IoT-AI Based Air Quality and Hazardous Gases Advisory System to Mitigate Effect of Climate Change on Public Health

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Abstract: Today, air pollution has become a major concern lowering the average life expectancy causing a wide range of diseases including stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma. In Pakistan, the hazards of noxious gases contamination have been reported throughout the country leading to a high number of casualties, specifically heater/car/indoor gas contamination-related deaths the release of toxic industrial gas into the environment (more than 300 people reported sudden difficulty in breathing and several deaths in south Karachi in 2020 due to gas leakage from industry. Such concerns are not only a threat to human life but also not complying with UN sustainable development goals and also impacting the ecosystem.In this study, we proposed the design solution and a working prototype based on a low-cost life-saving IoT gadget in combination with an AI-enabled mobile app to cope with the existing problem of airborne diseases, life-threatening contamination of hazardous gases and to mitigate climatic change related to Air Pollution. The gadget contains sensors to detect air pollutants including fine particulate matter (PM2.5, PM10), Carbon Dioxide (CO2), Sulphur, Nitrogen Dioxide (NO2), Flammable hazardous gases like Methane (CH_4), and LPG Gases (hydrocarbons), and life-endangering Carbon Monoxide (CO) and Smoke along with basic humidity, temperature and air pressure in real-time, buzzer for an alarm in case of hazardous gas crossing the threshold, integrated WiFi module for data replication to the database (Firebase) and colorful TFT screen to display the real-time measurements of air quality and other pollutants. On the backend, the real-time data from the gadget is logged into the cloud-based database, where a machine learning algorithm, 'Random Forest', is deployed and performs the task of air quality prediction for the next few hours. Our solution with mobile application aims to target the public healthcare and abrupt climatic change effect where GUI assist users with recommendations, public alerts, and possible solutions for prevention.

Keywords— **AQI Gadget, AI and IoT, Advisory System, Hazardous Gases, Sustainable Development Goals**

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I. INTRODUCTION

Air is what makes the environment, comprising mostly gases including nitrogen and oxygen in abundance [6][7]. Though, air also contains air pollutants that can have mild to severe impacts on human health [8]. Air pollutants are those contaminations that cause the quality of air to b degraded, that includes dust particles, soot, smoke, odor, radiation, heat, fumes, combustion, exhaust gases, noxious gases, and hazardous or radioactive [9].

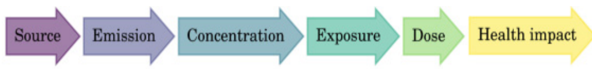


Figure-1. Air pollution path-cycle

Living organisms are confined to relying on the air to breath-in. With the overwhelming growth of the population, the rate of urbanization has far more gradually elevated which has paved the way for bad air quality [10]. Air quality is an identifier of how clean or toxic the air is to be consumed. Because contaminated air can be noxious to both the human and the well-being of the ecosystem, it is very important to monitor air quality [11]. The Air Quality Index (AQI) is a scale to signify air quality. AQI is the color differentiation for the intensity of air pollutants present in the atmosphere of a certain area [12][13]. The AQI color scheme goes from green for the best level of air to maroon for the least healthy level. Similar to this, AQI values range from the healthiest (0–50) to the unhealthiest (300+) [14].

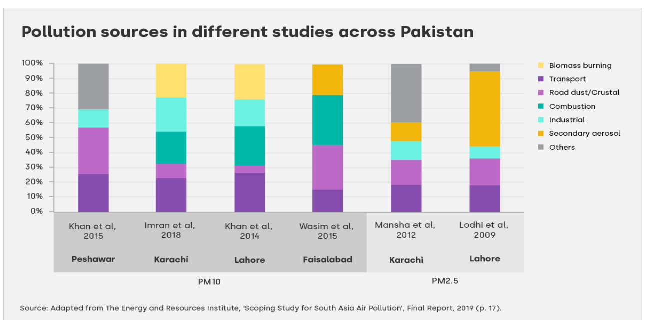


Figure-2. Pollution sources of Particulate Matter (PM2.5 and PM10) in different studies across cities of Pakistan [15]

Consistent or long exposure to bad indoor or ambient AQI carries the risk of a wide number of diseases. Asthma, bronchitis, pneumonia, tuberculosis, and lung cancer are just a few of the respiratory conditions that can be brought on by breathing in polluted air [16][17][18]. According to WHO research, 7 million people die from air pollution each year [19]. Moreover, the result of the process of heat being trapped in the atmosphere, global warming results in repercussions such as temperature increases, increasing sea levels, ailments brought on by the heat, and transmissions of infectious diseases [20].

Table-1. Improved life expectancy in cities of Pakistan in contrast to a 32% reduction in major air pollutants (PM) [21]

			$PM_{2.5}$ Concentration (μg/m³)		Life Expectancy Gain (Years) from Reducing $PM_{2.5}$ from 2016 Concentration		
Province	District	Population (Millions) [1]	2016	After 32% Reduction	To WHO Guideline of 10 μg/m³	To National Standard of 15 μg/m³	By 32% [2]
All Pakistan		203.2	37	25	2.7	2.2	1.2
Sindh	Karachi City	22.4	16	11	0.5	0.1	0.5
Punjab	Lahore	9.4	64	43	5.3	4.8	2.0
Punjab	Faisalabad	8.1	59	40	4.8	4.3	1.8
Punjab	Gujranwala	5.1	58	40	4.7	4.3	1.8
Punjab	Rawalpindi	4.9	41	28	3.0	2.5	1.3

Contrary to health impacts from long exposure to air pollutants, some pollutants carry instant severe health impacts [22]. One of the most catastrophic mishaps that can happen in industrial sites, warehouses, workshops, and laboratories that utilize or store these substances is the leakage of hazardous gases and chemical vapors [23]. To maintain a safe environment for the people and other living forms who operate in and surround these locations, early detection and warning of dangerous gases and volatile substances is crucial [24]. The transportable detection and warning systems for poisonous, hazardous gases and volatile chemicals, particularly in the laboratory setting, are studied in this paper.

II. PROPOSED RESEARCH METHODOLOGY

The requirements will be examined at this stage, and any development decisions made will be recorded in the artifact design. This will serve as the template for the implementation of the development process. A proof-of-concept (POC), developed for demonstration and review, will be implemented from the finalized design once it has been finalized and laid out. As this is an iterative process, the requirements, and objectives will be reviewed at each stage to make sure the system development is moving forward as planned. When a design artifact complies with the conditions and limitations of the issue it was created to address, it is said to be complete and effective [25].

A. System Block Diagram

This block diagram illustrates the complete details of our project in a very concise way.

- Industrialization and consumption of non-renewable energy are more account for the increase in air pollution [26]. Various surveillance stations have been set up worldwide to check the nature of air quality.
- This project's primary contribution is planning and actualizing an AI-IoT-based Real-Time AQI Reporting Gadget with Hazardous Gases Advisory System. It includes data collection, sensor data validation, data pre-processing, utilizing Machine Learning models, and model validation using performance indices.
- Optimal model deployment in Edge devices like ESP32, UI design, Google cloud server integration (Firebase), and enable the live and forecasted air pollutants monitoring through a remote dashboard [27]. It also facilitates precaution recommendations, Plantation & other doable proposed solutions, and specified alerts on Diseases.

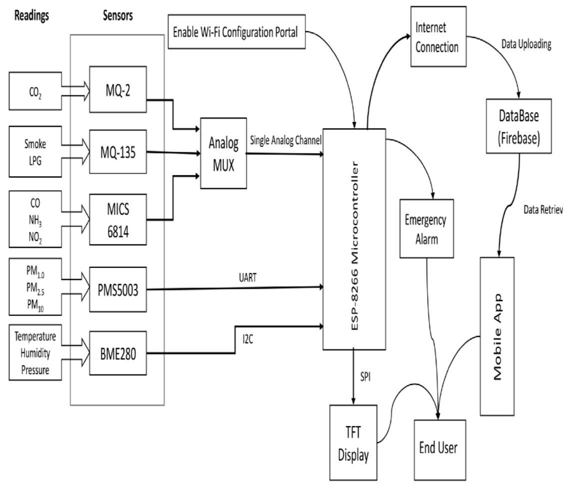
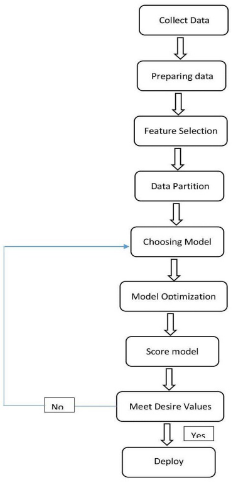


Figure-3. System Block Diagram

B. Machine Learning Model

The ML algorithm is selected based on its accuracy and performance time (less complexity) [28]. In this case, three algorithms as discussed earlier are to be tested and selected on the bases of several parameters discussed in the next section.



Figire-4. Flow Diagram of ML Model

C. Mobile Application

An interface with graphics is a kind of user interface where users communicate with electronic equipment via visual representations of indicators [29].

D. AQI Calculation Formula

The air quality object and standards were set in 1987, and since then there has been progress in making the lifestyle safer for the public and mitigating climatic change [30][31]. The challenges paved the path for technical and advanced solutions intended for a better lifestyle following UN Sustainable Development Goals (SDG) [32].

The Air Quality Index (AQI) is determined by taking the highest value for each contaminant [33] as follows:

Step-I: Determine which monitor has the highest concentration within each reporting area, then truncate it as follows.

Ozone (ppm) – truncate to 3 decimal places

$PM_{2.5}$ ($\mu g/m^3$) – truncate to 1 decimal place

PM_{10} ($\mu g/m^3$) – truncate to integer

CO (ppm) – truncate to 1 decimal place

SO2 (ppb) – truncate to integer

NO2 (ppb) – truncate to integer

Step II: Identify the two breakpoints where the concentration is contained (as given below).

Table-2. Breakpoints of Air Pollutant Concentration Levels

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

Step III: Calculate the index using the equation.

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

Where I_p = the index for pollutant p

C_p = the truncated concentration of pollutant p

BP_{Hi} = the concentration breakpoint that is greater than or equal to C_p

BP_{Lo} = the concentration breakpoint that is less than or equal to C_p

I_{Hi} = the AQI value corresponding to BP_{Hi}

I_{Lo} = the AQI value corresponding to BP_{Lo}

Step IV: The index is rounded off to the nearest integer.

E. Hardware Requirements and Schematics

Air Quality Index (AQI) is the measure of air pollutants, shows the degree of air cleanliness, and issues a corresponding health warning [34]. In this scope, we have been measuring Fine particulate matter (PM2.5, PM10), Carbon Dioxide (CO2), Sulphur Dioxide (SO2), Nitrogen Dioxide (NO2), Flammable hazardous gases like Methane (CH_4) and LPG Gases (hydrocarbons), and life-endangering Carbon Monoxide (CO) and Smoke [35] along with basic humidity, temperature and air pressure.

For this purpose to detect the concentration of several gases, many advanced sensors are used. Wifi-enabled Microcontroller (NODEMCU-8266) [36], particulate matter sensor module (PMS5003) [37], three-in-one carbon monoxide, ammonia, and nitrogen dioxide gas sensor module (MiCS-6814) [38], three-in-one humidity, temperature, air pressure sensor module (BME-280) [39], multi-parametric smoke, carbon dioxide, hydrocarbon (petrol, benzene compounds, etc.) sensor module (MQ-2 & MQ-135), GPS module and some necessary equipment including 3.3V/4000 mAH rechargeable battery, buzzer, MUX, etc. are used in device design. Moreover, PLA material was optimized for 3D print of case design.

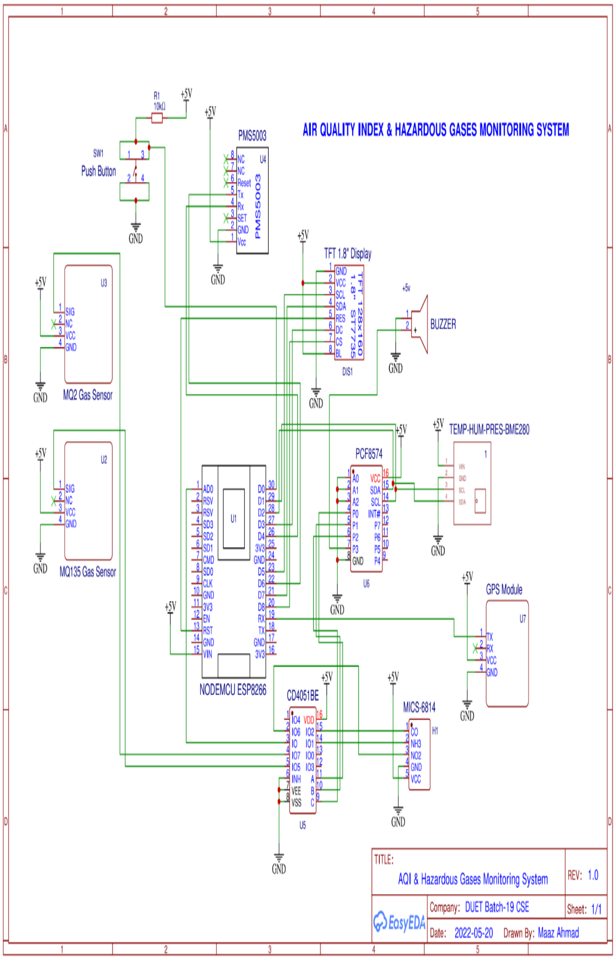


Figure-5. Schematics Diagram of Circuitry

III. SYSTEM IMPLEMENTATION AND RESULTS

A. Hardware Implementation

The consolidation of equipment yields circuitry.

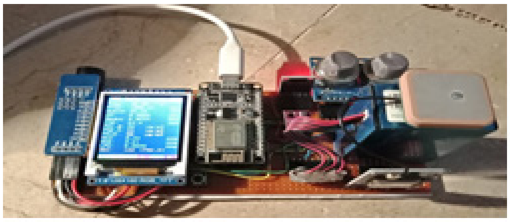


Figure-6. Internal view of the device (i.e. Circuitry)

The case design improved the insights, the circuitry was encapsulated inside the casing.

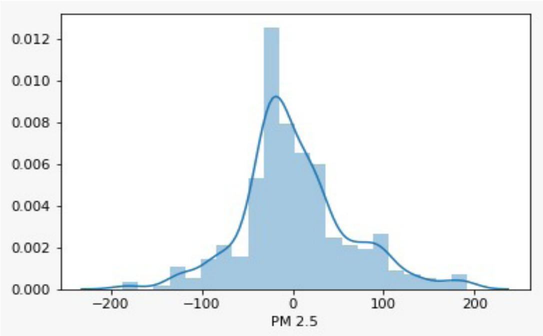
Figure-7. Sight of device

B. Machine Learning Model

We trained and tested three different models for the prediction of the Air Quality Index (AQI). The dataset utilized was used available online as well as the generated data from the device. The results gathered from those models are discussed briefly.

1. LASSO Regression

A regression method that makes use of shrinkage is LASSO regression. When the data's values are shrunk toward a common value, such as the mean of the values, this is referred to as shrinkage. It is a model of variable selection and shrinkage. Its major objective is to identify the variables that reduce prediction mistakes [40].



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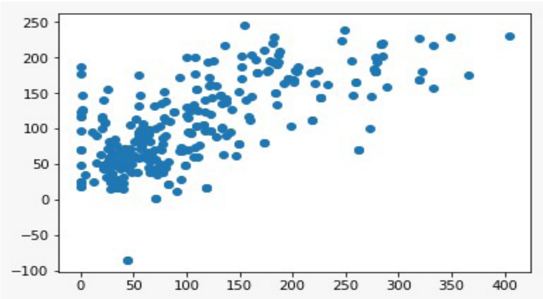
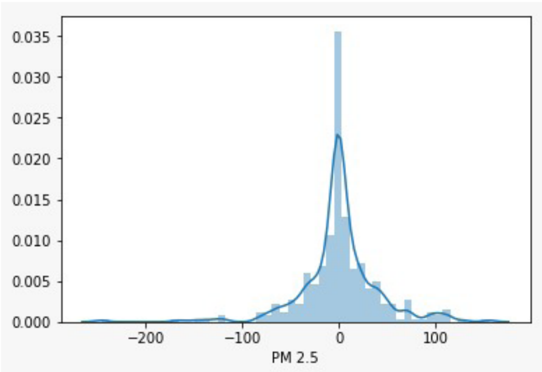


(ii)

Figure-8. Performance graphs of LASSO Regression depicting the value of 0.54321245122

2. Random Forest

In Random Forest, the decision trees are constructed independently, therefore if an algorithm contains five trees, they are all constructed simultaneously but with various features and data. Developers are forced to examine the trees and model them concurrently as a result [41].



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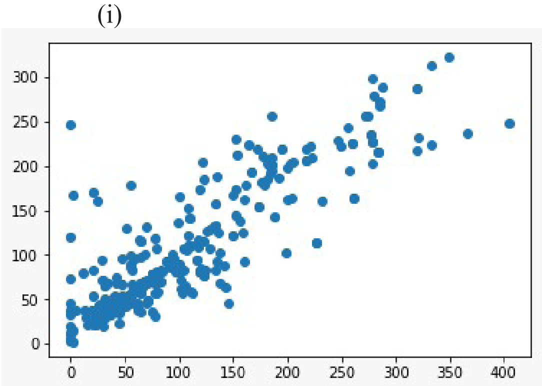


(ii)

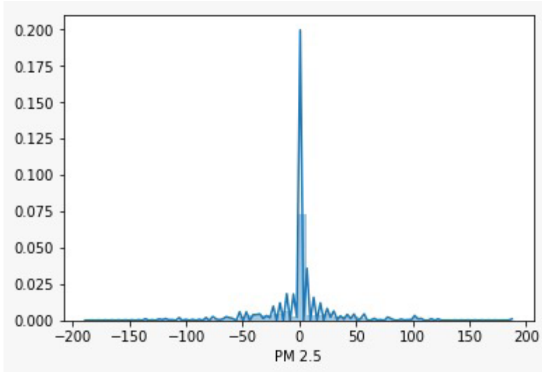
Figure-9. Performance graphs of Random Forest depicting the value of 0.70787635630

The results are computed by averaging the decision tree values once all the decision trees have been formed. This forces the developers to hold off on generating all of the decision trees until the conclusion, at which point the total results are considered.

3. XGBoost

Each decision tree's data is considered by XGBoost as it constructs one tree at a time, and any missing data is filled in. This makes it easier for programmers to combine the decision tree algorithm and gradient algorithms for better outcomes.

The gradient of the outcomes is taken into consideration while developers construct the decision trees since they compute and add the results for the following tree. Even though decision trees take time, this aids developers in getting a sense of the outcomes [42].



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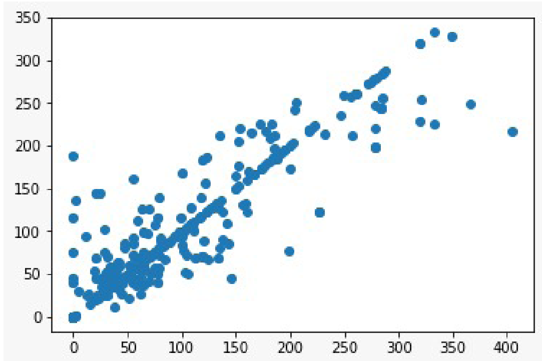

(ii)

Figure-10. Performance graphs of XGBoost depicting the value of 0.65828273677

In this study, the effectiveness of three distinct machine-learning models in solving the issue at hand was evaluated. The models were evaluated based on several important factors and available tools.

We concluded that each of the three models showed significant strengths and weaknesses across the assessed parameters after completing a thorough investigation.

After evaluating the performance of different models, the random forest showed a significant improvement in the result. We were able to take advantage of the benefits of this model while also ensuring its ideal deployment on Edge devices like the ESP32 and integration with Google Cloud servers by choosing Random Forest. It was the best option for our situation because of its accuracy, TFLite compatibility, and Google Firebase connectivity.

Table-3. Comparative Performance of Predictive Algorithms

	AQI Prediction Algorithms		
Performance Parameters	Lasso Regression	Random Forest	XGBoost
Mean Absolute Error (MAE)	44.50831199	25.24558181	25.24558181
Mean Squared Error (MSE)	3627.810939	1681.814278	1681.814278
Root Mean Squared Error (RMSE)	60.23131195	41.00992901	41.00992901

C.Database

Google Firebase is a cloud-based platform for several services including real-time database, algorithm deployment, authentication, etc. The data fetched from the device is updated on a real-time database periodically [43][44], the ML prediction algorithm is also deployed in the Custom Model deployment option on Firebase.

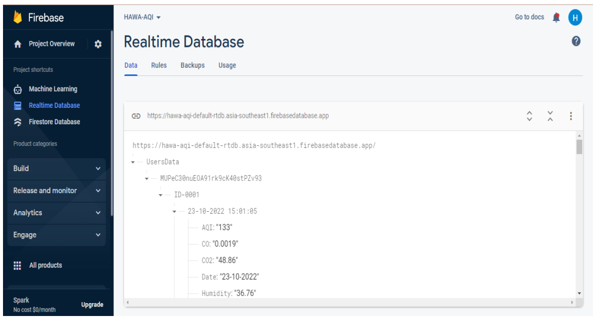

Figure-11. Real-time nodes in Google Firebase

D. Software Implementation

The GUI of a mobile application named 'Hawasaz' was designed, with features including credential registration (login/signup page), a home page, a recommendation page, and a map page. The mobile app is integrated with Google Firebase, it fetches data including the ML prediction from it and displays it on the interface. Additional features include recommendation pop-ups, map view, graphs/bar charts, settings, etc.

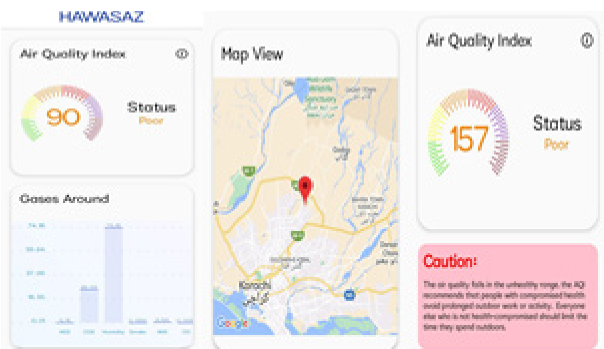

Figure-12. GUI glimpse of Hawasaz App

IV. DISCUSSION

We took samples of Carbon Dioxide (CO_2) from several designated places of Dawood University of Engineering and Technology (DUET) and found that there has been a distinction in values concerning the locations as per the parameters alike wind flow, congestion, machinery, etc. The purpose of conducting a test was to find the carbon emission of our university and help in further policies to overcome it.

Table-4. Carbon Emission Survey of Dawood University of Engineering and Technology (Main Campus)

S.NO	LOCATION	CO EMISSIONS (ppm)
1	Central Library	59.6
2	EE Class Room 1	56.1
3	Auditorium	56.9
4	CS Computer Lab	40
5	Main Lawn	38.9
6	Parking Area	50.3
7	Generator Area	75.5
8	Generator Control Room	59.1
9	Rhodes Photocopy Shop	45.1
10	Boys Canteen	73.8
11	Canteen Kitchen	81.8
12	Lift Control Room	79.1
13	Ground Floor Entrance	37.2
14	Outside University (M.G)	136.4

In addition, the AQI values were found lying often to be in the Moderate to Unhealthy range in parts of Karachi, though it has been noted on a rainy day; for instance; after the end of the Monsoon spell in August, the test in a room and outdoor environment showed that the AQI values were in Good/ Healthy Range (very low values).

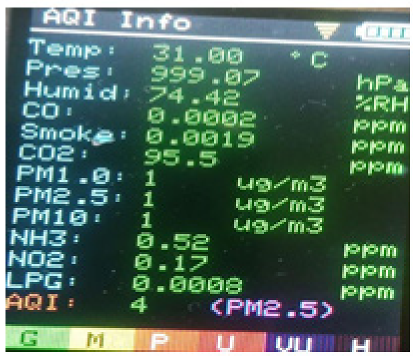

Figure-13. Lowest AQI (i.e. 4) measured amid Karachi Monsoon Season, 2022.

V. CONCLUSION

The idea brings the solution based on the combination of AI and IoT in the field of healthcare and climatic change. It not only intends to provide a real-time approach to the current environmental factors but also alarms the user upon befalling the critical situation alike a gas crossing the critical threshold. Moreover, it combines the cloud database and mobile app for remote and secure access to information. In addition, the recommendation system is also responsible for advertising the preliminary precaution as per the environmental factors.

The area of concern remains unvisited for decades in Pakistan, this project is headed to be implemented on the metropolitan scale for public healthcare interest and also an inspiration for industries and government to come forward to adopt it and take preliminary steps for a better environment by contributing to sustainable development thus mitigating climate change.

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