

Real-Time Ambient Environmental and Noise Pollution Monitoring System in High-Density Areas of Malang City using Internet of Things (IoT) Technology

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ABSTRAK

Penelitian ini mengevaluasi sistem pemantauan lingkungan ambien dan polusi suara secara *real-time* menggunakan *Internet of Things (IoT)*. Sistem ini mendeteksi berbagai parameter lingkungan, termasuk suhu, kelembaban, partikel halus (PM_{2.5}), karbon monoksida (CO), karbon dioksida (CO₂), dan tingkat kebisingan di enam area lalu lintas di Kota Malang selama jam sibuk. Dengan menggunakan berbagai sensor, sistem ini secara kontinu memantau parameter udara ambien dan polusi suara pada pukul 06:00-07:00, 11:00-12:01, dan 15:00-16:02. Alat pemantauan ditempatkan sekitar ±3 meter dari tepi jalan, dekat dengan lampu lalu lintas. Data dikumpulkan selama jam sibuk lalu lintas untuk mengetahui dampak langsung emisi kendaraan terhadap kualitas udara. Aktivitas kendaraan yang tinggi berkontribusi pada peningkatan suhu dan konsentrasi partikel halus di area tertentu. Namun, kadar CO, CO₂, dan kebisingan tetap berada dalam ambang batas yang dapat diterima. Studi ini juga mengidentifikasi hubungan terbalik antara suhu dan kelembaban. Sistem pemantauan lingkungan berbasis IoT yang diterapkan di enam lokasi dengan lalu lintas tinggi di Malang telah berhasil diimplementasikan dan beroperasi secara efektif. Studi ini meneliti faktor lingkungan yang melebihi ambang batas menggunakan sistem pemantauan IoT, yang memerlukan evaluasi lebih lanjut.

Kata kunci: Polusi udara, suhu, kelembaban, kebisingan, Internet of Things, analisis real-time

ABSTRACT

This study evaluated real-time ambient environment and sound pollution monitoring system using Internet of Things (IoT). This system detects wide range of temperature, humidity, fine particulate matter (PM_{2.5}), Carbon monoxide (CO), Carbon dioxide (CO₂), and noise level in six traffic areas in Malang City during peak hours. Using a variety of sensors, the system continuously monitors ambient environment and noise pollution at 06:00-07:00, 11:00-12:01, 15:00-16:02. The monitoring tools was placed ±3 meters from the roadside near to the traffic light. Data were collected during peak traffic hours, emphasizing the direct impact of car emissions on air quality. Intense vehicle activity has contributed to increased temperatures and higher particulate matter in specific areas. However, CO, CO₂ and noise levels were observed to remain within acceptable safety thresholds. Notably, this study identified an inverse correlation between temperature and humidity. The IoT-based environmental monitoring system, deployed across six high-traffic locations in Malang, has been successfully implemented and effectively operated. This study investigated environmental factors that greater than threshold using IoT monitoring system deserving further evaluation.

Keywords: air pollution, temperatures, humidity, noise, Internet of Things, Real-time analysis

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1. INTRODUCTION

The global average temperature has warmth to ~2°C per decade over the past 30 years (Hansen et al., 2006), and this number is anticipated to increase by 1,5°C in 2050 (Bauska, 2022; IPCC, 2015). Climate

change effects on air quality are estimated to be prominent in which affecting the dispersion, deposition, and formation of pollutant (Liu et al., 2024). The increased number of transportations, rapid urbanization, burning coal, economic growth,

and heating system in building is responsible for intensifying ambient air pollution. Therefore, outdoor air pollution became environmental problem that affecting human health (Zafirah et al., 2021, 2022), plant productivity, ecosystem biodiversity (Liu et al., 2024).

The emission released to the environment consists of particulate matter (PM), carbon monoxide (CO), Ozone (O₃), Nitrogen dioxide (NO₂), and Sulfur dioxide (SO₂). The exposure to air pollution has been linked to the premature deaths of 4.2 million people. World Health Organization (WHO) reported that air-pollution related mortality is mostly experienced in South-East Asia and Western Pacific Regions (WHO, 2024).

Additionally, traffic noise also poses a growing concern, defined as unwanted sound that can disrupt human activities or cause harm (Dewa & Santoso, 2022). Noise pollution originates from diverse sources such as road traffic, industrial machinery, railroad, and air road, in which road traffic ranked as number one primary contributor of higher noise levels in urban areas. Prolonged exposure to higher noise levels is related to the mental health issues including anxiety, depression, and sleep disorders (Gong et al., 2022; Mehrotra et al., 2024). The long and repeated exposure to sound at 85 dBA and above induce the risk of hearing loss (Atmaca et al., 2005; Jaafar et al., 2023).

The adverse effects of air pollution required further attention from both governments and society. One of the primary management efforts include providing easy access to air quality information, commonly available through government initiatives called the Air Pollution Standard Index (ISPU), which is monitored via air quality monitoring stations (Agista et al., 2020; Apriawati et al., 2017; Thara Seesaard, Kamonrat Kamjornkittikoon, 2024). According to the World Health Organization (WHO), such measures are essential in protecting public health and the environment (Deshmukh et al., 2020). The current system is usually relying on stationary monitoring stations to monitor ambient environment. Even though it will result reliable data, however this method often lacks of real-time data which needs laboratory analysis (Ramadan et al., 2024).

In response to the limitations, this study aims to develop comprehensive real-time data using Internet of Things (IoT)-based air quality and sound pollution monitoring systems. This system will consist of hardware components and a web platform providing real-time environmental reports. Through this system, users are able to easily access information about ambient environment including air quality, temperature, humidity, and noise levels, leveraging the accessibility of the internet (Ramadan et al., 2024).

The concept of IoT is central to enhancing continuous internet connectivity, enabling efficient collection and exchange of data. IoT connects global infrastructure with communities by linking physical and virtual objects through internet technologies, allowing devices to communicate seamlessly (Collado et al., 2024). This system integrates various sensors to monitor environmental conditions and to secure data transmission; encryption methods like Advanced Encryption Standard (AES) may be employed.

2. METHODOLOGY

2.1. Data Sources

With an area of 111.08 km² and reside of 885,27 inhabitants per 2024, this study selected six dense areas in Malang City including Tanggul Mas, Dinoyo, Sutami, Soekarno Hatta, LA Sucipto, and Belimbing. **Figure 1** displays the locations of ambient environment and sound pollution monitoring points in study areas. Data was only collected on peak hours 06.00-07.00, 11.00-12.00, and 15.00-16.00, in which, high mobility during those hours from the transportation crossing area is suggested to emit several pollutants in the air. The concentration of weather parameters and sound pollution including Carbon monoxide (µg/m³), Carbon dioxide (µg/m³), fine particulate matter (µg/m³), temperature (°C), humidity (%), and noise(dB) are measured and recorded every three minutes over the course of a day. The monitoring tools was placed ±3 meters from the roadside near to the traffic light.

2.2. IoT Prototype Deployment

This present study employed Internet of Things to monitor weather factors in selected locations in Malang City, thus, it will generate real-time outdoor air quality from sensors. The prototype is equipped with various types of sensors and processing units to collect data and enable to establish right actions. The materials are MQ-135 and MQ-7 for detecting CO and CO₂ in the air, DHT22 for detecting temperature and humidity, GP2Y1010AUF for detecting PM_{2.5}, GY-MAX4466 for detecting noise, and microcontroller to enable processing the data. Initial testing and pre-data collection was conducted to ensure the system works properly. Subsequently, the data collected from sensors will be transferred to cloud, making it easier to unify all data and data is available immediately. Further information on IoT air quality sensing node architecture is illustrated in **Figure 2**. Then users enable to easily access and monitor real-time outdoor air quality via web.

Data collection will be presented in descriptive statistic table, such as mean, maximum, and minimum to display the data of selected parameters.



Figure 1. Locations of Weather Observatories, Ambient Air Quality, and Noise Monitor Stations in Six Dense Areas in Malang City

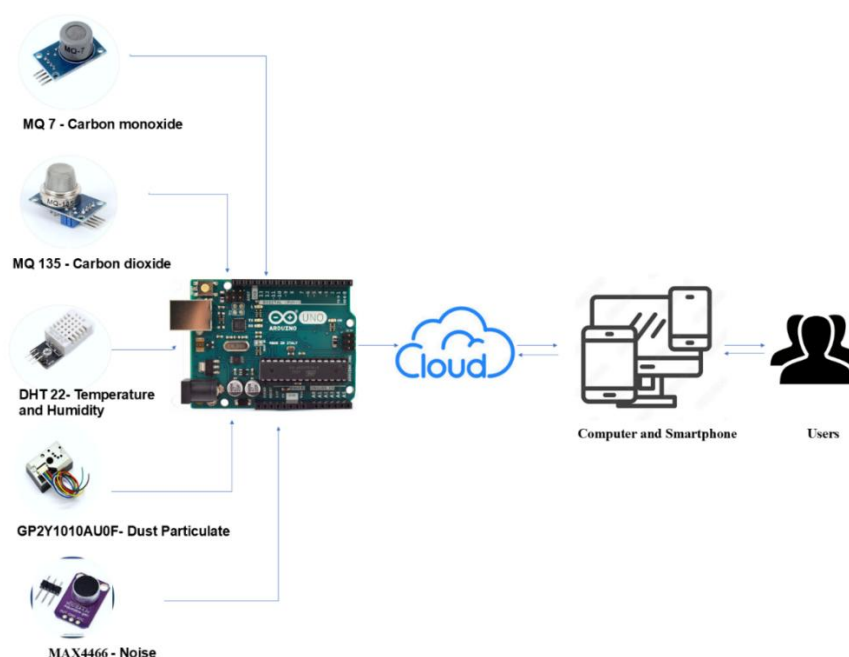


Figure 2. IoT Air Quality Sensing Node Architecture

3. RESULTS AND DISCUSSION

This study evaluated real-time outdoor air quality using IoT-based air and sound pollution monitoring systems to detect environmental factors such as humidity, temperature, PM_{2.5}, CO, and CO₂, and noise level. Prior studies have investigated the implementation of IoT devices to monitor air quality and predict the results whether the quality of air is good or not (Fischer, 2020; Irbah et al., 2024; Malleswari & Mohana, 2022; Ramadan et al., 2024). Hourly statistic of environmental factors is listed in

Table 1, with mean temperature was 30oC (range: 21 – 35oC), relative humidity of 46% (range: 33-68%), PM_{2.5} concentrations of 193 µg/m³ (range:22-603 µg/m³), CO concentration of 281 ppm (range:51-800 ppm), CO₂ concentration of 26 ppm (range:8-80 ppm), and noise of 54 dB(A) (range:27-98 dB(A)).

3.1. Trends of Temperature and Humidity in Six-Point Sources

Figure 3 displays trends of temperature from six-point sources that increase after reaching a peak at

11.00 a.m. The lowest temperature with 21°C was observed in Tanggul Mas at 06:00 am, while the highest temperature with 35°C was recorded in Soeakrno Hatta at 11:00-12:00 a.m.

Figure 4 shows that the humidity tended to decrease from early morning (06:00-07:00) to late morning (11:00-12:00) and slightly increased in the afternoon (15:00-16:00). The highest percentage of humidity was found in Tanggul Mas at 06:00 a.m. with humidity of 68%, while the lowest humidity had appeared in La Sucipto at 11:00-12:00 a.m. and in Tanggul Mas at 15:00-16:00 a.m., with humidity of 33%. As the temperature gets warmer, it will lead to a decrease in humidity. The mean temperature showed an upward trend compared to previous measurements. These results indicate that temperature affects humidity, where the relationship between humidity and temperature are inversely proportional. In terms of humidity, our finding found

that the mean humidity of 46%, however BPS Malang City reports that mean humidity ranged from 79% to 86%. This is likely attributable to the influence of the El Niño event that increase global mean surface air temperature that greater than pre-industrial average (World Meteorological Organization, 2024). According to the BMKG, effect of El Nino event is generally pronounced in dry season (July to October) significantly affecting several provinces in Indonesia including Java, Bali, Nusa Tenggara, etc (BMKG, n.d.). In addition, the point source of Tanggul Mas at 06:00 am appeared to have the lowest temperature (21°C) and humidity (68%). In agreement with our finding, previous study states that there was a negative association between relative humidity and temperature where rise in temperature is commonly affected by low humidity (Syed Othman Thani et al., 2017).

Table 1. Means and Ranges of Daily Ambient Environment and Noise Conditions in six Dense Areas in Malang City

Parameter	Temperature (°C)	Humidity (%)	PM _{2.5} (µg/m ³)	CO (ppm)	CO ₂ (ppm)	Noise (dB)
Mean	30	46	193	281	26	54
Minimum	21	33	22	51	8	27
Q1	27	40	139	143	16	37
Q2	32	43	188	267	21	51
Q3	33	52	237	408	32	67
Maximum	35	68	603	800	80	98

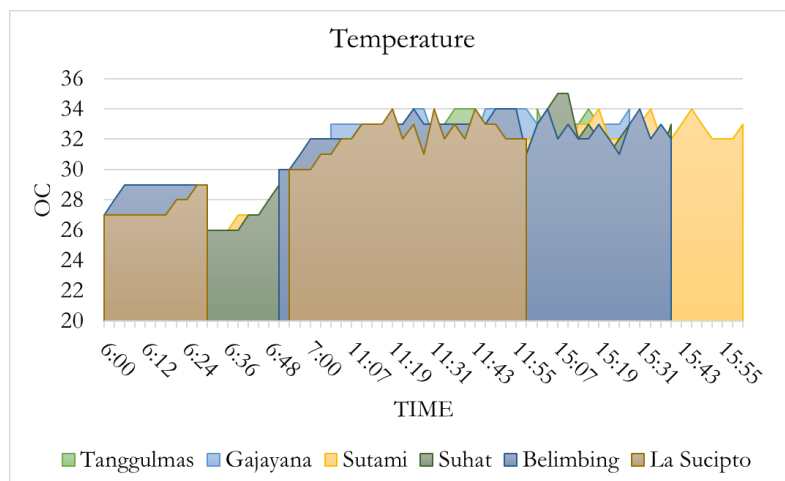


Figure 3. Temperature Timeline Graph

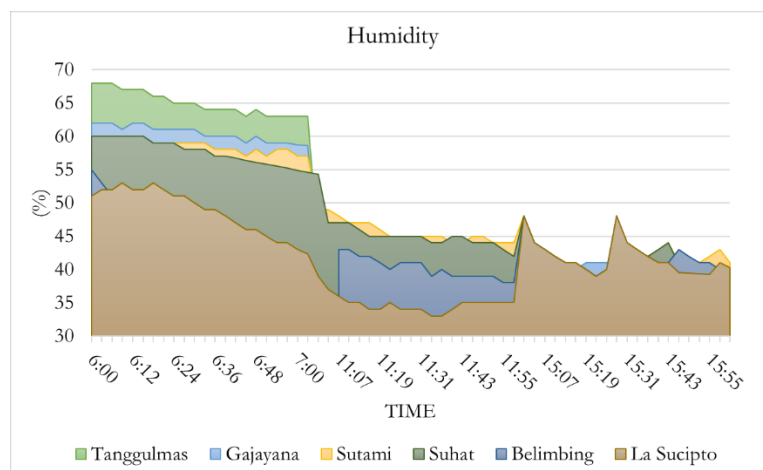


Figure 4. Humidity Timeline Graph

3.2. Trends of PM_{2.5}, CO, and CO₂ in Six-Point Sources

A fluctuate trend in the concentration of PM_{2.5}, CO, and CO₂ are shown in **Figure 5**, **6**, and **7**, respectively. The highest level of PM_{2.5} was reached to 603 µg/m³ in La Sucipto at 11:00-12:00 a.m. According to Air Quality Index (AQI) level, this number is going above the threshold standard, this indicates that air might be unhealthy.

This study found that the hourly level of PM_{2.5} is categorized high with number of 193 µg/Nm³. However, this data cannot be compared with air quality standards, because there is currently no national standard for the one-hour PM_{2.5} average. For example, the Indonesian government has set the value of PM_{2.5} roadside threshold not greater than 75 µg/Nm³ in 24- hour (PP Nomor 22 Tahun 2021, 2021). Air quality guideline under World health organization (WHO) regulates the standard of average

concentration of PM_{2.5} categorizing levels between 50-150 µg/m³ as "very poor " (Organization, n.d.).

We found that the highest level of PM_{2.5} was reached to 603 µg/m³ in La Sucipto at 11:00-12:00. In contrast, the lowest humidity had appeared of 33% in the same point sources and peak hours. Our study is supported by previous findings that relative humidity was the more influential factor for particulate matter rather than temperature. The concentration of PM_{2.5} and PM₁₀ increases as the relative humidity decreases (<50 %) (Zender-Świercz et al., 2024).

During the course of the experiment, the level of CO rose from 51 to 800 ppm. The dramatic increase of CO was monitored in Tanggul Mas at 06:00 am. In addition, the trend of CO₂ did not change in consistent manner throughout the hours, where there was a slightly decreased trend from 11:00 to 12:00. The highest number of CO₂ was reached in Soekarno Hatta, Belimbing, and La Sucipto at 15:00-16:02, with concentration of 80 ppm.

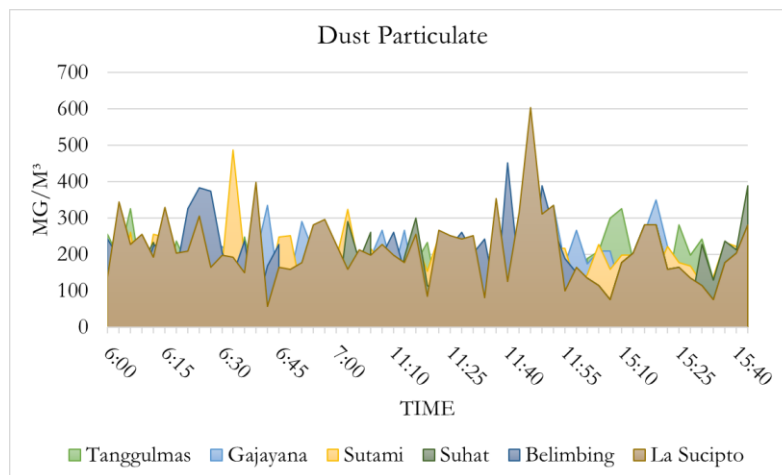


Figure 5. Particulate Matter Timeline Graph

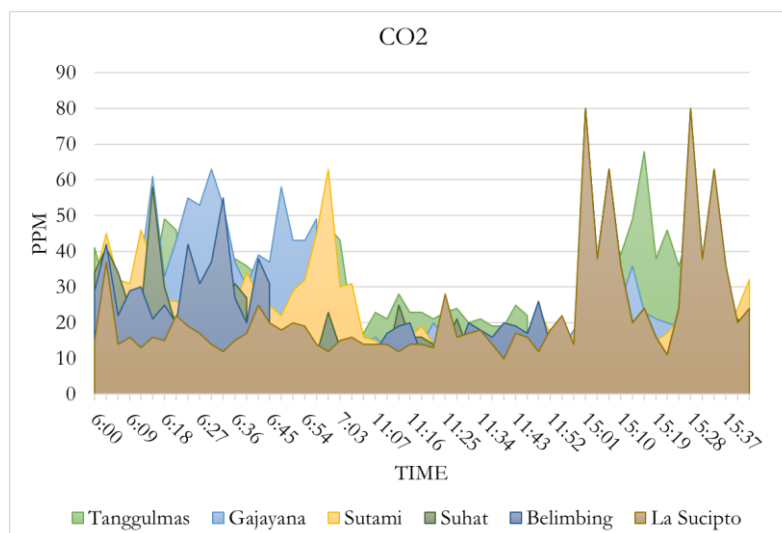


Figure 6. CO₂ Timeline Graph

According to the Government Regulation Number 22 of 2021, roadside threshold of one-hour CO average that can be accepted by human being is $10.000 \mu\text{g}/\text{Nm}^3$ (PP Nomor 22 Tahun 2021, 2021). The level of CO during this study course is in the acceptable level. According to the WHO bulletin, the CO_2 threshold in Indonesia for clean air is 310-330 ppm, while polluted air is 350-700 ppm (Harista. & Jurusan, Teknik, 2020). Our study indicated that CO_2 level remained at a safe level.

3.3. Trends of Noise Level in Six-Point Sources

Figure 8 depicted that the measured noise level was repeated in a uniform manner over the course of the day. The peak late morning maximum levels was 98 dB, which coincided exactly with the noise levels recorded at Soekarno Hatta, Belimbing, and La Sucipto at 15:00-16:02. In contrast, the lowest noise level of 29 dB was observed in Gajayana during the time frame of 11:00 to 12:01.

Our study observe that the mean noise level was remain remained within the acceptable range at 46 dB(A)., Decree of the Minister of State for the Environment No. 48 of 1996 set the threshold of noise level to 70 dBA within an hour (Menteri Negara Lingkungan Hidup, 1996). However, we found that the highest of noise level is 98 dB during 06:00-07:00 and

15:00 – 16:00 in particular area. The high density of transportation activities at each analysis point, involving private vehicles, public transport, and industrial vehicles, combined with the road's slope encouraging fast driving, contributes to noise from engines and horns in the surrounding area. Additionally, the presence of schoolchildren and workers commuting during those hours further amplifies traffic noise. As a result, traffic noise stands out as a significant source of environmental disturbance (Arregi et al., 2024; Lutman, 2000; Mutalib et al., 2018).

Several weather parameters appeared to have higher concentration than before, it will increase the risk of disease-related air pollution. There was a significant increase in the Acute Respiratory Tract Infection (ARIs) in Malang City from 2019 to 2023. Central Bureau of Statistics (BPS) of Malang City in 2019 reported that there were 15,736 cases of ARIs and the number of ARIs was drastically rising in 2022 with 56,000 cases of ARIs. While in 2023, the cases were reportedly increase to 43,000 cases in the first half-year (BPS, 2019). Multiple studies have linked the association between exposures of short-term ambient air pollution and the burden disease of respiratory illness (Croft et al., 2019; Monoson et al., 2023; Tran et al., 2023).

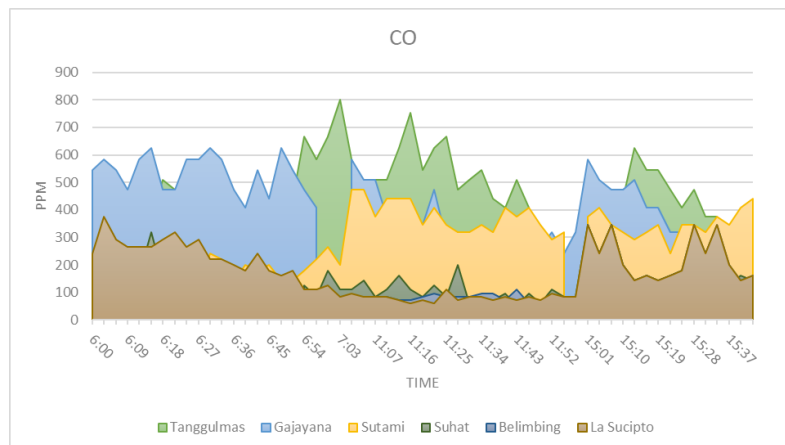


Figure 7. CO Timeline Graph

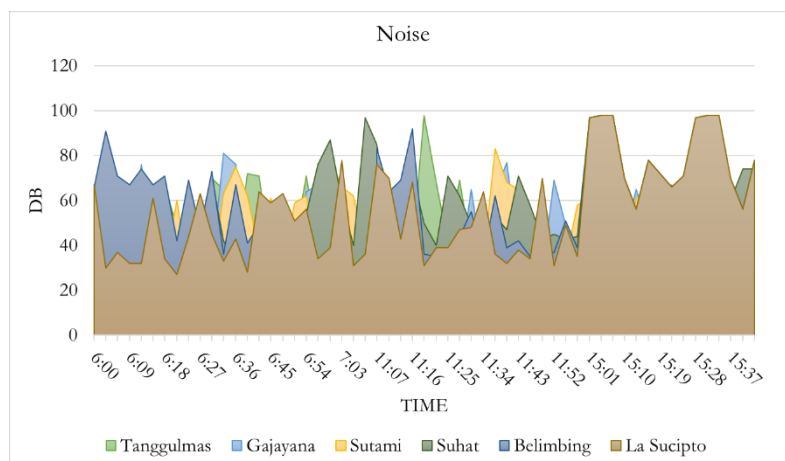


Figure 8. Noise Timeline Graph

In addition, the occurrence of extreme weather event in Malang City is suggested to lower the immune system of the body that induced by high level of particulate and pollution emitted by vehicles (Irwanto, 2023; Pemerintah Kota Malang, 2023b) dominated by motorbikes, the number of vehicles in Malang city has increased approximately 10,7% from 2015 (total number of motorbikes 436,123) to 2019 (total number of motorbikes 482,816), nevertheless these numbers is reportedly reduced due to covid-19 in 2020 to 2023, data available in <https://malangkota.bps.go.id/id>. In Malang City, the high concentration of air pollution emitted to the environment has mostly occurred due to vehicles emission rather than industrial activity.

Local government has established various strategies to improve air quality by managing public transportation rejuvenation, providing green open spaces, monitoring motor vehicle emission, increasing community participation, testing and monitoring ambient air quality and urban traffic performance (Pemerintah Kota Malang, 2023a; Utomo, 2012).

This study is strengthened by using IoT-based air and sound pollution monitoring system to understand the real-time level and concentration of environmental factors. We were able to provide real-time data in dense area. However, this study has several limitations. We were unable to monitor data for continuous 24-hous monitored data, yet we only investigated in peak hour time, we did not statically analyze the relationship between health and air pollution. In addition, the challenges of IoT monitoring system include data accuracy and the need for calibration to guarantee reliable measurements.

4. CONCLUSION

This study demonstrated real-time ambient environment and sound pollution monitoring system during peak hours using IoT sensors. Evidence suggested that high vehicle activity has led to elevated temperatures and dust concentrations, while CO, CO₂ and noise levels remain within safe limits. There is an inverse relationship between humidity to temperature and PM_{2.5}. The IoT system for monitoring environmental quality at six high-traffic locations in Malang has been successfully implemented and effectively functioned. Further improvements are necessary for sensor calibration and IoT communication stability. These results can guide local authorities in formulating policies to reduce vehicle emissions, improve air quality, and protect public health, especially in pollution-prone areas.

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