IoT-Enabled Air Quality Insights: A Real-Time Monitoring and Visualization System

Vignesh Elagandula
IoT and Smart Systems
West Saxon University of Applied Sciences of Zwickau
Germany
Vignesh.Elagandula.o9n@fh-zwickau.de

Ravi Verma
IoT and Smart Systems
West Saxon University of Applied Sciences of Zwickau
Germany
Ravi.Verma.odf@fh-zwickau.de

Gouri Pavagadhi
IoT and Smart Systems
West Saxon University of Applied Sciences of Zwickau
Germany
Gouri.Pavagadhi.o9x@fh-zwickau.de

ABSTRACT

Air pollution is still one of the biggest global environmental and public health challenges and placing urban sustainability and air quality management as top priorities. This research contributes to the air pollution literature by examining real-time PM2.5 The relationship between the concentrations of PM2. 5 and PM10 in Berlin and Delhi using …Sensor. Community", a citizen science project. Node-Red is used for data collection and processing, InfluxDB for database management, and Grafana for visualization and analytics. Delhi has the highest PM10 and Berlin the lowest PM2.5 levels long-term. 5 concentrations. Moreover, Delhi's high PM2.5-to-PM10 ratio highlights the dominance of fine particulate pollutants. The study finds a decentralized, community-based air quality monitoring approach using low-cost sensors and real-time data analytics to evaluate urban air pollution. The findings highlight the need for evidence-based environmental policies and urban planning that focus on pollution hotspots, temporal trends, and geographic disparities in order to avert threats to public health and build sustainable cities The study was conducted based on data up to October 2023. This provides an example of how community-mediated, technology-assisted monitoring can identify opportunities for targeted action and progress toward cleaner air and healthier cities.

CCS CONCEPTS

- Human-centered computing → Visualization systems and tools
- Computer systems organization → Embedded and cyber-physical systems
- Information systems → Data management systems
- Applied computing → Environmental sciences

KEYWORDS

IoT (Internet of Things), Real-time monitoring, Air quality sensors, Data visualization, Grafana, Node-RED, InfluxDB, Time-series data, Environmental monitoring

1 Introduction

Description The rapid industrialization and urbanization are a cause of concern with respect to battering of air quality around the globe. Node-RED is used for data aggregation, InfluxDB for time-series data storage, and Grafana is used for data visualization in the proposed system. Combining meteorological data from the air quality scores from sensor. community devices the platform provides detailed insights into environmental conditions. It focuses on the architecture of the dashboard and its visual elements including charts and graphs and the analytical insights generated from the data, highlighting its potential for real-time environmental monitoring and decision-making.

2 System Framework and Data Collecting

The system architecture integrated multiple diverse components to enable real-time environmental monitoring organized in three major horizontal layers: data acquisition, data storage and data visualization. The key elements and workflows are as follows:

2.1 Framework of Data Acquisition

2.1.1 Particulate Matter Data

PM10 (P1): Particles of coarse size (≤10 µm diameter) that are commonly associated with dust and pollen.

PM2. 5 (P2): Fine particles (≤2.5 µm diameter), which come from combustion and industrial emissions.

2.2 Node-RED pipeline for DataOrchestration

Node-RED, a low-code platform for workflow automation, was used to architect and deploy the back-end data pipeline for the system. It integrates Sensor. Community (air quality) — into an integrated processing chain. The sequence of this workflow composed as follow:

Trigger Layer:

Scheduled Injectors: Poll every 30 seconds to keep both APIs sync in terms of data fetching.

Data Ingestion Layer:

API Connectors: HTTP request modules to retrieve raw meteorological and particulate data, followed by JSON parsing to standardize outputs.

- **Transformation Layer:**

Custom JavaScript Functions: Refine raw API responses into structured JSON payloads, aligning fields (e.g., °C für temperature, µg/m³ for PM values) with InfluxDB schema requirements.

- **Storage Layer:**

InfluxDB Writers: Insert time-stamped datasets into partitioned buckets, tagging entries by metric type (e.g., “air quality.PM2.5”).

- **Validation Layer:**

Debug Monitors: Embedded at criitical junctions to log payloads, validate schema consistency, and flag anomalies (e.g., missing fields, API timeouts) in real time.

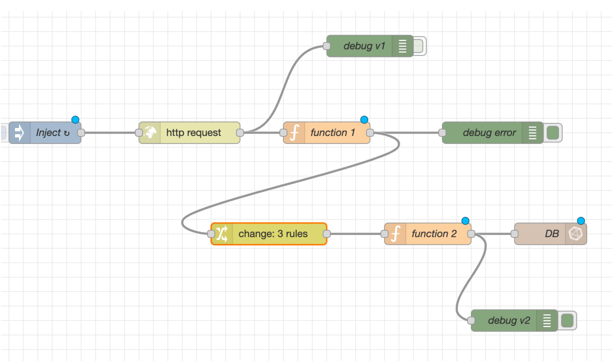

Figure 1: Node-Red Flow

2.3 InfluxDB for Time-Series Data Management

When building our environmental monitoring system, we chose InfluxDB as the core storage solution because it’s built to excel at managing time-stamped data—like the constant stream of metrics pouring in from sensors. Think of it as a highly organized, time-aware librarian for our environmental data. Here’s how we structured it to work intuitively:

We grouped data into logical categories, almost like folders, based on what’s being measured. For example, the "air quality" category acts as a dedicated space for tracking particulate concentrations—things like PM2.5 and PM10. Each piece of data is stamped with the exact time it was recorded and labeled with context—like which sensor collected it or where it’s located (GPS coordinates, for instance). This tagging system lets us ask precise questions later, like, “What was the air quality near Sensor #5 between 2 PM and 4 PM last Tuesday?”—and get answers lightning-fast.

By defining this structure upfront (a "schema-on-write" approach), we keep datasets clean and separated by purpose. This not only makes it easier to visualize trends in tools like Grafana but also powers deeper dives, like analyzing how pollution levels shift over weeks or pinpointing seasonal patterns.

3 Dashboard Design and Visualization

The dashboard is designed to provide an intuitive and comprehensive overview of air quality.

3.1 Chart Descriptions

PM2.5 and PM10 concentrations are tracked over time in this air quality graphic. Time is represented by the x-axis, while particulate content is measured in micrograms per cubic meter (µg/m³) on the y-axis. PM2.5 is represented by the yellow line, and PM10 by the green line. Both readings are low and consistent at first, but around 20:30 there is a dramatic increase, which is followed by notable oscillations. This points to fluctuating air quality that may be impacted by outside variables like traffic or environmental shifts. Unstable conditions are indicated by the numerous peaks and troughs, with PM2.5 exhibiting greater volatility. Air quality criteria may be indicated by the backdrop shading, which would aid in determining the level of pollution. Because high PM2.5 levels affect respiratory health, they are cause for alarm.This Data is essential for tracking pollution patterns and putting into practice efficient air quality control measures.

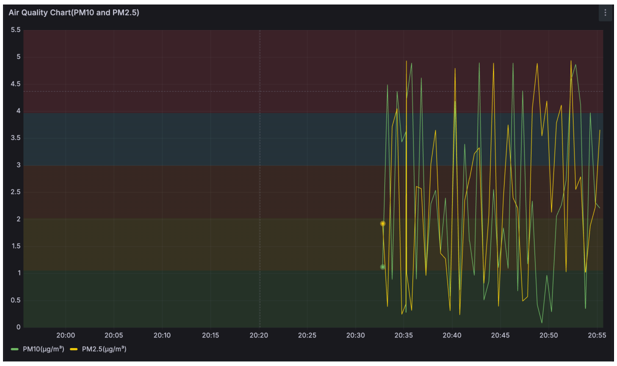

Figure 2: Air Quality chart (PM2.5 and PM10)

The PM10 concentrations (µg/m³) in Delhi and Berlin have been compared in this figure. With a PM10 concentration of 2.55 µg/m³, the gauge on the left represents Berlin, while the one on the right represents Delhi, where the value is somewhat higher at 2.72 µg/m³. Using color curves, the semi-circular design graphically represents the levels of air pollution: green shows lesser pollution, yellow shows moderate pollution, and red shows higher pollution. The air quality in both cities is similar, with PM10 levels falling into the moderate category. Delhi's somewhat higher PM10 could be a sign of more industrial or traffic-related pollution sources. By highlighting the relative variations in air quality, this comparison gives light on the levels of pollution exposure in each place. The graph is helpful for tracking patterns and evaluating how well air quality control measures are working.

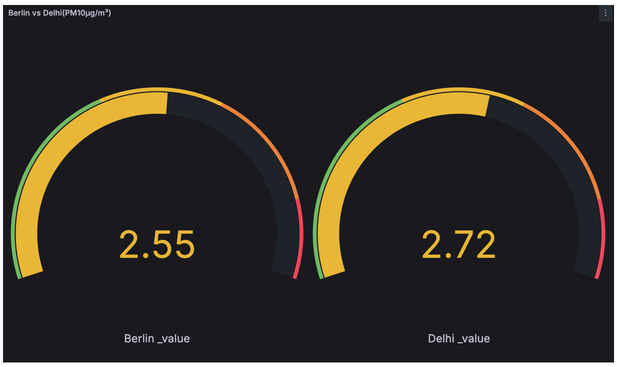

Figure 3: PM10 Concentration levels

The PM2.5 concentrations (µg/m³) in Delhi and Berlin have been compared in this figure. Berlin is represented by the left indicator, which displays a PM2.5 concentration of 2.29 µg/m³, while Delhi is represented by the right indicator, which has a little higher value of 2.30 µg/m³. Air quality is shown by semi-circular gauges using color coding, where low pollution is represented by green, moderate by yellow, and excessive by red. The very similar PM2.5 values in the two cities indicate comparable airborne fine particulate matter concentrations. PM2.5 pollutants are harmful to human health since they come from sources like burning fuels, industrial operations, and automobile emissions. In this case, a little difference between Delhi and Berlin suggests similar air quality conditions at the time of measurement. In order to make informed choices about environmental health policies, visualization helps in the assessment and monitoring of pollution levels.

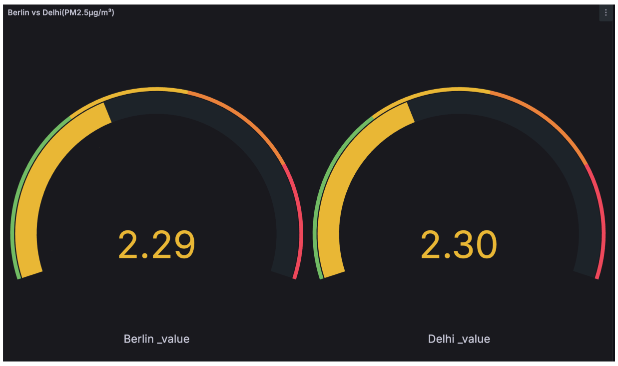

Figure 4: PM2.5 Concentration levels

Using IoT-enabled real-time monitoring, the figure compares the air quality measurements in Delhi with Berlin at different Time-Stamps. Through semi-circular gauges, it displays the PM1.0 (P1) and PM2.5 (P2) levels for Berlin and Delhi. With PM1.0 readings of 2.48 µg/m³ in Berlin and 3.24 µg/m³ in Delhi, that city has a greater concentration of small particles. The same pattern may be seen in the PM2.5 values, which are 1.20 µg/m³ for Berlin and 2.13 µg/m³ for Delhi.

The level of pollution is highlighted using a color-coded display, where red indicates poor air quality. Real-time collection of data is confirmed by timestamp indicators. Utilizing Internet of Things technology, the system collects and analyzes air quality data, providing important data for environmental monitoring. Differences that have been noticed highlight the effects of pollution control and urbanization.

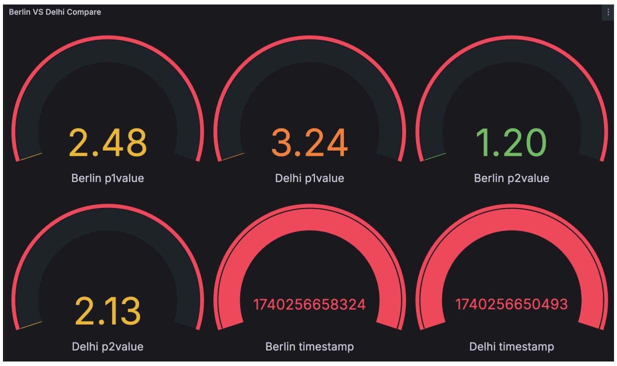

Figure 5: comparison between Delhi and Berlin

The dashboard uses Internet of Things-based monitoring to compare air quality measurements in real-time between Delhi and Berlin. It has several visual elements including gauge meters, numerical indicators, and a time-series air quality chart. Berlin and Delhi have different PM2.5 levels (Berlin: 1.51 µg/m³, Delhi: 1.51 µg/m³), but similar PM10 values (2.30 µg/m³) are continually observed. Delhi has a much higher PM1.0 value (3.24 µg/m³) than Berlin (2.48 µg/m³), which suggests that there are more tiny particle pollutants present. Red zones indicate possible health hazards, while color-coded signals show the intensity of pollution. Real-time data validation is ensured using timestamp values.This IoT-driven technology makes it possible to track the environment continuously, which helps with pollution control. Through data-based decisions for long-term improvements in urban air quality.

Figure 6: Dashboard Overview

4 Conclusion

- **PM10 Analysis**

Delhi shows higher PM10 gains (3.24 and 2.13) compared to Berlin (2.48 and 1.20), indicating significantly elevated coarse particulate pollution.
The disparity suggests Delhi faces greater challenges with dust, construction emissions, or industrial activity, common PM10 sources.

- **PM2.5 Analysis:**

Delhi also leads in PM2.5 gains (2.30), nearly double Berlin's value (1.51), reflecting a severe fine particulate pollution burden linked to vehicular exhaust, biomass burning, or fossil fuel combustion.
The higher PM2.5-to-PM10 ratio in Delhi aligns with its urban pollution profile, dominated by fine particles from combustion sources.

Delhi's consistently higher PM levels underscore urgent needs for stricter emission controls and pollution mitigation strategies. Berlin's lower values suggest better air quality management, though persistent PM2.5 levels warrant attention. The dashboard highlights the utility of real-time monitoring but calls for enriched metadata (e.g., timeframes, metric definitions) to enhance actionable insights for policymakers and urban planners.

REFERENCES

- Sensor.Community, "Open air quality data," 2024
- Khan, Arshad. Visual Analytics for Dashboards: A Step-by-Step Guide to Principles and Practical Techniques. Apress, 2024.
- IEEE VIS 2022. Dashboard Design Patterns – Revisions 8.