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Space-based monitoring of NO$_2$ levels during COVID-19 lockdown in Cairo, Egypt and Riyadh, Saudi Arabia

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1. Introduction

In December 2019, many cases of coronavirus (COVID-19) infection were reported in the Chinese city of Wuhan (Jiang et al., 2020). As the number of cases of COVID-19 grew up, the disease began to spread rapidly to the rest of the world and became the main global health problem (Wu et al., 2020; Gilbert et al., 2020). Globally, as of 6th July 2020, there have been 11,327,790 confirmed cases of COVID-19, including 532,340 deaths, reported to WHO (WHO, 2020).

As the number of COVID-19 deaths grew up, WHO advised governments worldwide to lockdown home and limit all industrial and commercial activities. This prompted the declaration of areas prohibited of the outbreak travel zones known as “red zones”, leading to a reduction of emissions sources from transport and industrial activities, especially NO$_2$. The lockdown measures reduced human activities and transportation, which reduced energy consumption and oil demands. These human activities and transportation changes have a significant effect on air pollution in many regions of the world. NASA (National Aeronautics and Space Administration) and ESA (European Space Agency) released some evidence for the reduction of NO$_2$ up to 30% (NASA, 2020; ESA, 2020; Muhammad et al., 2020).

Recent researches have reported NO$_2$ reduction due to the lockdown measures around the world such as China (Bauwens et al., 2020; Sicard et al., 2020), South Korea (Bauwens et al., 2020), Western Europe (Bauwens et al., 2020), United States (Bauwens et al., 2020), Italy (Collivignarelli et al., 2020; Sicard et al., 2020), Kazakhstan (Kerimray et al., 2020), France (Sicard et al., 2020), Spain (Sicard et al., 2020) and Turkey (Kaplan and Avdan, 2020). The reported reductions in NO$_2$ ranged from 20% in Western Europe to 63% in Valencia, Spain. These studies were based on ground stations measurements (Sicard et al., 2020; Kerimray et al., 2020) or space-based monitoring such as Tropospheric Monitoring...
In the Middle East and North Africa (MENA) Region, there are limited studies of the lockdown impacts on the air quality during COVID-19 such as Morocco (Otmani et al., 2020). Still, there were no published studies on major cities such as Cairo, Egypt or Riyadh, Saudi Arabia.

In Saudi Arabia, until 9th March 2020, a few imported cases were reported. On 12th March, the first case was reported in Riyadh. In the following days, the Saudi Government announced the closure of some activities and locations to reduce the contact between people such as schools, mosques, conferences halls, sports centres, gyms, cinemas, shopping malls and restaurants. The workers were advised to work from home if possible. On 20th March, the Saudi Government suspended flights and public transport and declared a partial curfew on 23rd March. The public was requested to stay home from 7 pm to 6 am then on 25th March, it was extended to be from 3 pm to 6 am in main cities such as Riyadh, Jeddah and Dammam (Yezli and Khan, 2020). On 6th April, 24-hour (total curfew) was declared and continued until 25th April. On 26th April, partial curfew was reactivated.

Egypt announced the first imported case on 14th February in the capital city, Cairo. Starting from 15th March, the Egyptian Government announced the closure of some activities and locations such as mosques, schools, gym, sports centres. Shopping mall and stores except food and drugs stores were totally closed only at the weekends. The Government declared the closure of borders and banning flights on 19th March and announced a partial curfew on 25th March, where the public was requested to stay at home from 7 pm to 6 am.

In this study, the effect of different regimens attained to try and curb COVID-19 situation in the capitals of Saudi Arabia and Egypt on NO2 levels was investigated. NO2 column data were retrieved from Ozone Monitoring Instrument (OMI) from April of 2017 to 2020. OMI was selected due to the availability of the data in this time frame unlike TROPOMI, which was available starting from 2018.

2. Materials and methods

2.1. Study area

This study was focused on the urban landscape of the Capitals of Egypt and Saudi Arabia, namely Cairo and Riyadh (Fig. 1). Cairo governorate is the most populated governorate in Egypt as its population reached 9.9 million capita. Riyadh governorate is located in the centre of Saudi Arabia, with a population of 7231 million capita. The urban landscape in Riyadh is located between 29°E to 46°E, 24°N to 46°N, while for Cairo, it is located between 30°11'E to 31°13'E, 29°44'N to 31°50'E. Saudi and Egyptian governments declared different procedures in the days of March. By the start of April, the lockdown and partial curfew were declared in both cities. Therefore, the month of April was chosen as a time period for this study.

2.2. OMI NO2 tropospheric columns

Satellite-based remote sensing can monitor different pollutants in the atmosphere on the global scale, which facilitates the study of the spatio-temporal distribution of air pollutants (Zhao et al., 2020). OMI (Ozone Monitoring Instrument) was launched in October 2004 on NASA Aura satellite. It is a nadir viewing spectrometer that measures the solar radiation backscattered by the Earth’s atmosphere and surface in the UV–visible domain between 270 and 500 nm (Levnet et al., 2006). It has a spatial resolution of 13×24 km at nadir, 26×128 km at the swath and a daily temporal resolution (Zhang et al., 2017). NO2 tropospheric columns of OMI shown to have a strong correlation to ground measures (Li et al., 2017; Wang and Wang, 2020).

In this study, OMI QA4ECV version 1.1 tropospheric NO2 product was used from the TEMIS network (Boersma et al., 2017). Recent work validated this data against ground measurements (Compernolle et al., 2020). The uncertainties in the QA4ECV tropospheric NO2 columns amount to typically 40% over polluted scenes (Boersma et al., 2018). However, this work is based on temporal and spatial averaging, which will cancel out the error’s random component, leaving only the systematic error. The major part of this systematic error was expected to be cancelled while calculating the reduction (%) between 2020 and baseline of 2017 to 2019 (Bauwens et al., 2020).

In this study, daily data of OMI QA4ECV NO2 of April 2017 to 2020 were used to monitor the changes in NO2 due to the lockdown and curfew of COVID-19.

2.3. NO2 levels over Cairo and Riyadh

As shown in Fig. 2, the daily tropospheric NO2 column data were clipped for the study areas of Cairo and Riyadh using ARCGIS for April of years 2017 to 2020. The uncertainty of the clipped data was checked to be less than 40%. The mean value for each day was calculated. Then the weekdays mean, weekends (Fridays and Saturdays) mean and monthly mean of NO2 column were calculated for April of 2017 to 2020.

To study the effect of lockdown and curfew on NO2, monthly mean NO2 column during April 2020 was compared to that of the 3-years baseline period (April 2017, 2018 and 2019). In
addition, values during weekends and weekdays of April 2020 were compared with those of the 3-years baseline to assess the impacts of lockdown regimens during those time.

3. Results

OMI data were used to monitor changes in tropospheric NO2 concentrations over Riyadh and Cairo during the COVID-19 lockdown period and compared with similar periods in three previous years. The monthly mean in the lockdown period (April 2020) was 3.32E + 15 and 5.60E + 15 molecule cm$^{-2}$ in Riyadh and Cairo, respectively. Reduction in NO2 column was calculated by comparing the NO2 concentrations in April 2020 by the concentration in the 3-years baseline. As shown in Fig. 3 and Table 1, the reductions in Cairo and Riyadh in April 2020 accounted for 23% and 40.3% respectively.

By comparing mean NO2 concentrations during April 2020 with mean concentrations during weekdays and weekends of the baseline (April over 2017–2019), the results show that during the 3-years baseline the mean values of NO2 for the weekdays were higher than weekends for both Cairo and Riyadh. During April 2020, the mean values of NO2 for the weekdays were higher than weekends in Cairo but slightly lower than weekends in Riyadh. When assessing the NO2 reduction patterns between the baseline and April 2020, the obtained data also indicated that in Riyadh the reduction in the weekdays (43.9%) was higher than weekends (29.2%) while in Cairo, the case was the opposite where the reduction was higher during weekends (31.9%) compared to weekdays (16.3%) (Fig. 3 and Table 1).

Figs. 4 and 5 depict the daily NO2 patterns during April 2020 in Riyadh and Cairo, respectively. Those figures demonstrate that in Riyadh, 10 out of 22 days attained NO2 values higher than the monthly mean, the majority was weekdays (8 days) which represents 45% of the month weekdays. Two weekends achieved NO2 values higher than the monthly mean, which represents 50% of the month weekends (Fig. 3). Seven out of 20 days in Cairo attained higher NO2 values than the monthly mean, where only one day was a weekend with a percentage of 25% of month weekends and six days were weekdays which represents 37.5% of month weekdays (Fig. 4).

4. Discussion

Modern human activities and unsustainable development practices are known as significant drivers of environmental degradation and air, water and soil pollution. When the WHO declared a universal pandemic of the SARS-CoV-2 (COVID-19) on 11th March 2020, countries around the globe started to take measures to control the spread of the disease including different actions ranging between lockdown and total curfew. In fact, such measures created
a particular opportunity to provide potential science-based evidence on the cause-effect relationship between human activities and air pollution in urban areas.

During this study, we showed that an exceptional lockdown in response to the spread of COVID-19 had reduced such activities in Cairo and Riyadh. Procedures such as closure of industrial plants, partial and total curfew may change the picture of air pollutants in cities. This study focused on the potential reduction in NO\textsubscript{2} as a result of lockdown and curfew. The daily mean of tropospheric NO\textsubscript{2} column was derived from OMI data. The reduction was calculated by comparing NO\textsubscript{2} in April 2020 with 3-years baseline data. Three years baseline is long enough to reduce inter-annual variability in NO\textsubscript{2} levels while using the data of the same month makes the data influenced by local short-term emissions rather than meteorological variations (Sicard et al., 2020).

Measures to counteract the spread of the infection achieved 40.3% and 23% reduction in NO\textsubscript{2} levels in Riyadh and Cairo, respectively compared to the baseline mean. The reduction was higher in Riyadh than in Cairo due to differences in the applied regimens of lockdown and curfew in both cities. In general, the measures taken...
by the Saudi Government were stricter than those made by Egypt. Saudi Arabia applied total curfew in Riyadh from 6 to 25th April while the Egyptian Government has not imposed any total curfew in dealing with the pandemic. Both Governments imposed partial curfew -which was imposed after the total curfew in Saudi Arabia- that was longer in Riyadh (3 pm to 6 am) than in Cairo (7 pm to 6 am). In Riyadh, schools, malls and restaurants were closed, while in Cairo schools, restaurants were closed but malls and stores were closed only at weekends. In addition, Riyadh reduced the human work capacity to 50% and advised companies to work from home. The Saudi Government forced a penalty of 10,000 SAR (almost 2700 US$) on violating the curfew. Collectively, those control measures forced more restricted human activities in Riyadh compared to Cairo corroborating our findings.

The difference in the reduction between Riyadh and Cairo may be related to socio-economic factors. The World Bank classified Saudi Arabia as a high-income country and Egypt as a lower-middle-income country. Per Capita GDP is much higher in Saudi Arabia (23,193 US$) than in Egypt (3020 US$) (World Bank classification, 2019). In Cairo, private car ownership is estimated at 0.23 car/capita, and the majority of its population depends on public transportation (CAPMAS, 2020). However, in Riyadh, the private car’s ownership represents 77% of transportation ways with an average of 2.2 car/household (Riyadh Urban Observatory, 2017). These percentages are considered very high compared with other cities like London with 0.8 car/household. Furthermore, in Riyadh, 98% of people use their private vehicles to go to work (Riyadh Urban Observatory, 2017).

The reduction of NO2 in Riyadh (40.3%) was higher than in Western Europe, the United States and Milan, Italy (Bauwens et al., 2020; Collivignarelli et al., 2020), but less than in Valencia, Spain (Sicard et al., 2020). While, the reduction in Cairo (23%) was higher than in Western Europe (Bauwens et al., 2020), but lower than United States, Milan, Italy and Valencia, Spain (Bauwens et al., 2020; Collivignarelli et al., 2020). Our results corroborated NASA’s report that the daily reduction in April 2020 ranges between 11 and 28% in Cairo and 20–51% in Riyadh (NASA, 2020).

This study indicated that during April of the 3-years baseline (2017–2019), the mean values of NO2 for the weekdays were higher than weekends for both Cairo and Riyadh. While during April 2020, the mean values of NO2 for the weekdays were higher than weekends in Cairo but slightly lower than weekends in Riyadh. The reduction of industrial activity and transportation during weekends leads to lower levels of emitted pollutants (Beirle et al., 2003; Tan et al., 2009; Sicard et al., 2020). In April 2020, due to the procedures of lockdown and curfew in Riyadh, the activities on weekends and weekdays were almost the same while in Cairo, the procedures were stronger on the weekends.

By calculating the reduction in NO2 column in weekdays and weekends between April 2020 and the 3-years baseline, it was found that in Riyadh, the reduction of weekdays (43.9%) much higher than weekends (29.2%). This was due to the procedures of lockdown, and the curfew was the same on weekdays and weekends. Therefore, the differences in human activities between April 2020 and the 3-years baseline was higher on weekdays due to working from home and closure of schools. In Cairo, the results indicated the reductions in weekdays (16.3%) was lower than at weekends (31.9%). This was due to the differences in the procedures of lockdown and curfew between weekends and weekdays as shopping malls, and stores were closed at weekends only, and the curfew was from 7 pm to 6 am which means it starts after the working hours. Therefore the changes in human activities were more at weekends than on weekdays.

The OMI instrument provides a good opportunity to study the chemical properties of tropospheric NO2 due to high spatial resolution (Zhao et al., 2021). This study provided further support and demonstrated the high potential of integrating remote sensing data with GIS techniques to investigate complex environmental and health problems such as linkages between air quality and governments’ policies to counteract pandemics. This potential will increase with developments in artificial intelligence and new satellite capabilities. The scientific community in our region should tap into these technologies and make them routine instruments in future environmental and public health research.

5. Conclusion

Our findings demonstrate an irony that a major global human health disaster has resulted in a positive impact on the human environment! Exceptional reductions in NO2 columns were detected over Cairo governorate, Egypt and urban areas in Riyadh, Saudi Arabia in April 2020 based on OMI data. The findings of the present study support earlier results that were indicating a link between COVID-19 related lockdown and curfew on one hand, and air pollution on the other. Our comparison between Cairo

![Fig. 5. The Daily NO2 column in Cairo in April 2020.](image-url)
and Riyadh demonstrated that the reduction in NO₂ was dependent on the strength of measures enforced by governments to curb the risk of infection spread. Finally, we advise countries to prepare for a sustainable and resilient come back following the control of this pandemic.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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