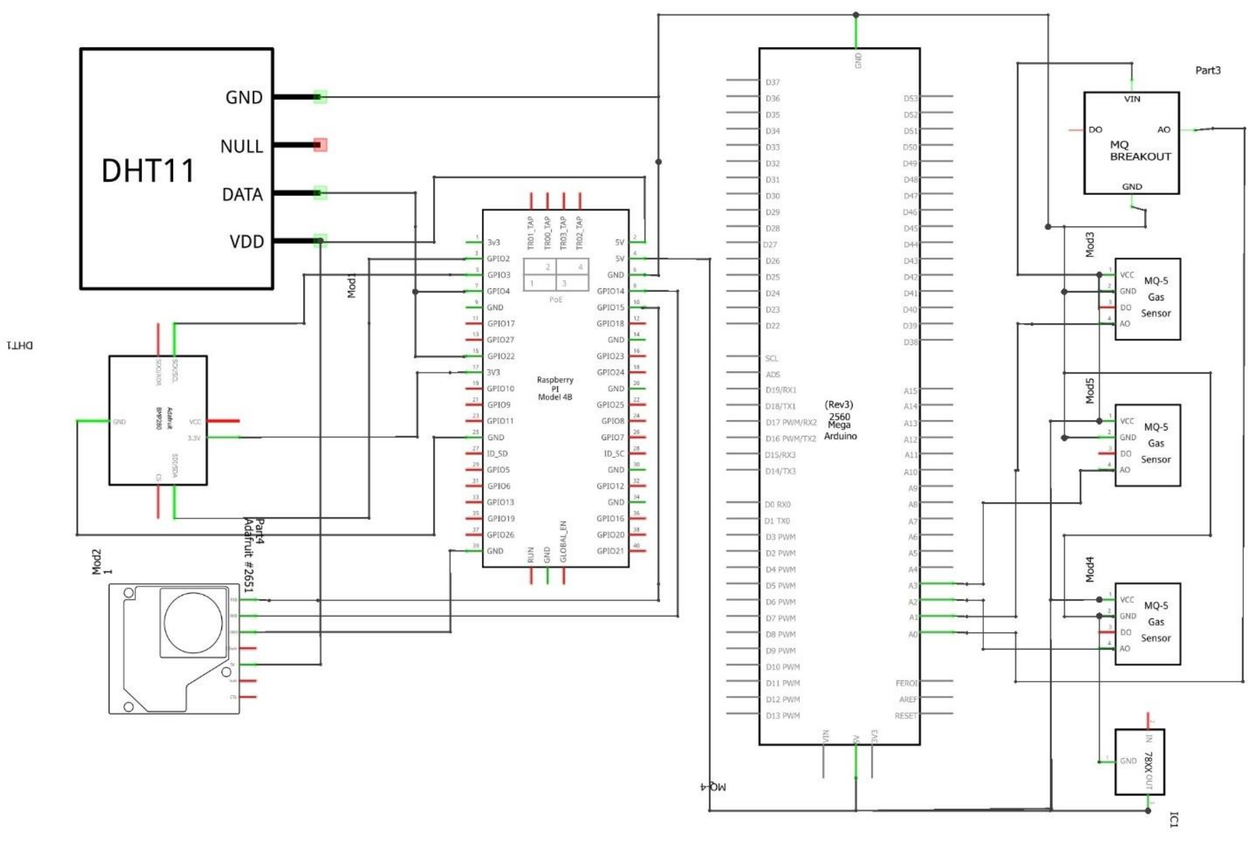

Figure 3.17: Schematics of the entire device

Hardware Setup

MQ sensors'

For our hardware setup we opted for the MQ sensors that come soldered on a board. The board provides 4 pins connecting for communicating. All the MQ sensor boards have similar layout and provide 4 pins for further connections. We connect all the MQ sensors used for our analysis to the Arduino Mega's analog pins. A table mentioning all the functionalities of each pins are as follows

MQ sensors draw a significant amount of power as it needs constant 5 Volts and 150 milli Amperes to heat its heater and receive data. Hence, we provide power to the MQ sensors from a 5 Volt 3 Ampere external source. We then connect its A_{out} pin to the analog pins of Arduino mega.

Pin name	Connection
V_{cc}	5V of external source
A_0	Analog pins of Arduino
D_0	Not used
GND	To external source's ground

Table 3.7: Configuring MQ sensors

We connect all the 4 MQ sensors similarly and connect each Aout pins of each sensor to a different analog input pin of Arduino mega.

BMP280

We will measure Temperature and Pressure using this sensor. It follows both I2C and SPI connection protocol for reading and sending data. We connect BMP280 to the Raspberry Pi 4 B+

using the I2C connection protocol. It is powered from the Raspberry Pi 4 B+. The connection of BMP280 with Raspberry Pi 4 B+ is as follows

Pins of BMP280	Connection with Raspberry Pi 4 B+
V_{cc}	Pin 1 (3.3V)
GND	Pin 9 (GND)
SDA/SDI	Pin 3 (SDA)
SCL/SCK	Pin 5 (SCL)
CSB	Left Unused
SDO	Left Unused

Table 3.8: Configuring BMP280

Nova SDS011 PM sensor

It follows a UART connection protocol for reading and sending data. We connect this sensor to the Raspberry Pi 4 B+ with the USB cable that it comes with. The digital data sent by the sensor is then coded to give raw value for PM10 and PM2.5 in $\mu g/m^3$ form. The connection of SDS011 with the Raspberry Pi 4 B+ is presented in the table.

Pins of Nova SDS011	Connection with Raspberry Pi 4 B+
TxD	Pin 10 (UART_RXD0)
RxD	Pin 8 (UART_TXD0)
GND	Pin 8 (GND)

25um	Left Unused
5V	Pin 2 (5V)
1um	Left Unused
NC	Left Unused

Table 3.9: Configuring Nova SDS011

DHT11

DHT11 is integrated to get the humidity present in the air. We get the value in percentage form. We connect the DHT111 and its 3 pins to the Raspberry Pi 4 B+ using the GPIO pins of the Pi for sending data. The connection that is implemented is as follows

Pins of DHT11	Connection with Raspberry Pi 4 B+
V_{cc}	Pin 2 (5V)
Data	Pin 15 (Data In)
GND	Pin 6 (GND)

Table 3.10: Configuring DHT11

Arduino Mega (Atmega 2560)

Arduino Mega is the implemented as the main Analog to Digital converter i.e. as an ADC for reading analog (Voltage) readings of all the MQ sensors utilized to measure sensitivity of gases. The value acquired by the Arduino Mega is then transferred to the Raspberry Pi 4 B+ for further calculation of the readings received in order to determine the part per molecule (ppm) concentration of each gases. As mentioned, each MQ sensors are connected to a different analog pin of the Arduino Mega. It is to be noted that, we must make sure the Vin and GND of Arduino Mega is connected to the Vin of the external power source.

Furthermore, Arduino Mega is connected to the Raspberry Pi 4 B+ with the USB ports of both the device. This is a secure and efficient connection method that maintains the Serial Communication methods for sending and receiving data. A program is written in the Arduino Mega to read and send the analog values.

Pins of Arduino Mega	Connection MQ sensors
A_0	A_{out} of MQ-4
A_1	A_{out} of MQ-7
A_2	A_{out} of MQ-131
A_3	A_{out} of MQ-135

Table 3.11: Configuring Arduino with The MQ sensors

Raspberry Pi 4 B+

Raspberry Pi 4 B+ is the main processing unit for our device. All the analog and digital readings from the sensors are calculated and converted to actual values. Furthermore, all the readings are stored locally in the Raspberry Pi 4 B+ SD card. Moreover, values are also sent to the IoT platform in order to integrate the IoT capabilities. All the calculations, processing of data and IoT interfacing are computerized by the powerful Raspberry Pi 4 B+.

Arduino Mega and Nova SDS011 are connected to the Raspberry Pi 4 B+ using serial communication. Moreover, DHT11 and BMP280 are connected to Raspberry Pi 4 B+ using the GPIO pins implementing serial communication

The Raspberry Pi 4 B+ needs a constant 5V 3A DC power to run hence, the power is provided separately to its power input through an adapter with the mentioned ratings

Power Supply

In order to get proper values from the MQ sensors we need to provide 5V 150 mA to each MQ sensors. To provide power to four such sensors we have integrated a power supply entirely from a different source and has connected a 5V voltage regulator to maintain a constant 5V and a maximum output of 1.5A current.

Integration with Cloud service: ThingSpeak

To implement the IoT capabilities of the device and presenting real-time values over the internet, we have integrated an IoT platform. Values obtained and processed in Raspberry Pi 4 B+ are sent to the ThinkSpeak platform using a dedicated API and address of the channel where the data will be stored and presented in real-time.

Free accounts can show 8 parameters with graphical presentation. Our python saves and sends data after every 5 seconds but ThingSpeak updates values after every 15 seconds saving the value over the internet. A screenshot of the dashboard for the web browsers is presented below

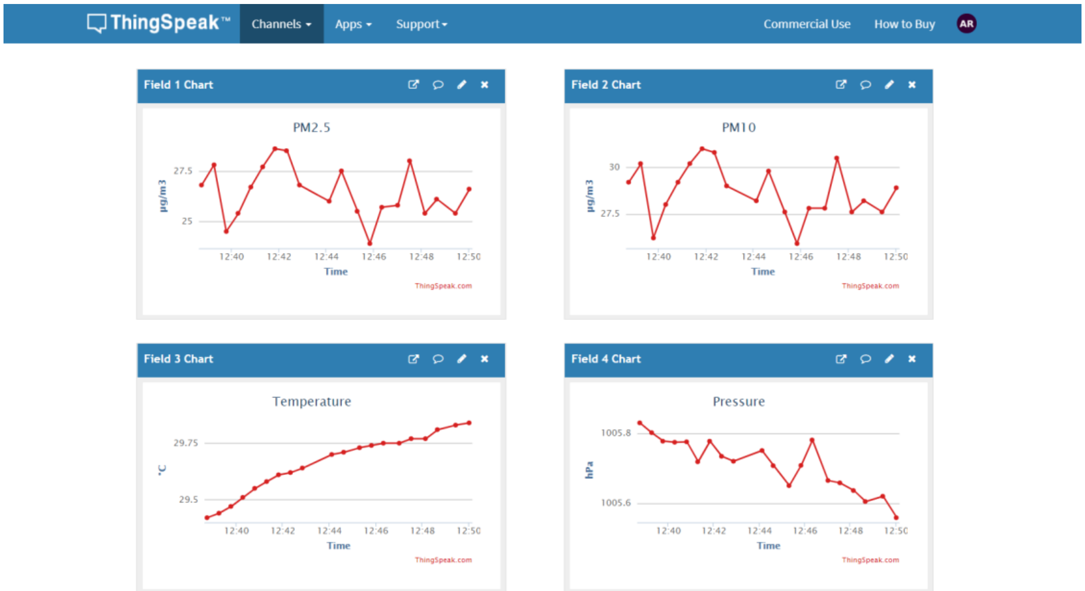

Figure 3.18: Presentation of values in the IoT platform ThinSpeak using a web browser

Figure 3.19: Presentation of values in the IoT platform ThinSpeak using an android application

Chapter 4

Result and Analysis

4.1 Introduction

In this part, the overall performance of the project is described with some comparative analysis between monthly data and also with the real-time data from some authentic sources.

The data collected for this research were frequent and the very first set of data was collected at April, 2020 (beginning of the lockdown). As the whole setup was not possible at that time, data were required to be taken individually from each of the sensors. After finishing the integration of all sensors in a single device, certainly some significant changes were noticed in the average readings. So, the next set of data was chosen to be taken from July, 2020. In the meantime, working on IoT were completed and so the last set of data was taken from early September, 2020. Each phase of data collection were around consecutive three to five days considering changes in per day weather condition.

The whole data was taken with an interval of 1000ms and every 5 minutes data were averaged in the program to be recorded for the data chart.

4.2 Sensor Data Chart

The Standard of our data was originated from EPA's Ambient Air Quality Standards where principle six pollutant gases' standard measurement has been set as the following:

Pollutants	Unit	Averaging Time	Concentration Level (own units)
Carbon Monoxide (CO)	ppm	8 hours	9 ppm
		1 hour	35 ppm
Ozone (O_3)	ppm	8 hours	0.07 ppm
Particulate Matter (PM 2.5)	µg/m^3	1 year	12.0 µg/m^3
		24 hours	35 µg/m^3
Particulate Matter (PM 10)	µg/m^3	24 hours	150 µg/m^3
Sulfur Dioxide (SO_2)	ppb	1 hour	75 ppb
		3 hours	0.5 ppb
Nitrogen Dioxide (NO_2)	ppb	1 hour	100 ppb
		1 year	53 ppb

Table 4.1: EPA Standard Air Quality Parameters [74]

Source. NAAQS Table | Criteria Air Pollutants | US EPA

AQI in based on 6 parameters such as PM 2.5, PM 10, O_3, CO, SO_2 and NO_2. Comparing with NAAQS's standard table, all the required data for AQI can be inspected whether they are relevant to standard form or not. In this case, the data we collected for this research, has been compared with this tables' range to understand how pertinent the data are in terms of international standard.

Since NO_2 and SO_2 were unavailable, some additional parameters were added to be compared which are also responsible for pollution of air. Among those, the standard unit of CO_2 gas in outdoor varies from 320 to 400ppm [75] and indoor is around or less than 700 to 800 ppm [76]. Other important perimeters were Ammonia and Methane.

As mentioned earlier, the data were taken in three phases so they were classified separately depending on the month when taken. Here is a small portion of each data chart that collected over time:

April, 2020

PM 2.5 (ug/m^3)	PM 10 (ug/m^3)	O_3 (ppm)	CO (ppm)	CO_2 (ppm)	CH_4 (ppm)	NH4 (ppm)	Temperature (degree)
19.3	34.2	0.012	3.99	700	3.68	4.12	28
19.3	34.2	0.012	3.99	715	6.21	4.31	29
19.1	33	0.012	3.99	708	3.84	4.31	29
19.1	33	0.012	3.94	693	5.11	4.31	28
19.2	32.8	0.0121	3.99	715	4.28	4.27	28
19.2	32.8	0.012	3.94	715	4.24	4.31	28
19.2	32.5	0.012	3.99	715	5.48	4.31	28
19.2	32.5	0.0121	3.99	708	3.80	4.39	29
19.2	32.5	0.012	4.05	693	5.88	4.31	29
19.2	32.5	0.012	4.05	693	3.92	4.31	29
18.9	32.4	0.012	4.11	693	4.96	4.35	28
18.9	32.4	0.012	3.94	700	4.36	4.31	27
19.1	33.2	0.0121	3.99	708	4.16	4.31	27
19.1	33.2	0.012	3.99	708	5.64	4.31	27
19	33.4	0.012	3.99	715	3.76	4.27	28
19	33.4	0.012	3.99	715	5.84	4.35	28
18.9	33.2	0.012	4.05	700	3.96	4.31	28
18.9	33.2	0.0119	3.99	708	4.76	4.31	28
19	33.3	0.012	4.05	715	4.44	4.31	27
19	33.3	0.0119	3.94	693	4.04	4.31	27
19	33.1	0.012	3.99	708	5.72	4.35	27
19	33.1	0.012	3.99	693	3.76	4.31	26
18.8	32.5	0.0119	3.94	678	5.84	4.35	26

Figure 4.1: Data Table from April, 2020

July, 2020

PM 2.5 (ug/m^3)	PM 10 (ug/m^3)	O_3 (ppm)	CO (ppm)	CO2 (ppm)	CH_4 (ppm)	NH_4 (ppm)	Temperature (degree)
24.3	39.9	0.0138	4.05	760	5.55	4.16	30
24.3	39.9	0.0138	4.11	760	4.94	4.35	30
24.3	41.3	0.0131	4.11	753	4.22	4.27	31
24.3	41.3	0.0139	4.11	760	3.94	4.39	30
24.4	41.1	0.0139	4.05	760	3.86	4.31	30
24.4	41.1	0.0139	4.11	768	4.26	4.39	30
24.4	40.4	0.0137	4.05	760	5.75	4.35	30
24.4	40.4	0.0136	4.11	753	4.06	4.43	30
24.4	40.6	0.0138	4.05	753	4.42	4.35	31
24.4	40.6	0.0139	4.11	760	4.98	4.31	30
24.4	40.4	0.0139	4.11	753	5.79	4.47	30
24.4	40.4	0.0139	4.05	768	5.83	4.43	30
24.5	40.7	0.0139	4.11	760	5.71	4.35	30
24.5	40.7	0.0130	4.16	760	5.35	4.31	29
24.5	41.2	0.0139	4.11	760	4.72	3.97	29
24.5	41.2	0.0139	4.05	760	4.11	4.12	29
24.7	40.5	0.0139	4.05	760	3.98	4.16	29
24.7	40.5	0.0139	4.11	760	3.86	4.28	29
24.6	40.4	0.0135	4.11	783	3.86	4.31	29
24.6	40.4	0.0139	4.05	775	3.94	4.24	29
24.4	40.2	0.0138	4.11	768	4.18	4.16	29
24.4	40.2	0.0139	4.11	768	4.62	3.92	29
24.6	40.4	0.0139	3.99	775	5.59	4.12	29
24.6	40.4	0.0140	4.05	775	5.79	4.21	29

Figure 4.2: Data Table from July, 2020

September, 2020

PM 2.5 (ug/m^3)	PM 10 (ug/m^3)	O_3 (ppm)	CO (ppm)	CO2 (ppm)	CH_4 (ppm)	NH_4 (ppm)	Temperature (degree)
31.6	45.9	0.0143	4.33	776	6.24	4.76	34
31.8	45.9	0.0143	4.71	783	4.82	4.68	33
31.8	47.5	0.0142	4.41	775	5.53	4.61	33
31.9	47.5	0.0143	4.28	744	5.28	4.68	33
31.9	47.3	0.0143	3.98	775	4.85	4.66	33
32.1	47.3	0.0141	4.53	773	4.69	4.68	33
32.1	46.5	0.0142	4.33	775	4.93	4.64	33
32.3	46.5	0.0142	4.40	721	5.23	4.68	34
32.3	46.7	0.0142	4.86	775	5.33	4.67	34
32.3	46.7	0.0142	4.40	775	5.17	4.72	34
32.3	46.5	0.0142	4.11	788	4.69	4.68	34
32.3	46.5	0.0141	3.94	812	4.62	4.47	33
32.3	46.8	0.0141	4.27	791	4.69	4.55	33
32.3	46.8	0.0142	4.45	783	4.74	4.60	32
32.3	47.4	0.0142	4.21	783	4.69	4.64	33
32.1	47.4	0.0143	4.18	783	5.17	4.68	33
32.0	46.6	0.0143	4.69	798	5.04	4.68	32
31.8	46.6	0.0143	3.88	791	4.96	4.60	32
31.8	46.5	0.0143	3..96	807	4.91	4.62	33
31.6	46.5	0.0142	4.85	798	4.62	4.64	33
31.6	46.2	0.0143	4.38	783	4.69	4.64	33
31.4	46.2	0.0142	4.49	798	5.48	4.72	33
31.4	46.5	0.0143	4.27	798	4.55	4.68	34

Figure 4.3: Data Table from September, 2020

4.3 Comparison with Standard Level

Comparing with NAAQS's table, we find like the below:

PM 2.5

24hr (1 day) average data = 35 $\mu g/m^3$

System detected 1-day average data = 24.9 $\mu g/m^3$

Decision: Data in range with similar unit

PM 10

24hr (1 day) average data = 150 $\mu g/m^3$

System detected 1-day average data = 42 $\mu g/m^3$

Decision: Data in nearer range with similar unit

O_3

8hr average data = 0.070 ppm

System detected 8hr average data = 0.016 ppm ^{s}

Decision: Data in range, with similar unit

CO

8hr average data = 9 ppm

System detected 8hr average data = 3.86 ppm

Decision: Data in range, with similar unit

These were the primary standard data provided by NAAQS but there are also secondary standard data as well. Some of them are calculated with one-year average, so only the data with one day or less period average were taken in for comparison to the system data. MQ sensors do not directly provide ppm value, so the results were converted to ppm in the program. However, SDS011 sensor provides data exactly in same unit to the NAAQS standard. So, range with unit of similar fashion, the system data can be referred as satisfying.

4.4 Comparative Analysis among different timeline

Sensor data changes time to time and in the element of air this change is very frequent. Though readings from sensors are nearly same but when the data were averaged, a goo variation was found. In the following figures the changes in data from phase to phase are going to be shown in charts with their calculated average readings:

Formula used: $D = \frac{|N1 - N2|}{(\frac{N1+N2}{2})} \times 100$

Where, D is the percentage of difference, N_1 is first value and N_2 is second value.

SDS011

PM 2.5

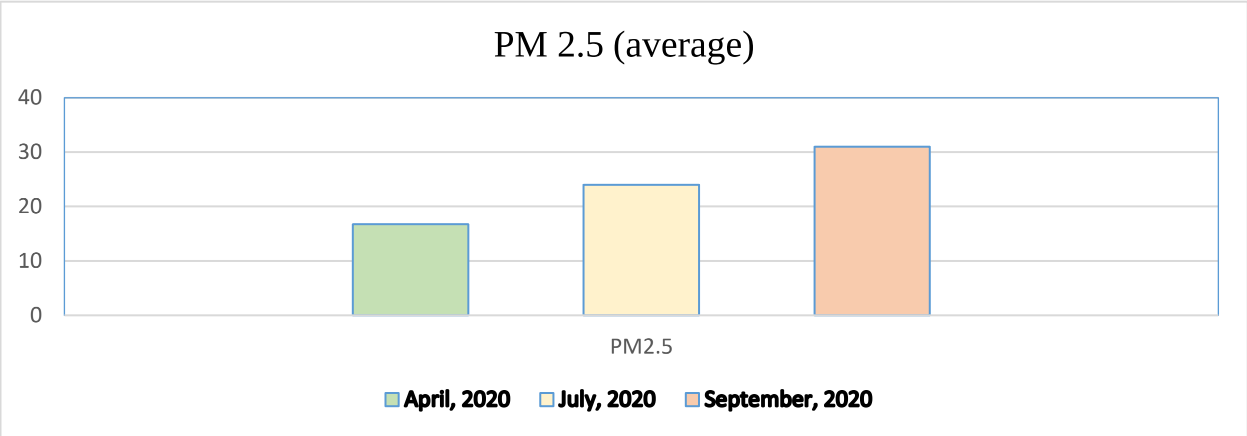

Figure 4.4: PM 2.5 Comparison Data

From April to July, 2020 the percentage of change in particulate matter was 35.6%

From July to September again it increased by 25.4%

And from April to September if it is compared, we can see, 59.7% of increase has been noticed in PM 2.5 dust.

PM 10

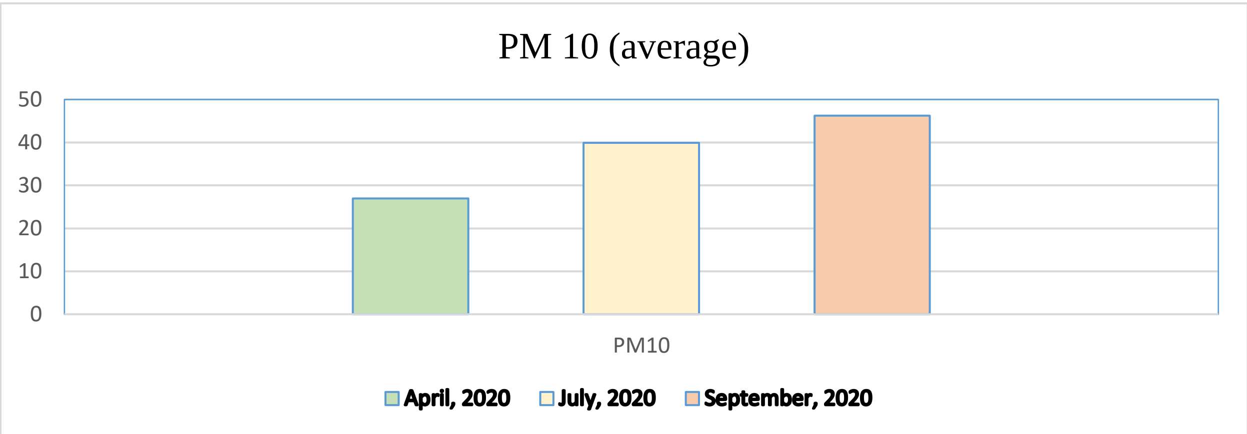

Figure 4.5: PM 10 Comparison Data

Here, from April to July, 38.6% increase has been noticed in PM 10

July to September, around 14.8% increase

And from April to September if we see, 52.7% change is clearly noticeable.

MQ-7

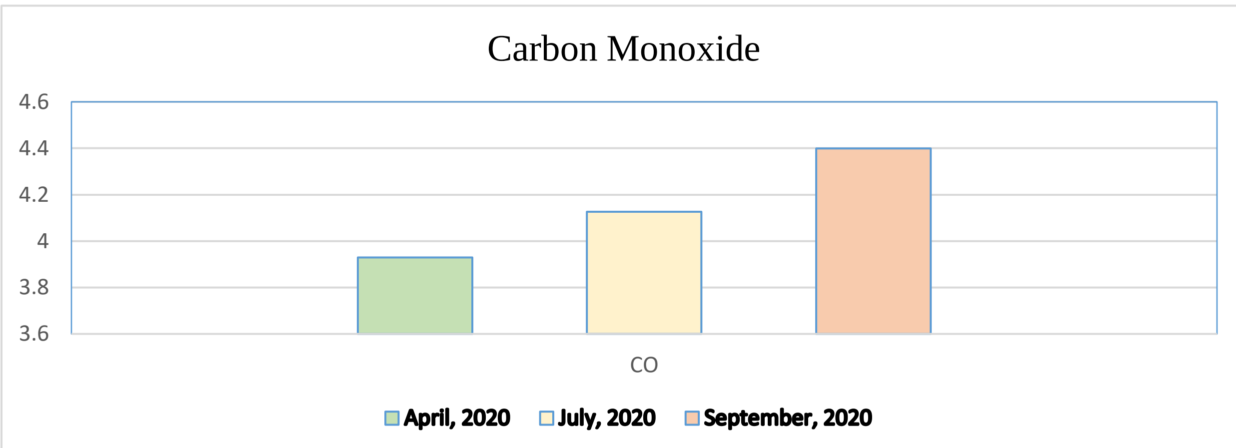

Figure 4.6: CO Comparison Data

From April to July here, we can see the rise of CO gas was from 3.929 to 4.126 ppm in average.

Which means around 4.89 % CO has increased in the atmosphere.

On the other side, from July to September, the difference was 6.41% in average

MQ-131

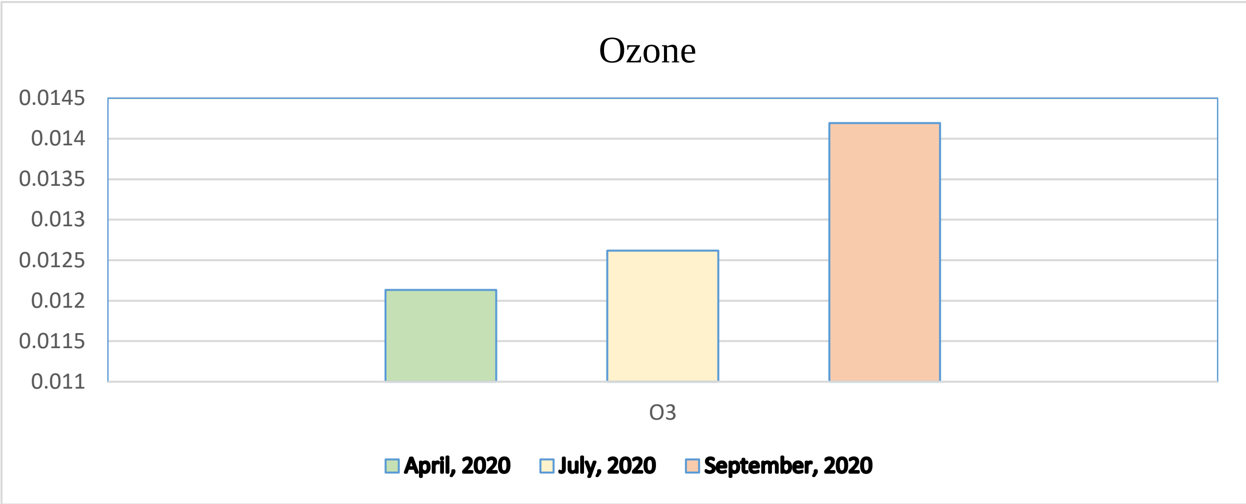

Figure 4.7: O3 Comparison Data

In Ozone, the first month average was 0.012619 whereas the July's average was 0.012135.

So, about 3.91% rise is visible in Ozone gas within these two phases.

And, from July to September the rise was noticed around 11.2% in average

MQ-135 (CO)

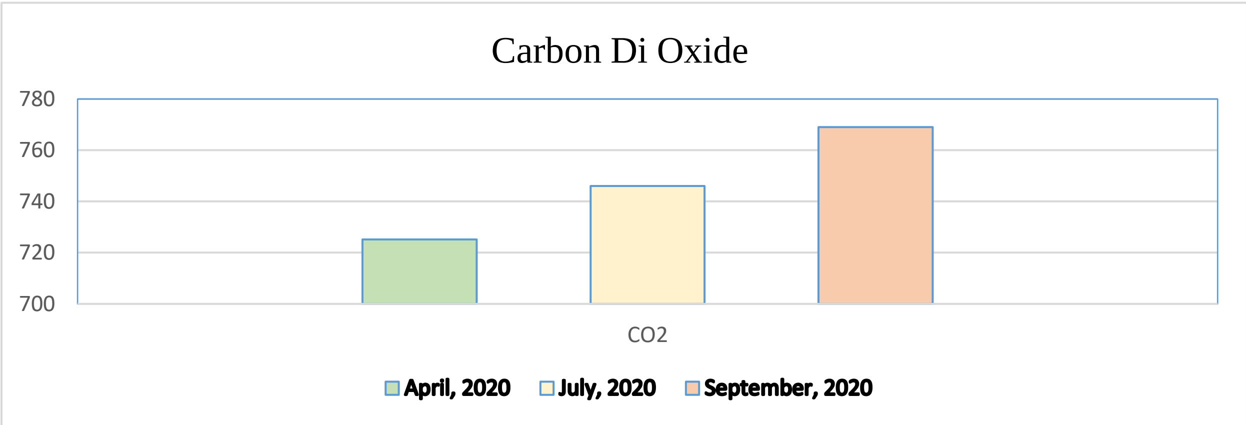

Figure 4.8: CO_2 Comparative Graph

Concentration of CO_2 from April to July has been noticed to rise about 2.86% and from July to September the rise was 3.03%.

MQ-135 (NH_4)

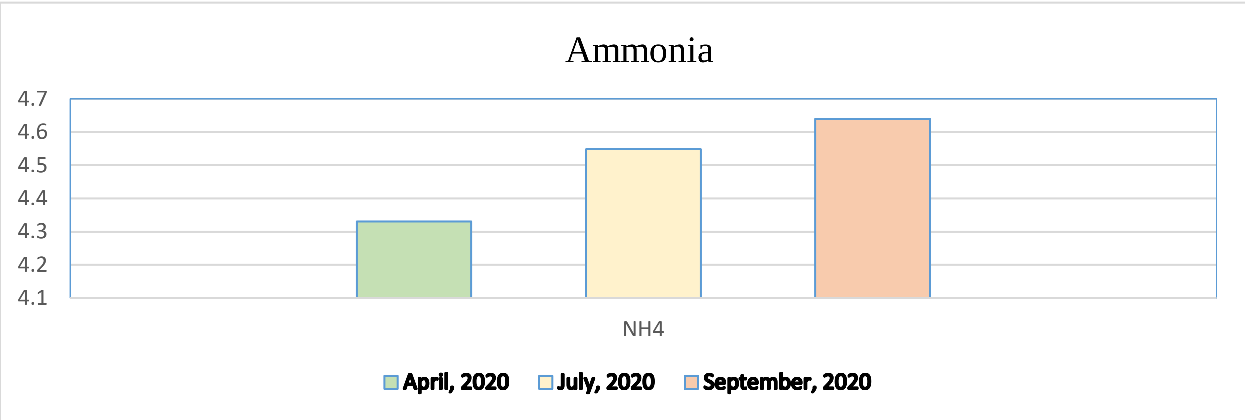

Figure 4.9: NH_4 Comparative Graph

In Ammonia, the percentage of change from April to July was 4.911% and the changes from July to September was increase of 2.002% in average. Ammonia is a mainly an indirect pollutant which pollute environment mixing up with other gases.

MQ-4

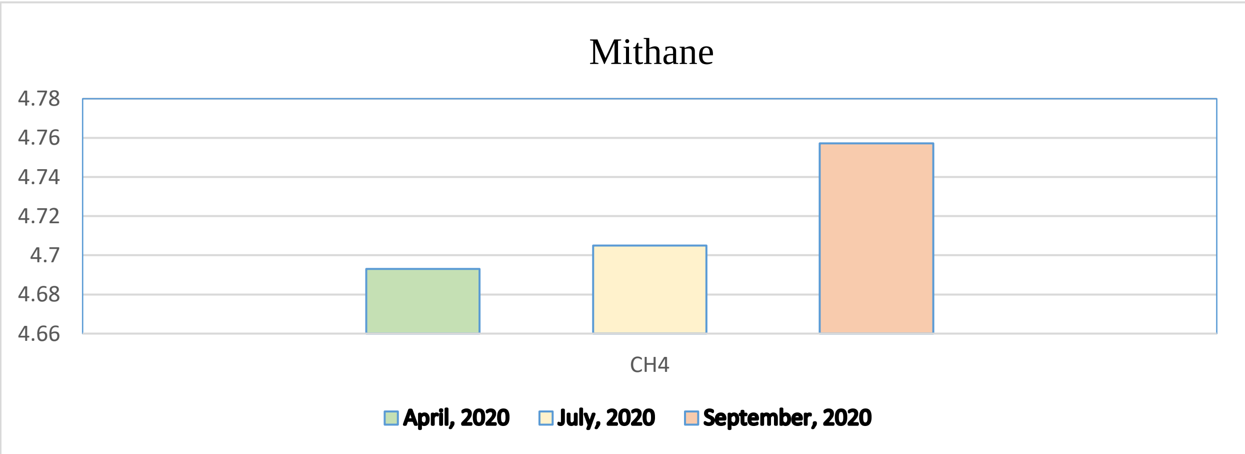

Figure 4.10: CH_4 Comparison Data

In Methane, a different change is visible. Over time, from April to July the change was less than 1% and from July to September's data we collected, the change was 1.099%. As an air element, methane is pollutant when it gets mixed with other polluting gases and the guess is this is why, the concentration of methane remains almost the same over time being.

Temperature

The variation in temperature is another essential part of the research with which the relation between air quality or air pollution and day to day temperature can be explained with the change of time.

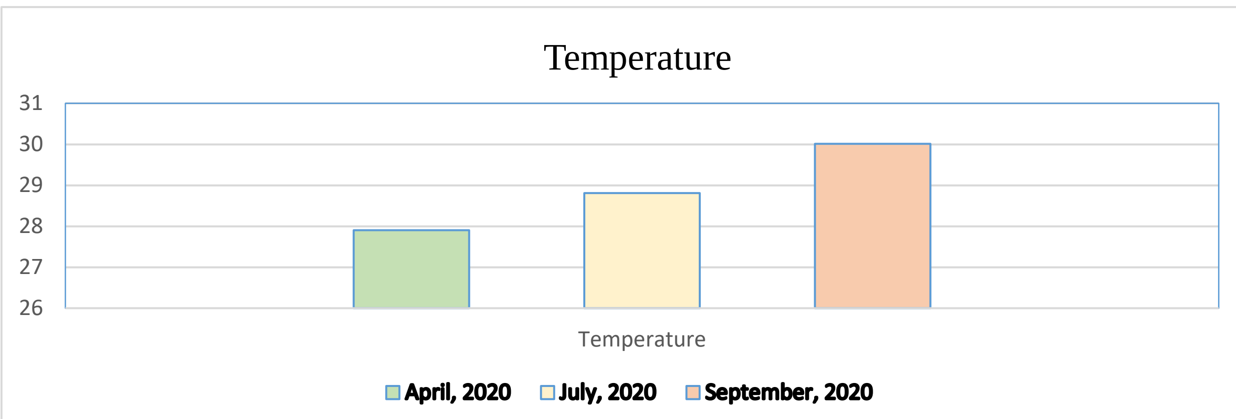

Figure 4.11: Temperature Comparison Data

From this graph, it's clear that temperature graphs are also in increasing trend. In percentage scale, the increase of temperature from April to July is around 3.2% and the temperature rise from July to September is 4.1686%

This is a noticeable thing. In climate of Bangladesh, April is the hottest month of summer and the average temperature is nearly maximum recorded at that time. However, in this year April, the system data has slightly lower average temperature than the average data from July. This, might be the reason of less pollution in air due to severe lockdown in the city of Dhaka.

4.5 Data Accuracy

After data collection, since the national weather forecasting websites were not enriched enough with Air Quality data, it had to be compared with some renowned websites data such as https://www.accuweather.com and https://www.calidadaire.net/daca.html

Although a Govt. site was found where air quality data is available, but their only air quality measuring parameter was PM 2.5. So, it was better to compare the data with those internationally recognized weather informing websites.

For accuracy test, some random real-time system data from September were taken and compared with the real-time website data of same time. Here are the results:

- PM 2.5

System data: 22 $\mu g/m^3$

Website data: 17 $\mu g/m^3$

Percentage of similarity: 78.73%

- PM 10

System data: 31 $\mu g/m^3$

Website data: 25 $\mu g/m^3$

Percentage of similarity: 81.64%

- Ozone

Website data: 39 μg/m^3

System data: 0.015021 ppm

1 ppm = 1000 ppb

So, 0.01502 ppm = 15 ppm

1 ppb ~ 2.0 μg/m^3

So, 15 ppb ~ 30 μg/m^3

Percentage of similarity ~ 78%

- Carbon Monoxide

Website data: 1302 μg/m^3

System data: 3.29 ppm ~ 3290 ppb ~ 2873 μg/m^3

This is a different scenario, where the percentage of difference is nearly double. But the reason behind it is indoor condition. However, in case of AQI scale, both of them are in similar range.

- Temperature

System temperature: 28° C

Website temperature: 27° C

Percentage of similarity: 96.4%

- Humidity

System humidity: 78%

Website humidity: 87%

Percentage of similarity: 90%

Some of the sensors data were not possible to compare because of unavailability of real-time data in websites. Since the sources were not relevant to compare, the rest data were compared with their standard form for usual atmosphere.

The collected system data were mostly around 80% similar to the real-time website data or standard data. Sensors used were basic sensors for student projects but acquiring this high percentage of similarity was satisfying and as the percentage of error were low, we can say our collected data were proper.

4.6 IoT Based Result

To access live data, a free IoT platform is used named “ThingSpeak”. The highest number of upload able parameters were seven and the real-time data is shown in graph and number as well in the site. However, the latency was 15 seconds per parameter and not more than 3million data is storable for each free account. Here are some sample data and graph among all parameters that were achieved real-time from the server:

Real-time PM 2.5 Data and Graph

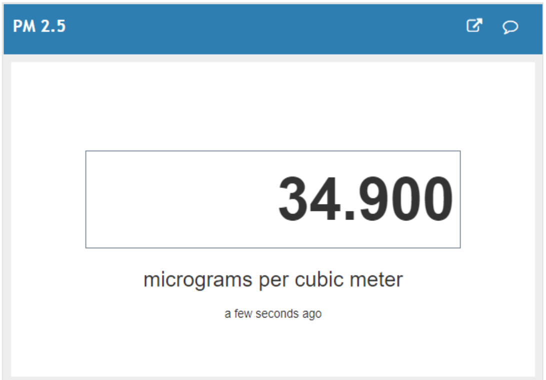

Figure 4.12: PM 2.5 Real-time Data

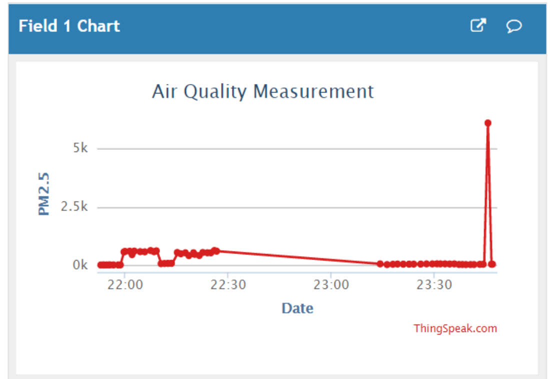

Figure 4.13: PM 2.5 Real-time Graph

Real-time PM 10 Data and Graph

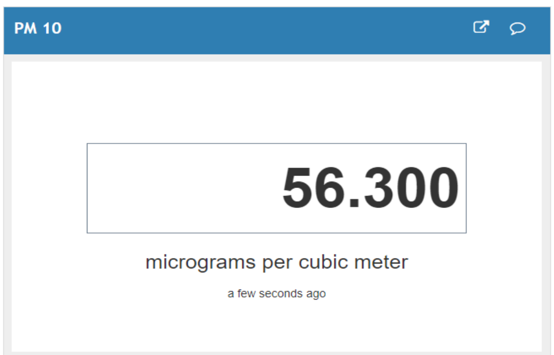

Figure 4.14: PM 10 Real-time Data

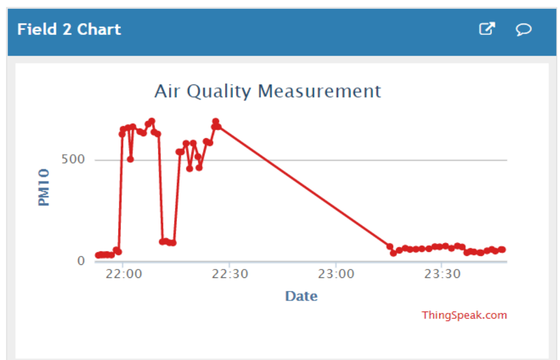

Figure 4.15: PM 10 Real-time Graph

Real-time Temperature Data and Graph

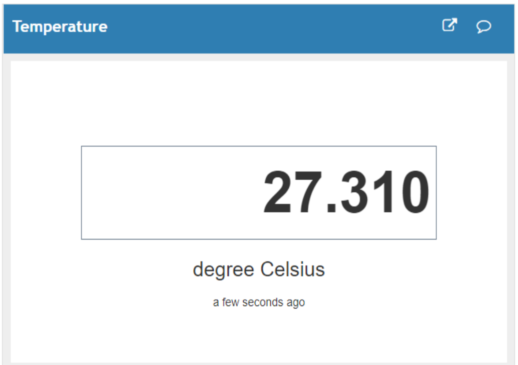

Figure 4.16: Temperature Data

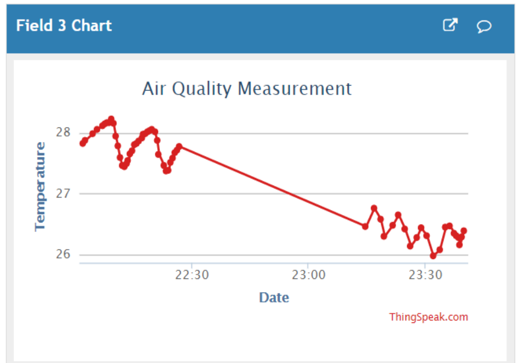

Figure 4.17: Temperature Graph

Chapter 5

Conclusion and Future Work

5.1 Conclusion

The impact of air pollution is the severe-most for environment in such a country like Bangladesh. In this paper, the parameters contaminating air quality and how they are damaging human health have been brough up. Moreover, with a comparative analysis between lockdown days and more like regular days of Dhaka city was inspected. The result says, due to less air pollution during proper lockdown at April, the environment was in a finer condition. On the other hand, in spite of April being the average hottest month of a year, the temperature and overall environment condition during lockdown was quite different than its usual. When less people gone out of home, there were less vehicle in the road, very few factory-industries open, no infrastructural work on going etc. altogether decreased air pollution in a very large amount and the result was visible to everyone.

Summarizing the whole research, we find one thing that is environment stays in the finest condition when air pollution is minimum. Even in beginning of summer, the temperature stays lower for a clean atmosphere. Now, fresh air means a lot for the livability of a city or country. Due to massive air pollution by dust and toxic gases, the air of Dhaka city looks yellowish in many places and even the sky is no blue for the city. If two snaps are taken at the same time one for Dhaka city's sky and another from Rangamati, a huge difference would come into the eyes. Both are from a same country but at Dhaka sky looks only white whereas the sky of Rangamati looks bluish. This is the difference between a polluted environment and a non-polluted environment. Not only for livability or good visual, fresh air is mandatory for human and other lives. For polluted environmental air, innumerable disease may occur and harm body for short and long term. Deaths can also happen for extremely unhealthy air. So, it is a must to take steps for improving air quality for such a small over crowded city like Dhaka and the whole country as well. From Government perspective different initiatives being taken but their implementation is not satisfactory. However, the citizens should come forward to prevent those environmental pollution otherwise this would create a big loss for everyone.

So, the suggestion would be plating more trees, stop using unfit vehicles that emits more carbon, using technologies for infrastructural works that spread less dust, control industrial airborne discharges, keep city cleaner and rise social awareness to prevent air pollution so that no life stands in risk of environment pollution.

5.2 Future Work

Working with environmental parameters we found that some of the pollutants are principle and some of them are secondary. In this paper, two of the gases that are responsible for air pollution and measuring air quality index (NO_2 and SO_2) were absent. They could not be taken as the cost of those two parameters measuring sensors are not available for student research at low cost. As a result, a proper air quality index was unable to be found. So, in future work, implementation of those two parameters would be done so that an appropriate AQI can be measured with more accuracy. Those AQI parameters along with CO_2 almost fulfils the air quality detection for any area. Also, there are some secondary elements of gas by analyzing whom we can get a proper idea about air quality. This would be also brought in future work. Taking data for longer time as a full one month or more than that, to compare again is a future work plan.

Moreover, for this research a free IoT server was used. There not more than seven parameters could be read at a same time. Also, the data received real-time were having 15 seconds delay which was a disappointing thing for us. This happened, because of using more sensors and in a free server. There were 3 million free data counts whereas we had to take each data for a millisecond interval. It required us to make multiple accounts on free server to see if the data were accurately transferring or not. For this, we have a plan of buying server storage in future so that we can keep our unlimited data stored in cloud. Even, we have a plan of developing an own html based dynamic website where we will be only showing our sensor data. Furthermore, as a reflection of this research we may work on how airborne pollution can be minimized in the perspective of Bangladesh.

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