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Real-Time IoT-Based Air Quality Monitoring and Health Hazards Indicator System for Mines Regions: A Case Study of Bulyanhulu Gold Mine

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Abstract— Air quality in mining regions is a significant concern due to the release of pollutants from mining activities, posing health risks to nearby communities. However, limited information on air quality levels often leads to neglect of this issue. Inhaling pollutants like PM2.5/PM10, CO, CO2, SO2, and NO2 can result in chronic diseases such as respiratory issues, asthma, and cancer. To tackle this problem, a study suggests the implementation of a real-time Internet of Things (IoT)-based air quality monitoring and health hazards indicator system for mining regions. The proposed system utilizes a reliable wireless sensing system, incorporating sensors like MQ7, MQ135, MQ136, MiCS4514, PMS7003, and DHT22, along with ESP8266, STM32, ATmega328 microcontroller, LoRa shields, and the ThingSpeak IoT server. It ensures continuous operation with a self-contained design, including a solar charger shield connected to a photovoltaic solar panel and rechargeable battery. The smart sensing device continuously monitors air quality and uploads real-time data to the cloud through a coordinator node. The collected data is processed to calculate the Air Quality Index (AQI), which is analyzed to generate early warnings and indicate potential health hazards. The results are accessible through a web-based dashboard for easy visualization. This system simplifies monitoring and provides accurate pollutant data. It supports environmental stakeholders by aggregating and analyzing air quality data, generating reports, and facilitating public access to air quality information. Additionally, it helps identify health hazards, enabling informed decision-making, policy formulation, and mitigation strategies.

Keywords— Air quality monitoring, IoT, LoRa, Air pollution, Mining

I. INTRODUCTION

Air quality monitoring and health hazard indicator systems are essential for ensuring the well-being of individuals living in mining regions. Mining activities release pollutants and hazardous gases into the air, posing risks to the environment and human health [1]. The proximity of mining operations to residential areas further increases the exposure of local communities to these pollutants [2].

Exposure to air pollution can lead to various health risks such as respiratory problems, lung damage, cancer, asthma, reproductive system damage, premature death, bronchitis, cardiovascular issues, eye and throat irritation, increased infection susceptibility, and lung tissue inflammation [3]–[7].

According to World Health Organization [8], major Air pollutants include carbon monoxide (CO), carbon dioxide (CO2), sulfur dioxide (SO2), particulate matter (PM2.5/PM10), and nitrogen dioxide (NO2)

Particulate matter (PM) consists of liquid droplets and solid particles suspended in the air, with hazardous components. PM is classified into PM10 (2.5 to 10 micrometers) and PM2.5 (less than 2.5 micrometers). PM10 is mostly made up of dirt, dust, and smoke from mining activities, while PM2.5 is made up of oil, diesel fuel, gasoline, metals, and hazardous organic compounds from metal processing and automobiles. PM2.5 can have a more significant impact on health due to its composition of harmful substances [5].

Carbon monoxide (CO) is a poisonous gas produced by the inefficient burning of fuels, leading to oxygen deprivation in the brain and heart [8]. Sulfur dioxide (SO2) is emitted from burning sulfur-containing fuels and can exacerbate asthma symptoms [6]. Nitrogen dioxide (NO2) is a powerful oxidant produced by combustion activities and can aggravate respiratory diseases and contribute to the formation of ozone [8].

Mining activities contribute to air pollution through various processes, such as blasting, drilling, material handling, and transportation [9]. Proper air quality management should be integrated into mine environmental planning to address these emissions and their potential impacts.

Monitoring air quality in mining regions is crucial to understand the level of pollution and its impact on public health. It helps establish exposure-response relationships and provides data for policymaking, environmental impact assessment, and early warning systems.

This study focuses on using sensors to detect common pollutants and analyzes data to identify health hazards and monitor air quality in real-time, providing early alerts to residents, policymakers, and researchers.

II. LITERATURE REVIEW

Several works on air quality monitoring have been performed, and several air quality monitoring systems have been developed. This section discusses the ones that are relevant to this study. This covers both outdoor and indoor-related air quality monitoring works.

A. Global Air Quality Concentrations and Trends

Air quality management and epidemiological studies rely on permanent monitoring stations to measure pollutant concentrations in the air. However, the number of monitoring sites worldwide is still insufficient, mainly limited to major cities. This leads to challenges in accurately estimating exposure in various locations where people live, particularly in rural areas and outside large cities [8].

The WHO Global Ambient Air Quality Database and OpenAQ are two accessible sources of worldwide air quality data. The WHO database provides annual average concentrations of PM10 and PM2.5 for different cities, derived from available data, often averaging readings from multiple stations within a city [8]. OpenAQ collects and stores historical and real-time air quality data from government agencies [10].

Despite progress in monitoring and data accessibility, many publicly supported organizations do not make their data easily available. The ambient concentrations of air pollutants vary significantly from place to place, even within a single region. In 2019, more than 90% of the global population lived in areas where pollutant concentrations exceeded the WHO air quality guideline of 10 g/m3 [8].

B. Air Quality Case Statistics in Tanzania

According to a WHO ambient air pollution, press release of 2016 [11], poor air quality is considered the world's biggest environmental health risk, accounting for approximately 87% of global deaths in low and middle-income countries, with over three million premature deaths attributed to poor air quality. A total of 211,000 which is 7%, of the three million premature deaths, occurred in Sub-Saharan Africa. According to a 2016 WHO report, ambient air pollution caused 5765 deaths in Tanzania, with the primary causes being acute respiratory, ischemic heart disease, and stroke [11].

C. Disease and economic burden

Air pollution poses the most significant threat to the environment worldwide, causing around 7 million deaths annually, primarily from noncommunicable diseases [8]. Ambient air pollution alone leads to 4-9 million deaths yearly, with the largest disease burden in low- and middle-income countries [8]. Air pollution is linked to various diseases, including heart disease, lung cancer, and stroke [8], [12]. Additionally, it has adverse effects on newborns, labor productivity, and the global economy, resulting in millions of premature deaths and trillions of dollars wasted each year [8]. Currently, air pollution stands as the leading environmental threat to human health and well-being [8].

D. Related Works

Several studies have been conducted on air quality monitoring using IoT technology. However, most of these studies have limitations and do not provide a comprehensive solution. For example, Nirosha et al. [13] developed an IoT system to monitor various parameters but did not include important pollutants such as PM2.5, PM10, and NO2. Dhingra et al. [14] focused on specific gases and disregarded PMs, while Truong et al. [15] utilized LoRa technology but lacked health hazards indication. Fuertes et al. [16] monitored CO2, CO, and dust but neglected other pollutants and environmental factors. Firdhous et al. [17] only monitored ozone concentration, which is not sufficient for comprehensive air quality monitoring. Manikannan et al. [18] developed an application for monitoring certain gases but overlooked important parameters like PM2.5/PM10. Hareva and Marsyaf [19] developed an IoT based system for monitoring air quality but lacked health warnings. Wu et al. [20] designed a device for monitoring air quality during biking but did not provide health warnings. Jo et al. [21] focused on indoor air quality monitoring but did not calculate the Air Quality Index (AQI) or indicate specific health effects. AbdulWahhab [22] developed a system for indoor air quality but lacked sufficient parameters. Rane et al. [23] presented a fuzzy logical control system for indoor air quality but did not cover all pollutants comprehensively.

III. PROPOSED SYSTEM

A. System Architecture Design

The architecture of the proposed system is mainly divided into two parts: a sensor node, and a gateway node or Sink node. The overall system architecture consists of mainly four parts: (a) several sensors used to sense and measure different air pollutants parameters, (b) a LoRa network that consists of a LoRa shield in the sensor node, and a gateway node, (c) ThingSpeak cloud server for data storage, visualization, and integration, (d) a user application system that consists of a web-based application that can be accessed via a computer or smartphones web-browsers.

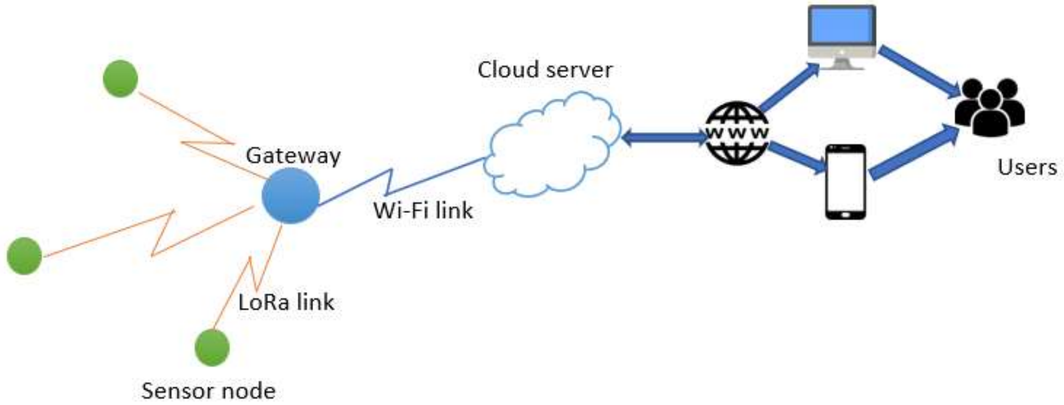

Fig 1. System architecture design framework

B. Sensor Node Design

The sensor node consists of the Atmega328 microcontroller, STM32, sensors, and LoRa shield. Sensors are utilized in this system for tracking and collecting air pollutants parameters such as SO2, CO2, CO, NO2, PM2.5, PM10, temperature, and related humidity. Sensors are attached to the Atmega328 microcontroller which is integrated with a STM32 connecting LoRa shield. The sensed data from sensors are transmitted to the sink node or gateway node which is then transmitting the data to the cloud through Wi-Fi. The gateway or sink node is composed of STM32 microcontroller connecting LoRa receiver used to receive data sent from different sensor nodes, and ESP8266 microcontroller that sends received data to the cloud. The PMS7003 sensor monitors PM2.5 and PM10, while MQ135 measures CO2, MQ136 measures SO2, MiCS4514 detects NO2, DHT22 reads the temperature and humidity, and MQ7 measures CO. In addition, Solar panels with a rechargeable battery, and a lithium-ion 12v battery is used to supply power to the sensor node.

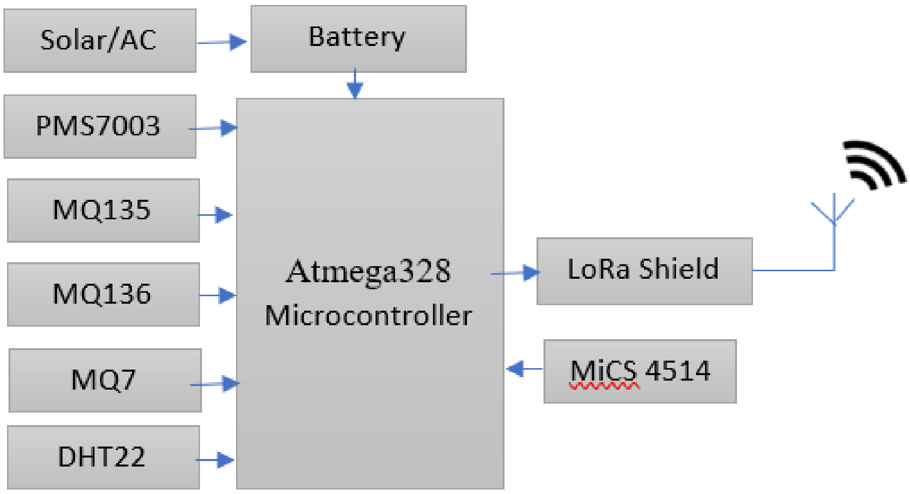

Fig 2. Sensor node framework design

IV. RESULTS AND DISCUSSION

A. System Implementation Overview

The air quality monitoring and health hazards indication system has been successfully implemented. This cutting-edge system is the result of successful development and implementation, employing sensor nodes and a gateway node to ensure accurate and continuous monitoring.

At its core, the system relies on state-of-the-art sensor nodes, ingeniously powered by a solar panel and lithium-ion battery, ensuring its self-sustainability and uninterrupted operation. These sensor nodes utilize LoRa technology, enabling seamless transmission of vital data to the coordinator.

Sensors were connected to the Atmega328 microcontroller. The data collected encompassing crucial parameters such as CO, CO2, NO2, SO2, PM2.5/PM10, temperature, and humidity. The collected data from sensor were sent to the STM32. Before transmission data were encoded into JSON format and encrypted for security purpose. The STM32 on the transmitter side communicates with the LoRa Ra-02 SX1278 Module via SPI. The LoRa module was configured with appropriate settings like frequency, spreading factor, bandwidth, and coding rate. The encoded data were then sent to the LoRa module for transmission.

On the receiver side, the LoRa Ra-02 SX1278 Module connected to the STM32 waits for incoming data. It is configured with the same parameters used by the transmitter for proper communication. When a LoRa signal containing the data is received, the LoRa module forwards it to the STM32. The STM32 on the receiver side receives the raw data from the LoRa module. It then decodes the data using the same format in which it was encoded before transmission. Once the data is decoded, the STM32 on the receiver side sends data to the ESP8266 which handle the further transfer to the cloud via Wi-Fi. The ESP8266, which is connected to the internet, sends the data to the ThingSpeak IoT server using MQTT protocol.

To ensure the system's efficacy, rigorous testing was conducted in the Bulyanhulu ward over six weeks. During this period, sensor nodes were strategically relocated to various positions, capturing invaluable spatial and temporal variations in air quality levels.

Throughout this testing phase, the system excelled in providing accurate and reliable air quality data for each parameter, enabling us to gain crucial insights into potential health hazards. The utilization of ThingSpeak as our IoT platform proved to be a game-changer, as it facilitated seamless data visualization and analysis, empowering us to make informed decisions based on concrete evidence.

With a solid foundation in place, the air quality monitoring and health hazards indication system stands ready to pave the way for a cleaner and healthier environment.

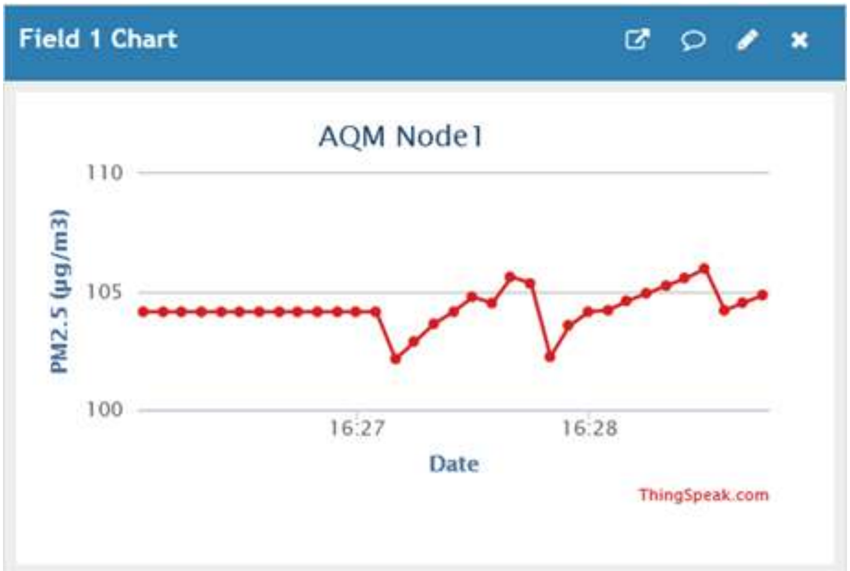

Fig 3. Sample live graph for PM2.5

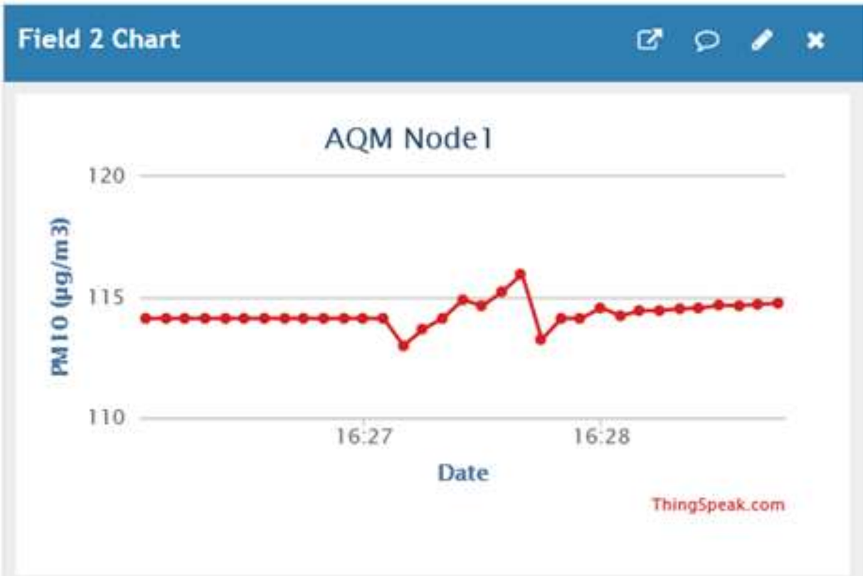

Fig 4. Sample live graph for PM10

B. Hardware Design and Implementation

To enhance the system's stability and minimize interference, a meticulously designed printed circuit board (PCB) serves as the backbone, linking various electrical and electronic components through conductive tracks. LoRa modules and sensors are skilfully soldered onto the PCB, fostering robust connections and reliable data transmission. Utilizing the GPIOs header, the microcontroller seamlessly communicates with the modules and sensors, enabling efficient data gathering. This streamlined and efficient architecture fortifies the system against disruptions, ensuring optimal performance and reinforcing our commitment to engineering excellence.

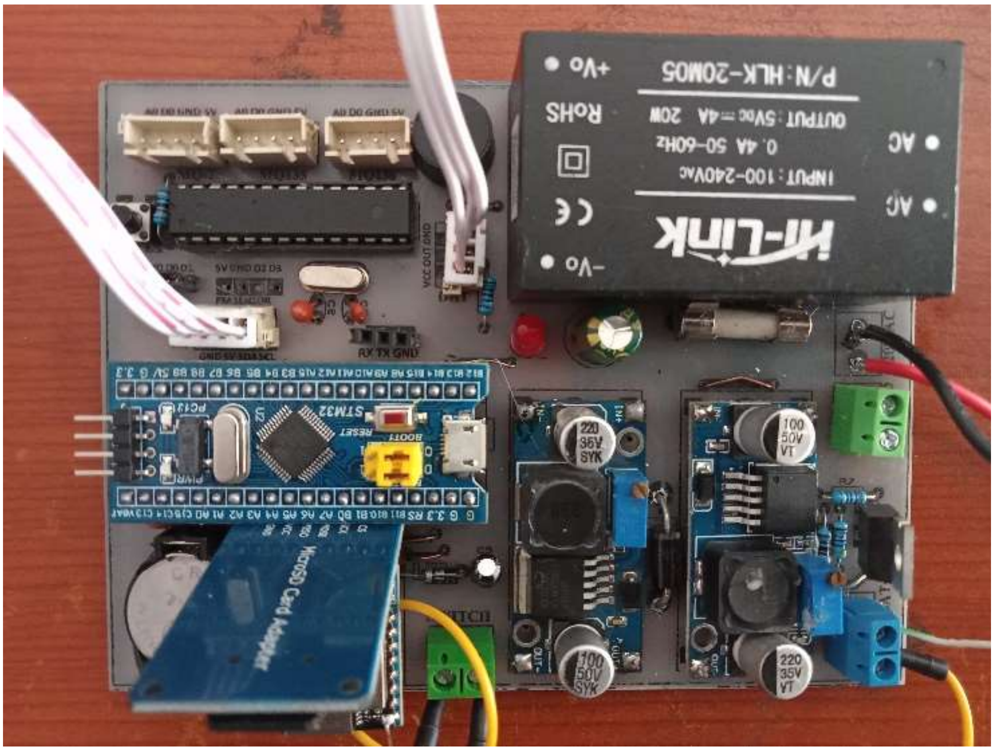

Fig 5. Sensor node circuit design

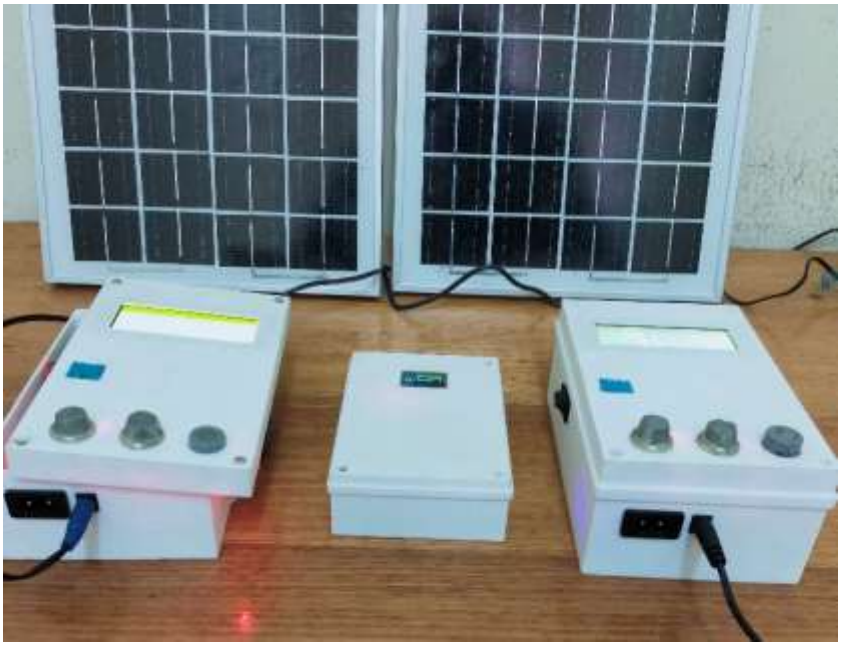

Fig 6. System physical hardware design

C. The Web-based System

Our cutting-edge web-based system represents a significant milestone in air quality monitoring, leveraging a dynamic blend of HTML, PHP, JavaScript, Bootstrap, and a MySQL database to offer users seamless access to real-time air quality data. At the heart of this innovative system lies a meticulously designed dashboard, visually presenting essential air pollutant parameters such as CO, CO2, NO2, SO2, PM2.5/10, temperature, and humidity, sourced from each sensor node. The system goes beyond mere data representation, calculating and displaying the Air Quality Index (AQI), serving as a critical indicator of potential health hazards when it surpasses defined thresholds. The dashboard provides a comprehensive overview, summarizing real-time readings from the two sensor nodes (Node-1 and Node-2), continuously updating the data every 10 seconds to ensure accuracy and responsiveness. With a user-friendly interface, our system empowers stakeholders to monitor parameter trends, AQI fluctuations, and associated health risks effectively, bolstering our commitment to advancing air quality monitoring technology.

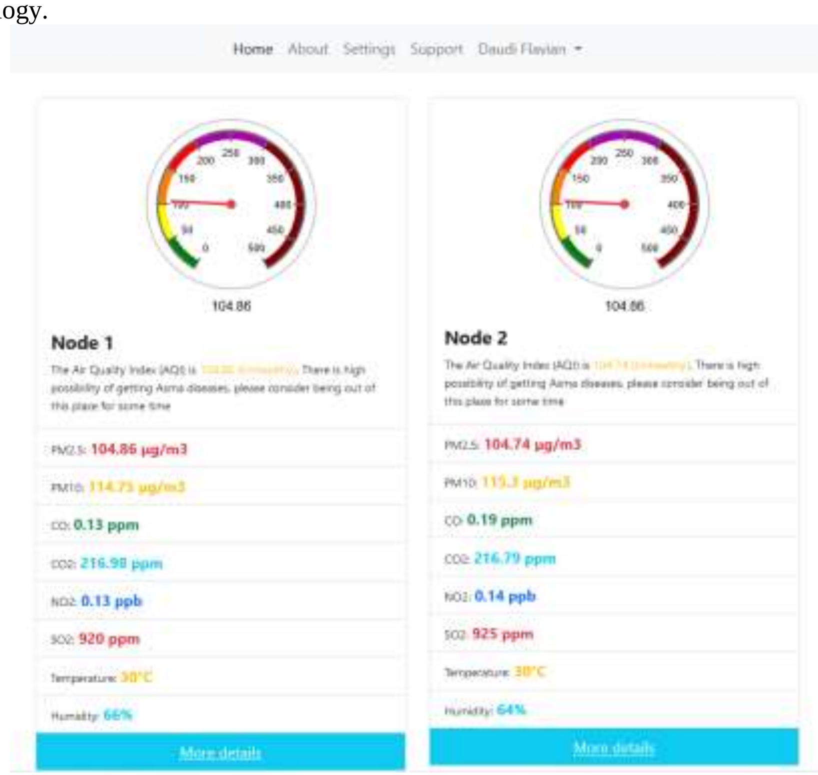

Fig 7. Web-based real-time air quality monitoring system, Dashboard page

Our state-of-the-art web-based system goes the extra mile in delivering comprehensive air quality insights through an intuitive "More Details" button link thoughtfully incorporated into the dashboard. Upon clicking this link, users are granted access to dedicated pages for each sensor node, unveiling a treasure trove of in-depth data and visualizations for every parameter.

The dedicated page is designed to offer a wealth of information, featuring precise gauge readings for vital parameters such as PM2.5, PM10, CO, CO2, NO2, SO2, temperature, and humidity. These gauges provide at-a-glance assessments of the current environmental conditions, empowering users to quickly grasp the air quality status in the area.

To further augment the user experience, real-time graphs are meticulously displayed on the page for each parameter. These dynamic visualizations offer a comprehensive view of how air quality trends unfold over time, facilitating a more nuanced understanding of the atmospheric dynamics.

This powerful feature empowers users to make informed decisions and take prompt action in response to the information provided. Whether it's identifying spikes in pollutant levels or observing patterns in temperature and humidity, this level of detail fosters a heightened awareness of the local air quality, enabling individuals, communities, and relevant authorities to take proactive measures in safeguarding health and environmental well-being.

At the core of our system lies a commitment to providing accessible and actionable data, arming users with the tools needed to contribute to a cleaner and healthier environment. With the "More Details" feature, we empower individuals to be proactive stewards of air quality, promoting a collective effort towards a sustainable future.

The web-based system offers additional visualization and detailed information through a "More Details" button link on the dashboard. Clicking on this link provides access to a dedicated page for each sensor node, offering more in-depth data and visualizations for each parameter. The page includes gauge readings for parameters such as PM2.5, PM10, CO, CO2, NO2, SO2, temperature, and humidity. Real-time graphs for each parameter are also displayed on the page. This feature allows users to have a more comprehensive understanding of air quality trends in the area and enables them to take prompt action based on the information provided.

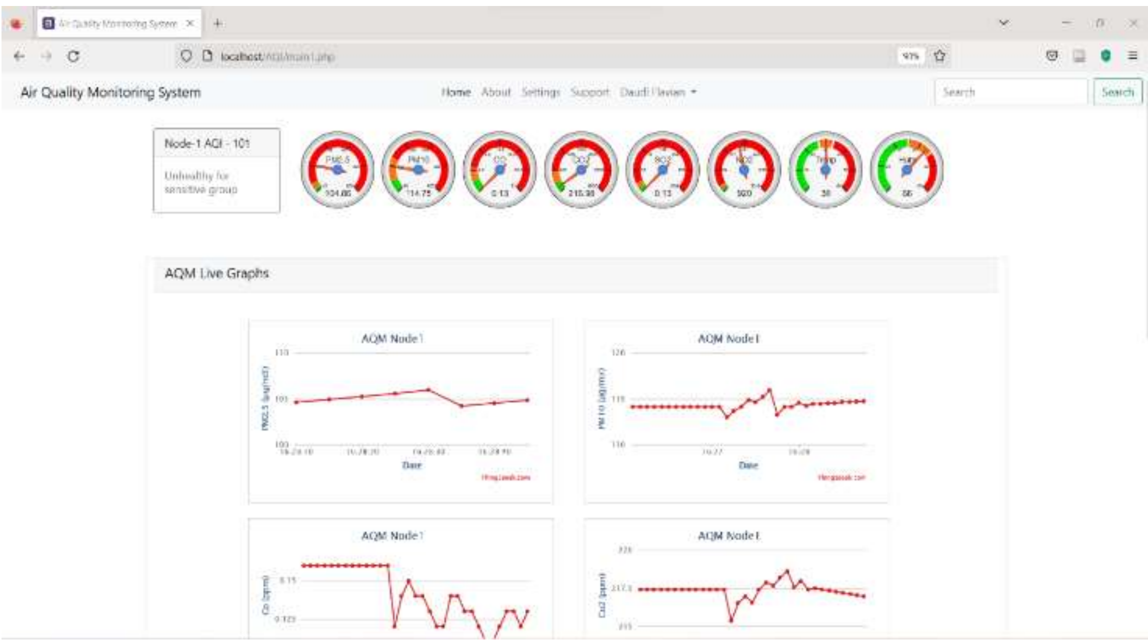

Fig 8. A web-based air quality monitoring system, Node-1 dashboard

D. Health Hazards Indication

The Air Quality Index (AQI) provides valuable information about the quality of the air based on data collected by various sensors. It serves as an indicator to assess air quality by comparing it to different standards and thresholds. The AQI categorizes the state of the air based on various variables and indications.

The AQI levels reflect the cleanliness or dangerousness of air pollution, following specific guidelines. A value between 0 and 50 signifies "good" air quality, while 51 to 100 is considered moderate. An AQI between 101 and 150 indicates "Unhealthy for sensitive groups," and 151-200 signifies "Unhealthy" air. AQI levels from 201 to 300 are labeled as "Very unhealthy," and if the AQI value is 301 or higher, it falls into the "Hazardous" category.

FIGURE 1. SIX AIR QUALITY INDEX (AQI) CATEGORIES

Index Values	**Levels of Concerns**	**AQI Color**
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 and higher	Hazardous	Maroon

Using advanced technology, a system has been developed to calculate the AQI and identify potential health risks based on World Health Organization (WHO) criteria for air quality. If the system detects that the current AQI level exceeds a predefined threshold, it will generate an alert notification to notify users of the potential risks.

The equation used to calculate the air quality index (AQI) is as follows:

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

Where:
Ip = the index for pollutant p
Cp = pollutant P’s truncated concentration
BPHi = the breakpoint greater than or equal to Cp
BPLo = the breakpoint less than or equal to Cp
IHi = the AQI value corresponding to BPHi
ILo = the AQI value corresponding to BPLo

E. Discussions

The developed IoT-based air quality monitoring system simplifies the monitoring process and provides valuable insights. The study found that the Air Quality Index (AQI) level is influenced by the proximity of mining operations, and there were geographical and temporal variations observed at different monitoring node placements.

The study also highlighted the potential health risks associated with exposure to pollutants such as PM2.5, PM10, CO, CO2, SO2, NO2, temperature, and humidity, including respiratory and cardiovascular diseases, asthma, and lung cancer.

The findings indicate that mining activities and vehicle traffic contribute to the concentrations of these pollutants. Higher concentrations of Particulate Matter (PM) were observed near mining operations compared to areas further away.

The study also revealed variations in pollutant concentrations between day and night, with higher levels during the day due to increased activities and traffic.

The study underscores the concerns of residents regarding air pollution from mining activities in the Bulyanhulu area and provides important data on pollutant concentrations and their temporal patterns.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This study presents an IoT-based air quality monitoring and health hazard indicator system that operates in real-time. The system utilizes LoRa technology for long-distance connectivity and incorporates sensors to measure various pollutants and environmental parameters. The collected data is transmitted to the Thing-Speak IoT server for storage and display, allowing easy access for users. This system addresses the need for monitoring air quality in regions with high pollutant levels, such as mining areas, and serves as an indicator of potential health hazards for residents and miners. By providing timely information on air quality, the system helps raise awareness and enables informed decision-making to mitigate the adverse effects of poor air quality.

B. Recommendations

The study successfully achieved its goals of implementing a real-time IoT-based air quality monitoring system using LoRa technology and sensors. However, further research is recommended to enhance data accuracy and performance measures, as well as explore the impact of such systems on healthcare, particularly during pandemics. Additionally, predictive approaches can be developed to forecast future air quality based on collected data. The deployment of a larger LoRa network with more sensor nodes would enable users to access a broader range of information.

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