

Article

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Monitoring Air Quality Using Low-Cost Internet of Things

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Abstract: Air pollution poses a severe threat to public health and the environment, particularly in crisis-affected regions like Aleppo, Syria. The Heavy reliance on diesel generators due to frequent power outages, compounded by the aftermath of conflict, has led to dangerously high levels of airborne pollutants. There is an urgent need for accessible and reliable air quality monitoring to identify pollution sources and assess risks. This study presents an innovative, low-cost air quality monitoring system based on the Internet of Things (IoT) technology. The system utilizes MQ-7 (CO), MQ-135 (CO₂), and DHT22 (temperature and humidity) sensors connected to an Arduino Uno microcontroller. Real-time data are transmitted and visualized via the Blynk Console cloud platform, enabling remote monitoring and analysis. Field conducted in Aleppo across four locations (university campus, traffic intersection, diesel generator and residential area) during autumn and winter revealed critical findings. Pollution levels were significantly higher near traffic intersections and generators. Carbon monoxide (CO) concentrations near generators reached up to 11.23 ppm, and carbon dioxide (CO₂) levels peaked at 1877.6 ppm—both substantially exceeding World Health Organization (WHO) safety guidelines (4.0 ppm for CO over 8 hours, and 1000 ppm threshold for CO₂). The study demonstrates the system's effectiveness in providing transparent, reliable, and accessible environmental data, highlighting its potential for deployment in resource-limited and crisis-affected environments to support informed decision-making and public awareness.

Keywords: Air quality, Internet of Things, Air monitoring station, Blynk.Console, Environmental sensing

1. Introduction

Rapid urbanization, industrialization, and the burning of fossil fuels have led to the emergence of the global issue of air pollution. Air pollution refers to the excess of recommended national limits of liquid and solid particles, as well as organic and inorganic materials suspended in the air, which is a common problem faced by many countries. The most significant environmental risks related to air pollution affect various forms of life, including humans, wildlife, and agricultural crops. Long-term exposure to pollution can lead to serious health consequences, such as the exacerbation of respiratory and cardiovascular diseases, as well as an increased risk of stroke and heart disease.

Environmentally, air pollution can lead to a loss of biodiversity, damage to plants, and the spread of diseases, which negatively impact vegetation and crops. Therefore, global attention has shifted toward the threat of environmental pollution. As a result, the need for reliable solutions to monitor air quality has become more important than ever [1].

However, without adequate amounts of molecular oxygen in the atmosphere, humans and other air-breathing animals could not survive for more than a few minutes [2].

2. Literature Review

As highlighted in the proceedings edited by Tuba et al. [3], an experiment conducted near New Delhi, India, in an industrial zone with a diameter of one kilometer found that concentration in parts per million (PPM) was more than 10,000. This level is very high and unacceptable because a pollution level exceeding 600 PPM is unsafe for humans.

Zheng et al. [4] introduced an architecture designed for low-power wide-area IoT devices. The system uses sensors to detect the presence of harmful gases, transmitting the data seamlessly to a web-based server through a radio frequency (RF) module and a common computer. Then, the data stored in the web-based server are analyzed.

Shah and Mishra [5] developed a solution for air monitoring. They used temperature and humidity as parameters to assess the quality of air and build a wireless sensing and monitoring platform consisting of sensors and a microcontroller. The data are stored on a personal computer (PC) and can be accessed remotely via an Android phone.

Sardey et al. [6] developed a solution for air quality monitoring using carbon monoxide, carbon dioxide, and smoke as the parameters to evaluate the air quality, measured using the MQ7, MQ135, and MQ6 sensors, respectively. To detect the measurements and process these signals from the sensors, a microcontroller was used, and a liquid crystal display (LCD) screen was used to monitor the data. They added an ESP8266 Wi-Fi module to the system to access it remotely.

Thirunavukkarasu et al. [7] used an Arduino Uno with the MQ7, MQ135, and DHT11 sensors to detect different gases—carbon monoxide, carbon dioxide, and temperature, respectively. In addition, they used a GP2Y1010AU0F dust sensor to detect dust and an ESP8266 to connect to the Arduino via a Wi-Fi network to transmit the data to a related server.

Benedict et al. [8] used the concept of merging IoT and blockchain technologies to collect air quality measurements by using three sensors, MQ2, MQ7, and MQ135, to collect the parameters of smoke, carbon monoxide, and carbon dioxide, respectively. They measured the gases to indicate the air quality and used the concept of blockchain technology to connect to an Arduino Uno.

Different sensors were used to measure the parameters of carbon monoxide, carbon dioxide, emperature, and humidity, respectively. All of these sensors were connected to an Arduino and then connected to a Raspberry Pi, which sends the data to an online platform and then connects to a cloud service. This results in very high-power consumption and a relatively higher cost for this solution [9].

Kullig et al. [10] presented a solution consisting of a Raspberry Pi, which is a single-board computer on a single chip. It is connected to a DHT11 temperature and humidity sensor and a laptop, which uses software to simulate a blockchain platform.

The Internet of Things (IoT) refers to a network of devices and objects connected to each other via the internet, allowing them to exchange data and interact with their surrounding environment. The concept of IoT lies in connecting traditional objects to the internet, enabling them to collect, analyze, and control data remotely.

Data obtained with high accuracy from IoT-enabled monitoring stations can be used to improve transportation, optimize schedules, and ensure efficient movement of goods and people. Additionally, IoT enables farmers to make informed decisions regarding irrigation, agriculture, and pest control, leading to increased crop yields and sustainable farming practices.

IoT serves as a model where devices can sense, process, and communicate with each other autonomously, without human intervention. Examples of IoT applications include smart home devices, fitness trackers, smart lighting systems, and more. IoT is a rapidly growing field, presenting numerous opportunities and challenges.

Cloud-based IoT systems provide a unified platform to access resources, allowing programmable applications (apps) to perform specific tasks efficiently. These systems operate within a cloud infrastructure, facilitating data analysis and storage, ultimately leading to more effective solutions for managing air pollution.

Hassan et al. [11] demonstrated the design and implementation of a low-cost air quality monitoring station using the Internet of Things, supported by blockchain technology to ensure data transparency and reliability. The system relies on specialized sensors (DHT11, MQ7, and MQ135) to monitor temperature, humidity, carbon monoxide, and carbon dioxide as key indicators for assessing air pollution. This initiative aims to provide accurate and accessible environmental data to support decision-makers, researchers, and citizens, thereby contributing to the promotion of sustainable policies and the realization of smarter, healthier cities.

3. Methodology:

There are several methods for monitoring air pollution, the most important of which include: Fixed Monitoring Stations, Drone Technologies, Mobile Vehicles and Smart IoT Sensors.

This study presents an innovative, low-cost air quality monitoring station using the Internet of Things (IoT), aimed at measuring levels of carbon dioxide (CO₂), carbon monoxide (CO), temperature, and humidity. The system transmits real-time data to the Blynk.Console cloud platform. A simulation of the platform was developed using the Arduino IDE, version 2.3.2.

IoT technologies provide small, intelligent sensors that monitor air quality with high precision. These devices collect data and transmit it over the internet for real-time analysis, and consist of the following:

3.1 MQ-135

This gas detector can detect a wide range of gases, including ammonia, benzene, nitrogen oxides, smoke, and carbon dioxide. It operates effectively in both indoor and outdoor environments, offering good sensitivity to CO₂, cost-efficiency, and a long operational lifespan [12].

3.2 MQ-7

This sensor detects carbon monoxide (CO), a major contributor to air pollution and numerous life-threatening diseases. The MQ-7 is specifically designed to measure CO concentrations ranging from 20 to 2000 ppm and is cost-effective [6].

3.3 DHT22

Used to measure temperature and humidity, this sensor provides critical data for assessing air quality. It is low-cost, highly accurate, and functions as a digital hygrometer and thermometer [13].

3.4 Arduino Uno

A versatile microcontroller board that interacts with various devices efficiently. It is user-friendly, flexible, and widely used in different environments. The Arduino Uno is energy-efficient, cost-effective, and supports expanded features [14].

3.5 Blynk.Console

An open-source, web-based IoT platform that allows users to collect, analyze, and visualize data from various IoT devices in real time. It provides an organized and user-friendly graphical interface (GUI) for managing connected devices and analyzing data [15].

System components and connected devices are shown in figures 1-6.



Figure 1. MQ-135 Gas Sensor [12]



Figure 2. MQ-7 Carbon Monoxide Sensor [6]

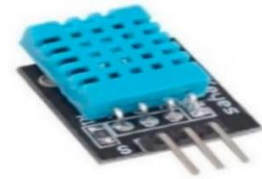


Figure 3. DHT22 Temperature/Humidity Sensor [13]

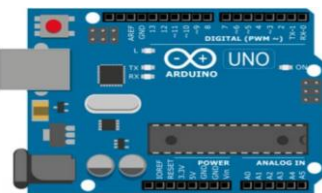


Figure 4. Arduino Uno Control Circuit [14]

Table 1. The estimated prices for the sensors.

Sensor Name	Purpose / Function	Estimated Price Range
DHT22	Measuring temperature and humidity	\$2 - \$4
MQ-135	Measuring general air quality and gases (e.g., Ammonia, Sulfur, CO ₂)	\$2 - \$4
MQ-7	Measuring carbon monoxide (CO)	\$3 - \$7

The system collects critical air quality data through three sensors:

- MQ-7 – for measuring carbon monoxide (CO)
- DHT22 – for monitoring temperature and humidity
- MQ-135 – for detecting carbon dioxide (CO₂)

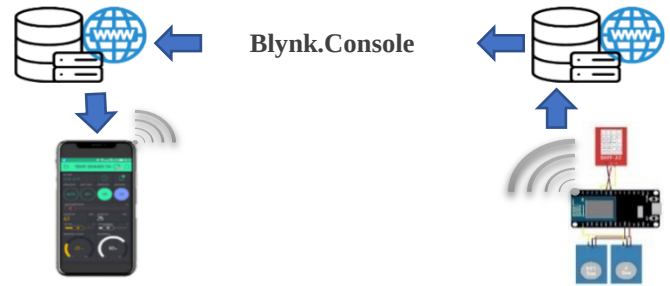


Figure 5. Schematic Diagram of the Proposed System.

The System Features:

- Arduino Uno microcontroller with GPIO (General Purpose Input/Output) ports
- Advantages:
 - Supports multiple peripheral connections
 - Low power consumption
 - Cost-effective solution
 - Direct Wi-Fi connectivity to the Blynk.Console cloud platform for:
- Real-time data visualization
- Remote monitoring
- Cloud-based analytics

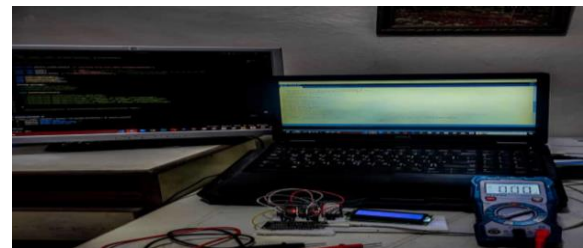


Figure 6. Hardware Implementation of the Air Quality Monitoring Station

Data (temperature, humidity, CO, and CO₂ levels) were collected during:

1. Sunrise hours
2. Midday
3. Sunset

Across four strategic locations in Aleppo, Syria:

1. University Campus (Technical Engineering College)
2. Traffic Intersection (Al-Sakhra Roundabout)
3. Diesel Generator Site
4. Residential Area (Railway Neighborhood)

Rationale for Site Selection:

These locations were chosen to:

- measure pollutant concentrations in high-traffic and residential zones
- Assess air quality variations near combustion sources (generators)
- Validate IoT monitoring the performance of the IoT monitoring station across urban microenvironments

Blynk.Console Interface Configuration

Step-by-Step Setup:

1- Access Developer Zone

Navigate to the Blynk.console web platform

Select:

Developer Zone → My Templates → New Template

The Developer Zone of Blynk is described in Figure 7. Display on the console.

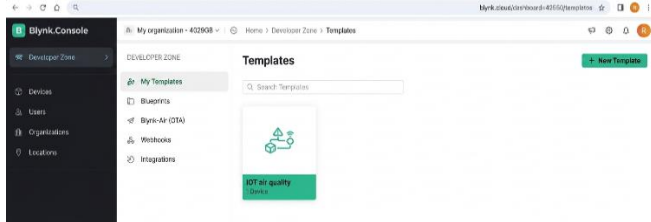


Figure 7. The Developer Zone Blynk.Console.

2- The "Create New Template" window appears: Enter the project name, device type (chip), connection type, and project description, as shown in

Figure 8.

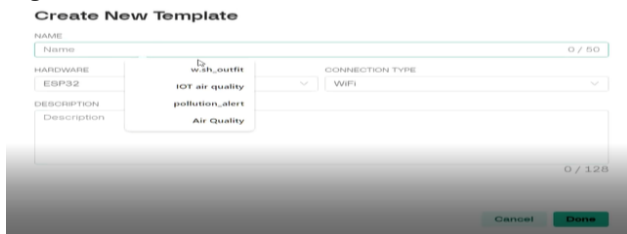


Figure 8. Create New Template

3- Upon clicking "Done", the project template "IoT Air Quality" will be created as shown in

Figure 9.



Figure 9. IoT Air Quality

4- When clicking on "IoT Air Quality" → "Home", the template name and number are displayed. We copy them for use in C++ programming. A confirmation message appears: "Code copied to clipboard" as shown in Figure 10.

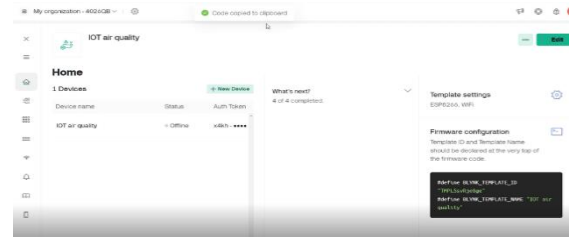


Figure 10. Code copied to clipboard

5- We copy the Auth Token from the Devices menu, as shown in

Figure 11.

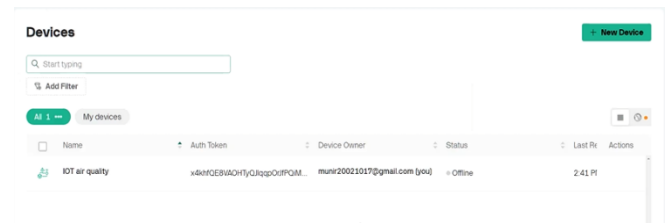


Figure 11. The Devices menu

6- We configure the required parameters by adding gauges, setting units, colors, data types, and min/max values for temperature, humidity, and gas measurements. This is done by selecting **Data Streams**, as shown in

Figure 12.

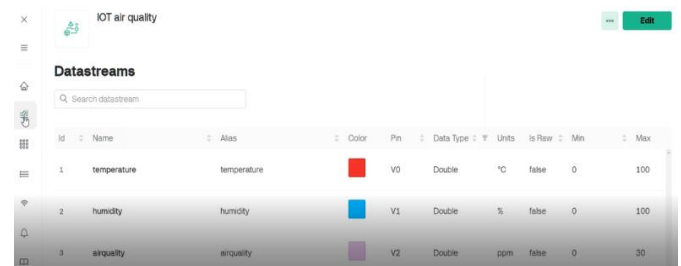


Figure 12. Data Streams.

7- We add both the chart and the gauges to display the values of temperature, humidity, and gas concentrations. This is done through:

IoT Air Quality → Web Dashboard → Edit → Widget Box

as shown in Figure 13.



Figure 13. Web Dashboard.

8- Arduino Uno Programming: Download & Install the Board Package:

Install the Arduino Uno board definition to enable communication between the computer and the Arduino.

As shown in Figure 14.

Figure 14

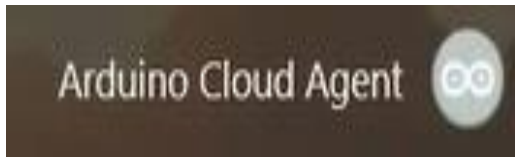


Figure 14. Arduino Cloud Agent.

Downloading Arduino IDE for Code and Sensor Library Setup

Download Arduino IDE to upload code and install necessary libraries for sensors and the circuit.

Open the software, go to:

Tools → **Board** → **Select "ESP8266"** (as the connected board type)

As in Figure 15.

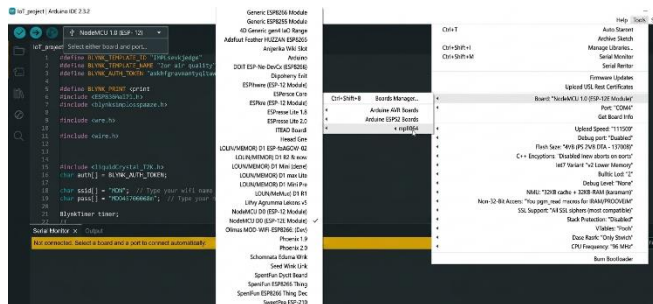


Figure 15. Board Select "ESP8266".

Device Definitions:

```
#define DHTpin 2
#define DHTTYPE DHT22
DHT dht(DHTpin, DHTTYPE);
MQ135 m135s = MQ135(A0);
MQ7 mq7(A0, 5.0);
Adding Network Name and Password:
char ssid[] = "MON"; // type your wifi name
char pass[] = "M0945700044m"; // type your wifi password
Data Conversion and Processing:
float h = dht.readHumidity();
float t = dht.readTemperature();
float ppm_135 = 5 * (m135s.getPPM());
float ppm_7 = 0.35 * (mq7.readPpm());
```

Printing and Uploading Results:

```
Blynk.virtualWrite(V0, t);
Blynk.virtualWrite(V1, h);
Blynk.virtualWrite(V2, ppm_7);
Blynk.virtualWrite(V3, ppm_135);
Serial.print("MQ-135 sensor Value: ");
Serial.print(ppm_135, DEC);
Serial.print("MQ-7 sensor Value: "); Serial.print(ppm_7, DEC);
Serial.print("DHT-Temperature: "); Serial.print(t);
Serial.println(" °C");
Serial.print("DHT-Humidity: "); Serial.print(h);
Serial.println(" %");
```

Click the arrow icon as shown in Figure 16.

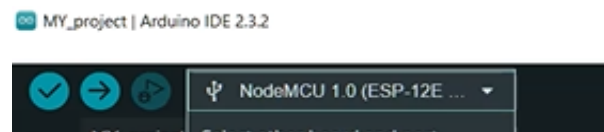


Figure 16. Uploading the Code to the Circuit.

Circuit Connection:

We have an ESP8266 circuit that includes power pins, analog and digital data inputs. The DHT22 temperature and humidity sensor is powered with 3.3V and connected to the digital data pin D2.

The **MQ7** sensor is powered with **5V**.

The **MQ135** sensor is powered with **3.3V**.

Both sensors are connected to the **analog input A0**, with their ground (GND) pins connected to the **GND** port.

Figure 17 shows the sensors connection to the ESP8266 circuit.

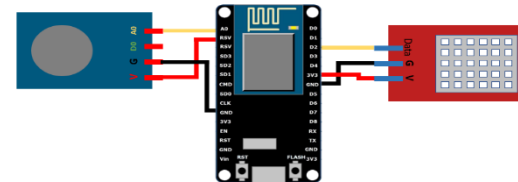


Figure 17. The sensors are connected to the ESP8266 circuit.

4. Results and Discussion:

Sample of the results collected by the station during different seasons of the year at different times of the day are listed in tables 2-7.

Table 2. Sample of the results collected by the station during the autumn season at sunrise.

Date	Location	T	H	CO	CO ₂
27-Sep.	Residential	18	71.5	0.27	183.66
	University Campus	17	73	0.3	190.3

Date	Location	T	H	CO	CO ₂	Date	Location	T	H	CO	CO ₂
28-Sep.	Traffic Signals	18	69.1	2.29	327	2-Oct.	Residential	21.4	78.9	1.45	288.22
	Next to the Generator	18	72	0.35	193.4		University Campus	21.6	78.1	1.59	377.3
	Residential	17	72	0.26	176.9		Traffic Signals	20.8	79.7	2.36	1573.48
	University Campus	16	74.2	0.29	183.4		Next to the Generator	21.4	78.7	2.07	293.7
	Traffic Signals	19	68	2.43	352	3-Oct.	Residential	20.2	78.4	1.09	277.42
	Next to the Generator	17	72	0.37	182.1		University Campus	20.6	78.1	1.31	380.12
29-Sep.	Residential	20	70	1.2	176.9		Traffic Signals	20.1	78.9	1.55	1345.25
	University Campus	19.7	72.9	1.1	181.5		Next to the Generator	21.6	77.4	2.09	277.92
	Traffic Signals	21	64	2.24	215	From Table 2, we observe that the highest carbon dioxide (CO₂) value reached 1573.48 ppm at the traffic signals location due to high traffic density and temperature inversion conditions, while carbon monoxide (CO) peaked at 2.43 ppm at the same location due to incomplete combustion of fuel from congested vehicles. These results are in clear agreement with Reference [11], as the carbon dioxide value reported therein (434 ppm) falls within the wide range recorded in the table (176.9 to 1573.48 ppm). Table 3. Sample of the results collected by the station during the autumn season during the afternoon.					
	Next to the Generator	20.3	71	1.3	179.6						
30-Sep.	Residential	20.8	71	1.13	198.65	Date	Location	T	H	CO	CO ₂
	University Campus	20.3	74.6	1.2	202.81	27-Sep.	Residential	31.1	35.2	0.84	148.3
	Traffic Signals	21.7	68.1	2.19	206.97		University Campus	31.4	34.9	1.01	151.7
	Next to the Generator	21.1	71.1	1.46	211.13		Traffic Signals	35.6	29.1	2.87	543.4
1-Oct.	Residential	21	72	1.055	183.66		Next to the Generator	34.7	29.7	3.17	513
	University Campus	21.5	76	1.15	227.8	28-Sep.	Residential	37	14	0.88	136.2
	Traffic Signals	23.7	70.2	2.09	265.93		University	37.3	21	0.963	140.09
	Next to the Generator	21.6	71.6	1.7	187.73						

Date	Location	T	H	CO	CO ₂
29-Sep.	Campus				
	Traffic Signals	39.1	11	3.43	616
	Next to the Generator	39.7	9.7	4.1	677
	Residential	33.7	28	1.98	384.15
	University Campus	32.1	31.1	2.33	457.76
	Traffic Signals	36.7	21.7	4.15	691.4
	Next to the Generator	37.1	20.3	4.88	756.12
30-Sep.	Residential	34.2	34	1.76	470.61
	University Campus	32.9	42.5	2.16	645.76
	Traffic Signals	36	30.3	3.68	813.4
	Next to the Generator	35.8	32.7	4.43	1107.3
1-Oct.	Residential	30	37.3	1.62	378
	University Campus	29.8	34.5	2.185	634.7
	Traffic Signals	33.6	30.4	4.83	679.3
	Next to the Generator	34	29.2	5.11	875.3
	Residential	31.1	35.2	0.84	148.3
2-Oct.	University Campus	30.6	31.2	1.95	640.2
	Traffic Signals	35.4	33.4	3.92	801.4

Date	Location	T	H	CO	CO ₂
3-Oct.	Next to the Generator	34.4	29.6	4.35	1005.3
	Residential	30.5	37.5	0.91	352.5
	University Campus	31.4	34.8	2.52	630.4
	Traffic Signals	34.5	37.6	4.35	652.2
	Next to the Generator	35.2	29.5	3.52	1121.5

From the data table, we observe that the highest carbon dioxide (CO₂) value reached 1121.5 ppm at the location **Next to the Generator** on **October 3**, while carbon monoxide (CO) peaked at **5.11 ppm** at the **same location** on **October 1**.

Table 4. Sample of the results collected by the station during the autumn season at sunset hours.

Date	Location	T	H	CO	CO ₂
27-Sep	Residential	33	27.8	0.93	146
	University Campus	33.6	27.1	1.06	151.7
	Traffic Signals	34	26.8	3.04	621
	Next to the Generator	34	29.5	2.78	385
	Residential	31	34.1	1.22	198
28-Sep.	University Campus	31.4	33.3	1.35	220.01
	Traffic Signals	34.3	30.8	4.6	645
	Next to the Generator	35	32.8	6.15	817
29-Sep.	Residential	27.4	54	1.3	226.17
	University Campus	26.8	59.6	1.43	267.3

Date	Location	T	H	CO	CO ₂
30-Sep.	Traffic Signals	30.5	45.3	4.44	625
	Next to the Generator	30.8	43.83	6.13	974.22
	Residential	28.4	52.1	1.34	237.4
	University Campus	27.1	54.8	1.57	307.8
	Traffic Signals	30.8	47.7	4.11	540.21
1-Oct.	Next to the Generator	30.2	48.4	5.19	758.37
	Residential	27.1	58.12	1.27	312.6
	University Campus	25.5	61.7	1.838	424.4
	Traffic Signals	26.5	59.1	3.45	630.19
	Next to the Generator	27	56.2	4.3	871.2
2-Oct	Residential	28.4	42.1	2.3	492.7
	University Campus	29.1	40.4	2.24	480.67
	Traffic Signals	27.7	43	4.59	732.4
	Next to the Generator	27.7	43	11.23	1877.6
	Residential	29.3	37.6	1.86	276.3
3-Oct.	University Campus	31.6	31.7	2.17	381.4
	Traffic Signals	27.7	43.2	6.96	1205.7
	Next to the Generator	32.5	41.1	9.11	1650.8

From the data table, we observe that the highest carbon dioxide (CO₂) value reached 1877.6 ppm at the location ****Next to the Generator**** on ****October 2****, while carbon

monoxide (CO) peaked at ****11.23 ppm**** at the ****same location and date****.

Table 5. Sample of the results collected by the station during the winter season at sunrise hours.

Date	Location	At Sunrise			
		T	H	CO	CO ₂
20-Mar.	Residential	2	73	0.95	195.2
	University Campus	4	81	0.94	182.6
	Traffic Signals	-1	75	2.54	475.2
	Next to the Generator	1	77	1.08	187.6
	Residential	1	84	1.13	200.7
21-Mar.	University Campus	0	87	0.94	182.4
	Traffic Signals	-1	91	2.71	473.2
	Next to the Generator	1	83	1.08	187.6
	Residential	3	79	1.24	213.7
	University Campus	4	81	1.17	193.4
22-Mar	Traffic Signals	2	71	3.07	731.2
	Next to the Generator	3	77	1.38	276.8
	Residential	2	81	1.04	215.5
	University Campus	-1	75	2.45	182.2
	Traffic Signals	3	74	0.95	187.6
23-Mar.	Next to the Generator	2	86	1.13	200.7

From the sunrise data table, we observe that the highest carbon dioxide (CO₂) value reached ****731.2 parts per million (ppm)**** at the ****Traffic Signals**** location on ****March 22nd****, while carbon monoxide (CO) peaked at ****3.07 ppm**** at the ****same location and on the same date****.

Table 6. Sample of the results collected by the station during the winter season in the afternoon hours.

Date	Location	Afternoon Hours			
		T	H	CO	CO ₂
20-Mar	Residential	9	54	2.23	411.95
	University Campus	7	51	2.15	520.5
	Traffic Signals	8	48	5.95	1521.5
	Next to the Generator	11	50	10.5	1752.4
21-Mar	Residential	8	52	2.33	412.2
	University Campus	9	50	2.51	473.7
	Traffic Signals	11	48	6.31	1301.2
	Next to the Generator	15	41	10.2	1717.8
22-Mar	Residential	12	35	2.48	489.4
	University Campus	12	39	3.01	519.4
	Traffic Signals	14	27	6.78	1372.1
	Next to the Generator	17	22	9.15	1672.8
23-Mar	Residential	10	38	2.25	470.5
	University Campus	12	34	2.96	610.6
	Traffic Signals	14	28	5.52	1405.4

Date	Location	Afternoon Hours			
	Next to the Generator	12	24	10.4	1640.5

From the afternoon data table, we observe that the highest carbon dioxide (CO₂) value reached ****1752.4 parts per million (ppm)**** at the ****Next to the Generator**** location on ****20 March ****, while carbon monoxide (CO) peaked at ****10.5 ppm**** at the **** same location on the same date****.

Table 7. A sample of the results collected by the station during the winter season at sunset.

Date	Location	At Sunset			
		T (°C)	H%	CO	CO ₂
20-Mar.	Residential	5	79	1.84	342.1
	University Campus	8	67	2.85	352.5
	Traffic Signals	4	75	9.22	1543.5
	Next to the Generator	7	60	10.5	1700.5
21-Mar.	Residential	5	75	1.73	274.5
	University Campus	7	69	2.17	390.4
	Traffic Signals	6	72	8.19	1580.4
	Next to the Generator	9	66	9.11	1684.2
22-Mar.	Residential	9	48	1.94	308.6
	University Campus	9	53	2.48	419.1
	Traffic Signals	8	41.5	8.76	1607.9
	Next to the Generator	11	36	9.07	1626.8
23-Mar	Residential	10	53	1.81	298.5
	University Campus	8	42.5	2.52	304.6
	Traffic Signals	7	38	7.95	1405.6

Date	Location	At Sunset				
	Next to the Generator	11	51	8.45	1750.4	

From the sunset data table, we observe that the highest carbon dioxide (CO₂) value reached **1750.4 parts per million (ppm)** at the **Next to the Generator** location on **23 March**, while carbon monoxide (CO) peaked at **10.5 ppm** at the **Next to the Generator** location on **20 March**.

The results presented in Tables 1 – 6 can be discussed as follows:

1. Areas near traffic signals and generators recorded the highest pollution levels in Tables 1 - 6.
2. Residential areas and university campuses showed lower levels in all tables 1 - 6.
3. Some recorded CO values, especially next to the generator (e.g., 11.23 ppm, table 3) exceeded safe exposure limits (9 ppm for 8 hours).
4. Some CO₂ readings (e.g., 1877.6 ppm, Table 3) surpassed normal levels (400-1000 ppm).
5. Peak pollution concentrations occurred in the afternoon (Tables 2 and 5) due to increased human activity and traffic.
6. Winter (Tables 4-6) showed higher humidity with relatively lower pollution, likely due to climate variation and seasonal atmospheric conditions.
7. Autumn (Tables 1-3) exhibited higher pollution levels, particularly in traffic areas.

After collecting the data, the system displays them and compares them to the acceptable values as in the figures below

The average values of environmental parameters measured during the autumn season are shown in Figure 18.

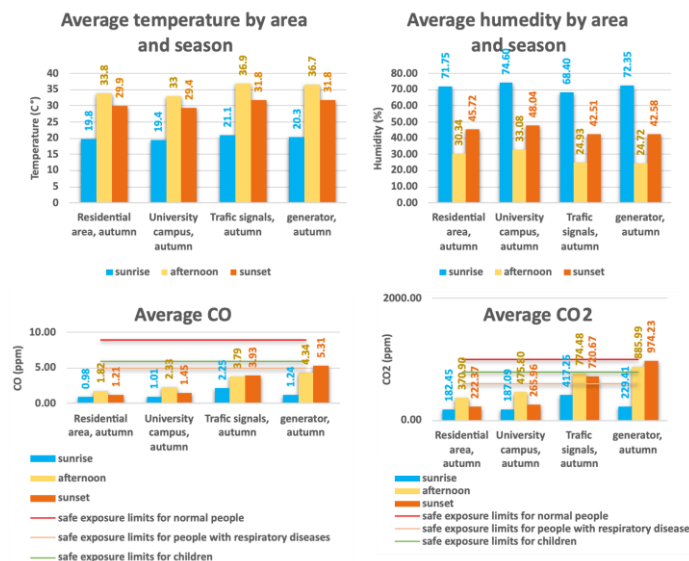


Figure 18. The bar charts represent the average values of environmental parameters measured during the autumn season.

The average values of environmental parameters measured during the winter season are shown in Figure 19.

The results indicate that that pollution levels were significantly higher during the autumn season, especially in areas near generators and traffic signals, whereas the winter season showed higher humidity and lower average pollution values across most areas.

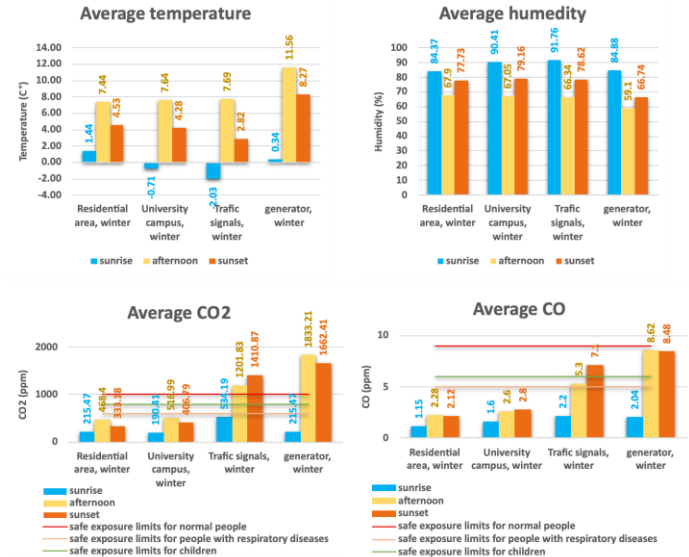


Figure 19. The bar charts represent the average values of environmental parameters measured during the winter season.

5. Recommendations

1. Replace conventional generators with renewable energy systems (e.g., solar power)
2. Improve traffic flow through smart traffic systems to reduce congestion
3. Implement continuous monitoring and public awareness campaigns about pollution impacts, along with installing air quality sensors
4. Increase green spaces through tree planting to absorb harmful gases
5. Regulate industrial emissions by enforcing strict environmental laws on industrial facilities

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مراقبة جودة الهواء باستخدام إنترنت الأشياء منخفض التكلفة

المخلص: يشكل تلوث الهواء تهديداً خطيراً للصحة العامة والبيئة، خاصة في المناطق المتأثرة بالأزمات مثل حلب، سوريا. أدى الاعتماد الكثيف على مولدات الديزل بسبب انقطاع التيار الكهربائي المتكرر، إلى جانب آثار النزاعات، إلى ارتفاع خطير في مستويات الملوثات الهوائية. هناك حاجة ملحة لمراقبة جودة الهواء بطرائق سهلة الوصول وموثوقة لتحديد مصادر التلوث وتقييم المخاطر. تقدم هذه الدراسة نظاماً مبتكراً منخفض التكلفة لمراقبة جودة الهواء يعتمد على تقنية إنترنت الأشياء (IoT). يستخدم النظام أجهزة استشعار (MQ-7) لأول أكسيد الكربون، و (MQ-135) لثاني أكسيد الكربون، و (DHT22) لدرجة الحرارة والرطوبة المتصلة بلوحة تحكم دقيقة (Arduino Uno). يتم نقل البيانات في الوقت الفعلي وعرضها عبر المنصة السحابية Blynk.Console، مما يتيح المراقبة والتحليل عن بُعد. كشفت القياسات الميدانية في حلب في أربعة مواقع (الحرم الجامعي، تقاطع مروري، موقع مولد ديزل، منطقة سكنية) في خلال فصلي الخريف والشتاء عن نتائج حرجية. كانت مستويات التلوث أعلى بشكل ملحوظ بالقرب من حركة المرور والمولدات. وصلت تراكيزات أول أكسيد الكربون (CO) بالقرب من المولدات إلى 11.23 جزءاً في المليون، وبلغت مستويات ثاني أكسيد الكربون (CO₂) ذروتها عند 1877.6 جزءاً في المليون -متجاوزة بكثير إرشادات السلامة الصادرة عن منظمة الصحة العالمية (4.0 جزءاً في المليون لـ CO خلال 8 ساعات، وعتبة 1000 جزء في المليون لـ CO₂). تثبت الدراسة فعالية النظام في توفير بيانات بيئية شفافة وموثوقة وسهلة الوصول، وتبسيط الضوء على إمكانية نشره في البيئات محدودة الموارد والمتأثرة بالأزمات لدعم صنع القرار المستند إلى الأداء وزيادة الوعي العام. الكلمات المفتاحية: جودة الهواء، إنترنت الأشياء (IoT)، محطة مراقبة الهواء، منصة Blynk.Console، الاستشعار البيئي.