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An IoT Based Real-Time Environmental Monitoring System for Developing Areas

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ABSTRACT

Rapid urbanization and industrialization have raised concerns about environmental quality and sustainability in recent years. The Internet of Things (IoT) has played an important role in monitoring physical phenomena by generating data that can be sent and preserved in the cloud. This work explores an IoT-based environmental monitoring system's potential, using an Arduino-based device for real-time tracking of environmental parameters including sound levels, humidity, dust concentration, total volatile organic compounds (TVOC), carbon dioxide (CO2), and carbon monoxide (CO). Real-time data are collected from various semi-residential and marketplace locations named in Pach raster More, Tomaltola, DowamoyiMore, Fojdarimore, and station road in Jamalpur district of Mymensingh Division, Bangladesh on non-holiday days, providing a representative snapshot of typical environmental conditions. The collected data is stored in a cloud server named firebase database. The implemented monitoring system offers several key features including accuracy and reliability, real-time monitoring data analytics alerts and notifications historical data as well as it can lead to various benefits and impacts of Improved Air and Water Quality Healthier Urban Environment (IAWUE) to enable local authorities and individuals to make educated decisions for a healthier and more sustainable urban environment. Graphical representations of the data revealed distinct patterns and trends, offering valuable insights into air quality variations across different areas. Interestingly, the results showed sound levels slightly below the standard range, indicating a relative control of noise pollution in the sampled areas. The findings of the work will serve as a vital resource for further research and guide policy-making for environmental improvement and sustainable practices in urban settings.

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1. Introduction

The last few decades have witnessed vast research on new types of heat transfer fluids, namely nanofluids. Our life depends solely on nature; the more we pollute nature, the more we risk our existence. The effects of air pollution are evident globally, and movements for clean air are becoming dominant daily. Premature mortality in booming countries like China and India is primarily because of air pollution in those countries. Scientists suggest carbonaceous particles are more lethal than others, i.e., crustal material, nitrates, or sulphates [1]. A model developed to estimate premature mortality suggested that around 3.15 million people were victims of air pollution globally, with China at the top and Bangladesh in the fifth position [2]. In a recent study, it was found that most prefectures in China have Fine Particulate Matter (PM2.5) is more significant than ten µg/m3, which violates the air quality guideline of the World Health Organization (WHO) [3]. On the other hand, WHO suggested that more than 2 million people die yearly due to air pollution in urban areas, and many more suffer from prolonged respiratory illness [4]. Despite the emission control measures implemented in industrialized countries to minimize air pollution, emissions of pollutants have either stabilized or increased due to the increased growth of activities, particularly in countries with emerging economies [5]. It is time to monitor these emission processes' air quality and their effects on climates and global weather [6]. Internet of things (IoT) can play a vital role to monitor the air quality. It has a vast application in environmental management monitoring like water quality monitoring [7-11], air quality [12,13]. However, current trends are giving more focus to low-cost, scalable monitoring systems, and such an example is the low-cost air quality monitors used in Nairobi quite recently [14]. The Global Carbon Budget for the year 2017 estimated that global CO2 emissions would be distributed among coal (40 %), oil (34 %), gas (19%), cement (5.6 %), and gas flaring (0.7%) [15]. For every 1 kg of cement produced, the cement industry emits nearly 900 gm of CO2 gas. A study to find air pollutants like PM2.5, PM10, SO2, and NO2 in a plant was performed, and due to the use of improved technology, the average concentration values were below the permissible limits [16]. Green cement is being manufactured in India to reduce and even eliminate the production and release of air pollutants (mainly CO2) [17]. An investigation into the sources of coarse particles in the air of any City in Bangladesh attributed to road dust, motor vehicle, and cement from construction [18]. The risks of working in or residing around a cement factory were depicted thoroughly in [19]; they suggested that all the cement industries should be monitored to maintain the air quality. Bangladesh, a developing country, is currently going through an industrialization process, and it was found that the environmental Kuznets curve exists between CO2 emissions and industrialization in Bangladesh [20]. This work suggests that air pollutants in Bangladesh are correctly measured and must be taken to control the pollution while sustaining industrial growth. Although people in Bangladesh are becoming more aware of the environment, pollution prevention initiatives are considerably low in the case of the tannery, pulp & paper, fertilizer, textile, and cement industries [21]. Current development projects in Bangladesh have given a big thrust to the construction sector, resulting in higher production and consumption of steel and cement. Several flyovers and other construction projects are ongoing throughout the country's Metropolitan cities. Bangladesh, with its commercial-level cement production companies, is marginally self-sufficient in fulfilling local demand for cement; now, time demands to make these cement industries more environment-friendly and profitable by adopting modern technology [22]. According to the Washington Post, pollution around the globe now contributes to an estimated 9 million deaths annually, or roughly one in six people. With extensive population growth, more industrial-based jobs resulted in massive increases in pollution. Combine swelling population growth and pollution with more severe droughts, floods, and storms, and it becomes clear that finding a solution to climate change is of the utmost importance.

The cost-effective system exhibits robust scalability and is capable of delivering stable and accurate services in real-time. Its applications extend to precise agriculture, healthcare facilities, educational institutions, industrial zones, and the general populace in urban areas [23]. The proposed system was designed to address the specific challenges of air pollution in Jamalpur, with a focus on being affordable, scalable, and providing real-time data. The City of Jamalpur and relevant government agencies stand to benefit by leveraging this system for effective environmental management and policy formulation.

This work makes the following contribution:

i. Development of IoT Monitoring System: The study contributed by creating a low-cost, real-time IoT environmental monitoring system using an Arduino-based device, setting a precedent for future research and applications.
ii. Diverse Environmental Data: The research collected environmental data from various urban settings in Jamalpur, offering a rich resource for future studies and assessments.
iii. Graphical Data Analysis: Through the use of graphs to represent collected data, the study provides valuable insights into environmental conditions and trends, guiding future research and policy-making.

The remaining sections are arranged as follows. Section 2 deals with the literature review, while Section 3 deals with the methodology. The result analysis, discussion, and conclusion are explained in Sections 4 and 5.

2. Related Studies

Previously, there have been some research and experiments undertaken by researchers on air pollution monitoring systems. As we are moving forward to a bright system day by day, the objective for making the system was to take the environment automatically and analyse the system using intelligent technologies. Previously we worked on "A Real-Time Industrial Level Atmospheric CO, CO2, and Sound Level Monitoring in Bangladesh- A Part of Smart City Planning for Next Generation Advancements." The previous studies conducted in different cities in Bangladesh showed that only some have intensively examined the effect of environmental pollution and how to get off from this situation at different time scales. Environmental monitoring has undergone a revolution as a result of the Internet of Things (IoT) era. Mahrad *et al.,* [25] highlight how IoT devices have been instrumental in gathering real-time environmental data due to their remote sensing capabilities and seamless internet connectivity. This aligns with the findings of Kang *et al.,* [26], who explored the potential of IoT in providing detailed spatiotemporal data crucial for efficient environmental management. Using specific devices for data collection, like Arduino-based systems, has gained traction in recent years. A study by Sung *et al.,* [27] on Arduino's application in environmental monitoring underscores its advantages, such as low-cost, flexibility, and ease of integration with various sensors. Furthermore, Tripolitsiotis *et al.,* [28] emphasize that real-time Arduino monitoring aids in prompt data analysis, enhancing the precision and reliability of environmental assessments. Jony *et al.,* [29] presents an intelligent sewerage management system using water sensors, a GSM module, and a microcontroller for real-time monitoring. Islam *et al.,* [30] propose a real-time IoT-based system for fish farming in Bangladesh, utilizing water temperature, turbidity, pH, and CO3 gas. Urban environmental quality, especially air quality and noise pollution, is a growing worldwide concern. While studies like those by Diener *et al.,* [31] provide comprehensive insights into the adverse effects of deteriorating air quality on public health, Hussin *et al.,* [32] focus on the socioeconomic impacts of noise pollution in urban settings. Both studies accentuate the need for advanced, real-time monitoring systems to keep these environmental challenges in check. The literature strongly advocates for real-time, IoT-based environmental monitoring, mainly using versatile platforms like Arduino, to address the pressing environmental challenges in urban landscapes.

3. Method and Materials

The proposed technique revolves around establishing an advanced environmental monitoring system, leveraging the Internet of Things (IoT) to gather important information about the surrounding area's temperature, humidity, air quality, dust, and other environmental factors which is shown in Figure 1.

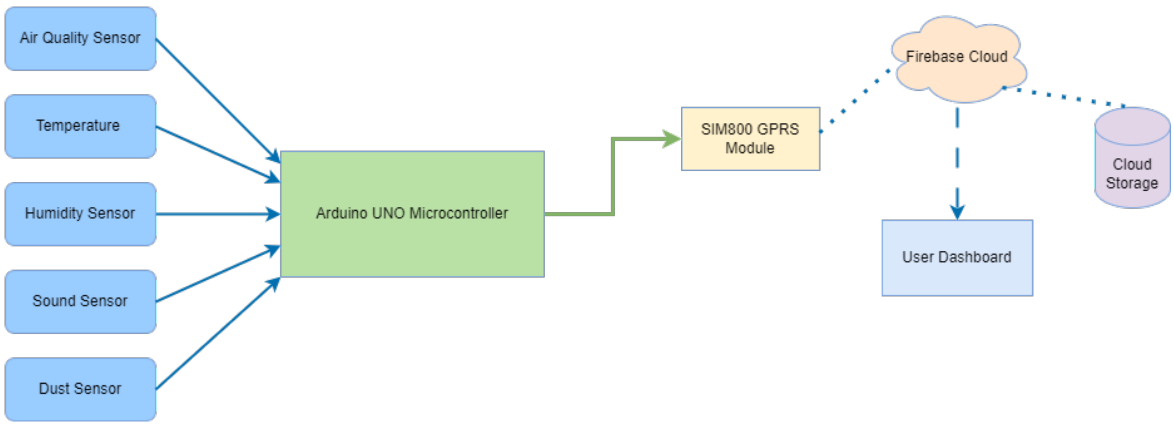


Fig. 1. The complete block diagram of the work

The core of the system is the Arduino microcontroller, serving as the central processing unit. It interfaces with five essential sensors, namely CO2 sensors, CO sensors, Hydrogen sensors, noise sensors, and air quality sensors. These sensors yield analogue data, transformed into digital form utilizing the Arduino's proficient internal A/D converter.

The SIM800 GPRS module facilitates smooth data transfer and storage, enabling connectivity between the Arduino and Google Firebase. This component effectively gathers information from the Arduino through the UART connection and sends it to the Firebase platform for centralized administration and storage.

An Android application has been developed to retrieve data from Firebase for real-time monitoring and control. The user-friendly application uses server-side scripting to send data from the server to the browser, ensuring safe and efficient transmission. The Arduino microcontroller is battery-powered, so minimizing power consumption is crucial. Data uploads to Firebase are strategically planned every 10 minutes, balancing data freshness and battery life.

In Figure 2 visually depicting the system flowchart is a valuable reference, outlining the sequential steps and decision-making processes involved in the data acquisition and transmission workflow. Using this methodical approach, we expect to develop a sophisticated environmental monitoring system capable of producing comprehensive and immediate insights into the environment around us. This comprehensive approach will enable academics and stakeholders to make decisions while supporting sustainable solutions and improving the management of the environment.

The main goal of this research is to ensure the data's integrity and suitability for analysis. Preprocessing involves careful management of missing values and outliers, enabling the following methods to extract knowledge and efficiently make reliable predictions from the dataset. The

Decision Trees algorithm will then take the lead, using its tree-based technique to divide the data into subsets determined by the characteristics cleverly; after output interfacing, we can check data by using APP, and we can store data on Google Drive (To the Firebase platform for centralized administration and storage).

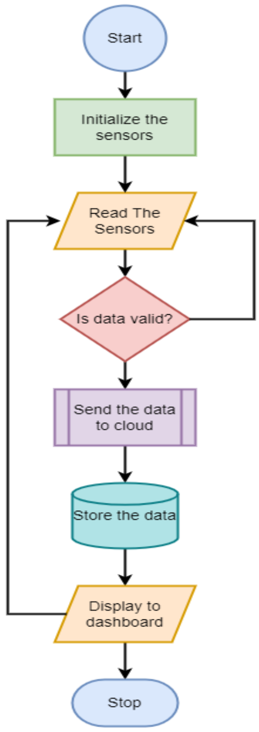


Fig. 2. The flowchart of our work process

3.1 Data Collection

Jamalpur Pourashava has a population of 116754 and an area of 53.28 square km. This Pourashava consists of 12 wards, and the population density is 2191 per sq km. It has an aggregate 231.05 km road network; the roads to be repaired are 28.375 km, and the drain to be repaired is 3.105 Km. All the samples were collected on working days. For the determination of the number of factors in

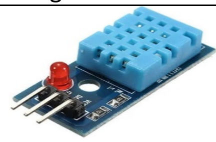
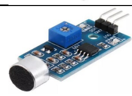
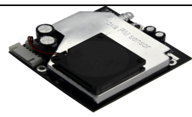
PMF, the primary consideration was to obtain a good fit of the model to the original data. We have arranged the values we collected from "Pach raster More, Tomaltola, Dowamori More, Fojdarimore, and station road in Jamalpur Pourashava, Bangladesh. The Figure 3 below demonstrates that we gathered information from several parts of Jamalpur town.

Fig. 3. Picture represents that Samples were collected from several locations across Jamalpur Town

3.2 Architecture of IoT Devices

The development of IoT devices is centred on developing a balance between functionality and energy efficiency. These devices can operate for extended durations without frequent maintenance using low-power components, optimizing power management, and implementing energy harvesting techniques. As a result, the system is reliable, cost-effective, and adequate for long-term environmental monitoring and data acquisition. Table 1 shows the specifications of the devices that were used.

Table 1
Specifications of devices used in the experiment

Sensor	Specification	Image
DHT11	Measurement Range: Humidity: 20% to 90% RH Temperature: 0°C to 50°C Accuracy: Humidity: ±5% RH Temperature: ±2°C	
MG811 CO_2	Measurement Range: 350 ppm to 10,000 ppm (Parts per Million) of CO_2 Sensitivity: Typically, 30 to 50nA/ppm in 400ppm CO_2	
MQ-7 CO	Detection Range: 10 ppm to 500 ppm of CO in air Sensitivity: Approximately 20mV/ppm CO	
LM393	Voltage Supply: Typically, 3.3V to 5V Output: Digital (comparator output) and sometimes Analog (direct microphone output)	
SDS011	Measurement Range: PM2.5: 0.0 to 999.9 µg/m³ PM10: 0.0 to 999.9 µg/m³ Accuracy: ±10% or ±10µg/m³, whichever is greater	

We mainly used a Python script controlled by a Java application to interface with the Pi with the DHT11 Temperature/Humidity Sensor.

The sensor MG-811 onboard is the sensor component. There is an onboard signal conditioning circuit for amplifying the output signal and an onboard heating circuit for heating the sensor. The MG-811 is highly sensitive to CO_2 and less sensitive to alcohol and CO. It could be used in air quality control, fermenting processes, and indoor air monitoring applications. The output voltage of the module falls as the concentration of CO_2 increases.

MQ-7 Carbon Monoxide Coal Gas Sensor Module detects the concentrations of CO in the air and outputs its reading as an analogue voltage. The sensor can measure concentrations of 10 to 10,000 ppm.

LM393 sensor can determine noise levels within DBs or decibels at 3 kHz 6 kHz frequencies, approximately wherever the human ear is sensitive. In smartphones, an Android application, namely a decibel meter, is used to measure the sound level.

SDS011 is a professional laser dust sensor. The fan mounted on the sensor automatically sucks air. The sensor uses the laser light scattering principle to measure the value of dust particles suspended in the air. The sensor provides high precision and reliable readings of PM2.5 and PM10 values. Any environmental change can be observed instantly- a short response time below 10 seconds.

4. Result and Discussion

We have collected all the data on non-holiday days. These data include sound, humidity, dust, TVOC, CO2, and CO. We collected these samples from several semi-residential and marketplace areas in Jamalpur via Arduino's electronic device. Using these data, we have drawn some graphs, which include sound, humidity, dust, TVOC, CO2, and CO. This graph provides proper information about the air quality in these places. We understand the prevailing environmental conditions by scrutinizing the trends and patterns depicted in the graphs. Moreover, the graphical representation enables easy comparison and identification of variations in air quality between the different locations. In our research, we meticulously gathered data from non-holiday days to ensure a representative assessment of environmental conditions. These data encompass essential parameters such as sound levels, humidity, dust concentration, TVOC, CO2, and CO. The data collection process was facilitated by an Arduino-based electronic device, which allowed for accurate and real-time measurements. The selected sampling locations encompassed a mix of semi-residential areas and marketplaces in Jamalpur, offering a comprehensive perspective on various urban environments.

Our data collection and graphical analysis offer a comprehensive and illuminating assessment of air quality in Jamalpur's sampled semi-residential and market areas. These findings serve as a foundation for further research and decision-making processes such as aiding city corporations in implementing air quality monitoring applications for informed urban planning and environmental management [33,34].

4.1 Results for Sound

Figure 4 for sound levels in Jamalpur provides encouraging insights, indicating that the sound levels are slightly lower than the standard (acceptable) range. This positive observation brings good news for the city's residents, suggesting that noise pollution is relatively under control. The data collection process involved sampling from various locations in Jamalpur at different dates and times. Through this comprehensive approach, we discerned distinct patterns in sound levels across the city.

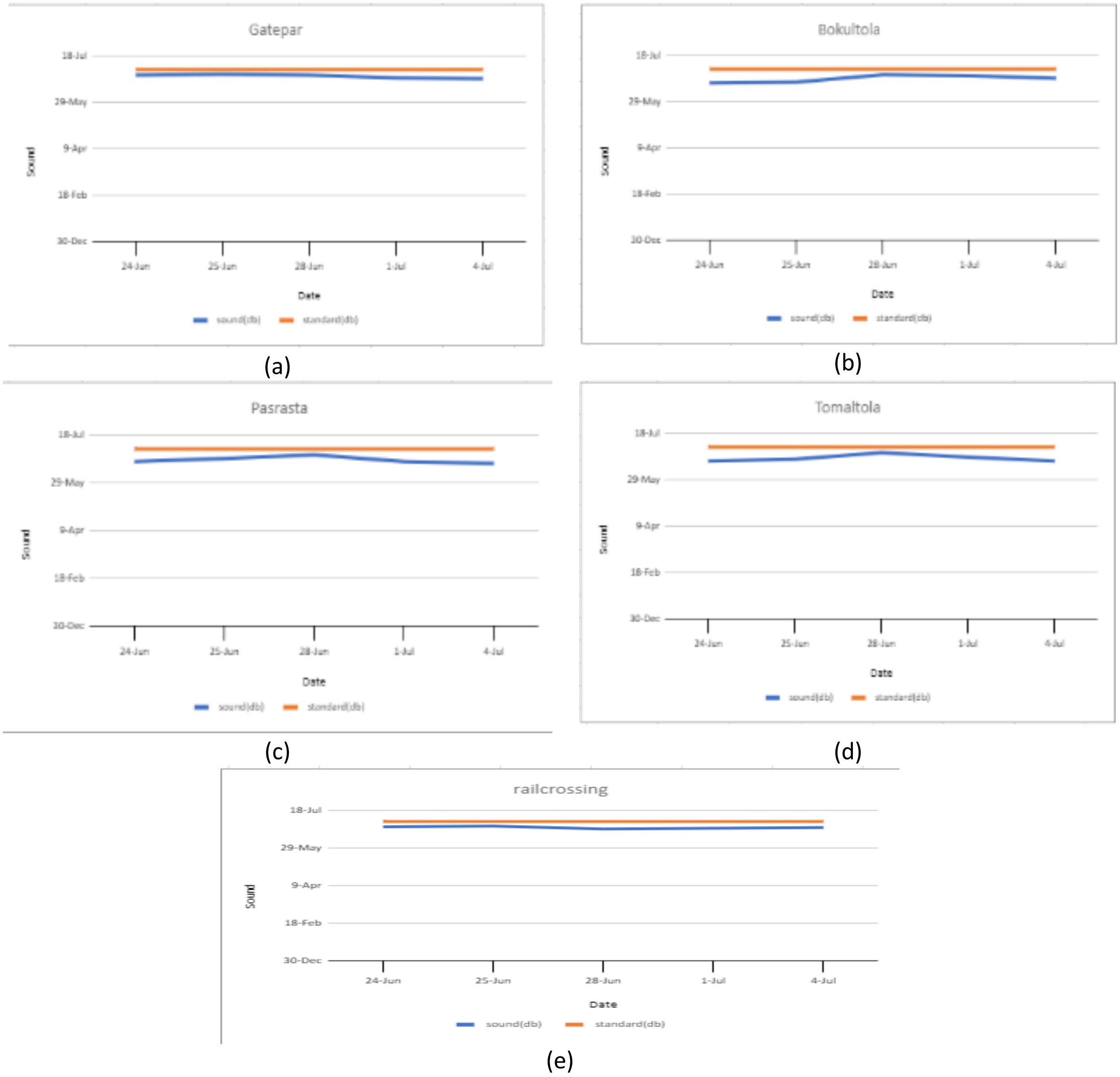


Fig. 4. Result for final sound, (a) Gatepar, (b) Bokultola, (c) Pasrasta, (d) Tomaltola, (e) Railcrossing

4.2 Results for Humidity

Figure 5 for humidity, we can observe that the air in Jamalpur is more humid in July than in June. Here, we have collected the samples from different locations on different dates and times. We have also noticed that the morning air is more humid than the evening air.

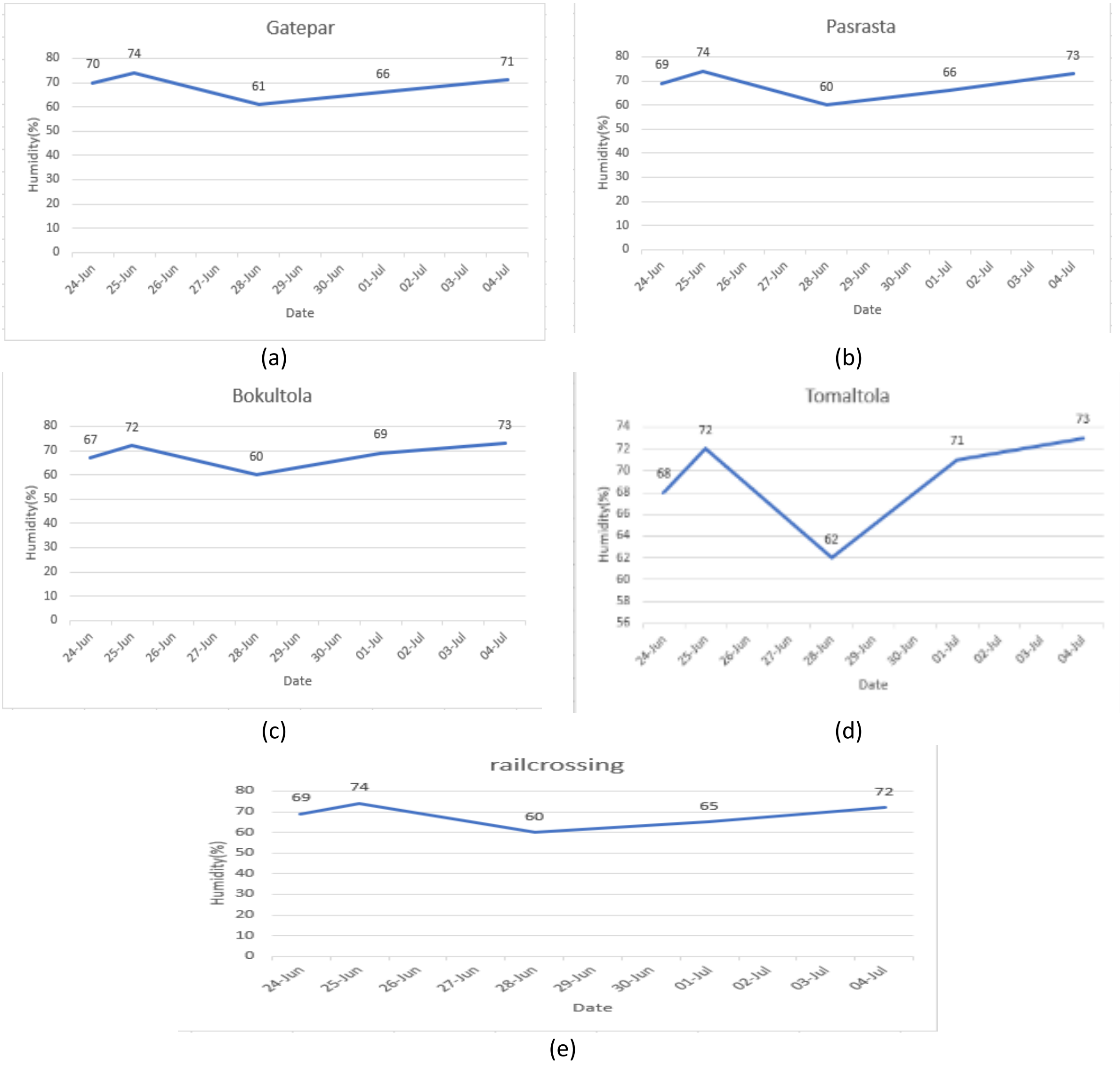


Fig. 5. Result for final Humidity, (a) Gatepar, (b) Bokultola, (c) Pasrasta, (d) Tomaltola, (e) Railcrossing

4.3 Result for Co2

Figure 6 for CO2, we can observe that the air in Jamalpur contains more CO2 than the standard range. Here, we have collected the samples from different locations on different dates and times. We have noticed that the morning air contains less CO2 than the midday and evening air. We have also noticed that air in a few locations contains much higher CO2 than the acceptable range, which is not a good sign for the city's residents.

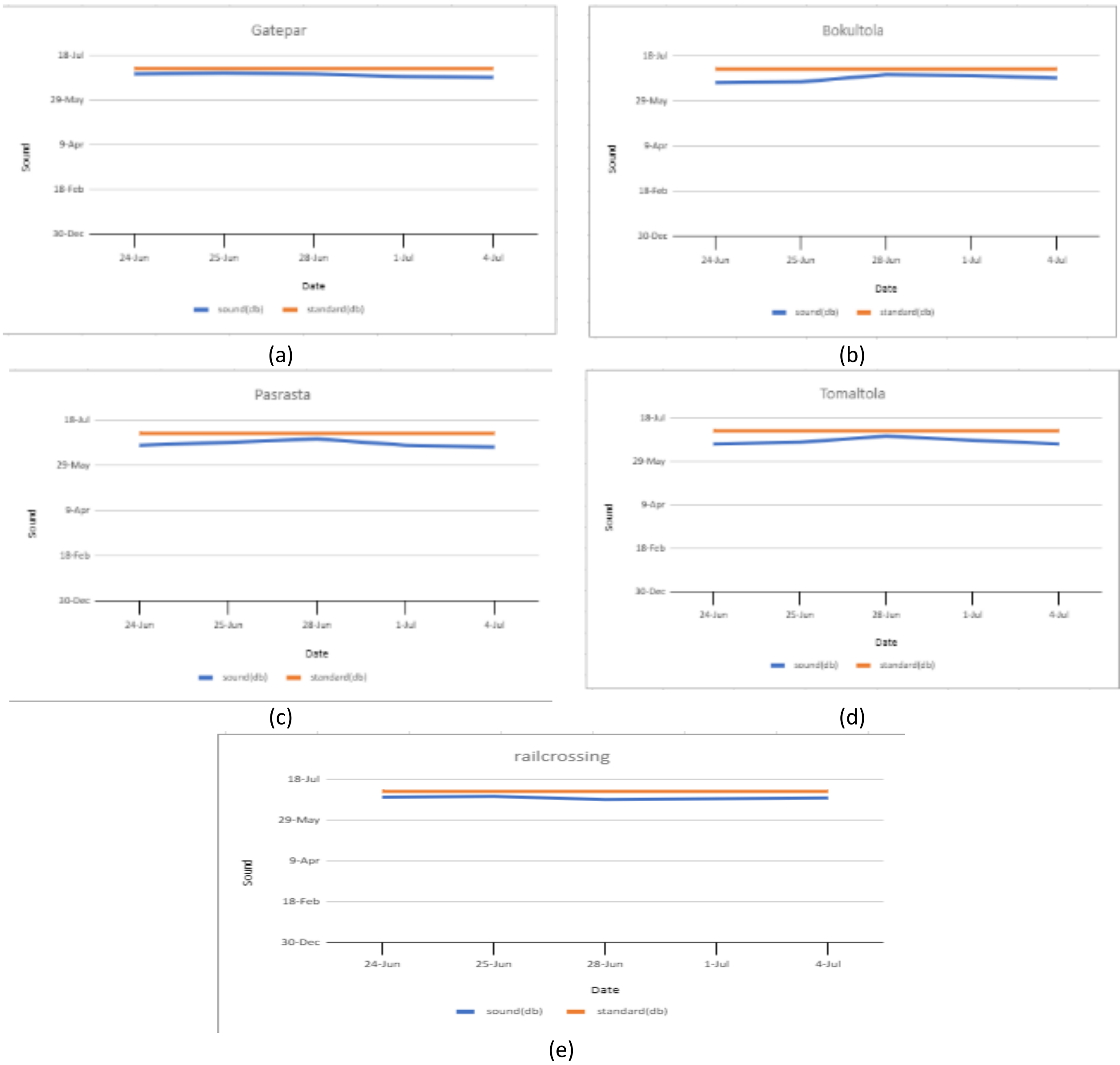


Fig. 6. Result for final Co2, (a) Gatepar, (b) Bokultola, (c) Pasrasta, (d) Tomaltola, (e) Railcrossing

4.4 Results for CO

Figure 7 shows that the air in Jamalpur has less CO than the recommended (acceptable) level, which is a positive development. We have gathered samples from several sites at various times and dates. We have discovered that the CO content of the early air is lower than that of the midday and evening air.

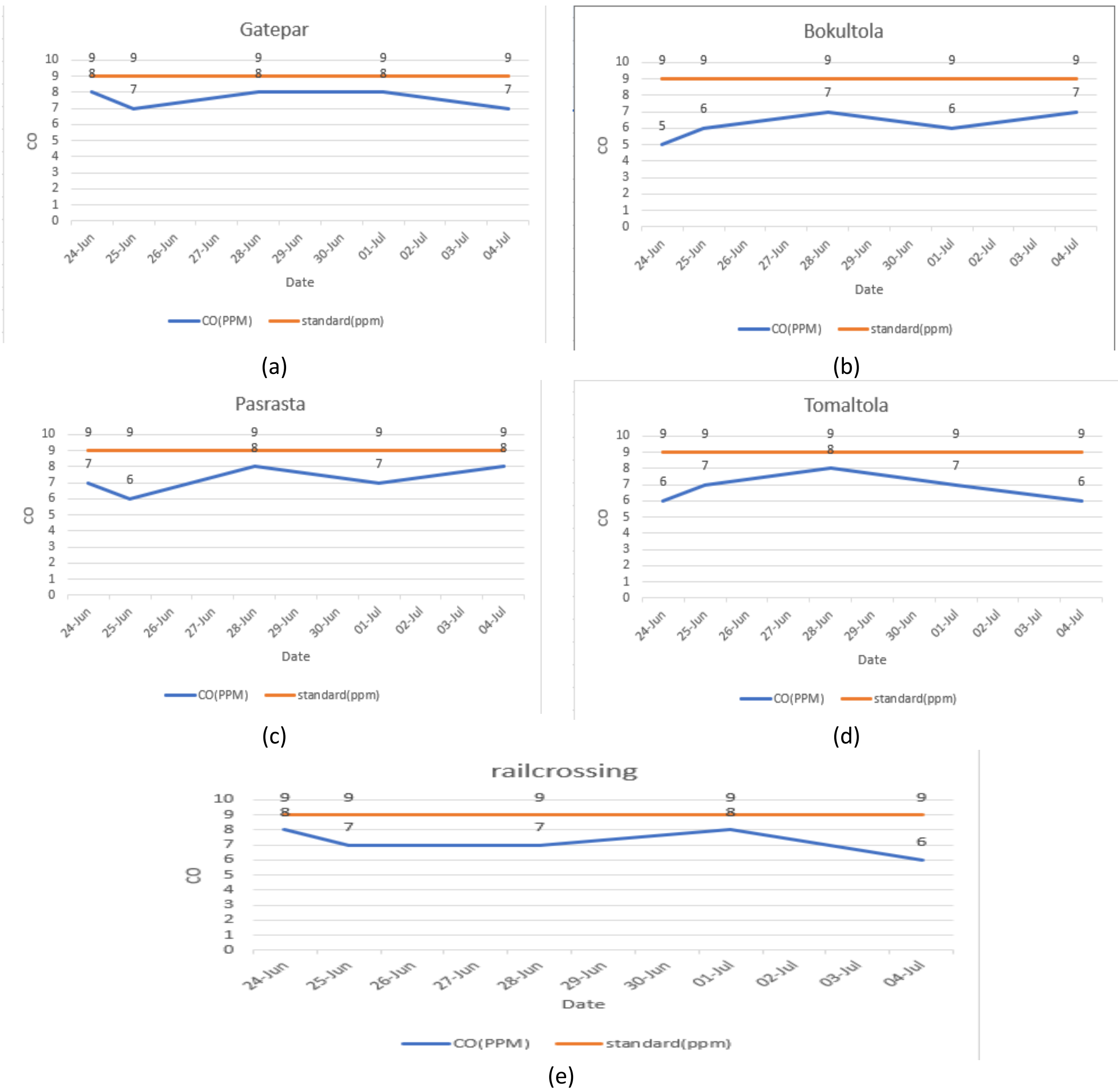
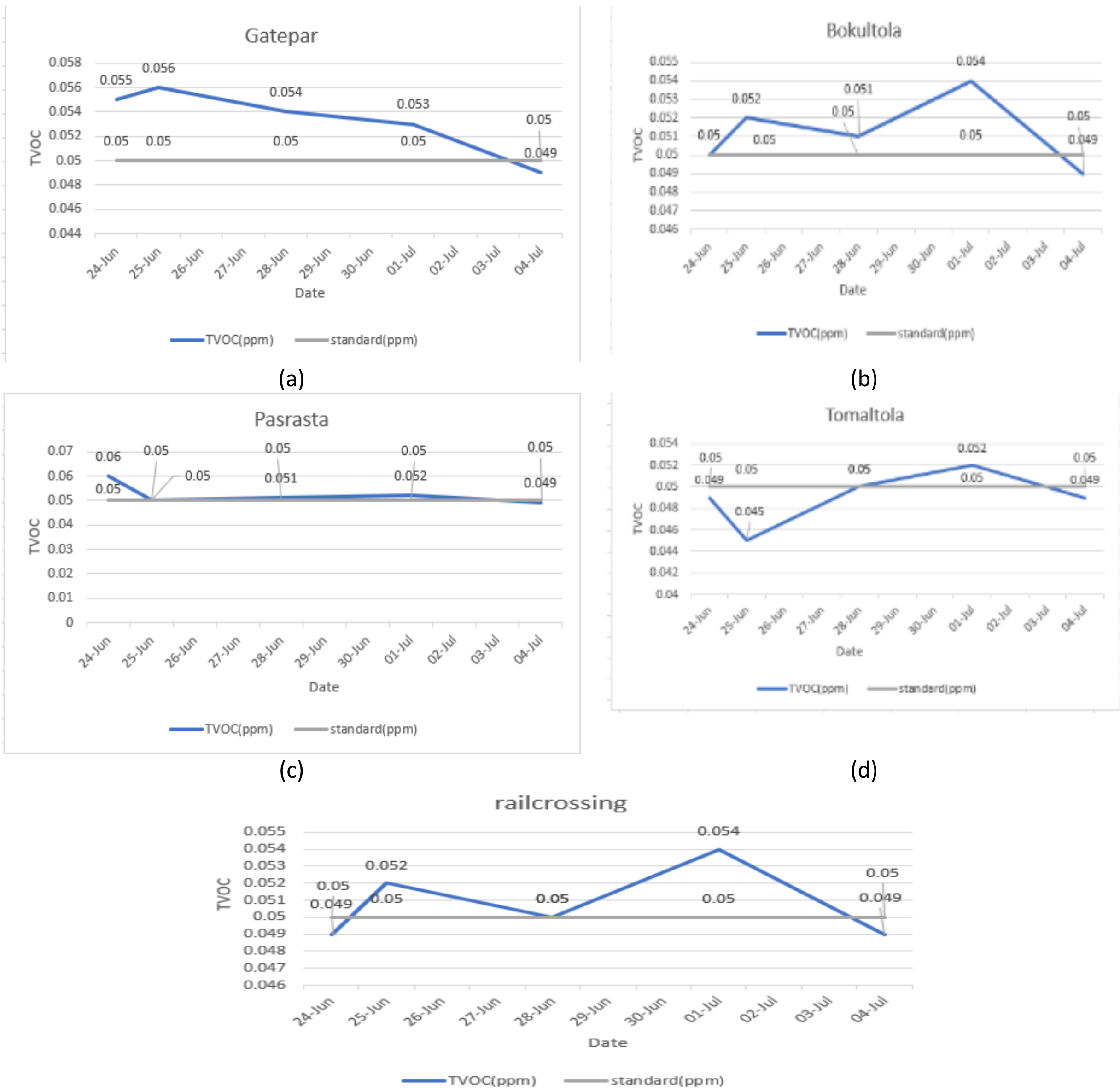


Fig. 7. Result for CO, (a) Gatepar, (b) Bokultola, (c) Pasrasta, (d) Tomaltola, (e) Railcrossing

4.5 Result for TVOC

We can observe from Figure 8 for TVOC that the air in most of the places of Jamalpur contains more TVOC than the standard range, which can cause harm to the residents. Here, we have collected the samples from different locations on different dates and times. We have noticed that the morning air contains less CO2 than the midday and evening air.



(a) (b) (c) (d) (e)

Fig. 8. Result for TVOC, a) Gatepar, b) Bokultola, c) Pasrasta, d) Tomaltola, e) Railcrossing

4.6 Results for Dust

Figure 9 demonstrates how much more dust is present in Jamalpur's air than is typical. We have gathered samples from several sites at various times and dates. We have discovered that the early air has less dust than the lunchtime and evening air.

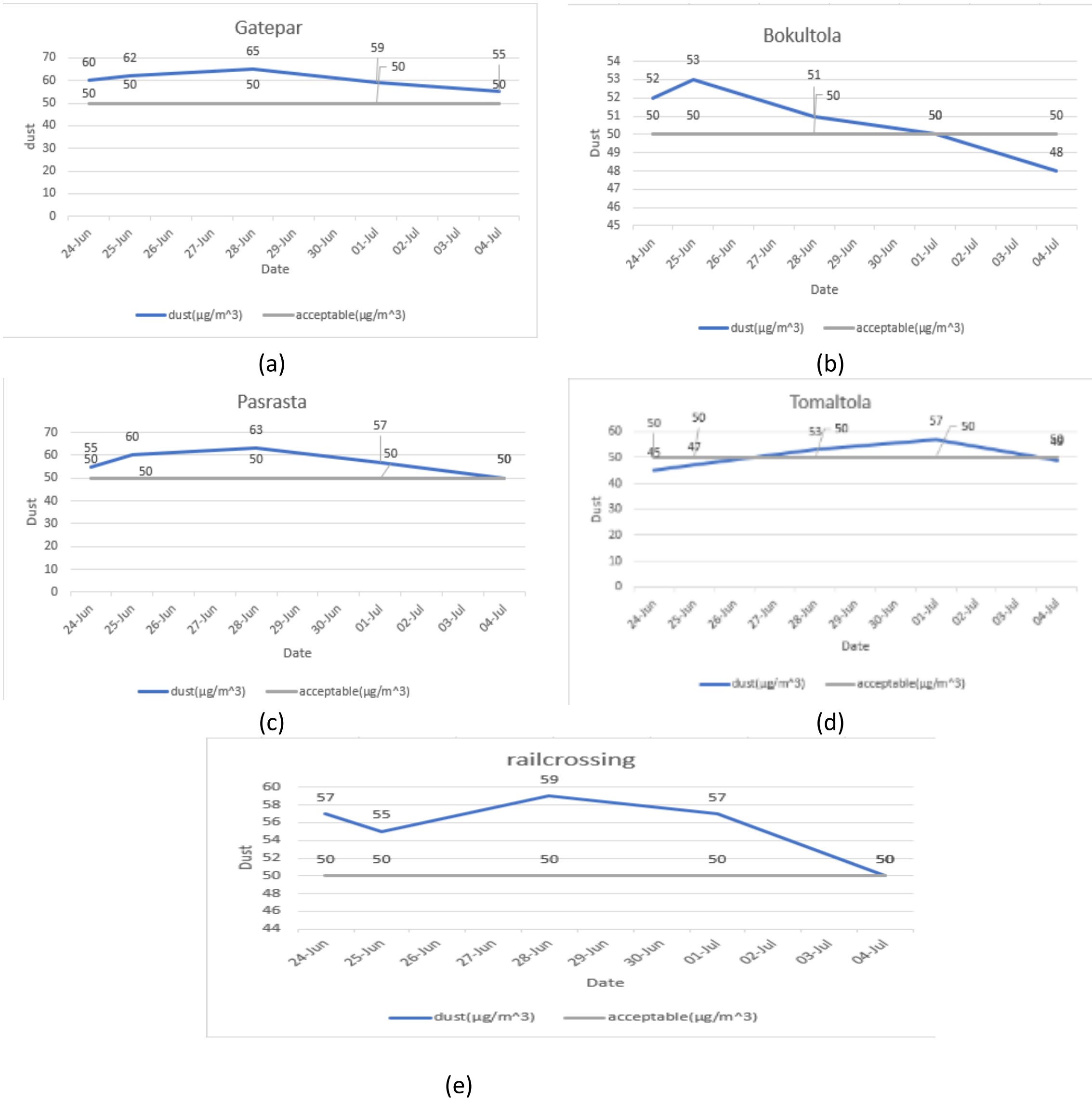


Fig. 9. Result for DUST, (a) Gatepar, (b) Bokultola, (c) Pasrasta, (d) Tomaltola, (e) Railcrossing

4.7 Software Architecture

Developing IoT (Internet of Things) apps includes developing software that interacts with and controls IoT devices. These applications can run on any number of platforms, such as mobile devices, web browsers, and desktop computers. Figure 10 shows our application.

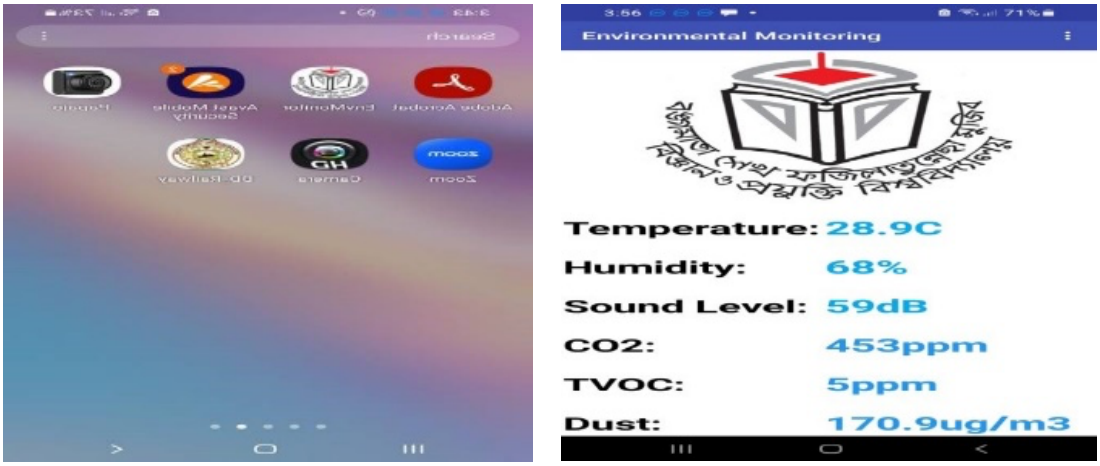


Fig. 10. IoT Based Real-Time Environmental Monitoring App

5. Conclusions

A low-cost but efficient and embedded system that monitors the environment, air, and sound pollution. The suggested architecture includes functionalities for various sensors and their operating procedures. How they work, functionality, ideal usage, data collection processes, and comparison with average base data are all covered in this paper. The noise and air pollution monitoring equipment were tested to monitor the gas levels named TVOC, CO2, and CO in various city regions. The sensor parameters were also relayed to the data server. Our experimental device demonstrates the effectiveness and low cost of various highly functional sensors. Its data will be crucial in taking essential actions for the betterment of society since it will assist in identifying the impacted area so that we can take early steps to reduce damage for the next generation. The findings of this study can assist authorities in any environmental field in acting at the examined stations to make short-term and long-term decisions to achieve long-term development goals.

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