Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Research article

The impact of COVID 19 on air pollution levels and other environmental indicators - A case study of Egypt

Mohamed K. Mostafa a,*, Gamil Gamal b, A. Wafiq c

a Faculty of Engineering and Technology, Badr University in Cairo (BUC), Cairo, Egypt
b Department of Natural Resources, Faculty of African Postgraduate Studies, Cairo University, Egypt
c Chemical Engineering Department, Faculty of Engineering, Cairo University, Egypt

ARTICLE INFO

Keywords:
Absorbing aerosol index
Carbon monoxide and ozone
COVID-19
Environmental impacts in Egypt
Nitrogen dioxide and greenhouse gas emissions
Medical and municipal solid wastes

ABSTRACT

The outbreak of coronavirus disease (COVID-19) not only affected health and economics, but also its effect extended to include other aspects, such as the environment. Using Egypt as a case study, this paper presents the impact of COVID-19 pandemic on air pollution levels by studying nitrogen dioxide (NO₂), ozone (O₃), particulate matter represented in absorbing aerosol index (AAI), carbon monoxide (CO), and greenhouse gas (GHG) emissions. The paper also highlights the impact of COVID-19 pandemic on other environmental indicators including environmental noise, medical and municipal solid wastes. The paper presents the Egyptian COVID-19 story from its different angles including the development of confirmed COVID-19 cases, containment measures from the government, the impact on the country’s economy and the national energy consumption so as to effectively evaluate the effect on both the air pollution levels and the other studied environmental indicators. For the other environmental indicators, a strong link was observed between COVID-19 lockdown and the reduction in environmental noise, beaches, surface and groundwater pollution. For environmental noise, this has been confirmed by officially governmental announcements which reported that the level of environmental noise in Egypt was reduced by about 75% during the lockdown period. On the other hand, there are some negative effects, including an increase in medical solid waste (from 70 to 300 ton/day), municipal solid waste, as well as a less efficient solid waste recycling process. For air pollution levels, the data were obtained from National Aeronautics and Space Administration (NASA) and European Space Agency satellite data sets. The data for the lockdown period in 2020 have been extracted and compared to the corresponding months in the selected baseline period (2015–2019) to identify the effect that the lockdown period had on the air pollution levels in Egypt with focus on Cairo and Alexandria governorates. It was found that the AAI decreased by about 30%, the NO₂ decreased by 15 and 33% over Cairo and Alexandria governorates, respectively, and that the CO decreased by about 5% over both governorates. In addition, the GHG emissions in Egypt were reduced by at least 4% during the pandemic. In contrast, ozone levels increased by about 2% over Cairo and Alexandria governorates. It can be concluded that the implemented containment measures during COVID-19 pandemic had resulted in both positive and negative environmental impacts. The positive environmental impacts are not sustainable and deterioration on them is expected to occur after the lockdown as it was before the pandemic. Therefore, stricter laws must be enacted to protect the environment in Egypt.

1. Introduction

The novel coronavirus disease 2019 (COVID-19 or SARS-CoV-2) originated in Wuhan city, China, on December 2019 (Gautam, 2020a, 2020b). The World Health Organization (WHO) declared COVID-19 a pandemic on March 11, 2020 after the confirmed cases globally have reached 118,319 cases in over 110 countries (WHO, 2020a; TIME, 2020). As of June 4, 2020, the virus has spread further to reach almost every country on the earth (216 in total) (WHO, 2020b). According to the situation Report number 136 published by WHO on June 4, 2020, the total number of confirmed cases of COVID-19 has exceeded 6.4 million, while the total deaths have exceeded 382,000 people (WHO, 2020c). These cases are distributed all over the world as following: 47.1% in Americas, 34.5% in Europe, 8.9% in Eastern Mediterranean.
4.8% in South-East Asia, 2.9% in Western Pacific, and 1.8% in Africa (WHO, 2020b). The novel coronavirus was reported to be an acute respiratory disease attacking both upper and lower respiratory systems resulting in a severe respiratory distress syndrome (Gautam and Trivedi, 2020; Bherwani et al., 2020a). The COVID-19 pandemic brought new challenges to both underdeveloped and well-developed healthcare systems all over the world (Wang et al., 2020a, 2020b; Wang and Su, 2020). At the beginning of March 2020, Egypt has recorded the first case of pneumonia caused by COVID-19 between Egyptians. From March 7 to April 23, the number of confirmed cases per day was under control and did not exceed 200 cases (Trading Economics, 2020). This may be related to “Stay at home” campaign that has been launched by the Egyptian government (Ahramonline, 2020a), as well as the containment actions implemented by the government to control COVID-19 pandemic. The containment actions included: (1) closing all schools and universities, in-dining restaurants, places of worship, and monuments; (2) cancelling touristic trips and cultural events; (3) applying curfew between 8 p.m. and 6 a.m. (Egypt local time); (4) closing all airports and suspending international flights; (5) banning the export of infection control products based on two decrees issued by the Ministry of Industry and Trade (MTI) for a period of three months, including alcohol, face masks, and derivatives; (6) cutting the number of public sector employees going to work in half; and (7) providing a fund for 300,000 seasonal workers to encourage them to stay at home (OECD, 2020; Ahramonline, 2020b). From the beginning of April 24, the number has increased rapidly. This may be attributed to people preparation for the holy month of Ramadan (Muslims’ month of fasting which began on April 23 and ended on May 23) by going to grocery stories for shopping. This increase is also due to families and friends gathering to break their fast together (WHO, 2020d). Fig. 1 shows the daily confirmed cases from March 6 to June 5 in 2020. On June 1, the number of confirmed cases in Egypt reached its peak, with about 1540 new cases. From May 22 to June 1, the number of reported COVID-19 cases per day increased rapidly. This may be related to Festival of Breaking the Fast (Eid al-Fitr) which follow the month of Ramadan. From June 1 to June 7, the number of reported COVID-19 cases per day has decreased, referring to the stringent quarantine measures applied by the government. This decrease may also be due to the new ministerial decree that enforce people to wear face masks in public, where the uncommitted people will be subject to a fine that may reach 4000 Egyptian pound (~250 US dollar) (Ahramonline, 2020c).

The outbreak of coronavirus disease (COVID-19) not only affected health and economics, but also its effect extended to include other aspects, such as the environment (Bai et al., 2020; Sohrabi et al., 2020; Bherwani et al., 2020b; Lai et al., 2020; Wang et al., 2020c). Based on literature, the environmental indicators that are potentially affected by COVID-19 include surface and groundwater, beaches, noise, municipal and medical solid wastes, water and wastewater treatment, as well as the air quality (Zambrano-Monserrate et al., 2020). Air pollution is a global issue especially in developing countries like Egypt. Approximately 19, 200 people died prematurely in 2017 due to ambient air pollution alone in Cairo governorate (capital of Egypt) (World Bank, 2019). Nitrogen Dioxides (NO\textsubscript{2}), Ozone (O\textsubscript{3}), Absorbing Aerosol Index (AAI), and carbon monoxide (CO) are important indicators for air pollution. The creation of atmospheric NO\textsubscript{2} is mainly related to partial fossil fuel combustion, motor vehicle exhausts, burning of biomass, soil emissions and natural lightning (Richter and Burrow, 2002; Cheng et al., 2012). It has a key role in the formation of tropospheric Ozone via a complex set of reactions with oxygen and free radicals generated from volatile organic compounds (VOCs) in presence of sunlight (Crutzen, 1979; Odman et al., 2009). It is also a source of tiny particle pollution, as well as acid rain and summer smog (e.g., WHO, 2000; Youjiang et al., 2007; Pilar et al., 2010; Shen et al., 2011). Tropospheric NO\textsubscript{2} has harmful influences on human health, plants growing and climate change. Several epidemiological studies have shown a strong relationship between long-term NO\textsubscript{2} exposure and the decrease in respiratory function (Ackermann-Liebrich et al., 1997; Schindler et al., 1998; Paneo et al., 2000; Smith et al., 2000; Gauderman et al., 2000). Strong relationship also exists between NO\textsubscript{2} emission and non-accidental mortality as reported in daily time series studies (Steib et al., 2003; Burnett et al., 2004; Samoli et al., 2005). NO\textsubscript{2} at the troposphere is mostly removed by its reaction with Hydroxyl radical (OH) (Yugo et al., 2007; USCAR, 2010). NO\textsubscript{2} concentrations are also highly correlated with other pollutants either emitted by the same sources or formed through complex reactions in the atmosphere (Brook et al., 2007). Therefore, a complete spatial coverage of NO\textsubscript{2} level in the ground is needed for exposure assessment. As mentioned above, ground-level Ozone (O\textsubscript{3}) is a secondary pollutant that results from a photochemical reaction between nitrogen oxides (NO\textsubscript{x}) and VOCs. According to the VOC/NO\textsubscript{x} ratio, the O\textsubscript{3} concentration is determined via a complex chain of reactions. For example, in case of high VOC/NO\textsubscript{x} ratio, there are enough radicals that convert NO to NO\textsubscript{2} which then forms O\textsubscript{3} and vice-versa. O\textsubscript{3} can be removed via its rapid reaction with NO forming Oxygen and NO\textsubscript{2}; however, the latter forms O\textsubscript{3} during the day again according to the available VOC/NO\textsubscript{x} ratio (National Research Council, 1992). The US EPA considers O\textsubscript{3} to be the most serious air quality problem, and it was even found to be the second highest air pollutant causing mortality (Health Effects Institute, 2017). O\textsubscript{3} causes accurate health problems to human beings including asthma and lungs inflammation (McDonnell et al., 1999; Holz et al., 1999; Schelelegle et al., 2001; Brunekeef and Holgate, 2002; McConnell et al., 2002). Moreover, O\textsubscript{3} results in damage of crops (Emerson et al., 2018), and it is widely considered to be more damaging to vegetation compared to the cumulative effects all other air pollutants (Hill, 2012). The AAI is another indicator for air quality which indicates the existence of elevated absorbing aerosols in the atmosphere like smoke and dust (ESA, 2020). Particulate matter (PM) has been reported to be the fifth global

![Fig. 1. Daily Changes in new confirmed cases of COVID-19 in Egypt (Trading Economics, 2020).](image-url)
factor causing mortality and the top air pollutant in this regards (Health Effects Institute, 2017). Carbon monoxide (CO) is an air pollutant which is mainly sourced from incomplete combustion of carbon-containing fuels. It is famous for being a silent killer in unventilated areas where it replaces the Oxygen in hemoglobin (Blumenthal, 2001). It has been reported that CO causes around 10% of the congestive heart failure cases for elderly people (Hill, 2012). On the other hand, greenhouse gases (GHG) are the main reason for the global air pollution problem. GHG refer to any gas that has the ability to absorb infrared radiation emitted by Earth’s surface and reradiating it back down. The most important greenhouse gases include carbon dioxide (CO$_2$), water vapour, and methane (NIWA, 2020).

The relationship between the environment and the economic growth is complex. Theoretically speaking, the impact of the economic growth on environmental degradation (including air pollution) can be generally classified into 4 relationships; namely, inverted U-shaped according to the Environmental Kuznets Curve (EKC) theory, linearly increasing, U-shaped, and N-shaped relationships (Jiang et al., 2020). EKC theory is one of the most famous relationships between economic growth and air pollution (Grossman and Krueger, 1991; Panayoto, 1993). It assumes that the environmental degradation (e.g. air pollution) increases with economic growth up to certain threshold point after which the environmental degradation decreases (Ozcan et al., 2020) because of increasing the dependence on cleaner production technologies (Akbostanci et al., 2009) and the economy shift towards less polluting industries (Baglani et al., 2008). While several researchers proved the applicability of EKC theory for air pollution (Dasgupta et al., 2002; Xu et al., 2016), some others recommended different relationships. This included research work on general environmental degradation (Marsigli, 2011; Wang et al., 2019; Nasrollahi et al., 2020), in addition to air pollutants like SO$_2$, NO$_x$ (Aslanidis and Xepapadeas, 2004), Particulate matter (Zhu et al., 2019), and CO$_2$ (Raupach et al., 2007; Halicioglu, 2009). Some authors proved that the “linearly increasing” relationship between economic growth and air pollution is applicable for Indonesia (Chandrani and Tang, 2013), Viet Nam (Al-Mulali et al., 2015), France (Ang, 2007), and a pool of 130 countries (Holtz-Eakin and Selden, 1995). On the other hand, some authors found that the normal U-shaped curve is applicable for Malaysia, Thailand (Chandrani and Tang, 2013), and other Middle East and Asian countries (Ozcan, 2013), while others found that the N-Shaped is applicable in various OECD countries (Moonaw and Unruh, 1997). Since coronavirus pandemic led to economic decline, the pollution level is expected also to decrease during the pandemic (Dutheil et al., 2020). Furthermore, the climate experts believe that the greenhouse gas emissions may drop to their lowest level since World War II (Zambrano-Monserrate et al., 2020). However, and as was the case with the previous economic crisis in 2008, it is estimated that there will be post-crisis rebound in the air emissions (Le Quere et al., 2020). The exact relationship between the economic decline that occurred as a result of coronavirus pandemic and the corresponding air pollution consequences during and after the pandemic is an important area to be investigated in the future.

Several research work has been done on the economic decline during the pandemic (Gopinath, 2020; McKibbin and Fernando, 2020; Fernandez, 2020; Wang and Su, 2020; Baldwin and di Mauro, 2020) and the current status of air pollution during the pandemic (Wang and Su, 2020; Gautam, 2020a; Sharma et al., 2020; Muhammad et al., 2020; Dantas et al., 2020; Nakada and Urban, 2020; Collivignarelli et al., 2020; Tobias et al., 2020; Sciadisci et al., 2020). The impact of COVID-19 on various air pollution parameters has been studied for various countries and cities: however, as per the authors’ knowledge, no similar research work has been conducted in African or Arabian country so far. In addition, the impact of COVID-19 on other environmental indicators like environmental noise, medical and municipal wastes have been rarely discussed in the literature. Hence, in this paper, we analyzed the changes that have occurred on some local air pollutants, such as NO$_2$, O$_3$, particulate matter (in terms of AAI) and CO over Egypt with focus on Cairo and Alexandria Governorates during the coronavirus pandemic compared to the baseline period (2015–2019). The variations that have occurred in GHG emissions were also addressed in this research. An important contribution of the paper is the discussion of both positive and negative consequences covering various environmental indicators. The uniqueness of this study as well is that the containment actions implemented by the Egyptian government to control COVID-19 pandemic differ from other countries, and thus the effect on the different environmental indicators will vary too. Hence, the paper presents the Egyptian COVID-19 story from its different angles including the development of confirmed COVID-19 cases, containment measures from the government, the impact on the country’s economy and the national energy consumption so as to effectively evaluate the effect on the studied environmental indicators.

2. Potential impact on environmental indicators based on literature

The start will be with an analysis to the potential impacts of COVID-19 on various environmental indicators (other than air pollution) based on literature. For some indicators, such analysis has been confirmed by the officially announced governmental numbers as will be shown below.

2.1. Surface and groundwater

Egypt is suffering for a long time from a deterioration of its ground and surface water. This is mainly due to discharge of heavily polluted industrial and domestic wastewaters into its waterways without sufficient treatment (Mostafa and Peters, 2016; Abdel-Satar et al., 2017). The Nile River represents the main freshwater source which provides the country with almost all drinking and irrigation water needs (Mostafa, 2014). The Nile River also provides Egypt with about 65% of its industrial water demands (Abdel-Satar et al., 2017). The quality of the Nile River and its two main branches (Rosetta and Damietta), as well as canals and drains networks located in the Nile Delta are expected to significantly improve during the SARS-CoV-2 pandemic since most of the industries in Egypt are not working with their full capacities, which lead to a decrease in wastewater effluent. For example, the production of ready-made clothes has decreased by about 8.9% in February 2020 comparing to January 2020 due to the SARS-CoV-2 pandemic (CAPMAS, 2020a). The quality of the Nile River is also expected to improve due to the suspension of tourist ships from operation which represents the main source of oil spill in the river (Shara and Moustafa, 2009). All the lakes in Egypt are suffering from poor water quality due to receiving partially or untreated industrial wastewater (Abd El-Hamid et al., 2020). The water quality in these lakes are also expected to improve due to the temporary closure of some industries.

The reduction in industrial activities in Egypt is also expected to some extent to improve groundwater quality since the main aquifer in Egypt (Nile aquifer) is recharged from the Nile river and its branches, as well as canals and drains networks located in the Nile Delta. The pollution in the Mediterranean Sea is also expected to decrease since its connected to both Rosetta and the Damietta branches. The water quality at the Suez Canal is also expected to improve during the SARS-CoV-2 pandemic due to the reduction in the number of ships. A report published by International Food Policy Research Institute (IFPRI) expects a 15% reduction in Suez Canal revenues during the pandemic (Breisinger et al., 2020).

2.2. Beaches

The coastlines of the Egypt are over 3500 km in length that extend along the Red Sea and the Eastern Mediterranean (Masria et al., 2014). Beaches are located in some areas along the coastlines and represent important natural capital assets for these areas. Consequently, they must be protected against overexploitation. They provide services, such as
recreation, tourism, sand, and land (Lucrezi et al., 2016; Zambrano-Monserrate et al., 2020). Some beaches in Egypt are suffering from careless behavior that lead to beaches pollution, such as North coast, Ain Sokhna, Alexandria, and Baltim. These beaches are the biggest winners from the containment actions that have been applied in Egypt since the occurrence of SARS-CoV-2 pandemic. They are closed to all forms of public access and use (Egypt Today, 2020a), and thus they are now to look cleaner and with clear waters. Similar observation was reported in many beaches worldwide, such as Barcelona (Spain), Acapulco (Mexico), and Salinas (Ecuador) (Zambrano-Monserrate et al., 2020).

2.3. Environmental noise

Environmental noise is one of the top environmental risks to public health and it is defined as an unwanted or harmful sound generated by commercial or industrial activities, as well as human activities, such as transportation (railway, road traffic, and aircraft), and melodies at high volume (WHO, 2020c; Zambrano-Monserrate et al., 2020). High exposure to environmental noise may lead to release of stress hormones and may cause some diseases, such as arteriosclerosis, hypertension, a stroke, or myocardial infarction (Muzet, 2007). The containment actions applied in Egypt since the SARS-CoV-2 pandemic, especially the curfew and the quarantine, have encouraged people to stay at home, and thus decreasing commercial, industrial, and transportation activities. Such analysis has been confirmed by officially governmental announcements which reported that the reduction in these activities have significantly decreased the level of environmental noise in Egypt by about 75% (Masrawy, 2020;Abramolnline, 2020d), as is the case in most cities around the world.

2.4. Municipal and medical solid wastes

The food consumption in Egypt has increased since the outbreak of COVID-19 as a result of the curfew and “Stay at home” campaign. According to the Community Mobility Report published by Google, mobility trends for places of residence increased by about 20% compared to the baseline (Google, 2020). Staying at home encourages people to overeat which lead to an increase in organic solid waste generated per capita. Egypt has also witnessed a significant increase (940%) in the online shopping due to COVID-19 transmission fears (Nile Fm, 2020), which in turn led to an increase in both organic and inorganic solid wastes. Since the outbreak of COVID-19, safe disposal of municipal solid waste has become a big challenge, especially that the prevailing disposal practice in Egypt is through dropping the wastes in opened unregulated site without precautions to protect the environment. This wastes are now considered hazardous because they may include waste from infected residents, as well as an infected personal protective equipment such as gloves and masks. There is also a big concern worldwide regarding the risk of SARS-CoV-2 spreading in recycling facilities. For example, USA has suspended the recycling programs in some cities to prevent the spread of the virus (Zambrano-Monserrate et al., 2020). In Egypt, recycling facilities are operating normally even during the COVID-19 lockdown. However, they are operating with less than half of their workforce after allowing the workers who have chronic diseases or compromised immune systems to stop working and stay at home. This action negatively affects the efficiency of the recycling process, as well as the quality of the final products (composts and refused derived fuel (RDF)). Hotels in Egypt produces an average of 70.5 tons/day of medical waste (SWEEP-Net, 2014), less than 50% of these amount are safely and efficiently discarded through incineration (El Dirini, 2017). The remaining amount is either illegally traded for recycling or mixed with municipal solid waste (SWEEP-Net, 2014). The International Solid Waste Association (ISWA) has announced an increase in medical waste contaminated with Coronavirus by 30%-50% (Al Mal, 2020). During the SARS-CoV-2 outbreak, and as confirmed by the Egyptian government, the quantity of medical waste generated from hospitals in Egypt increased significantly reaching 300 tons/day (Al-Masy Al-Youm, 2020a; Egypt Independent, 2020a). Consequently, this is another serious challenge facing officials in Egypt. Since the SARS-CoV-2 outbreak, the Egyptian Ministry of Environment has checked about 1537 medical facilities to ensure the efficiency of the medical waste management system (Egypt Today, 2020b; Daily News Egypt, 2020a).

One of the indirect positive effects of COVID-19 is the removal of solid waste accumulated in streets during the curfew period, where about 3.3 million tons of municipal solid waste has been removed since the beginning of COVID-19 outbreak in March (Daily News Egypt, 2020b; Youm7, 2020a). Another positive effect is the cleanup of the Red Sea bed in Dahab City, where divers in Dahab have taken advantage of halting tourism to remove about 7 tons of wastes and impurities which gives another life to the coral reefs (Al-Masy Al-Youm, 2020b; Egypt Independent, 2020b).

2.5. Water and wastewater

The concern regarding the transmission of COVID-19 in water and wastewater has increased after detecting COVID-19 (as well as other coronaviruses) in the anal swabs and stool samples of some patients (La Rosa et al., 2020). Many researchers have proved the presence of COVID-19 in municipal wastewater after analyzing samples collected from some cities worldwide, such as Massachusetts (Wu et al., 2020) and Italy (La Rosa et al., 2020). La Rosa et al. (2020) have concluded that COVID-19 has low stability in the environment and is characterized by fast inactivation in water compared to other nonenveloped human and animal enteric pathogenic viruses. The authors have also concluded that SARS-CoV-2 is very sensitive to disinfectants/oxidants, like chlorine. Till now, there is no any published research or document that support the theory of COVID-19 survival in drinking water or wastewater (Zambrano-Monserrate et al., 2020; WHO, 2020). In Egypt, the chlorine dosages used in water and wastewater treatment plant are adequate for virus inactivation and there is no need to enhance the disinfection process through increasing the injected dosage of chlorine (Youm7, 2020b). However, a more restricted risk management strategy is currently implemented by collecting and analyzing water samples regularly to ensure that the water quality meets the standard (Youm7, 2020b). Some other countries have decided to increase the chlorine dosage in the wastewater treatment plants, like China, to prevent the spread of COVID-19 through the wastewater (Zambrano-Monserrate et al., 2020). It is also worth noting that the excess of chlorine in tap water may cause an adverse health effects in people (Mohsen et al., 2019; Zambrano-Monserrate et al., 2020).

3. Economic activity and energy consumption

There are several indicators that COVID-19 will cause greater global economic damage than any recent economic crisis or disease outbreak (Shretta, 2020; Kumar et al., 2020), where the International Monetary Fund (IMF) forecasts at least 3% contraction in global economy (IMF, 2020). This is mainly due to uncertainty and the reduction in the movement of goods and people (Gopinath, 2020; McKibbin and Fernando, 2020; Fernandes, 2020), which may outweigh the recession that has occurred during 2008 financial crisis (Wang and Su, 2020). According to a article published by CNN, air travel decreased by about 96% due to the coronavirus pandemic (Muhammad et al., 2020). Another important reason for that is that the list of top countries hit by COVID-19 is nearly the same as the list of largest world economies (Baldwin and di Mauro, 2020). For Egypt specifically, and according to the IMF, the country was following an improving economic performance before the COVID-19 pandemic. The enhanced performance metrics include gross domestic product (GDP) growth rate, unemployment rate, inflationary and debt-to-GDP ratio (OECD, 2020). However, the COVID-19 pandemic will have significant negative implications on the
Egyptian economy at least in 2020 and 2021. This is attributed to several factors including the slowing down of the global trade and accordingly negatively affecting the revenues of Suez Canal, the nearly stoppage of the tourism activities, and the decline of remittances (the three factors constituting considerable share of the foreign currency revenues to the country) (Breisinger et al., 2020). For Suez Canal, and as it is a vital shortcut for global commerce, it is negatively affected by COVID-19 pandemic where it is estimated that its revenues may decline by between 10 and 15 percent according to the Egyptian Center for Economic Studies (ECES). Actually, Suez Canal revenues may be even affected much more as the World Trade Organization expects that the World trade in 2020 will decline by 13%-32% (World Trade Organization, 2020). As for the tourism, and according to the ECES as well, between 70 and 80 percent of hotel bookings have been cancelled (Egyptian Center for Economic Studies, 2020a). The Government of Egypt has just recently announced the partial activation of the local tourism activities in coastal touristic cities; however, it is expected that the international tourism will be nearly blocked till the end of 2020. The government estimates losses of around USD 12.5 billion this year from this sector, and about 1.4 million people employed by the sector is expected to be negatively affected. For remittances, it is expected that they will decline between 10 and 15% due to the facts that the workers are not able to return back to their countries because of flight restrictions, and some low-skilled labour may lose their jobs due to the current economic crisis affecting all the businesses (Egyptian Center for Economic Studies, 2020b). Another factor which indicates the negative impact of COVID-19 on Egypt’s economy is the IHS Markit Egypt Purchasing Managers’ Index for non-oil private sector. The latter has decreased to 42.2 in March 2020 from 48.2 in December 2019 hitting the lowest value since more than 3 years. In addition, the main index of the Egyptian Stock Exchange (EGX30) had a significant decrease of 39% compared to February 2020 (OECD, 2020). Based on interviews with many of the key industrial facilities in Egypt, a lot of them are working on lower production capacity compared to the business as usual due to the generally lower demand during the pandemic crisis. As for the big commercial facilities like malls, social and sports clubs, and restaurants, the partial curfew imposed by the government will significantly cause to cutting off some of the jobs. On the other hand, and away from the formal sectors, COVID-19 pandemic is causing severe negative economic impacts on the informal sector which represents 63% of the total employment and between 30 and 40% of GDP. Due to the lack of health and social insurance in such sector, a lot of workers will lose their jobs, causing around 12% of people to fall from poverty into extreme poverty and driving 44.4% (12.9 million workers) below the poverty line (OECD, 2020). A report published by IFPRI expects between 0.7 and 0.8% reduction in national GDP for each month during the pandemic (Breisinger et al., 2020).

In addition to the clear negative impact of COVID-19 pandemic on the Egyptian economy, many of the above-mentioned economic factors (especially the partial curfew imposed by the government, reduction of industrial activities, general economy slow down, and stoppage of touristic activities) have their clear impact on the country’s energy consumption during COVID-19 pandemic. According to official statements from the National Ministry of Petroleum and Mineral Resources, the average daily consumption of gasoline has reduced by about 25% (from 18,000 to 14,000 ton), while the average daily diesel consumption reduced by about 6–10% (from about 36,500 to 33,000 ton). As for electricity consumption, the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EgyptERA) has announced that the consumption has reduced in the range of 4–7% (about 2 GW) compared to the same period last year. According to EgyptERA, the commercial sector was the main contributor to such decrease (especially that their business as usual before the pandemic was operation till late times at night), while the domestic consumption rates have slightly increased due to the longer periods that citizens stay at home during the pandemic. The potential impact of such reduction in energy consumption on the air pollution levels in Egypt during the lockdown will be investigated in this research work.

4. Materials and methods

The authors have mainly relied on satellite monitoring to get measurements for the different air pollutants during COVID-19 lockdown period and the baseline period (2015–2019). The efficiency of satellite devices for remote sensing of the lower troposphere have greatly improved. For example, the aerosol factors can be verified on spatial scales of a few kilometers using the space-borne radiometers (Veefkind et al., 2007). Additionally, the nitrogen dioxide and other trace gases can also be identified on urban levels using the spectrometers (Veefkind et al., 2007). Field monitoring stations can only forecast variations in air quality and assess emissions at separate points; however, the satellite data can overcome this drawback, where it is able to model the horizontal transportation of air pollutants on long and short periods (Engel-Cox et al., 2004) and thus enhancing synoptic and geospatial knowledge to ground-based air quality data (Engel-Cox et al., 2004). Satellite data can be used to distinguish regions of highest concentrations, as well as providing warnings of upcoming air quality events, especially, wildfires and dust storms (Engel-Cox et al., 2004). Another advantage of satellite systems is that they can provide information about the air quality in regions that have no surface-based monitors (Engel-Cox et al., 2004). Limitations associated with using satellite tools for air quality monitoring and analysis include lack of specificity with respect to some air pollutants, as well as an occasionally absence of data normally obtained by polar-orbiting satellites due to non-covering bands in tropics (Veefkind et al., 2007; Engel-Cox et al., 2004). Therefore, a combined use of ground-based monitoring and information of satellite sensors are generally recommended to obtain more accurate results and enhance scientific knowledge (Veefkind et al., 2007; Engel-Cox et al., 2004).

4.1. Nitrogen dioxide measurement

Satellite instruments are able to precisely detect air pollutants such as NO2, ozone, sulfur dioxide (SO2), carbon monoxide (CO) and methane (CH4) (Somvanshi et al., 2019). These tools calculate backscattered radiation from the sun in a broad spectral range from ultraviolet (UV) to infrared wavelengths. Advanced retrieval algorithms are applied to transform the measured radiation to pollutant concentrations, such as a tropospheric column density of NO2. The National Aeronautics and Space Administration (NASA) has launched Aura satellite on July 15, 2004 which is equipped with ozone monitoring instrument (OMI) to monitor the changes in air quality for many regions worldwide (NASA, 2020a). It is used in this study to monitor the changes in NO2 emissions over Egypt before and during the COVID-19 pandemic (NASA, 2020b).

4.2. Ground-level ozone and carbon monoxide measurement

The Geospatial Interactive Online Visualization and Analysis Infrastructure (Giovanni) has been utilized to get the O3 and CO concentration data over Egypt. Giovanni web-based tool was developed by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC). The tool provides the researchers with numerous satellite data with about 1600 variables including concentrations of the key air pollutants and other climatological parameters.

4.3. Absorbing aerosol index

European Space Agency (ESA) has launched Sentinel-5 Precursor satellite on October 13, 2017 which is equipped with TROPOspheric Monitoring Instrument (TROPOMI) to measure the level of NO2, SO2, CH4, CO, and ozone (O3) in the atmosphere (TROPOMI, 2020; Omrani et al., 2020). It can also calculate the AAI value based on wavelength.
changes in Rayleigh scattering in the ultraviolet spectrum range. TROPOMI is 13 times more accurate than the OMI developed by NASA, where it can daily provide a full map of the global pollutant concentrations, with a resolution of 7 km × 3.5 km (Theys et al., 2019). It is used in this study to get the AAI data over Egypt for 2019 and 2020. For data before 2019, no data on TROPOMI was available; hence, OMI has been utilized.

5. Results and discussion

5.1. Changes in nitrogen dioxide emissions

The data for NO₂ emissions was retrieved from OMI for three months (February, March, and April) for the period from 2015 to 2020. The measured data for the targeted three months in year 2020 representing the pandemic time (Fig. 2a) was compared to the data for the same months from the previous years (from 2015 to 2019) (Fig. 2b) to logically identify whether the implemented containment measures during COVID-19 outbreak has caused a change in NO₂ emission or not. In Fig. 2, the darker the color, the higher NO₂ concentration/emission. It is obvious that the orange color in Fig. 2a is darker than the orange color in Fig. 2b, indicating a reduction in NO₂ emission in 2020 during the pandemic comparing to previous 5 years. Fig. 2c also shows that the NO₂ emission has decreased in year 2020 by about $3 \times 10^{15}$, $0.8 \times 10^{15}$, and $1.5 \times 10^{15}$ molecules/cm² for February, March, and April, respectively, comparing to the same month from the previous 5 years. This is mainly attributed to reductions in traffic and industrial activities during the pandemic. This is also matching with the figures generated from the Google community mobility reports which have been developed based on the anonymized data-sets from users (Google, 2020). Therefore, the implemented containment measures during COVID-19 outbreak have improved the air quality in Egypt.

Cairo governorate is the capital of Egypt and has a population of 9.94 million, while Alexandria governorate is the second-largest city in Egypt after Cairo with a population of 5.37 million (CAPMAS, 2020b). Fig. 3 shows a comparison between the NO₂ concentration measured in 2020 by OMI over Cairo and Alexandria with the average concentration for the same period in 2015–2019. The results indicated that the 2020 NO₂ emissions in Cairo and Alexandria is lower than the average level during the same period in 2015–2019. A percentage difference was calculated inside a 1° x 1° box over the city center. At March 15, 2020, where the containment actions were taken to reduce the spread of coronavirus disease, the concentration of NO₂ over Cairo and Alexandria has dropped by about 15% and 33%, respectively, compared with the baseline period. From April 1 to May 1, 2020, the NO₂ emission over Cairo and Alexandria dropped on average by only 13% and 9%, respectively, because most of the factories resumed their operation to provide the essential products needed during the holy month of Ramadan. These findings are also supported by an area chart in supplementary Figure 1 that shows the tropospheric NO₂ emission in the first 120 days of years 2019 and 2020 over Cairo and Alexandria governorates (CESBIO multitemp, 2020). The values are generally in line with the percentage reduction of the gasoline and diesel consumption referred to above. In addition, the values seem logic due to the fact that in normal conditions, the vehicles in Greater Cairo are responsible for 50% of the NO₂ emissions (Abou-Ali and Thomas, 2011; Heger et al., 2019). Fig. 3 also shows that the impact of COVID-19 pandemic on the level of tropospheric on air is not limited to Cairo and Alexandria, but can also be seen over the Nile Delta. Reduction of NO₂ levels during the COVID-19 pandemic has also been observed in several countries/cities including China (Wang and Su, 2020), India (Gautam, 2020a; Sharma et al., 2020), USA (Muhammad et al., 2020), Rio de Janeiro (Dantas et al., 2020), São

Fig. 2. Nitrogen dioxide emissions levels in Egypt; (a) from February to April 2015–2019, (b) from February to April 2020, (c) difference between 2015 and 2019 and 2020 (NASA, 2020b).
Paulo (Nakada and Urban, 2020), Milan (Collivignarelli et al., 2020), Barcelona (Tobías et al., 2020), Nice, Rome, Valencia and Turin (Sicard et al., 2020). It is clear that the implemented containment measures during COVID-19 pandemic have reduced the NO\textsubscript{2} emission and thus improved air quality, however, this improvement is not sustainable and deterioration on air quality is expected to occur after the lockdown as it was before the pandemic, as the case in China (Abnett, 2020). Therefore, stricter laws must be enacted to protect the environment in Egypt.

5.2. Changes in ground-level ozone

Fig. 4a presents the difference in concentrations between 2019 and 2020 (2019 subtracted from 2020) during March and April. As shown, the O\textsubscript{3} concentrations in 2020 is less than 2019 in all locations including Cairo and Alexandria; however, it is to be noted that the absolute concentrations are in the range of 300 DU, so the difference is nearly negligible (around 1%). So, it can be said from such results that the
monthly \(O_3\) concentrations in March and April are nearly constant and not affected by COVID-19 and its associated partial lockdown. Such results can seem strange especially that the \(NO_2\) which is the precursor of \(O_3\) has decreased over Cairo and Alexandria by 13% and 9%, respectively in April and decreased by higher values in March. However, such inconsistent relation between the \(NO_2\) and \(O_3\) concentrations has been previously observed in a lot of previous research work” (Qin et al., 2004; Lin et al., 2005; Jiménez et al., 2005; Blanchard et al., 2008; Schipa et al., 2009; Castell et al., 2010; Wolff et al., 2013; Adame et al., 2014; Shen et al., 2014; Diéguez et al., 2014; Xie et al., 2016; Silva et al., 2018; Zou et al., 2019; Ezimand and Kakroodi, 2019; Tang et al., 2020; Soares et al., 2020; Liao et al., 2020; Mozaffar et al., 2020; Fang et al., 2020; Barcelo, 2020). In addition, several researchers have recently reported that \(O_3\) levels increased in some cities during COVID-19 lockdown in complete contrast to the \(NO_2\) concentrations (Sicard et al., 2020; Siciliano et al., 2020; Tobías et al., 2020). Such results can be attributed to the complex reaction mechanism governing the generation of ground-level \(O_3\) which depends on various parameters including the VOC/\(NO_x\) ratio. In traffic-congested urban cities, where the \(NO_x\) levels from the automobiles are high, the VOC/\(NO_x\) ratio is low. In such conditions, and in case of any significant reduction in \(NO_x\), the complex photochemical reaction mechanism favors the formation of \(O_3\). On the other hand, in rural areas and where the VOC/\(NO_x\) ratio is relatively high, the \(O_3\) is directly proportional to \(NO_x\) (Finlayson-Pitts and Pitts, 2000). This is even clearer in Fig. 4b which presents the difference in concentrations between February 2020 (directly before COVID-19 partial lockdown) and March–April 2020 (February subtracted from March–April). As can be noticed, the traffic-congested urban cities like Cairo and Alexandria witnessed an increase in \(O_3\) concentrations during the partial lockdown with about 3%. Hence, and despite having an overall positive influence on primary pollutant levels, it is important to highlight that COVID-19 also has some negative air pollution consequences. On the other hand, it can be observed from Fig. 4b that most of the rural areas had reductions in \(O_3\) concentrations during the partial lockdown with values that can reach about 5% in some locations. In order to assess whether the air pollution levels are more influenced by the aforementioned hypothesis compared to the variation in the meteorological conditions, the \(O_3\) concentrations during March and April 2020 has also been compared to the same months but over a longer baseline period (2015–2019). As shown in Fig. 5, nearly the same conclusions were observed where the traffic-congested urban cities like Cairo and Alexandria witnessed an increase in \(O_3\) concentrations during the partial lockdown with about 2%, while most of the rural areas had reductions in \(O_3\) concentrations with values that can reach about 2%. Deeper interpretation of \(O_3\) behavior in Egypt during the COVID-19 partial lockdown needs further investigation by analyzing several other factors like reactivity of the VOC mixture (Atkinson, 2000), reduced particulate matter concentration and its impact on increased solar irradiance (Heuss et al., 2003), in addition to the exact prevailing meteorological conditions (Dantas et al., 2019). It worth noting that the measured hourly-average \(O_3\) concentrations comply with the local ambient air quality regulations (180 \(\mu g/Nm^3\)). While the \(O_3\) concentrations were not measured on 8-h averaging period; however, it is safe to say that the \(O_3\) also comply with the WHO ambient air quality limits since the measured hourly-average \(O_3\) levels are less than the WHO 8-h limits (100 \(\mu g/Nm^3\)). This matches with the literature where it has been reported that the \(O_3\) levels in Egypt significantly increase during summer months compared to other seasons (Steiner, 2014) to the extent that the local ambient air quality regulations can be exceeded during summer (Khoder, 2009).

5.3. Changes in absorbing aerosol index

As shown in Fig. 6, the 2020 AAI in Egypt was about 30% lower than the AAI level during the same period in 2019, which confirms the positive effect of COVID-19 on the air quality in Egypt. These results agree with the results obtained from OMI, where the AAI was lower at March 15, 2020 compared to April and May 2020. It has been reported in the literature that about 30% of the PM\(_{2.5}\) and PM\(_{2.5}\) emissions are generated from the transport sector (especially from old private cars and taxis) at normal conditions in Egypt (World Bank Group, 2013; El-Derghamy et al., 2015; Heger et al., 2019). A previous statistical study done in Egypt (Heger et al., 2019) has shown that there is a linear correlation between car density and PM\(_{2.5}\) pollution load, where it was deduced that reducing the number of vehicles by 1% lead to a PM\(_{10}\) load reduction of 0.27%. Another recent study on Cairo during normal conditions (Abbass et al., 2020) has shown that the PM\(_{2.5}\)/PM\(_{10}\) ratio is less than 0.5 which was attributed to the tyre and brake wear (due to traffic congestion), desert environment, having many areas undergoing construction activities and the presence of many unmaintained roads. The containment measures undertaken by the Egyptian government has led to less traffic flow and relatively less construction activities. The less traffic flow generally causes less PM emissions from vehicles’ engines especially from the old taxis and public transportation buses, less PM emissions from tyre and brake wear, in addition to less entrained PM emissions from the unmaintained roads. In order to assess whether the air pollution levels are more influenced by the partial lockdown compared to the variation in the meteorological conditions, the AAI values in 2020 has also been compared to a longer baseline period (2015–2019). As shown in Fig. 7, the same conclusions were observed where the AAI levels in Cairo and Alexandria have dropped during the lockdown months in 2020 by about 30%. Reduction of PM levels during the COVID-19 pandemic has also been observed in several countries/cities including China (Wang and Su, 2020; Wang et al., 2020c), India (Sharma et al., 2020), Rio de Janeiro (Dantas et al., 2020), Sao Paulo (Nakada and Urban, 2020), Milan (Collivignarelli et al., 2020), Barcelona (Tobías et al., 2020), Nice, Rome, Valencia and Turin (Sicard et al., 2020). The PM emissions in big cities like Cairo has always been reported to be exceeding the national regulations (230 \(\mu g/Nm^3\) for 24-h averaging period) (Huzayyin and Salem, 2013; Hassan and Khoder, 2017; Marchetti et al., 2019).

5.4. Changes in carbon monoxide

Fig. 8 presents the difference in concentrations between 2019 and 2020 (2019 subtracted from 2020). As shown, the CO concentrations in 2020 are less than 2019 in nearly all locations including Cairo and Alexandria. The absolute concentrations are in the range of 120 ppb, so the reduction in CO concentrations in Cairo and Alexandria is about 5%. The decrease in CO emissions is clearly attributed to the less traffic congestion resulting from the partial lockdown policy (Dantas et al.,...
which should lead to less CO emissions especially from the light-duty vehicles (Heywood, 1998; Pérez-Martínez et al., 2014). Such results seem logic especially that it has been reported in a previous study by the Egyptian Ministry of Environment that the transport sector accounts for about 90% of the CO emissions. In order to assess whether the air pollution levels are more influenced by the partial lockdown compared to the variation in the meteorological conditions, the CO concentrations in 2020 has also been compared to a longer baseline period (2015–2019). As shown in Fig. 9, the same conclusions were observed where the CO concentrations in nearly all the locations including Cairo and Alexandria have dropped during the lockdown months in 2020 (Cairo and Alexandria also in the range of 5%
Fig. 7. Absorbing Aerosol Index for Egypt from March 15 to May 1 in 2020 and the baseline (2015–2019).
reduction). Reduction of CO levels during the COVID-19 pandemic has also been observed in several countries/cities including China (Wang and Su, 2020), Southern and Central India (Sharma et al., 2020), Rio de Janeiro (Dantas et al., 2020), Sao Paulo (Nakada and Urban, 2020), and Milan (Collivignarelli et al., 2020). It was not possible to compare the CO levels to the local environmental limits (30 and 10 mg/Nm$^3$ for 1-h and 8-h averaging period respectively) since the available satellite measured CO concentration data were not available on 1-h or 8-h averaging period.

5.5. Changes in greenhouse gas emissions

One of the main positive environmental impacts of COVID-19 worldwide is the reduction in the greenhouse gas (GHG) emissions. In Egypt specifically, and due to the reduction in fossil fuels and electricity consumption as mentioned above, the GHG emission levels decreased compared to the business as usual scenario. According to Egypt’s first biennial update report (BUR) submitted to UNFCCC, the energy sector represents 64.5% of the country’s GHG emissions, of which the electricity generation represents 43% and transport represents 23%. In transport, Gasoline fuel nearly represents 38% of the GHG emissions, and Diesel fuel represents 51%. Hence, the consumption of electricity and transport fuels constitute around 43% of the country’s GHG emissions. Knowing the percentages reduction in resources consumption during COVID-19 situation (listed above), it can be calculated that Egypt has at least reduced 4% of its GHG emissions. This value is conservative since a lot of other activities has not yet been quantified especially the industrial ones. The global estimates for the potential GHG reductions in 2020 range between 4.5% and 8% (Evans, 2020; Gabbatiss, 2020). It is interesting to note that the current global GHG reduction levels can be considered as a simulation to the efforts needed by all the countries to help achieve the annual 7.6% GHG reduction required to be on the ambitious 1.5 °C global warming pathway.

It worth noting that after noticing the improved air quality and environmental noise, the Egyptian prime minister’s cabinet is currently considering to shorten the night working hours of shopping and dining (Egypt Independent, 2020c). This will not only improve the environmental situation of the country, but also impose economic benefits by decreasing the import of fossil fuels (due to the foreseen reduction of energy consumption) and social benefits by allowing the families to spend more time together in the evenings. If such initiative will be really applied, this will be a rare case study for mitigating the expected rebound after the end of the pandemic.

The environmental conventions have always called for decoupling the economic growth from environmental degradation. The results of this research work and the similar ones mainly present the environmental benefits achieved during COVID-19; however, it is clear that this is not sustainable at all due to the acute economic losses associated. In addition, it is expected that the economic crisis that resulted from the COVID-19 pandemic will postpone the investment in clean and innovative technologies; hence, outweighing the environmental benefits achieved during the COVID-19 lockdown period (Gillingham et al., 2020). Moreover, and as was the case with previous economic crisis in 2008, it is estimated that that there will be post-crisis rebound in the emissions (Le Queré et al., 2020). Hence, all the countries still have a lot of work to do to be effectively on the sustainable economic growth pathway.

6. Conclusions

This study revealed that the COVID-19 pandemic has a great effect on all aspects of life in Egypt including health, economic, and environment. Between 0.7 and 0.8% reduction in Egypt’s national GDP is expected for each month during the pandemic. There is also a strong link between economic growth and energy consumption, where the average daily consumption of gasoline and diesel has reduced by about 25 and 9%, respectively, during the pandemic. This paper also revealed that the COVID-19 pandemic has positively affected some environmental aspects and negatively affected some other aspects. The positive effects include a reduction in beaches, surface and groundwater pollution, as well as a reduction in environmental noise (around 75%) and some air pollutants. The reduction in NO$_2$ reached 15 and 33% over Cairo and Alexandria governorates, respectively. This is mainly attributed to reductions in traffic and industrial activities during the pandemic, is matching with the figures generated from the Google community mobility reports, and also matches with the fact that in normal conditions, the vehicles in Greater Cairo are responsible for 50% of the NO$_2$ emissions. The AAI of Egypt decreased by about 30% during lockdown. This is attributed to the containment measures undertook by the Egyptian government that led to less traffic flow and relatively less construction activities. The less traffic flow generally causes less PM emissions from vehicles’ engines especially from the old taxis and public transportation buses, less PM emissions from tyre and brake wear, in addition to less entrained PM emissions from the unmaintained roads. A 5% reduction was also recorded for CO in Cairo and Alexandria due to the less traffic...
congestion resulting from the partial lockdown policy especially from the light-duty vehicles. Such results seem logic especially that it has been reported in a previous study by the Egyptian Ministry of Environment that the transport sector accounts for about 90% of the CO emissions. In total, the GHG emissions in Egypt has reduced by at least 4% during the pandemic. This value is conservative since a lot of other activities has not yet been quantified especially the industrial ones. The negative environmental effects for the COVID-19 include an increase in medical waste generation (from 70 to 300 ton/day), municipal and solid waste management, less efficient solid waste recycling process, as well as an increased in ozone level by about 2% over Cairo and Alexandria governorates. The ozone increase has been attributed to the low VOC/NOₓ ratio in traffic-congested urban cities (where the NOₓ levels from the automobiles are high), where in such conditions the complex photochemical reaction mechanism favors the formation of ozone when NOₓ decreases. It is expected that there the economic crisis that resulted from the COVID-19 pandemic will postpone the investment in clean and innovative technologies; hence, outweighing the environmental benefits achieved during the COVID-19 lockdown period (Gillingham et al., 2020). Moreover, and as was the case with previous economic crisis in 2008, it is expected that that will have post-crisis rebound in the emissions. Putting into consideration that it is expected to have post-crisis rebound in the environmental emissions, it has to be noted that the positive impacts of COVID-19 on the environment in Egypt is not sustainable and actions must be taken by officials in Egypt to control water air pollution while keeping a balance between economic growth and protecting the environment.

CRediT authorship contribution statement

Mohamed K. Mostafa: Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Visualization, Supervision.
Gamal Gamal: Writing - original draft, Resources, Investigation, Validation, Writing - review & editing. A. Wafiq: Writing - original draft, Data curation, Investigation, Validation, Writing - review & editing.

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.

Acknowledgements

This research was supported by Badr University in Cairo (BUC) and Cairo University. Some of the analyses and visualizations used in this paper were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2020.111496.

References

Abbass, R.A., Kumar, P., El-Gendy, A., 2020. Car users exposure to particulate matter and gaseous air pollutants in megacity Cairo. Sustainable Cities and Society 56, 102090. https://doi.org/10.1016/j.scs.2020.102090.
Abd El-Hamid, H.T., El-Alfy, M.A., Elbaggar, A.A., 2020. Prediction of future situation of land use/cover change and modeling sensitivity to pollution in Edku Lake, Egypt based on geospatial analyses. Geojournal. https://doi.org/10.1007/s10708-020-10107-4.
Abdel-Sater, A.M., Ali, M.H., Goher, M.E., 2017. Indices of water quality and metal pollution of Nile River, Egypt. Egyptian Journal of Aquatic Research 43, 21–29. https://doi.org/10.1016/j.ejaqr.2016.12.006.
Ahmert, K., 2020. China Sees Post-lockdown Rise in Air Pollution: Study. REUTERS. Accessed date. https://www.reuters.com/article/us-health-coronavirus-china-pol-ution/china-sees-post-lockdown-rise-in-air-pollution-study-idUSKBN221099. (Accessed 9 August 2020).
AbouAll, H., Thomas, A., 2009. Regulating traffic to reduce air pollution in Greater Cairo, Egypt. In: Economic Research Forum Working Papers. No. 664.
Ackermann-Liebrich, U., et al., 1997. Lung function and long-term exposure to air pollutants in Switzerland: study on air pollution and lung diseases in adults (SAPALDIA) team. Am. J. Respir. Crit. Care Med. 155, 122–129. https://doi.org/10.1164/ajrccm.155.1.9001300.
Adame, J.A., Hernandez-Ceballos, M.A., Sorribas, M., Lozano, A., De la Morena, B.A., 2014. Weekend-weekday effect assessment for NOₓ, NO, CO and PM₁₀ in Andalusia, Spain (2003-2008). Aerosol Air Qual. Res. 14 https://doi.org/10.4209/aap.2014.02.0026, 1862–1874.
Ahramonline, 2020a. Stay Home, Stay Safe, and Enjoy Theatre. http://english.ahram. org.eg/NewsContent/7/13/365997/Business/Econ-How-is-Egypt-supporting-seasonal-workers-amid-the-aspx. (Accessed 8 June 2020).
Ahramonline, 2020b. How Is Egypt Supporting Seasonal Workers amid the Coronavirus Crisis? http://english.ahram.org.eg/NewsContent/13/3/12595797/Business/Econ-How-is-Egypt-supporting-seasonal-workers-amid-the-aspx. (Accessed 7 June 2020).
Ahramonline, 2020c. Egypt Makes Wearing Facemasks Mandatory in Public Places. http://english.ahram.org.eg/NewsContent/7/13/369635/Politics/Politics-Egypt-makes-wearing-facemasks-mandatory-in-public-aspx. (Accessed 9 June 2020).
Ahramonline, 2020d. As Lockdown Cures the Air, Cairo Looks to Keep Pollution Low. http://english.ahram.org.eg/NewsContent/7/13/369992/Politics/As-lockdown-clears-the-air,-Cairo-looks-to-keep-p-po-aspx. (Accessed 10 August 2020).
Ahkostane, E., Türiö-Apsk, S., Tüng, G.L., 2009. The relationship between income and environment in Turkey: is there an environmental Kuznets curve? Energy Pol. 37 (3), 861–867. https://doi.org/10.1016/j.enpol.2008.09.088.
Al Mal, 2020. The Association ‘ISWA’ Announces an Increase in Medical Waste Contaminated with Coronavirus by 30% to 50%. https://almalnews.com. (Accessed 20 August 2020).
Al-Masry Al-Youm, 2020a. A Briefing Request Warns of ‘Corona Waste’: ‘It Has Reached 300 Tons Per Day. https://www.almasryalyoum.com/news/details/1972441 (Accessed 20 August 2020).
Al-Masry Al-Youm, 2020b. They Extracted 7 Tons of Waste. Divers in Dahab Are Taking Advantage of the Halting of Tourism to Clean the Seabed. http://www.almasryalyoum.com/news/details/1968969. (Accessed 14 June 2020).
Al-Mula, U., Saboori, B., Ozturk, I., 2015. Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Pol. 76, 123–131. https://doi.org/10.1016/j.enpol.2014.11.019.
Ang, J.B., 2007. CO2 emissions, energy consumption, and output in France. Energy Pol. 35 (10), 4772–4776. https://doi.org/10.1016/j.enpol.2007.03.026.
Atalindis, N., Xepapadeas, A., 2004. Smooth ‘inverted V-Shaped & Smooth N- Shaped pollution-Income Paths. No. 0405.
Atkinson, R., 2000. Atmospheric chemistry of VOCs and NOₓ. Atmos. Environ. 34, 2063–2101. https://doi.org/10.1016/S1352-2310(99)00460-4.
Bagliani, M., Bravo, G., Dalmazzone, S., 2008. A consumption-based approach to environmental Kuznets curves using the ecological footprint indicator. Ecol. Econ. 65 (3), 650–661. https://doi.org/10.1016/j.ecolecon.2008.01.010.
Bai, Y., Yao, L., Wei, T., Tian, F., Jin, D.-Y., Chen, L., 2020. Presumed asymptomatic carrier transmission of COVID-19. Jama 323, 1406–1407. https://doi.org/10.1001/jama.2020.2569.
Baldwin, R., di Mauro, B.W., 2020. Introduction. In: Baldwin, R., di Mauro, B.W. (Eds.), Economics in the Time of COVID-19. https://voxeu.org/content/economics-time-co vid-19. (Accessed 18 June 2020).
Barcelo, D., 2020. An environmental and health perspective for COVID-19 outbreak: meteorology and air quality influence, sewage epidemiology indicator, hospital disinfection, drug therapies and recommendations. Journal of Environmental Chemical Engineering 8, 104066. https://doi.org/10.1016/j.jece.2020.104066.
Bherwani, H., Anjum, S., Kumar, S., Gautam, S., Gupta, A., Kumhare, H., Anshul, A., Kumar, R., 2020a. Understanding COVID-19 transmission through bayesian probabilistic modelling and GIS based voronoi approach: a policy perspective. Environ. Dev. Sustain. https://doi.org/10.1007/s10668-020-00849-0.
Bherwani, H., Nair, M., Munsgu, K., Gautam, S., Gupta, A., Kapley, A., Kumar, R., 2020b. Valuation of air pollution externalities: comparative assessment of economic damage and emission reduction under COVID-19 lockdown. In: Air Quality Atmosphere and Valuation of air pollution externalities: comparative assessment of economic damage and emission reduction under COVID-19 lockdown. In: Air Quality Atmosphere and.
Burnett, R.T., Steh, D., Brook, J.R., Cakmak, S., Daales, R., Raizenne, M., Vincent, R., Danu, T., 2004. Associations between short-term changes in nitrogen dioxide and mortality in Canadian cities. Arch. Environ. Health 59, 226–236. https://doi.org/10.3200/AEOH.59.5.226-236.

Castell, N., Mantilla, E., Salvador, R., Stein, A.F., Millan, M., 2010. Photochemical model evaluation of the surface ozone impact of a power plant in a heavily industrialized area of southwestern Spain. J. Environ. Manag. 91 (3), 662–676. https://doi.org/10.1016/j.jenvman.2009.09.030.

Central Agency for Public Mobilization and Statistics, 2020a. Manufacturing and

Evans, S., 2020. Analysis: Coronavirus Set to Cause Largest Ever Annual Fall in CO2

El Dirini, A., 2017. Medical Waste in Cairo: Impact and Health Problems. Shorthand

Dasgupta, S., Laplante, B., Wang, H., Wheeler, D., 2002. Confronting the environmental
dangers of the 21st century. Ecological Economics 40 (3), 407–420. https://doi.org/10.1016/S0921-8009(01)00275-9.

Finlayson-Pitts, B.J., Pitts, J.N., 2000. Chemistry of the Upper and Lower Atmosphere: Theory, Experiments and Applications, third ed. Academic Press, San Diego. https://doi.org/10.1016/S0001-850X(98)80017-1.

Gbabigbo, P.O., 2020. IEA: Coronavirus great or CO2 Emissions Six Times Larger than 2008 Financial Crisis. Carbon Brief. https://www.carbonbrief.org/iea-coronavirus -impact-on-co2-emissions-six-times-larger-than-financial-crisis. (Accessed 12 June 2020).

Gauci, W., Giullandi, G.F., Vora, H., Alleva, J., Stram, D., McConnell, R., Thomas, D., Lurmann, F., Margolis, H.G., Rappaport, E.B., Berhane, K., Peters, J.M., 2000. Association between air pollution and lung function growth in southern California children. Am. J. Respir. Crit. Care Med. 162, 1383–1390. https://doi.org/10.1164/rccm.2111-1021.

Gautam, S., 2020. Covid - 19: air pollution remains low as people stay at home. Air Quality Atmosphere and Health 13, 853–857. https://doi.org/10.1109/sain19920-0267.

Gautam, S., 2020. The influence of COVID - 19 on air quality in India: a boon or intute. Bull. Environ. Contam. Toxicol. 104 (6), 724–726. https://doi.org/10.1007/s00128-020-02877-y.

Gough, K.T., Kneitl, C.R., Li, J., Ovaere, M., Reguant, M., 2020. The short-run and long-run effects of covid-19 on energy and the environment. Joule. https://doi.org/10.1016/j.joule.2020.06.010.

Google, 2020. COVID-19 Community Mobility Report. https://www.gstatic.com/covid19/mobility/Report.pdf. (Accessed 5 June 2020).

Gopinath, G., 2020. The Great Lockdown: Worst Economic Downturn since the Great Depression. https://blogs.imf.org/2020/04/14/the-great-lockdown-worst-eco micdownturn-since-the-great-depression/. (Accessed 28 April 2020).

Grootman, G.M., Krueger, A.R., 2020. The economic impacts of a North American Free Trade Agreement (No. W9314). National Bureau of economic research.

Halcihoglu, F., 2009. An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey. Energy Pol. 37 (3), 1156–1164. https://doi.org/10.1016/j.enpol.2009.04.003.

Hassan, S.K., Khoder, M.I., 2017. Chemical characteristics of atmospheric PM2.5 loads during air pollution episodes in Giza, Egypt. Atmos. Environ. 150, 346–355. https://doi.org/10.1016/j.atmosenv.2016.11.020.

Health Effect Institute, 2017. State of Global Air 2017. Special Report. Health Effects Institute, Boston, MA. https://www.stateofglobalair.org. (Accessed 18 June 2020).

Heger, Martin, Wheeler, David, Zens, Gregor, Meinzer, Craig, 2019. Motor Vehicle Density and Air Pollution in Greater Cairo: Fuel Subsidy Removal and their Effects on Pollutant Emissions. The World Bank.

Hees, J.M., Kaibling, D.F., Wolff, G.T., 2003. Weekday/weekend ozone differences: what can we learn from them? J. Air Waste Manag. Assoc. 53, 772–788. https://doi.org/10.1002/jawa.1046227.

Heywood, J.I., 1988. Pollution Control and Formation. Internal Combustion Engine Fundamentals.

Hill, M.K., 2012. Understanding Environmental Pollution. Cambridge University Press. https://doi.org/10.1017/cbo9780511846564.

Holz-Eakin, D., Selden, T.M., 1995. Stoking the fires? CO2 emissions and economic growth. J. Publ. Econ. 57 (1), 85–101.

Holz, O., Jorres, R.A., Timm, P., Müller, R., 2018. Health effects of CO2 emissions— are health effects of CO2 emissions really relevant? An overview. Environ. Int. 122, 24–32. https://doi.org/10.1016/j.envint.2018.10.005.

Huang, Z., Wang, W., Jin, L., Wang, Y., 2020. Impact of COVID-19 pandemic on the air quality of China. Atmos. Environ. 221, 117047. https://doi.org/10.1016/j.atmosenv.2020.117047.

IMF, 2020. World Economic Outlook (Chapter 1): The Great Lockdown. https://www. imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020.

Independence, 2020. Egyptian MP Requests Hazardous Waste Bins to Combat Coronavirus. https://egyptindependent.com/egyptian-mp-requests-hazardous-waste -bins-to-combat-coronavirus/. (Accessed 17 September 2020).

Independence, 2020b. Diverting Tons of Waste from Red Sea off the Egyptian Coast. https://egyptindependent.com/divers-lift-7-tons-of-waste-from-red-sea-off-the-egyptian-coast/. (Accessed 17 September 2020).

Independence, 2020c. Shorter Hours, Cleaner Air? Egypt May Extend its COVID-19 Evening Curfew. https://egyptindependent.com/egypt-colourful-shorter-hours-cleaner-air?Egypt-may-extend-its-covid-19-evening-curfew/. (Accessed 20 August 2020).

Livingston, G.A., 2008. Financial Crisis. Carbon Brief. https://www.carbonbrief.org/iea-coronavirus -impact-on-co2-emissions-six-times-larger-than-financial-crisis. (Accessed 12 June 2020).

La Rosa, G., Bonadonna, L., Lucintini, L., Kenmoe, S., Saffredi, E., 2020. Coronavirus in water environments: occurrence, persistence and concentration methods - a scoping review. Water Res. 179, 115899. https://doi.org/10.1016/j.watres.2020.115899.
Mostafa, M.K., Peters, R.W., 2016. Improve effluent water quality at Abu-Rawash wastewater treatment plant with the application of coagulants. Water Environ. J. 30, 11–22. https://doi.org/10.1002/wenj.10730.

Lucrezi, S., Saayman, M., Van der Merwe, P., 2016. An assessment tool for sandy beaches: a case study for integrating beach description, human dimension, and economic factors to identify priority management issues. Ocean Coast Manag. 121, 25–36. https://doi.org/10.1016/j.ocecoaman.2016.05.028.

Marchetti, S., Hassan, S.K., Shetaya, W.H., El-Mekawy, A., Mohamed, E.F., Mohammed, A.M., Manecta, P., 2019. Seasonal variation in the biological effects of PM2.5 from greater cairo. Int. J. Mol. Sci. 20 (20), 4970. https://doi.org/10.3390/ijms20094970.

Marsiglio, S., 2011. On the relationship between population change and sustainable economic factors to identify priority management issues. Ocean Coast Manag. 121, 25–36. https://doi.org/10.1016/j.ocecoaman.2016.05.028.

Marchetti, S., Hassan, S.K., Shetaya, W.H., El-Mekawy, A., Mohamed, E.F., Mohammed, A.M., Manecta, P., 2019. Seasonal variation in the biological effects of PM2.5 from greater cairo. Int. J. Mol. Sci. 20 (20), 4970. https://doi.org/10.3390/ijms20094970.

Marsiglio, S., 2011. On the relationship between population change and sustainable economic factors to identify priority management issues. Ocean Coast Manag. 121, 25–36. https://doi.org/10.1016/j.ocecoaman.2016.05.028.
Sohrab, C., Alasfi, Z., O’Neill, N., Khan, M., Kerwan, A., Al-Jabir, A., Isifidin, C., Agha, R., 2020. World health organization declares global emergency: a review of the 2019 novel coronavirus (COVID-19). Int. J. Surg. 76, 71–76. https://doi.org/10.1016/j.ijsu.2020.02.034.

Somvanshi, S.S., Vashishth, A., Chandra, U., Kauahik, G., 2019. Delhi air pollution modeling using remote sensing technique. In: Hussain, C.M. (Ed.), Handbook of Environmental Materials Management. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-58583-1_174-1.

Steib, D., Judek, S., Brunet, R.T., 2003. Meta-analysis of time-series studies of air pollution and mortality: update in relation to the use of generalized additive models. J. Air Waste Manag. Assoc. 53, 258–261. https://doi.org/10.1080/10473292.2003.10466149.

Steiner, A.L., Tawfik, A.B., Shalaby, A., Zakey, A.S., Abdel-Wahab, M.M., Salah, Z., Solmon, F., Stillman, S., Zveri, R.A., 2014. Climatological simulations of ozone and atmospheric aerosols in the Greater Cairo region. Clim. Res. 59 (3), 207–228.

SWEEP-Net, 2014. Country Report on the Solid Waste Management in EGYPT. https://www.retech-germany.net/fileadmin/retech/05_mediathek/laenderinformationen/Aegypten_RA,ANG,14_J.Laenderrprofile.sweep_net.pdf. (Accessed 20 April 2020).

Tang, X., Gao, X., Li, C., Zhou, Z., Ren, C., Feng, Z., 2020. Study on spatiotemporal distribution of airborne ozone pollution in subtropical region considering socioeconomic driving impacts: a case study in Guangzhou, China. Sustainable Cities and Society 54, 101989. https://doi.org/10.1016/j.scs.2019.101989.

TIME, 2020. World Health Organization Declares COVID-19 a ‘Pandemic’. Here’s what that means. https://time.com/5791661/who-coronavirus-pandemic-declaration/. (Accessed 10 April 2020).

Toibis, A., Carnerero, C., Reche, C., Massagué, J., Via, M., Minguillón, M.C., Blastuey, A., Querol, X., 2020. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Sci. Total Environ. 726, 138540. https://doi.org/10.1016/j.scitotenv.2020.138540.

Tobias, A., Carnerero, C., Reche, C., Massagué, J., Via, M., Minguillón, M.C., Blastuey, A., Querol, X., 2020. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Sci. Total Environ. 726, 138540. https://doi.org/10.1016/j.scitotenv.2020.138540.

Veefkind, P., Van Oss, R.F., Eskes, H., Borowiak, A., Dentner, F., Wilson, J., 2007. The modeling using remote sensing technique. In: Hussain, C.M. (Ed.), Handbook of Environmental Materials Management. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-58583-1_174-1.

Wang, Q., Su, M., Li, R., Ponce, P., 2019. The effects of energy prices, urbanization and economic growth on energy consumption per capita in 186 countries. J. Clean. Prod. 208, 25–38. https://doi.org/10.1016/j.jclepro.2019.04.008.

Wang, D., Hu, B., Hu, C., Zhu, F., Liu, X., Zhang, J., Wang, B., Xiang, Z., Chong, Z., Xiong, Y., Zhao, Y., Li, Y., Wang, X., Peng, Z., 2020a. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus (COVID-19) patients in Wuhan, China. J. Air Waste Manag. Assoc. 63, 292–299. https://doi.org/10.1080/10473292.2020.1196224.2012.749312.

World Bank, 2019. Arab Republic of Egypt: Cost of Environmental Degradation-Air and Water Pollution. Washington, DC, USA.

World Bank Group, 2013. Egypt - for Better or for Worse : Air Pollution in Greater Cairo : Sector Note (English). Washington, D.C. http://documents.worldbank.org/curate/df/79225146021516501880/Egypt-For-better-or-for-worse-air-pollution-in-Greater-Cairo-sector-note.

World Health Organization, 2020. Environmental Noise Guidelines for the European Region (WHO). http://www.euro.who.int/en/publications/abstracts/environmen
tal-noise-guidelines-for-the-european-region-2018. (Accessed 2 June 2020).

World Health Organization, 2000. World Health Organization air quality guidelines (WHO). Air Quality Guidelines for Europe, second ed. WHO Regional Publications, European Series, no. 91.

World Health Organization (WHO), 2020a. Coronavirus Disease 2019 (COVID-19), Situation Report – 51. https://apps.who.int/iris/bitstream/handle/10665/331767/WHO-2019-nCoV-Ramadan-2020.1-eng.pdf?sequence=1&isAllowed=y. (Accessed 29 March 2020).

World Health Organization (WHO), 2020b. Water, Sanitation, Hygiene, and Waste Management for the COVID-19 Virus (WHO). https://www.who.int/publications/i/item/water-sanitation-hygiene-and-waste-management-for-the-covid-19-virus-interim-guidance. (Accessed 4 June 2020).

World Health Organization (WHO), 2020. Trade Set to Plunge as COVID-19 Pandemic Unpers Global Economy. https://www.wto.org/english/news_e/pren20_e/pr585_e.pdf. (Accessed 15 June 2020).

Wu, F., Xiao, A., Zhang, J., Gu, X., Lee, W.L., Kaufman, K., Hanage, W., Matus, M., Ghebrial, N., Endo, N., Devallet, C., Moniz, K., Erickson, T., Chai, P., Thompson, J., Alm, E., 2020. SARS-CoV-2 titers in wastewater are higher than expected from clinically confirmed cases. medRxiv preprint. https://doi.org/10.1101/2020.04.05.20051400.

Xie, M., Zhu, K., Wang, T., Chen, P., Han, Y., Li, S., Zhang, B., Shu, L., 2016. Temporal characterization and regional contribution to O3 and NOx at an urban and a suburban site in Nanjing, China. Sci. Total Environ. 551–552, 532–545. https://doi.org/10.1016/j.scitotenv.2016.02.047.

Xu, B., Liu, L., Lin, H., 2016. A dynamic analysis of air pollution emissions in China: evidence from nonparametric additive regression models. Ecol. Indicat. 63, 346–358. https://doi.org/10.1016/j.ecolind.2015.11.012.

Youjiang, H., Itsushi, U., Zifa, W., Toshimasa, O., Nobuo, S., Atsushi, S., Andreas, R., Shigeru, T., Yuichi, K., Shigeru, T., Yoko, Y., 2019. Do economic activities cause air pollution? Evidence from nonparametric additive regression models. Ecol. Indicat. 63, 346–358. https://doi.org/10.1016/j.ecolind.2015.11.012.

Youm7, 2020a. Minister of Local Development: 3.3 Million Tons of Waste Was Removed from the Streets within 55 Days. https://www.youm7.com/story/. (Accessed 17 September 2020).

Youm7, 2020b. President of the Water Holding Company: Preventive Measures in Various Stations and Alternative Plans to Face Corona Virus. https://www.youm7.com/story/. (Accessed 29 August 2020).

Yugo, K., Hirshi, T., Jun, M., Hiroshi, F., Shigueru, H., Yuichi, K., Shigeru, T., Yoko, Y., Shungs, K., Yoshizumi, K., Hajime, A., 2007. Diurnal variations in HNO3, HONO, and aldehyde concentrations and NO/NO2 ratio at Sishiri Island, Japan: potential influence from iodine chemistry. Sci. Total Environ. 376, 185–197. https://doi.org/10.1016/j.scitotenv.2007.01.073.

Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. Sci. Total Environ. 728, 138813. https://doi.org/10.1016/j.scitotenv.2020.138813.

Zhu, L., Hao, Y., Lu, Z.N., Wu, H., Ran, Q., 2019. Do economic activities cause air pollution? Evidence from China’s major cities. Sustainable Cities and Society 49, 101593. https://doi.org/10.1016/j.scs.2019.101593.

Zou, Y., Charlesworth, E., Yin, C-Q., Yan, X.L., Deng, X.J., Li, F., 2019. The weekday/weekend ozone differences induced by the emissions change during summer and autumn in Guangzhou, China. Atmos. Environ. 199, 114–126. https://doi.org/10.1016/j.atmosenv.2018.11.019.