Impact of Car-Free Day activities in Dago area, Bandung, West Java in reducing CO and CO₂ gas concentrations

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Abstract. Every Sunday between 06.00 to 10.00, the government of Bandung holds Car-Free Day (CFD) activities on Jalan Ir. H. Juanda (Dago) as a solution to reduce the impact of air pollution caused by vehicle emissions. In this study, we conducted observations that examine the difference in pollutant concentration values and their interactions with atmospheric boundary layer factors during CFD and the usual days in the Dago area. The observations were conducted on every Saturdays, Sundays and Mondays for five consecutive weeks (26 September - 26 October 2015). We made observations at three observation points, **Dago Cikapayang** (DCK), **Dago Ganesha** (DGN), and **Dago Dayang Sumbi** (DDS). The parameters we observed include potential virtual temperature, meridional wind velocity, carbon dioxide (CO₂) concentration, and carbon monoxide (CO) concentration. The observations indicate that the virtual potential temperature drop is always followed by a decrease in CO₂ concentration, but not vice versa. In addition, the data signify that CO concentration is more influenced by the number of vehicles and wind meridional rather than influenced by the virtual potential temperature. In conclusion, this study shows that CFD activities can decrease CO and CO₂ gas concentrations in Dago area.

1. Introduction

Various human activities such as industry and transportation played an important role in generating air pollution in urban areas. Air pollutants produced by human activities such as nitrogen oxide (NO_x), methane (CH₄), nonmethane (Non-CH₄), sulfur oxide (SO_x), and pollutant particles (SPM₁₀) can degrade ambient air quality [9]. 70% of major urban air pollution sources in Indonesia, such as Bandung; Surakarta; Yogyakarta; Semarang; Surabaya; Denpasar; and Serang, caused by motor vehicle activities [6].

Studies conducted by [1] and [8] previously discussed the relationship between air pollution in Bandung with meteorological parameters. The results of research conducted by [1] during the dry season showed that in strong background wind conditions, CO emission emitted from Bandung city tend to spread to Northwest, while when background wind conditions are weak, CO pollutants tend to settle and forming a layer on the local atmosphere in Bandung. Study on CO accumulation on a diurnal time scale by [8] states that in the morning the accumulation is influenced by valley breeze,

while in the afternoon influenced by the resultant mountain breeze from the mountains in the northern part of Bandung. Therefore, the pattern of local wind circulation plays an important role in the air pollution phenomena in Bandung. Bandung topography in the basin morphology form with hilly-surrounding hills led to the emergence of local circulation patterns in the Bandung in the form of katabatic and anabatic winds [5]. As a solution to air pollution problems in Bandung, the government held Car-Free Day (CFD) activities every Sunday from 06.00 to 10.00 [3].

The purpose of this study was to observe the interactions of meteorological parameters and air pollutants to assess the difference of concentrations of pollutants during CFD (Sunday) and non-CFD (Saturday and Monday) activities and to examine the interaction of meteorological parameters with pollutants. The study area is located on Jalan Ir. H. Djuanda (Dago), Bandung.

2. Data and Methods

Data that used in the study includes virtual potential temperatures (θ_v), meridional wind (v), CO and CO₂ pollutant concentrations, and vehicular traffic. The first three data was obtained through direct observation every five minutes, while vehicular traffic data was taken every thirty minutes. The observation time span is for four hours (06.00 - 10.00) on every Monday and Saturday (non-CFD), and Sunday (CFD) for five consecutive weeks (26 September - 26 October 2015). In addition to these four data, we also took observation data from ITB observation station (6 ° 54 '0" 'S, 107 ° 35' 60 " E) as supporting data to be compared with observed data of meteorological parameters in this study.

There are three instruments used in this research, namely Automatic Weather Station (AWS) Davis Vantage Vue, CO Meter (Extech C010 Carbon Monoxide), and CO₂ meters (Extech SD800 Carbon Oxide). AWS is used for automatic weather data collection (air temperature, relative humidity, pressure, wind velocity, and rainfall). AWS observation data is taken every five minutes at 06.00 - 10.00. The observation of these three instruments is done simultaneously at all three points on Jalan Ir. H. Djuanda (**Figure 1**), in order to cover local weather variabilities in that area. Figure 1. Location of observation stations.

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Once collected, the temperature and pressure parameter data cannot be directly processed just because there is still influence from the topography [7]. The temperature parameters will be converted to potential temperature (θ) and then into virtual potential temperature (θ_v) using equations (1), (2), and (3) to eliminate the effects of moisture, then air pressure parameters are also converted to MSLP

(mean sea level pressure) using equation (4). The wind speed data is then converted to meridional wind velocity (v) using equation (5).

$$\theta = T \left(\frac{P_0}{P} \right)^{0.286} \quad (1)$$

$$r = 0.622 \frac{e}{P - e} \quad (2)$$

$$\theta v = \theta(1 + 0.61r) \quad (3)$$

$$P_0 = P \left(1 - \frac{0.0065h}{T + 0.0065 + 273.15} \right)^{-5.257} \quad (4)$$

$$v = -v_{mag} \cos \left(\phi \left(\frac{\pi}{180^\circ} \right) \right) \quad (5)$$

, where

T : air temperature (K),
 P : air pressure (mb),
 P_0 : mean sea level pressure (mb),
 θ : potential temperature (K),
 θv : virtual potential temperature (K),
 e : vapor pressure (mb),
 r : mixing ratio (g/g),
 h : height of weather observation station (m),
 v : meridional wind velocity (m/s),
 v_{mag} : wind speed (m/s),
 ϕ : wind direction (°).

Subsequently, data processing was performed by using the linear interpolation method (IDW) to the θv , MSLP, and v data [2]. This interpolation process aims to see diurnal or semi-diurnal patterns through Hovmöller diagrams [4].

CO and CO₂ data from all observation points will be collected, then displayed in the form of time series plots. After that, the analysis of both parameters change periodically and then we made a comparison of each observation points. We analyzed the anomalous values of the two parameters separately, then interpolated with the IDW method [2].

3. Results and Discussion

3.1. Observation results of meteorological parameters

Based on the wind rose plots shown in **Figure 2**, it is seen that the dominant wind direction on all three observation points (DCK, DGN, and DDS) originated from the south on Saturday, Sunday, and Monday. Wind speeds on Monday appear to be larger than Saturday and Sunday. The wind speed at the DCK station appears larger relative to the two other observation points. Overall wind speed values range in the range 0 – 2 m/s, with the dominant values being in the range 0 – 1 m/s.

Figure 2. Wind rose plot at each observation stations (a) DCK, (b) DGN and (c) DDS.

The increase in θv values are directly proportional to the observation time either on Saturday, Sunday or Monday (**Figure 3**). This phenomenon is caused by an increase in solar radiation that is directly proportional to the observation time [10]. The wind parameter data shows a random variation at each observation time. There was no rainfall events during observation times, so the rainfall values on the three observation stations were zero.

Figure 3. Graphs of observed meteorological parameters at DGN station: (a) v wind, (b) θv and (c) rainfall.

Meanwhile, the wind observation at the ITB station (**Figure 4**) shows the difference in pattern with the nearest observation station, i.e. DGN. This is because of the difference in instrument placement locations. The θv pattern in the ITB station shows a similar pattern to the other three points of observation. At the time of observation also rainfall did not occur at this station. Radiation observation at the ITB station showed an increase in value that was directly proportional to the observation time.

Figure 4. Graphs of observed meteorological parameters at ITB station: (a) v wind, (b) θv and (c) rainfall.

θv anomalies in all observation points showed positive values at 06.00 - 06.30, then the negative value at 07.00 - 08.30, and again positive value at 08.30 - 10.00 (**Figure 5**). A positive anomaly indicates the phenomenon of reduced air density, resulting in a mild air parcel, whereas a negative anomaly value indicates increased air density and heavy air parcels [10].

Figure 5. Virtual potential temperature (θv) anomalies on: (a) Saturday, (b) Sunday and (c) Monday for DCK (blue), DGN (green) and DDS (red) stations.

The anomalous value of v at all observation points and times showed the diverse pattern (**Figure 6**). The negative anomaly v values indicates that the wind is heading southward, on the other hand, if the positive value signifies the wind is moving northward. Having quantified positive anomaly values at three points of observation is almost the same when compared with the negative anomaly, with the percentage of 47% positive anomalies while the negative anomalies are 53%. However, the wind speed of positive anomaly is greater than the negative anomaly values.

Figure 6. Meridional wind (v) anomalies on: (a) Saturday, (b) Sunday and (c) Monday for DCK (blue), DGN (green) and DDS (red) stations.

3.2. Observation results of air pollutants

Air pollutant parameters used in this study are the concentrations of CO and CO₂. The mean values of CO and CO₂ concentrations from all three observation points were respectively 8.25 ppm and 451.02 ppm. CO anomaly values differed on three days of observation (Saturday, Sunday, and Monday) (**Figure 7**). On Saturday there was a significant increase in value from 08.00 - 09.00, then decreased at 09.00 - 09.30 and again increased to 09.30 - 10.00 (**Figure 7a**). On Sunday there was a phenomenon where CO's anomaly was negative at 06.00 - 10.00 (**Figure 7b**). The decrease of CO value at 06.00 - 09.30 was due to CFD activity, so the main sources of CO pollution, namely vehicle (Seinfeld and Pandis, 2006) was banned from Dago. Then the CO values have increased significantly at 09.30 - 10.00, where the CO values are greater than the average value. This indicates the occurrence of abnormal vehicle accumulation during that period. On Monday the increase in CO values actually occurred at 06.30 - 09.00, then its values decreased at 08.00 - 08.30, then increase again at 09.00 - 10.00 (**Figure 7c**). CO concentrations on Monday is greater than on Saturday and Sunday. This is because Monday is a working day, so activity in the Dago area is more crowded than on Saturday and Sunday.

Figure 7. Graph of anomalous CO concentration at: (a) Saturday, (b) Sunday and (c) Monday for DCK (blue), DGN (green) and DDS (red) stations.

Meanwhile, the pattern of CO₂ pollutant concentrations on Saturdays, Sundays, and Mondays appears similar, although there is a difference in its values (**Figure 8**). The CO₂ anomaly values on Saturdays and Sundays at 06.00 - 07.30 is lower than the mean value, then decreases at 07.30 - 09.30, and again rises at 09.00 - 10.00 (**Figure 8a** and **Figure 8b**). On Monday, the CO₂ anomaly values is greater than its average at 06.00 - 07.30, decreasing at 07.30 - 08.30, and again rising at 09.00 - 10.00 (**Figure 8c**). In general, the CO₂ anomaly values decreased at 07.30 - 08.30, then increased from 09.00 - 10.00 on this three days. The CO₂ anomaly values on Monday at 06.00 to 07.00 is greater when compared with values on the other two days, this is suspected due to crowded activities on weekdays.

Figure 8. Graph of anomalous CO₂ concentration at: (a) Saturday, (b) Sunday and (c) Monday for DCK (blue), DGN (green) and DDS (red) stations.

3.3. Comparative analysis of meteorological parameters with pollutant concentrations

On Saturday (**Figure 9a**), the positive anomaly phenomena θv at 06.00 - 06.15 is followed by an increase in the concentrations of CO₂. Then at 06.45 - 08.45 there was a decrease in the θv anomaly values which also coincided with the decrease of CO₂ concentrations. At 09.00 - 10.00, there is an increase in the anomaly values of θv which also occurs simultaneously with increasing of CO₂ concentrations. On Monday (**Figure 9c**), the positive θv anomaly at 06.00 - 06.15 also coincides with an increase in CO₂ concentrations. Then at 06.45 - 08.45 there is a decrease in the θv values which also occurs along with the decrease in CO₂ concentrations. At 08.45 - 10.00, there is a phenomenon of increasing θv values but not followed by an increase in CO₂ concentrations. On Sunday (**Figure 9b**), the anomaly values of θv are positive from 06.00 to 06.15 which is not followed by an increase in CO₂ concentrations. Then at 06.45 - 08.45 there was a decrease in the θv anomaly values which coincided with the decrease of CO₂ concentrations. At 08.45 - 10.00 an increase in the anomaly values of θv is not followed by an increase in CO₂ concentrations. In general, the decrease in the anomaly values of θv occurs simultaneously with a decrease in CO₂ concentrations, but an increase in the values of θv is not always followed by an increase in CO₂ concentrations. This is evident in the case of Sunday at 06.00 to 06.15, when the θv anomaly value has increased to approximately one, but the CO₂ concentrations did not increase significantly when compared to Saturday and Monday.

Figure 9. Comparison of CO₂ and θ_v composite anomalies in the form of Hovmöller diagrams on (a) Saturday, (b) Sunday, and (c) Monday from three observational stations.

The influence of meteorological parameters on CO pollutants is different from CO₂. This is due to the lighter density of CO than the dry air masses, making it more easily dispersed by the influence of wind [9]. On Saturday at 08.00 - 09.00 the wind moves northwards from the DCK causing CO pollutants to accumulate at the DGN, while at 09.30 the wind moves southward from the DDS and DGN stations so that CO pollutants move from the DGN to DCK (**Figure 10a**). On Sunday at 06.00 - 09.00, the wind direction does not affect the CO pollutants spread because the pollutant anomaly values are negative at the time of CFD activity, while at 09.30 - 10.00 the wind blows southward from the DDS and DGN stations so that CO pollutants tend to accumulate at DCK (**Figure 10b**). On Monday at 06.30 the wind moves northwards from the DCK and southwards at the DGN and DCK, so the CO tends to be concentrated at the DGN and DCK, then at 07.00 and 07.30 - 08.30 the wind moves northwards from the DCK and DGN so that the CO tends to accumulate at the DGN station and the concentration decreases as it is dispersed to the DDS (**Figure 10c**). At 09.00 the wind moves southwards from the DCK station so that the CO is concentrated at the DCK. From 09.30 to 10.00 the wind moves southward from DGN and DDS so that the CO accumulates at DCK.

Figure 10. Comparison of CO and v composite anomalies in the form of Hovmöller diagrams on (a) Saturday, (b) Sunday, and (c) Monday from three observational stations.

In general, the value of CO pollutant anomalies on Sundays is smaller than on Saturdays and Mondays. This is closely related to the number of vehicles that pass in Dago area. This can be seen in **Figure 11**, it appears that on Saturday there was an increase in the number of vehicle volumes at the three observation points at 08.00 - 09.00 and 09.30 - 10.00. This occurs along with an increase in CO concentrations. Likewise, on Monday the increase in vehicle volume at 06.30 - 08.30 is directly proportional to the increase in CO concentrations. Meanwhile on Sunday, when the CFD activities were held from 06.00 - 08.30, it was seen that the anomaly was negative because vehicles were not allowed to pass in Dago area during that time. Then at 09.00 - 10.00 when vehicles are allowed to enter the Dago area again, CO anomalies show a positive value.

Figure 11. Graph the number of vehicles passing through the stations (a) DDS, (b) DGN and (c) DCK on Saturday (left panel), Sunday (center panel) and Monday (right panel).

4. Conclusion

The decrease in the anomaly values of θv is directly proportional to the decrease in CO₂ concentrations, but this does not apply to the increase of the anomaly values of θv which is not always directly proportional to the increase in CO₂ concentrations in Dago. CO concentrations itself is more influenced by the wind and the number of vehicles that pass. The results of this study indicate that the activities of CFD which organized by the government of Bandung play an active role in reducing CO and CO₂ concentrations in Dago area.

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