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Spatial Analysis of Carbon Monoxide Concentrations in Banda Aceh Using Google Earth Engine

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Abstract: This study investigates greenhouse gas (GHG) emissions, with a focus on carbon monoxide (CO), in Banda Aceh City to identify their sources and spatial distribution. Google Earth Engine (GEE) was utilized to process and analyze Sentinel-5P satellite data from November 2023 to November 2024. The results indicate that CO emissions are mainly generated by transportation, industrial activities, and forest fires, reflecting the significant influence of human activities on air quality. Spatial analysis reveals that northern coastal sub-districts, including Kutaraja, Kuta Alam, and Syiah Kuala, experience the highest CO concentrations, while Meuraxa and Jaya Baru show moderate levels, and southern and inland sub-districts such as Banda Raya, Ulee Kareng, and Lueng Bata exhibit low concentrations. The distribution pattern highlights the role of population density, economic activity, and land cover in shaping emission intensity. By leveraging near real-time satellite monitoring, this study provides detailed emission mapping that can guide urban air quality management and climate mitigation strategies. These findings serve as a valuable reference for policymakers and researchers in formulating emission reduction measures and enhancing climate resilience in urban environments.

Keywords: Banda Aceh; Carbon monoxide; Emissions; Google earth engine; Greenhouse gases

Introduction

Urban air pollution continues to present a substantial challenge for numerous Indonesian cities, including Banda Aceh, where accelerated urbanisation and the proliferation of motorised transportation have contributed significantly to deteriorating air quality. Among the various air pollutants, carbon monoxide (CO) merits particular attention due to its direct impact on human health and its role as an indicator of incomplete fuel combustion in urban environments. In contrast to major greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), or nitrous oxide (N_2O), CO does not directly cause long-term global warming but is a key pollutant regulated for public health protection and urban air quality standards (Jafari et al., 2021; Kumar et al., 2016; Pratama, 2016).

High concentrations of carbon monoxide (CO) in urban areas are typically associated with three main factors. Firstly, dense traffic flow is a significant contributing factor. Secondly, inefficient vehicle engines are another key factor. And finally, industrial activities are a primary cause. Prolonged exposure to CO has been demonstrated to reduce oxygen delivery in the human body, which can result in various health risks, particularly for vulnerable groups such as children and the elderly (Tjiwidjaja et al., 2023). In Banda Aceh, the transportation sector has been identified as the primary source of air pollutants, with additional contributions from industrial emissions and household activities (Butler et al., 2018). Despite its significance, studies focusing on the spatial distribution of CO in Banda Aceh remain limited.

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Advancements in remote sensing and cloud-based platforms, such as Google Earth Engine (GEE), have led to the development of efficient and scalable methodologies for the monitoring of air pollutants, including CO, through satellite observations. The utilisation of Sentinel-5P imagery through GEE facilitates researchers in conducting time-series analysis and spatial mapping without the necessity for extensive field measurements (Latue et al., 2023). Although analogous approaches have been implemented in other urban areas, including Palembang, Bogor, and Yogyakarta, there remains a paucity of studies conducted in Banda Aceh.

This research addresses this lacuna by estimating and mapping the distribution of carbon monoxide concentrations in Banda Aceh using Sentinel-5P data processed in GEE. The novelty of this study lies in its provision of a detailed spatial overview of CO pollution for Banda Aceh, which can serve as an initial reference for local authorities to develop targeted mitigation strategies and urban air quality management plans. The objective of this study is threefold: firstly, to analyse the spatial variation of CO concentrations across different sub-districts within Banda Aceh; secondly, to identify potential hotspot areas; and thirdly, to discuss plausible factors influencing the observed patterns.

Method

This study was conducted in Banda Aceh City, which is located at the westernmost point of Sumatra Island. The city is located at an average elevation of approximately 0.80 meters above sea level, with geographic coordinates ranging from 05° 16' 15" to 05° 36' 16" North Latitude and 95° 16' 15" to 95° 22' 35" East Longitude. This serves to underscore its status as a significant urban centre within the province of Aceh. In light of the escalating levels of urban activity and traffic density, it is imperative to establish a comprehensive monitoring system for carbon monoxide (CO) levels in this area. This initiative is crucial in order to ensure the preservation of local air quality and the safeguarding of public health.

In order to address this issue, the present research employed the Google Earth Engine (GEE), a cloud-based geospatial analysis platform that allows for the efficient and large-scale processing of satellite imagery. The CO concentration data were obtained from the Sentinel-5P satellite, which provides near real-time observations suitable for air pollution studies.

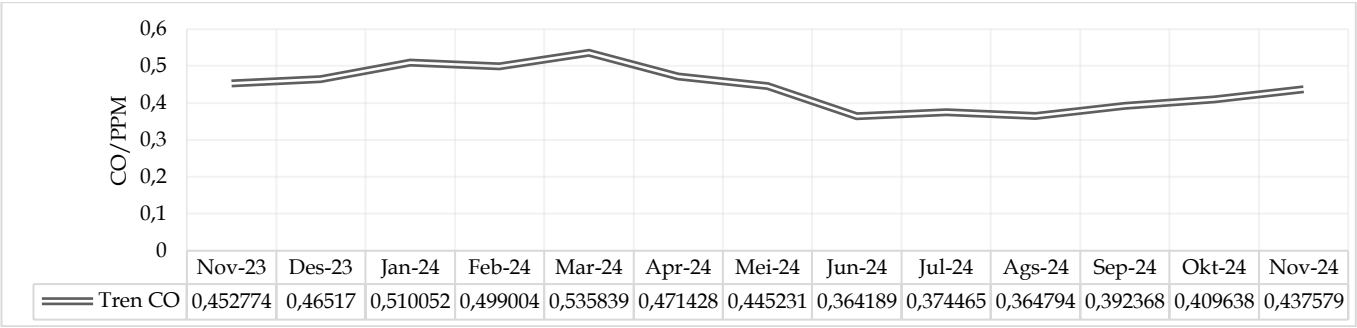
The methodology comprised three primary stages. Initially, CO satellite data were collected and pre-processed using the tools available within the GEE platform. Secondly, a time series analysis was performed in order to examine the spatial and temporal distribution patterns of CO in Banda Aceh. This analysis enabled the identification of areas characterised by either consistently high or fluctuating CO concentrations. Thirdly, the processed results were exported and visualised using ArcGIS 10.8 to produce thematic maps showing the distribution of CO across sub-districts.

The final maps and associated datasets were compiled with the aim of supporting interpretation and providing evidence-based insights for local policymakers seeking to manage air quality more effectively.

Result and Discussion

The levels of carbon monoxide (CO) emissions in Banda Aceh are influenced by multiple sectors, particularly transportation, energy use, open burning, and both domestic and commercial activities. Based on the analysis, CO concentrations in the city show a seasonal fluctuation pattern rather than a consistent upward or downward trend over the observation period from November 2023 to November 2024. These trends are illustrated in Figure 1, which presents the monthly average CO concentrations.

The analysis conducted indicates that there is a monthly fluctuation in carbon monoxide (CO) emissions in Banda Aceh. These fluctuations are influenced by factors such as transportation activities, fuel combustion, and changes in community activity patterns.



	Nov-23	Des-23	Jan-24	Feb-24	Mar-24	Apr-24	Mei-24	Jun-24	Jul-24	Ags-24	Sep-24	Okt-24	Nov-24
Tren CO	0,452774	0,46517	0,510052	0,499004	0,535839	0,471428	0,445231	0,364189	0,374465	0,364794	0,392368	0,409638	0,437579

Figure 1. The pattern of carbon monoxide (CO) concentration in Banda Aceh from November 2023 to November 2024

The highest CO concentration was recorded in March 2024, peaking at 0.536 ppm, with the maximum daily concentration reaching 0.663 ppm on March 17 (Google Earth Engine, 2024). After March, CO levels gradually declined, reaching the lowest point in June 2024, before rising again toward the end of the year. Despite these fluctuations, the measured values remain well below the WHO guideline limit of 8.7 ppm for 8-hour exposure and the Indonesian government's regulatory limits of 7.8 ppm for 24-hour exposure and 26 ppm for 1-hour exposure (WHO, 2021). Therefore, the overall air quality in Banda Aceh can be considered safe, with no immediate health risks to the general population.

These seasonal fluctuations are likely influenced by meteorological variables such as temperature, humidity, wind speed, and direction, all of which can affect the dispersion of air pollutants (Chaudhry et al., 2024; Pérez et al., 2020; Sharma et al., 2022; Shelton et al., 2022). Human activities, including traffic volume and open burning, are also major contributors to CO emissions (Jiang et al., 2025). Notably, the sharp increase in March 2024 aligns with a reported wildfire incident, which according to BPBA (2024), contributed approximately 54% of total emissions during that period. This finding is consistent with Thakur et al. (2019), who emphasized that CO is a major by-product of incomplete combustion, especially from fires. Furthermore, Timofeev et al. (2024) noted that CO can persist in the atmosphere and contribute to tropospheric ozone formation, another harmful air pollutant.

The distribution of greenhouse gas (GHG) emissions in Banda Aceh is a crucial factor in understanding air quality and its impact on climate change. The distribution of these emissions, which are produced by various sectors, including transportation, industry, and biomass burning, can be unevenly dispersed throughout the city. This distribution is influenced by several factors, including population density, economic activities, and meteorological conditions, all of which can affect the dispersion of pollutants (Dong et al., 2020; Espira et al., 2023; Liang et al., 2019; Lv et al., 2021; Yang et al., 2020). Consequently, the mapping and analysis of the distribution of these emissions is imperative for the identification of significant pollution sources and the development of more efficacious mitigation strategies. The distribution of GHG emissions in Banda Aceh is illustrated in Figure 2.

The distribution of carbon monoxide (CO) emissions in Banda Aceh exhibits variability across different districts, influenced by human activity levels and major emission sources such as transportation and industry. The distribution of CO emissions can be observed in Figure 2.

Figure 2 shows the spatial distribution of carbon monoxide (CO) concentrations in Banda Aceh from November 2023 to November 2024. High CO concentrations (red zone) are predominantly located in the northern coastal districts of Kutaraja, Kuta Alam, and Syiah Kuala. These areas coincide with major roads, port access, and small-scale industrial clusters, which are potential contributors to local CO emissions (Hazaymeh et al., 2024).

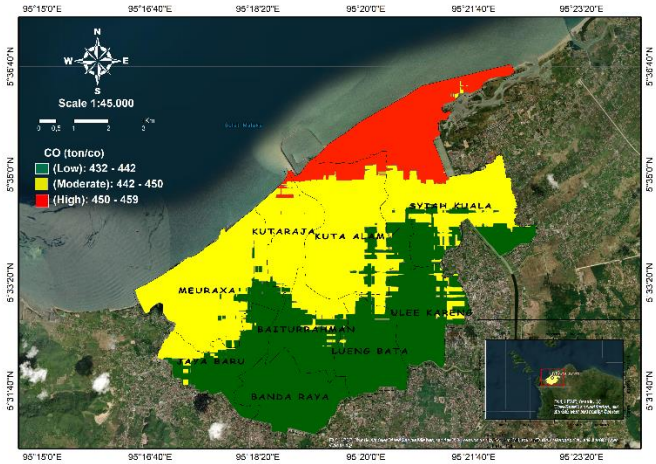


Figure 2. Map of carbon monoxide (CO) from november 2023 to november 2024 in Banda Aceh

Moderate concentrations (yellow zone) are mainly observed in Meuraxa, Kuta Alam, and parts of Kutaraja, reflecting mixed residential and urban activities. In contrast, the southern districts—Banda Raya, Jaya Baru, Lueng Bata, and Ulee Kareng—show predominantly low CO levels (green zone), which aligns with their lower traffic density and higher coverage of green areas.

This spatial pattern indicates that human activities, particularly trnsportation and localized industry, influence CO distribution in Banda Aceh, while meteorological factors may further affect pollutant dispersion. The extent of the areas affected by CO emissions can be seen in Table 1.

As illustrated in Table 1, the area of sub-districts in Banda Aceh affected by greenhouse gas emissions, specifically carbon monoxide (CO), is categorised according to concentration levels: low, medium, and high. The Baiturrahman sub-district has a total affected area of 415.16 ha, with 70.35% in the low category and 29.65% in the medium category. In contrast, the Banda Raya sub-district, which encompasses an area of 479.43 ha, is exclusively affected by low-level emissions. In Jaya Baru sub-district, 77.94% of the area is affected by the low category and 22.06% by the medium category.

The Kuta Alam sub-district, on the other hand, demonstrates a more widespread impact, exhibiting presence across all three categories. 12.92% low, 74.51% medium, and 12.57% high. The Kutaraja sub-district is

predominantly affected by the medium category (94.16%), followed by the low category (2.21%) and high category (3.63%). The Lueng Bata sub-district is predominantly affected by the low category (93.38%) and medium category (6.62%).

The Syiah Kuala sub-district has the most significant impact, with 44.77% of the area classified as high, 37.29% as medium, and 17.94% as low. The Ulee Kareng sub-district is predominantly affected by the low category (87.18%) and the medium category (12.79%).

Table 1. Area of Sub-districts Affected by Carbon Monoxide (CO) Concentration Based on Emission Levels in Banda Aceh

Sub-district Name	Low Area		Moderate Area		High Area	
	Ha	%	Ha	%	Ha	%
Baiturrahman	292.07	70.35	123.08	29.65	-	0.00
Banda Raya	479.42	100	-	0.00	-	0.00
Jaya Baru	339.35	77.94	96.07	22.06	-	0.00
Kuta Alam	120.74	12.92	696.55	74.51	117.55	12.57
Kutaraja	7.91	2.21	336.64	94.16	12.96	3.63
Meuraxa	94.14	10.74	782.40	89.26	-	0.00
Lueng Bata	400.95	93.38	28.40	6.62	-	0.00
Syiah Kuala	255.23	17.94	530.60	37.29	637.03	44.77
Ulee Kareng	435.11	87.21	63.81	12.79	-	0.00

The disparities in CO emissions between Syiah Kuala and Kutaraja sub-districts are influenced by factors such as population density, economic activity, and green spaces. Syiah Kuala, characterised by its higher population density and intense urban activity, exhibits higher CO emissions, while Kutaraja, with its smaller population and greater abundance of green spaces, demonstrates lower CO emissions. The geographical characteristics of both areas also have a significant impact on the accumulation of emissions.

Conclusion

The analysis of carbon monoxide (CO) emissions in Banda Aceh from November 2023 to November 2024 shows spatial variability strongly influenced by human activities, particularly transportation and industrial operations. The highest CO concentrations are detected in the northern coastal sub-districts of Syiah Kuala, Kuta Alam, and Kutaraja, which correspond to areas with dense urban and economic activity. Moderate concentrations are observed in Meuraxa and Jaya Baru, whereas Banda Raya, Lueng Bata, and Ulee Kareng exhibit the lowest levels of CO emissions. Areas with lower CO concentrations generally coincide with less densely built environments and the presence of green spaces, although a direct causal relationship cannot be conclusively established from this study. These findings highlight the importance of targeted emission mitigation efforts in high-concentration areas to support sustainable urban air quality management.

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Author Contributions

Dr. Ir. Wira Dharma, S.Si., M.P., M.Si., and Dr. Alia Rizki, S.Si., M.Sc., acted as thesis advisors, providing invaluable guidance in the planning, methodology, and data analysis of this study. Dr. Wira Dharma contributed to the direction of the research methodology and analysis approach, while Dr. Alia Rizki offered profound insights into data processing and interpretation. The author, Nakita Chairunnisa, was responsible for data collection, writing, and editing this paper, integrating the contributions from both advisors to achieve optimal results.

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Conflicts of Interest

No conflicts of interest were declared by the author.

References

Butler, C. D., & Whelan, J. (2018). Air Pollution and Climate Change in Australia: A Triple Burden. In *Climate Change and Air Pollution* (pp. 131–149). Springer Climate. https://doi.org/10.1007/978-3-319-61346-8_9

Chaudhry, S. K., Tripathi, S. N., Reddy, T. V. R., Kumar, A., Madhwal, S., Yadav, A. K., & Pradhan, P. K. (2024). Influence of seasonal variation on spatial distribution of PM2.5 concentration using low-cost sensors. *Environmental Monitoring and Assessment*,

196(12). https://doi.org/10.1007/s10661-024-13377-5

Dong, X., Zhao, X., Peng, F., & Wang, D. (2020). Population based Air Pollution Exposure and its influence factors by Integrating Air Dispersion Modeling with GIS Spatial Analysis. *Scientific Reports*, *10*(1), 479. https://doi.org/10.1038/s41598-019-57385-9

Espira, L. M., Gessese, B., Kassa, B. A., Wu, C.-C., Riley, J., Bedru, S., Sahilu, G., Desta, A., Baye, K., Jones, A. D., Love, N. G., & Eisenberg, J. N. S. (2023). Multiscalar Evaluation of the Water Distribution System and Diarrheal Disease Risk in Addis Ababa, Ethiopia. *Environmental Science & Technology*, *57*(36), 13313–13324. https://doi.org/10.1021/acs.est.2c08976

Hazaymeh, K., & Al-Jarrah, M. (2024). Assessing the impact of land cover on air quality parameters in Jordan: A spatiotemporal study using remote sensing and cloud computing (2019–2022). *International Journal of Applied Earth Observation and Geoinformation*, *135*, 104293. https://doi.org/10.1016/j.jag.2024.104293

Jafari, A. J., Charkhloo, E., & Pasalari, H. (2021). Urban air pollution control policies and strategies: a systematic review. *Journal of Environmental Health Science and Engineering*, *19*(2), 1911–1940. https://doi.org/10.1007/s40201-021-00744-4

Jiang, T., Jia, G., Yu, X., Zhang, T., & Feng, Y. (2025). Hydrologic Response to Extreme Climate Change in the Qinghai Lake Basin. *Climatic Change*, *169*(3). https://doi.org/10.2139/ssrn.5168485

Kumar, R., & Gupta, P. (2016). Air Pollution Control Policies and Regulations. In *Plant Responses to Air Pollution* (pp. 133–149). Springer Singapore. https://doi.org/10.1007/978-981-10-1201-3_12

Latue, P. C., Rakuasa, H., & Sihasale, D. A. (2023). Analisis Kerapatan Vegetasi Kota Ambon Menggunakan Data Citra Satelit Sentinel-2 dengan Metode MSARVI Berbasis Machine Learning pada Google Earth Engine. *Sudo Jurnal Teknik Informatika*, *2*(2), 68–77. https://doi.org/10.56211/sudo.v2i2.270

Liang, D., Wang, Y., Wang, Y., & Ma, C. (2019). National air pollution distribution in China and related geographic, gaseous pollutant, and socio-economic factors. *Environmental Pollution*, *250*, 998–1009. https://doi.org/10.1016/j.envpol.2019.03.075

Lv, W., Wu, Y., & Zang, J. (2021). A Review on the Dispersion and Distribution Characteristics of Pollutants in Street Canyons and Improvement Measures. *Energies*, *14*(19), 6155. https://doi.org/10.3390/en14196155

Pérez, I. A., García, M. Á., Sánchez, M. L., Pardo, N., & Fernández-Duque, B. (2020). Key Points in Air Pollution Meteorology. *International Journal of Environmental Research and Public Health*, *17*(22), 8349. https://doi.org/10.3390/ijerph17228349

Pratama, R. (2016). Efek rumah kaca terhadap bumi. *Buletin Utama Teknik*, *3814*(2), 120–126. Retrieved from https://jurnal.uisu.ac.id/index.php/but/article/view/1096

Sharma, P., Peshin, S. K., Soni, V. K., Singh, S., Beig, G., & Ghosh, C. (2022). Seasonal dynamics of particulate matter pollution and its dispersion in the city of Delhi, India. *Meteorology and Atmospheric Physics*, *134*(2), 28. https://doi.org/10.1007/s00703-021-00852-8

Shelton, S., Liyanage, G., Jayasekara, S., Pushpawela, B., Rathnayake, U., Jayasundara, A., & Jayasooriya, L. D. (2022). Seasonal Variability of Air Pollutants and Their Relationships to Meteorological Parameters in an Urban Environment. *Advances in Meteorology*, *2022*, 1–18. https://doi.org/10.1155/2022/5628911

Thakur, J., Thever, P., Gharai, B., Sesha Sai, M., & Pamaraju, Vnr. (2019). Enhancement of carbon monoxide concentration in atmosphere due to large scale forest fire of Uttarakhand. *PeerJ*, *7*, e6507. https://doi.org/10.7717/peerj.6507

Timofeev, Y. M., & Nerobelov, G. M. (2024). Satellite Investigations of the Atmospheric Gas Composition. *Izvestiya, Atmospheric and Oceanic Physics*, *60*(6), 660–688. https://doi.org/10.1134/S0001433824700658

Tjiwidjaja, H., & Salima, R. (2023). Dampak Energi Fosil Terhadap Perubahan Iklim Dan Solusi Berbasis Energi Hijau. *Jurnal Wilayah, Kota Dan Lingkungan Berkelanjutan*, *2*(2), 166–172. https://doi.org/10.58169/jwikal.v2i2.625

WHO. (2021). *Air quality and health*. Retrieved from https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

Yang, J., Shi, B., Shi, Y., Marvin, S., Zheng, Y., & Xia, G. (2020). Air pollution dispersal in high density urban areas: Research on the triadic relation of wind, air pollution, and urban form. *Sustainable Cities and Society*, *54*, 101941. https://doi.org/10.1016/j.scs.2019.101941