



Evaluating the Impact of the G20 Presidency on CO Emission Concentration in Bali: A Spatiotemporal Analysis Using Google Earth Engine

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ABSTRACT

This study aims to measure the effectiveness of the CO emission reduction policy implemented, by analyzing the spatiotemporal distribution of CO emissions before, during, and after the implementation of the G20 Summit centered in the cities of Denpasar and Nusa Dua, Bali. This study uses a mixed method approach with primary data collection using remote sensing technology, namely the Sentinel-5 Precursor satellite (NRTI CO product), and secondary data collection from journals and online media. Based on the analysis of CO density in Bali during the period from July 2022 to March 2023, it was found that during the implementation of the G20 Summit in November 2022, there was a decrease in CO emissions. Further analysis showed that this decrease was largely controlled by weather factors, especially high rainfall in November - December, which accelerated the wet deposition process to clean pollutants from the atmosphere. While policies such as traffic engineering management, the use of electric vehicles, and vehicle restrictions during the G20 Summit contributed to the reduction in emissions, the impact was temporary because their implementation was limited only during the event. After the policy was stopped, emissions increased again approaching normal patterns. So this emphasizes the importance of integrated and long-term transportation and environmental policies to maintain air quality in Bali. Ultimately, the use of Google Earth Engine proved effective in mapping changes in CO density spatially and temporally, providing in-depth insight into the distribution of pollutant emissions in relation to human activities and weather conditions.

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ARTICLE INFO

Article History:

Submitted/Received 7 April 2025

First Revised 16 August 2025

Accepted 09 Oct 2025

First Available online 31 Oct 2025

Publication Date 31 Oct 2025

Keyword:

G20,

Carbon monoxide emissions,

Air quality,

Environmental policy,

Google Earth Engine

1. INTRODUCTION

The G20 or Group of Twenty is a multilateral cooperation forum consisting of countries with large economies in the world consisting of 19 countries and the European Union (EU). (Putri, 2020). This inter-country meeting was officially held for two days on November 15-16, 2022 in Bali, Indonesia, carrying the theme "Recover Together, Recover Stronger". Indonesia discussed three main things in the G20 Presidency, including: First, inclusive health care. Second, digital-based transformation. Third, the transition to sustainable energy. The goal of the G20 is to realize strong, sustainable, balanced, and inclusive global growth (Ariyanti, 2023 and Amalika et al, 2024; Astari et al; 2021).

According to Circular Letter Number 35425/SEKRET/2022 issued by the Ministry of State Secretariat (2022), restrictions on community activities were imposed in preparation for the G20 Summit around the event area, namely in Kuta District, South Kuta District, Badung Regency, and South Denpasar. This policy was implemented through the implementation of work from home for State Civil Apparatus (ASN), online learning for all students, and the elimination of religious and cultural activities for 12-19 November 2022. In addition, a low-emission transportation policy was enforced by implementing an odd-even system for conventional vehicles, reducing commercial flights both domestically and internationally, and procuring various electric vehicle transportation fleets complete with electric vehicle charging stations. At least the government has prepared 30 red and white electric buses (BLMP), in addition, 90 electric motorcycle taxis and 66 SPKLU with ultrafast charging and fast charging are also provided (Andro, 2022). This effort was made as a form of Indonesia's commitment as a G20 presidency country in 2022 as well as to reduce carbon monoxide emissions resulting from this major event.

Carbon monoxide is a major pollutant in the form of a colorless, tasteless, non-irritating, and odorless gas (Nindiati et al, 2023 in Santamajati and Suharyadi, 2024). This gas has a lower specific gravity than air and is very stable with a residence time in the air of 2 to 4 months. Excess concentrations of carbon monoxide, along with several other gases such as methane, can act as greenhouse gases and can increase the temperature of the earth's surface due to the trapping of long-wave radiation (Harahap, 2021; Winata, 2020). Carbon monoxide emissions are the emissions most emitted by motor vehicle exhaust emissions. CO emissions themselves are produced by incomplete combustion of carbon compounds. around 64% of CO emissions in urban areas are caused by motor vehicles (Dey and Dhal, 2020). In addition to combustion activities, the concentration of CO in the atmosphere is also influenced by weather and climate conditions, one of which is the concentration of OH radicals in the atmosphere. OH radicals are the main absorbers of CO in the atmosphere through oxidation reactions that form CO₂ and H, with their concentrations influenced by water vapor produced from ozone photolysis and convective activities such as lightning (Seinfeld, J. H, 2016; Arwin, 2019; Feig, 2014). Thus, in this study, rainfall in the Bali area was also observed as one of the weather factors that affect CO concentration. Although rain does not directly absorb CO, high rainfall can increase OH levels through the availability of water vapor and the removal of CO precursors, thereby accelerating CO oxidation in the atmosphere (Seinfeld and Pandis, 2016). In conclusion, this study was conducted to determine the distribution of carbon monoxide (CO) emissions produced during the G20 Summit in Bali and the policies that influence it.

2. METHODS

This study uses a mixed method approach that uses primary data obtained from remote sensing methods and secondary data collection in the form of journals to online media. This

study was conducted in the Bali Island area using primary data in the form of Level 3 satellites from the Sentinel-5 Precursor type of NRTI (Near Real-Time) CO (Carbon Monoxide) product. The Sentinel-5P satellite was issued by ESA (European Space Agency) in 2018 to observe the appearance of the earth's atmosphere. Google Earth Engine (GEE) itself is a cloud platform/computing that allows users to analyze environmental data on a global scale and is based on the JavaScript programming language (Shelestov et al, 2017; Indriyaningtyas et al, 2021; Piraliluo et al, 2022). Google Earth Engine is an effective cloud computing platform for processing spatial data on a large scale in a relatively short time. The integration of multi-spectral data with machine learning in GEE has proven effective in extracting information so that it can reveal detailed environmental change patterns from satellite image time series data (Aldiansyah et al, 2021; Faj'ri et al, 2024; Sutrisno et al, 2024). Furthermore, to analyze data requirements, carbon monoxide (CO) information processing is carried out using JavaScript syntax in the Google Earth Engine Code Editor to obtain CO concentration column information representing CO levels in the atmosphere (Giananti et al, 2023; Yusuf et al, 2024).

The CO concentration value was obtained by first extracting the daily maximum value from the Sentinel-5P image. The Sentinel-5P image has a pixel size of 1,113.2 meters with a spatial resolution of 7x7 km². From the daily maximum data, the median function was used to extract the CO concentration value. The median provides a better picture of the condition of the CO data experienced during a month (Yusuf et al, 2024). The selection of the data observation time for the GEE was carried out during the implementation period of the G20 Summit in 2022 that located in Bali Island (Figure 1), where the months before the event were July - October 2022, during the G20 event in November 2022, and after the G20 event in December 2022 - March 2023. Data sampling was conducted during the period July 2022 – March 2023 to obtain complete data so that an evaluation of CO emissions during the G20 Summit could be conducted (Table 1). In addition, to determine the CO change factors, a comparison was also carried out with rainfall data obtained from GEE data processing and domestic tourist visit data during 2018-2023 from the Bali Provincial Statistics Agency data. Other software used is Quantum GIS where QGIS software is open source and can be used to create, edit, visualize, analyze, and publish geospatial data (Santamajati and Suharyadi, 2024). In addition, secondary information mining was also carried out by reviewing the policies and regulations issued by the central and regional governments during the G20 Summit in Bali which have the potential to affect the spatiotemporal spread of CO (Figure 2).



Figure 1. Research location map CO Emission Concentration in Bali Island.

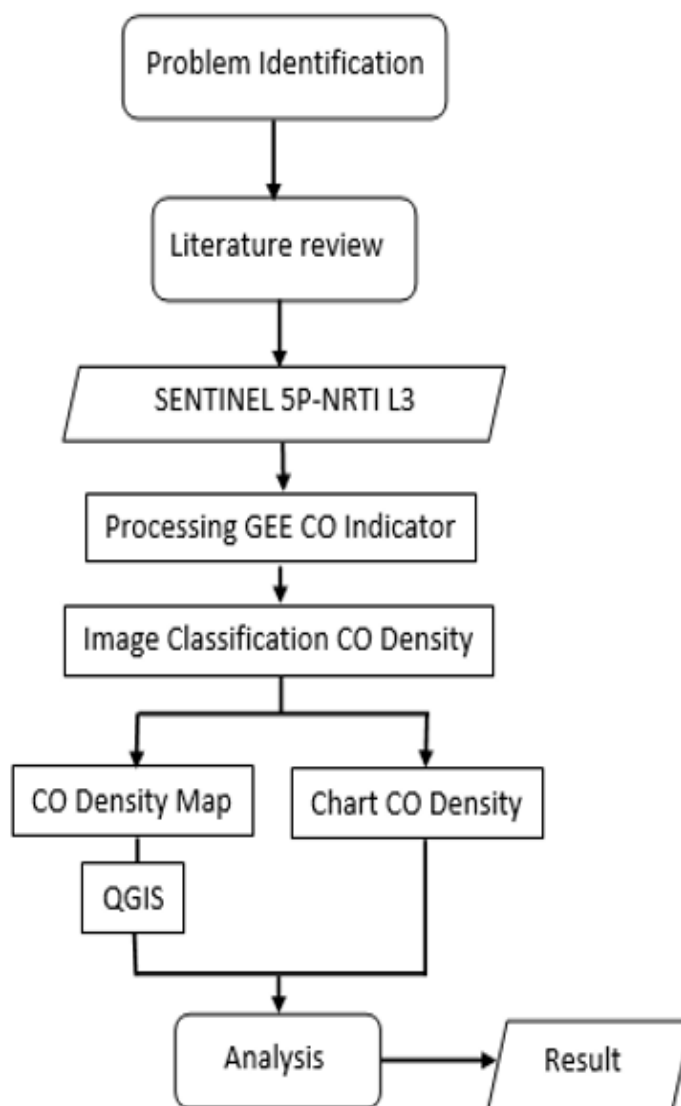


Figure 2. Flow Chart of Spatiotemporal Analysis of CO Concentration Using Google Earth Engine.

Table 1. Observation period of carbon monoxide emission distribution in Bali.

Month	Category
July - October 2022	Pre-Event G20
November 2022	Main-Event G20
December 2022 - March 2023	Post-Event G20

3. RESULTS AND DISCUSSION

Google Earth Engine Data Analysis

Data analysis on GEE uses the JavaScript programming language. Data analysis is carried out by importing Sentinel-5P NRTI CO: Near Real-Time Carbon-Monoxide data. Furthermore, a date/time period filter is carried out, namely 3 time periods (before, during, and after the G20 Summit event) with a total of 9 months and image masking is carried out based on the

research boundaries so that changes in CO density in Bali Province are obtained. Google Earth Engine can be used to analyze high-resolution satellite data, manage geospatial data, and create geospatial visualizations and applications (Indriyaningtyas et al, 2021; Piraliluos et al, 2022). GEE also provides a large collection of satellite data integrated with analysis tools to extract useful information from the data (Figure 3).

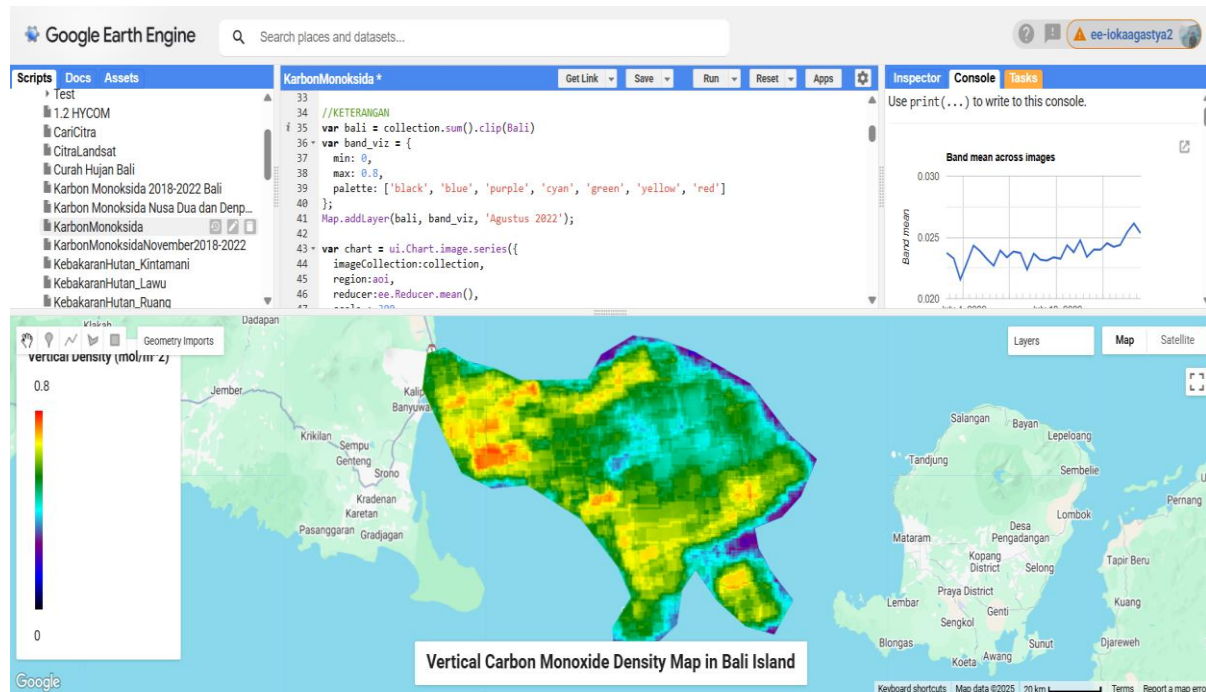


Figure 3. Google Earth Engine cloud computing platform appearance and carbon monoxide (CO) density analysis script in Bali the research location.

Changes in Carbon Monoxide Levels During July 2022 – March 2023 in Bali

Based on the analysis of the vertical density graph of carbon monoxide in Bali Island from July 2022 to March 2023, a fluctuating pattern is seen (Figure 3). The graph shows fairly consistent daily fluctuations throughout the period, except on certain days. One of them is in the time span approaching the implementation of the G20 Summit on November 15-16, there was a significant increase in CO concentration with a value of 0.030 - 0.031 mol / m². Meanwhile, the average CO concentration from July 2022 - March 2023 ranged from 0.023 - 0.028 mol / m². In the Pre-G20 Summit period, July 2022 to October 2022 showed a relatively stable CO concentration pattern with small fluctuations, with an average monthly CO concentration in July 2022 of 0.024 mol/m², August 2022 of 0.025 mol/m², September 2022 of 0.026 mol/m², October 2022 of 0.027 mol/m², November 2022 of 0.028 mol/m², while December 2022 after the G20 Summit recorded a lower CO value and showed a stable pattern with an average monthly CO concentration in December 2022 of 0.025 mol/m². However, in January 2023, there was a significant decrease in CO concentration to the lowest figure of 0.019 mol/m² and began to increase and tended to be stable again, although it fluctuated in the range of 0.025 - 0.028 mol/m² in February to March 2023 (Figure 4).

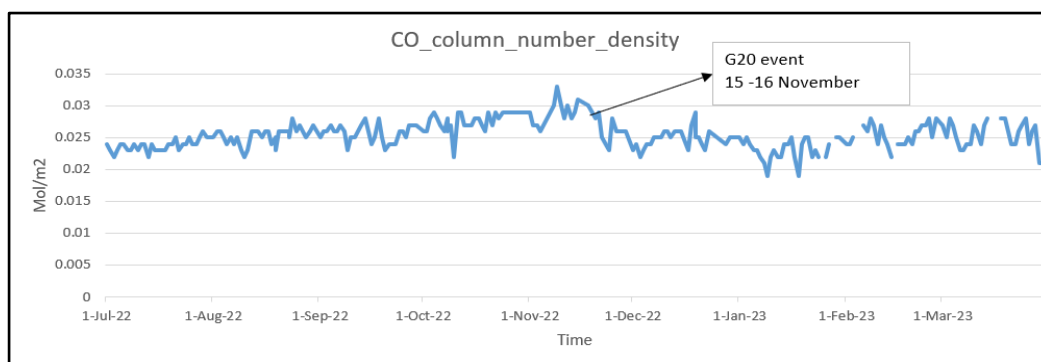


Figure 4. CO column density graph July 2022 – March 2023 in Bali Island.

To determine the relationship between CO distribution and rainfall, a comparison of both data was obtained from the collection of rainfall and CO data from 2018 - 2023 on the island of Bali using GEE (**Figure 5**). The graph shows that the highest CO concentration value occurred in November 2019, reaching 1.4 mol / m² and the highest rainfall occurred in January 2021, reaching 431 mm. Meanwhile, the lowest CO value occurred in January 2023, reaching 0.019 mol / m² and the lowest rainfall occurred in September 2018, reaching 15.69 mm. From the data obtained, if observed, there is a pattern of CO distribution that tends to decrease significantly and rainfall increases in November-April. Meanwhile, during the period June-October, the distribution of CO tends to be stable and increase and rainfall decreases relatively. This indicates a strong relationship between weather conditions such as rain and the decrease and increase in CO in certain months related to the rainy season and dry season in Bali. The influence of weather such as rainfall plays a role in cleaning pollutants in the atmosphere directly through a cleaning process under the clouds (Santamajati and Suharyadi, 2024).

If we look at the comparison of CO Density and domestic tourist visits to Bali in 2018-2023 data from BPS Bali, 2024 (**Figure 5**), it shows a pattern of increasing CO density (blue bars) which is in line with the spike in the number of domestic tourists (orange line). Where every time there is an increase in the number of domestic tourists, CO density tends to increase. If we look at the phenomenon during that period in 2019 (pre-pandemic), domestic tourists tended to increase significantly, accompanied by an increase in CO density. However, if we look at 2022-2023, when domestic tourists increased again after the pandemic, CO density also showed the same pattern, namely tending to increase. In addition, the decline in domestic tourists was clearly seen during the Covid-19 pandemic at the same time, CO density also decreased drastically, indicating a correlation between the decline in human activity due to mobility restrictions and the spread of carbon monoxide. This confirms that tourist visits are one of the factors that influence the level of CO pollution in Bali.

The impact of the increasing economy of Bali Province after Covid-19 due to the increasing pattern of tourist visits to Bali, seen from the increase in foreign tourist visits of up to millions of percent in 2022 in line with the recovery of the tourism sector after the Covid-19 pandemic and continues to increase in 2023 with a percentage change of 144% (Amalika et al, 2024). However, if observed in November - December 2022 there was an increase in domestic tourist visits but CO density decreased relatively. This is because the peak of tourist visits does not always reflect the peak of CO density, this shows that there are other factors such as weather in this case rainfall or environmental regulations and policies that affect.

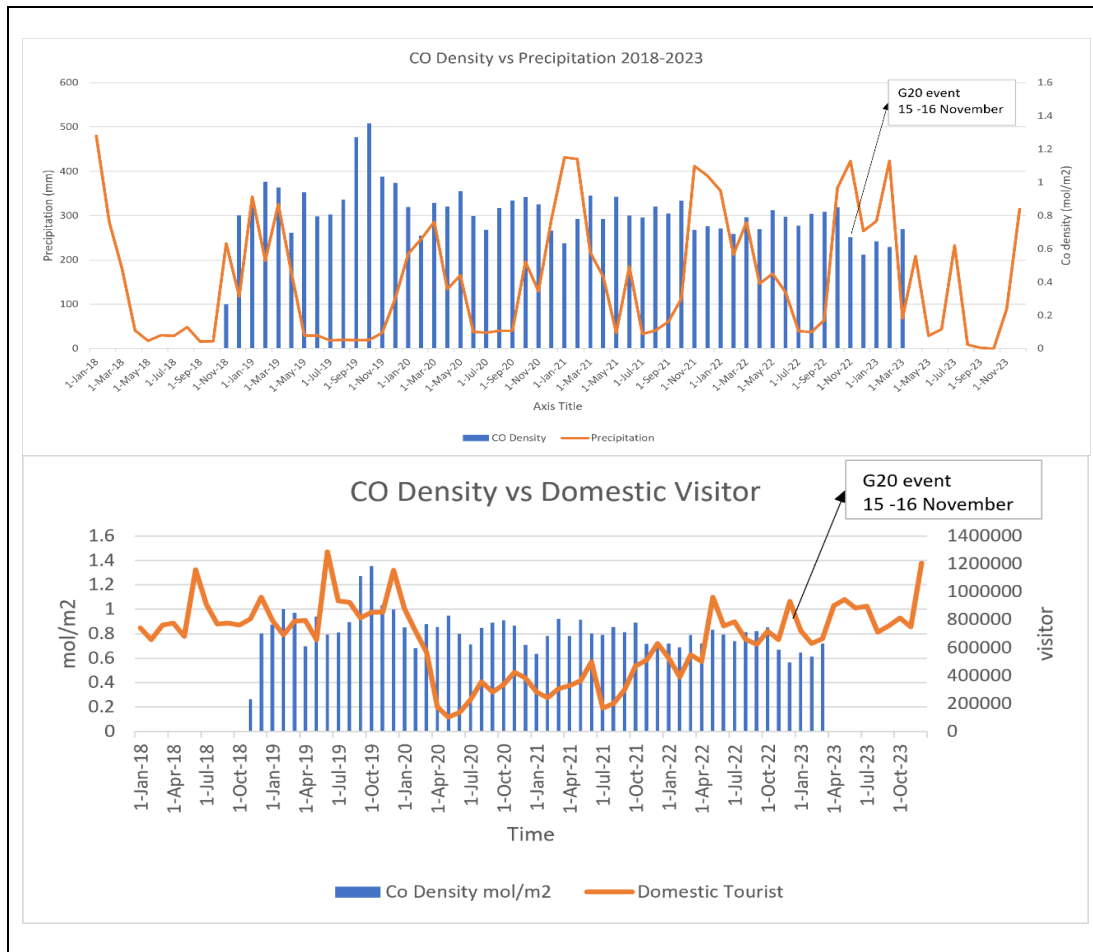


Figure 5. Combination graph between CO Density vs Rainfall and CO Density vs Domestic Tourist Visits during the period 2018-2023 in Bali Island.

If you look at the CO Density map on the island of Bali spatially from July 2022 to March 2023 (**Figure 6**) from time to time the increase in CO Density occurs especially in urban areas or urban areas such as Denpasar City, Badung Regency, and part of Tabanan Regency. The southern areas of Bali such as Denpasar, Badung and Gianyar consistently have higher CO densities than other areas, because it is known that these areas have a greater concentration of population, tourists, and economic activity. Meanwhile, the central and northern areas of Bali Island such as Bangli, Buleleng and Karangasem show lower CO densities, because these areas have less human activity and are more covered by vegetation.

From July to October 2022, high CO density was seen in the southern region of Bali (Denpasar, Badung, Gianyar), with a distribution of orange to red colors. In November 2022, there was a drastic decrease in CO density, marked by green in almost all areas of Bali, but some areas were still quite high, such as Denpasar City and Nusa Dua, which are the venues for the G20 Summit, and the Jembrana area which has the Gilimanuk port. Meanwhile, from December 2022 to March 2023, CO density increased slowly again in most areas of Bali. The orange color began to appear again in the southern and central regions of Bali (Denpasar, Badung, Gianyar, Tabanan), although the intensity was not as high as in July - October 2022.

When associated with the G20 Summit, there was a slight increase in September and October compared to July and August, due to increased transportation activity during the preparation of the G20 Summit. This can be seen from the concentration of CO density in venue areas such as Denpasar and Nusa Dua. The peak concentration of carbon monoxide in October - November, especially during the G20 Summit, this is a direct impact of human activity on increasing pollutant emissions. However, when the G20 Summit took place, CO decreased until December 2022 and increased again in December 2022 - March 2023.

When associated with several factors such as rainfall, human activities spatially, the high and low distribution of CO density on the island of Bali is largely controlled by weather factors such as minimal rainfall in the July-October season worsening pollution levels because CO particles are difficult to deposit on the ground by rainwater. The low CO density factor in November 2022 - March 2023 was influenced by the start of the rainy season, which helped reduce pollutants through the wet deposition process especially CO pollutant (Lee et al, 2014; Ramadhan et al, 2023). The low emission policy during the implementation of the G20 Summit, especially in the period of November 2022, also contributed locally in areas close to the event location, although the overall impact was small compared to the rainfall factor.

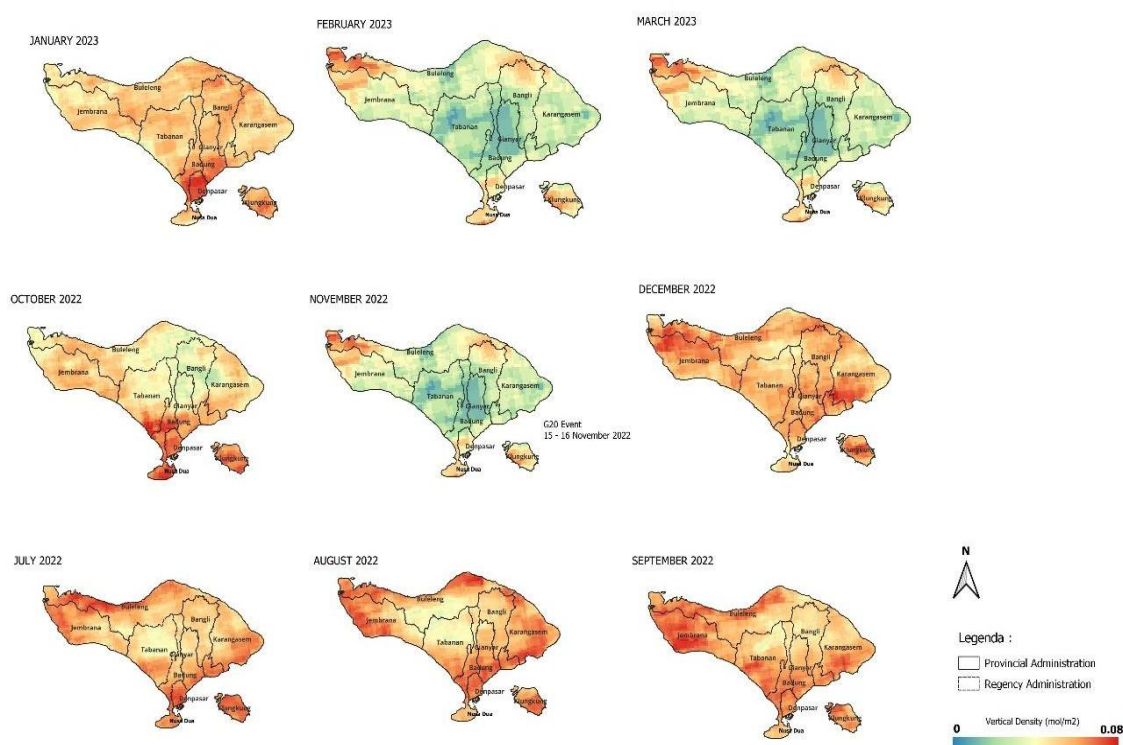


Figure 6. CO Density Map of Bali Area July 2022 - March 2023.

Policies and regulations during the implementation of the G20 in Bali

In general, during the G20 event on the island of Bali, emissions were relatively low in the area around the G20 Summit, but some increases occurred in several locations outside the area, causing the average density value on November 14-16 to be relatively high. The policy of using electric vehicles and a series of vehicle restriction rules during the G20 Summit were only felt after the G20 Summit activities ended, as seen in the relatively low density value in early December. The policies implemented during the G20 Summit, especially traffic engineering management, airport operational adjustments, and work

from home (WFH) instructions, have proven effective in reducing CO emissions. The graph shows that despite an increase in activity before the event, CO concentrations showed a downward trend at the peak of the event, namely November 15-16, 2022. This decrease indicates that the management of transportation and citizen mobility has an important role in maintaining air quality. After the event ended, CO concentrations increased again, reflecting the temporary impact of this policy.

Effective policies in suppressing CO emissions during the implementation of the G20 Summit are traffic engineering management and work from home (WFH) instructions. Both of these policies directly affect the transportation element as the main contributor to CO emissions by reducing the number of vehicles operating on the road, thus impacting air quality. Adjusting airport operations also helps control emissions from the air transportation sector, especially by restricting commercial flights. The implementation of emission control policies, such as the low-carbon city pilot policy in China, for example, has significantly reduced carbon emissions. The impact of this policy is not only consistent but also strengthens over time, driven by long-term policy implementation (Zhang et al., 2025).

The decrease in CO in December confirms that the impact of this policy is temporary, and without the implementation of sustainable transportation management policies, CO emissions tend to increase again in normal activities. This shows that better transportation planning and vehicle emission restrictions can be a long-term solution to maintain air quality in Bali. However, after the G20 ended, CO emissions increased again to normal levels. This shows that mobility control policies only have a temporary impact. Without long-term efforts such as the development of environmentally friendly public transportation or sustainable vehicle restriction policies, emissions will continue to return to their original levels. In addition, weather conditions such as rainfall also affect the distribution of CO density in Bali where November is also a month with high rainfall intensity, so that the significant impact of the low emission policy is not felt in the long term and is temporary considering that the implementation of the policy is limited to the time of the G20 Summit. This reminds us of how important it is to think about policies that are not only temporary, but also support long-term environmental sustainability in Bali.

4. CONCLUSIONS

Based on the analysis of carbon monoxide (CO) density in Bali during the period from July 2022 to March 2023 using Sentinel-5P data through the Google Earth Engine (GEE) platform, it was found that the implementation of the G20 Summit in November 2022 was followed by a decrease in CO emissions. Further analysis shows that this decrease is more controlled by weather factors, especially high rainfall in November - December, which accelerates the wet deposition process to clean pollutants from the atmosphere. While policies such as traffic engineering management, the use of electric vehicles, and vehicle restrictions during the G20 Summit contributed to the reduction in emissions, the impact was temporary because their implementation was limited only during the event. After the policy was stopped, emissions increased again approaching normal patterns. So that this emphasizes the importance of integrated and long-term transportation and environmental policies to maintain air quality in Bali. Ultimately, the use of Google Earth Engine proved effective in mapping changes in CO density spatially and temporally, providing in-depth insights into the distribution of pollutant emissions in relation to human activities and weather conditions.

5. RECOMMENDATIONS

The use of electric vehicles or mass transportation for delegates and policies to reduce transportation to work from home (WFH) can reduce the impact of transportation emissions during the event, but the implementation of the policy needs to be carried out over a long period of time to see significant changes. The impact of meteorological factors such as weather conditions, wind and rain during the event needs to be taken into account to support data-based environmental policies. Traffic control such as odd-even or restrictions on heavy vehicles can be adopted regularly in Denpasar City and its surroundings to maintain air quality. In addition, developing public transportation based on renewable energy (such as electric buses) can be a good investment in reducing CO emissions in the future. In the future, more detailed measurements need to be carried out, especially using field measurement instruments to confirm the results obtained spatially using GEE, in addition, a more detailed analysis is needed on the influence of human activities, especially infrastructure development on the island of Bali and elements of weather changes such as wind direction before the G20 Summit on the distribution of CO.

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