Analysis of CO Air Quality Parameters Based on Satellite Imagery in Makassar City

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Abstract *Carbon monoxide (CO) is one of the most common hazardous air pollutants in urban areas and requires effective monitoring methods. This study aims to estimate CO concentrations in Makassar Metropolitan City using Sentinel-2 and Landsat 8 satellite imagery and to evaluate the differences between the two datasets. The estimation was conducted using the Somvanshi algorithm, which incorporates green, red, and SWIR reflectance bands, followed by Root Mean Square Error (RMSE) analysis to assess consistency between the datasets. exhibit relatively homogeneous and narrow ranges, reflecting stable spatial distributions of CO, with RMSE values ranging from 0.02 to 0.05, indicating minimal discrepancies. Sentinel-2, with higher spatial resolution, provides greater detail in identifying variations across road types and urban activity centers, whereas Landsat 8 yields more generalized patterns. These findings highlight the potential of multi-satellite approaches in air quality monitoring while emphasizing the need for local calibration to improve accuracy in tropical urban environments.*

Keywords: Air quality, Carbon monoxide, Sentinel-2, Landsat 8, Remote sensing, Makassar Metropolitan City.

1. Introduction

Makassar Metropolitan City, one of the largest urban centers in Eastern Indonesia, faces growing air quality challenges due to increasing transportation and industrial activities. Among urban air pollutants, carbon monoxide (CO) is particularly concerning due to its colorless and odorless characteristics that pose serious health risks. Satellite-based monitoring offers a spatially continuous and cost-effective approach to observe CO distribution, especially in regions where ground monitoring networks are limited. Sentinel-2, with its high-resolution multispectral sensors, and Landsat 8, with its well-established atmospheric monitoring applications, provide valuable opportunities for estimating air pollutant concentrations. However, comparative studies focusing on CO estimation between these two satellites in tropical metropolitan environments remain limited. This study addresses this gap by applying a spatial index-based modeling approach to both Sentinel-2 and Landsat 8 imagery and evaluating their differences using statistical testing.

2. Literature Review

Previous research has explored the application of remote sensing for air quality monitoring, particularly for pollutants such as NO_2, SO_2, and PM_{10}. Sentinel-2 and Landsat 8 have demonstrated effectiveness in detecting environmental changes, yet CO-focused studies remain limited. Somvanshi et al. (2019) developed a regression model linking satellite reflectance values with CO concentrations, which has since been adapted in several studies. Other research has highlighted the effectiveness of platforms such as Google Earth Engine in processing large satellite datasets efficiently. Harusi et al. (2019) emphasized that ecological connectivity in Makassar Metropolitan City has declined significantly due to increasing built-up land, indirectly affecting the ability of the environment to absorb CO. Similarly, Nurannisa (2024) demonstrated the feasibility of using Sentinel-2 imagery to estimate PM_{10} and CO levels in industrial areas, while Dede et al. (2020) applied remote sensing to evaluate air quality changes around PLTU Cirebon, showing that satellite imagery can effectively capture pollution patterns over time. Despite these advancements, studies directly comparing Sentinel-2 and Landsat 8 for CO estimation in tropical metropolitan contexts are still scarce. This study addresses that gap by applying the same algorithm to both satellites and statistically comparing the estimation results for Makassar Metropolitan City.

3. Methodology

This study followed a multi-stage research design involving satellite image processing, statistical validation, and comparative analysis. Sentinel-2 and Landsat 8 imagery were selected according to availability during the observation period in MMC (Makassar Metropolitan City). Preprocessing was performed to extract surface reflectance values from selected bands (green, red, and SWIR). The Somvanshi algorithm was then applied to estimate CO concentrations. To evaluate the level of agreement between Sentinel-2 and Landsat 8, the Root Mean Square Error (RMSE) was used as a statistical measure of accuracy. Spatial analysis and visualization were conducted using ArcGIS and Google Earth Engine.

3.1 Research Location

The research was conducted in MMC (Makassar Metropolitan City), South Sulawesi Province, Indonesia. The study area was limited to the mainland region, excluding the island districts. A total of 30 observation points were distributed across strategic locations considering traffic activity, population density, and proximity to potential CO emission sources such as commercial zones, industrial areas, and major transportation routes.

Table 1: Research Location in MMC

Road Type	Point	Location	District
6/2 D	1	Veteran Makassar	Makassar
	2	Centre Point of Indonesia (CPI)	Tamalate
	3	Makassar Town Square	Tamalanrea
	4	Bumi Tamalanrea Permai	Tamalanrea
	5	Panakkukang Mall	Panakkukang
	6	Heroes Cemetery	Panakkukang
	7	Nipah Mall	Panakkukang
	8	PLN Hertasning	Rappocini
4/2 D	9	Reformasi Toll Gate	Ujung Tanah
	10	Central Market	Wajo
	11	Phinisi Point Mall & Rinra Hotel	Mariso
	12	Trans Studio Mall	Tamalate
	13	Makassar Industrial Zone (KIMA)	Biringkanaya
	14	Ratu Indah Mall	Mamajang
	15	Primaya Hospital Hertasning	Rappocini
4/1 UD	16	Makassar Grand Mosque	Bontoala
	17	Terong Market	Bontoala
	18	Bawakaraeng Street	Makassar
2/2 UD	19	Paotere Port Gate	Ujung Tanah
	20	SMA 17 Makassar	Tallo
	21	Galangan Kapal Intersection	Tallo
	22	Daya New Market	Biringkanaya
	23	Toddopuli Intersection	Manggala
	24	Antang Raya–Pannara Bridge Intersection	Manggala
	25	Borong–Antang Raya Area	Manggala
	26	Rajawali Fish Auction Market	Mariso

Road Type	Point	Location	District
2/1 UD	27	Makassar Port	Wajo
	28	Losari Beach	Ujung Pandang
	29	Kayu Bangkoa Pier	Ujung Pandang
	30	Toko Satu Sama	Mamajang

Source: Research Location Map (MMC), 2025

3.2 Research Tools and Data

This study utilized open-source satellite imagery and geospatial platforms. Sentinel-2 imagery was acquired from the Copernicus Open Access Hub, while Landsat 8 imagery was retrieved from the USGS Earth Explorer. Data processing and visualization were performed using ArcGIS and Google Earth Engine (GEE).

Table 2: Satellite Image Acquisition Data

Components	Sentinel-2	Landsat 8
Satelit	Sentinel-2 Level 2A Surface Reflectance	Landsat 8-9 OLI/TIRS C2 L2
Sensor	MSI (Multispectral Instrument)	OLI (Operational Land Imager) + TIRS (Thermal Infrared Sensor)
Acquisition Date	4 March 2025	11 March 2025
Resolusi Spasial	10 m (Band 2, 3, 4, 8)	30 m (Band 1–7, 9)
	20 m (Band 5, 6, 7, 8A, 11, 12)	15 m (Band 8)
	60 m (Band 1, 9, 10)	100 m (Band 10 dan 11)
Number of Bands	12 band	11 band
Revisit Time	5 day	16 day
Orbital Period	100,6 minute	99 minute
Cloud Conditions	25%	25%
Coverage Width	290 km	185 km

Source: USGS Earth Explorer dan Copernicus Data Space

3.3 Research Flow Chart

To illustrate the research procedure in a systematic and comprehensive manner, a research flow chart was developed. The diagram represents the methodological framework adopted in this study, beginning with the formulation of research objectives, followed by data collection, data processing, and analysis. Presenting the workflow in this format ensures that the sequence of activities is clearly organized and facilitates a better understanding of the overall research design.

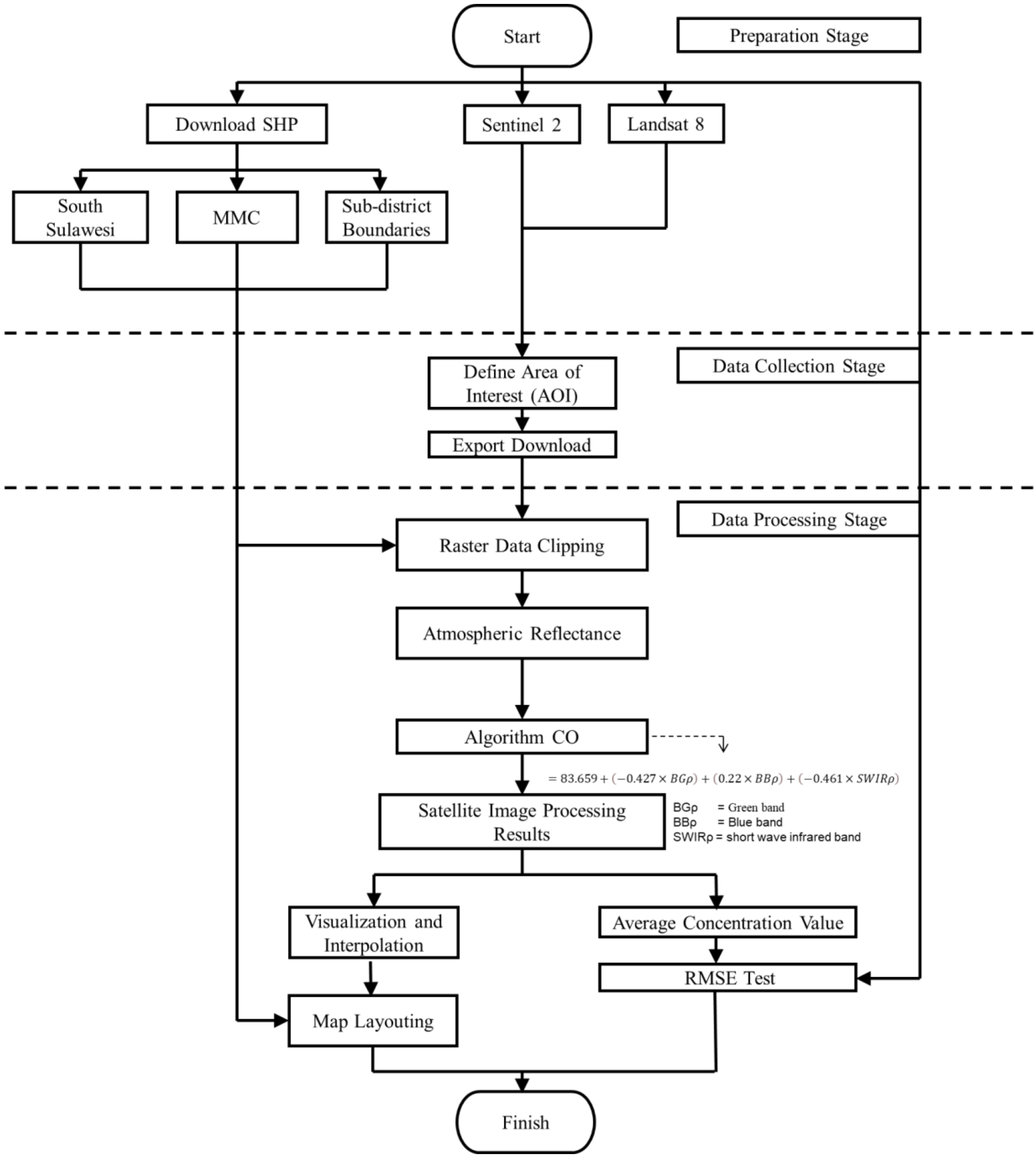

Figure 1: Research Flowchart

As shown in Figure 1, the research flow chart provides a step-by-step representation of the study process. Each stage is interconnected to maintain consistency and logical progression from one step to the next. This visualization not only enhances the clarity of the methodology but also demonstrates how the different phases of the study contribute to achieving the research objectives.

3.3.1 Preparation Stage

The preparation stage consisted of identifying the research location, selecting observation points, and organizing the required datasets. The selection of 30 observation points was specifically based on urban functions, particularly areas designated for commercial and service activities, which are expected to have higher air pollutant loads due to traffic density and anthropogenic emissions.

3.3.2 Data Collection Stage

The data collection process involved acquiring Landsat 8 and Sentinel-2 imagery for the study period. Landsat 8 bands (Band 3 – Green, Band 4 – Red, Band 7 and Band 12 – SWIR) were prioritized, as these bands have been previously identified as significant predictors in CO estimation models (Somvanshi et al., 2020). Additionally, road network and land-use data were obtained to guide the spatial distribution of observation points within the commercial and service zones.

3.3.3 Data Processing Stage

(a) Atmospheric Reflectance Correction

Satellite imagery was first processed to convert Digital Number (DN) values into Top-of-Atmosphere (TOA) reflectance, using radiometric calibration parameters provided in the metadata. The TOA reflectance was further refined by isolating the atmospheric component, following Somvanshi et al. (2019).

$$\rho_\lambda = (M_\rho \, Q_{cal} + A_\rho)/\cos(\theta_{sE})$$

M_ρ = *REFLECTANCE_MULT_BAND_*x, *where x is the band number*

Aρ = *REFLECTANCE_ADD_BAND_*x, *where x is the band number*

Qcal = *digital number* (DN)

θSE = *Sun elevation*

$$R_{atm} = R_s - R_r$$

Dengan:

Rs = reflectance recorded by satellite sensor

Rr = reflectance from surface references

Ratm = reflectance from atmospheric components

(b) CO Estimation Algorithm

The estimation of Carbon Monoxide (CO) concentrations was adapted from Somvanshi et al. (2020):

$$CO\ (\mu g/m^3) = \beta 0 + (-0.427 \times BG\rho) + (0.22 \times BB\rho) + (-0.461 \times SWIR\rho)$$

dengan koefisien:

- β_0 = 83.659
- $BG\rho$ = green band
- $BB\rho$ = blue band
- $SWIR\rho$= *short wave infrared band.*

The results of the satellite image processing were then used to obtain the spatial distribution of pollutants through visualization and interpolation, and processed into thematic maps depicting air quality conditions in the study area. Then, the average concentration and RMSE values were generated to provide an overview of how far the predicted values deviated from the actual values. The concentration results were analyzed in the Air Pollution Standard Index category.

4. Results and Discussion

This study estimated carbon monoxide (CO) concentrations in Makassar Metropolitan City (MMC) using Sentinel-2 and Landsat 8 imagery processed with the Somvanshi algorithm. The estimation aimed to evaluate the differences in performance between the two datasets and assess the consistency of results using the Root Mean Square Error (RMSE).

4.1 Descriptive Results

The estimation of carbon monoxide (CO) concentrations in Makassar Metropolitan City (MMC) was conducted at 30 sampling points distributed across five road types: 6/2 D, 4/2 D, 4/1 UD, 2/2 UD, and 2/1 UD. Estimation was performed using Sentinel-2 and Landsat 8 imagery processed with the Somvanshi algorithm.

Table 3. Recapitulation of estimated CO concentration by road type

Road Type	Point	Sentinel-2 (µg/m³)	Landsat 8 (µg/m³)
6/2 D	1	83,67	83,65
	2	83,68	83,65
	3	83,67	83,65
	4	83,68	83,65
	5	83,72	83,65
	6	83,66	83,65
	7	83,68	83,65

Road Type	Point	Sentinel-2 (µg/m³)	Landsat 8 (µg/m³)
	8	83,66	83,65
4/2 D	9	83,67	83,65
	10	83,68	83,65
	11	83,67	83,65
	12	83,67	83,65
	13	83,70	83,65
	14	83,70	83,66
	15	83,76	83,65
4/1 UD	16	83,67	83,65
	17	83,69	83,66
	18	83,66	83,65
2/2 UD	19	83,69	83,66
	20	83,68	83,65
	21	83,69	83,66
	22	83,66	83,66
	23	83,67	83,66
	24	83,69	83,66
	25	83,69	83,65
	26	83,67	83,65
2/1 UD	27	83,71	83,66
	28	83,67	83,65
	29	83,72	83,67
	30	83,68	83,65

Source: Data processing, 2025

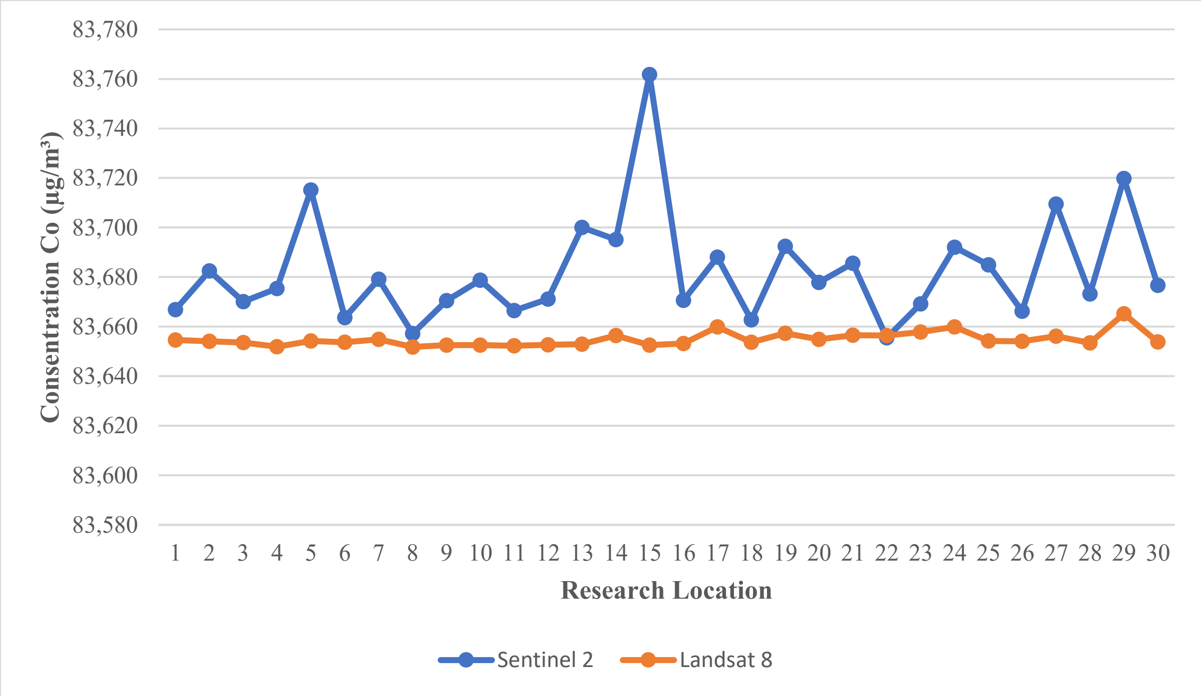

Figure 2 : Comparative CO concentrations from Sentinel-2 and Landsat 8 across road types

To better visualize these differences, Figure 2 presents a comparative chart of Sentinel-2 and Landsat 8 estimates across all road types. The chart clearly indicates that Sentinel-2 values consistently exceed those from Landsat 8, although the absolute differences remain small (generally within 0.01–0.06 µg/m³). Importantly, the relative divergence between datasets becomes more noticeable in specific road categories, particularly in wider arterial roads such as 6/2 D and 4/2 D, where higher traffic intensity and complex surrounding land use may contribute to increased spatial heterogeneity.

The consistency of Landsat 8 estimates across road types reflects the averaging effect of its larger pixel size, which integrates emissions from multiple road segments and adjacent land covers into a single measurement. Conversely, Sentinel-2 captures sharper contrasts between neighboring road segments, revealing subtle intra-urban variations. For example, several points along 2/1 UD roads recorded Sentinel-2 values above 83.70 µg/m³, while Landsat 8 estimates remained nearly uniform at around 83.65 µg/m³. Such differences highlight the potential of Sentinel-2 imagery for identifying micro-scale hotspots of CO emissions in dense urban settings.

Beyond point-based comparisons, the spatial distribution of CO concentrations across the metropolitan area is depicted in Figures 3 and 4. Figure 3 illustrates the results from Sentinel-2, while Figure 4 shows the corresponding distribution from Landsat 8.

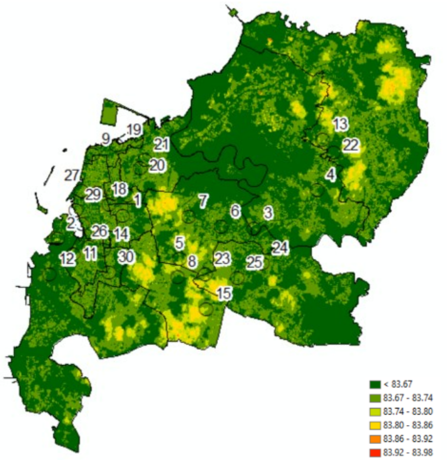

Figure 3 : Spatial distribution of CO concentrations estimated from Sentinel-2

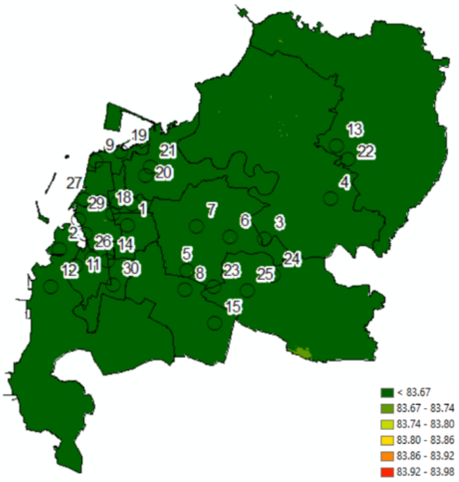

Figure 4 : Spatial distribution of CO concentrations estimated from Landsat 8

The Sentinel-2 map (Figure 3) reveals clear differentiation across the urban landscape. Higher concentrations are detected in central business districts, commercial corridors, and along major arterial roads, while lower values are found in residential and peripheral areas with lighter traffic activity. This ability to capture fine-scale variation reflects the advantage of Sentinel-2's finer spatial resolution. In contrast, the Landsat 8 map (Figure 4) exhibits a smoother and more generalized spatial pattern. Although it successfully delineates the overall distribution of CO—highlighting urban centers as concentration peaks—it fails to capture smaller variations at the neighborhood or corridor level.

Together, these results emphasize the complementary strengths of the two satellite datasets. Sentinel-2 excels at detecting micro-scale variations that are crucial for urban air quality management, while Landsat 8 provides a stable and consistent overview suitable for regional-scale monitoring. The integration of both datasets could therefore offer a more comprehensive assessment of CO pollution, combining detail with broader coverage.

4.2 RMSE Validation

To evaluate the consistency between Sentinel-2 and Landsat 8 estimates, the Root Mean Square Error (RMSE) was applied. RMSE provides a quantitative measure of the differences between two datasets, where lower values indicate higher agreement.

The validation results reveal that RMSE values varied across road types. The lowest discrepancies were observed along 4/1 UD (0.02 µg/m³) and 2/2 UD roads (0.02 µg/m³), indicating strong consistency between both satellites in areas with relatively moderate traffic flows. Similarly, the 6/2 D road showed a relatively low RMSE of 0.03 µg/m³, reflecting stable agreement despite higher road capacity. In contrast, higher RMSE values were recorded along 2/1 UD (0.04 µg/m³) and 4/2 D roads (0.05 µg/m³). These patterns suggest that discrepancies are more pronounced in road segments with complex traffic conditions, where Sentinel-2 captures localized micro-scale variations that Landsat 8 tends to smooth out.

Overall, these validation results confirm that although both satellites produce consistent CO concentration ranges, Sentinel-2 provides higher spatial sensitivity and is able to capture subtle variations across different road types, while Landsat 8 serves as a reliable but more generalized estimator..

4.3 Discussion

The findings of this study highlight the complementary strengths of Sentinel-2 and Landsat 8 in air quality monitoring. Sentinel-2, with its higher spatial resolution, is more effective in identifying fine-scale differences in CO concentrations, making it suitable for urban-scale studies where pollutant distribution varies sharply across road networks. Landsat 8, despite its coarser resolution, offers stability and consistency, which may be advantageous for regional-scale assessments.

The relatively narrow concentration ranges in both datasets reflect the smoothing effect of the Somvanshi algorithm, which reduces noise while preserving general trends. However, this also indicates that further refinement, such as local calibration with field-based reference data, is necessary to improve accuracy. Moreover, the observed discrepancies between Sentinel-2 and Landsat 8 underscore the importance of considering spatial resolution when selecting remote sensing data for air quality studies in urban environments.

5. Conclusion and Recommendation

5.1 Conclusion

This study successfully estimated CO concentrations in Makassar Metropolitan City (MMC) using Sentinel-2 and Landsat 8 satellite imagery with the Somvanshi algorithm. The results indicate that Sentinel-2 CO concentrations ranged between 83.66 and 83.76 µg/m³, while Landsat 8 concentrations ranged between 83.65 and 83.67 µg/m³. Sentinel-2 demonstrated greater variability, effectively capturing micro-scale differences across road types. Validation using RMSE between Sentinel-2 and Landsat 8 produced values ranging from 0.02 to 0.05 µg/m³, with the largest discrepancies observed along 4/2 D roads, highlighting Sentinel-2's capability to capture detailed variations in high-traffic areas. Overall, both satellites provided consistent results; however, Sentinel-2 proved to be more suitable for urban-scale air quality studies, whereas Landsat 8 delivered more generalized but stable spatial patterns.

5.2 Recomendation

1. Future studies should integrate ground-based measurements with satellite-derived estimates to strengthen model calibration and validation.
2. Application of machine learning algorithms is recommended to enhance prediction accuracy and reduce residual errors.
3. Multi-temporal analysis should be conducted to evaluate diurnal and seasonal variations of CO concentrations.
4. The integration of Sentinel-2 and Landsat 8 can be optimized for multi-scale monitoring, with Sentinel-2 focusing on detailed urban patterns and Landsat 8 covering broader regional trends.

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