IoT-based Carbon dioxide (CO_2) Management system in Bengaluru

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Abstract: **As urbanization intensifies in cities like Bengaluru, the management of carbon dioxide (CO_2) emissions has become critical to ensuring environmental sustainability and public health. This paper examines the application of Internet of Things (IoT)-based monitoring systems for detecting and managing CO_2 levels in Bengaluru. Through the use of low-cost sensors like the MQ135 and microcontrollers like the NodeMCU ESP8266, IoT solutions make decentralized, real-time monitoring of indoor and outdoor air quality possible. These systems gather and send data to cloud platforms for analysis, facilitating dynamic visualization and rapid decision-making. Their use in residential complexes, schools, hospitals, and industrial estates enables community-scale awareness and focused mitigation measures. In addition, integration with smart city infrastructure enables programs such as the Bengaluru Climate Action Plan (BCAP), enhancing data-driven environmental governance. The report demonstrates that IoT-based monitoring of CO_2 is a cost-effective and scalable solution to improve urban air quality management and support overall climate resilience strategies.**

INTRODUCTION

Bengaluru, also known as the "Silicon Valley of India," has seen fast growth in urbanization and industry over the last few decades. This growth, although propelling economic progress, has also contributed considerably to environmental problems —first among these being degrading air quality and higher carbon dioxide (CO_2) levels. Having a population of over 13 million, increasing and higher vehicle density, the metropolis experiences higher levels of greenhouse gas emissions, which seriously threaten public health, environmental sustainability, and city livability.

To address these issues, the Government of Karnataka and Bruhat Bengaluru Mahanagara Palike (BBMP) have set up various sustainability initiatives, one of them being the Bengaluru Climate Action and Resilience Plan (BCAP). One of the central areas of concentration for BCAP is the mitigation and efficient management of CO_2 emissions within the city. Yet, traditional air quality monitoring techniques—usually confined to a limited number of fixed stations—are not capable of recording the dynamic and localized changes in CO_2 concentrations over a sprawling urban environment.

This environmental monitoring shortfall has led the way for the incorporation of Internet of Things (IoT) technologies into air quality management systems. IoT-based CO_2 monitoring solutions entail the application of low-cost, sensor-based devices with microcontrollers and wireless communication modules. These sensors can be installed over residential estates, schools, commercial areas, industrial estates, and transportation corridors to generate real-time, high-resolution data on CO_2 concentration levels. The information gathered from these distributed sensors is sent to cloud-based or centralized platforms for aggregation, visualization, and analysis. These systems allow for the early detection of air pollution hotspots, enable policymaking based on data, and allow for citizen engagement by publishing air quality data in the public domain. Furthermore, IoT networks can be linked with machine learning models in order to predict CO_2 patterns and urban planning approaches like traffic management, energy utilization, and green area planning.

In Bengaluru, multiple stakeholders—such as civic authorities, private industry, research institutions, and non-governmental organizations—are coming together to pilot and scale IoT-based monitoring networks. Some of the prominent initiatives include the installation of air quality sensors by organizations such as Ambee, the deployment of low-cost microcontrollers like the NodeMCU ESP8266, and the introduction of real-time dashboards to guide municipal response and public outreach campaigns.

LITERATURE REVIEW

1. Sarkar et al. (2023) – Low-Cost IoT-Based CO_2 Monitoring System
Title: Design and Development of IoT Based Instrument to Monitor Indoor Air Quality
Summary: Sarkar and colleagues developed an IoT-based air quality monitoring device using:
NodeMCU ESP8266 (microcontroller with Wi-Fi capability),
MQ135 gas sensor (for the detection of CO_2 and other gases such as NH_3, benzene),
DHT-11 (for measuring temperature and humidity).
Real-time sensor data is transmitted to cloud platforms such as ThingSpeak or Firebase, enabling users to remotely monitor air quality. The system was designed for indoor settings like residences, classrooms, or offices.
Relevance to Bengaluru: Because of Bengaluru's high-density residential and commercial areas, this system is perfectly suited for localized monitoring. It is affordable enough to scale for community-based deployment, particularly in resource-poor environments.
Key Contributions:
• Real-time mobile interface alerts.
• Data visualization and storage on the cloud.
• Can be combined with smart home systems for ventilation control.

2. Karmakar et al. (2024) – DALTON: Air Quality Sensing in Developing Countries
Title: DALTON: Indoor Air Quality Monitoring in the Global South
Summary:
This project performed a six-month field deployment over 30+ Indian homes, creating an IoT platform named DALTON. The objective was to monitor and analyze indoor pollutants, with particular emphasis on environments depending on biomass cooking with inadequate ventilation.
Technological Framework:
Low-cost sensors designed specifically for the purpose.
Real-world home environment data collection.
Pollutant source classification and hotspot identification algorithms.
Relevance to Bengaluru: Similar issues with biomass use, inferior infrastructure, and ventilation can be found in many low-income areas and peri-urban Bengaluru. DALTON offers a template for scalable real-world air quality monitoring in such environments.
Key Contributions:
• Context-specific recommendations (such as window openings).
•Public health interventions based on data.
•Enabling grassroots environmental policy in developing urban areas.

3. Kumar & Doss (2022) – AIRO: Intelligent Air Quality Monitoring
Title: AIRO: An Intelligent IoT-Based Air Quality Monitoring System Based on Deep Learning
Summary:
In this research, AIRO is proposed, an IoT-based system that utilizes the MQ135 sensor to monitor air quality parameters such as CO_2, ammonia, and nitrogen oxides. AIRO stands out from other systems because it also makes use of deep learning models (CNN-BiLSTM) for predicting AQI levels in real time.
System Features:
Wi-Fi wireless data transmission.
Mobile application integration for AQI display.
Notifications and alerts for hazardous air quality levels.
Relevance to Bengaluru: AIRO's intelligent forecasting model is perfect for a city that has very variable traffic and construction activity. The model's real-time forecasts can guide decision-makers or warn users to stay indoors during rush-hour pollution periods.
Key Contributions:
• Combines IoT with deep learning for greater accuracy.
• Personalized warning for sensitive populations (e.g., children, elderly).
• Scalable for smart city projects like BBMP's BCAP.

4.Saini et al. (2020) – Systematic Review of Indoor Air Quality Monitoring
Title: IoT-Based Indoor Air Quality Monitoring Systems: A Systematic Review

Summary: The paper reviews more than 40 IoT-based air quality systems, comparing their hardware designs, sensors, data transmission, and analysis models.

Highlights:

- Mentions sensors such as MQ135, MH-Z19 (NDIR), and SDS011 (for PM2.5).
- Identifies the importance of real-time dashboards, mobile interfaces, and cloud analytics.
- Aspects of scalability, cost, and energy efficiency are evaluated.

Relevance to Bengaluru: The review gives a basis for choosing and implementing suitable IoT hardware and communication protocols according to Bengaluru's infrastructure. It also fits nicely into smart building specifications in IT parks and residential estates.

Key Contributions:

• Best practices for sensor deployment and calibration.
• Comparative evaluation of open-source platforms.
• Suggestions for future urban deployments.

PROBLEM STATEMENT

Bengaluru, India's second-fastest-growing metropolitan city, is grappling with the huge problem of controlling its air quality as it suffers from growing carbon dioxide (CO_2) emissions from road traffic, industry, and urbanization. In spite of government-initiated projects such as the Bengaluru Climate Action Plan (BCAP), there is presently very limited air quality monitoring infrastructure in place with infrequent sensor networks that are incapable of producing real-time, localized, and continuous information across the city's varied zones.

This absence of detailed CO_2 monitoring data hinders timely decision-making, public perception, and efficacious emission control policy implementation. High costs of installation and maintenance of conventional air quality monitoring stations, coupled with unaffordable widespread deployment, further adds to these limitations.

Thus, what is needed is a low-cost, scalable, and real-time monitoring system that is able to continuously monitor CO_2 concentrations across various areas of the city. An IoT-based CO_2 monitoring system involving sensors, cloud connectivity, and data analysis has the potential to fill this gap and provide data-driven environmental management for Bengaluru.

OUR METHODOLOGY

1. Hardware Setup

We are employing the following components:

- NodeMCU ESP8266: A compact Wi-Fi-based microcontroller to transmit data to the cloud.
- MQ135 or MH-Z19 sensor: To find out CO_2 concentration and other gases
- DHT11 sensor: To find temperature and humidity.
- Power supply: USB power or battery (with optional solar).

Why these?

They are low-cost, easy to code, and can be used outdoors or indoors in Indian cities.

2. Data Transmission

We make the device Wi-Fi-enabled to upload the sensor readings to a cloud platform (such as ThingSpeak or Firebase).

We transmit data in bursts every few seconds using protocols such as MQTT or HTTP.

3. Data Storage & Visualization

Data gets stored in the cloud.BWe represent CO_2 levels graphically over time through charts and graphs. We are creating a minimal dashboard and mobile-supported view to allow users to view:

Live CO_2 levels.

- Temperature and humidity.
- Warnings when CO_2 goes beyond safe levels.

4. Smart Analytics (Optional)

We can then apply simple machine learning (such as linear regression) to:

- Foresee upcoming CO_2 readings.
- Detect pollution "hotspots" in Bengaluru through mapping tools.

5. Testing & Deployment

We will install the device in various locations: Around traffic, In residential neighborhoods, and close to parks. This allows us to contrast how CO_2 readings vary in different areas of Bengaluru. We'll collect data for a few weeks and analyze it.

WHAT MAKES OUR TOOL DIFFERENT

Our IoT-based CO_2 monitoring system is different from traditional methods in several key ways. Unlike conventional air quality stations that are expensive, stationary, and offer delayed data, our system provides real-time, location-specific CO_2 readings using low-cost sensors and Wi-Fi-enabled microcontrollers. This enables real-time monitoring and instant access to air quality information anywhere via a web or mobile dashboard. The system is also simple to scale, so multiple devices can be used over a number of areas in Bengaluru to monitor pollution more precisely. It also has smart alerts, which inform users when CO_2 exceeds safe limits—something the majority of conventional systems do not have. Through being portable, affordable, and connected, our IoT solution makes air quality monitoring more accessible, responsive, and actionable for students, citizens, and policymakers alike.

RESULTS AND WHAT WE HAVE LEARNED

1. Real-Time CO_2 Level Readings

Continuous monitoring of carbon dioxide concentrations (in parts per million or ppm). Readings are refreshed every few minutes or seconds, depending on the setup. Assists in determining when and where CO_2 levels are highest (e.g., rush hours or traffic areas).

2. *Location-Based Pollution Insights*

If GPS is included, we can track the levels of pollution in various areas of the city. This identifies hotspots where CO_2 levels are perilously high. Practical for urban planning green zones, traffic flow, and city design.

3. Visualization Using Graphs and Dashboards

Graphs of day-to-day or weekly CO_2 fluctuations. Simple-to-grasp dashboards showing:

Live figures

- CO_2 highs and lows
- Comparison of different regions
- Makes air quality information available to all, not only to experts.

4. Mobile & Cloud Accessibility

Remotely view data from any computer or smartphone. Allows government agencies, students, or citizens to monitor air quality in real time. Encourages public consciousness and participation in lowering emissions.

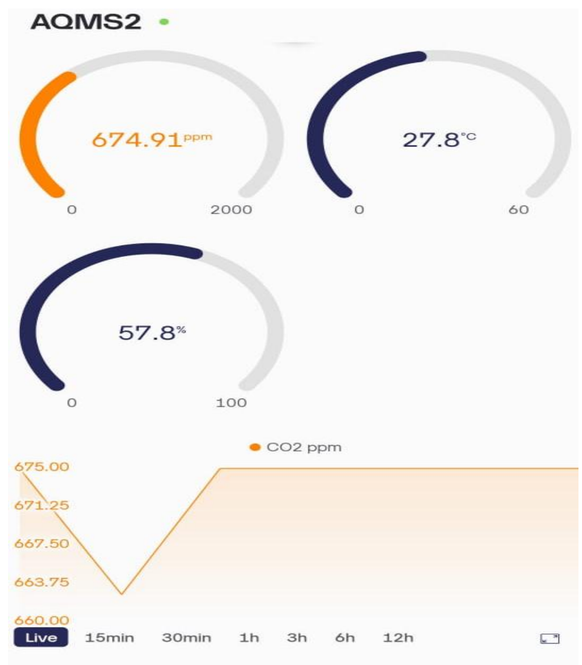
5. Smart Alerts and Warnings

Can be set to issue alerts (e.g., app notifications, SMS) when CO_2 exceeds safe thresholds. Assists in taking immediate action such as steering clear of areas or ventilating indoors.

6. Support for Long-Term Policy and Decision-Making

Collected data over time can be analyzed to:

- Follow the trend of pollution over months or seasons.
- Assess the impact of policies such as banning vehicles or going green.
- Support the city in planning improved climate resilience plans.



RESULT: WHY IT MATTERS

- Real-time data - Immediate action can be taken.
- Low-cost & scalable system - Can be applied in schools, homes, traffic areas.
- Public involvement -Empowers people to make eco-friendly decisions.
- Data-driven planning - Assists government to enhance urban and traffic planning.

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