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Egypt. J. Soil. Sci. Vol. **60**, No. 4, pp. 437-448 (2020)

Egyptian Journal of Soil Science

http://ejss.journals.ekb.eg/

Soil and Air Pollution in the Era of COVID-19: A Global Issue

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THE COVID-19 pandemic began to emerge by the end of 2019, creating an unprecedented and dramatic world-wide catastrophe. The SARS-CoV-2 virus has already changed the global map and forced the world to start a new era in which no one can predict the volume of social, economic and environmental changes that will occur world-wide. Soil and air are two compartments of the agroecosystem that represent two vital columns of the environment's structure. Due to social distancing, lockdowns and quarantines, air pollution was reduced in several cities worldwide, whereas this relationship for soil as a complex system still needs more investigation. The most immediate impacts of the COVID-19 pandemic on soils and vice versa probably depend primarily on human activities. Management of soils may include restoring soils from and increasing resilience to viral impacts and sustaining crop yields for long-term sustainability to keep the soil healthy for future generations. Therefore, this review is an attempt to highlight the mutual impact of COVID-19 on pollution of soil and air. Many open questions are discussed in this review article, including the expected environmental impacts of COVID-19 on soil and air, does soil play a role in spreading COVID-19, soil pollution status under the COVID-19 outbreak, and what are the projected management scenarios for soil and air pollution under the COVID-19 outbreak?

Keywords: Environmental pollution; Corona virus; SARS-CoV-2; Soil health; Air quality.

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DOI: 10.21608/ejss.2020.49996.1411
Received: 16/11/2020; Accepted: 30/11/2020

Introduction

Pollution is a serious challenge facing the whole word, especially in developing countries (Verma 2020). Due to intensive anthropogenic activities, several deleterious effects on the environment and its resources have been created (Brevik et al. 2018; Siddiqa and Faisal 2020). These human activities may include agriculture, smelting, mining, traffic and machinery manufacturing, which have been recognized as main contributors to environmental pollution (Boente et al. 2020; Brevik et al. 2020; Qiao et al. 2020). Soil pollution may reduce crop yield and quality, as well as change soil organic matter, biodiversity, and groundwater quality (Singh et al. 2020). Air pollution may originate from different anthropogenic and natural sources, which are able to bio-accumulate and bio-magnify in the trophic levels, and thus increase their toxicity in the food chain (Lee et al. 2020). The most common air pollutants that threaten human health and other components of the biosphere include particulate matter (PMs; Daiber et al. 2020), heavy metals (HMs), inorganic air pollutants (IAP; Talaiekhozani et al. 2021), volatile organic compounds (VOCs; Jia et al. 2021), persistent organic pollutants (POPs; Cindoruk et al. 2020) and black carbon (Sitnov et al. 2020).

A number of global problems, in addition to the global corona virus disease-2019 (COVID-19) pandemic, represent great challenges for all countries worldwide beside (Wang and Su 2020) (Fig. 1). By March 11, 2020, the World Health Organization (WHO) officially declared COVID-19 to be a global pandemic and health threat (WHO 2020). The COVID-19 pandemic has been spreading at a frenetic pace with more than 12,500,000 confirmed cases worldwide at the time this article was written (Bilal et al. 2020). Temperature has a significant correlation with the spread of COVID-19, and environmental pollutants (mainly air pollution) probably also play a role (Bilal et al. 2020). Therefore,the impact of air pollution has gained a considerable amount of attention related to the COVID-19 outbreak as reported in several recent articles (e.g., Guatam 2020; Mele and Magazzino 2020; PenaLevano and Escalante, 2020). There is currently little original research that addresses COVID-19 issues in soil (Conde-Cid et al. 2020; Steffan et al. 2020).

Therefore, this review is an attempt to highlight COVID-19 and its relationship with the pollution of soil and air through the following topics: what are the links between air pollution and COVID-19? How might the COVID-19 outbreak affect soil pollution status? What are the expected broader environmental impacts of COVID-19?

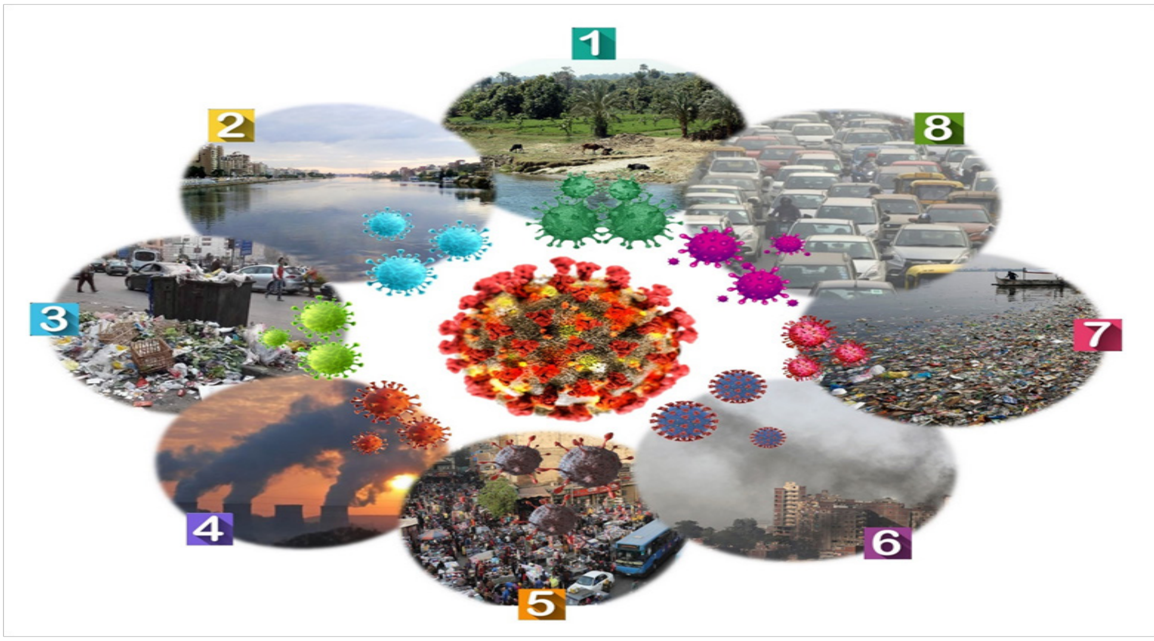

Fig. 1.General features of different environmental pollution problems affecting soil, water, plants and air and their pathways under the umbrella of COVID-19 as presented in an agroecosystem (photo 1), surface water (photo 2), agro-wastes and other wastes (photo 3), power plants (photo 4), crowded societies that are very sensitive to COVID-19 (photo 5), air pollution changes (photo 6), intensive water pollution (photo 7) and air pollution from vehicle emissions (photo 8)

Soil and air pollution and their sources

Environmental pollution is considered a crucial issue because of the way it penetrates all aspects of human life. Hundreds of thousands of published materials have been issued regarding air and soil pollution by the main publishing houses like Springer and Science direct (Table 1). The types of soil and air pollutants and their environmental fate was and still is an important issue regarding environmental protection, particularly in the era of COVID-19. Proper monitoring and remediation strategies for contaminated soils are selected after evaluating (1) sources of soil pollutants, their distribution, and transport, (2) chemical transformations and accumulation in soils, (3) changes in soil ecosystem functions and its structure due to pollution, (4) ecotoxicological effects and risk assessment of these pollutants and (5) different strategies for soil remediation and its protection (Duarte et al. 2018). Several reviews also recently discussed soil pollution by materials like micro- and nano-plastics (Iqbal et al. 2020; Sarker et al. 2020), pesticides (Wołejko et al. 2020), thallium (D'Orazio et al. 2020), mercury (Liu et al. 2021) and heavy metals (Yuan et al. 2021). The main sources of soil and air pollution may include natural and anthropogenic sources.

TABLE 1. Survey of the Springer and Science direct websites searching for "air pollution" and "soil pollution" on the 12th of November, 2020

Item or publishing material	Springer Link	Science direct
Air pollution	292,755	337,223
Articles including reviews	185,213	253,733
Chapters	100,066	25,623
Soil pollution	215,567	179,000
Articles including reviews	146,019	137,550
Chapters	64,950	15,053

Air pollutants consist of primary pollutants (PMs, CO, SO_2, and nitrogen oxides) and secondary pollutants (e.g., particular ozone, CO_2 and SO_3). Natural air pollutants may be generated from sandstorms, forest fires, volcanic eruptions, photochemical reactions and the carbon and nitrogen cycles (Lee et al. 2020). Anthropogenic sources of air pollutants may include energy production, fossil fuel combustion, transportation, agricultural management, and municipal and industrial activities (Agarwal et al. 2018). Furthermore, the air pollutants that may be most harmful to human health and other biosphere components include PMs (the most toxic air pollutants), volatile organic compounds (VOCs; e.g., benzene, toluene, ethylbenzene and xylene), indoor air pollution (IAP; e.g., O_3, CO_2, CO, SO_2 and nitrogen oxides or NO_X), persistent organic pollutants (POPs; e.g., furans, pesticides, dioxins and polychlorinated biphenyls), heavy metals (HMs; e.g., As, Cd, Cr, Cu, Hg, Pb, Sb and Zn), and black carbon (Lee et al. 2020).

Links between air pollution and COVID-19

COVID-19, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was declared a global public health threat in December 2019 (Mohan et al. 2021). The initial stages and development of severe acute respiratory syndrome as a timeline for COVID-19 are presented in Table 2. COVID-19 is a novel disease that emerged in Wuhan city, China, caused by a novel coronavirus as a causative agent of pneumonia and presumed to have jumped species from another mammal to humans (Zhang et al. 2021). This virus has caused a rapidly spreading global pandemic. However, the factors that affect the severity and mortality of COVID-19, beyond gender and age (Mallapaty 2020), have not been clearly identified although a speedy progress has been achieved in managing this disease. Several recent studies on COVID-19 in multiple countries identified links between air pollution and health impacts, including death rates (Table 3). In England, for example, a study explored potential links between air pollutants related to fossil fuels and the mortality of COVID-19 victims (Travaglio et al. 2021). They found that an increase in the long-term average of $PM_{2.5}$ was associated with a 12% increase in COVID-19 cases. A confirmed association between air pollution and the COVID-19 epidemic during a quarantine period in China has reported by Zhang et al. (2021), who showed that quarantine measures can not only reduce direct transmission of the virus, but also retard spread by improving ambient air quality, which might help prevent and control COVID-19. There is a relationship between air pollution, wind speed, and the diffusion of COVID-19, which suggests that air pollutants in high concentrations may correlate with low wind speeds and lead to longer residence time for viral particles in polluted air (Coccia et al. 2020a, b). Other studies showed that climatology parameters or climate indicators (humidity, wind speed and solar radiation) may correlate with the COVID-19 pandemic (Ahmadi et al. 2020). Bashir et al. (2020a) found a significant correlation among the average temperature, minimum temperature and air quality with the COVID-19 epidemic. A decrease in air pollution (e.g., $PM_{2.5}$, PM_{10}, NO_2 and CO) has been recorded in several studies in different countries worldwide due to social distancing after COVID-19 (Ju et al. 2021).

TABLE 2. Different initial stages and the timeline of development of severe acute respiratory syndrome for COVID-19 (adapted from Yan et al. 2020 and Mofijur et al. 2021)

Date	Event
Dec. 01, 2019	The symptom onset date of the first patient identified
Dec. 08, 2019	Patients with pneumonia of unknown etiology were reported in Wuhan, China
Dec. 31, 2019	Wuhan municipal health commission reported problems to WHO
Jan. 07, 2020	Chinese scientists identified a new type of coronavirus
Jan. 12, 2020	The new type of viral pneumonia was temporarily named 2019-nCoV infected pneumonia
Jan. 23, 2020	Wuhan, China suspended all public transport to stop SARS-CoV-2 from spreading
Feb. 07, 2020	The National Health Commission of China announced that the coronavirus would be named Novel Coronavirus Pneumonia (NCP)
Feb. 11, 2020	The novel coronavirus was named as SARS-CoV-2 as announced by CSG of the International Committee on Taxonomy of Viruses
Feb. 12, 2020	The WHO officially named the disease caused by SARS-CoV-2 COVID-19

TABLE 3. A survey of some published studies that investigated the links between air pollution and COVID-19

Country	The most important findings of the study or aim of the study	Reference
Egypt	The COVID-19 pandemic has had a great effect, reducing the air pollution levels of NO_2, O_3, PMs, CO, and greenhouse gas emissions, environmental noise, medical and municipal solid wastes, and health and economic issues	Mostafa et al. (2021)
Korea	A significant reduction in $PM_{2.5}$, PM_{10}, NO_2 and CO air pollution levels resulted due to social distancing after COVID-19	Ju et al. (2021)
England	There is apositive relationship between air pollutant concentrations, particularly nitrogen oxides, and COVID-19 mortality and infectivity	Travaglio et al. (2021)
Pakistan	A correlation was found between precipitation level, normal temperature, maximum temperature, and COVID-19	Aslam et al. (2020)
Japan	The epidemic growth of COVID-19 resulted from the increase in daily temperature or sunshine hours (as climatic indicators) and ambient air pollution	Azuma et al. (2020)
Italy	How climatological factors (wind speed) and high levels of air pollution can affect the diffusion of COVID-19 in human society; high air content of pollutants may associate with low wind speeds and may promote a longer permanence of viral particles in polluted air of cities	Coccia (2020a)
Italy	A positive association of ambient $PM_{2.5}$ concentration on excess mortality related to the COVID-19 epidemic was found in Northern Italy	Coker et al. (2020)
India	This study verified a causal link between $PM_{2.5}$, CO_2, NO_2, and COVID-19 deaths using machine learning	Mele and Magazzino (2020)
India	$PM_{2.5}$ and NO_2, relative humidity, temperature, and air quality index improved during the pre-lockdown and lockdown periods, leading to lower mortality rates during the COVID-19 pandemic	Karuppasamy et al. (2020)
The USA	The air pollution of urban regions, especially NO_2 pollution, may enhance population susceptibility to death from COVID-19	Liang et al. (2020)
The USA	Changes in air pollution during the COVID-19 pandemic including NO_2, declined 25.5% during the pandemic compared to historical years (2017–2020)	Berman and Ebisu (2020)
The USA	The concentration of air pollutant emissions and sources were associated with COVID-19 prevalence and its fatality rates	Hendryx and Luo (2020)
China	In a retrospective study from Wuhan, $PM_{2.5}$ and diurnal temperature range were strongly associated with COVID-19 deaths. PM_{10}, CO and SO_2 were also significantly associated with increased deaths.	Jiang and Xu (2020)
China	Meteorological conditions (rising temperature) and air pollution index linked to COVID-19 transmission (non-linear dose-response relationship) In southern cities, the rising temperature restrained the facilitating effects of air pollution on COVID-19	Zhang et al. (2020)
China	The transport pathway and source distribution of air pollutants during the COVID-19 outbreak in China may be controlled by the wind speed and relative humidity	Zhao et al. (2020)
China	A significant relationship was found between studied air pollutants ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 and O_3) and COVID-19 infection	Zhu et al. (2020)
Croatia	A 35% decrease in NO_2 and PM_1 particles and 26% decrease in total polycyclic aromatichydrocarbons from traffic were found during a lockdown caused by the COVID-19 pandemic	Jakovljević et al. (2020)
Ecuador	Concentrations of NO_2 and $PM_{2.5}$ decreased significantly during the COVID-19 pandemic due to lockdown, however, concentrations of O_3 increased	Zambrano-Monserrate and Ruano (2020)

TABLE 3 Cont

France	A significant relationship was found between air pollution indicators ($PM_{2.5}$ and PM_{10}) and COVID-19-related deaths	Magazzino et al. (2020)
Germany	PM_{10}, humidity and environmental quality index had a significant relationship with active COVID-19 cases	Bilal et al. (2020)
Mexico	The COVID-19 lockdown resulted in a19–36% reduction in NO_2, CO, SO_2, $PM_{2.5}$ and PM_{10}, and increased O_3 by 14% compared to average values from 2015–2019	Kutralam-Muniasamy et al. (2020)
Nigeria	The COVID-19-induced lockdown was responsible for a decrease in inorganic pollutants (like NO_2) in selected studied locations	Fuwape et al. (2020)
Saudi Arabia	A significant reduction in PM_{10}, CO and SO_2 (up to 70, 55 and 30%, resp.) was found due to the COVID-19 lockdown, while concentrations of O_3 increased up to 45%	Anil and Alagha (2020)
Spain	Air quality ($PM_{2.5}$), which may speed up the COVID-19-transmission rate, while daily aver. temperature (6-22) may reduce virus transmission	Shahzad et al. (2020)
The Netherlands	There is a positive relationship between air pollution, particularly $PM_{2.5}$ concentration, and Covid-19 cases, hospital admissions and deaths	Cole et al. (2020)
TheUK	Comparing 100 days post-lockdown with the same period from the previous 7 years, nitrogen oxides levels dropped 50%, however, O_3 levels increased 10% and S-dioxide levels more than doubled	Higham et al. (2020)
Turkey	Air pollution decreased in Turkey due to increasing unemployment, slowdown in the economic growth, and the tourism industry as a result from COVID-19 transmission	Ali et al. (2020)

Abbreviations:$PM_{1,}$ $PM_{2.5}$ and PM_{10}: Primary particulate matter < 1, 2.5 and 10 µm, respectively

COVID-19 and its environmental impacts

COVID-19, a respiratory infectious disease caused by a new coronavirus, spread worldwide at unexpectedly fast speed causing cancelations in global flights and transportation and the closing of entire nations and international borders (Rupani et al. 2020). Economic activities were severely curtailed and stock markets dropped worldwide during the COVID-19 lockdown period, which impacted global migration and had a number of social and economic effects. On the other hand, the lockdowns and resulting minimal human mobility had several positive impacts on the natural environment such as reduced air pollution (Bera et al. 2020), a drop in carbon emissions, and a reduction in water pollution in many cities around the world (Rupani et al. 2020). Other environmental impacts of the COVID-19 pandemic included changes in waste management (biomedical or health care wastes), wildlife (in people-dominated areas as wildlife activities are restricted and banned), waste fires (in general increasing the domestic wastes during the lockdown), global migration (decreased due to banned international travels), and the global sustainability due to all previous impacts (Rupani et al. 2020).

Several reports have addressed the impacts of COVID-19 on environmental issues such as energy domains (Mofijur et al. 2021) and socio-economic issues (Bashir et al. 2020b) through reshaped investment in energy affecting the energy sector and its investment activity, which is facing disruption due to mobility restrictions. The solid wastes (Urban and Nakada 2021), forest degradation (Golar et al. 2020), household food wastages (Jribi et al. 2020), which may represent environmental stressors (Bakadia et al. 2020) and indirect impact of COVID-19 on the environment (Lokhandwala and Gautam 2020). Many environmental issues have been influenced by COVID-19 such as the urban park visitation (Geng et al. 2020), people with physical disabilities (Lebrasseur et al. 2020), global environment, poverty incidence and fertility rate during the period from 1980 to 2019 (Anser et al. 2020), environmental pollution (Juan-Reyes et al. 2021) and public health and safety nets (Fan et al. 2021). The sustainable consumption and social responsibility (Severo et al. 2020), global agricultural markets (Elleby et al. 2020), the stock market and tourism-related companies (Nhamo et al. 2020), environmental economics (Elliott et al. 2020) also are very important issues linked to the COVID-19 transmission.

It can be concluded that COVID-19 had several impacts on all aspects of our lives and these impacts may be positive, negative, or not yet identified (Fig. 2). For example, there is a positive relationship between air pollution and COVID-19 infection. The reduction in greenhouse gas emissions and decline in industrial refineries and activities as well as the decreased use of vehicles and transportation systems due to social distancing, lockdown and quarantine led to higher air quality and reduced risk to human health (Heet al. 2020; Juan-Reyes et al. 2021). Many very recent studies are expected to be published to highlight the complex interactions of the coupled human-environment system amid COVID-19 (Sarkar et al. 2021), increasing plastic pollution due to COVID-19 as very common materials (gloves and masks) used during this pandemic (Patrício Silva et al. 2021) are disposed of, the significant reduction of industrial NOx emissions in China due to COVID-19 (He et al. 2021), the enhancement of air pollution levels and other environmental indicators in Egypt (Mostafa et al. 2021), the pollution of wastewater by COVID-19 virus (Lahrich et al. 2021), impact of COVID-19 on forest fires (Paudel 2021), environmental surfaces during the incubation period of COVID-19 (Hu et al. 2021). On the other hand, COVID-19 may negatively impact human society through (1) public health risks, (2) the global economic recession, (3) global food crisis or insecurity and (4) lowering psychological resilience (Sarkar et al. 2021). It is worth mentioning that Lal et al. (2020) discussed managing soils to address disruption of the food supply chain, labor shortages, difficulties in performing farm operations, adverse impacts on staple and high value commodities, and food and medicinal waste disposal issues in the COVID-19 pandemic.

Soil pollution under the COVID-19 outbreak

The main soil pollutant problems (e.g., persistent organic pollutants, organochlorines, polycyclic aromatic hydrocarbons, organophosphates, carbamates and HMs) may cause human health problems through means such as immune system alterations and affects on the respiratory system similar to viral diseases (Espejo et al. 2020). The soil is a vital component of agroecosystems, which supply humanity with food, fiber, fuel, shelter, and feed for animals. The pollution of soils through natural or anthropogenic sources represents a serious threat to global food security, particularly under the COVID-19 pandemic (Lal et al. 2020). During the COVID-19 outbreak, huge amounts of medical wastes (e.g., face masks, gloves, plastic bags, paper tissues and empty bottles of hand soaps and sanitizers) have been produced, which may pollute soils and should be closely monitored (Lal et al. 2020). Thus, there is a need to understand the inter-connectivity between the COVID-19 pandemic and human activities that are linked to soil pollution (e.g., HMs, antibiotics, polycyclic aromatic hydrocarbons and petroleum products) and its functionality (Lal 2020; Lal et al. 2020). Therefore, there is a strong need to address the role of soil science in understanding and mitigating problems caused by the COVID-19 crisis over the short- and long-terms (Lal et al. 2020; Steffan et al. 2020).

Soil has an important role in human health, as reported by many studies (e.g., Brevik et al. 2017; Iqbal et al. 2020; Singh and Singh 2020). This role includes both positive and negative influences. On the positive side, soil is the main source for almost all human nutrients, which are obtained through cultivated plants and animal products, and is the

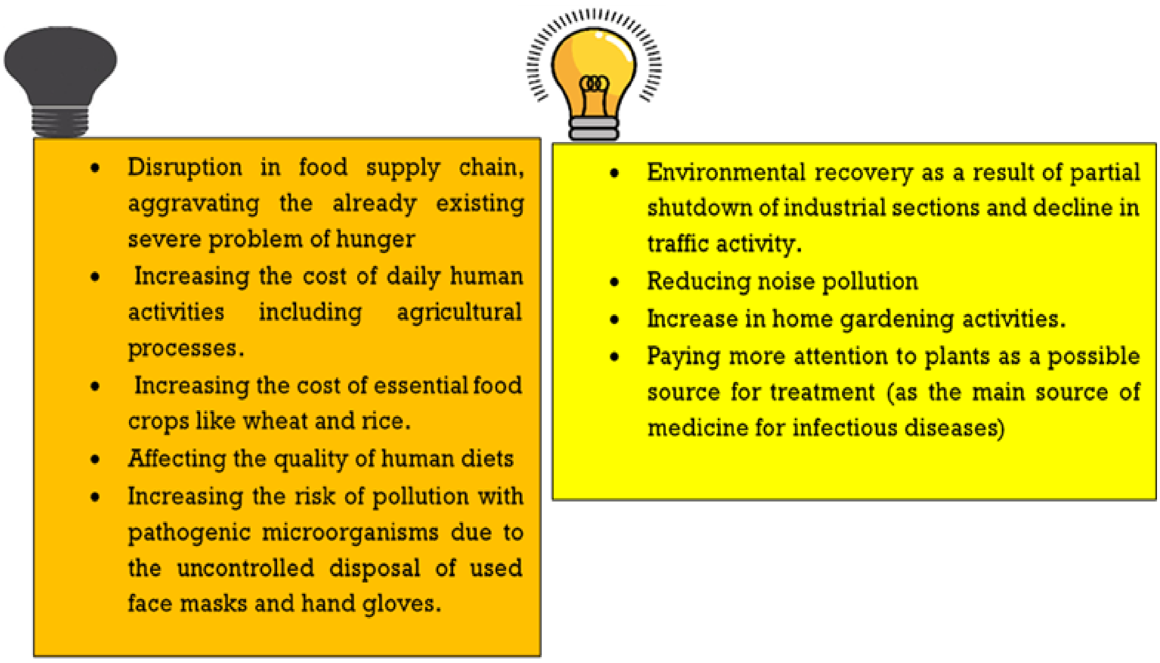

Fig. 2. A list of some negative and positive environmental impacts of the COVID-19 pandemic

source for several medications (Brevik et al. 2017). Polluted soils present several problems for human health including deterioration of ground water quality (Singh and Singh, 2020) and exposure to soil-borne diseases, including viral diseases (Iqbal et al. 2020). However, whether or not soils may be a reservoir for the transmission of COVID-19 is not currently known and studies specifically directed at this question are needed (Lal et al. 2020; Steffan et al. 2020). There are several soil pathogenic microbes (i.e., indigenous or exogenous microbes), that have the potential to cause diseases such as melioidosis, anthrax, tularemia, and tetanus caused by *Burkholderia pseudomallei*, *Bacillus anthracis*, *Francisella tularensis* and *Clostridium tetani* soil pathogens, respectively (Qian et al. 2020). There is a need for a broader awareness of the importance of soils to human health (Brevik et al. 2019), especially in the era of COVID-19, and how to manage soil to enhance soil health and the entire environment (Lal et al. 2020). There are a few studies already published concerning soil and COVID-19 (Núnez-Delgado 2020; Mishra et al. 2020; Lal et al. 2020; Steffan et al. 2020). It is very important to identify how to best study COVID-19 in soils (Conde-Cid et al. 2020) and also are there any lights at the end of this long tunnel of COVID-19 and its impacts on global farming and food system? (Holden 2020).

Conclusions

Environmental pollution is still one of the most important issues facing the world today, and is closely linked to human activities and health. The pollution of soil and air as vital components of agroecosystems is a global issue. COVID-19 has impacted all aspects of our lives, causing several impacts that reach all sectors of public health, socio-economic issues, and the broader environment. How soil management can help us address the COVID-19 pandemic, and how SARS-CoV-2 may survive and be transmitted through soil, are major questions that need to be addressed. There is a positive association between air pollution and COVID-19 infection. Several open questions still need to be investigated concerning soil and air pollution in the era of COVID-19 because human activity patterns were changed worldwide leading to a number of related impacts.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication

All authors declare their consent for publication.

Contribution of authors

This study was designed and implemented by authors, where all authors contributed in writing the manuscript, interpreting information presented and have read and agreed to the version of the manuscript.

Funding

This research received no external funding.

Conflicts of Interest

The author declares no conflict of interest.

Acknowledgement

The authors thank the all-staff members in the Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University and the Soil Fertility and Plant Nutrition Lab, Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University for their help with and support of this work.

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