ABSTRACT

The world is currently going through the COVID-19 pandemic which has caused hundreds of thousands of deaths in just a few months. Considering the need for lockdown measures, most countries, including Malaysia, have implemented ‘Movement Control Orders’ (MCOs) as a prevention step to reduce the deadly spread of this disease. Local and worldwide media have reported the immediate improvement of air quality due to this event. Nevertheless, data on the effects of MCOs on air quality at local scales are still sparse. Here, we investigate changes in air quality during the MCO at an urban area using the air sensor network AiRBOXSense which measures monoxide (CO) and particulate matter (PM$_{2.5}$ and PM$_{10}$). In this study, air pollutant data during normal days were compared with MCO days using a reference analyser and AiRBOXSense. The results showed that the levels of the measured pollutants dropped by ~20 to 60% during the MCO days at most locations. However, CO in Kota Damansara (KD) dropped to 48.7%, but PM$_{2.5}$ and PM$_{10}$ increased up to 60% and 9.7% respectively during MCO days. Local burning activities in the residential area of KD are believed to be the main cause of the increased PM levels. This study has proven that air pollutant levels have significantly fallen due to the MCO. This air quality level information showed that the reduction of air pollutants can be achieved if traffic and industry emissions are strictly controlled.

Keyword: Movement Control Order; Carbon monoxide; Particulate matters.

INTRODUCTION

The World Health Organization (WHO) declared the COVID-19 outbreak as a pandemic on 11th March 2020 (WHO, 2016, 2020). In many countries, including Malaysia, a pandemic action plan has been announced by authorities.

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One of the action plans is known as a Movement Control Order in Malaysia (MCO) to stop the spread of COVID-19 while transmission and mitigation can be further understood (Hadei et al., 2020; Hsiao et al., 2020). Owing to the restriction of movement, only limited essential services such as healthcare, logistics, the food supply chain and banking are allowed to operate. Therefore, there are fewer vehicles on the roads, many cancelled flights and restricted construction and industrial activities which has led to plummeting levels of air pollutants. Hence, there has been an ancillary health benefit of reducing air pollution due to the MCO.

Air quality is an important factor that any government needs to manage and control. Increased levels of air pollutants will affect human health, causing respiratory and skin problems. According to data supplied by the World Health Organization, air pollution and poor air quality result in 5.5 million unnecessary deaths annually (WHO, 2016).

The main sources of air pollution in urban areas are combustion from vehicles, power generation plants, landfill sites, wastewater treatment plants and unsustainable farming. The emissions of air pollutants such as volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen dioxides (NOx), ozone (O3), sulphur dioxides (SOx) and particulate matter (PM) need to be monitored at high resolution in urban areas since these compounds will deteriorate human health if present at high concentrations (Latif et al., 2012; Banan et al., 2013; Mohd Nadzir et al., 2018).

Recently, satellite measurements of air pollutants during the COVID-19 pandemic from the European Space Agency have shown that during late January and early February 2020, air pollution decreased markedly. The maps on changes in NO2 produced by the Royal Netherlands Meteorological Institute (KNMI) using a Tropomi instrument on the Copernicus Sentinel-5P satellite (https://theconversation.com) showed lockdown in Europe resulted in reductions in NO2 emissions. In India, air pollution levels have dropped by 71% in just one week and PM2.5 dropped from 91 to 27 µg m⁻³ from the 20th to the 27th March 2020 (https://www.ecowatch.com/india-air-pollution-coronavirus-2645617908.html).

A model study suggested that air quality in India has improved slightly if similar emission reduction during MCO occurs under unfavourable meteorological conditions in India. In addition, Xu et al. (2020) reported that three cities in central China, the Hubei Province, Wuhan, Jingmen, and Enshi, recorded total reductions of air pollutants during the pandemic of 30.1%, 40.5%, 33.4%, 27.9%, and 61.4% for PM2.5, PM10, SO2, CO, and NO2, respectively.

In Malaysia, PM2.5 reductions of 58.4% were first observed over the Peninsular Malaysia region during the MCO period (Abdullah et al., 2020). However, this study focused on PM10 and does not cover other crucial pollutants such as CO and PM2.5. Although the 65 reference monitoring stations provide a good overview of air quality in the country, they are generally located away from emission sources and are unable to provide observations at high spatial resolutions. Therefore, low-cost air quality sensors for air quality measurements are deployed by local authorities and researchers globally to fill in the research gap (Alavi-Shoshasti et al., 2013; Austin et al., 2015; Alhassa et al., 2018). One potential solution for air pollution monitoring in urban areas is the use of ‘Low-cost Air Quality Sensors’ or LAQS. These provide good air pollution data at high spatial-temporal resolutions.

This study aims to investigate the air quality pollutants carbon monoxide (CO) and particulate matter (PM10 and PM2.5) at a local scale in an urban area both during normal days and the MCO period using LAQS, namely AirBOXSense. Secondary data from the Department of Environment Malaysia (DOE) and the AirBOXSense data will be used for validations. The meteorological and wind trajectory influences will be evaluated using ERA5 data. Finally, this study will provide an insight into a potential future with less air pollution and will assist us in formulating achievable air quality management and control procedures.

**METHODS**

**Field Measurement and Data Analyses**

Details of the AirBOXSense system have been published in previous work by Alhassa et al. (2018), where it was known as ‘Dirac Sense’. There are slight modifications of the system now named AirBOXSense. The specific requirements for our sensing system were reliability and durability while being low cost, portable and easy to install by the user. AirBOXSense collects, analyses and shares air quality data using the wireless communication network. Using the Internet of Things (IoT) scenario allows data to be sent to remote cloud storage such as Thingspeak periodically as well as the near-real-time visualization of numerical and graphical values over time. In this study, the CO electrochemical sensor (EC) and the optical particle sensor (OPC-N2) for PM measurements were manufactured by Alphasense (Alphasense Ltd., Great Notley, Braintree, UK). Details of the AirBOXSense calibrations, configurations and operations were described in our previous work (Alhassa et al., 2018). In this study, a GRMM portable aerosol spectrometer (PAS-1.108) was used as a reference instrument for validation purposes for PM2.5 and PM10 with correlation coefficient r² values of 0.71 and 0.83 for PM2.5 and PM10, respectively.

In addition, we used secondary data obtained from the Malaysia Department of Environment’s (DOE) continuous air quality monitoring system (CAQMS) to support the sensor data. However, due to the introduction of PM2.5 measurement components in 2017, we are limited to using historical data from 2017 to 2018 at the nearest CAQMS stations. The DOE data will be compared with the sensor data during a normal day (~20th November 2019–17th March 2020) and during the MCO (18th March 2020–12th April 2020) from the sensor. The wind data used in this study was the ERA5 data from the European Centre for Medium-Range Weather Forecasts (ECMWF). The data used were 10 m wind components with 31 km horizontal resolution and an hourly temporal resolution. The ERA5 data are provided freely by the Copernicus Climate Change Service of the ECMWF on their website (C3S, 2017). While there are five different locations of sensor stations in this study, they are all within the same 31 km × 31 km grid with similar data values.
Sensors and CAQMS Stations
In this study, two types of data will be obtained, the first by the air quality sensors and the second by reference instruments for comparison and validation. Five AirBOXSense sensors were deployed at different locations in Petaling Jaya: Bukit Gasing (BG), Petaling Jaya City (PJ), Kelana Jaya (KJ), Uptown PJ (UP) and Kota Damansara (KD), respectively (see Fig. 1). Secondary data from seven CAQMS stations close to the AirBOXSense sensor locations were used in this study to investigate the background levels of CO, PM$_{2.5}$ and PM$_{10}$ during normal days from the previous year, November 2017 to April 2018. All stations are located less than 20 km from PJ.

Backward Trajectories Analysis
To investigate the possible sources that could contribute towards high concentration events of the measured pollutants during the MCO period, the backward trajectory analysis was conducted to track the origin of air masses arriving at the measurement sites. The analysis was performed using the Hybrid Single Particle Lagrangian Integrated Trajectory model (HYSPLIT) developed by the National Oceanic and Atmospheric Administration (NOAA)'s Air Resource Laboratory (ARL) (Draxler and Rolph, 2003; Rolph, 2003) which is available online (https://ready.arl.noaa.gov/hypub-bin/trajectories.pl). The model was run in the backward mode for 72 hours from 0–100 m above the surface of the measurement sites where the high pollution event was observed.

MODIS Active Fire Product
Active fire/hotspot data from NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) (Justice et al., 2002) were retrieved during the MCO period to examine possible sources from active fires near the measurement sites. The collection 6 Terra and Aqua MODIS active fire data which produced moderate resolution (~1 km) was downloaded from the Fire Information for Resource Management System (FIRMS) of NASA’s Land, Atmosphere Near-real-time Capability for Earth Observing System (LANCE).

RESULTS AND DISCUSSION
Ground Station Data
The overall average concentration values during the normal period (28th November 2019 to 17th April 2020) from the CAQMS stations for CO, PM$_{2.5}$ and PM$_{10}$ were 1.2 ± 0.3 ppm, 22.1 ± 4.4 µg m$^{-3}$ and 45.4 ± 10.8 µg m$^{-3}$, respectively (See Table 1). The maximum concentrations for CO, PM$_{2.5}$ and PM$_{10}$ were in the ranges 1.92 to 3.51 ppm, 43.1 to 155 µg m$^{-3}$, 57.9 to 180 µg m$^{-3}$, respectively.

Fig. 1. CAQMS stations and sensor locations in the Petaling Jaya district and Klang Valley region.
Table 1. Daily average concentrations of CO, PM$_{10}$ and PM$_{2.5}$ over Cheras, Shah Alam, Batu Muda, Klang and Petaling Jaya recorded by CAQMS stations from 1$^{st}$ November 2017 to 14$^{th}$ April 2018.

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Cheras</th>
<th>Shah Alam</th>
<th>Batu Muda</th>
<th>Klang</th>
<th>Petaling Jaya</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (ppm)</td>
<td>Min</td>
<td>0.42</td>
<td>0.28</td>
<td>0.33</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>2.54</td>
<td>1.94</td>
<td>1.92</td>
<td>3.51</td>
</tr>
<tr>
<td></td>
<td>average</td>
<td>0.99</td>
<td>0.86</td>
<td>0.91</td>
<td>1.05</td>
</tr>
<tr>
<td>PM$_{10}$ (µg m$^{-3}$)</td>
<td>Min</td>
<td>15.3</td>
<td>10.0</td>
<td>8.20</td>
<td>20.7</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>127</td>
<td>131</td>
<td>141</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>36.8</td>
<td>41.7</td>
<td>34.8</td>
<td>43.5</td>
</tr>
<tr>
<td>PM$_{2.5}$ (µg m$^{-3}$)</td>
<td>Min</td>
<td>7.83</td>
<td>7.40</td>
<td>5.15</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>46.6</td>
<td>51.3</td>
<td>47.9</td>
<td>155</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>21.4</td>
<td>24.1</td>
<td>17.6</td>
<td>26.5</td>
</tr>
</tbody>
</table>

Sensor Data

**Normal Day**

During the normal days, the daily average concentrations for CO, PM$_{2.5}$ and PM$_{10}$ in the PJ area measured by AiRBOXSense were 0.54 ± 0.14 ppm, 19.1 ± 9.75 µg m$^{-3}$ and 35.5 ± 17.6 µg m$^{-3}$, respectively. The highest concentrations were observed during peak hours between 0700 to 0900 and 1700 to 2000. This is due to the heavy traffic emissions at those times. These average daily concentration values were similar to the observations from the CAQMS station except CO where the AiRBOXSense data were slightly lower than the CAQMS data (see Table 2, Figs. 2(a)–2(e) and Fig. 3(a)–3(c)). During normal days, the BG site recorded the highest amount of PM$_{2.5}$ (1540 µg m$^{-3}$) and PM$_{10}$ (7110 µg m$^{-3}$) despite being a recreation park where people came for fresh and clean air. KD and KJ stations that are along the main road and highway each recorded high amount of PM$_{10}$ (3460 µg m$^{-3}$ and 2260 µg m$^{-3}$) capturing the mobile emission from the daily commute. The daily concentrations of CO, PM$_{2.5}$ and PM$_{10}$ are shown in Fig. 2(a)–2(e) and Fig. 3(a)–3(c).

**MCO day**

The period of MCO has three phases which were 18$^{th}$ March–31$^{st}$ March 2020 (1$^{st}$ phase), 1$^{st}$ April–14$^{th}$ April 2020 (2$^{nd}$ phase) and 15$^{th}$ April–28$^{th}$ April 2020 (3$^{rd}$ phase). However, the sensor data shown in this study is runs to 8$^{th}$ April 2020. The air pollutant levels recorded dropped at most of the sensor locations. The levels dropped ~20% to 60% (see Table 3). The sensors were deployed close to residential areas such as flats and apartments. Table 2 summarizes the daily average concentrations during MCO at the five sensor locations in PJ. The KD site recorded increases of both PM$_{2.5}$ and PM$_{10}$ – these were increased by 60% and 9.7%, respectively. The KD area is mainly surrounded by residential areas and small industries. To support this finding, we ran the back trajectories over the KD site (see Fig. 4). The period of the back trajectories was chosen to coincide with the MCO period (18–22 Mar 2020). Fig. 4 shows that the hotspot of burning activities in Peninsular Malaysia is some distance from the KD site and large-scale burning (detectable from satellite data) is not the major source of emission. The predominant origins of the back trajectories were from the north-east region.

Table 2. Daily average concentrations of CO, PM$_{10}$ and PM$_{2.5}$ measured by AiRBOXSense at Bukit Gasing (BG), Kelana Jaya (KJ), Kota Damansara (KD), Petaling Jaya (PJ) and Uptown.

<table>
<thead>
<tr>
<th>Locations</th>
<th>Normal day</th>
<th>MCO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO (ppm)</td>
<td>PM$_{2.5}$ (µg m$^{-3}$)</td>
</tr>
<tr>
<td>BG</td>
<td>Min</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>8.88</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.400</td>
</tr>
<tr>
<td>KJ</td>
<td>Min</td>
<td>0.0100</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.560</td>
</tr>
<tr>
<td>KD</td>
<td>Min</td>
<td>0.0100</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>7.78</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.550</td>
</tr>
<tr>
<td>PJ City</td>
<td>Min</td>
<td>0.0100</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>8.02</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.540</td>
</tr>
<tr>
<td>UP</td>
<td>Min</td>
<td>3.46</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>8.59</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.680</td>
</tr>
</tbody>
</table>
Fig. 2. Daily concentrations of CO, PM$_{2.5}$ and PM$_{10}$ measured by *AirBOXSense* over Petaling Jaya district from normal (red line) to MCO (blue line) periods with stations based at (a) Bukit Gasing, (b) Kelana Jaya, (c) Uptown PJ, (d) Kota Damansara, (e) PJ Town.
Fig. 2. (continued).
Fig. 2. (continued).

Fig. 3. Box and whisker plots of daily average (a) CO, (b) PM$_{2.5}$ and (c) PM$_{10}$ concentrations during normal days and the MCO period. (Note: The top and bottom of each box represent the 75th percentile and 25th percentile respectively and the upper and lower whiskers represent the 90th percentile and 10th percentile, respectively. The horizontal bar in each box represents the data median.)
Nevertheless, the increase in both PM$_{2.5}$ and PM$_{10}$ can be explained due to the high concentration of construction activities in the area, mainly the construction of the Damansara-Shah Alam Elevated Expressway (DASH Highway), in the surrounding area of KD that occurred during this short period of time. Due to the wind direction, particulate matter was transported to the sensor location. Another contributor was suspected to be small-scale burning activities by residents and construction workers who live and work nearby. This is to protect themselves from mosquito bites which can transmit dengue fever. These small fires are likely to have caused the increase in both the PM$_{2.5}$ and PM$_{10}$ levels (personal conversation with MBPJ enforcement officer). This suggests that despite the extensive implementation of emission control strategies, other emissions such as local burning or leakage from industries are difficult to control.
Table 3. Overall reduction of the CO, PM$_{2.5}$ and PM$_{10}$ recorded during MCO in Petaling Jaya. (Note: red bold indicates an increase in emissions.)

<table>
<thead>
<tr>
<th>Station</th>
<th>Sensor deployment</th>
<th>Type of area</th>
<th>Air pollutants</th>
<th>Average reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG</td>
<td>Car park</td>
<td>Recreation area</td>
<td>CO</td>
<td>40.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{2.5}$</td>
<td>58.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{10}$</td>
<td>51.8</td>
</tr>
<tr>
<td>KJ</td>
<td>Facing highway</td>
<td>Main highway</td>
<td>CO</td>
<td>45.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{2.5}$</td>
<td>32.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{10}$</td>
<td>34.9</td>
</tr>
<tr>
<td>PJ City</td>
<td>Main road</td>
<td>Township and industrial</td>
<td>CO</td>
<td>44.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{2.5}$</td>
<td>39.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{10}$</td>
<td>42.0</td>
</tr>
<tr>
<td>UP</td>
<td>Main road</td>
<td>Residency, Mall, Shops and restaurant area</td>
<td>CO</td>
<td>47.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{2.5}$</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{10}$</td>
<td>28.8</td>
</tr>
<tr>
<td>KD</td>
<td>Main road</td>
<td>Residency and small industries</td>
<td>CO</td>
<td>44.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{2.5}$</td>
<td>+41.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{10}$</td>
<td>+14.2</td>
</tr>
</tbody>
</table>

Fig. 4. The cluster means of backward trajectories of KD stations during high pollution period (18–22 Mar 2020) with green (45%), blue (40%) and white (15%) triangles. The red dot marks the fire hotspot data from MODIS satellite during the same period (source map is from Google Earth).

**Other Observations**

The other interesting events detected during normal days are the week day and weekend effects observed by the sensors. The station that is most affected by the weekend effects is the one at BG. In order to determine the origins of CO, PM$_{2.5}$ and PM$_{10}$, bivariate polar plots of the concentrations have been used to relate average values for the measurements with the wind speed and direction (November 2019–February 2020) measured at PJ during the normal period using ERA 5 data (see Figs. 5–7). The highest PM$_{2.5}$ and PM$_{10}$ levels were observed at BG compared to other locations, especially during the weekend. The BG station represents the air quality at the car park of a big recreation park. The higher numbers of visitors to the BG recreation park during the weekend contributed to the related increment of vehicle emissions which was picked up by the downwind sensor (see Fig. 5(a)). Furthermore, high peaks were also observed over PJ Town and Kelana Jaya (KJ) (a highway area) but these were on weekdays during the rush hour (0700–0900) and were associated with strong north-easterly (NE) winds (see Figs. 5–7).

The northeast monsoon season begins in November and ends in March and April is the start of the intermonsoon period, but the wind direction is still mostly north-easterly and easterly. For effective emission controls, the weather conditions should also be taken into consideration (Wang et al., 2020). During this period of study (March–April), the Klang Valley region experienced the transitional period of
Fig. 5. Bipolar plots of (a) CO, (b) PM$_{2.5}$ and (c) PM$_{10}$ using the wind data at BG during normal day using ERA5 data from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Fig. 6. Bipolar plots of (a) CO, (b) PM$_{2.5}$ and (c) PM$_{10}$ over PJ using the wind data at KJ during normal day using ERA5 data from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Fig. 7. Bipolar plots of (a) CO, (b) PM$_{10}$ and (c) PM$_{2.5}$ at PJ City using the wind data at PJ BG during normal day using ERA5 data from the European Centre for Medium-Range Weather Forecasts (ECMWF).

intermonsoon weather with strong local convection and precipitation (Ooi et al., 2017). It also receives clean northeastern air masses entering from the central backbone of Peninsular Malaysia as seen in Figs. 5–7.

CONCLUSIONS AND PERSPECTIVES

In this study, the concentrations of CO, PM$_{2.5}$ and PM$_{10}$ were observed by AirBOXSense sensors and CAQMS over the Klang Valley region. The historical data from CAQMS stations were used to identify the background level air quality close to the sensor locations. The sensors measured the air quality during normal days and the MCO period. Both monitoring techniques were used to explain the spatial variation in the reductions in concentrations of the measured pollutants over the urban Petaling Jaya district in Klang Valley. According to these results, average daily concentrations from historical data observed by CAQM were in the same range as daily average concentrations measured by the sensors during normal days for CO and PM$_{2.5}$ and PM$_{10}$. All
the maximum levels for all pollutants were observed during peak rush hours during normal days due to traffic emissions. During MCO, however, the concentrations reduced by ~40–50% for CO and ~20–60% for particulate matter for most of the PJ sensor locations due to the reduction in vehicle numbers and industrial operations. Both PM$_{2.5}$ and PM$_{10}$ were increased in KD during the MCO period and this was suspected to be due to local burning activities and the highway construction nearby. North-east airflows cause pollutants to build up close to the sensor locations during both normal days and the MCO period. The meteorological effects on emission controls will be further discussed in the future using observation data with longer periods as well as numerical modelling tools.

**AUTHOR CONTRIBUTIONS**

Data analysis was done by MSMN, AAAM, MAAB, KMA, NMA and MFFMN. MSMN, MCCG, MTL, SHMA, HHAH and MZMN contributed to the discussion and interpretation of the results. MSMN, MCCG, MZMN, FA, NMH, AA and JA wrote the manuscript. MSMN, SHMA and KMA carried out the measurements. All the authors commented on the manuscript.

**COMPETING INTERESTS**

The authors declare that they have no conflict of interest.

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