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Identifying Concentration of Carbon Dioxide at Heights of 1.5 M and 15 M in Six Locations in Urban Areas

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ABSTRACT

Several activities in urban areas emit CO_2 gas and the amount of the emission is closely related to land use. This will, in turn, increase global warming phenomena in urban areas. So far, the estimation of pollutant concentrations in the ambient air has been carried out at the height of human breath, and very rarely the concentration values at low-level altitudes have been studied in Indonesia. This study tries to analyze the CO_2 concentration based on different altitudes and different locations.

Measurements of this study were carried out in industrial, residential, commercial, and highway areas using drones at two altitudes of 1.5 m and 15 m. The use of altitude variations to know the homogeneity of CO_2 spatial distribution at different heights. The results of the study showed CO_2 concentrations on weekday mornings and afternoons, and weekend mornings in the sampling areas at 1.5 m and 15 m in the range of 393 – 462 ppm and 391 – 460 ppm, respectively. The statistical test showed that there is no significant CO_2 concentration difference between altitudes of 1.5 m and 15 m, with only a 0.17% difference value on average. The Tugu Industrial Estate area has the highest concentration of CO_2, while the area on Jalan Perintis Kemerdekaan has the lowest concentration.

1. INTRODUCTION

Global warming, whose main source is CO_2 gas emissions, has been studied worldwide by many researchers, and the largest emitter of CO_2 is mainly caused by various human activities (Ahundjanov & Akhundjanov, 2019). Several direct and indirect impacts will occur when the concentration of CO2 gas in the atmosphere is very high (Houghton, J.T., GJ. Jenkins, 2018). Based on current measurements, average global CO_2 concentrations have reached around 417 ppm, which is a 50% increase from the 18th century (Betts, 2021). There are three main factors related to human activities that produce CO_2 emissions, namely the use of buildings, industrial activities, and the increasing number of vehicles for transportation. The nature of the resulting CO_2 emission, which is the main greenhouse gas (GHGs), has a temporal and spatial distribution. In India, based on the data obtained from the monitoring program, it is found that the major contributors are from the industry (Chaudhari et al., 2007). Meanwhile, in 2010 the main contributor to GHGs emissions in Indonesia was the forestry sector (49%), followed by energy use (34%) (KLHK, 2021). Meanwhile, related to energy use in daily activities, the energy use for residential buildings, commercial activities, and office areas is a contributor to GHG emissions in the building sector. The high concentration of CO_2 in the ambient can also affect the

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concentration of CO_2 in the indoor air (Kim & Choi, 2019). The high concentration of inhaled CO_2 poses a dangerous risk for indoor occupants (Brown et al., 2017). In addition, Earth's temperature is getting higher due to the increasing amount of CO_2 in the atmosphere (Liu, Waqas, Wang, Xiong, & Wan, 2017). The high temperature on earth is due to the reflection of sunlight energy into space that has reached the earth.

UAVs (Unmanned Aerial Vehicles or drones) equipped with air quality monitoring devices have been widely used to improve monitoring efficiency and accuracy nowadays. With the increasing number of air pollution episodes that need to be handled quickly, UAVs equipped with air monitoring devices are widely used to detect air pollution in various areas (Yao, Wei, Zhang, & Li, 2018). During in situ air quality measurement, UAVs could be equipped with various sensors. Thus making this method more effective and becoming a trend, especially in the study of air quality and climate change (Villa, Gonzalez, Miljievic, Ristovski, & Morawska, 2016). Generally, serial gas sensors and microcontrollers are integrated into the UAV to ensure the implementation of the air quality monitoring system. With this system, measurements of air quality or GHGs can be carried out at various heights according to the operating height of the UAV (Abdelrahman, Balkis, Abou-Elnour, & Tarique, 2018).

Currently, air pollutant monitoring systems using UAVs can be used in a real-time mode so that they can better describe the real conditions at the measurement location. The integration of the sensors in the UAV with the measuring coordinate position on earth can be facilitated by the system's modular design. These tools can be carried simultaneously on the UAV (Gu, R. Michanowicz, & Jia, 2018). However, the use of UAVs for air quality measurements has a weakness, namely the limited flight time because it is limited by the characteristics of the UAV size (rotor size, rotor configuration, diameter) and the weight of the UAV itself (Al-Hajjaji, Ezzin, Khamdan, Hassani, & Zorba, 2017). Therefore, before the experiment, the detector is mounted on a UAV with a position that is minimally disturbed by rotor rotation by being analyzed based on a Computational Fluid Dynamics (CFD) simulation (Zhou, Peng, Wang, Shen, & Liu, 2018).

Various types of UAVs have been developed, some of which include fixed-wing aircraft, helicopters (chopper), multi-copter, parachute and glider motors, UAVs with vertical take-off landing, assembled UAVs, and commercialized UAVs (Hassanalian & Abdelkefi, 2017). All types are made based on certain interests and have their own advantages and disadvantages. Current UAV implementations include environmental monitoring, traffic management, pollution monitoring, civil security control, and shipping of goods (Mohamed, Al-Jaroodi, Jawhar, Idries, & Mohammed, 2020). Air quality assessments have traditionally been carried out by monitoring land bases with manned aircraft or satellites. To measure the effects of atmospheric pollution on human health and the environment, detailed information about the characteristics of aerosol spatial distribution and pollutant concentration is needed (Peng, Wang, Wang, Gao, & Lu, 2015). However, data from land bases and satellite measurements are relatively sparse and often inadequate in terms of not having enough data to be used for ground-level analysis in the source-receptor study. In addition, satellites and land-based sensors require expensive costs that result in limitations in the analysis. The limitation related to effectively measured spatial aerosol distribution triggers the use of UAVs for atmospheric measurement and monitoring. UAV methods can cover large areas and can monitor locations that are remote, dangerous, or difficult to access, increasing operational flexibility and resolution of land-based methods (Villa et al., 2016). The advantages of UAVs compared to other methods include accuracy, flexibility, flexible height exploration, and continuous data collection (Babaan, Ballori, Tamondong, Ramos, & Ostrea, 2018).

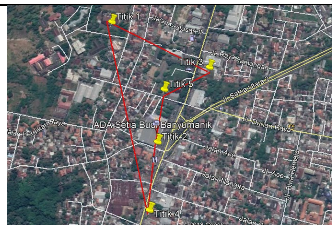
This study aims to analyze differences in CO_2 gas concentrations based on different heights. Six locations were selected for research observation sites which represent industrial, commercial, residential, and transportation areas.

2. METHODS

In this study, 6 different study sites were selected in the city of Semarang, which represent industrial, residential, transportation, and commercial areas. At that six locations, 30 points of CO_2 concentration (each location site has 5 points measurements) were measured and measured at different heights (1.5 m and 15 m). Tugu Industrial Estate in the North-Western Part of Semarang was selected to represent the industrial area. The commercial area includes 2 different locations, namely the Paragon City Mall area and the Ada Swalayan Setiabudi area. Measurement in the housing area took place at Tugurejo Village and housing, Central Semarang. While Perintis Kemerdekaan, as an inter-province connection road, was chosen to represent the use of transportation land. To represent the conditions in the field, measurements were made on weekdays and holidays in the morning and evening. Measurements were carried out in the period 13 July - 22 July 2019. Location details (location description, coordinates, and map) are shown in Table 1.

Sampling was carried out using AZ Instrument China CO_2 meter production with type AZ-7755 which was calibrated with the manufacturing standard (calibrating at 400 ppm standard CO_2). This tool has a reading specification of CO_2 gas concentrations in the numbers 0 to 2000 ppm with an accuracy of ± 5%. CO_2 concentration readings run every second. The response time for measuring CO_2 gas is 30 seconds, with a warm-up time of 30 seconds. Furthermore, CO_2 meters will be installed in the UAV body and flown using a UAV-type DJI Phantom 4 Standard, which has the specifications for the farthest flight range of 3.1 miles with a flying time of 28 minutes. This is a small UAV that has an operating altitude of < 1200 ft and a weight of only 1.38 kg. DJI Phantom 4 is capable of flying with a maximum speed of 44.7 mph. CO_2 measurements were carried out at an altitude of 1.5 m and 15 m with 2 repetitions. Before flying, wait 30 seconds to wait for the CO_2 meter warm-up time. After 30 seconds, the UAV was flown to the first height of 1.5 m and measured for 10 seconds, then to the second height of 15 m and again measured for 10 seconds. Due to the measurement repetition, thus we got 20 measurement events at each point. Thus, the CO_2 concentration data obtained from the measurement results amounted to 40 data with 20 data for each height. The measurement data storage is done by recording the CO_2 meter screen using a UAV camera which is then stored on a microSD.

Table 1. Site Sampling Description

Location	Coordinates	Map
Tugu industrial area	6°58'29.84"-6°57'55.73"S 110°19'31.43"-110°20'5.24"E	
Mall Paragon City area	6°59’4,64”–6°58’56,92” S 110°24’33,04”–110°24’58,02” E	
Central Semarang residential area	6°59’1,58”–6°59’1,15” S 110°25’9,84”–110°25’33,08” E	
Tugurejo residential area	6°59'1.72"-6°59'0.62"S 110°20'39.50"-110°21'20.83" E	
ADA Supermall	7°3'28.88"-7° 3'50.53"S 110°24'41.59"-110°24'45.71" E	
Perintis Kemerdekaan road	7°4'36.71"-7°6'8.51"S 110°24'41.65-110°24'33.48" E	

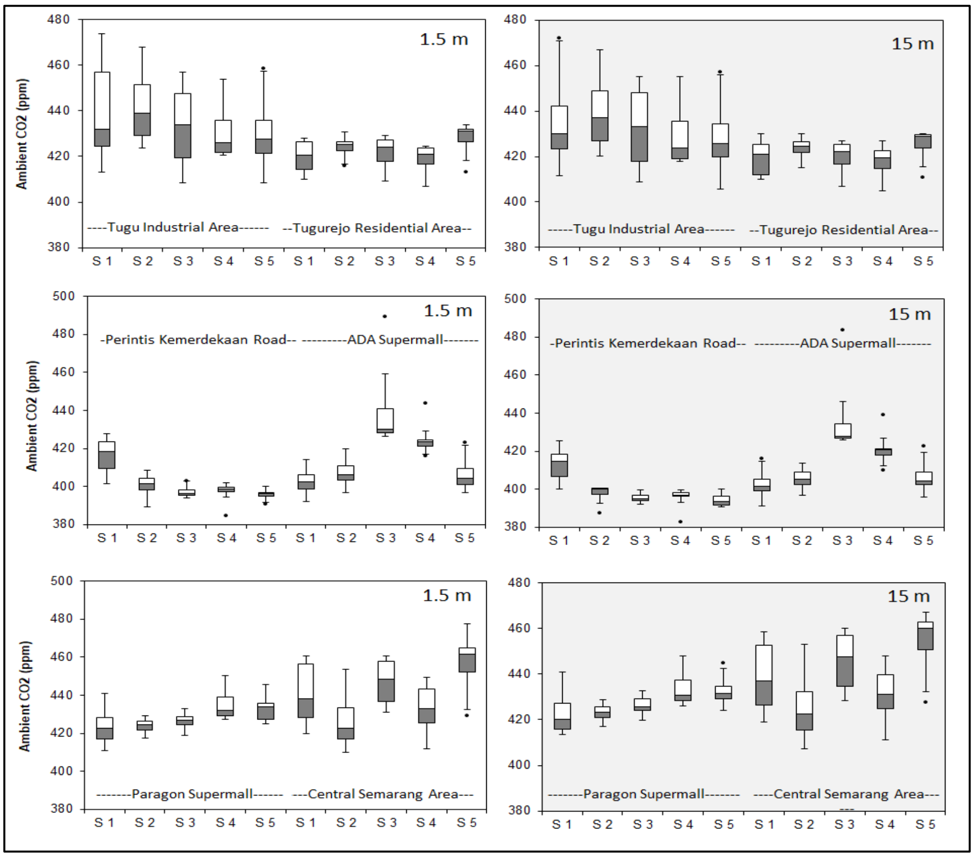


Figure 1. Distribution of CO_2 Concentration at Each Measurement Point on Weekend-Weekday and Morning-Afternoon Conditions

3. RESULTS AND DISCUSSION

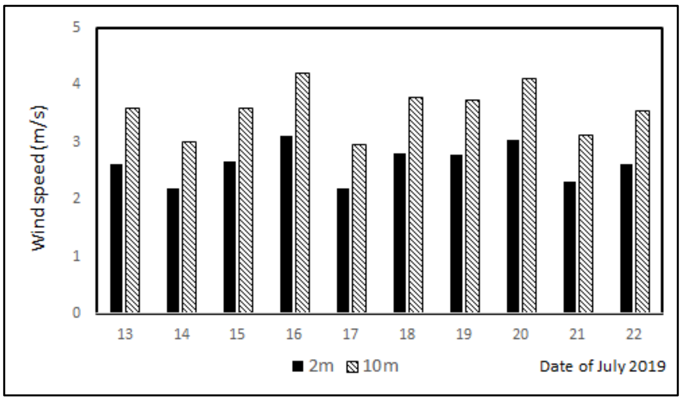
Measurements were made during the dry season, so there was no rain during the measurement period. Figure 1 shows the distribution of the measurement results (averaged 10 times measurements) for each location on weekday-weekend and morning-evening conditions for point 1 (S1) to point 5 (S5). Figure 1 revealed that there is a difference in the average concentration between locations, but in one location, there is no difference in the average concentration at the height of 1.5 m and 15 m.

The following Table 2 shows a recapitulation of the measured CO_2 gas results.

Based on table 2, CO_2 concentration from 1.5 m to 15 m height tends to decrease. The condition in which 1.5 m height is closer to the source of emission and gradually gets further until the height of 15 m, altering this reduction of CO_2 concentration. The wind speed ratio at Semarang during the measurement period ranged from 1.34 to 1.37 according to secondary data on wind speed (Figure 2) (Significantly different). Therefore, it was reasonable to predict that the wind speed between 1.5 m and 15 m heights varied significantly. According to Turgut & Usanmaz (2016), the reduction of CO_2 concentration is also caused by wind speeds that increase along with the level of land surface elevation. In line with the results of the study of Tasić, Kovačević, & Milošević (2013), the higher the wind speed, the concentration of gas in the air will be smaller because the gas is carried by the wind away from the measurement location.

To test the assumption above, data on CO_2 concentrations were processed with SPSS analysis. Independent sample T-test revealed that all Sig. (2-tailed) results are more than 0.05. Therefore, it can be said that there is no statistically significant difference between the average CO_2 gas concentration measurements at 1.5 m and 15 m. The significant variation in wind speed had little impact on CO_2 concentration at these two heights since both locations are presumably too close in the distance. Thus, CO_2 gas concentrations are not significantly different.

It is necessary to know the variation in different CO_2 concentrations at certain altitudes to see the homogeneity of concentrations based on altitude. Furthermore, the Surfer program is used to map the CO_2 distribution to make it easier to describe the spatial distribution. The following Figures represent the distribution of CO_2 concentrations for each measurement location.



** Data taken from NASA USA (NASA, 2022)*

Figure 2. Wind Speed at Altitude of 2 m and 10 m

Table 2. Recapitulation of CO_2 Gas Measurement Results

Location	Sampling time	Concentration CO_2 (ppm)						Independent T-Test Sig. (2-tailed)
		Measurement 1			Measurement 2			
		1,5 m	15 m	% reduction	1,5 m	15 m	% reduction	
Tugu industrial area	Weekend Morning	434.42	428.78	1.30	428.56	426.9	0.39	0.254
	Weekend Afternoon	420.18	418.66	0.36	419.46	417.66	0.43	
	Weekday Morning	462.16	460.92	0.27	459.46	458.14	0.29	
	Weekday Afternoon	429.56	428.7	0.20	427.94	426.2	0.41	
Tugurejo residential area	Weekend Morning	427.28	427.76	0.11	427.54	426.8	0.17	
	Weekend Afternoon	426.04	423.9	0.50	425.3	423.58	0.40	
	Weekday Morning	419.54	419.28	0.06	417.58	415.6	0.47	
	Weekday Afternoon	417.18	415.64	0.37	417.6	416.04	0.37	
ADA Supermall	Weekend Morning	411.34	410.34	0.01	405.94	404.96	0.009	0,597
	Weekend Afternoon	408.34	406.24	0.021	408.96	405.58	0.034	
	Weekday Morning	412.72	412.3	0.004	413.46	412.1	0.014	
	Weekday Afternoon	433.86	431.36	0.025	432.2	428.72	0.035	
Perintis Kemerdekaan road	Weekend Morning	398.44	398.06	0.004	393.32	391.6	0.017	
	Weekend Afternoon	404.5	401.44	0.031	404.56	401.54	0.030	
	Weekday Morning	401.46	399.36	0.021	403.64	400.12	0.035	
	Weekday Afternoon	401.62	401.06	0.006	403.86	400.96	0.029	
Mall Paragon City area	Weekend Morning	424,22	422,66	0,016	420,24	421,2	-0,009	0,754
	Weekend Afternoon	426,58	424,68	0,019	423,54	423,1	0,004	
	Weekday Morning	431,9	431,52	0,004	430,98	429,04	0,019	
	Weekday Afternoon	436,34	436,08	0,003	436,3	435,24	0,011	
Central Semarang residential area	Weekend Morning	447,5	445,5	0,02	441,64	441,12	0,005	
	Weekend Afternoon	422,9	420,72	0,022	420,3	418,9	0,014	
	Weekday Morning	457,48	455,92	0,016	454,7	453,52	0,012	
	Weekday Afternoon	441,78	437,4	0,044	438,7	437,62	0,011	

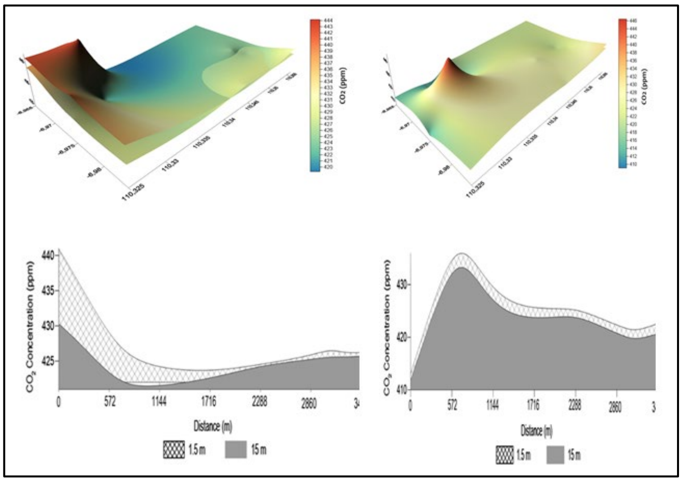
Figure 3 and Figure 4 below show the distribution of CO_2 concentrations in the Tugurejo District and Tugu Industrial Estate.

Figure 3 and Figure 4 revealed that Tugu Industrial Estate had a higher CO_2 concentration than Tugurejo sub-district housing. In comparison to the residential sampling area, Tugu Industrial Estate probably has more pollution-producing sources. The confluence of the road and the railroad line at Tugu Industrial Estate frequently results in traffic bottlenecks during peak hours. In addition, the emission load from factories at Tugu Industrial Estate is also quite large. On the weekend afternoon, however, CO_2 concentrations in Tugu

Industrial estates were lower than Tugurejo Housing. The reduction of industrial activity by all companies in Tugu Industrial Estate during weekend afternoon presumably takes part in this CO_2 concentration drastic decline. Therefore, it can be concluded that the source of emissions came from all activities that support the production process within Tugu Industrial Estate. While the cross-section image of the 3D map shows that the concentration value at an altitude of 1.5 m tends to be higher than the concentration at an altitude of 15 m, the difference in concentration between altitudes is not significant.

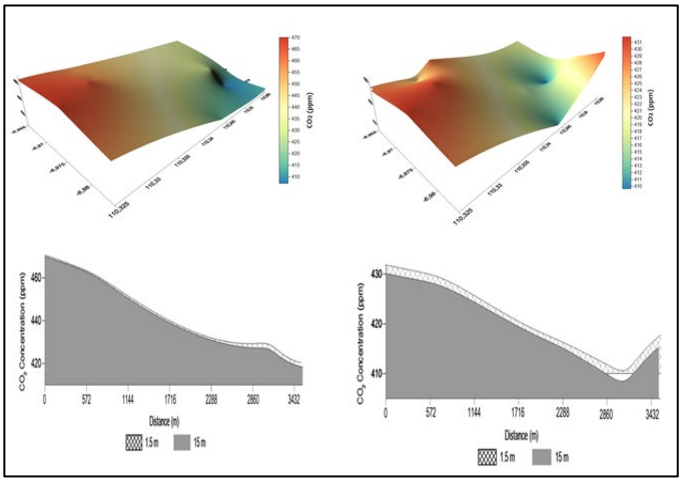
Figure 5 and Figure 6 below show the distribution of CO_2 concentrations in the Commercial Area of the ADA Mall and the Perintis Kemerdekaan Road.

Figures 5 and 6 show that the Commercial Area of the ADA Mall has greater CO_2 concentrations than the Perintis Kemerdekaan Road. This is due to the supermarket's high building density in the commercial area, which results in poor air circulation. Due to its location at the intersection of three major roads—the toll road, Perintis Kemerdekaan Road, and Setiabudi Road—ADA Mall sees a lot of traffic. A high-level emission in this location is also a result of activity in the mall parking lot. These finally led to CO_2 concentration values that were greater than those on Perintis Kemerdekaan road. The findings of CO_2 concentrations in the morning and evening at the same location point are not significantly different, as shown in Figures 5 and 6. However, the CO_2 concentration can vary greatly across these two different sites. In conclusion, rather than having a vertical or temporal distribution, CO_2 gas was distributed spatially.



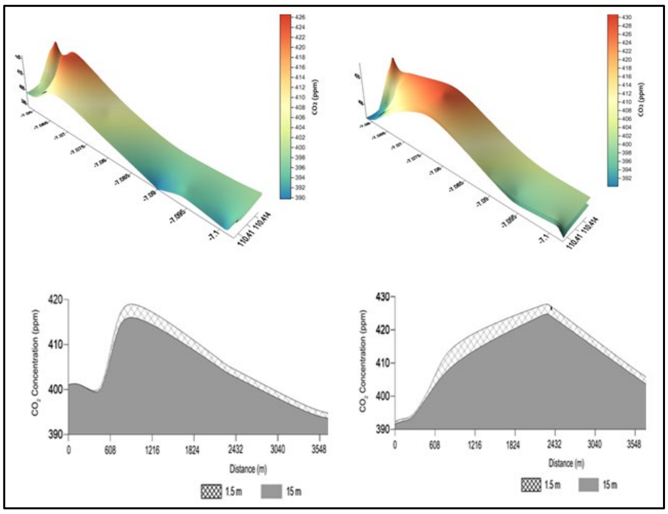
(a) *Weekend* Morning (b) *Weekend* Afternoon

Figure 3. Map and Cross section of CO_2 Concentration Distribution in Tugu Industrial Estate and Tugurejo Village Housing in Weekend



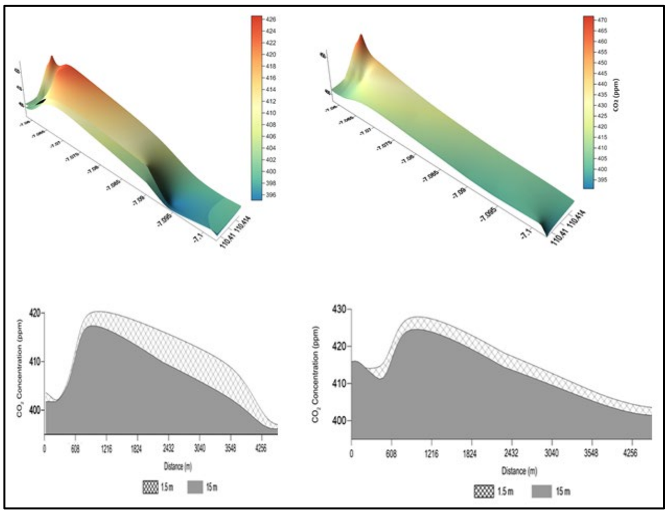
(a) *Weekday* Morning (b) *Weekday* Afternoon

Figure 4. Map and Cross section of CO_2 Concentration Distribution in the Tugu Industrial Estate and Tugurejo Village Housing on Weekday



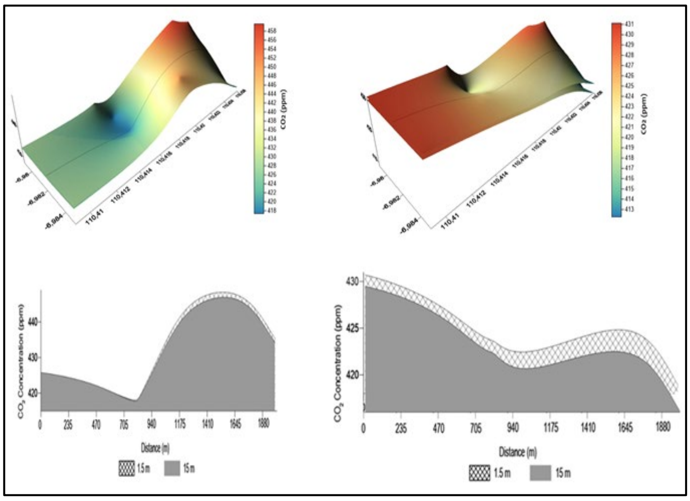
(a) *Weekend* Morning (b) *Weekend* Afternoon

Figure 5. Map and Cross section of CO_2 Distribution in Commercial Areas. There are Supermarkets and Independence Pioneer Roads on Weekend



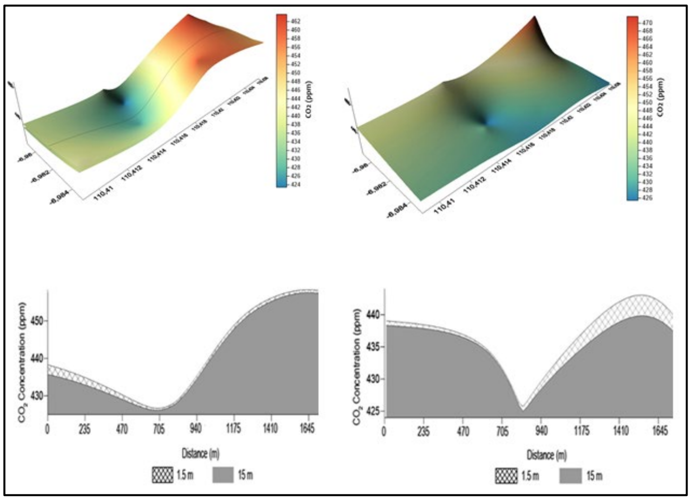
(a) *Weekday* Morning (b) *Weekday* Afternoon

Figure 6. Map and Cross section of CO_2 Distribution in ADA Mall Commercial Areas and Perintis Kemerdekaan Roads on Weekday



(a) *Weekend* Morning (b) *Weekend* Afternoon

Figure 7. Map and Cross section of CO_2 Concentration Distribution in Paragon Mall Commercial Area and Housing Around Central Semarang at Weekend



(a) *Weekday* Morning (b) *Weekday* Afternoon

Figure 8. Map and Cross-section of CO_2 Concentration Distribution in Paragon City Mall Commercial Area and Housing Around Central Semarang on Weekday

The distribution of CO_2 concentrations in the Paragon Mall's commercial area and the housing near Central Semarang is depicted in Figures 7 and 8 below. According to Figures 7 and 8, the Central Semarang Housing area tends to have a higher distribution of CO_2 gas on weekday and weekend mornings, as seen by the significant CO_2 concentration on the right. This is brought on by household and domestic-related activities, as well as high waste disposal that produces additional CO_2 emissions. However, on a Saturday afternoon, the Paragon Mall's commercial area had a greater CO_2 concentration as a result of increased commercial activity, which was reflected in an increase in the number of visitors. According to the cross-section analysis, although there is no significant difference in concentration between the heights, the concentration at 1.5 m tends to be larger than the concentration at 15 m.

There was no significant difference in CO_2 gas content between 1.5 m and 15 m, per the findings of measurements taken at all six locations. As a result, gas measurements at the height of around 15 m are equivalent to 1.5 m. However, given that they have a larger density than gas, particulates as a contaminant need more study. The fact that there are variations in CO_2 gas content and spatial distribution is another intriguing fact. This suggests that it is important to quantify pollutant concentrations in a more constrained location in order to assess the impact of air pollution on health. This is to prevent inhalation concentration bias in health impact studies due to the spatial distribution of pollutants.

Above all, there are drawbacks in this study where the level of accuracy of the instrument is 5% while the difference in measurement results is <5%, especially those in commercial and residential areas, so the differences that occur are still within the error range of the CO_2 monitor.

4. CONCLUSION

According to the study's results and discussion, we can draw the following conclusions:

1. The results of carbon dioxide (CO_2) gas concentration measurements from 6 regions show that the Industrial area has the highest CO_2 concentration value. Complex sources (transport and industry) influence air pollution, particularly in Tugu Industrial Estate, resulting in higher carbon dioxide (CO_2) gas concentration compared to the other measurement locations.
2. Based on the statistical analysis, there are no significant differences in CO_2 concentrations at 1.5 m and 15 m at any of the measurement sites. Only 0.17 percent, on average, separates the concentration at 1.5 and 15 meters sampling points. However, there are variations in the spatial distribution of CO_2 gas concentration.

Reflecting on the results of this study, measuring gas concentrations in urban areas, where setting up the instrument at the height of human breath is constrained by the location condition, then measurements at an altitude of up to 15 m instead of 1.5 m above ground are still feasible to be done. Further research is needed to determine whether the particulate parameters at the height of 15 m could be done similarly.

5. ACKNOWLEDGMENT

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