The Egyptian Journal of Remote Sensing and Space Sciences 24 (2021) 659–664

HOSTED BY

Contents lists available at ScienceDirect

The Egyptian Journal of Remote Sensing and Space Sciences

journal homepage: www.sciencedirect.com

Research Paper

Space-based monitoring of NO_2 levels during COVID-19 lockdown in Cairo, Egypt and Riyadh, Saudi Arabia

Amal Abdelsattar [a,*], Rahma Al Nadhairi [b], Ali N. Hassan [c]

[a] Prince Sultan University, Riyadh, Saudi Arabia
[b] Ministry of Environment and Climate Affairs, Sultanate of Oman
[c] Institute of Environmental Studies & Research, Ain Shams University, Cairo, Egypt

ARTICLE INFO

Article history:
Received 10 August 2020
Revised 16 February 2021
Accepted 17 March 2021
Available online 27 March 2021

Keywords:
COVID-19
Ozone Monitoring Instrument
Air pollution
Nitrogen dioxide

ABSTRACT

The lockdown of COVID-19 pandemic has affected air quality due to the changes in human activities. Researchers worldwide observed reductions in NO_2 concentrations due to lockdown and related diminished human activities, notably the reduced industrial and vehicular use. However, limited information was available for the MENA Region. In this study, the impact of lockdown due to COVID-19 on NO_2 in two MENA major cities: Cairo, Egypt and Riyadh, Saudi Arabia was assessed. NO_2 column was retrieved from the Ozone Monitoring Instrument (OMI) on Aura for April 2017 to 2020. The monthly mean value of NO_2 concentrations of April 2017–2019 was used as a baseline. NO_2 concentration in April 2020 was compared to the baseline to assess the impact of lockdown on NO_2. The results demonstrated that the lockdown was associated with a reduction in NO_2 in both cities. NO_2 decreases by 40.3% and 23% in Riyadh and Cairo. By comparing the decrease of NO_2 at weekends and weekdays, it was found that in Cairo, the decrease in weekdays (16.3%) was lower than weekends (31.9%). While in Riyadh, the decrease in weekdays (43.9%) was higher than weekends (29.3%). Variation in the reduction rates appears to be related to the different lockdown regimens taken by the two countries, among other factors. The findings of the present investigation alert countries in the region about the impact of human activities on urban air population and urge them to take appropriate mitigation measures to maintain good ambient air quality to protect human health and the environment.

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 zone", 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

Peer review under responsibility of National Authority for Remote Sensing and Space Sciences.
* Corresponding author.

https://doi.org/10.1016/j.ejrs.2021.03.004
1110-9823/

Instrument (TROPOMI) and Ozone Monitoring Instrument (OMI) (Bauwens et al., 2020; Kaplan and Avdan, 2020).

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 NO_2 levels was investigated. NO_2 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 46°29′E, 24°20 N to 46°58′E, 24°58′N, while for Cairo, it is located between 31°13′E, 30°11′N to 31°50′E, 29°44′N. 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 NO_2 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 (Levelt et al., 2006). It has a spatial resolution of 13x24 km at nadir, 26 × 128 km at the swath and a daily temporal resolution (Zhang et al., 2017). NO_2 tropospheric columns of OMI shown to have a strong correlation to ground measures (Liu et al., 2017; Wang and Wang, 2020).

In this study, OMI QA4ECV version 1.1 tropospheric NO_2 product was used from the TEMIS network (www.temis.kl) (Boersma et al., 2017). Recent work validated this data against ground measurements (Compernolle et al., 2020). The uncertainties in the QA4ECV tropospheric NO_2 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 NO_2 of April 2017 to 2020 were used to monitor the changes in NO_2 due to the lockdown and curfew of COVID-19.

2.3. NO_2 levels over Cairo and Riyadh

As shown in Fig. 2, the daily tropospheric NO_2 column data were clipped for the study areas of Cairo and Riyadh using ARC/GIS 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 NO_2 column were calculated for April of 2017 to 2020.

To study the effect of lockdown and curfew on NO_2, monthly mean NO_2 column during April 2020 was compared to that of the 3-years baseline period (April 2017, 2018 and 2019). In

Fig. 1. The location of the study area.

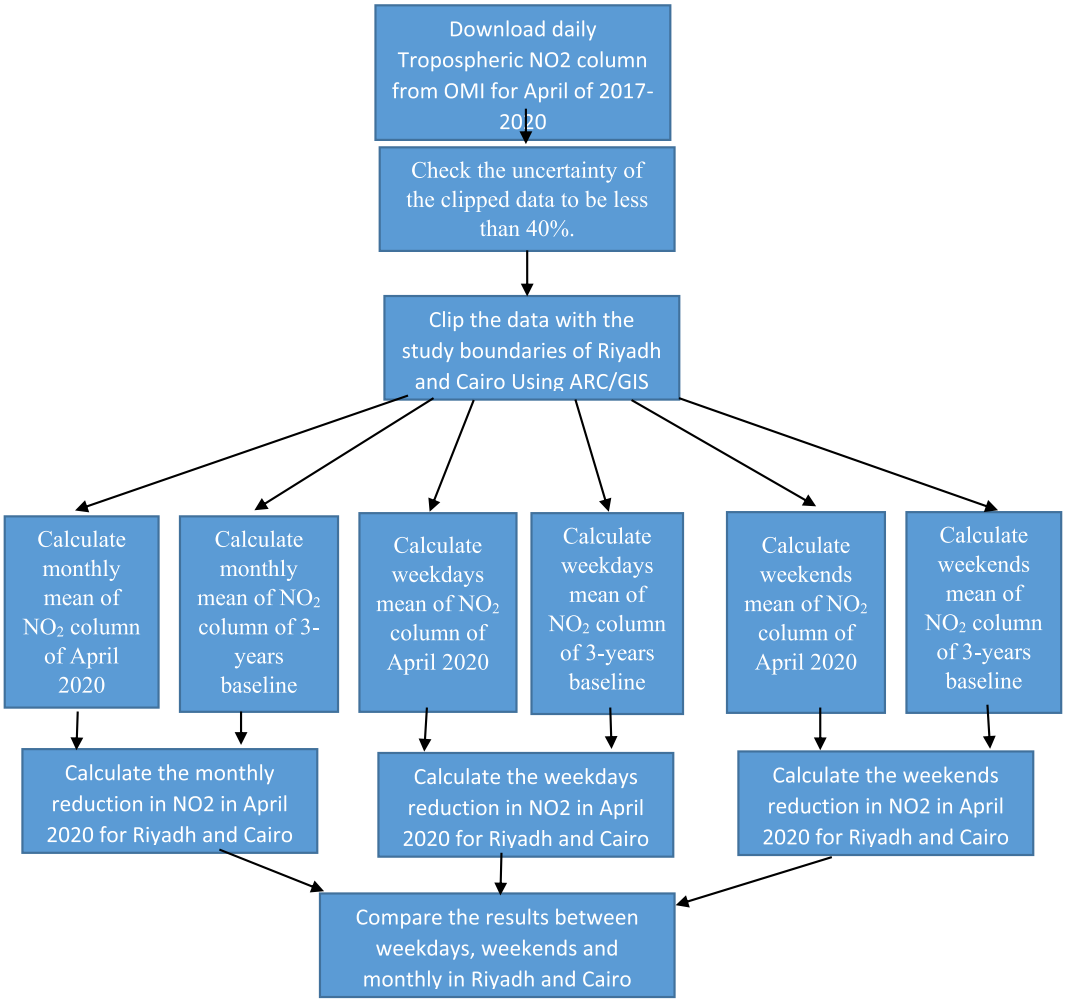

Fig. 2. Methodology for calculating the NO_2 reduction in Riyadh and Cairo.

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 NO_2 column was calculated by comparing the NO_2 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 NO_2 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 NO_2 for the weekdays were higher than weekends for both Cairo and Riyadh. During April 2020, the mean values of NO_2 for the weekdays were higher than weekends in Cairo but slightly lower than weekends in Riyadh. When assessing the NO_2 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 NO_2 patterns during April 2020 in Riyadh and Cairo, respectively. Those figures demonstrate that in Riyadh, 10 out of 22 days attained NO_2 values higher than the monthly mean, the majority was weekdays (8 days) which represents 45% of the month weekdays. Two weekends achieved NO_2 values higher than the monthly mean, which represents 50% of the month weekends (Fig. 3). Seven out of 20 days in Cairo attained higher NO_2 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

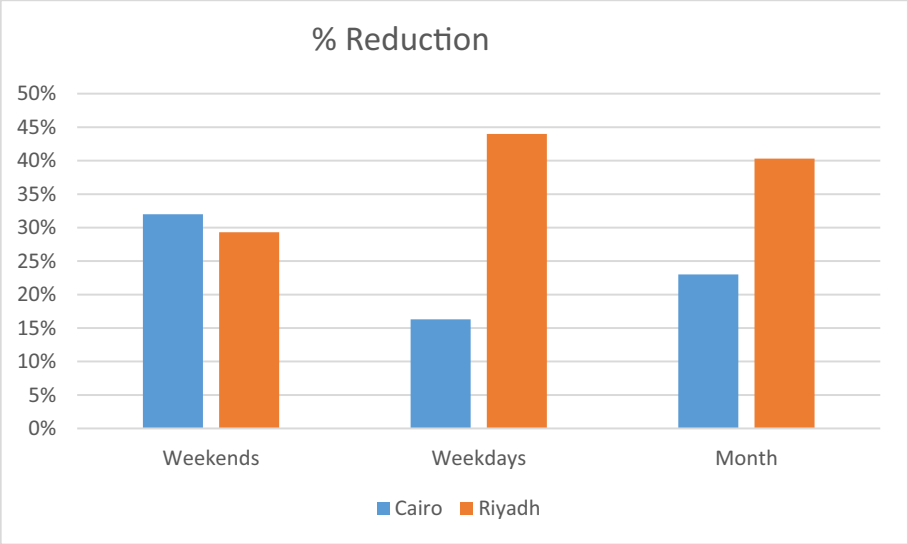

Fig. 3. %Reduction of NO_2 column in weekday, weekend and whole month between April 2020 and 3-years baseline in Cairo and Riyadh.

Table 1
Mean values of NO_2 column in weekends, weekday and full month as well as the differences and relative differences in Cairo and Riyadh.

	Riyadh			Cairo		
	Weekends	Weekdays	Month	Weekends	Weekdays	Month
3 years baseline-mean	5.05E + 15	5.82E + 15	5.56E + 15	5.60E + 15	6.25E + 15	6.24E + 15
April 2020	3.57E + 15	3.26E + 15	3.32E + 15	3.82E + 15	5.23E + 15	4.8E + 15
% Reduction	29.2%	43.9%	40.3%	31.9%	16.3%	23%

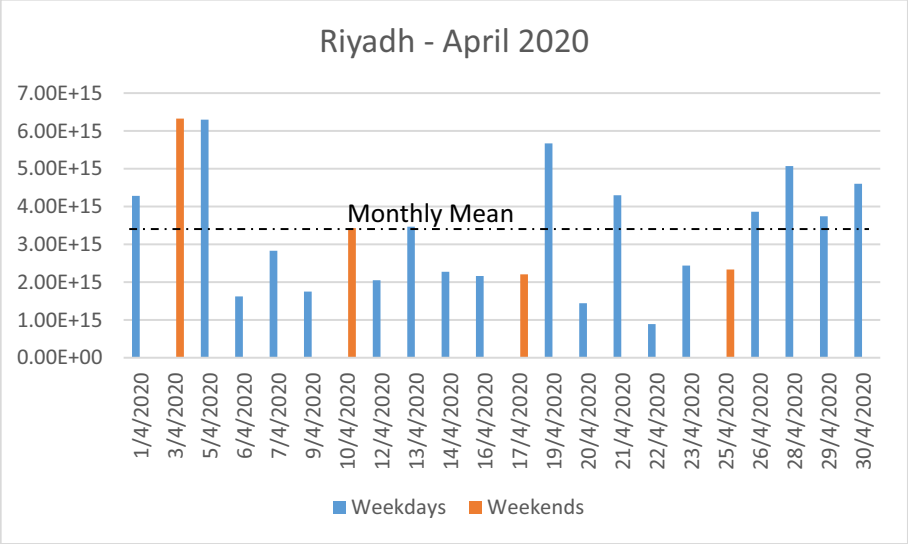

Fig. 4. The Daily NO_2 column in Riyadh in April 2020.

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_2 as a result of lockdown and curfew. The daily mean of tropospheric NO_2 column was derived from OMI data. The reduction was calculated by comparing NO_2 in April 2020 with 3-years baseline data. Three years baseline is long enough to reduce inter-annual variability in NO_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_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

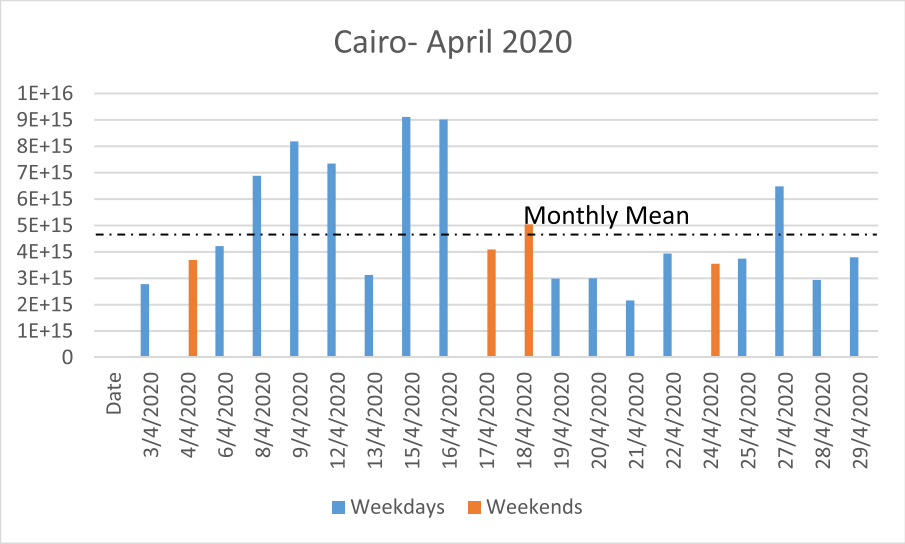

Fig. 5. The Daily NO_2 column in Cairo in April 2020.

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 transportations 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 NO_2 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 NO_2 for the weekdays were higher than weekends for both Cairo and Riyadh. While during April 2020, the mean values of NO_2 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 NO_2 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 NO_2 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

and Riyadh demonstrated that the reduction in NO_2 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.

References

Bauwens, M., Compernolle, S., Stavrakou, T., Müller, J.-F., Gent, J., Eskes, H., Levelt, P. F., A, R., Veefkind, J.P., Vlietinck, J., Yu, H., Zehner, C., 2020. Impact of coronavirus outbreak on NO_2 pollution assessed using TROPOMI and OMI observations. Geophys. Res. Lett. 47 (11). https://doi.org/10.1029/2020GL087978.

Beirle, S., Platt, U., Wenig, M., Wagner, T., 2003. Weekly cycle of NO_2 by GOME measurements: A signature of anthropogenic sources. Atmos. Chem. Phys. 3 (6), 2225–2232. https://doi.org/10.5194/acp-3-2225-2003.

Boersma, K.F., Eskes, H., Richter, A., De Smedt, I., Lorente, A., Beirle, S., et al. 2017. QA4ECV NO2 tropospheric and stratospheric vertical column data from OMI (Version 1.1). Royal Netherlands Meteorological Institute (KNMI) . https://doi.org/10.21944/qa4ecv-no2-omi-v1.1.

Boersma, K.F., Heskes, H.J., Richter, A., De Smedt, I., Lorente, A., Beirle, S., et al., 2018. Improving algorithms and uncertainty estimates for satellite NO_2 retrievals: Results from the quality assurance for the essential climate variables (QA4ECV) project. Atmos. Meas. Tech. 11 (12), 6651–6678. https://doi.org/10.5194/amt-11-6651-2018.

CAPMAS, 2020. www.capmas.gov.eg.

Collivignarelli, M.C., Abbà, A., Bertanza, G., Pedrazzani, R., Ricciardi, P., Carnevale, R., 2020. Lockdown for CoViD-2019 in Milan : What are the effects on air quality ?. Sci. Total Environ. 732,. https://doi.org/10.1016/j.scitotenv.2020.139280 139280.

Compernolle, S., Verhoelst, T., Pinardi, G., Granville, J., Hubert, D., Keppens, A., et al., 2020. Validation of Aura-OMI QA4ECV NO_2 climate data records with ground-based DOAS networVs: Role of measurement and comparison uncertainties. Atmos. Chem. Phys. Discuss. https://doi.org/10.5194/acp-2019-877 in review.

ESA, 2020. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P.

Gilbert, M., Pullano, G., Pinotti, F., Valdano, E., Poletto, C., Boëlle, P.-Y., D'Ortenzio, E., Yazdanpanah, Y., Eholie, S.P., Altmann, M., Gutierrez, B., Kraemer, M.U.G., Colizza, V., 2020. Preparedness and vulnerability of african countries against importations of COVID-19: A modelling study. Lancet 395 (10227), 871–877.

Jiang, F., Deng, L., Zhang, L., Cai, Y., Cheung, C.W., Xia, Z., 2020. Review of the clinical characteristics of coronavirus disease 2019 (COVID-19). J. Gen. Intern. Med. 35 (5), 1545–1549.

Kaplan, G.J., Avdan, Z.Y., 2020. COVID-19: spaceborne nitrogen dioxide over Turkey. J. Sci. Technol. A Appl. Sci. Eng. 21 (2), 251–255. https://doi.org/10.18038/estubtda.724450.

Kerimray, A., Baimatova, N., Ibragimova, O.P., Bukenov, B., Kenessov, B., Plotitsyn, P., Karaca, F., 2020. Assessing air quality changes in large cities during COVID-19 lockdowns : The impacts of traffic-free urban conditions in Almaty, Kazakhstan. Sci. Total Environ. 730,. https://doi.org/10.1016/j.scitotenv.2020.139179 139179.

Levelt, P.F., van den Oord, G.H.J., Dobber, M.R., Malkki, A., Huib Visser, Johan de Vries, , Stammes, P., Lundell, J.O.V., Saari, H., 2006. The ozone monitoring instrument. IEEE Trans. Geosci. Remote Sens. 44 (5), 1093–1101.

Liu, L., Zhang, X., Xu, W., Liu, X., Lu, X., Chen, D., Zhang, X., Wang, S., Zhang, W., 2017. Estimation of monthly bulk nitrate deposition in China based on satellite NO_2 measurement by the Ozone Monitoring Instrument. Rem. Sens. Environ. 199, 93–106.

Muhammad, S., Long, X., Salman, M., 2020. COVID-19 pandemic and environmental pollution: A blessing in disguise?. Sci. Total Environ. 728,. https://doi.org/10.1016/j.scitotenv.2020.138820 138820.

NASA, 2020. https://earthobservatory.nasa.gov/images.

Otmani, Anas, Abdelfettah Benchrif, Mounia Tahri, Moussa Bounakhla, El Mahjoub, Mohammed El, and M Krombi, 2020. Impact of Covid-19 Lockdown on PM10, SO2 and NO2 Concentrations in Salé City (Morocco) in Salé City. Sci. Total Environ. 735 (2): 139541. https://doi.org/10.1016/j.scitotenv.2020.139541.

Riyadh Urban Observatory, 2017. http://www.ruo.gov.sa/EN/.

Sicard, P., De Marco, A., Agathokleous, E., Feng, Z., Xu, X., Paoletti, E., Jaime, J., Rodriguez, D., Calatayud, V., 2020. Amplified ozone pollution in cities during the COVID-19 lockdown. Sci. Total Environ. 735,. https://doi.org/10.1016/j.scitotenv.2020.139542 139542.

Tan, P.-H., Chou, C., Liang, J.-Y., Chou, C.-C.-K., Shiu, C.-J., 2009. Air pollution 'holiday effect' resulting from the Chinese New Year. Atmos. Environ. 43 (13), 2114–2124. https://doi.org/10.1016/j.atmosenv.2009.01.037.

Wang, Y.i., Wang, J., 2020. Tropospheric SO2 and NO_2 in 2012–2018: Contrasting views of two sensors (OMI and OMPS) from space. Atmos. Environ. 223, 117214. https://doi.org/10.1016/j.atmosenv.2019.117214.

WHO, 2020. www.who.int

World Bank classification, 2019. https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=EG.

Wu, Y., Guo, C., Tang, L., Hong, Z., Zhou, J., Dong, X., Yin, H., Xiao, Q., Tang, Y., Qu, X., Kuang, L., Fang, X., Mishra, N., Lu, J., Shan, H., Jiang, G., Huang, X.i., 2020. Prolonged presence of SARS-CoV-2 viral RNA in faecal samples. Lancet Gastroenterol. Hepatol. 5 (5), 434–435. https://doi.org/10.1016/S2468-1253(20)30083-2.

Yezli, S., Khan, A., 2020. COVID-19 social distancing in the Kingdom of Saudi Arabia : Bold measures in the face of political, economic, social and religious challenges. Travel Med. Infect. Dis. April,. https://doi.org/10.1016/j.tmaid.2020.101692 101692.

Zhang, L., Sheng, C., Zhang, R., Chen, L., 2017. Spatial and temporal evaluation of long term trend (2005–2014) of OMI retrieved NO2 and SO2 concentrations in Henan Province, China. Atmos. Environ. 154 (2), 151–166. https://doi.org/10.1016/j.atmosenv.2016.11.067.

Zhao, F., Liu, C., Cai, Z., Liu, X., Bak, J., Kim, J., Hub, Q., Xia, C., Zhang, C., Sun, Y., Wang, W., Liu, J., 2021. Science of the Total Environment Ozone pro fi le retrievals from TROPOMI: Implication for the variation of tropospheric ozone during the outbreak of COVID-19 in China. Sci. Total Environ. 764, 142886.