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Research Paper

Impacts of short-term lockdown during COVID-19 on air quality in Egypt

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ABSTRACT

COVID-19 is a pandemic disease that is actively spread over the globe in a few months. Most of the Nations took the appropriate measures including lockdown to reduce the risk of spreading and safe human health and life. Egypt took the measures of partial and complete lockdown from 15th March till 30th June 2020. Such short-term lockdown has had a significant impact on the reduction of emissions from transportation, industrial and human activities. This research used multi-data sensors from space to map the changes of air quality over Egypt in the first 6 months from January to June 2020 due to the lockdown and compare with previous years of 2018 and 2019. It is clearly observed that the air quality over the whole country is improved as a result of reducing pollutants emissions, with NO2 reduced by 45.5%, CO emissions reduced by 46.23%, Ozone concentration decreased by about 61.1%, and AOD reduced by 68.5% compared to the previous 2 years. It is found that the lockdown is an effective mitigation measure against air pollution to improve air quality and reduce the air pollution that creates pressure on the human health and health system. It might be difficult to implement long lockdown, as a mitigation measure, due to its direct impact on social and economic needs. However, we recommend a complete lockdown for 2–3 days (long weekend) every at least 2-3 months, on national and/or global level, which will significantly enhance our air quality and improve the health environment of the planet.

1. Introduction

The novel coronavirus (COVID-19) outbreak is an outstanding global epidemic that was first detected in late 2019 at Wuhan, Central China (Huang et al., 2020). The virus spread worldwide by March 2020 and the World Health Organization (WHO) has announced that it has become a pandemic disease. By 30 June 2020, the confirmed infected cases worldwide reached 10,193,278 cases, and there were 503,913 registered deaths; though on the national level, Egypt has confirmed nearly 66,754 cases and 2872 death cases globally (WHO, 2020).

Coronavirus is an acute respiratory disorder that causes pneumonia with symptoms like fever, cough, and dyspnea (Jiang et al., 2020) and has a mortality rate of about 2–3% (Rodriguez-Morales et al., 2020). A nationwide lockdown is enforced in Egypt from 15th March till the end of June 2020 due to COVID-19 conta-

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lockdown on air quality have been investigated globally (Wafdy and Abdallah, 2020) and over different regions of the world such as Morocco (Otmani et al., 2020), Delhi, India (Mahato et al., 2020), China (Dutheil et al., 2020; Fan et al., 2020). Several studies have indicated that the reduction of anthropogenic activity during the COVID-19 contagion plays an important role in the formation of air pollution and could affect the ambient air quality (He et al., 2020; Isaifan, 2020).

Air pollution is a complex mixture of particulate matter and gaseous pollutants released into the atmosphere from anthropogenic and natural sources (Li et al., 2020). PM_{10}, NO_{2}, and SO_{2} are considered popular air pollutants in urban surroundings. Multiple studies have elucidated the severe health issues associated with these pollutants, which involve respiratory and cardiovascular diseases, blood pressure, and lung cancer (Koken et al., 2003; Le Terrete et al., 2002). These pollutants are produced from anthropogenic sources like transportation and industrial activities (Thorpe and Harrison, 2008; He et al., 2020), as well as the long-range transport of pollutants from other nations. NO_{2} produced in the atmosphere from anthropogenic processes (mostly from vehicles and power plants combustion of fossil fuel) and natural processes (e.g. soil processes and lightning) (Ogen, 2020). WHO reported that 4.6 million people die each year from illnesses related to air pollution (Cohen et al., 2017). Deaths associated with poor air quality involve but are not limited to lung and heart disorders, respiratory sensitivity, asthma, and bronchitis (Brauer, 2010).

The most important ambient pollutant in the monitoring of air quality is fine particulate matter (PM_{2.5}). Sulfur dioxide (SO_{2}), and nitrogen dioxide (NO_{2}) gaseous emissions are usually estimated to track pollution rates for fossil fuel combustion and exhaust from vehicles. Ozone (O_{3}) is produced from the photochemical reaction among nitrogen oxides (NO_{x}) and volatile organic compounds (VOCs), which occur under high-temperature and extreme sunshine conditions. Epidemiic studies proved that there is a strong correlation between the level of exposure to air pollution and high morbidity and mortality rates from respiratory and cardiovascular illnesses (Pope III et al., 2002).

In Egypt, the rising economy, urbanization, socio-economic development, and associated increasing motorized vehicles along with overpopulation have a major impact on air quality, particularly in highly developed and populated regions such as Greater Cairo and the Nile Delta (Abou El-Magd et al., 2020). The present research aimed to investigate the degree of improvement of air quality over Egypt during the high peak duration of COVID-19 from January to June 2020. The spatial and temporal variations in aerosols and trace gases (NO_{2}, CO, and O_{3}) will be comprehensively studied. This duration will be contrasted with the same months from the previous 2 years (2018 and 2019), to obtain a full picture of the real effect of the COVID-19 short-term lockdown measures on air quality over Egypt.

2. Data and methods

2.1. Study area

Egypt occupies the northeastern corner of the African continent surrounded from the North by the Mediterranean Sea, from the east by the Red Sea, from the west by Libya, and from the south by Sudan. Fig. 1 shows Egypt's location, highlighting its main cities. Because of Egypt’s geographical location, together with industrialization and overpopulation change, there are several contributing factors to the pollution created in Egypt. This includes its geomorphological characteristics, the rapid population growth, transportation, biomass burning, and industrialization. During the spring season, high wind accelerates the dust movement from the desert and contribute to increased pollution levels throughout the country (Zakey et al., 2008; Shokr et al., 2017; Abou El-Magd et al., 2020). Egypt’s population is counted 98,101,011 in 2019 as declared by the Central Agency for Public Mobilization and Statistics (CAPMAS, 2019). In this research, a study site around Egypt at 24.5654E, 21.4613N, and 37.0459E, 32.0082N was used for data analysis. Nile Delta region and Cairo are the most densely populated region in Egypt and also the highly polluted.

2.2. Data set

In this research, various satellite sensors have been used to examine the variations in air quality over Egypt during the period between January and June 2020 in comparison with the same months in previous years (2018 and 2019). Aerosol and gaseous air pollutants were analyzed including Aerosol Optical Depth (AOD), Nitrogen dioxide (NO_{2}), Carbon monoxide (CO), and Ozone (O_{3}).

2.2.1. MODIS aerosol Product

Almost regular global observations of aerosol and cloud properties can be obtained from the Moderate Resolution Imaging Spectro-radiometer (MODIS) sensor onboard Terra and Aqua satellites since 2000 and 2002, respectively, with a broad range of 0.4–14 μm and a spatial resolution of 250 m–1 km. Aerosol retrieval over land from MODIS can be achieved using the dart target (DT) algorithm (Kaufman et al., 1997), while the Deep Blue (DB) algorithm has been developed to recover aerosols over bright surfaces like deserts and urban areas (Hsu et al., 2013). In this research, MODIS Level-3 Terra DT&DB AOD data with a spatial resolution of 1° were analyzed. The analysis was carried out on a daily and weekly basis for 6 months from January to June, in three consecutive years 2018, 2019, and 2020 to detect and map the changes in AOD loading in 2020 influenced by the nationwide lockdown due to COVID-19 spreading. MODIS data were acquired freely from https://modis.gsfc.nasa.gov/data/. Table 1 shows the properties of the products analyzed in this research.

2.2.2. OMI NO_{2} Product

The hyperspectral instrument of Ozone Monitoring Instrument (OMI) onboard the Aura satellite since 2004 (https://aura.gsfc.nasa.gov/omi.html) with a spectral resolution of approximately 0.5 nm (Torres et al., 2007). OMI passes the equator with a swath of 2600 km around the local time of 13:30, as a sun-synchronous satellite instrument. The sensor has a daily global coverage at nadir with a pixel size of 13 × 24 km. OMI measures sunlight backscattered from the Earth over a wide spectrum of Ultraviolet–visible (UV–VIS) range (270 nm to 500 nm) to obtain abundances of trace gases including ozone which are critical for monitoring air quality and climate (Krotkov et al., 2016). NO_{2} is the output from the fossil fuels combustion in urban regions, which can be emitted from vehicles and by thermal power plants.

In this study, daily level-3 NO_{2} measurements were acquired from OMI data at a spatial resolution of 0.25° × 0.25° that cover Cairo and the Nile Delta of Egypt.

2.2.3. AIRS CO and O_{3} products

Throughout this analysis, the Atmospheric Infrared Sounder (AIRS) instrument (https://airs.jpl.nasa.gov/mission_and_instrument/overview), which was launched in 2002 on-board NASA's Aqua Satellite, was used to analyze both Carbon Monoxide (CO) and Ozone (O_{3}) concentrations. Tropospheric CO measurements can be acquired twice daily with near-global coverage from AIRS (Warner et al., 2013). It is a graticule spectrometer measuring the TIR emission from the Earth within a spectral range of 493–500 nm.
650–2665 cm\(^{-1}\) (Aumann et al., 2003). AIRS is a cross-track scanning instrument that provides regular global coverage of measurements. AIRS (Warner et al., 2007) has a high sensitivity for estimating atmospheric Ozone and CO. In this research, AIRS version 6 is used to generate daily CO and O\(_3\) measurements at 1°×1° that cover Egypt.

3. Results and discussion

Satellite data of trace gases and aerosols were presented and discussed for the period before and after the implementation of the complete lockdown in the country and compared with other similar time frames of the previous 2 years. A daily time series analysis of trace gases’ emissions including NO\(_2\), CO, O\(_3\), and aerosol optical depth (AOD) is shown in Fig. 2(a, b, c, and d) which presents the impacts of the containment measures implemented by the Egyptian government during the period of COVID-19 spreading in Spring (March–June) 2020. Investigation of data during the period from January to June in the years of 2018, 2019, and 2020 showed the variability in the emissions and concentrations in the three years. Since applying the national lockdown in Egypt on the 15th of March 2020, there was an observed reduction in NO\(_2\), CO, O\(_3\), and AOD concentration compared to the previous 2 years. This reduction may return to the partial lockdown applied at day time as well as the complete lockdown at night time. The analysis of CO distribution and variability does not show drastic changes after the implementation of the lockdown. The trend of CO (Fig. 2b) started to decrease from May in each year, this may be related to changes in meteorology and climatic conditions. This period coincided with the spring season, which has unstable conditions with a slightly higher temperature and wind speed than the winter season (January-February). Fig. 3 shows the monthly temperature curvature from January to June, which shows a general normal increasing trend in this time of the year as a transitional period from spring to summer, together with days of heat waves and heat islands (Abou El-Magd et al., 2016).

Further analysis performed on atmospheric ozone showed slightly lower values in 2020 than in 2018 and 2019, particularly after the implementation of control measures due to COVID-19 spreading (Fig. 2c). The same status is observed in the ozone curve,
which shows a higher reduction in 2020 than in previous years, which in return is the function of the lockdown.

The lockdown implementation does not only affect trace gasses emissions in Egypt but also influences aerosol loading. Aerosols are the prevalent pollution type in Egypt, especially during this 2020 Spring season, because of the frequent wind that influences the migration of desert dust to the urban region of Cairo and Nile Delta. In addition, the sea-spray from the Mediterranean Sea is influencing the aerosols loading at this time of the year. Besides these common natural sources of aerosols, the anthropogenic aerosols from various daily human activities play a great role in the formation of aerosol loading. Fig. 2d shows the aerosols status due to the lockdown, which reflects the reduction in concentration and spatial distribution as a direct impact of lockdown and low emissions, however, the effects of natural sources, meteorology, and/or long-range transport continued to affect the emissions. This is aligned with the findings by Li et al. (2019), and Abou El-Magd et al. (2020).

Fig. 2 clearly presents the low concentration of trace gases and aerosol loading during the period of complete quarantine (day and night) for 2 weeks that was obligatory implemented by the Egyptian government during late April 2020 on 20th–030th, which coincided with the long holiday of the Easter holiday “Sham El-Naseem” on 20th April, “Sinai Liberation Day” on 25th April and “Labor Day” on the first of May 2020. Furthermore, the reduction observed in late May from 23rd–31st, as this period coincided with the end of the Holy Month of Ramadan and Feast of “Eid Al-Fitr” holiday together with a weekend.

Fig. 4(a, b, c, and d) show the spatial variability of the NO2, CO, O3, and AOD for the period of late May between averaging concentrations in 2018–2019 and 2020. For NO2 (Fig. 4a), we can observe the reduction in the Nile Delta region and Greater Cairo, which is the highly populated metropolitan region in Egypt. This region has huge daily emissions of pollutants due to industrial activities and transportation together with other background pollution sources. During the long holiday time (complete lockdown), it is noticed that household and urban emissions are reduced due to the fact that a large population from Greater Cairo take this opportunity and migrated to their origin outer cities and rural areas outside Cairo. This resulted in a reduction of social and economic activities in the area and consequently reduced the emissions of pollutants. Moreover, the spatial differences in CO concentration distribution is noticed in different regions covering North Egypt. Ozone showed high spatial variations all over the country. For aerosol loading, changes are observed in the Nile delta and Western desert.

There were daily differences in concentrations of the analyzed trace gases and aerosol loading between 2020 and the previous 2 years, starting from 15th March. In some days there was no higher change, and sometimes the values in 2020 are higher, this may return to the partially implemented lockdown during the daytime. Although people were asked to stay home and the lockdown was declared, some industries continued to work with low or medium efficiency, maybe 50% of its capacity to apply the containment measures as declared by the government in some cases. Transportation during the day time was active except for the days of full quarantine. Consequently, we noticed the changes up and down as after lockdown presented in Fig. 5(a), (b), (c), and (d). The positive values (more than 0) represent the reduction occurred in concentrations and emissions, which means that the concentration during 2018–2019 was higher than in 2020. In contrast, the negative values (less than 0) means that concentrations in 2020 were higher and there were no reduction in the pollutant emissions. This reveals that the air quality was improved throughout the country due to reducing the emissions of pollutants. Thus, NO2 reduced by 45.5%, CO emissions reduced by 46.23%, ozone concentration...
decreased by about 61.1%, and AOD reduced by 68.5% compared to the previous 2 years. Table 2 shows the statistics of the gases and AOD and the reduction level for each parameter during the period of analysis.

To quantitatively present the variations that occurred in 2020 as well as their spatial distributions, a map representing the pixel-by-pixel ratio of the trace gases and aerosols in the 3-years was produced. Fig. 6 presents the change after the lockdown in

**Fig. 4.** Spatial distribution of gases and aerosols a) OMI-NO2, b) AIRS-CO, c) AIRS-O3, and d) MODIS Terra AOD, during the last week of May (23th–31st) over Egypt, the image on the left side is the mean of 2018 and 2019, while the image on the right side is for 2020.
spring (March-June) 2020 comparing to spring 2018–2019. The map in Fig. 6 confirms that the largest reductions (positive values) exist in the highly populated metropolitan areas with intensive daily human activities such as Cairo and the Nile Delta. For NO2, the orange and yellow represent the reduction, while the blue colors in the CO map show the decline in CO, the blue and purple colors in the ozone map represent the reduction occurred, as well as the reduction in AOD represented by yellow, orange and red.

4. Conclusion

In conclusion, the impact of the short-term controlled measures implemented by the Egyptian government due to the COVID-19 had a direct impact on the improvement of the air quality over the country. Satellite data proofed gaseous and particle air pollution emissions reduction during this period of lockdown. Hence, it was not a complete reduction in pollution, because the lockdown was partial during the daytime and some industrial estates were working with medium to low efficiency (~50% of its capacity). The geographical location and the time of the year let the natural sources of pollution, meteorological parameters, and/or long-range transport influence the concentration and spatial dispersion of pollutants. We concluded that the concentrations of pollutants significantly reduced by 45.5%, 46.23%, 61.1%, and 68.5% for NO2, CO, O3, and AOD, respectively. Fig. 7 shows the 1:1 scatter plot of the pixel values of NO2 in 2020 and both in 2018 and 2019 confirming the reduction of NO2 concentration and spatial distribution by 46%. The lesson learned from this COVID-19 pandemic is to find an alternative mitigation measure to improve the quality of the air for human health. The lockdown is supposed to be an effective alternative mitigation measure to reduce air pollution over the country and improve air quality. Although, we know that this way of mitigation is not applicable, as it has social and economic impacts; it influences the entire economy of the country and the income of inhabitants. We propose a recommendation initiative for both national and/or global a complete lockdown for 2–3 days every 2–3 months that will enhance our air quality and improve the health environment of the planet. The advancement of satellite sensors and the short revisit time would enable to monitor the impact of such proposed lock-down.

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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