Measurement of Traffic-Related Air Pollution through BRT Route Peshawar

by

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Author’s Declaration

We declare that we are the sole authors of this project. It is the actual copy of the project that was accepted by our advisor(s), including any necessary revisions. We also grant UET University of Engineering and Technology permission to reproduce and distribute electronic or paper copies of this project.

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Exclusive Summary

Traffic-Related Air Pollution (TRAP) is the leading cause of deteriorating air quality. In research by (Sunil Gulia) it is concluded that the emission from vehicles contributes 70% of urban air pollution. These pollutants lead to health issues and increase mortality. The first step for taking action is getting the ability to measure it. This century's paramount need is to develop advanced technology that can help measure air pollution in real-time. This study uses Plug&Sense Smart Cities Pro, an IoT device, to form a measuring solution. It involves measuring several variables such as CO, NO_2, SO_2, PM_1, $PM_{2.5}$, PM_{10}, Temperature, Pressure and Humidity. In this research, TRAP data from 21 stations was collected in Peshawar. All data was transported using the 4G communication protocol and monitored daily, making it a real-time air pollution measurement.

Later, data was used to find Air Quality Index (AQI) for all the stations. The CO AQI values were not alarming, ranging from healthy to moderate, with the highest AQI of 63 at Malik Saad Shaheed, a mean concentration of 23 ppb. The Lowest CO AQI of 8 was reported at Mall of Hayatabad and Khyber Bazar. The highest NO_2 AQI was found to be 165 with a mean concentration of 442 ppb, having a peak concentration of 642 ppb which comes under the 'Unhealthy' AQI category, and the lowest NO_2 AQI was 127 at Karkhano Market, which is 'unhealthy for the sensitive groups' AQI category. The SO_2 highest AQI was 152 with a mean concentration of 189 ppb, having the highest concentration of 402 ppb reported at Tatara Park, which is unhealthy. The lowest SO_2 AQI was 37, found at Karnkhano Market, which said healthy. PM_{10} highest AQI was 162, which was unhealthy reported at Abdara Road with a mean concentration of 278 µg/m^3 having a peak concentration of 679 µg/m^3. Lowest PM_{10} AQI 57 at Railway Station, a moderated value. $PM_{2.5}$ highest AQI was 160 at Malik Saad Shaheed, with a mean concentration of 73 µg/m^3 having the highest concentration of 140.6 µg/m^3 reported unhealthy, and the lowest $PM_{2.5}$ AQI 71 was at the railway station. The highest mean concentration of PM_1 was 43.7 µg/m^3 having a peak concentration of 51 µg/m^3 at Malik Saad Shaheed. The result found that Khyber Bazar, Abdara Road, Malik Saad Shaheed, and the University of Peshawar have the worst air quality, mainly in the unhealthy range.

It was also found that there was more pollutant concentration in the early hour up to noon later decreasing

Acknowledgement

We want to express our gratitude to our Project Supervisor Dr Zeeshan Zahir, to whom we are heavily indebted, as he made this work possible. During this project, he always welcomed us with a sense of responsibility, provided us with guidance, and was always on time for the scheduled meeting. He further provided us with the device/equipment and resources essential for this project.

I will also like to acknowledge TransPeshawar for letting us collect data on the station. They always welcome us with hospitality; without their approval, this project would not be possible.

Dedication

This project is dedicated to our parents, who have provided us with the opportunity to study and have been a source of inspiration and motivation.

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List of Abbreviations

API	Application Programming Interface
AQI	Air Quality Index
BRT	Bus Rapid Transit
CO	Carbon Monoxide
EPA	Environmental Protection Agency
GUI	Graphic User Interface
IoT	Internet of thing
NO_2	Nitrogen Dioxide
PAQI	Pakistan Air Quality Initiative
PM	Particulate Matter
PM_1	Particulate Matter with Diameter ≤ 1 μm
PM_{10}	Particulate Matter with Diameter ≤ 10 μm
$PM_{2.5}$	Particulate Matter with Diameter ≤ 2.5 μm
ppb	Part Per Billion
ppm	Part Per Million
SO_2	Sulfur Dioxide
TRAP	Traffic Related Air Pollution
WHO	World Health Organization

List of Symbols

μ	Micro (10^{-6})
A	Ampere
℃	Centigrade
I	Current
k	Kilo (10^{+3})
P	Pressure
Pa	Pascal
T	Temperature
BP_{high}	Concentration breakpoint that is ≥ C_p
BP_{low}	Concentration breakpoint that is ≤ C_p
C_p	Truncated pollutant concentration,
I_{high}	Index breakpoint corresponding to BP_{high}
I_{low}	Index breakpoint corresponding to, BP_{low}
I_p	Index for the pollutant

United Nations Sustainable Development Goals

The Sustainable Development Goals (SDGs) are the blueprint for achieving a better and more sustainable future. They address the global challenges we face, including poverty, inequality, climate change, environmental degradation, peace and justice. Our project aligns and goes hand in hand with the following four goals.

- Good Health and Well being
- Industry, Innovation and Infrastructure
- Sustainable Cities and Communities
- Climate Action

This project uses innovative technology (IoT) that can be used to build a system of monitoring the environment for sustainable cities to reduce climate change and improve health.

Similarity Index Report

Following students have compiled the final year report on the topic given below for partial fulfilment of the requirement for a Bachelor's degree in 2018-2022.

Project Title: Measurement of Traffic-Related Air Pollution Through BRT Route Peshawar.

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This is to certify that the Plagiarism test was conducted on complete a report, and the overall similarity index was found to be less than 20%, with a maximum of 5% from single source, as required.

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Dr. Muhammad Zeeshan Zahir

Chapter 1: Introduction

Traffic-Related Air Pollution (TRAP) is the primary source of air pollution such as particulate matter (PM), nitrogen dioxide (NO_2), carbon monoxide (CO), and Sulphur dioxide (SO_2). This TRAP research uses new technology (Sensor, IoTs) to measure the pollutant across different areas in Peshawar, Khyber Pakhtunkhwa (KPK), Pakistan. Measurement of Traffic-Related Air Pollution is not something new. However, there is a conflict and a lack of adequate data.

"This research aims to provide data on Peshawar air quality by using the most advanced technology and by not limiting the data to once a day but finding throughout the day after some time". This chapter will provide an introduction to the study by first discussing the background, followed by significance and motivation, aim and objective, and Report Layout.

1.1 Background Information

The air we breathe is polluted, which leads to various health problems. It has been estimated by WHO that there are 7 million deaths each year, and 1 out of every eight people die from air pollution exposure (Kuehn, 2014). Household combustion devices, motor vehicles, energy production, and industrial facilities are human-made sources of air pollution. Combustion produces air pollution, which also acts as a greenhouse gas, increasing global warming and causing climate change.

Air pollution is composed of aerosol or gases. These gases are NO_2, SO_2, CO, O_3, Pb, etc. Aerosol is suspended solid and liquid particles in the air. One of the leading concerns of these pollutants is the adverse health effects. Transport is the most important source of these pollutants, reported to contribute 70 to 80% of urban air pollution (Sunil Gulia).

Nitrogen Dioxide (NO_2) is produced during fuel combustion. Because of the high temperature during combustion, nitrogen oxide (NO) is produced and on oxidation, it reacts to make nitrogen dioxide.

$$2NO + O_2 \square\ 2NO_2$$

It has a distant brown colour and can be seen in clouds. Sulfur Dioxide also comes from the combustion of fuel. Sulphur Dioxide, on oxidation, makes Sulphur trioxide (SO_3). At the beginning of the 20th century, there was a fast upward trend of increasing concentration of sulfur (S) throughout the world, but after the London Great Smog a deadly disaster in 1952, it attracted the attention of the west and because of Strick regulation there has been a decrease in Sulfur (S) concentration in the atmosphere within Europe and America. But there is still a high concentration in Asian countries (Kazuhiko Ito Ph.D., 1993). SO_3 reacts with water, in hydrolysis reaction, to make Sulfuric Acid(H_2SO_4). This reaction usually occurs in suspended vapors, such as clouds and it makes the clouds acidic. This results in the rains being harmful for life

Carbon monoxide (CO) is produced due to the incomplete combustion of fuel, mainly emitted from vehicles. Its concentration is higher inside of the car, as compared to the outside. Exposure to CO in non-smokers is due to its production in vehicles (Katsouyanni, 2003).

Particulate matter is solid and liquid particles suspended in the air. Those having size up to 2.5 to 10μm is known as the coarse particle. The main sources of the coarse particle are mechanical, i.e., emissions from road tire wear, brake linings, and resuspension, each of these depend on several factors such as road surface, humidity intensity, and wind speed. The particle matter having a size smaller than 2.5 μm is known as the ultrafine particle. Sources of these are combustion processes such as diesel power vehicles. This ultrafine particle travels more distance when suspended in the air compared to a coarse particle which could travel less. i.e., PM_1 settle more later than $PM_{2.5\ \text{and}}$ PM_{10}.

Most transport vehicles have Internal Combustion (IC) engines that are either petrol engines or diesel engines. For a petrol engine, the fuel is mixed with air in control stochiometric ratio so it can get cleaned by a three-way catalyst, but it operates appropriately at 250℃; however, in the initial stage, the temperature is not that high hence causing poor exhaust cleaning known as Cold start phase. In a Diesel engine, it is useless as the three-way principal exhaust cannot work; the most toxic emissions produced by a diesel engine are nitrogen oxides and particulate matter. In this type of engine, Particulate Matter can be removed from the exhaust by filtration and the collected soot fraction removed by combustion. The soot requires a high temperature for combustion, generally starting at temperatures above 500°C, but the exhaust gases do not often reach such a high temperature (Krzyżanowski, 2005). All these emissions are engineering problems, mostly due to the failure to design machines with less and controlled emissions.

From a bigger perspective, the major cause of air pollution is rapid urbanisation, unplanned industrialisation, and growth. Pakistan has an area of 881,993 km^2 with a population of 225 million in 2021. The World Bank estimates Pakistan's annual environmental degradation costs 365 billion rupees or 6% of GDP, with a health service costing more than 65 billion rupees, causing 220 thousand premature deaths and 700 deaths among children (Rasheed, 2015). Pakistan is one of the most polluted countries in the world and ranks 3rd in mortality rate. The principal cause is NO_x, primarily emitted from 23.6 million transport vehicles (58%), followed by industry and power, which accounts for 34% of emissions. Due to these emissions, Lahore, Peshawar, Islamabad, and Karachi are major polluted cities that do not meet WHO air quality guideline (Bilal, 2021). Pakistan ranked 7th most affected country to the climate-related hazard (Khan, 2021). Increased temperature, heatwave in Karachi in recent years and flood, one can see the impact of climate change. The scarcity of data and research in Pakistan makes it hard to determine how much air pollution sources contribute to overall emissions. In 2018, a study was conducted by the Food and Agriculture Organization (FAO) on several pollutants, it showed the most polluting sectors are; transport 43%, industry 25%, agriculture 20% and power 12%. Hence vehicles carry the highest share, no maintenance of vehicle, poor fuel quality and use of two-stroke vehicles such as rickshaw and motorcycle tell us all about the large percentage of vehicle emissions. Under European Union's, standards, Pakistan's fuel quality falls under euro two, which lags far behind the standard used in European counties. However, the federal government has signaled to switch to euro 5 to the supplier.

Motorcycles and autorickshaws use two-stroke engines that are inefficient as compared with today's modern engines that reduces emissions to appreciably low (Vasic, 2006). According to Pakistan Board of Statistics, number of motorcycle compromise of 74% of total registered vehicles.

In Peshawar, particulate matter concentration is increasing daily because of unplanned and rapid urbanisation and mass industrialisation. The main source of Particulate Matter pollutants are vehicle emissions, these pollutants are very harmful to public health and environment when it is compared to other pollutants (Alam, 2015). In Peshawar the second biggest source of air pollution is the waste produced by hospitals; 300 kg of waste by Peshawar Lady Reading Hospital, 250 kg of waste by Hayatabad medical complex and 300 kg of waste by Khyber teaching hospital, among others, is produced daily without any incineration facility which makes a total of 965 kg of waste, which adds to the already present air pollution upon burning (Ullah, 2019)

The description of air quality limitations requires consideration of some standards and guidelines. World Health Organization (WHO) gave some of the most widely used guidelines, which uses US Environmental Protection Agency (EPA) methods of Air Quality Index (AQI) calculation. Although each country may have established their own standards which depends on their requirements. However, for this research we will be using WHO guidelines.

Table 1-1: WHO guideline for air quality, impact on health for daily and yearly mean value of pollutant (Organiation, 2021)

Parameter	WHO Maximum Daily limit	WHO Maximum yearly limit	Health/Environmental Impact
$PM_{2.5}$	25 µg/m³	10 µg/m³	Respiratory, coronary diseases, and lung cancer
PM_{10}	50 µg/m³	20 µg/m³	Respiratory, coronary diseases, and lung cancer
SO_2	20 µg/m³	500 µg/m³ (10-minute)	Predecessor of H_2S and cause acid rain
NO_2	200 µg/m³ (1-hour)	40 µg/m³	NO_2 is toxic, causes respiratory problems and acid rain

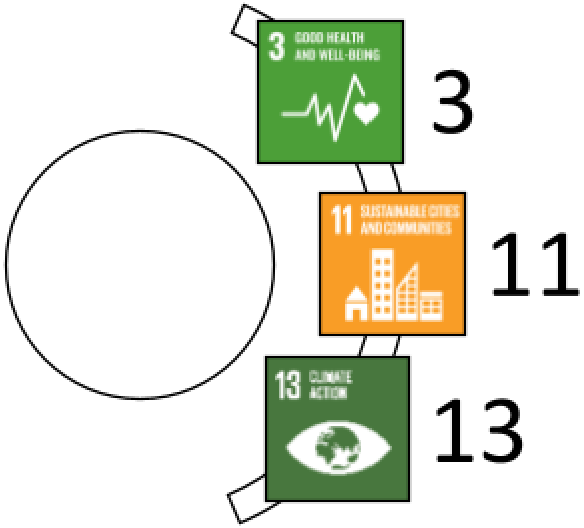
Table 1-1 shows the daily and yearly limits of maximum concentration for different parameters. Below these limits, the human life is comparative safe from harmful air pollution. Exceeding these limits for particulate matter will have negative affects to human life and will cause diseases in lungs and other organs. Children and adults with lung problems, such as asthma and chronic obstructive pulmonary disease, are more effected.

Today the world is going through the fastest changes in the fields of technology. The advancement is made possible by the continuous struggle of mankind in the field of technology but it lacks considerations of the future for the most part. Although these advancements have benefits but also become a cause for the accelerating climate change. The air we breathe is no longer clean, the contaminants in the air cause health problems; the life expectancy is getting shorter and shorter. which makes us think whether these advancements are blessing or a challenge rather.

1.2 Motivation and Significance

Today, air pollution is one of the most concerning issues. Prolonged exposure can lead to health issues. It is one of the leading causes of lung related problems which causes diseases and even deaths. According to WHO there are about 600,000 premature deaths each year worldwide due to air pollution and in Pakistan there are about 23,000 premature adult deaths yearly.

This study contributes to the knowledge and skill by developing strategies and methods for measurements and visualization of air pollution. Further this will help address the current shortage of research data. This project aligns with sustainable development goals as shown in Figure *1-1*.



1.3 Aim and Objectives

Given the lack of research and data regarding traffic related air pollution in Peshawar, Pakistan, this project aims to measure traffic related air pollution through the BRT route in Peshawar using the modern solutions.

The objectives of this research are as follows;

1. To calculate Air Quality Index Across twenty-one BRT stations in Peshawar.
2. To have a comparative analysis.
3. To suggest solution and highlight areas that needs attention.

1.4 Methodology

Measurement of air pollutant concentration is not something new, but the use of new technology and methods are necessary to develop cheap and reliable ways of measurement. The method used in this thesis includes literature review, configuration of hardware, programming, deployment and data analysis.

This research project focuses on getting a clear picture of traffic related air pollution in Peshawar through measurement of concentration of air pollution. Afterwards, the measured concentration is used to find corresponding AQI, and also performing comparative analysis and making deductions based on the measurements.

1.5 Report Outline

The thesis has been divided into seven chapters, in this chapter the context of study, background, aim, objective, motivation, significance and methodology have been discussed. In Chapter II existing literature will be reviewed. In Chapter III, equipment, and sensors have been explained. In Chapter IV Data storage, Data management and Libelium cloud have been explained. Chapter V explains the Methodology and Management. Chapter VI Analysis and Comparison of data, Chapter VII is the Conclusion and in last Chapter VIII is recommendations.

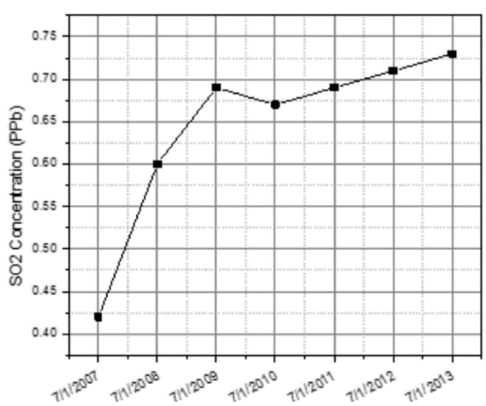
Chapter 2: Literature Review

2.1 Introduction

Air pollution is an increasing concern due to its effects on health, environment and the economy. In the past, research has been conducted to find the air quality in different parts of the world. Similar research was conducted in Peshawar, in this chapter we will review some of the previous works published by different authors followed by reviewing different trends in different periods such as during Covid-19. The next Part of this chapter includes a Height Profile i.e., relation between concentration and height. Further this chapter discuses different sources, traffic trends, different methods and devices used in the study, and lastly Impact of Traffic Related Air Pollution (TRAP) on health. After reviewing this research, the reader will get an understanding of TRAP study and its significance.

2.2 Prior Research

In the past, some efforts were made to find the air quality in Pakistan. Similarly, (Ullah, 2019) obtained a realistic picture of Peshawar's air quality and generated a baseline data in Peshawar. In which the concentration of NO_2 on 1 July of each year was measured and it was observed that the NO_2 concentration showed an upward trend from 24.8 ppb in 2007 to 32.8 ppb in 2013. Similarly, concentration of CO climbed from 3.5 ppb in 2007 to 13.8 ppb in 2013 and SO_2 first showed an upward trend but fell in 2010 and again showed in upward trend in 2011 till 2013 as shown in Figure 2-1. The study concluded vehicles as the major source of air pollution in Pakistan.



Another research was carried out in Peshawar in which the data was collected for 20 days in the month of April in 2011. It was observed that the average concentration of PM_{10} was 480 μg/m^3, with a maximum and minimum measured values of 553±101 μg/m^3 and 410±95 μg/m^3 respectively. Similarly, the average concentration of $PM_{2.5}$ was 172 μg/m^3, with a maximum and minimum measure readings of 187±19 μg/m^3 and 159±18 μg/m^3 respectively. In the research, the measured reading for the parameters was observed to be comparatively higher in the mornings and evenings. (Alam, 2015).

During Covid-19 lockdown, research conducted from March to May in 2020, suggested that there was a downtrend in the pollutant concentration in the air. It was estimated that there was a decrease of approximately 35 to 50% in the air pollution levels in Karachi, Peshawar, Lahore, Islamabad, Quetta and many cities across the country. The AQI for $PM_{2.5}$ reduced from unhealthy to moderate levels. One could conclude that it was the result of factories, market and industries closing. Similarly, it was observed that there was a huge decrease, of upto 65%, in NO_2 emissions because vehicle traffic was reduced (Khan K. A., 2020).

Traffic-related air pollution was measured outside 24 schools which were situated at a maximum distance of 400 m from the motorway, the concentration of $PM_{2.5,}$ NO_2 and Benzene (C_6H_6) was measured. It showed that the distance of the schools from the motorway had a significant impact the air pollution levels (Nicole A.H Janssen, 2001).

2.3 Vehicle in Peshawar

A study was conducted by (Ali, 2012), a teacher in University of Peshawar, to find growth in the number of vehicles in Peshawar. It was revealed that from 1998 to 2009, there was an increase of 126.4% in the number of vehicles which constitutes mostly of private vehicle cars, of about 75.35%, and has shown an increase of 228.98% in between 1998 to 2009, while improvement in road structure and expansion was only 0.85%.

2.4 Source of Air Pollution

The Positive Matric Factorization (PMF) was used to find sources of air pollution in Peshawar, result revealed five main sources in Peshawar; resuspension of PM, of about 35.9%, vehicular emission causing about 27.4% of PM, industrial emission about 12.9% of PM, brick kiln emission about 11% of PM and household combustion emission causing 12.8% of the total PM (Alam, 2015).

2.5 Pollutant concentration and Height

Vertical and horizontal profile of Particular matter were studied in Macao, China. It was concluded that there is a significant relation between height and concentration of particulate matter. Particulate matter decreases above ground with a height from 2 to 79 m. The maximum concentration of PM_1, $PM_{2.5}$, and PM_{10} occur at 2 meter and its concentration decrease to 80%, 62%, and 60% respectively at a height of 79 meter. This suggests that the particle concentration is affected significantly as the distance from sources is changed. The horizontal profile didn't show any significant difference, at a distance of 228 m maximum decrease occur which is 10%, 9%, 7% for PM_1, $PM_{2.5}$ and PM_{10} (Wu, 2002).

2.6 Method of Measurement and devices

The method used to measure the concentration of pollutants in the air by (Ullah, 2019) include analyzer CO APMA-370, a Non dispersive method used for determining carbon monoxide, for SO_2 APS-370, a pararosaniline method was used to determine the concentration of Sulfur (S) and for NO_x APNA-370, a chemiluminescence's technique was used to determine (Ullah, 2019).

The research carried out to find the distribution of aerosol size and concentration of PM by using GRIMM spectrometer and Positive matrix factorization model was used to appoint the source of particulate matter in Peshawar (Alam, 2015).

There was another study that used the satellite Image retrieved from Center of Research and Clean Air Pakistan, further methods and techniques were involved in collection and caparisons of raw data (Khan K. A., 2020).

Traditionally PM_{10} measurements were based on weight to volume techniques, where dust was collected from filter and weighed. It used to be very time-consuming, with the introduction of $PM_{2.5}$ and PM_1, much finer particles, it was hard to differentiate using the old methods. The new methods involve use of aerosol spectrometer. Using this method, concentrations of PM_{10} and $PM_{2.5}$ were measured from January 2012 up to October 2013 at Riyadh Airport and King Fahad Road using Grimm model EDM 365 aerosol spectrometer an Optical Particle Counter (OPC), it measured and monitored Real-time particulate matter concertation (Modaihsh, 2015).

2.7 TRAP impact on health

Cross-sectional research was carried out in Peshawar between January to May of 2017 with 94 participants, they were recruited using non probability convenance sampling technique. Air pollutant was determined using air quality detector, it was found that 17% participants had vital capacity, 9% had forced vital capacity, and 22% had forced expiratory volume in 1 sec, less than normal. Further elaborating, in females out of total results, Vital Capacity of 13%, Forced Vital Capacity of 16% & 37% Forced Expiratory Volume in 1st Second, was less than normal value of 70%. Whereas, 16% Vital Capacity, 6% Forced Vital Capacity and 9% Forced Expiratory Volume in 1st Second in males was less than the normal value of 70% (Iftikhar, 2018).

2.8 Conclusion

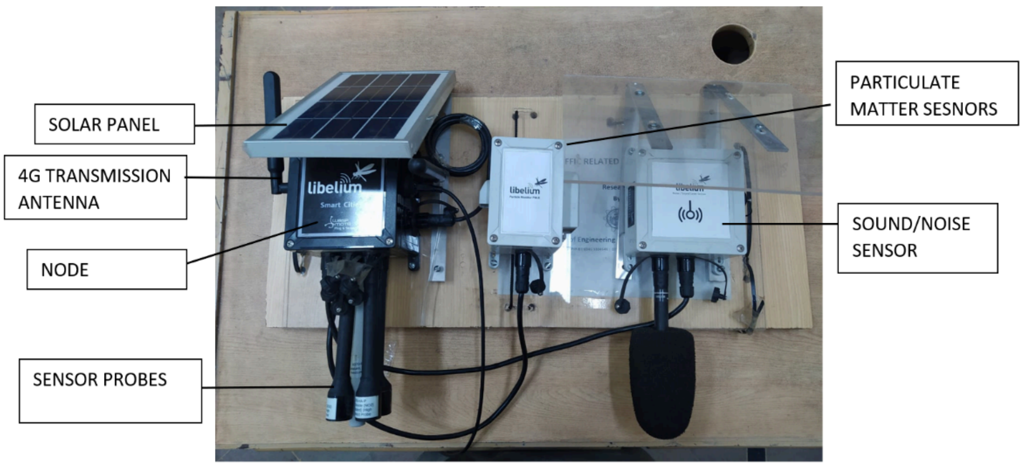
Traffic-Related air pollution (TRAP) changes from area to area and from time to time depending on the economy and other factors of a country. Peshawar's air quality is deteriorating at an alarming rate, this increase in pollution can be related to an increase in the number of vehicles in Peshawar. It is the need of the time to develop an advance TRAP measurement method and device, and from literature survey it was found that there is no reliable method available that uses IoT to measure traffic related air pollution. This research uses advance IoT device capable to measure several parameters and provide a real time solution. These parameters include CO, SO_2, NO_2, PM_1, $PM_{2.5}$, PM_{10} as well as temperature, humidity and pressure.

Chapter 3: Libelium Device; IoT Project

3.1 Introduction

The device used during this project is Libelium Waspmote Plug&Sense! Smart Cities Pro as shown in Figure 3-1. This device is equipped with Sensor Board v3.0. This board was designed for new product lines of Waspmote v15 and Plug & Sense! v15, released in October 2016 (Libelium, n.d.). The new board makes it capable to extend its functionalities from indoor to outdoor locations, by adding support for the Noise Level

Sensor to perform IoT projects in Smart Cities and urban environments. The main applications for this Waspmote Plug & Sense, are air quality, waste management, smart lighting, noise maps, etc.

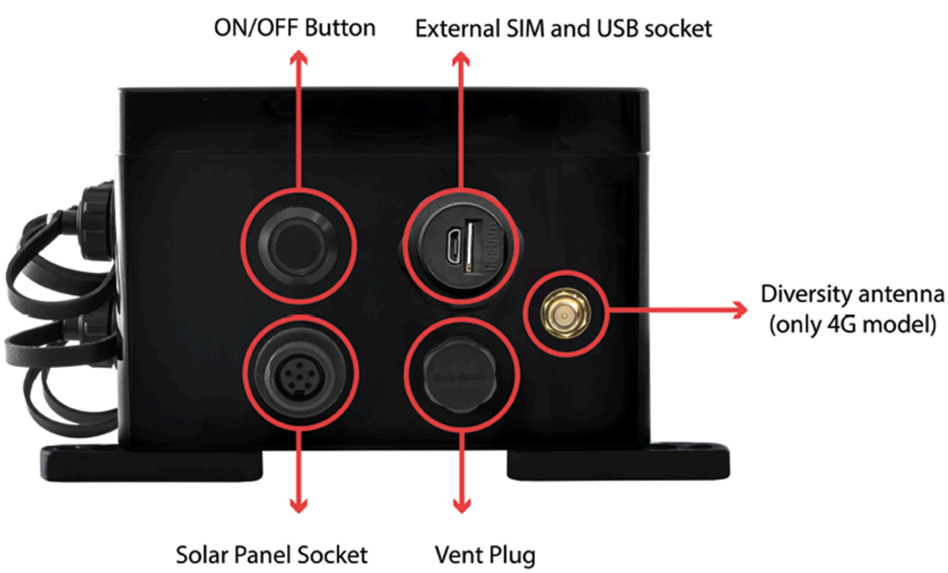


This device supports a large variety of sensors, that can measure concentration may be Noise/Sound Level Sensor, Particulate Matter Sensor, Carbon Monoxide Sensor, Carbon Dioxide Sensor, Molecular Oxygen (O_2) Sensor, Ozone (O_3) Sensor, Nitric Oxide (NO) Sensor, Nitrogen Dioxide (NO_2) Sensor, Sulfur Dioxide (SO_2) Sensor, Ammonia (NH_3) Sensor, Methane (CH_4) Sensor, Hydrogen Sulfide(H_2S) Sensor, Temperature Humidity Atmospheric pressure integrated Sensor, Luminosity Sensor,

Ultrasound Sensor. These sensors can be connected to the socket of the node in form of a sensor probe, the node can connect up to six probes, which means six sensors can be attached at a time, these six sockets are shown in Figure 3-2.

For our project, we opted for Temperature Pressure Humidity Sensor, Particulate matter Sensor, Carbon Monoxide Sensor, Sulfur Dioxide Sensor, nitric Dioxide Sensor. As the sound sensor wasn’t the scope of our project so the sound sensor was removed to save the battery.

Looking at the Bottom view, we can see there are six sockets as shown in_Figure 3-2, These sockets are not general, the specific sensor must be attached like; Particulate matter probe can be only connected in socket D, it cannot be connected in socked A, B, C, E, and F. These sockets must be sealed properly during arranging or it can lead to damages the device.Looking at the right view as shown in_Figure 3-3, we can see there is one solar panel socket that is used to connect the solar panel to the node, on top of the solar panel socket is an ON/OFF button pressing it will blink red light three-time showing it is responding, there is antenna socket on the extreme right where 4G antenna is connected for transmission i.e., communication protocol, and lastly, there is SIM and USB Socket on right to ON/OFF Button.



While putting the SIM one should be careful; SIM should be inserted with its chip face (Golden side) facing toward the micro-USB port. The USB port is used for charging and uploading programs.

3.2 Temperature, Pressure, Humidity sensor:

The BME280 is a digital temperature, humidity, and atmospheric pressure sensor, integrated by Bosch Sensortec as shown Figure 3-5, this sensor can be connected in sockets A, B, C, E, and F in the form of sensor probe Plug&Sense version as shown in Figure 3-6, the power consumption of BME280 is 3.3 V, with an average sleeping current (I) of 0.1 μA while its operating temperature (T) range is -40 to 85℃.

The humidity sensor provides an extremely fast response time of 1 sec (63% of step 90 to 0% or 0 to 90%) making it good for awareness applications, it has a high overall accuracy of ±3% of RH (at 25ºC, range 20 to 80%). The pressure sensor measures pressure in pascal, it is an absolute barometric pressure (P) sensor with extremely high accuracy ±0.1 kPa (0 to 65ºC). Its Measurement range is 30 to 110 kPa with an average current consumption of 2.8 μA.

Digital temperature sensing method in a noisy environment is difficult because the noise gets easily coupled with circuit and can result in a large temperature error, for that integrated temperature sensor has been optimized for the lowest noise and highest resolution with Accuracy of ±1ºC (at a range of 0 to 65ºC) with a fast response time of 1.65 sec (63% response from 30 to 125°C). It has an average consumption of 1 μA current.

3.3 Particulate Matter Sensor:

Particulate matter is composed of small solid or liquid particles floating in the air. Sources can vary from the exhaust of automobiles, industries emission, household burning, construction projects, pollen, etc. These particles are harmful to the human body, they can cause respiratory and coronary diseases and sometimes even be responsible for lung cancer.

The smaller the particle more dangerous it gets, particulate matter is classified into

PM1: If diameter of all particles is equal to or smaller than 1 μm.

PM2.5: If diameter of all particles smaller than 2.5 μm.

PM10: If diameter of all particles smaller than 10 μm.

The sensor used to measure the concentration of particulate matter in this project is OPC-N3, it can only be connected in socket D of the Plug&Sense node. The total flow rate of air that can be accommodated by the sensor is 5.5 L/min. It can measure the cleanroom to a pollution level of 2000 μg/m^3. OPC-N3 has a unique feature to classify the size of pollen making it good to distinguish between PM_1, $PM_{2.5}$, and PM_{10}. The Max particle count rate is 10000 particles/second. Due to its high current consumption, it is preferred to be kept off as its voltage ranges from 4.8 to 5.2 V, DC while Operating conditions include a temperature (T) of 10 to 50 ºC and humidity of 0 to 99%.

First, the air enters in particulate matter sensor of Libelium using a low-power fan creating an airstream when the air come in contact with the sensor, the sensor throws a laser beam on the air. The particle in the air scatters the light, now the light scattered by the particle in the air is measured, the intensity of light scattered by particles that range from 0.35 to 40 μm is calibrated and is used to determine the size and concentration of particle, from this Particle loading mass $PM_{2.5}$ or PM_{10}, are calculated using the particle size spectra and concentration data, assuming density and refractive index.

3.4 Nitrogen Dioxide (NO_2) Sensor:

The Sensor for measuring Nitrogen dioxide emission is "NO_2-A43F" as shown in Figure 3-8, the NO_2 probe Plug&Sense Version is shown in Figure 3-9, This sensor can measure NO_2 ranging from 0 to 20 ppm with a maximum overload range up to 50 ppm while having a response time of fewer than 60 seconds. Its current (I) consumption is less than 1 mA.

Operation conditions include a temperature (T) from -30 to 40ºC, humidity from 15 to 85% RH, and Pressure 80 to 120 kPa. NO_2 sensor Probe can only be connected to sockets B, C, and F.

3.5 Sulfur Dioxide (SO_2) Sensor:

The sensor used to measure Sulfur Dioxide gas is SO_2-A4 as shown in Figure 3-10, the SO_2 probe Plug&Sense version is shown in Figure 3-11. This Sensor can measure concentrations ranging from 0 to 20 ppm, with a maximum Overload of 100 ppm. It has a response time of 20 seconds, with Accuracy as good as ±0.1 ppm. Its current (I) consumption is less than 1 mA.

Operation Conditions include Temperature (T) Ranging from -30 to 50ºC, operating humidity of 15 to 90%, and, Pressure ranging from 80 to 120 kPa. SO_2 Sensor Probe can only be connected to sockets B, C, and F.

3.6 Carbon Monoxide (CO) Sensor:

The sensor for Carbon Monoxide concentration measurement from Libelium is CO-A4 as shown in Figure 3-12. The sensor can measure concentrations ranging from 0 to 25 ppm, with maximum overload up to 2000 ppm, and its response time is less than 20 seconds, with accuracy as good as 0.1 ppm. Its current consumption is less than 1 mA.

Operation Conditions include Temperature (T) Ranging from -30 to 50ºC, operating humidity of 15 to 90%, and, Pressure (P) ranging from 80 to 120 kPa. CO Sensor Probe can only be connected to sockets B, C, and F.

Chapter 4: Cloud Computing Architecture

4.1 Introduction

The transfer of different services through the Internet such as networking, data storage, server's database, connectivity, and software is called Cloud Computing. It requires a structure to work we call it cloud computing architecture. The cloud computing architect consists of following Components;

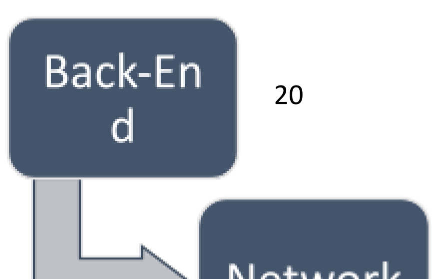
- Client Infrastructure
- Application
- Service
- Infrastructure
- Management
- Security
- Internet

We can classify these components into two main categories one is the front end, which includes the client-side infrastructure providing a Graphical User Interface (GUI), the application platform such as software, the client-server (Opera, Firefox, etc.), and Device. The second category knowns as the back-end help in managing the resources it provides cloud computing services such as

- Software as a service (SaaS); provides the capacity to store data.
- Platform as a service (PaaS)
- Infrastructure as a Service (IaaS); include host level, network level, and application-level

It includes everything required for successful cloud computing servers traffic control mechanics, security virtual machine, etc.

Internet connection acts as the bridge or medium between the front and backend. It allows user to establish the interaction and communication between the frontend and backend. (Peterson, 2022)



4.2 Why Cloud Computing?

One may ask why we have chosen cloud computing? Its answer is very easy Cloud computing helps user to keep data protected from disaster by storing it in the cloud, it can be available anytime. Secondly, we can do analytical analysis; analytics solution provides business value. For instance, a person can see the trend of a product whether the sale increasing or decreasing, as it uses data to inform the direction of a business. In the absence of a business problem, it can be set as building a minimum viable product, or in the case of this project (analytics of sensor data), for AQI report. The output of this analysis can be used by people to make informed decisions that impact the business.

Figure STYLEREF 1 \s 4 SEQ Figure * ARABIC \s 1 1: Cloud Computing Architecture

For our research project we opted for Libelium cloud service. It provides storage, analysis, reporting, dashboarding, and warning, Libelium cloud is user-friendly, reliable could be handled remotely.

4.3 Libelium Cloud and Cloud Computing;

The Libelium cloud services collect data from the sensory node it pulls data in a secured way to store or send it to another cloud service. Afterwards, the data can be analyzed, user may implement dashboards, data analytics applications can be utilized, data can be visualized with graphs.

Sensor nodes uses communication protocols such as NB-IoT / Cat-M, 4G, and Wi-Fi to send data directly to the Libelium cloud for which it requires three things;

The sensor node must be registered in the Libelium Cloud user account, a valid authentication API Key has to be associated with the sensor node. Integrity of the Libelium Cloud Bridge service encryption layer is respected.

By using Programming Service, nodes will automatically include a valid API Key and the encryption layer functions. Programming the sensor nodes using the manual coding in Waspmote IDE will require the user to manually include the API key and the encryption function. It will be explained later in this chapter.

4.4 Libelium Cloud

New Libelium Cloud is a platform that allows the management of IoT devices from front to the backend. All data from the sensor is taken and can be stored, visualized, and analyzed in the new Libelium cloud as it allows to completely manage an IoT Project. Some functions are following; (libelium, n.d.)
Programming of sensor devices for remote configuration.

- Data storage
- Data download
- Graphical display of data
- Connectivity to another cloud platform
- High multi-operability
- Management of subscriptions
- Premium technical support service contract.

In Short, it is a cloud service which provides connectivity, services, hardware control, and software and programming tool (generating code).

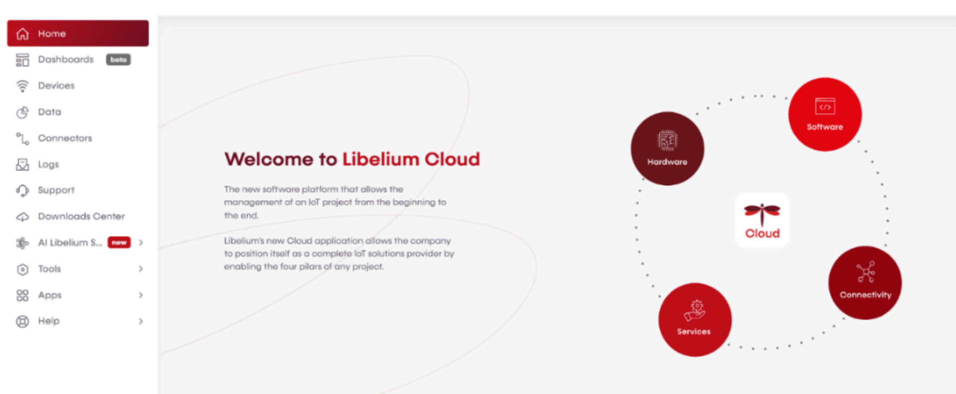
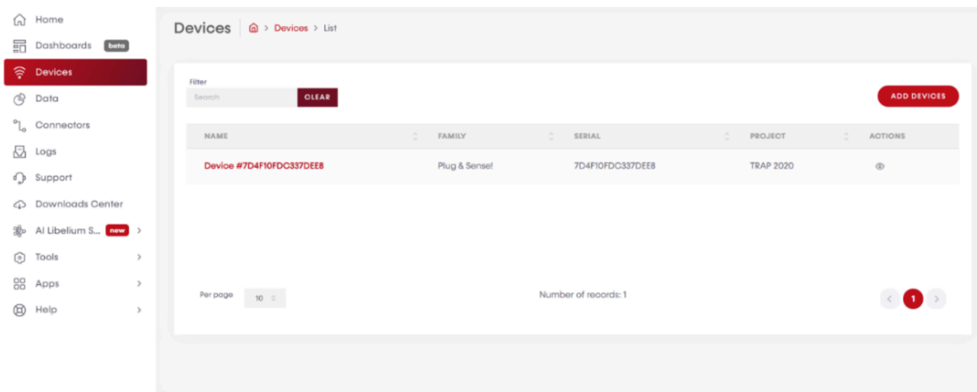


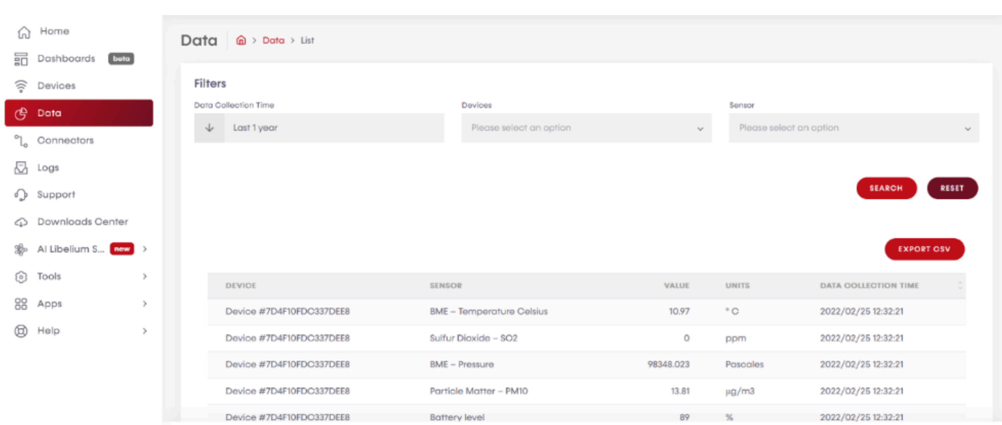
Figure STYLEREF 1 \s 4 SEQ Figure * ARABIC \s 1 2: Libelium Cloud Home Interface

4.5 Steps for activating Libelium cloud

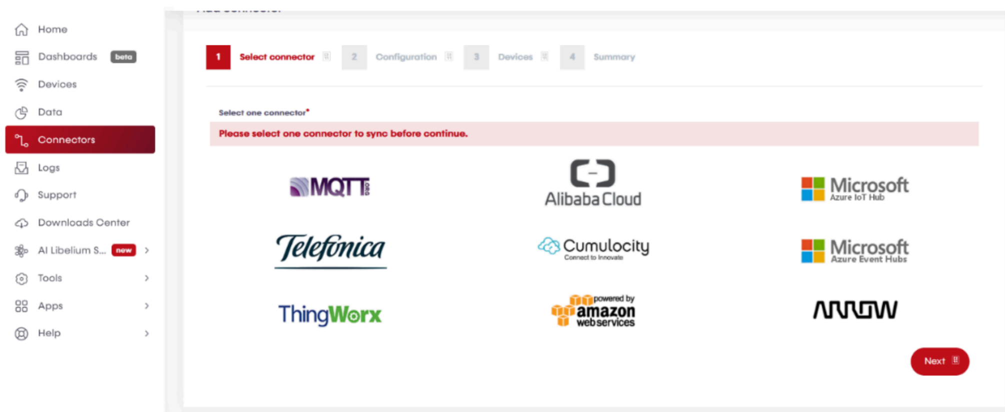
1. In order to start working with Libelium Cloud or to add any device, an activation code is required. After adding the device, if the communication protocol is established and subscription is completed, the Libelium cloud listens to HTTPS requests received from the sensor node.

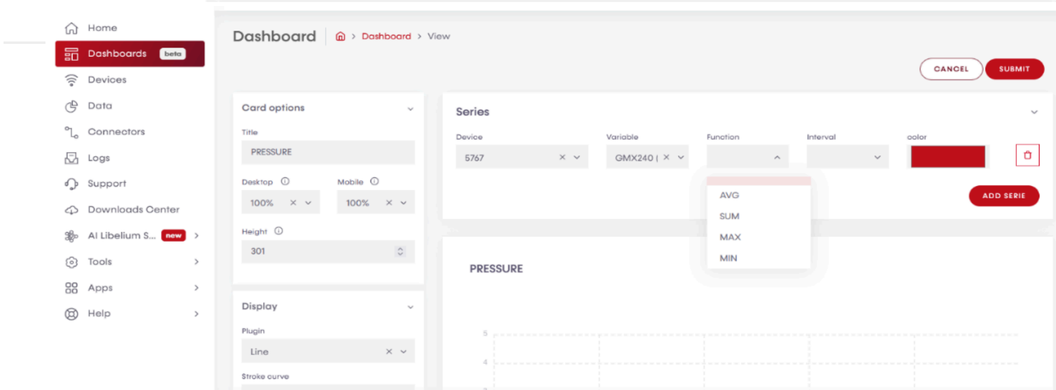


2. After receiving the data, it can be stored in the cloud. The data can be recalled any time as need of the user. The data can be categorized based on the sensor, time and device data. List can be opened to check the data; it can also be exported to MS excel files as shown in Figure 4-4.



3. Libelium provides an option to connect to the connector available in market, if user needs to use clouds available in the market, that can be done through MQTT and HTTPS. Some of the clouds are MQTT, Amazon Web Services, Alibaba Cloud, Microsoft Azure IoT Hub, thing Worx etc. as shown in Figure 4-5. For our project, we didn't need those clouds, as after the update on December 2021 Libelium cloud could do everything which was required for this project.





4. A Dashboard was made for the project. By adding card, we can choose a large variety of options in which we want to visualize the data, different graphs and charts can be made with many functions such as; AVG, SUM, MAX, MIN shown in Figure 4-6. We can use different colors to represent different variables such as PM_1, $PM_{2.5}$, PM_{10} on the same graph and it can give a comparison trend after summation the data dashboard can be visualized anytime shown in Figure 4-7.

4.6 Programming:

The node and the sensor need to be programmed for which there are two ways.

4.6.1 Programming Manually:

For manual programming, high skills are needed in coding such as one’s command over the language C++ and java and they will need to check Libelium manual on their website for different libraries which are used to code for each of the following sensor and action; Accelerometer, GPS, Data Frame, Interruption, Waspmote, RTC, SD card, Security, Utilities. Then they need to connect the USB cable to the node and upload the program from Waspmote IDE to the node from the PC. Regarding program, it has to be written in Waspmote IDE and then uploaded to the node. It takes a few seconds to upload the code to the node. After uploading, the output of the sensor can be seen in the "serial monitor" tab, where the output data can be observed.

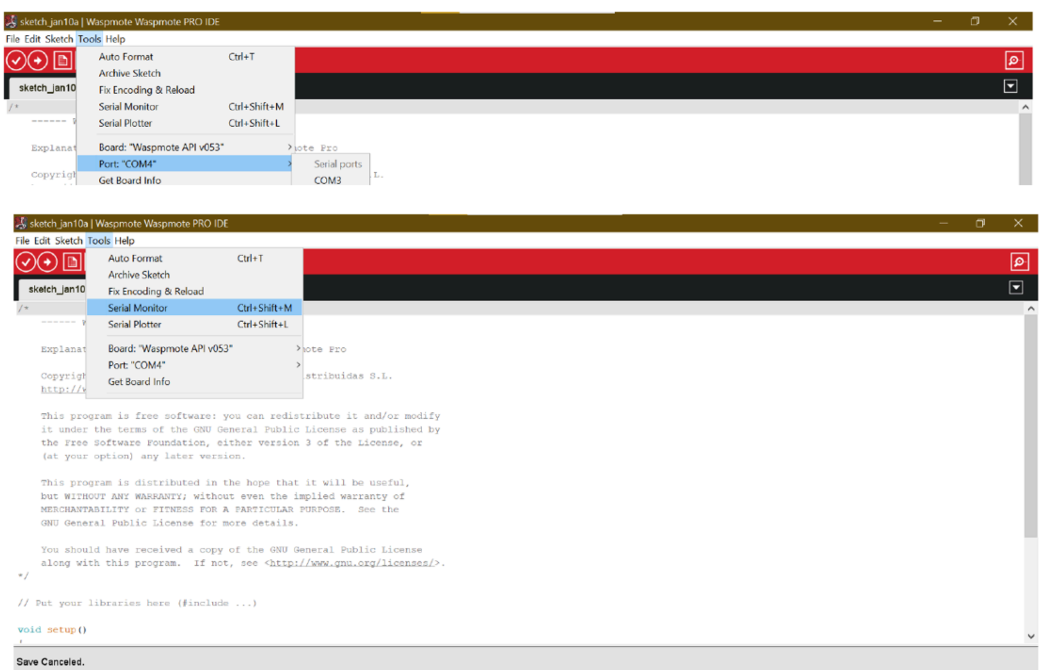
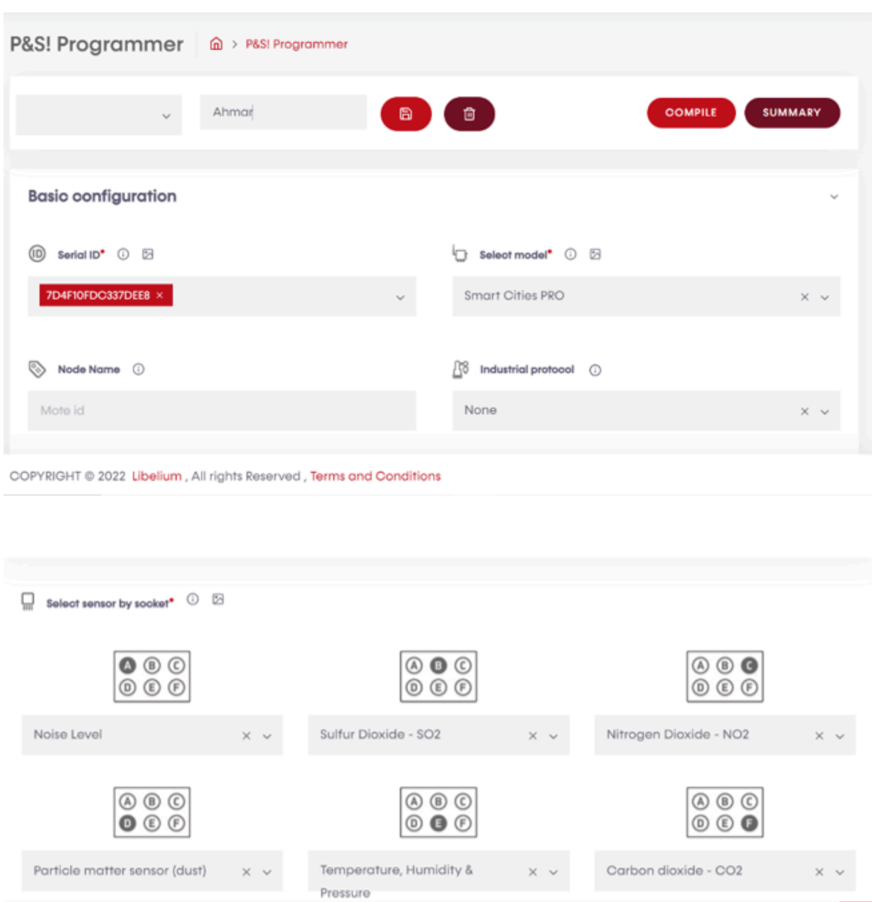


Figure STYLEREF 1 \s 4 SEQ Figure * ARABIC \s 1 8: Waspmote Pro IDE

In the Figure 4-8, it can be seen the USB cable connection is shown by the name "COM4". While "Serial Monitor" can be run to find the output.

4.6.2 Programming using P&S:

The sensor can be programmed using P&S service, for which a specific configuration is needed as show in Figure 4-9. The required information or the function needs to be selected in the drop-down options. In the sensor configuration, the order must be the same as physically installed. After which, communication protocol needs to be specified. We used the 4G Mobilink internet communication protocol, then destination must be given with all the encrypted keys and certificates. One can think of them as passwords and links as shown in Figure 4-11.



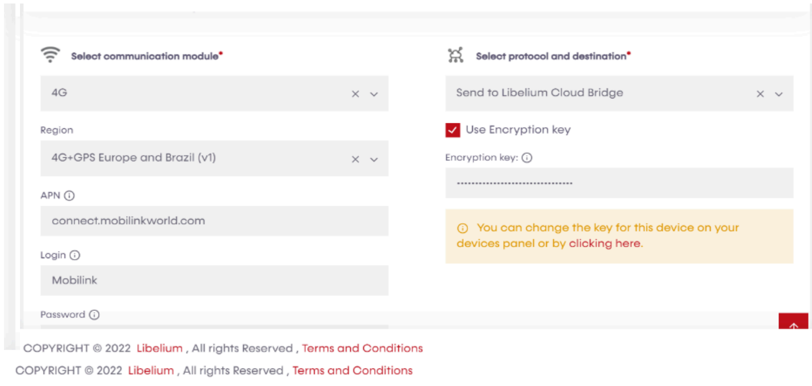


Figure STYLEREF 1 \s 4 SEQ Figure * ARABIC \s 1 11: P&S communication protocol

Sleep time of the device needs to be specified as shown in Figure 4-10. Due to limited battery, the device works in loops which consist of three steps; Read, Send, and Sleep. warning signal can be selected at a level of threshold.

Figure 4-9, Figure 4-11, and, Figure 4-10 show all the function that was selected for our project. P&S programming can be used to avoid manual programming.

4.7 Subscriptions

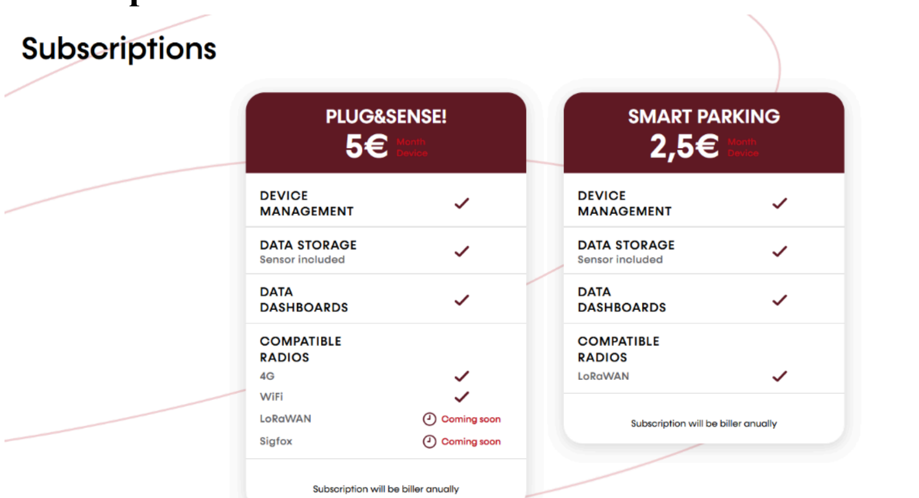


Figure STYLEREF 1 \s 4 SEQ Figure * ARABIC \s 1 12: Libelium Cloud Subscription Price

In order to use Libelium cloud and P&S services a subscription needs to be availed which charges 60 Euros annually. It provides management and programming. More benefits can be seen in Figure 4-12

After contacting Libelium cloud, we were provided with a student subscription program in which we were given a three-month Subscription as shown in Figure 4-13.

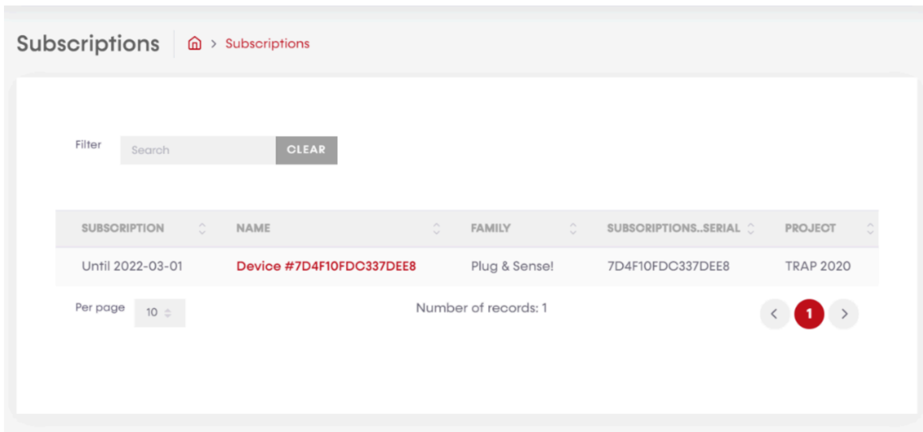


Figure STYLEREF 1 \s 4 SEQ Figure * ARABIC \s 1 13: Libelium Cloud Subscribed

Chapter 5: Methodology

5.1 Introduction

The project could be divided into three significant tasks, Configuration of the device, Deployment of the device and Data acquisition. The device used during this project is Libelium Plug&Sense smart cities pro and data is transmitted using 4G communication protocol. This device was deployed at 21 stations throughout the BRT route, data was exported to MS excel sheet, it was analyzed and visualized using graphs and charts. In this chapter, project planning, configuration of devices software and hardware, deployment location, schedule, data management, and AQI calculation is explained.

5.2 Project planning

The first primary task for the project was planning, which included defining the project, setting the goal, budget estimation, available resources and Time.

The goal and the project are already defined in chapter 1. For resources and budget evaluation, the device for Measurement of concentration of traffic-related air pollution was available in the TRAP lab of the University of Engineering and Technology Peshawar. Except for publication, the estimated cost of this project was less than 30,000 PKR. A Work breakdown structure was made after understanding the project. It consists of three major tasks; configuration, deployment and conclusion that further consist of other sub-tasks as show in Figure 5-1.

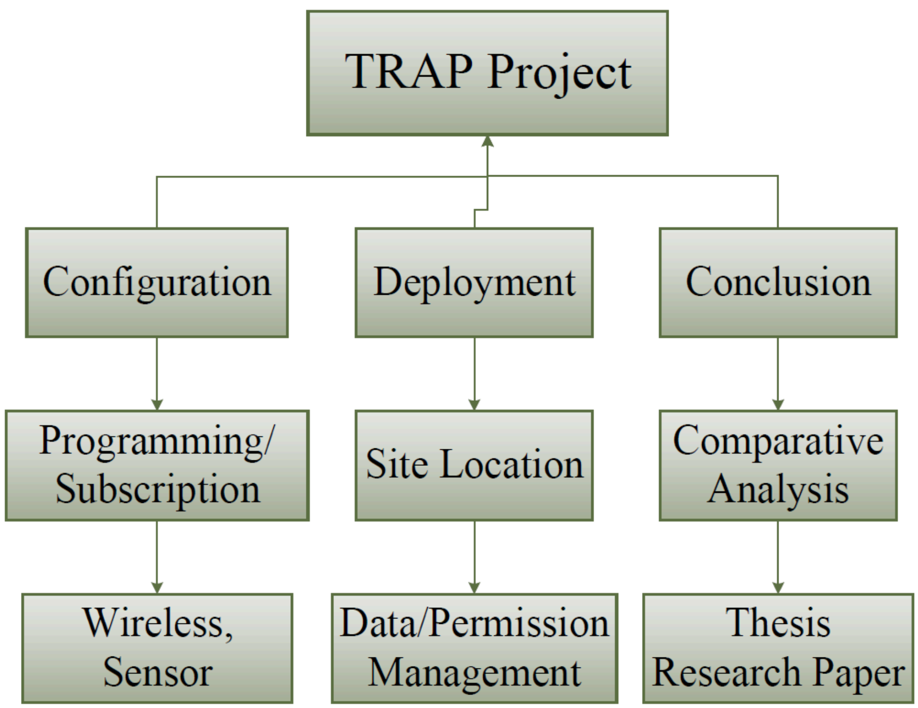


Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 1: Project Work Break structure

5.3 Configuration:

The configuration can be divided into two subtasks which includes software and hardware. The Hardware sub-task includes understanding the sensor and battery and calibrating the sensor. For more detail, see Chapter 3.

Sensor Node was powered by a rechargeable battery. This build-in battery was charged using solar power or a power adapter. Completely charging the battery takes 20 hours while charging it up using the power adapter takes 14 hours. Once fully charged, it can work on measuring intervals of 1 minute for 24 hours.

The Software sub-task includes understanding the Libelium cloud, subscription to its software, and programming the sensor.

The first task for this project was to make the device operable. For that, a subscription to the software running the device was needed; after getting it on request, we got access to transmission, storage and visualization of the data collected by the device. But in order to receive data, the device needed to be properly programmed, which is explained in the previous chapter.

P&S services was used to specify the sensor in slots and the sleep, send and read timings. Afterwards, the program was compiled, it was uploaded to the device via a USB data transfer port using an application designed by Libelium called Libelium smart device app. The device had to be turned on in order to upload the program, which was done by pressing the button. Once the ON button was pressed, it would blink three times indicating the device is working properly. Afterwards, the program could be uploaded using the application. Once it is complete, it will inform if it was successful or failed.

The data once collected needed to be uploaded to the cloud storage, these services were offered by Libelium. The data was automatically uploaded to the cloud. The connection between the device and the cloud was also automatic and both were bound to a single Libelium account.

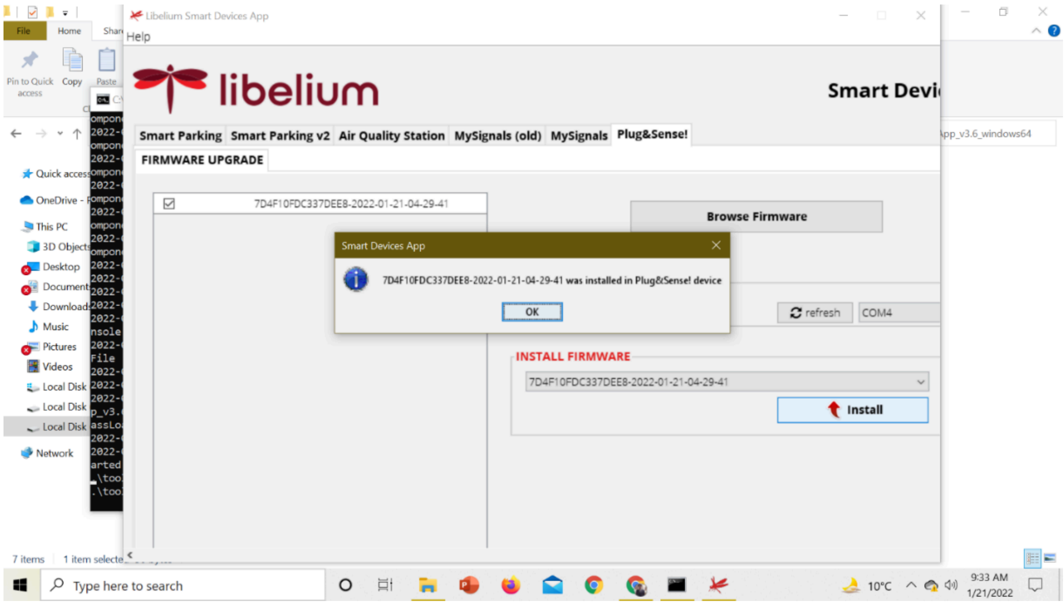


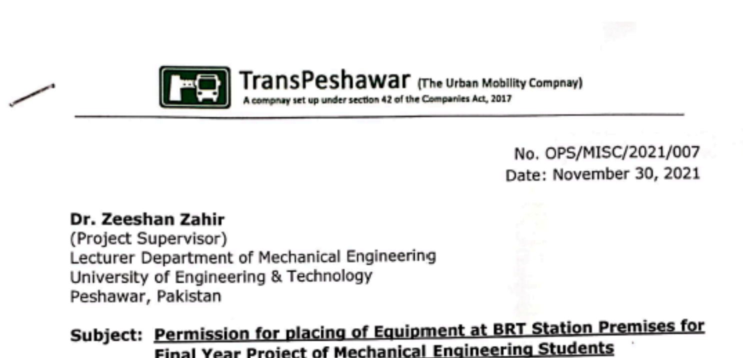
Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 2: Uploading program

5.4 Deployment:

The task of deployment can be divided into two subtasks Site location and Permission from authorities.

5.4.1 Permission from authorities:

In order to collect data for this research, permission was granted, allowing us to use BRT station and deploy our device outside corridor. The letter which was issued to us and the station managers shown in the Figure 5-3.



TransPeshawar (The Urban Mobility Compnay)
A compnay set up under section 42 of the Companies Act, 2017

No. OPS/MISC/2021/007
Date: November 30, 2021

Dr. Zeeshan Zahir
(Project Supervisor)
Lecturer Department of Mechanical Engineering
University of Engineering & Technology
Peshawar, Pakistan

Subject: Permission for placing of Equipment at BRT Station Premises for Final Year Project of Mechanical Engineering Students

5.4.2 Site Location:

The device was deployed at 21 different stations of BRT route as show in Figure 5-5, one may ask why BRT route? because it was safe to deploy the device. Each station is in middle of the road which was the best open environment for the collection of the data. Also, it includes the effect of both sides of traffic emissions concentration.

From 25 January to 25 February 2022 data was collected from different location as it can be seen in the Table *5-1*.

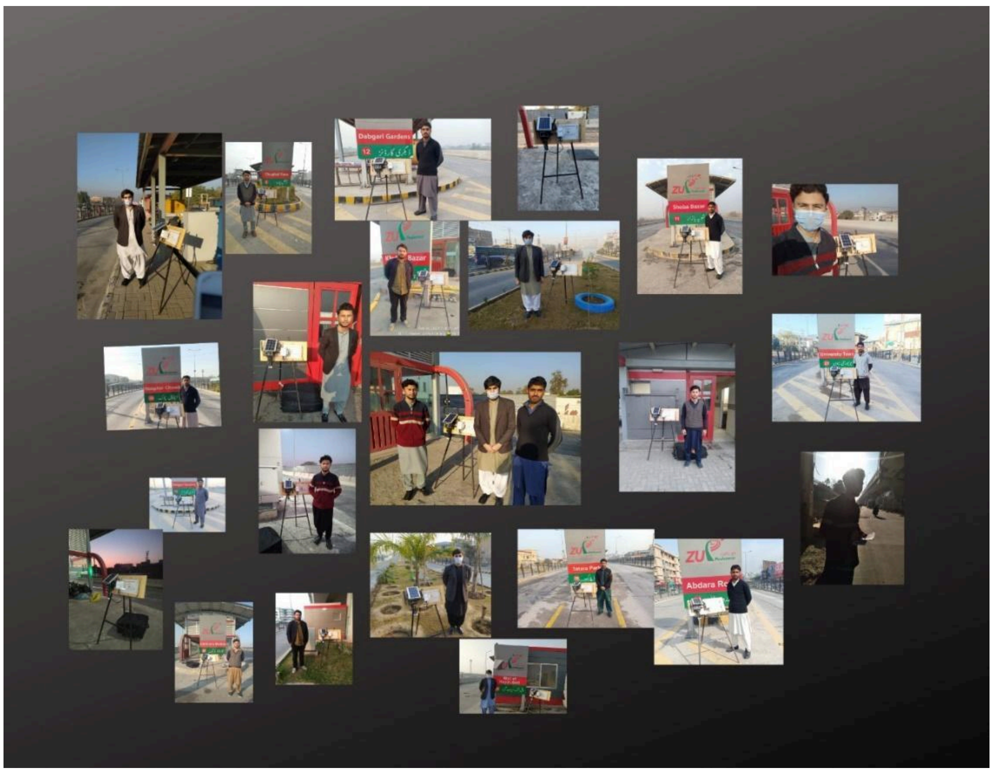
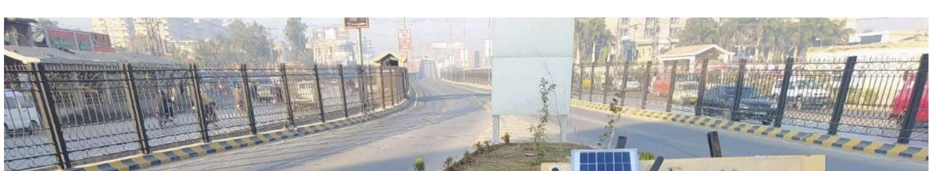


Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 4: Device Deployment

The setup was placed on a stand having a height of 1.5 m, as shown in Figure 5-6. If we add the height of BRT route from the road the height of setup would be 2 m. Study have concluded that maximum particulate matter concentration occurs at a heigh of 2 m to 3 m. Although not all station were on same height level, some were upto 20 m high which would be discussed in chapter 6.



Station	Coordinates	Bus station number
Railway Station	34.002578586896036, 71.549573996118	13
FC Chowk	33.9990921378662, 71.54446770981323	14
Saddar Bazar	33.99508097553913, 71.53827583939064	15
Tehkal Payyan Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 6: Deployment at Board	34.00911578022168, 71.51942790403407	18
Abdara Road	34.00296398744682, 71.50156686140608	20
University town	33.99957850194535, 71.49451111512886	21
University of Peshawar	33.997782835922976, 71.4872532800447	22
Board Bazar	33.99806224654481, 71.47096430267747	24
Mall of Hayatabad	33.99209188636296, 71.4613186187463	25
Bab-e-Peshawar	33.990281749331494, 71.45466909279429	26
Tatara Park	33.98576716436239,	28

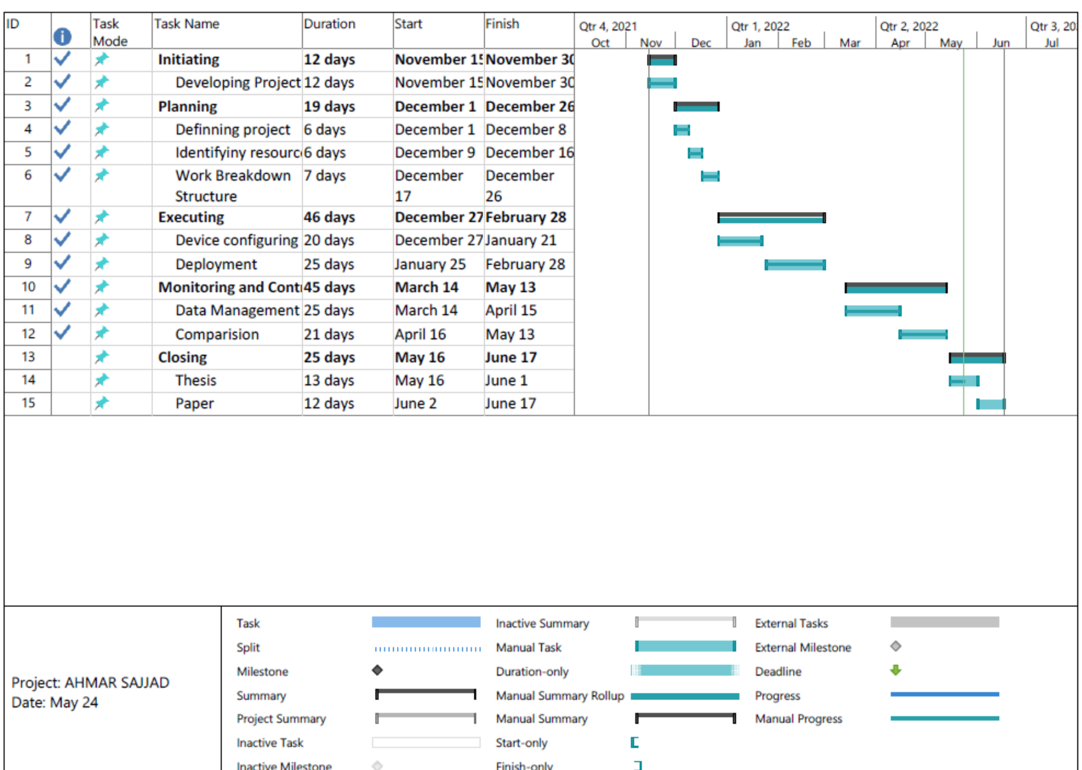
Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 5: Map of Peshawar and Deployment site location

	71.44291039472158	
Hospital Chowk	33.993814089014656, 71.44344504649166	30
Karkhano Market	33.9986822778383, 71.42484779591885	31
Dabgari Gardens	34.00607735424843, 71.55774856485827	12
Shoba Bazar	34.00824453807324, 71.56194368557942	11
Khyber Bazar	34.01002457376292, 71.56570273677384	10
Malak Saad Shaheed	34.01466016978297, 71.57212491288873	9
Lahore Adda	34.015983854711315, 71.60019531633067	6
Old Haji Camp Station	34.016424272423976, 71.60755211562325	5
Faisal Colony Station	34.01670114592128, 71.61459917794053	4
Chugal Pura	34.0175558196037, 71.62935766771604	3

Table 5-1: Location of Deployment

5.5 Project schedule:

A specific schedule and sequence were followed in the research. The sequence was mostly based on predecessors. A Gantt chart was made with all the plans, events scheduled on as show in Figure 5-7.



For deployment of device on different stations, a scheduled timetable was followed, starting on 25 January 2022 device was deployed at Railway Station (Station number 13 of BRT), it followed the timetable as shown in Figure 5-8 and it ended on 25 February 2022 at Chugal Pura Station (Station number 3).

JANUARY-FEBRUARY 2022

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
24 JANUARY	25 Railway Station	26 FC Chowk	27	28 Saddar Bazar	29 Tehkal Payyan	30
31 Abdara Road	1 University town	2 University of Peshawar	3 Board Bazar	4 Mall of Hayatabad	5 Bab-e-Peshawar	6
7 Tatara Park	8 Hospital Chowk	9	10 Karkhano Market	11	12	13
14 Dabgari Gardens	15 Shoba Bazar	16 Khyber Bazar	17 Malak Saad Shaheed	18	19	20
21 Lahore Adda	22	23 Old Haji Camp Station	24 Faisal Colony Station	25 Chugal Pura	26	27

Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 8: Timetable of Deployment

5.6 Project control

It involved control of all management system, involve monitoring resources, budget, cost, and quality.

5.6.1 Data Management

The purpose of this project is to measure traffic-related air pollution. Most handy traffic pollutants would be PM_1, $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2. These pollutant concentrations were measured with Libelium sensors probes attached to Smart Cities Pro node, as depicted in Figure 5-10.

Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 9: Rescheduling, Unexpected Event.

The Data Management includes all steps that ensure that the data is handled properly, it started with transmission of data to the Libelium cloud. For monitoring of data dashboard was created. A reporting system was established. The data needed to be stored, and maybe recalled for a data and time form the storage system.

5.6.2 Establishment of data monitoring, dashboarding and reporting system;

Data monitoring dashboard was established, these dashboards were dedicated to monitor traffic related air pollution. Data could be visualized in different ways and their maximum, minimum and average values could be displayed, at the time of deployment, data was constantly watched from 8 AM to 4 PM.

Figure STYLEREF 1 \s 5 SEQ Figure * ARABIC \s 1 10: Sensor probes attached to smart cities node

5.6.3 Time series data storage

Once the data was recorded it was stored in Libelium cloud and saved in time series sorted by time and pollutant type

5.6.4 Data recall system and Analytics

Data recall system was ensured in Libelium cloud as discussed in chapter 4. Data could be sent to excel sheet for further analysis and result.

AQI value	AQI category	Color
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple

301 and greater	Hazardous	Maroon

Table 5-2: AQI category and color

5.7 AQI calculation

Data collected is used to find Air Quality Index (AQI), they are presented categorically by mean of color scale for AQI, this helps in knowing the level of hazard or toxicity. AQI was calculated as a daily average value. For finding AQI US EPA was used; For AQI conversion Equation 5-1 was used.

To finding AQI, use Table 5-3 to find breakpoints, use value along with Equation 5-1.

Table STYLEREF 1 \s 5 SEQ Table * ARABIC \s 1 3: Break point for AQI

These Breakpoints...							...equal this AQI	...and this category
O_3 (ppm) 8-hour	O_3 (ppm) 1-hour[1]	$PM_{2.5}$ ($\mu g/m^3$) 24-hour	PM_{10} ($\mu g/m^3$) 24-hour	CO (ppm) 8-hour	SO_2 (ppb) 1-hour	NO_2 (ppb) 1-hour	AQI	
0.000 - 0.054	-	0.0 – 12.0	0 - 54	0.0 - 4.4	0 - 35	0 - 53	0 - 50	Good
0.055 - 0.070	-	12.1 – 35.4	55 - 154	4.5 - 9.4	36 - 75	54 - 100	51 - 100	Moderate
0.071 - 0.085	0.125 - 0.164	35.5 – 55.4	155 - 254	9.5 - 12.4	76 - 185	101 - 360	101 - 150	Unhealthy for Sensitive Groups
0.086 - 0.105	0.165 - 0.204	(55.5 - 150.4)[3]	255 - 354	12.5 - 15.4	(186 - 304)[4]	361 - 649	151 - 200	Unhealthy
0.106 - 0.200	0.205 - 0.404	(150.5 - (250.4)[3]	355 - 424	15.5 - 30.4	(305 - 604)[4]	650 - 1249	201 - 300	Very unhealthy
([2])	0.405 - 0.504	(250.5 - (350.4)[3]	425 - 504	30.5 - 40.4	(605 - 804)[4]	1250 - 1649	301 - 400	Hazardous
([2])	0.505 - 0.604	(350.5 - 500.4)[3]	505 - 604	40.5 - 50.4	(805 - 1004)[4]	1650 - 2049	401 - 500	Hazardous

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}.$$

Where;

I_p shows the index for the pollutant

C_p shows the truncated pollutant concentration,

BP_{low} show the concentration breakpoint that is $\leq C_p$

BP_{high}= the concentration breakpoint that is $\geq C_p$

I_{low}= the index breakpoint corresponding to, BP_{low}

I_{high}= the index breakpoint corresponding to BP_{high}

Chapter 6: Analysis

6.1 Introduction

To find the condition of air quality, this research measured parameters that contribute to air quality. These parameters are related to density of traffic. Based on the concentrations measured, the Air Quality Index (AQI) would be calculated for every contributing parameter. Similarly, to properly understand air quality variation all through the daylight hours and make an assessment among them, environmental variables, such as PM_1, $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, Temperature, Relative Humidity, had been measured with the help of Libelium Waspmote Plug&Sense! Smart Cities Pro.

Measurements of these parameters were taken on twenty-one BRT bus stations on the corridor between the roads so the measurements would be as accurate as possible. The measurements were taken in the months of January and February of 2022 check Figure 5-8 for timetable. Measurements were taken from 8 AM to 4 PM as these 8 hours are recognized by the WHO as the worst for traffic related pollution. Each measurement was taken after a 10-minute interval, making it an average of 48 data samples. In order to use the battery of the device in optimized condition, this 10-minute interval was implemented, even though the vendor recommends more than 10-minute interval for recording values.

6.2 Calculating Air Quality Index (AQI)

This thesis takes use of US EPA standard as figuring out every pollutant's AQI. AQI represents the degree of air pollution, suggests its elegance and suggests the extent of concernment to health. Status of the air satisfactory equated on a scale of 0-500 index, higher AQI value suggests lower air quality and vice versa. Conventionally AQI values less than fifty-one is considered good for the quality of air and from fifty-one to one hundred is the moderate quality while anything higher is considered as harmful with more than two hundred considered unsuitable for living. AQI values are categorized into six classes, each one with its health risks. These categorical classes are separated by means of particular AQI value ranges and represented by a selected color. US EPA categorization of AQI and its classification of color coding proven in Table 6-1 even as sensitive businesses are also proven in Table 6-2 for every parameter.

Table 6-1: Table for AQI categorization for Particle Matter and Ozone

AQI Class	AQI Category	Color Representation	Corresponding AQI Statements
0-50	Good	Green	Satisfactory Air Quality with little or no risk to sensitive people.
51-100	Moderate	Yellow	Acceptable air quality, while few people and sensitive groups may experience some risk.
101-150	Unhealthy for sensitive groups	Orange	General public is less effected, while the sensitive group may experience health problems.
151-200	Unhealthy	Red	Little effect for the general public, while higher health implication for a sensitive group.
200-300	Very Unhealthy	Purple	Health alert; high risk affecting everyone.
>300	Hazardous	Maroon	Emergency health caution; Dangerous to everyone

Table 6-2: Individual parameter + its corresponding Sensitive Groups (Source: US EPA)

AQI > 100 For following	Report these Sensitive Groups
$PM_{2.5}$	"People with heart or lung disease, older adults, children, and people of lower socioeconomic status are the groups most at risk."
PM_{10}	"People with heart or lung disease, older adults, children, and people of lower socioeconomic status are the groups most at risk."
SO_2	"People with asthma, children, and older adults are the groups most at risk."
NO_2	"People with asthma, children, and older adults are the groups most at risk."

This research follows the standards of NAAQS (National Ambient Air Quality Standards) of the US Environmental Protection Agency (US EPA). The maximum acceptable standard values for the core pollutants are presented in Table 6-3. These are the primary and secondary standards values which are not supposed to be exceeded. The primary standard is intended to protect the health of inhabitants while the secondary standards are for protecting public wealth.

Table 6-3: US EPA standards for air pollutants (NAAQS Table)

Pollutant	**Primary/Secondary**	**Averaging Time**	**Level**
$PM_{2.5}$	Primary	1-year mean	12 µg/m^3
	Secondary	1-year mean	15 µg/m^3
	Primary and Secondary	24- hour mean	35 µg/m^3
PM_{10}	Primary and Secondary	24-hour mean	150 µg/m^3
Sulphur Dioxide (SO_2)	Primary	1-hour mean	100 ppb
	Secondary	1-hour mean	53 ppb
Nitrogen Dioxide (NO_2)	Primary	1-hour mean	75 ppb
	Secondary	1-year mean	50 ppb

6.3 Graphic comparison of AQI

To better recognize the situation of air quality, AQI is calculated for each of the crucial parameters that contribute to the state of air quality while following the standards of US EPA. AQI for different parameters are compared with other stations. The AQI are shown on column charts where the AQI is calculated for the average concentration reading for each station. Figure 6-1 to Figure 6-4 shown AQI comparison for $PM_{2.5}$, PM_{10}, NO_2 and SO_2 respectively.

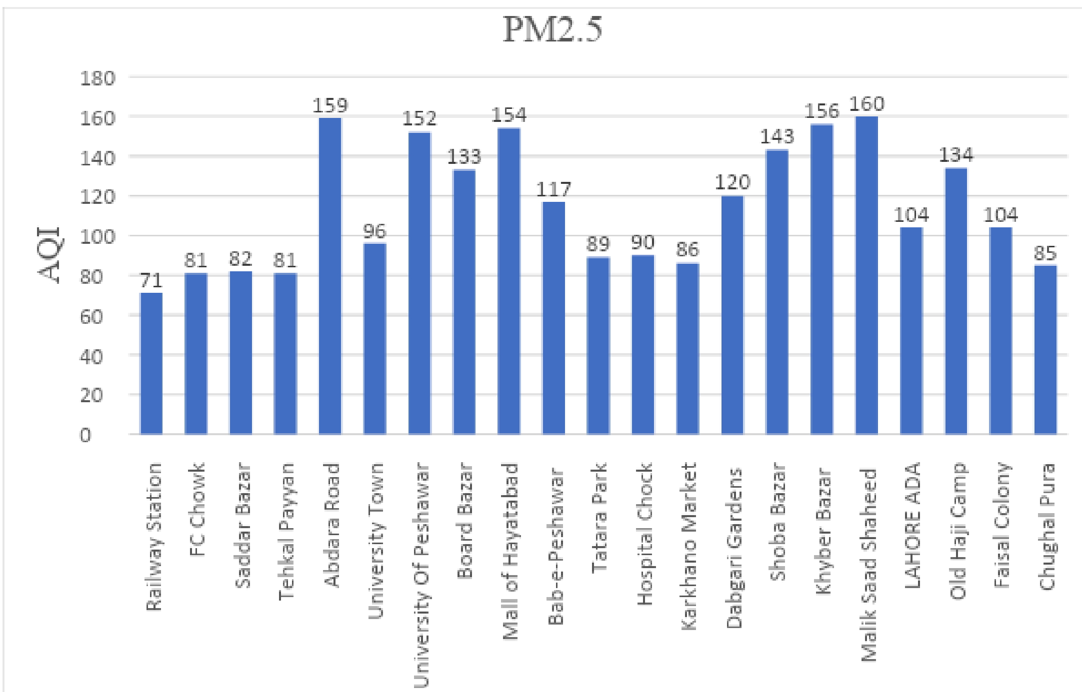


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 1: AQI $PM_{2.5}$ Comparison

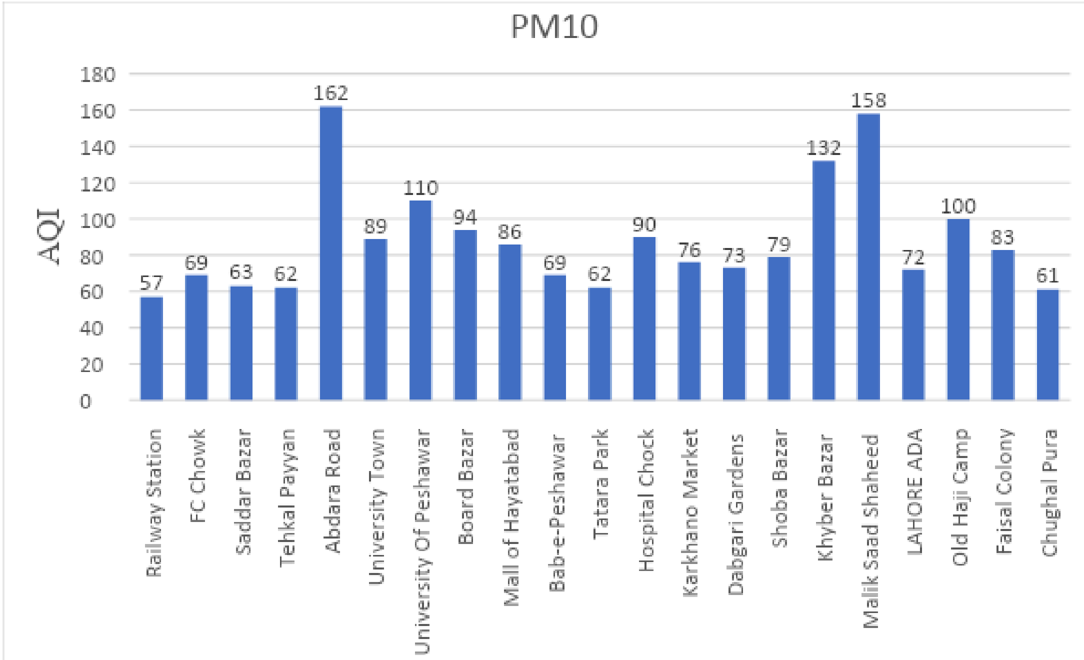


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 3: AQI PM_{10} Comparison

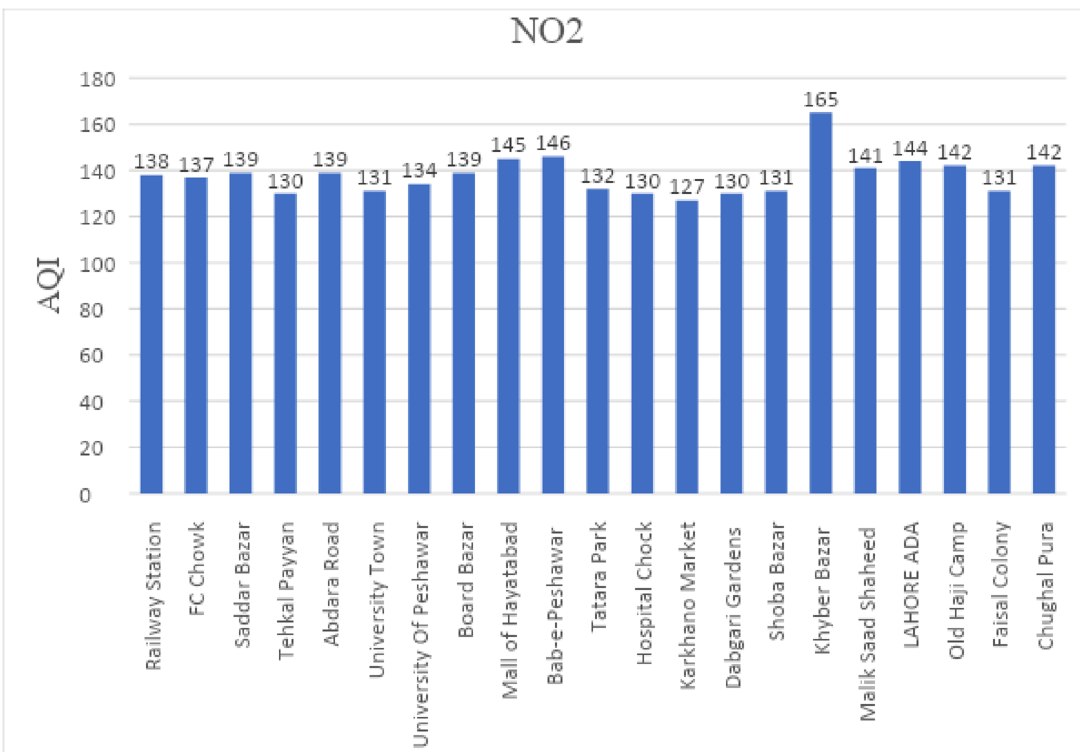


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 2: AQI NO_2 Comparison

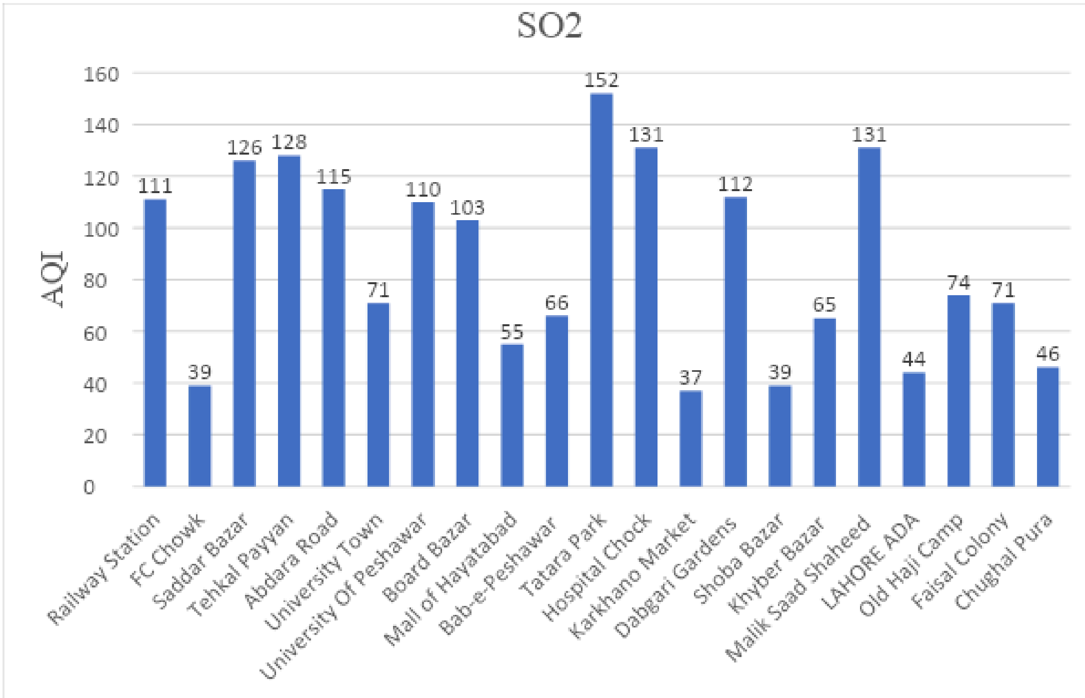


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 4: AQI SO_2 Comparison

It can be seen that Malik Saad Shaheed and Abdara Road have high AQI value in the 'unhealthy' and 'unhealthy for sensitive groups' AQI categories respectively. Similarly, $NO_{2,}$ in Figure 6-2, have a similar AQI values which are in the 'unhealthy for sensitive groups' AQI category with the exception of Khyber Bazar that have an AQI of 165 which lies in the 'unhealthy' AQI category. In $SO_{2,}$ high AQI value of 152 can be seen for Tatara Park which lies in the 'unhealthy' AQI category, other stations have readings in lower AQI categories which can be seen in Figure 6-4.

Table 6-4: AQI for different parameters for all stations

Stations	AQI				
	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO
Railway Station	71	57	111	138	15
FC Chowk	81	69	39	137	17
Saddar Bazar	82	63	126	139	27
Tehkal Payyan	81	62	128	130	13
Abdara Road	159	162	115	139	59
University Town	96	89	71	131	31
University Of Peshawar	152	110	110	134	49
Board Bazar	133	94	103	139	32
Mall of Hayatabad	154	86	55	145	8
Bab-e-Peshawar	117	69	66	146	17
Tatara Park	89	62	152	132	13
Hospital Chock	90	90	131	130	14
Karkhano Market	86	76	37	127	8
Dabgari Gardens	120	73	112	130	18
Shoba Bazar	143	79	39	131	23
Khyber Bazar	156	132	65	165	28
Malik Saad Shaheed	160	158	131	141	63
LAHORE ADA	104	72	44	144	25
Old Haji Camp	134	100	74	142	40
Faisal Colony	104	83	71	131	22
Chughal Pura	85	61	46	142	22

Table 6-4 shows the AQI values for different measured parameters. AQI is scale use to know about quality of air regarding some parameters, so

Table 6-4 shows the quality of air measured at different stations. As it can be seen in the table, Abdara Road and Malik Saad Shaheed show the worst measured air quality as their AQI is comparatively the highest followed by Khyber Bazar Station. Karkhano Market Station and Lahore Adda are observed to have the lowest values of AQI.

6.4 Condition throughout the day

The recorded values for each parameter are given in detail and will be discussed afterwards in depth. For each variable, frequency analysis along with their graphs are drawn, which helps in the visualization of data. Figure 6-5 to Figure 6-10 shows the trends for different Parameters throughout the day.

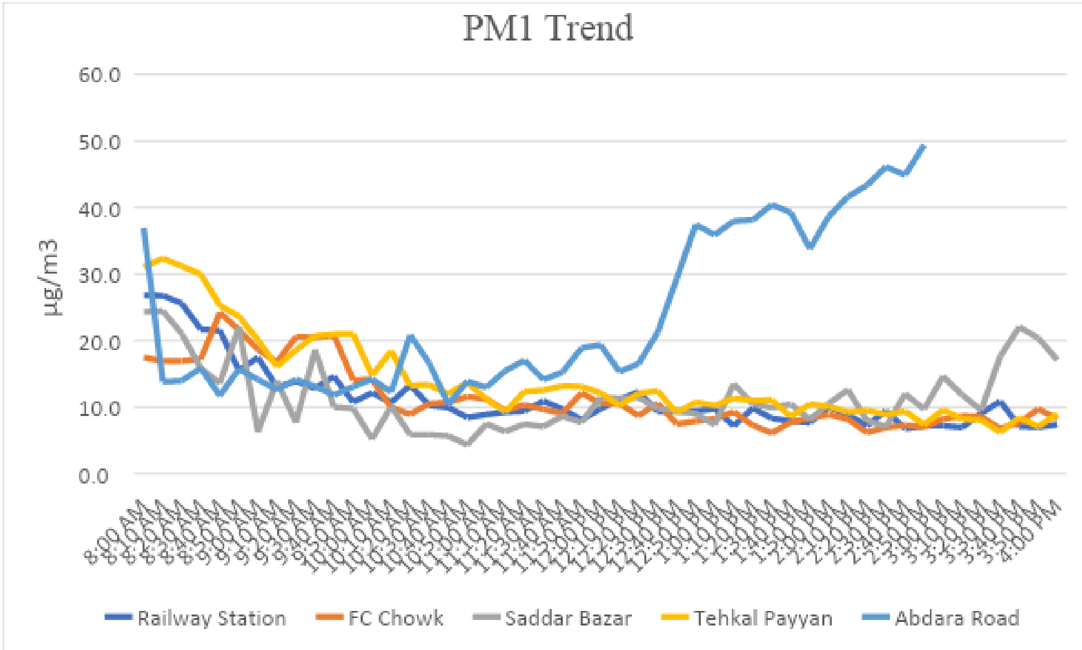


Figure 6-5: Trends for PM_1 for some stations throughout the day

As seen in Figure 6-5 for five stations, at the start of the data collection time in the day, at 8 AM, the readings recorded by the device ae higher and it gradually decreases and remains somewhat consistent until the end of the data collection period. If we look at the yellow trend line, we will find that at 8:00 AM there is a concentration within the range of 30 µg/m^3 while at 12:00 PM there is a concentration of 13 µg/m^3 at the end of day there is concentration of 7 µg/m^3 it shows that the concentration is high at the early rush hour. If we look at the dark blue line, we find that initial concentration of 26 µg/m^3 at early hours followed by a decrease in concentration to 8 µg/m^3 and later it further goes down to 7 µg/m^3. Just like these two stations, the other stations follow the same trend throughout the data collection period except Abdara Road which show an abnormality.

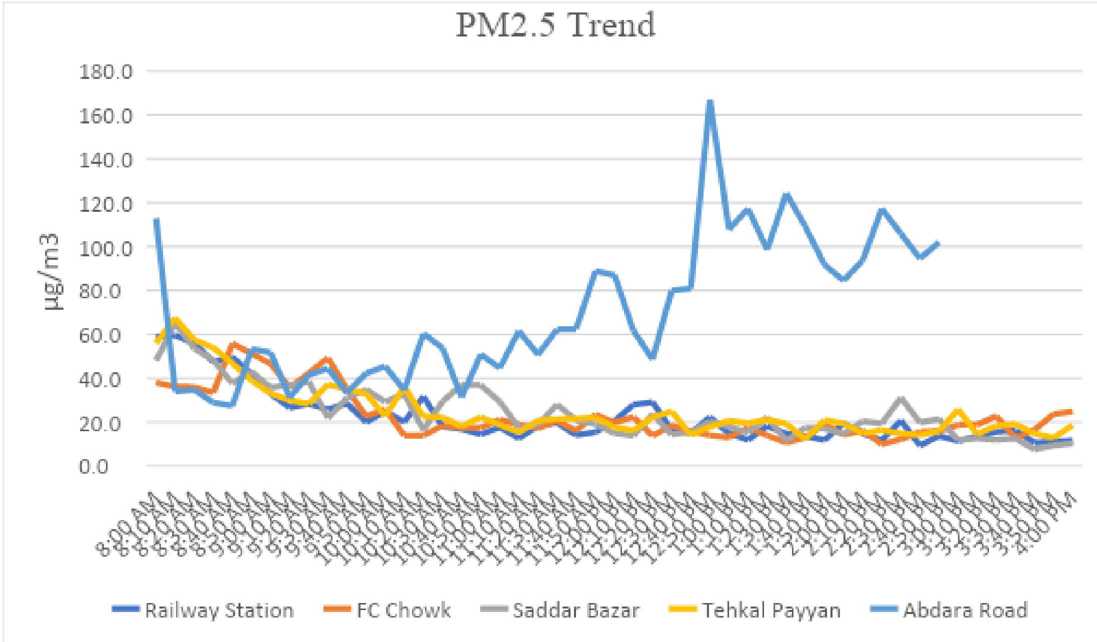


Figure 6-6: $PM_{2.5}$ trend throughout the day

Similarly, when it comes to $PM_{2.5}$ we see that the trend shows a similar behavior to that of PM_1 trend. If we see at the beginning of day the yellow line representing Tehkal Payyan has initial concentration of 56 µg/m^3 at noon there was a recorded concentration of 22 µg/m^3, later it further decreased to a value of 12 µg/m^3. If we look at Dark blue line representing Railway Station trend, it shows that it has an initial concentration of 59 µg/m^3, at noon it has a concentration of 15 µg/m^3 and at the end of the day recorded concentration was 11 µg/m^3. likewise, all these graphs follow same trend, readings at the start of the day, concentration is high and it gradually decreases and remains somewhat consistent until the end of day. This trend can be seen in Figure 6-6.

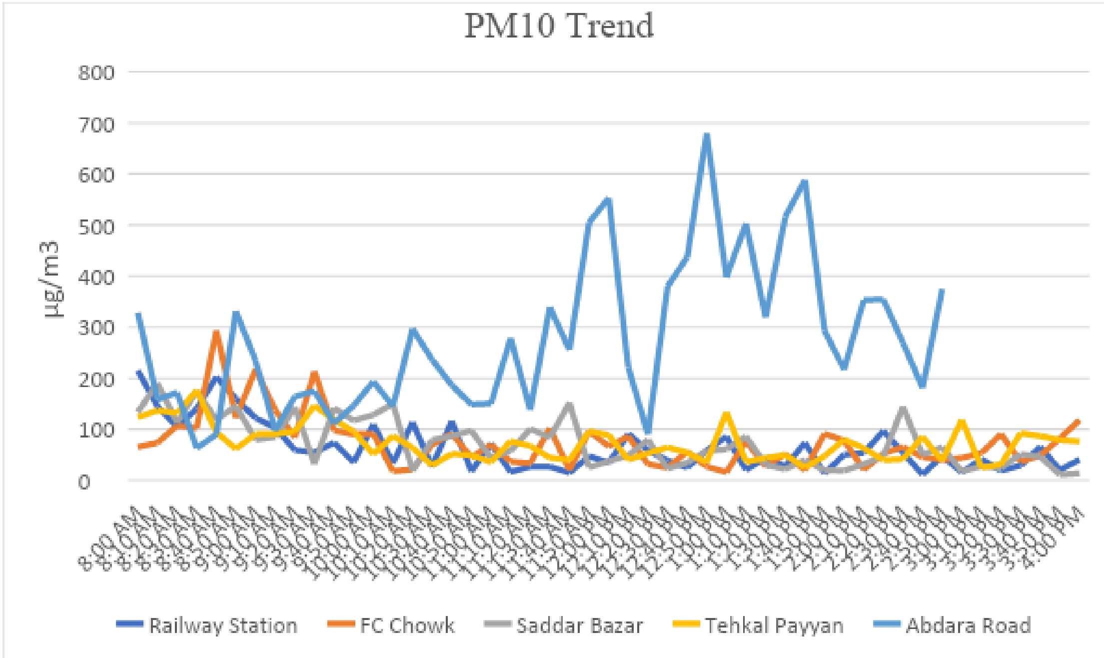


Figure 6-7: PM_{10} trend throughout the day

Figure 6-7 shows trend lines for PM_{10} for five stations throughout the day. This figure shows the same trend as that of PM_1 and $PM_{2.5}$. If we look at yellow line which represents the Tehkal Payyan trend, there was a concentration of 124 µg/m^3 at the beginning at 8:00 AM followed by a decrease to 79 µg/m^3 at the end. Similarly, these reading show a comparatively higher concentration at the start and the concentration get lower and lower as we go through the day. Abdara road is an exception in all figures as it experiences worse air conditions than most of the other stations. All Abdara road trend lines show abnormality from the other stations.

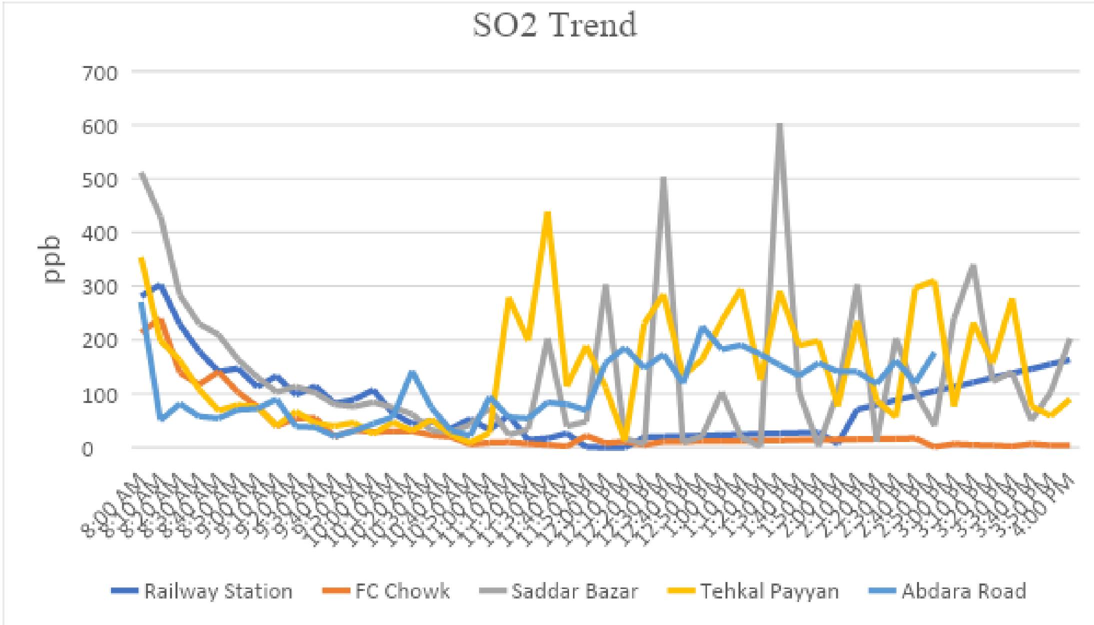


Figure 6-8: SO_2 trend throughout the day

Figure 6-8 shows the trend throughout the day for SO_2 concentration readings for five stations. The concentration readings trends for particulate matter (PM) and gasses are different. The particulate matter trends show a high number at the start with a gradual decrease in about 2 hours and it stays low until about 3:00 PM after which the concentration remains relatively the same. The SO_2 shows a similar trend of high readings at the start of the day and a gradual decrease but the increase starts at a much earlier time than that in particulate matter. After the increase the SO_2 concentration sees a random increase and decrease.

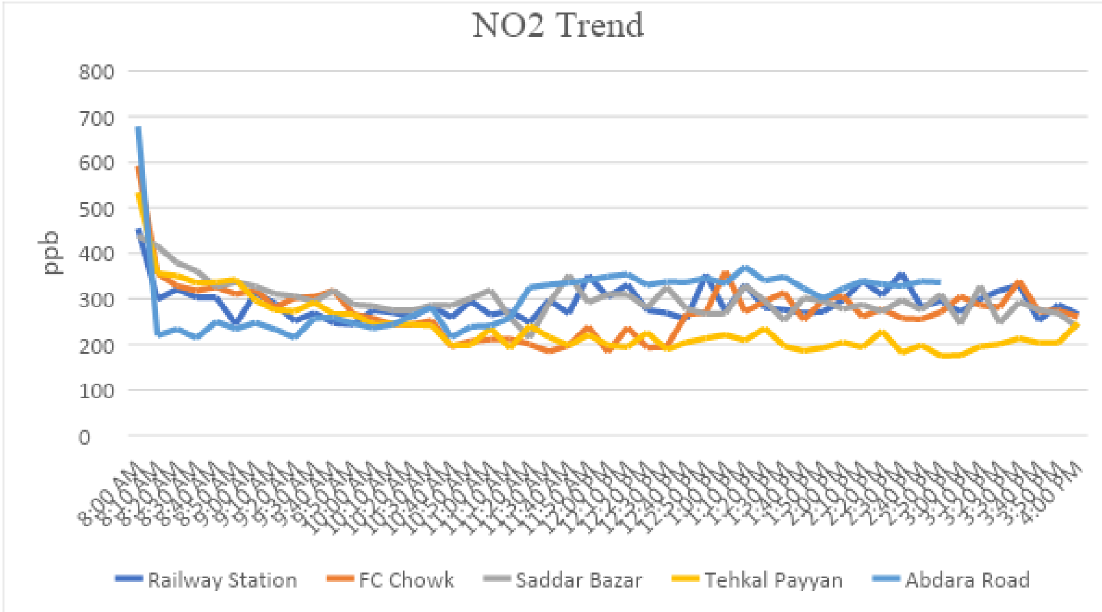


Figure 6-9: NO_2 trend throughout the day

Figure 6-9 shows the trends for NO_2 throughout the day for five stations. NO_2 follows the trend of high readings at the start and decrease but the decrease is rather sudden as compared to trends of other parameters. NO_2 concentration trend does not see much change throughout the day.

Figure 6-10 shows the trends for CO concentration throughout the day for five stations. CO concentration trend Is unique as it has normal readings at the start instead of being high. The trend and CO concentration sees a similar behavior to NO_2 concentration trend with a much smaller drop except Abdara Road station whose concentration increase in the middle of the day and stays there.

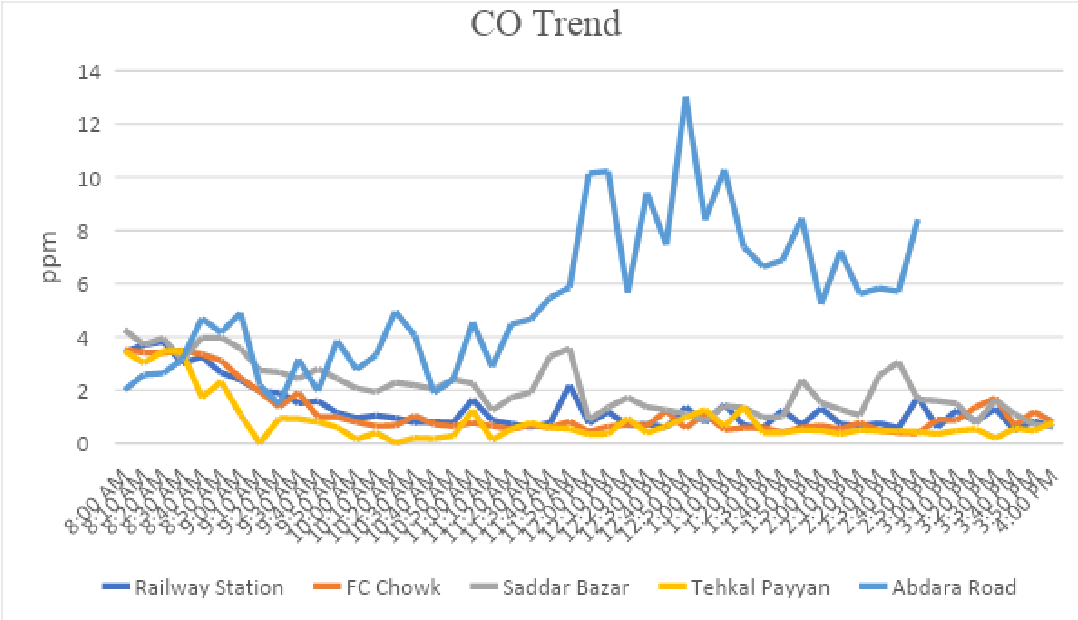


Figure 6-10: CO trend throughout the day

6.5 Abnormalities

This section deals with the abnormalities noticed in the readings of concentrations of different parameters. Abdara Road, Malik Saad Shaheed and Mall of Hayatabad show trends that are not consistent with reading trends of other stations. Figure 6-11, Figure 6-12 and Figure 6-13 shows the trends for the PM_1, $PM_{2.5}$ and PM_{10} respectively on the Abdara Road Station. As seen in the figures the reading sees a gradual increase from the start but a greater increase starting at about 12:20 PM in the day. The increase leads to a peak value which is higher than other stations for the given time. This station is in between two narrow roads which slows down the traffic and leads to high pollution due to vehicles.

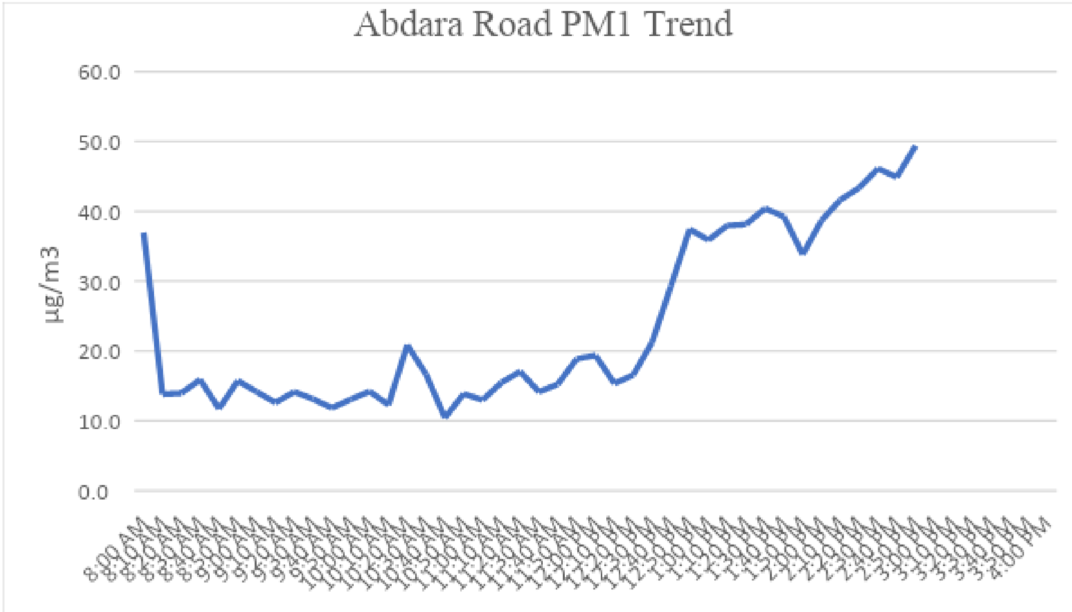


Figure 6-11: PM_1 trend for Abdara Road Station throughout the day

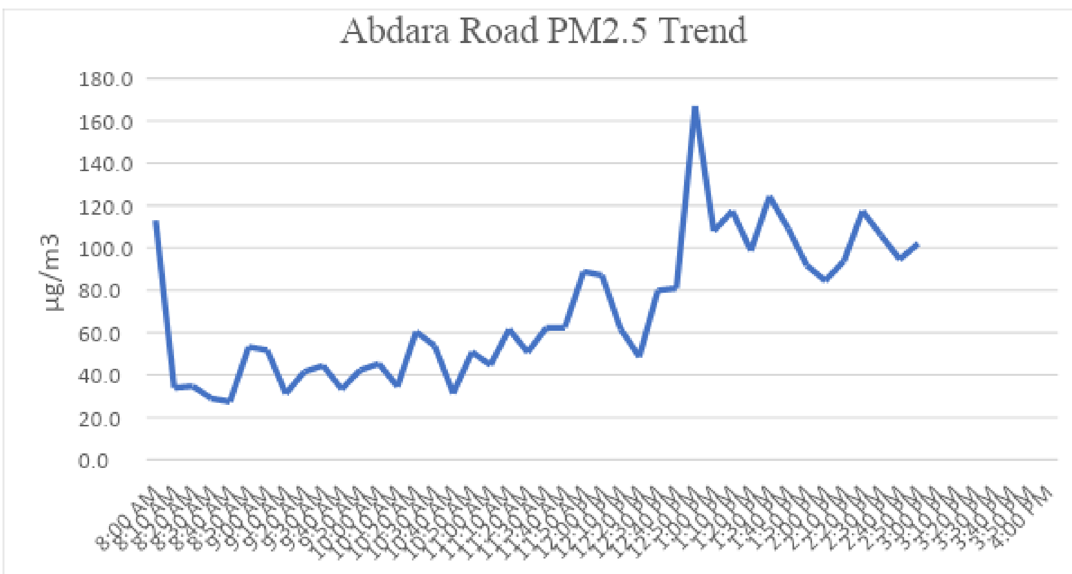


Figure 6-12: $PM_{2.5}$ trend for Abdara Road Station throughout the day

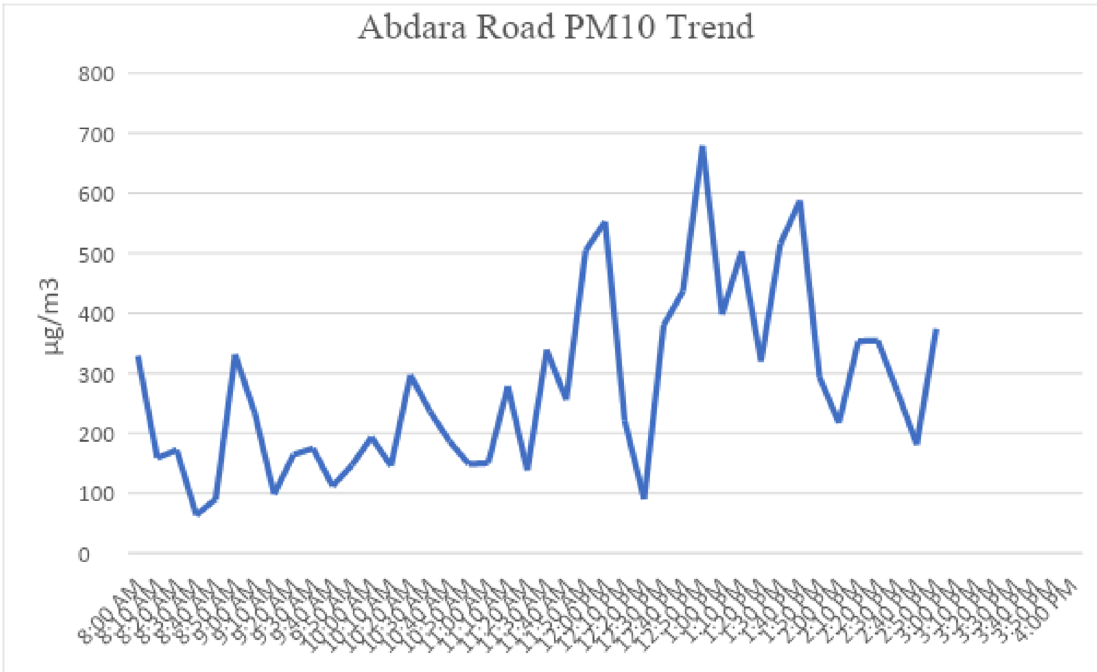


Figure 6-13: PM_{10} trend for Abdara Road Station throughout the day

Figure 6-14, Figure 6-15, and Figure 6-16 shows the trend throughout the day of PM_1, PM_{10} and $PM_{2.5}$ respectively for Mall of Hayatabad Station. The figures show a small increase in the trend until about 2:00 PM in the day and afterword's there is a gradual decline until about 4:00 PM. The PM_{10} trend line is different from PM_1 and $PM_{2.5}$ as it does not have much of a trend, it sees great increase and decrease around 12:00 PM and also around 3:30 PM, but the whole data collected has great difference in readings. The reason for the constant high concentration reading is the production of Deck Beams next to the station.

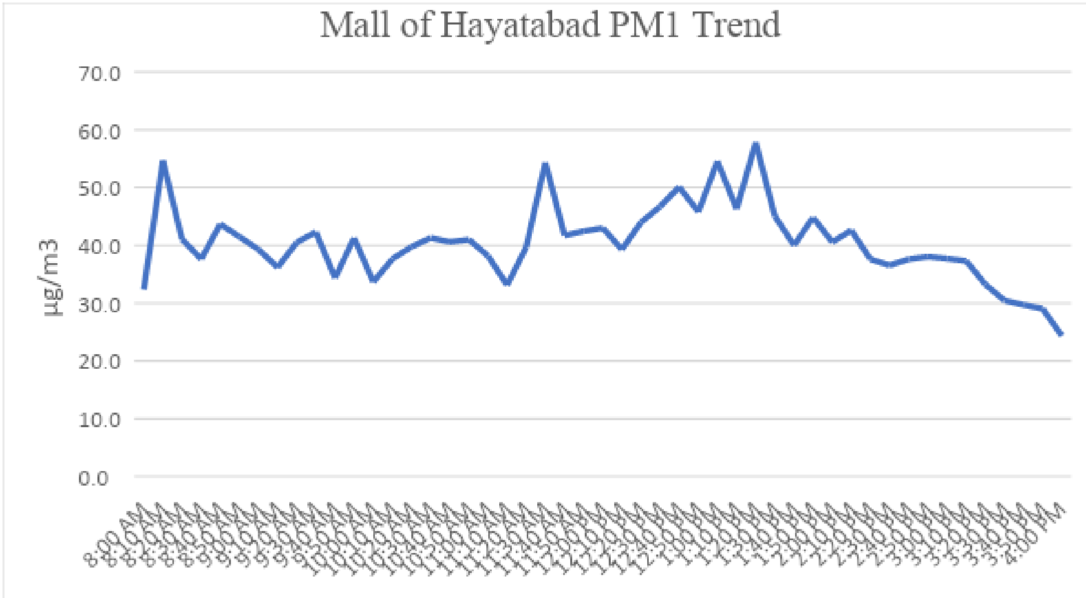


Figure 6-14: PM_1 trend for Mall of Hayatabad Station throughout the day

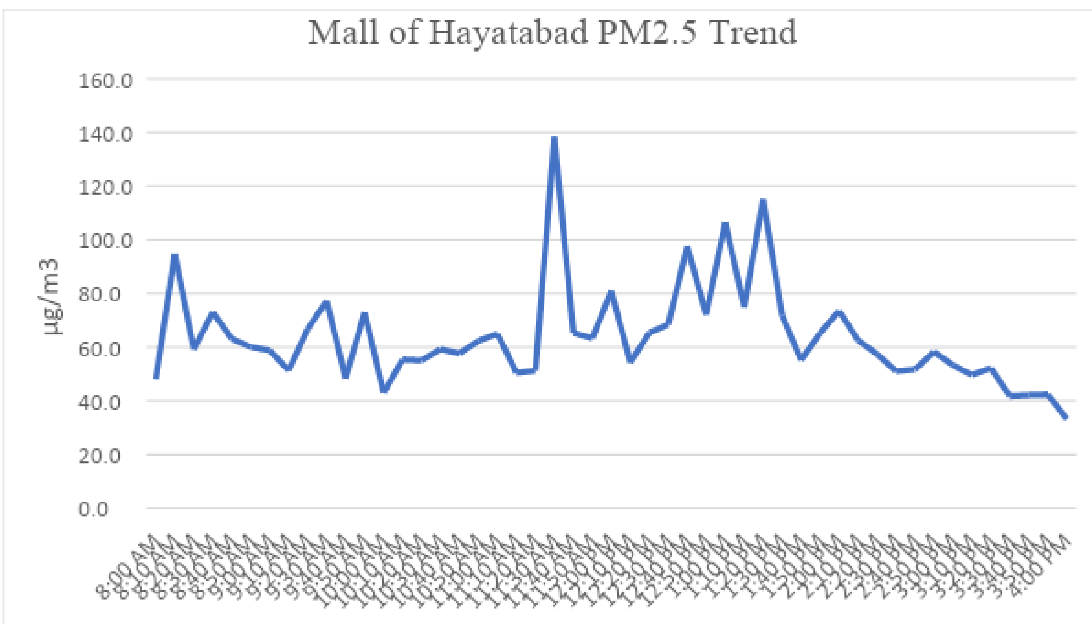


Figure 6-15: $PM_{2.5}$ trend for Mall of Hayatabad Station throughout the day

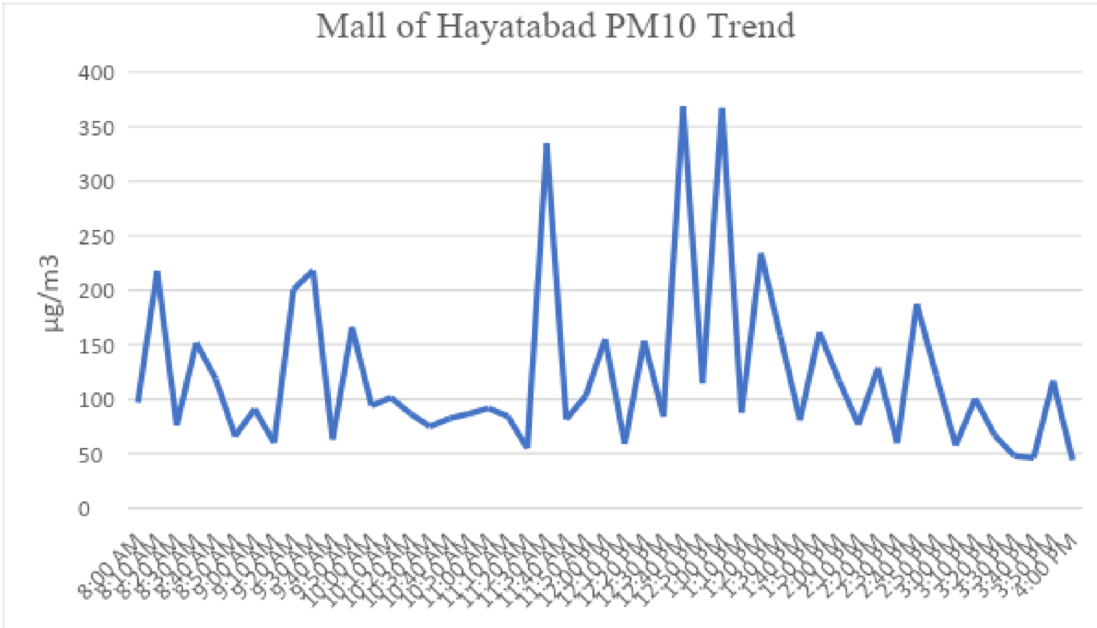


Figure 6-16: PM_{10} trend for Mall of Hayatabad Station throughout the day

Figure 6-17, Figure 6-18, and Figure 6-19 shows the trend throughout the day of PM_1, $PM_{2.5}$ and PM_{10} respectively for Malik Saad Shaheed Station. The PM_1 trend figure for this station shows an un usually high number with a small decrease until about 12:00 PM and then again, an increase. The $PM_{2.5}$ trend line shows a random behavior with a general decrease throughout the day. PM_{10} shows a gradual decrease with reading spikes at 9:00 AM, 11:10 AM and 1:50 PM. The roads next to the station might not be that narrow but the presence of a service road and an interchange slows down the traffic, moreover, the presence of an overpass further increases the vehicle count in the area, increasing the pollution due to vehicles.

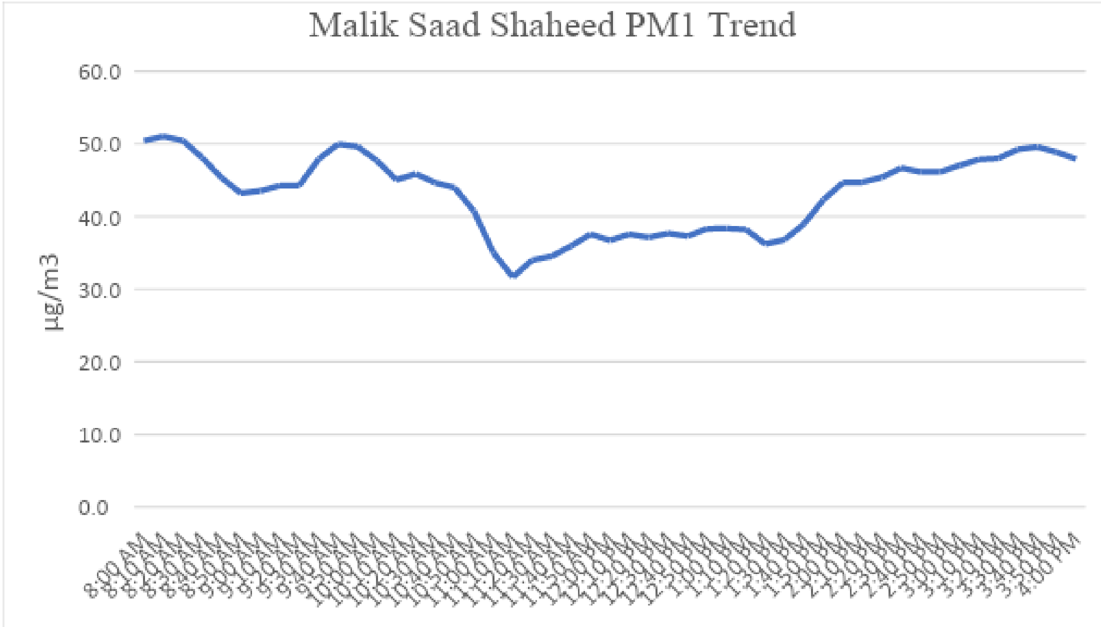


Figure 6-17: PM_1 trend for Malik Saad Shaheed Station throughout the day

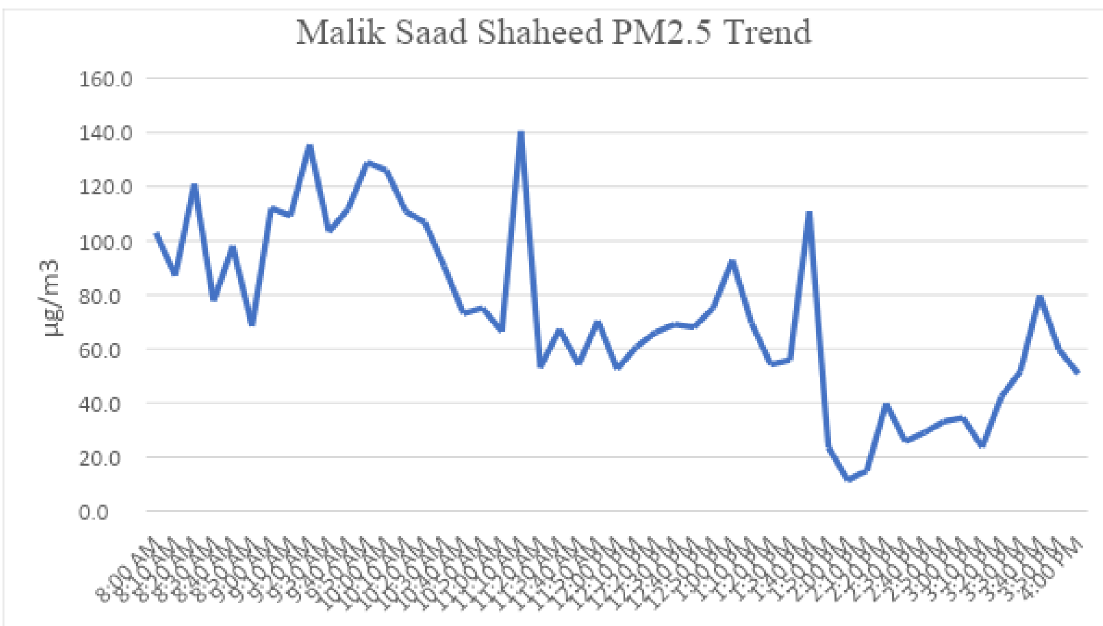


Figure 6-18: $PM_{2.5}$ trend for Malik Saad Shaheed Station throughout the day

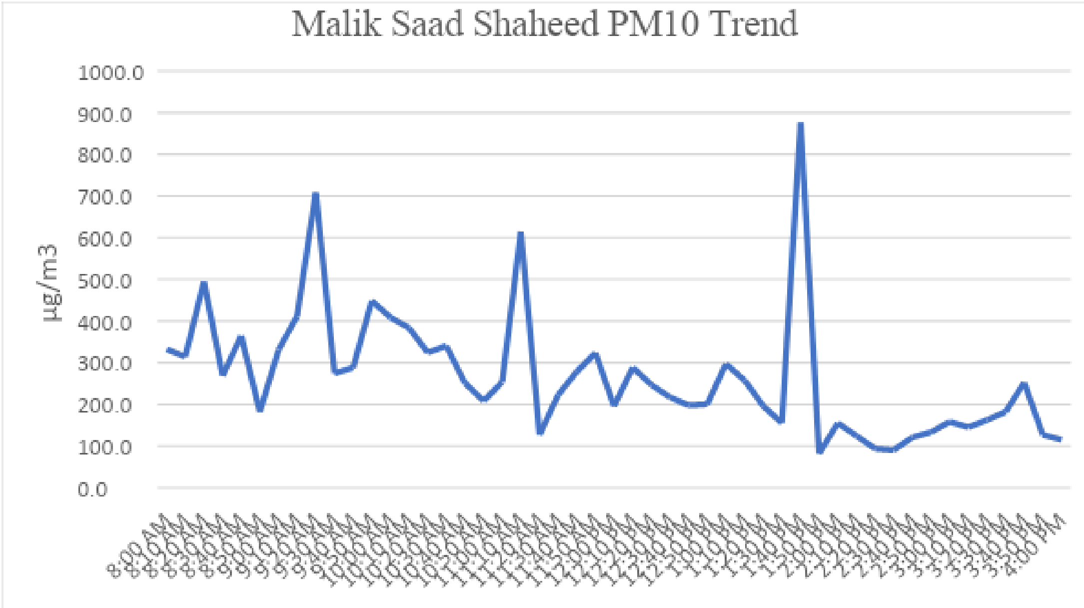


Figure 6-19: PM_{10} trend for Malik Saad Shaheed Station throughout the day

6.6 Concentration Comparison

The visual comparison of different stations concentration measurements for PM_1 (µg/m^3), $PM_{2.5}$ (µg/m^3), PM_{10} (µg/m^3), Relative Humidity (%), Temperature (^OC), CO (ppm), SO_2 (ppb), and NO_2 (ppb) are shown in Figure 6-19 to Figure 6-26 below respectively. The measured data is documented in Appendix A 1 to Appendix A 9, not ignoring the effects of Humidity and Temperature on these parameters.

The concentration of PM_1 is depicted in Figure 6-19, where above average is assigned a blue color while below average is assigned the orange color.

The highest maximum reading for PM_1 concentration is observed to be on Mall of Hayatabad station and then comes Dabgari Gardens station while the lowest recorded reading, Dabgari Garden, Tatara Park and Dabgari Garden stations are the lowest. When looking at the highest average reading, Malik Saad Shaheed comes first and Mall of Hayatabad is second while Tatara Park, University Town and Railway Station had the lowest average.

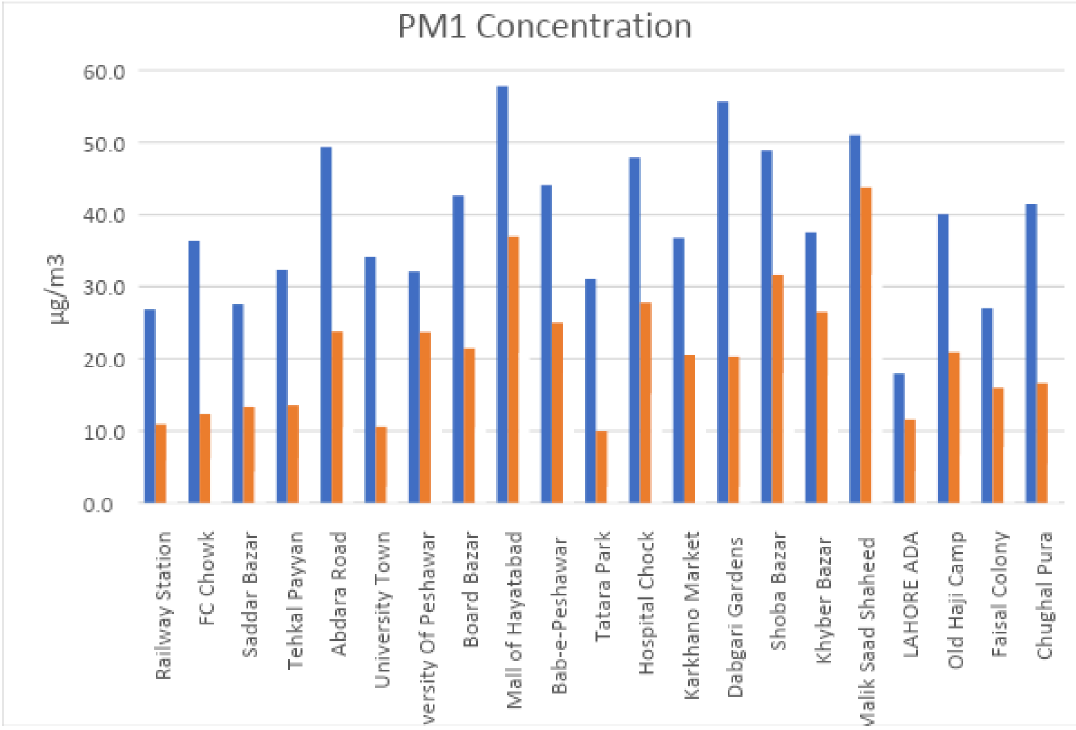


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 20: Comparison of PM1 concentration

Similarly, when looking at Figure 6-20 of $PM_{2.5}$ concentration comparison, it can be observed that Abdara Road has the highest reading with Malik Saad Shaheed at second. Tatara Park and Saddar Bazar station have the lowest recorded readings. For highest average concentration, Malik Saad Shaheed and Abdara Road station are first and second respectively while Railway Station has the lowest average and FC chowk, Saddar Bazar and Tehkal Payan comes after.

Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 21: Comparison of PM2.5 concentration

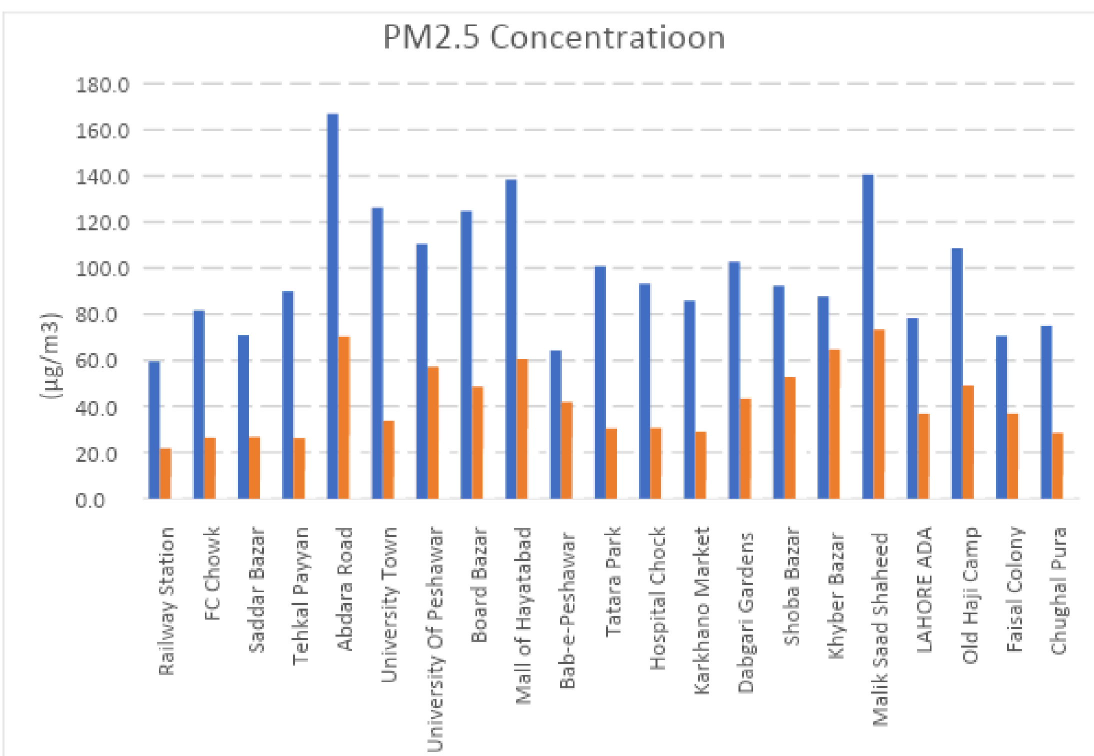
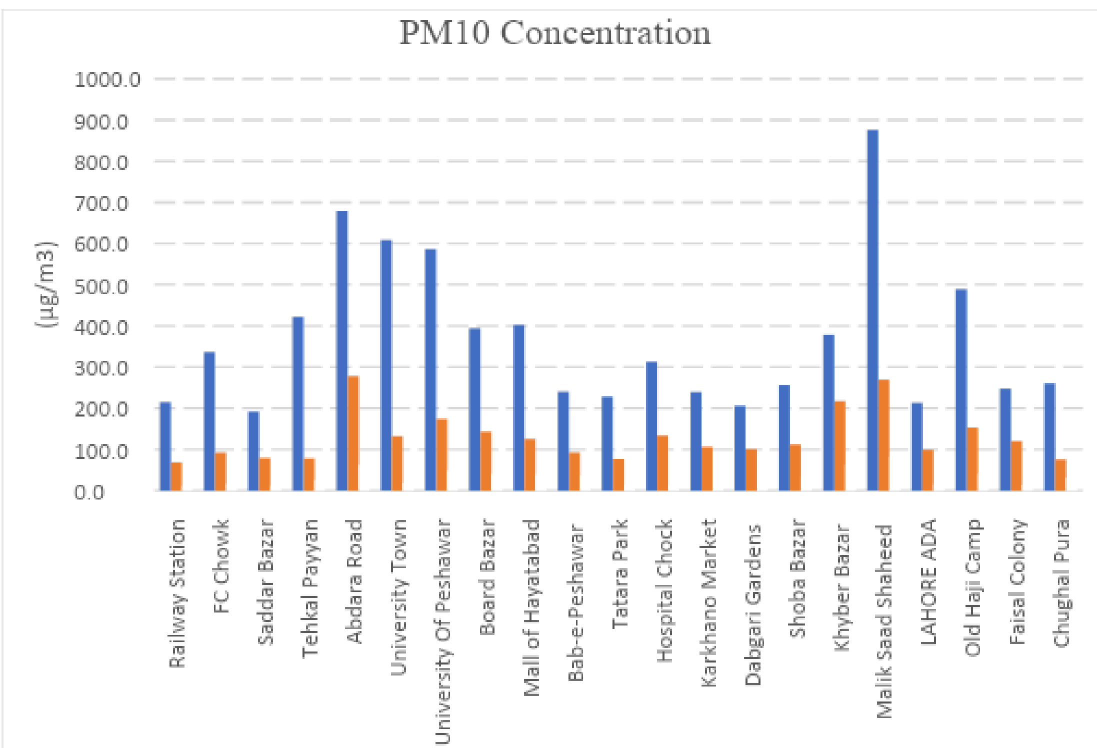


Figure 6-21 shows PM_{10} concentration comparison. The PM_{10} concentration show the same trend of Abdara Roard and Malik Saad Shaheed being the top in both highest concentration reading and highest average concentration. In the case of highest concentration Malik Saad Shaheed station is on top and Abdara Road Station comes after, while in the case of highest average concentration the values measured at Abdara Road station is only a bit greater than Malik Saad Shaheed. Hospital Chowk and Railway Station have the lowest recorded reading while railway station and Tatara Park have the lowest averages

Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 22: Comparison of PM_{10} concentration



Comparison of Relative Humidity is Depicted in Figure 6-22. The maximum reading for Relative Humidity has been observed to be on Chughul Pura station with Mall of Hayatabad at second. The highest average reading for Relative humidity is the same as of the maximum reading, Chughual Pura and Mall of Hayatabad being first and second respectively. University Town and Hospital Chowk have the lowest readings while University Town and Karkhano Market

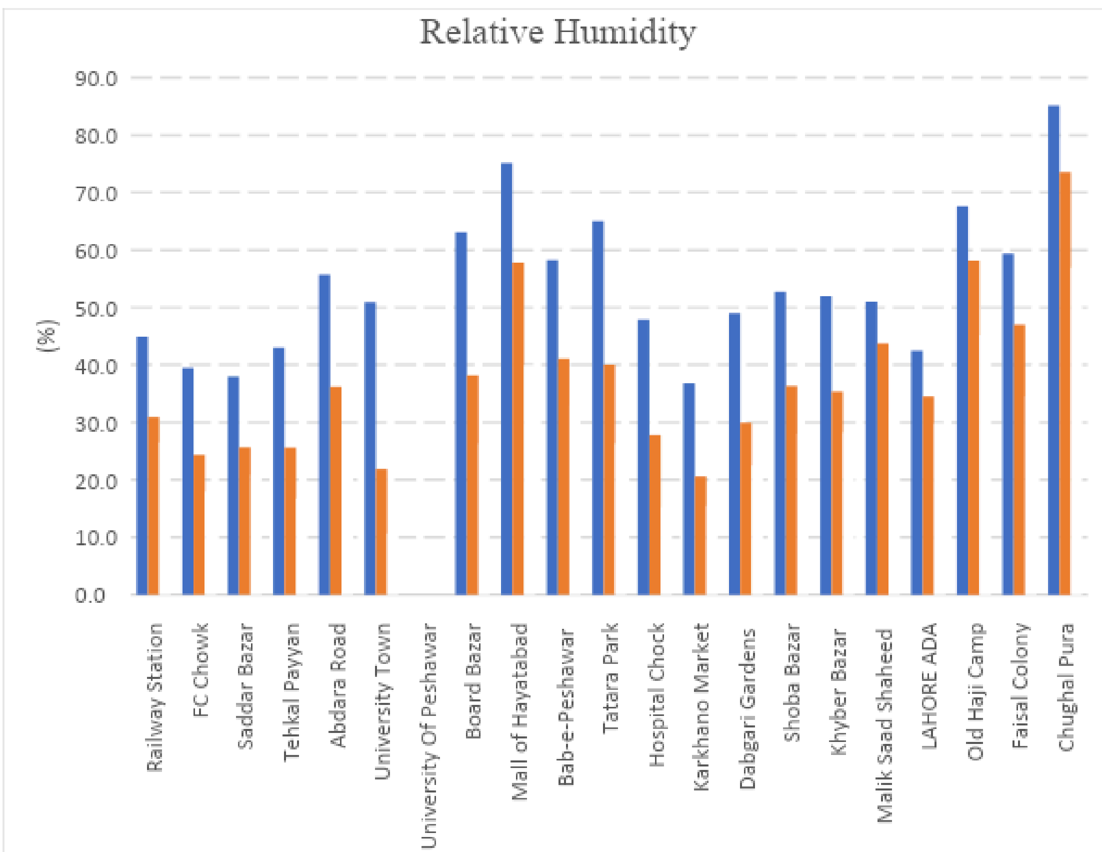


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 23: Relative Humidity comparison

This data was collected at the end of January to February 2022. Temperature is dependent on the time of the year this data was collected. Figure 6-23 shows temperature comparison. The highest temperature recorded was on Dabgeri Garden station and University Town station coming in on second while the lowest was on Mall of Hayatabad. The odd one in this figure is the University of Peshawar Station as the highest and lowest had the difference of only 2ºC.

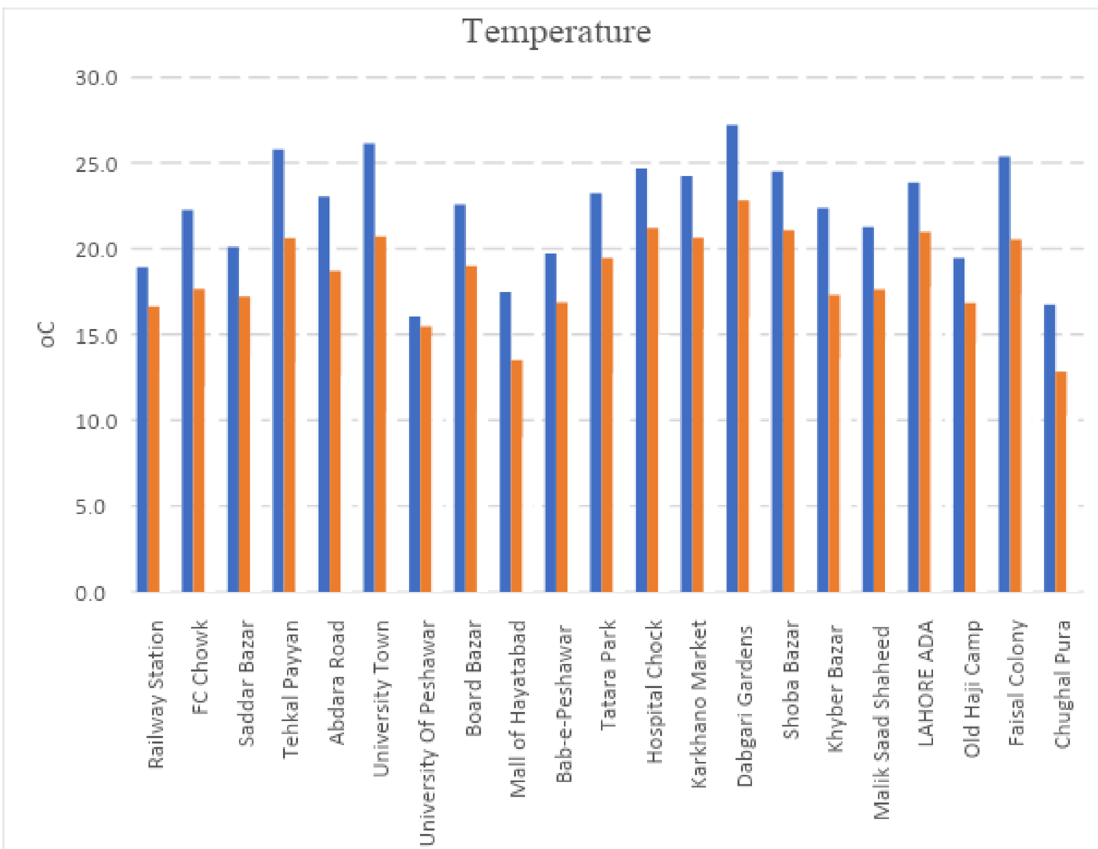


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 24: Temperature comparison

The comparison of concentrations of Carbon Monoxide between different station is represented in Figure 6-24. the highest concentrations are observed to be on malik Saad

Shaheed and Abdara Road having the second highest concentration. Tehkal Payan and Karkhano Market are observed to have the lowest concentration. Abdara Road and Malik Saad Shaheed have the highest average concentration, while Mall of Hayatabad and Karkhano Market have the lowest concentration on average.

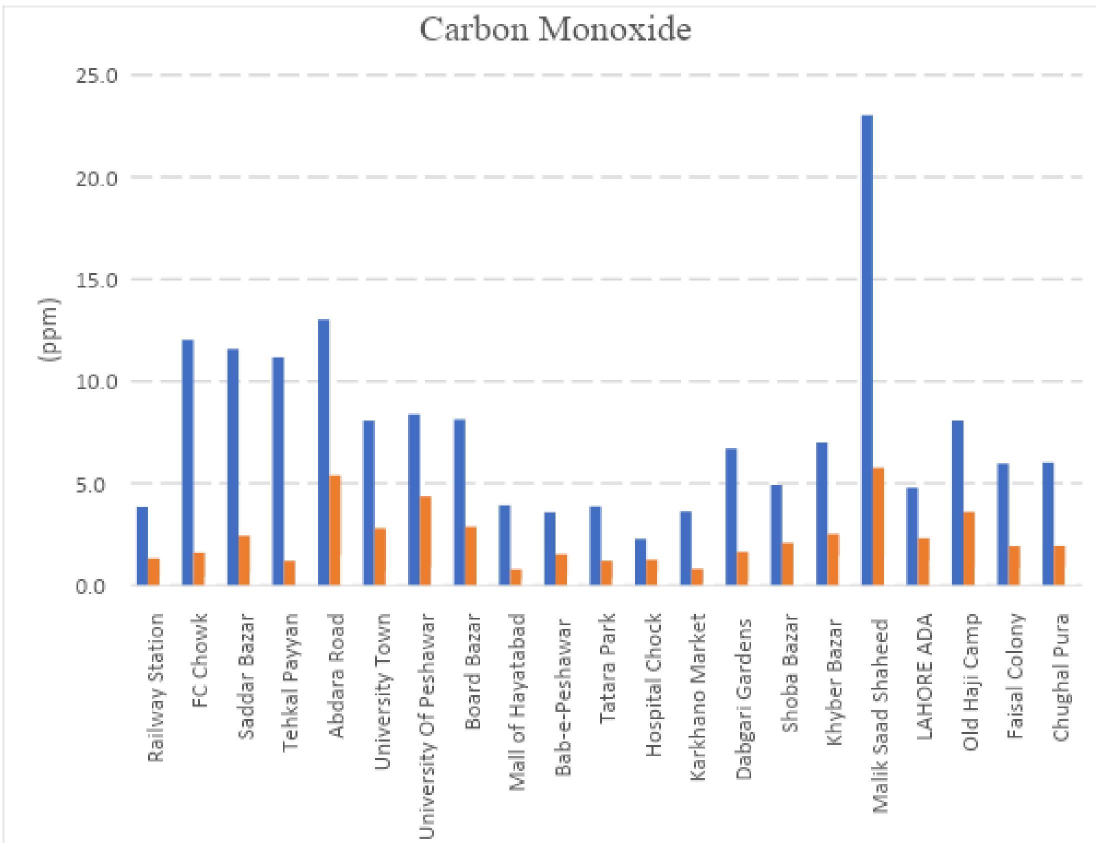


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 25: Carbon Monoxide concentration comparison

The comparison of concentrations of Sulphur Dioxide between different station is represented in Figure 6-25. The Highest measured values was scene at Saddar bazar, Tehkal Payyan, Tatara Park and Hospital Chowk. Except a couple of the stations, most of the stations have lowest measured values. Karkhno market and FC Chowk have the lowest averages with many other stations have the measured values in the range of ±100.

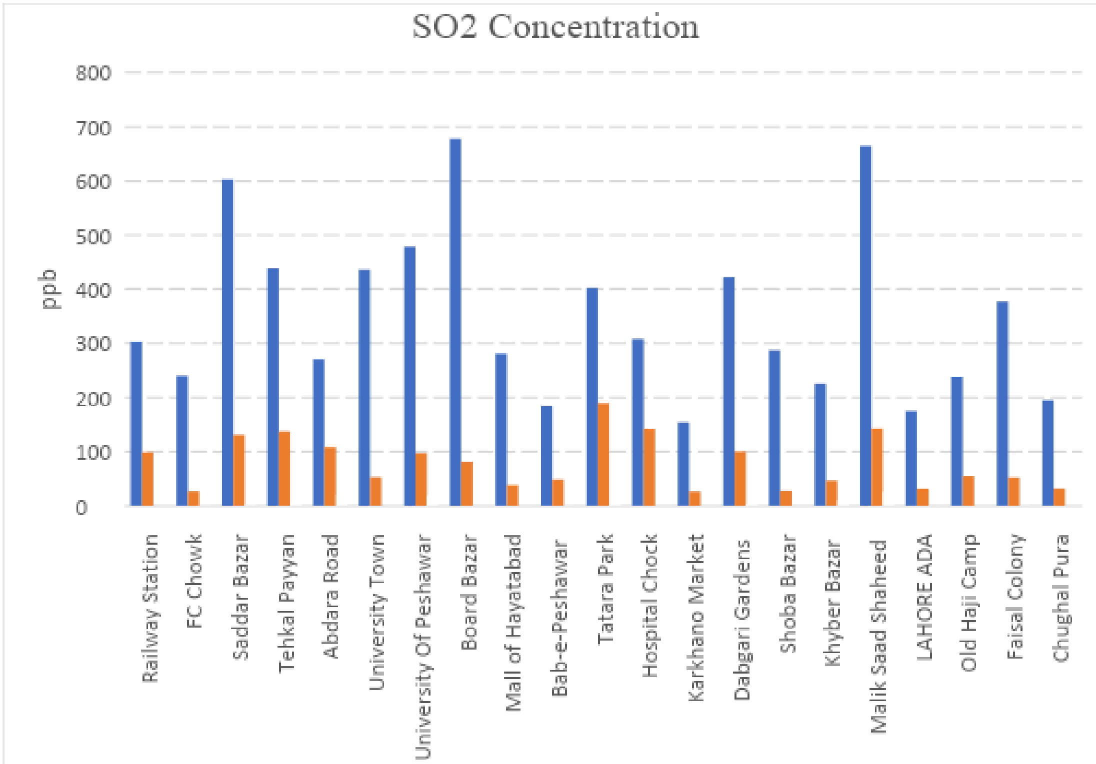
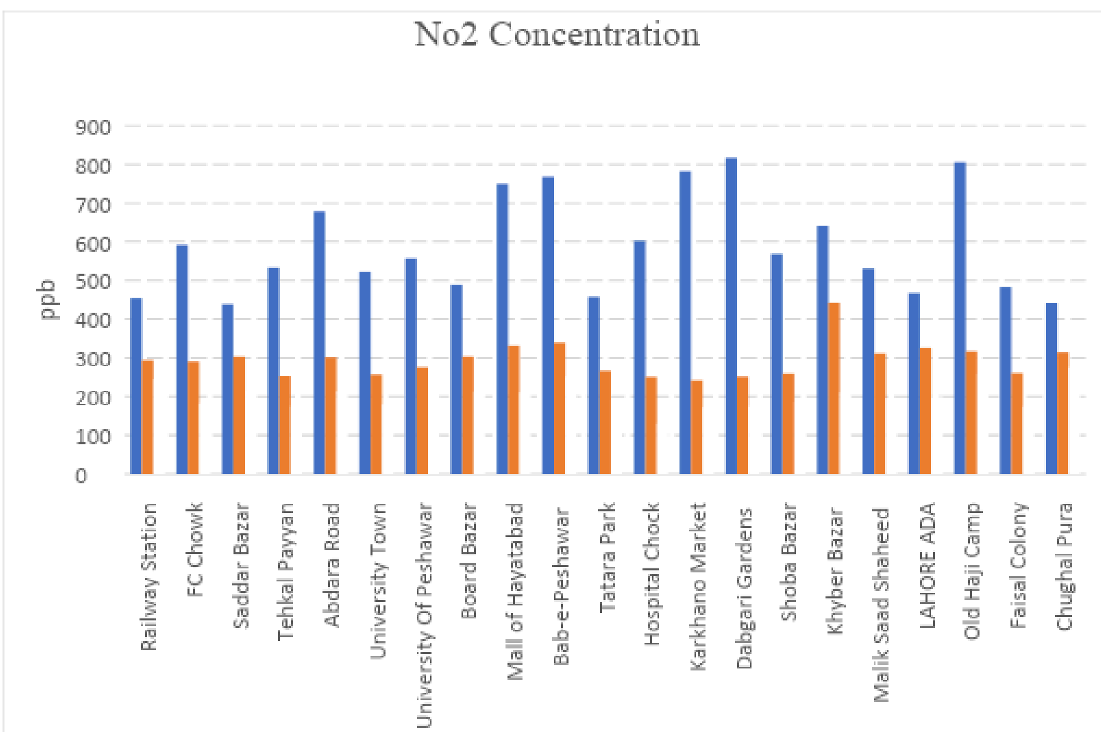


Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 26: Sulphur Dioxide concentration comparison

Figure 6-26 shows the comparison of different values of NO_2 measured at different stations. Dabgari Garden and Old Haji Camp have the highest and second highest measured values respectively with Karkhano Market, Bab-e-Peshawar and Mall of Hayatabad not far behind. Bab-e-Peshawar has the highest average value measured while Mall of Hayatabad has the second highest average. Hospital Chock and Karkhano Market have the lowest and second lowest measured values and the lowest average measured values as well.

Figure STYLEREF 1 \s 6 SEQ Figure * ARABIC \s 1 27: NO_2 concentration comparison



6.7 Summary

The analysis of this chapter leads to the conclusion that concentration of $PM_{2.5}$ and PM_{10} at Abdara road and Malik Saad Shaheed station is higher as compared to other stations, AQI figures show the same standings as well. For PM_1, Mall of Hayatabad and Malik Saad Shaheed have the highest readings throughout the day. For NO_2 and SO_2, Khyber Bazar, Mall of Hayatabad and Hospital Chowk have the highest measured readings through the day.

Chapter 7: Conclusion

Traffic-Related Air Pollution was measured in Peshawar, Pakistan, to know the condition of air across different BRT stations. Twenty-one out of the 32 BRT stations were selected where various parameters, such as SO_2, NO_2, PM_1, $PM_{2.5}$, PM_{10}, and CO were measured, which contribute to air quality and are used to calculate AQI. While recording the readings for the mentioned parameters, ambient conditions that affect these parameters, such as pressure, temperature and humidity, were also measured. The data was collected in January and February. The reading of these parameters was transmitted using Jazz 4G communication protocol, where the SIM was inserted into the Waspmote Smart Cities Pro Model. The data was sent to Libelium Cloud, where it was stored, monitored and visualised. Later exported as MS Excel Datasheets and then manually organised. Data was visualised through the charts and figured drawing feature within MS Excel. Column charts, Clustered column charts and line charts were used to visualise the data, which depicted the conditions at different stations and at different times throughout the day.

Tables were also used to represent the AQI ranges and the severity of those ranges, and also the maximum recommended values for safe living. A table showing the average AQI values for different parameters at the various stations was used to represent the condition of the stations across different parameters.w

For the AQI calculations, the values for AQI of $PM_{2.5}$, PM_{10}, SO_2 and NO_2 were plotted using a column chart showing the AQI for the average concentration measured for the parameter. For AQI $PM_{2.5}$, Railway station, FC Chowk, Saddar Bazar, Tehkal Payan, Tatara Park, Hospital Chowk, Karkhano Market and Chughal Pura came under the Moderate AQI category, which is only safe for healthy individuals. Board Bazar, Bab-e-Peshawar, Dabgeri Garden, Shoba Bazar, Lahore Adda, Old Haji Camp and Faisal Colony came under the 'Unhealthy for sensitive groups' AQI category. Abdara road, University of Peshawar, Mall of Hayatabad, Khyber Bazar and Malik Saad Shaheed came under the 'Unhealthy' AQI category. No station came under the Healthy, Very Unhealthy or Hazardous AQI categories. For AQI PM_{10} Measurements, all stations came under the 'Moderate' AQI category except Abdara Road, Malik Saad Shaheed, and Khyber Bazar, the latter of which came under 'Unhealthy for sensitive groups and the other two came under the 'Unhealthy' AQI category. For AQI NO_2, all stations came under 'Unhealthy for sensitive groups' except Khyber Bazar, which came under

the 'Unhealthy' AQI Category. For SO_2 FC Chowk, Karkhano Market, Shoba Bazar, Lahore Adda and Chugahl Pura came under the 'Healthy' AQI Category, and all other stations came under the 'Unhealthy for sensitive groups' AQI category except Tatara Park, which came under 'Unhealthy' AQI category.

For the concentration measurement, concentrations of Railway station, FC Chowk, Saddar Bazar, Tehkal Payan and Abdara Road are selected to represent the trend of concentrations measurement as they, as a group, represent the trend for all of the stations accurately, including a couple of abnormalities. The trend lines show that concentration measured at the start of the day, at 8:00 AM, is comparatively high and gradually decreases throughout the day. The lowest concentration measured is usually measured at the end of the data collection period, at about 4:00 PM, for almost all of the stations. Three abnormalities in the trend are seen in Abdara Road station, Malik Saad shaheed Station and Mall of Hayatabad station, which do not follow the usual trend of concentration but have their concentration trend measured.

The CO AQI values were not alarming, ranging from healthy to moderate, with the highest AQI of 63 at Malik Saad Shaheed, a mean concentration of 2.5 ppb. The Lowest CO AQI of 8 was reported at Mall of Hayatabad and Khyber Bazar. The highest NO_2 AQI was found to be 165, on Khyber bazar station, with a mean concentration of 442 ppb having a peak concentration of 642 ppb. Although Khyber bazar had the highest AQI, it was dabgari garden station which had the highest measured concentration of 817 ppb of a single reading. The lowest NO_2 AQI was 127 at Karkhano Market, which is unhealthy for the sensitive group. For SO_2, the highest AQI was 152 with a mean concentration of 189 ppb, having a peak concentration of 402 ppb reported at Tatara Park, which is unhealthy. The lowest SO_2 AQI was 37, found at Karnkhano Market and declared healthy. PM_{10} highest AQI 162, which was unhealthy, was reported at Abdara Road with a mean concentration of 278 μg/m^3 having a peak concentration of 679 μg/m^3. Lowest PM_{10} AQI of 57 at Railway Station, a moderated value. $PM_{2.5}$ highest AQI was 160 at Malik Saad Shaheed, with a mean concentration of 73 μg/m^3 having the highest concentration of 140.6 μg/m^3 reported unhealthy, and the lowest $PM_{2.5}$ AQI 71 was at the railway station. The highest mean concentration of PM_1 was 43.7 μg/m^3 having a peak concentration of 51 μg/m^3 at Malik Saad Shaheed. Throughout the result, it was found that Khyber Bazar, Abdara Road, Malik Saad Shaheed, and the University of Peshawar had the worst air quality, mainly in the 'unhealthy' AQI category.

It was also found that there was more pollutant concentration at early hours as compared to after mid-day later.

Chapter 8: Recommendations

Based on data and conclusion following are some recommendations;

8.1 Mitigation measures

Mitigation measure can be applied that can reduce this pollutant from it source by reducing the emission using strategies that help in long run

- Reduce the use of vehicle i.e., walking, use of public transport.

- Drive car at steady speed.
- Don’t leave car engine running idly.
- Periodic maintenance of vehicle i.e., exhaust.
- Switch to car with less emission i.e., Electric Vehicles.

8.2 Establishment of air monitoring and management system

Development of a network of cloud connected air monitoring station. Pollutant concentration will be measured at a station and will be communicated to cloud storage center the data will be displayed on devices i.e., mobile phone. In this way a real time monitoring system will be established. The priority should be populated or polluted area that include Board Bazar, Malik Saad Shaheed, Tatara Park, Abdara Road, University of Peshawar, Khyber Bazar, Lahore ada.

8.3 Construction of smog tower

Another recommendation will be construction of smog tower specially where road is clustered such as chowk i.e., Malik Saad shaheed should be on top priority because of several service road and interchanges.

8.4 Making alternative paths

The University Road and the Grand trunk Road are the busiest roads in Peshawar, going from one point to another in Peshawar mostly requires using one of the roads or even both. Alternative routes already exist such as the Ring Road but a single alternative route is not sufficient enough for the number of vehicles present in Peshawar. Another route between the University Road and the Ring Road which leads directly to Saddar Bazar as that is the main destination for most vehicles. Canal Road would be perfect for this purpose; it starts at Board Bazar and ends at Bara Road which is between Saddar Bazar and Ring Road. Canal Road is not made to support heavy traffic as it is divided into two sides with a canal between them. If the canal is move to one of the sides to make one of the roads narrower and the other wider and the wider road is renovated into a heavy traffic road, then the traffic at the University Road can be divided in two.

Appendix A 1: Descriptive statistics of PM_1 measurement

PM_1 ($\mu g/m^3$)				
Station	**Median**	**Mean**	**Minimum**	**Maximum**
Railway Station	9.4	10.8	5.9	26.8
FC Chowk	9.9	12.3	6.1	36.4
Saddar Bazar	11.6	13.3	4.3	27.6
Tehkal Payyan	11.1	13.5	6.1	32.4
Abdara Road	16.6	23.8	10.4	49.4
University Town	7.5	10.5	2.3	34.1
University Of Peshawar	23.8	23.7	14.3	32.1
Board Bazar	19.5	21.4	10.4	42.6
Mall of Hayatabad	37.6	36.9	20.8	57.8
Bab-e-Peshawar	23.5	25.0	18.0	44.1
Tatara Park	6.4	10.0	2.2	31.1
Hospital Chock	27.3	27.8	15.2	47.9
Karkhano Market	18.2	20.6	15.5	36.8
Dabgari Gardens	14.6	20.3	2.2	55.7
Shoba Bazar	29.4	31.6	18.0	48.9
Khyber Bazar	26.5	26.5	17.6	37.5
Malik Saad Shaheed	45.4	43.7	31.7	51.0
Lahore Adda	11.7	11.6	4.4	18.0
Old Haji Camp	20.7	20.9	6.6	40.1

Faisal Colony	14.3	15.9	7.7	27.0
Chughal Pura	10.8	16.6	5.4	41.4

Appendix A 2: Descriptive statistics of $PM_{2.5}$ measurement

$PM_{2.5}$ ($\mu g/m^3$)					
Station	**Median**	**Mean**	**Minimum**	**Maximum**	**AQI**
Railway Station	18.0	21.8	9.3	59.6	71
FC Chowk	20.5	26.3	9.9	81.6	81
Saddar Bazar	21.4	26.7	7.5	70.9	82
Tehkal Payyan	21.5	26.2	12.2	90.0	81
Abdara Road	61.6	70.3	27.4	166.9	159
University Town	23.8	33.6	9.4	126.2	96
University Of Peshawar	56.8	57.1	25.4	110.4	152
Board Bazar	41.1	48.4	21.2	124.8	133
Mall of Hayatabad	57.7	60.6	30.3	138.4	154
Bab-e-Pesha war	41.6	41.8	26.6	64.2	117
Tatara Park	21.7	30.4	5.9	100.8	89
Hospital Chock	25.0	30.6	9.7	93.1	90
Karkhano Market	23.0	28.9	7.8	85.9	86
Dabgari Gardens	35.5	43.2	8.4	102.7	120
Shoba Bazar	47.8	52.6	28.4	92.3	143
Khyber Bazar	63.8	64.8	48.0	87.6	156
Malik Saad Shaheed	69.1	73.2	11.5	140.6	160
Lahore Adda	35.7	36.7	9.5	78.1	104
Old Haji	49.6	49.0	15.4	108.4	134

Camp					
Faisal Colony	35.0	36.8	12.5	70.6	104
Chughal Pura	19.3	28.3	9.9	75.0	85

Appendix A 3: Descriptive statistics of PM_{10} measurement

PM_{10} (µg/m^3)					
Station	**Median**	**Mean**	**Minimum**	**Maximum**	**AQI**
Railway Station	54.2	68.4	11.3	214.9	57
FC Chowk	77.9	92.7	15.9	336.5	69
Saddar Bazar	66.25	79.2	11.1	192.0	63
Tehkal Payyan	64.8	78.2	24.9	422.2	62
Abdara Road	246.1	278.0	63.3	679.4	162
University Town	103.7	131.8	18.9	609.0	89
University Of Peshawar	134.1	173.7	48.7	586.0	110
Board Bazar	127.7	142.8	39.6	394.4	94
Mall of Hayatabad	101.3	125.5	38.9	402.4	86
Bab-e-Peshawar	85.0	92.9	36.3	240.6	69
Tatara Park	66.5	77.0	14.4	228.5	62
Hospital Chock	126.2	133.8	11.0	313.0	90
Karkhano Market	107.0	106.4	29.5	239.9	76
Dabgari Gardens	91.4	100.7	42.2	205.7	73
Shoba Bazar	103.7	111.8	34.5	256.6	79
Khyber Bazar	218.5	217.2	62.5	378.6	132
Malik Saad Shaheed	251.2	269.8	81.8	875.9	158
Lahore Adda	97.3	98.8	15.4	213.4	72

Old Haji Camp	132.0	153.3	40.2	489.0	100
Faisal Colony	116.1	120.1	14.2	247.6	83
Chughal Pura	70.4	75.8	32.1	260.6	61

Appendix A 4: Descriptive statistics of SO_2 measurement

SO_2 (ppb)					
Station	**Median**	**Mean**	**Minimum**	**Maximum**	**AQI**
Railway Station	89	99	0	303	111
FC Chowk	11	27	1	240	39
Saddar Bazar	102	131	2	603	126
Tehkal Payyan	107	137	6	439	128
Abdara Road	92	108	21	271	115
University Town	27	52	0	436	71
University Of Peshawar	77	97	19	479	110
Board Bazar	48	81	0	678	103
Mall of Hayatabad	42	39	0	281	55
Bab-e-Pesha war	45	48	1	184	66
Tatara Park	175	189	3	402	152
Hospital Chock	176	143	0	308	131
Karkhano Market	22	26	0	154	37
Dabgari Gardens	82	101	3	422	112
Shoba Bazar	13	27	0	287	39
Khyber Bazar	15	47	10	225	65
Malik Saad Shaheed	111	143	26	665	131

Lahore Adda	23	31	0	175	44
Old Haji Camp	23	54	0	238	74
Faisal Colony	40	52	1	377	71
Chughal Pura	20	32	0	195	46

Appendix A 5: Descriptive statistics of NO_2 measurement

NO_2 (ppb)					
Station	**Median**	**Mean**	**Minimum**	**Maximum**	**AQI**
Railway Station	287	294	244	455	138
FC Chowk	288	291	183	592	137
Saddar Bazar	296	303	215	438	139
Tehkal Payyan	235	254	175	533	130
Abdara Road	323	301	214	679	139
University Town	237	258	180	523	131
University Of Peshawar	263	275	229	557	134
Board Bazar	305	303	212	489	139
Mall of Hayatabad	312	331	210	751	145
Bab-e-Pesha war	313	339	253	769	146
Tatara Park	252	266	195	458	132
Hospital Chock	226	252	131	602	130
Karkhano Market	216	241	172	782	127
Dabgari Gardens	223	253	174	817	130
Shoba Bazar	230	260	186	568	131

Khyber Bazar	461	442	210	642	165
Malik Saad Shaheed	320	313	196	531	141
Lahore Adda	326	326	199	467	144
Old Haji Camp	307	318	260	807	142
Faisal Colony	254	261	174	484	131
Chughal Pura	317	316	275	441	142

Appendix A 6: Descriptive statistics of CO measurement

CO (ppm)				
Station	**Median**	**Mean**	**Minimum**	**Maximum**
Railway Station	0.943	1.311	0.500	3.825
FC Chowk	0.982	1.578	0.379	12.029
Saddar Bazar	1.922	2.419	0.637	11.583
Tehkal Payyan	0.572	1.182	0.000	11.154
Abdara Road	4.932	5.384	1.459	13.028
University Town	2.089	2.789	0.671	8.065
University Of Peshawar	3.948	4.346	0.869	8.372
Board Bazar	2.236	2.857	0.950	8.118
Mall of Hayatabad	0.633	0.773	0.257	3.917
Bab-e-Peshawar	1.245	1.501	0.453	3.562
Tatara Park	0.929	1.186	0.335	3.852
Hospital Chock	1.223	1.240	0.630	2.263
Karkhano Market	0.536	0.794	0.120	3.612
Dabgari Gardens	1.018	1.622	0.210	6.692
Shoba Bazar	1.841	2.058	0.632	4.906

Khyber Bazar	1.961	2.507	1.438	6.984
Malik Saad Shaheed	5.405	5.751	1.333	23.040
Lahore Adda	2.093	2.295	1.177	4.770
Old Haji Camp	3.205	3.581	0.874	8.071
Faisal Colony	1.663	1.911	0.832	5.955
Chughal Pura	1.661	1.926	0.882	6.008

Appendix A 7: Descriptive statistics of Temperature measurement

Temperature (ºC)				
Station	**Median**	**Mean**	**Minimum**	**Maximum**
Railway Station	17	17	13	19
FC Chowk	17	18	12	22
Saddar Bazar	17	17	14	20
Tehkal Payyan	21	21	13	26
Abdara Road	19	19	13	23
University Town	21	21	10	26
University Of Peshawar	15	15	15	16
Board Bazar	20	19	11	23
Mall of Hayatabad	14	14	9	17
Bab-e-Peshawar	18	17	11	20
Tatara Park	20	19	13	23
Hospital Chock	21	21	15	25

Karkhano Market	21	21	15	24
Dabgari Gardens	23	23	16	27
Shoba Bazar	22	21	15	25
Khyber Bazar	17	17	14	22
Malik Saad Shaheed	18	18	15	21
Lahore Adda	21	21	18	24
Old Haji Camp	17	17	15	19
Faisal Colony	20	21	17	25
Chughal Pura	11	13	10	17

Appendix A 8: Descriptive statistics of Pressure measurement

Pressure (KPa)				
Station	**Median**	**Mean**	**Minimum**	**Maximum**
Railway Station	97982.1	97979.5	97912.8	98069.8
FC Chowk	97539.7	97583.5	97454.2	97746.4
Saddar Bazar	97605.6	97650.8	97482.7	97864.8
Tehkal Payyan	97622.8	97656.9	97472.8	97880.4
Abdara Road	97070.6	97099.2	97018.6	97260.0
University Town	97325.3	97337.8	97050.7	97589.7
University Of Peshawar	96795.0	96795.0	96789.6	96800.3
Board Bazar	96551.7	96572.5	96331.5	96857.1
Mall of Hayatabad	97768.6	97596.6	97148.4	97990.2
Bab-e-Peshawar	97043.8	97036.2	96849.9	97208.0
Tatara Park	97354.6	97321.3	97115.9	97481.9

Hospital Chock	96825.5	96868.8	96463.2	97247.5
Karkhano Market	97130.9	97160.7	96974.1	97374.2
Dabgari Gardens	97436.6	97441.2	97250.5	97645.0
Shoba Bazar	97679.3	97603.3	97323.7	97764.8
Khyber Bazar	97673.6	97673.6	97558.1	97770.9
Malik Saad Shaheed	97768.6	97596.6	97148.4	97990.2
LAHORE ADA	97655.5	97655.5	97511.3	97818.2
Old Haji Camp	97982.1	97979.5	97912.8	98069.8
Faisal Colony	98192.9	98179.4	97977.1	98378.7
Chughal Pura	98390.1	98394.3	98348.0	98433.3

Appendix A 9: Descriptive statistics of Humidity measurement

Humidity (%)				
Station	**Median**	**Mean**	**Minimum**	**Maximum**
Railway Station	29.7	30.9	26.5	44.9
FC Chowk	22.3	24.3	18.0	39.5
Saddar Bazar	24.6	25.6	20.8	37.9
Tehkal Payyan	23.8	25.6	16.8	43.0
Abdara Road	32.7	36.2	23.5	55.7
University Town	19.8	21.9	10.6	51.0
University Of Peshawar			0.0	0.0
Board Bazar	36.0	38.1	26.3	63.1

Mall of Hayatabad	59.3	57.8	39.9	75.1
Bab-e-Peshawar	38.1	41.1	33.0	58.2
Tatara Park	39.1	40.0	26.3	65.0
Hospital Chock	27.3	27.8	15.2	47.9
Karkhano Market	18.2	20.6	15.5	36.8
Dabgari Gardens	26.1	29.9	22.5	49.0
Shoba Bazar	32.7	36.3	28.1	52.7
Khyber Bazar	31.0	35.3	28.2	52.0
Malik Saad Shaheed	45.6	43.8	31.7	51.0
LAHORE ADA	34.5	34.5	29.8	42.4
Old Haji Camp	57.8	58.1	45.2	67.6
Faisal Colony	47.2	47.0	34.5	59.3
Chughal Pura	77.3	73.6	56.9	85.2

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Glossary

Term	**Definition**
Positive Matrix Factorization	It is a mathematical receptor model developed by EPA scientists that provides scientific support for the development and implementation of air and water quality standards, and environmental forensics
Non-Dispersive methods	Non-Dispersive Infra-Red (NDIR) detectors are the industry-standard method of measuring the concentration of carbon oxides (CO & CO2).
Cross-Sectional study	A type of observational research that analyzes data of variables collected at one given point in time across a sample population or a pre-defined subset.
Vital Capacity	The total volume of air that can be displaced from the lungs by maximal expiratory effort.
Forced vital Capacity	The maximum amount of air you can forcibly exhale from your lungs after fully inhaling
Forced Expiratory Volume in 1 second	It is the volume of air (in liters) exhaled in the first second during forced exhalation after maximal inspiration.
Optical Particle Counter	It detects and sizes particles by measuring the amount of light scattered by individual particles as they pass through a beam of light.
Part Per Billion	It is the number of units of mass of a contaminant per 1000 million units of total mass
Part Per Million	It is the number of units of mass of a contaminant per 1 million units of total mass
Response Time	It is time taken to transmit the inquiry, process it by the computer, and transmit the response back to the terminal.