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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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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 (PM2.5), 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, CO_2 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

INTRODUCTION
The global average temperature has warmth to ~2°C per decade over the past 30 years [1], and this number is anticipated to increase by 1,5°C in 2050 [2], [3]. Climate change effects on air quality are estimated to be prominent in which affecting the dispersion, deposition, and formation of pollutant [4]. The increased number of transportations, rapid of urbanization, burning coals, economic growth, heating system in building is responsible to intensifying ambient air pollution. Therefore, outdoor air pollution became environmental problem that affecting human health [5], [6], plant productivity, ecosystem biodiversity [4].
The emission released to the environment is consisting of particulate matter (PM), carbon monoxide (CO), Ozone (O_3), Nitrogen dioxide (NO_2), and Sulfur dioxide (SO_2). The exposure to air pollution has linked to the premature deaths for 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 [7].

Additionally, traffic noise also poses a growing concern, defined as unwanted sound that can disrupt human activities or cause harm [8]. Noise pollution is originated from diverse sources such as road traffic, industrial machinery, rail road, and air road, in which road traffic ranked as number one primary contributor of higher noise level in urban area. Prolonged exposure to higher noise levels is related to the mental health issues including anxiety, depression, and sleep disorders [9], [10]. The long and repeated exposure to sound at 85 dBA and above induce the risk of hearing loss [11], [12].

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 [13], [14], [15]. According to the World Health Organization (WHO), such measures are essential in protecting public health and the environment [16]. The current system is usually relying on stationary monitoring station to monitor ambient environment. Even though it will result reliable data, however this method often lacks of real-time data which needs laboratory analysis [17].

In response to the limitation, this study aims to develop the comprehensive real-time data using Internet of Things (IoT)-based air quality and sound pollution monitoring system. 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 [18]. The concept of IoT is central to enhancing continuous internet connectivity, enabling the 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[19]. This system integrates various sensors to monitor environmental conditions and to secure data transmission; encryption methods like Advanced Encryption Standard (AES) may be employed.

METHODS

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. **Fig. 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 ($\mu g/m^3$), Carbon dioxide ($\mu g/m^3$), fine particulate matter ($\mu g/m^3$), temperature (^oC), 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.

IoT prototype deployment

This present study employed Internet of Things to monitor weather factor in selected locations in Malang City, thus, it will generate real-time outdoor air quality from sensors. The prototype is equipped by various types of sensors and processing unit to collect data and enable to establish right actions. The materials are MQ-135 and MQ-7 for detecting CO and CO_2 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 collected data from sensors will be transferred to cloud, make it easier to unify all data and data is available immediately. Further information of 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

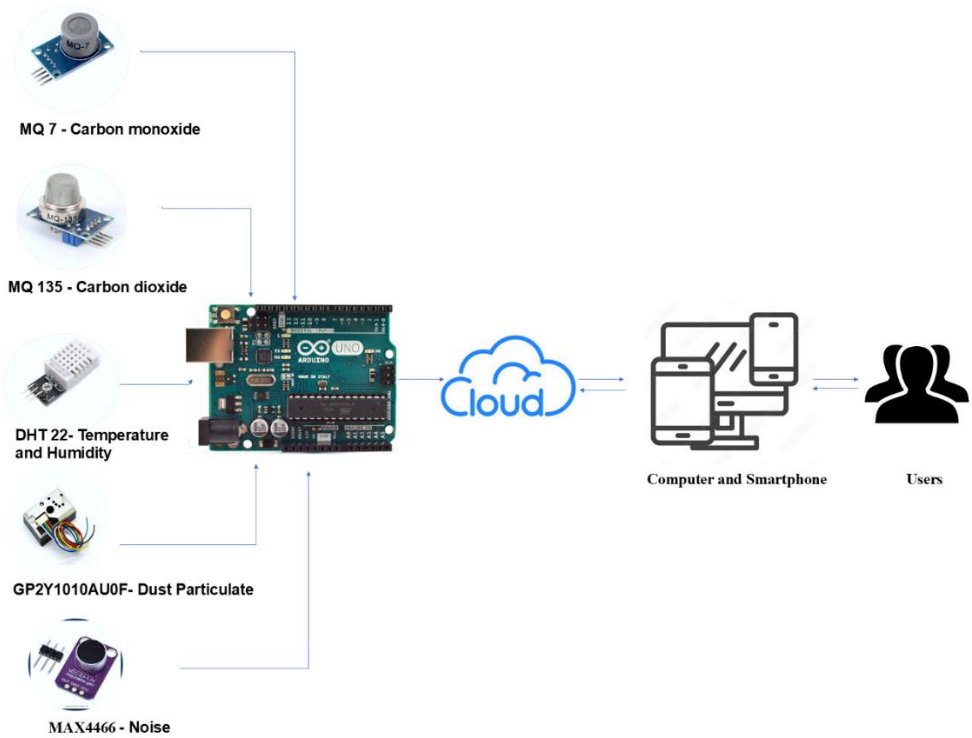

Figure 2. IoT air quality sensing node architecture

RESULT AND DISCUSSION

This study evaluated real-time outdoor air quality using IoT-based air and sound pollution monitoring system to detect environmental factors such as humidity, temperature, $PM_{2.5}$, CO, and CO_2, 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 [17], [20], [21], [22]. 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%), PM2.5 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))

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^{o}C was observed in Tanggul Mas at 06:00 am, while the highest temperature with 35^{o}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 increase 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 was 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 the decrease in humidity. The mean temperature showed an upward trend compared to previous measurements. These results indicated 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 [23]. 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 [24]. In addition, the point source of Tanggul Mas at 06:00 am appeared to have the lowest temperature (21^{o}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 [25]

Trends of PM2.5, CO, and CO2 in six-point sources

A fluctuate trend in the concentration of PM2.5, CO, and CO2 are shown in Fig. 5, Fig. 6, and Fig. 7, respectively. The highest level of PM2.5 was reached to 603 μg/m^3 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/Nm^3. 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/Nm^3 in 24- hour [26]. Air quality guideline under World health organization (WHO) regulates the standard of average concentration of $PM_{2.5}$ categorizing levels between 50-150 μg/m^3 as "very poor " [27].

We found that the highest level of $PM_{2.5}$ was reached to 603 μg/m^3 in La Sucipto at 11:00-12:00. In contrast, the lowest humidity was appeared of 33% in the same point sources and peak hours. Our study is supported by previous finding that relative humidity was the more influential factor for particulate matter rather than temperature. The concentration of PM2.5 and PM10 increases as the relative humidity decreases (<50 %) [28].

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 decrease trend during 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.

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 μg/Nm^3 [26]. 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 [29]. Our study indicated that CO_2 level remained in safe level.

Trends of noise level in six-point sources

Figure 8 depicted that the measured noise level was repeated in a uniformed manner over the course of a 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 [30]. 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 [31], [32], [33].

Several weather parameters are appeared to have higher concentration than before, it will increase the risk of disease-related air pollution. There was a significantly increment of 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 rise 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 [34]. Multiple studies have linked the association between exposures of short-term ambient air pollution and the burden disease of respiratory illness [35], [36], [37].

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 [38], [39] dominated by motorbikes, the number or 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 is 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 [40], [41].

This study is strengthened by using IoT-based air and sound pollution monitoring system to understand the real-time level and concentration of environmental factor. 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 includes data accuracy and the need for calibration to guarantee reliable measurements.

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

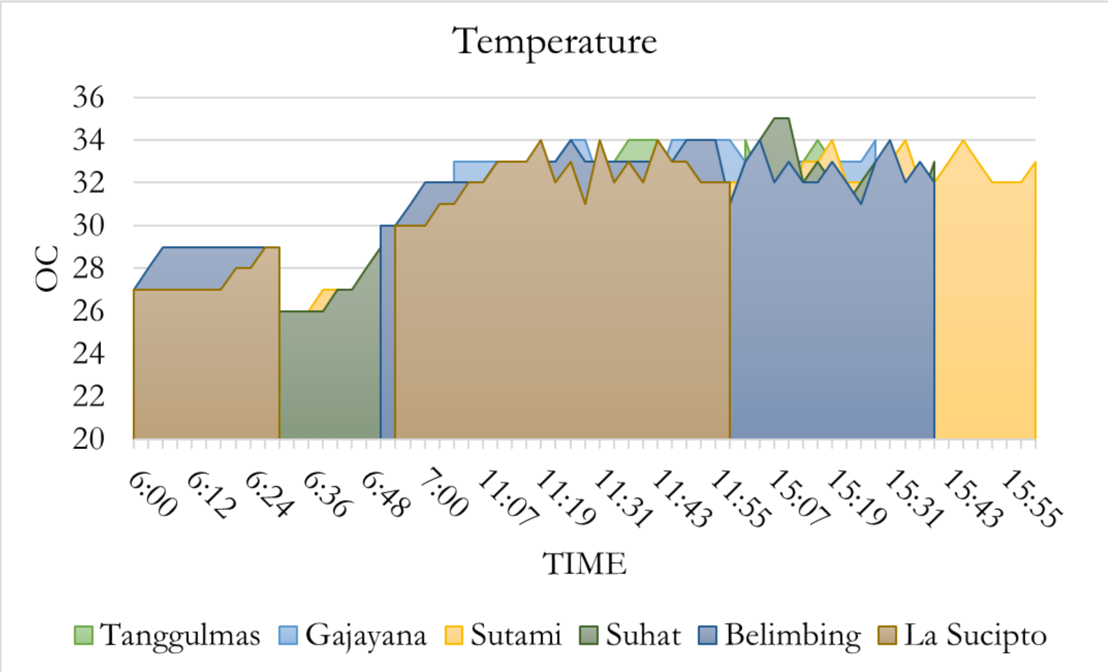

Figure 3. Temperature timeline graph

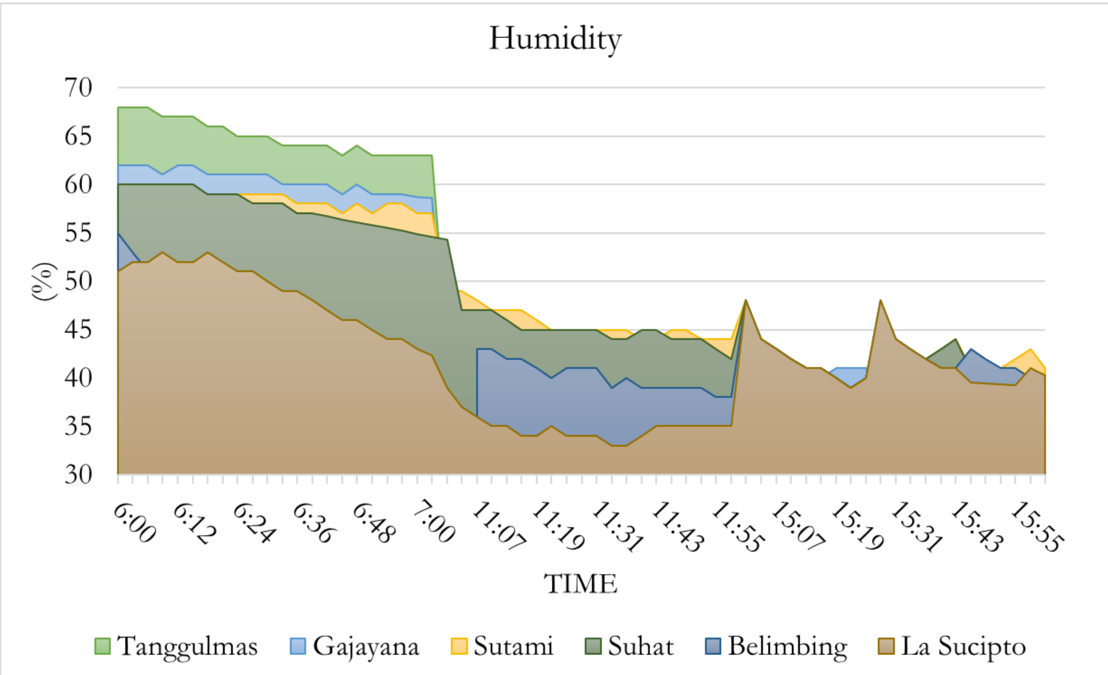

Figure 4. Humidity timeline graph

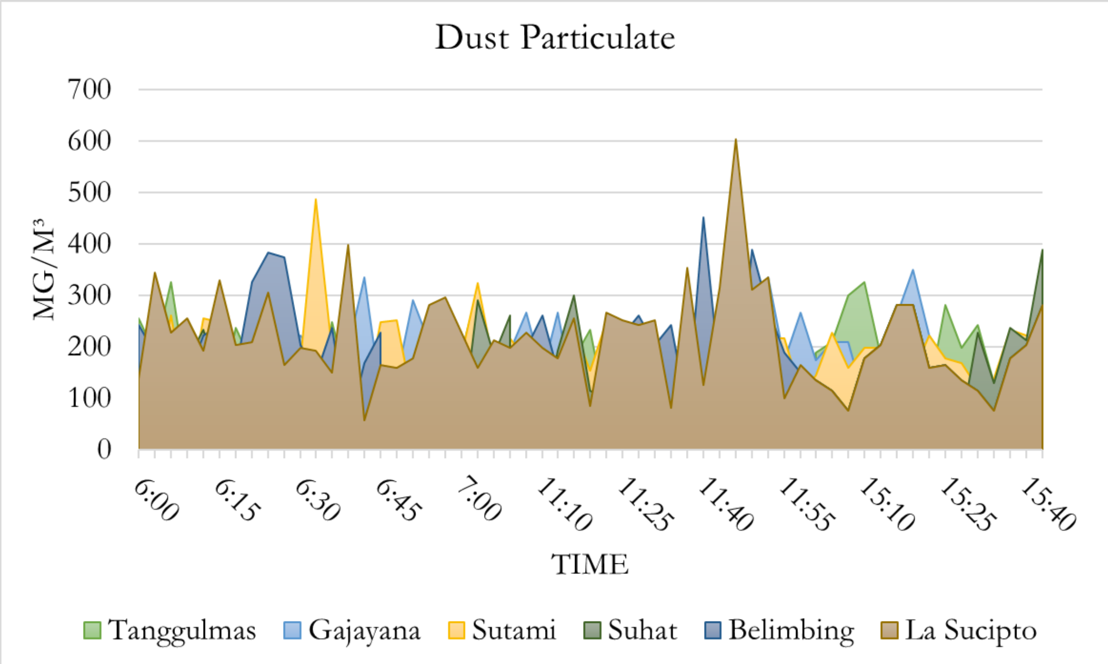

Figure 5. Particulate matter timeline graph

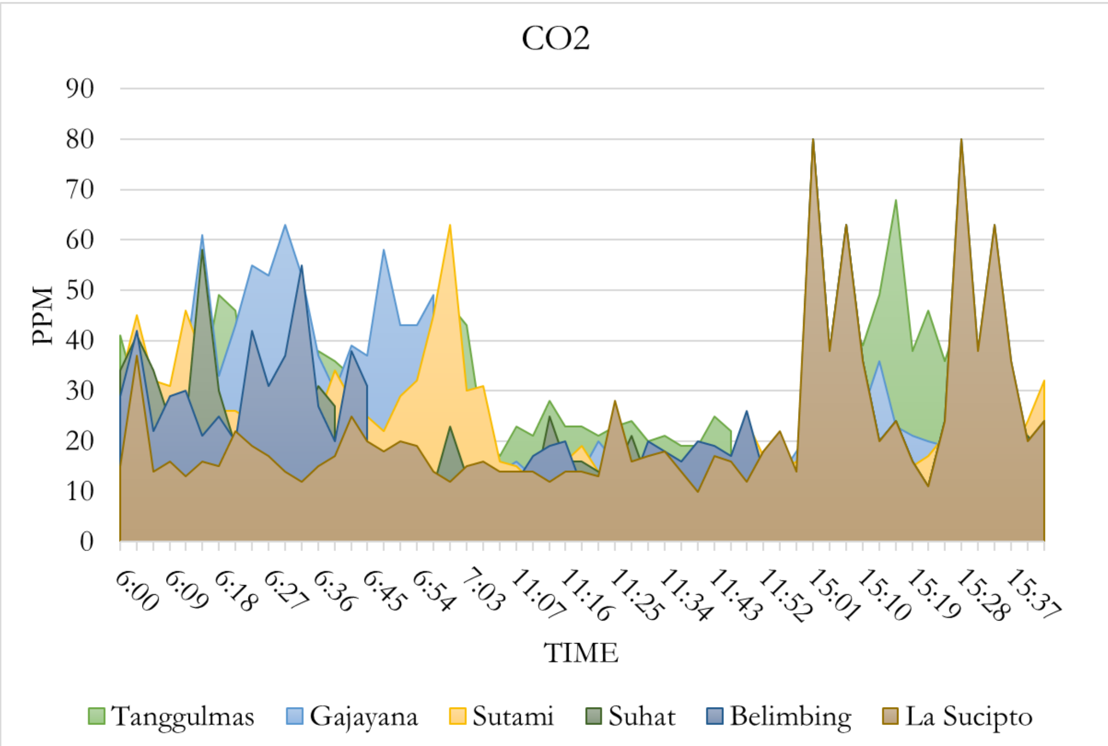

Figure 6. CO_2 timeline graph

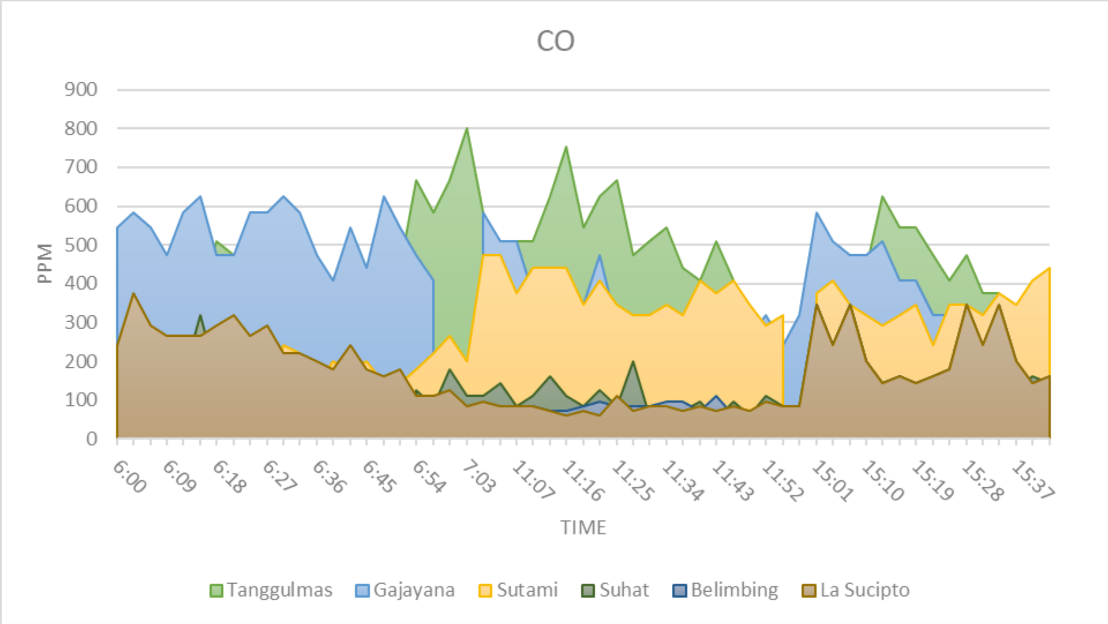

Figure 7. CO timeline graph

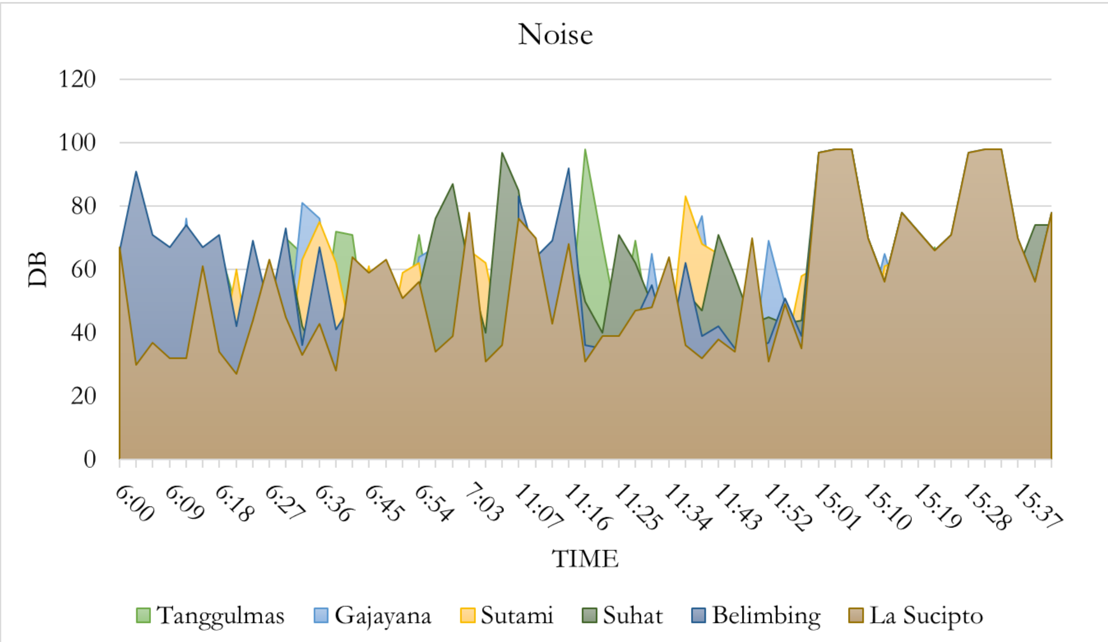

Figure 8. Noise timeline graph

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 functionated. 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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References

[1] J. Hansen, M. Sato, R. Ruedy, K. Lo, D. Lea, and M. Medina-Elizalde, "Global temperature change," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 103, pp. 14288–14293, Oct. 2006, doi: 10.1073/pnas.0606291103.

[2] T. Bauska, "Ice cores and climate change," British Antarctic Survey.

[3] IPCC, "Climate Change 2014 Synthesis Report," 2015. doi: 10.1016/S0022-0248(00)00575-3.

[4] Y. Liu *et al.*, "Impact of net zero policy scenarios on air pollution inequalities in England and Wales," *Environment International*, vol. 193, p. 109065, 2024, doi: https://doi.org/10.1016/j.envint.2024.109065.

[5] Y. Zafirah, Y. K. Lin, G. Andhikaputra, L. W. Deng, F. C. Sung, and Y. C. Wang, "Mortality and morbidity of asthma and chronic obstructive pulmonary disease associated with ambient environment in metropolitans in taiwan," *PLoS ONE*, vol. 16, no. 7 July, pp. 1–16, 2021, doi: 10.1371/journal.pone.0253814.

[6] Y. Zafirah, Y. K. Lin, G. Andhikaputra, F. C. Sung, L. W. Deng, and Y. C. Wang, "Mortality and morbidity of chronic kidney disease associated with ambient environment in metropolitans in Taiwan," *Atmospheric Environment*, vol. 289, no. June, p. 119317, 2022, doi: 10.1016/j.atmosenv.2022.119317.

[7] WHO, "Ambient (outdoor) air pollution," World Health Oraganization. Accessed: Nov. 22, 2024. Available: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health?gad_source=1&gclid=Cj0KCQiA0fu5BhDQARIsAMXUBOKc7O36qpuJLOibqlZTsHJH12zwAvci0a3Jh93gHHUxQhSO_A6LeecaAoESEALw_wcB

[8] B. S. Dewa and I. H. Santoso, "Perancangan Dan Implementasi Alat Pendeteksi Kebisingan Kendaraan Bermotor Berbasis Internet Of Things Dengan Menggunakan Sensor KY-037 Dan Sensor MAX4466 The Design And Implementation Of Motor Vehicle Noise Detection Equipment Based On Internet Of Things," *eProceedings of Engineering*, vol. 8, no. 6, p. 3463, 2022.

[9] A. Mehrotra, S. P. Shukla, A. K. Shukla, M. K. Manar, S. K. Singh, and M. Mehrotra, "A Comprehensive Review of Auditory and Non-Auditory Effects of Noise on Human Health," *Noise and Health*, vol. 26, no. 121, 2024.

[10] X. Gong *et al.*, "Association between Noise Annoyance and Mental Health Outcomes: A Systematic Review and Meta-Analysis," 2022. doi: 10.3390/ijerph19052696.

[11] E. Atmaca, I. Peker, and A. Altin, "Industrial Noise and Its Effects on Humans," vol. 14, no. 6, pp. 721–726, 2005.

[12] N. Jaafar, M. Y. Baharuddin, S. Aminudin, N. Yazid, M. Salleh, and M. Tahir, "Hearing Loss and Noise Exposure: A Review," vol. 6, pp. 128–134, Aug. 2023.

[13] C. W. Thara Seesaard, Kamonrat Kamjornkittikoon, "A comprehensive review on advancements in sensors for air pollution applications," *Science of the Total Environment*, vol. 951, 2024, doi: https://doi.org/10.1016/j.scitotenv.2024.175696.

[14] E. Apriawati, A. A. Kiswandono, and B. Lampung, "Kajian Indeks Standar Polusi Udara (ISPU) Nitrogen Dioksida (NO 2) Di Tiga Lokasi Kota Bandar Lampung," vol. 2, no. 01, pp. 42–51, 2017.

[15] P. Agista, N. Gusdini, and M. Maharani, "Analisis Kualitas Udara Dengan Indeks Standar Pencemar Udara (ISPU) Dan Sebaran Kadar Polutannya Di Provinsi Dki Jakarta," *Sustainable Environmental and Optimizing Industry Journal*, vol. 2, pp. 39–57, Sep. 2020, doi: 10.36441/seoi.v2i2.491.

[16] P. Deshmukh, S. Kimbrough, S. Krabbe, R. Logan, V. Isakov, and R. Baldauf, "Identifying air pollution source impacts in urban communities using mobile monitoring," *Science of the Total Environment*, vol. 715, p. 136979, 2020, doi: 10.1016/j.scitotenv.2020.136979.

[17] M. N. A. Ramadan, M. A. H. Ali, S. Y. Khoo, M. Alkhedher, and M. Alherbawi, "Real-time IoT-powered AI system for monitoring and forecasting of air pollution in industrial environment," *Ecotoxicology and Environmental Safety*, vol. 283, no. August, p. 116856, 2024, doi: 10.1016/j.ecoenv.2024.116856.

[18] M. N. A. Ramadan, M. A. H. Ali, S. Y. Khoo, M. Alkhedher, and M. Alherbawi, "Real-time IoT-powered AI system for monitoring and forecasting of air pollution in industrial environment," *Ecotoxicology and Environmental Safety*, vol. 283, no. August, p. 116856, 2024, doi: 10.1016/j.ecoenv.2024.116856.

[19] E. Collado *et al.*, "Open-source Internet of Things (IoT)-based air pollution monitoring system with protective case for tropical environments," *HardwareX*, vol. 19, no. January, 2024, doi: 10.1016/j.ohx.2024.e00560.

[20] S. M. S. D. Malleswari and T. K. Mohana, "Air pollution monitoring system using IoT devices: Review," *Materials Today: Proceedings*, vol. 51, pp. 1147–1150, 2022, doi: https://doi.org/10.1016/j.matpr.2021.07.114.

[21] N. Irbah, G. Nurika, and A. Ramani, "Implementation of Indoor Air Quality Monitoring Systems of Particulate Matter 2.5 Based on the Internet of Things," *Jurnal Kesehatan Lingkungan*, vol. 16, no. 3, pp. 266–276, 2024, doi: 10.20473/jkl.v16i3.2024.266-276.

[22] T. Fischer, "IoT Based Noise Monitoring System (NOMOS) IoT Based Noise Monitoring System (NOMOS)," 2020, doi: 10.1088/1757-899X/884/1/012080.

[23] World Meteorological Organization, "2024 is on track to be hottest year on record as warming temporarily hits 1.5°C," World Meteorological Organization. Accessed: Nov. 20, 2024. [Online]. Available: https://wmo.int/news/media-centre/2024-track-be-hottest-year-record-warming-temporarily-hits-15degc

[24] BMKG, "Potensi Wilayah Terdampak El Nino," Indonesia.

[25] S. Syed Othman Thani, N. Mohamad, and S. Syed Abdullah, "Influence of Urban Landscapes to Microclimatic Variances in a Tropical City," *Asian Journal of Behavioural Studies*, vol. 2, p. 31, Jul. 2017, doi: 10.21834/ajbes.v2i7.40.

[26] PP Nomor 22 Tahun 2021, "Peraturan Pemerintah Nomor 22 Tahun 2021 tentang Pedoman Perlindungan dan Pengelolaan Lingkungan Hidup," *Sekretariat Negara Republik Indonesia*, vol. 1, no. 078487A, pp. 1–483, 2021.

[27] W. H. Organization, *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. Geneva PP - Geneva: World Health Organization.

[28] E. Zender-Świercz, B. Galiszewska, M. Telejko, and M. Starzomska, "The effect of temperature and humidity of air on the concentration of particulate matter - PM2.5 and PM10," *Atmospheric Research*, vol. 312, p. 107733, 2024, doi: https://doi.org/10.1016/j.atmosres.2024.107733.

[29] D. Harista. and L. Jurusan, Teknik, "dihasilkan dari kegiatan penerbangan maupun kegiatan ground handling dan kegiatan main power station di Bandara Halim Perdanakusuma pada tahun 2014-2018. Lewat karya ilmiah ini, dapat mengetahui aktivitas pencemaran emisi atau GRK terhadap lingkungan di B," pp. 2014–2017, 2020.

[30] Menteri Negara Lingkungan Hidup, "Baku Tingkat Kebisingan," *Menteri Negara Lingkungan Hidup Nomor : KEP-48/MENLH/11/1996*, vol. 66, no. December, pp. 37–39, 1996.

[31] A. Arregi *et al.*, "Road traffic noise exposure and its impact on health: evidence from animal and human studies—chronic stress, inflammation, and oxidative stress as key components of the complex downstream pathway underlying noise-induced non-auditory health effects," *Environmental Science and Pollution Research*, vol. 31, no. 34, pp. 46820–46839, 2024, doi: 10.1007/s11356-024-33973-9.

[32] N. Mutalib *et al.*, "Disturbance of Traffic Noise: Evaluation on the Effects and Management on Road Corridors," *IOP Conference Series: Earth and Environmental Science*, vol. 143, p. 12049, Apr. 2018, doi: 10.1088/1755-1315/143/1/012049.

[33] M. Lutman, “What Is the Risk of Noise-Induced Hearing Loss at 80, 85, 90 dB(A) and Above?,” *Occupational medicine (Oxford, England)*, vol. 50, pp. 274–275, Jun. 2000, doi: 10.1093/occmed/50.4.274.

[34] BPS, “Jumlah Kasus Penyakit Terbanyak di Kota Malang (Jiwa),” BPS-Statistic Malang Municipality. Accessed: Nov. 20, 2024. [Online]. Available: https://malangkota.bps.go.id/id/statistics-table/2/MzcxIzI=/jumlah-kasus-penyakit-terbanyak-di-kota-malang.html

[35] D. P. Croft *et al.*, “The Association between Respiratory Infection and Air Pollution in the Setting of Air Quality Policy and Economic Change.,” *Annals of the American Thoracic Society*, vol. 16, no. 3, pp. 321–330, Mar. 2019, doi: 10.1513/AnnalsATS.201810-691OC.

[36] A. Monoson *et al.*, “Air pollution and respiratory infections: the past, present, and future.,” *Toxicological sciences : an official journal of the Society of Toxicology*, vol. 192, no. 1, pp. 3–14, Mar. 2023, doi: 10.1093/toxsci/kfad003.

[37] H. M. Tran *et al.*, “The impact of air pollution on respiratory diseases in an era of climate change: A review of the current evidence,” *Science of The Total Environment*, vol. 898, p. 166340, 2023, doi: https://doi.org/10.1016/j.scitotenv.2023.166340.

[38] Pemerintah Kota Malang, “Kasus ISPA Naik, Ini Imbauan Kadinkes Kota Malang,” *Pemerintah Kota Malang*, Malang, Sep. 26, 2023.

[39] D. Irwanto, “Cuaca Ekstrem Picu Lonjakan Ispa di Malang,” *Metro News*, Malang, 2023.

[40] Pemerintah Kota Malang, “Dinas Lingkungan Hidup,” *Profil Dinas Lingkungan Hidup*, no. 6, pp. 0–96, 2023.

[41] B. J. W. Utomo, “Mengurangi Emisi Co2 Dan Co Untuk Menuju Ruang Kehidupan Kota Yang Nyaman Dan Berkelanjutan Di Kawasan Kota Malang,” *Spectra*, vol. 10, no. 20, pp. 1–10, 2012.

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