Environment and COVID-19: Pollutants, impacts, dissemination, management and recommendations for facing future epidemic threats

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HIGHLIGHTS

- Unsustainable environmental management contributes to an increase of zoonotic diseases.
- Pollutants produce immune alterations and can affect the respiratory system similar to viral diseases.
- Indirect environmental impacts have been described. Negative impacts are projected to be greater over time.
- Climatic factors are not well established as factors influencing COVID-19 pandemic dissemination.
- One Health approach and biodegradable medical devices for future epidemiological threats should be considered.

GRAPHICAL ABSTRACT
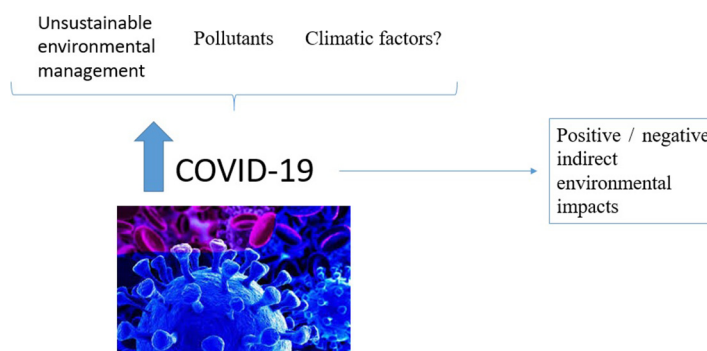
ARTICLE INFO

ABSTRACT

Coronavirus disease 2019 (COVID-19) has become a global pandemic. Its relationship with environmental factors is an issue that has attracted the attention of scientists and governments. This article aims to deal with a possible association between COVID-19 and environmental factors and provide some recommendations for adequately controlling future epidemic threats. Environmental management through ecosystem services has a relevant role in exposing and spreading infectious diseases, reduction of pollutants, and control of climatic factors. Pollutants and viruses (such as COVID-19) produce negative immunological responses and share similar mechanisms of action. Therefore, they can have an additive and enhancing role in viral diseases. Significant associations between air pollution and COVID-19 have been reported. Particulate matter (PM2.5, PM10) can obstruct the airway, exacerbating cases of COVID-19. Some climatic factors have been shown to affect SARS-CoV-2 transmission. Yet, it is not well established if climatic factors might have a cause-effect relationship to the spreading of SARS-CoV-2. So far, positive as well as negative indirect environmental impacts have been reported, with negative impacts greater and more persistent. Too little is known about the current pandemic to evaluate whether there is an association between environment and positive COVID-19 cases. We recommend smart technology to collect data remotely, the implementation of "one health" approach between public health physicians and veterinarians, and the use of biodegradable medical supplies in future epidemic threats.

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1. Introduction

Coronavirus disease 2019 (COVID-19), caused by SARS-CoV-2, started in November 2019 in Wuhan (China), and from there it was transmitted and rapidly dispersed all over the world (Jin et al., 2020). In March 2020, the WHO declared COVID-19 to be a pandemic. The global emergency committee indicated the need for early detection, quarantine, and rapid treatment (Sohrabi et al., 2020). This pandemic has caused more uncertainty and debate globally than previous ones such as SARS (2002–2003), avian influenza (2003–2009), swine flu (2009–2010), and Ebola (2014–2016), and most of its impacts are still uncertain (Sarkodie and Owusu, 2020a). However, all the evidence so far indicates that these pandemics are not random diseases, but a consequence of inappropriate interaction between humans and wild fauna.

Environmental sciences must play an important role in understanding and mitigating the current changes and challenges at the global level (Bernhardt et al., 2017; Eagles-Smith et al., 2018). A global sustainable development approach is highly needed to address these global variations, which must consider all sectors simultaneously in order to understand the interactions between environment, diseases, and human activities (Liu et al., 2018).

The relationships between the environment and COVID-19, the factors that caused the virulence of the respiratory disease, the measures to control the pandemic and the future impacts associated with the disease, are issues that need to be well understood scientifically. This article aims to synthesize key topics about the environment and COVID-19, thus providing recommendations for future epidemic threats. These may be useful for government decision-makers and researchers.

Although this article focuses on the environment and COVID-19, we recognize that this pandemic is primarily a human tragedy, which has already taken half million people's lives. At present, human health must be the priority, along with avoiding the spread of the virus. Nevertheless, the need for critical analysis of this pandemic can be useful to anticipate what may happen when global activities return to normality and also what actions should be taken into consideration with future epidemiological threats.

2. Environmental management and its influence on the global pandemic

The management of natural resources has an impact on the quality of human life. The current economic system with a strong focus on unsustainable exploitation of natural resources, in addition to the modern lifestyle that encourages mega-cities, has heavily modified natural environments (Boger and Hart, 2008; Molina and Molina, 2004). This contributes to the generation of artificial environments ideal for the development and spread of new diseases, due to the agglomeration of people in small spaces and the lack of natural barriers that work as buffer zones between high density populated zones (Hunter, 2017). Natural ecosystems not only provide economically valuable resources but also provide services to human well-being, through its natural ecological functions. The ecosystem services allow the regulation of climatic conditions, the control of water and air quality, the purification of pollutants, and the control of pest/disease, and they provide habitat for wild species (Fisher et al., 2009). Inadequate environmental management reduces the benefits of ecosystem services, and threatens the sustainability of biodiversity, including human diversity.

In terrestrial ecosystems, the rising conflict between humans and wildlife has increased habitat competition to the detriment of flora and fauna, which has meant changes in land cover, especially in areas with increasing agricultural/forestry activities. Natural habitat loss favors the interaction between wildlife, domestic animals, and humans. Scientific evidence supports the idea that a greater interaction between humans and animals enhances the transmission of pathogens (Jones et al., 2013). Pathogenic viruses and bacteria have co-evolved with their original animal hosts in such a way that they do not produce

severe effects on them, but can have catastrophic health effects if they cross over to infect new human hosts (Zohdy et al., 2019), as evidenced by the current global scenario. A substantial number of the emerging infectious diseases that affect humans are zoonotic, mostly originated in wildlife (Chomel et al., 2007). The zoonotic capacity of viruses of the family Coronaviridae is not recent, as zoonotic outbreaks have been reported since 1960. The first coronavirus causing lethal severe acute respiratory syndrome (SARS) was reported in 2002. The SARS-CoV-1 outbreak originated in Guangdong (China) and spread to 29 countries. In 2012, a zoonotic outbreak of a β-coronavirus was reported in Saudi Arabia. This virus, called MERS-CoV, spread to 27 countries. In contrast, SAS-CoV-2 resulting from zoonosis has spread to over 166 countries (Docea et al., 2020). For these reasons, it is important to manage natural environments correctly, preventing pathogens from leaving their natural environment and the species with which they have co-evolved. At present, many of these infectious agents found in wildlife are unknown.

Ecosystems can degrade or retain anthropogenic pollutants (Philp et al., 2005). Net primary production through chemical weathering of mineral silicates, occlusion of carbon to soil phytoliths, and the oceanic biological silicon pump, can be powerful allies in atmospheric carbon reduction programs (Carey and Fulweiler, 2012). The scarcity of green spaces and the high atmospheric emissions of human activities in mega-cities, result in high concentrations of air pollution in nearby inhabited areas (Chen et al., 2019). Correct environmental management also allows regulating the climate, for example. But, if there are too few green areas in a city, the average temperature increases, and the humidity decreases (Fisher et al., 2009), generating a man-made microclimate within a city with its own rainfall, snowfall, air pressure, and wind patterns. The spread of emerging infectious diseases such as COVID-19 has a link to unsustainable use of the environment.

3. Pollutants and their relationship to COVID-19

Pollutants such as persistent organic pollutants (polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), organochlorines, organophosphates, carbamates, dioxins), heavy metals, methylmercury, and endocrine disrupters have increased their concentrations and widened their presence in the environment due to anthropogenic activities (intensive industrial activities and population increase). These chemicals pollutants are widely disseminated worldwide, and can be found in water, air, soil, vegetation, and animals (Hill, 2020). Their main route of exposure in animals and humans is through diet (Thompson and Darwish, 2019). They produce many biological effects on wildlife and humans, including immunological, mutagenic, and reproductive alterations (Yu et al., 2011). A continuous increase in chronic and infectious diseases associated with contaminant exposure has been observed in recent decades (DeSantis et al., 2019; Dimakakou et al., 2018; Liu et al., 2019). A relationship between pollutants and viral diseases (such as COVID-19) was recently reported (Tsatsakis et al., 2020). They found that these chemical stressors share some action mechanisms capable to alter Toll-like receptors, growth factors, cytokine receptors, and B cell receptors. Similarly, both can affect the metabolism of $Ca2+$, $K+$, $Cl-$, and vitamin D, and both affect inflammatory processes and disrupt redox biology (increasing reactive oxygen species and oxidative stress). This is an important finding, because pollutants can depress the immune system of animals and thus might increase the impacts of pathogens, such as the current global coronary disease (COVID-19).

The main effects of COVID-19 on human health are related to respiratory problems (Xu et al., 2020b). The respiratory system can also be affected by air pollution, mainly by fine particulate matter (PM2.5, PM10) produced by diesel engine combustion, coal and wood burning, and industrial emissions (Garcia-Chevesich et al., 2014). This fine particulate matter can obstruct the airways, exacerbating the effects of COVID-19. In addition, fine particulate matter contains organic pollutants, heavy metals, dust, and pollen that can disrupt immune

responses (Tsatsakis et al., 2020). Particulate matter can interfere with LL37 (a peptide involved in innate immune response) and may reduce effective immunity of the organism (Crane-Godreau et al., 2020). Some research has correlated fine particulate matter (PM2.5, PM10) with confirmed cases of deaths due to COVID-19 (Table 1).

In a study covering 98% of the United States population, Wu et al. (2020a, Table 1) considered more than 20 different factors that may influence deaths, among which were individual conditions (obesity, smoking, age), epidemiological (time of onset of outbreak and time in which confinement was decreed), population (size, density), socioeconomic (hospital beds), and climate. They found a strong relationship between PM2.5 and death risk from COVID-19. Similar findings were reported regarding China (Pansini and Fornacca, 2020; Xu et al., 2020a; Yao et al., 2020; Yongjian et al., 2020; Zhang et al., 2020), Italy (Fattorini and Regoli, 2020; Filippini et al., 2020; Zoran et al., 2020), England (Travaglio et al., 2020), Netherlands (Andree, 2020), France (Magazzino and Schneider, 2020), Malaysia (Suhaimi et al., 2020), Germany (Ogen, 2020), and India (Saha et al., 2020). The study conducted by Saha et al. (2020) also reported that areas with better air quality showed a larger number of COVID-19 recoveries. Concerns have been raised regarding an association of indoor air pollution with susceptibility to COVID-19, mainly in geographical areas where wood or coal is still used for cooking and heating (Mbandi, 2020; Sharma and Hossain, 2020).

All available research so far show a positive correlation between air pollution (PM2.5) and COVID-19. Moreover, a recent study showed that fine particulate matter (PM2.5) is a carrier of SARS-CoV-2, indicated by the presence of viral RNA (Setti et al., 2020), although more research is needed on this matter. The evidence indicates that particulate matter appears to play a key role in the incidence and severity of cases of COVID-19, because it acts as a carrier of viruses, influences lung obstruction, and produces immunological effects by chemicals associated with it. The underlying question here is whether multiple pollutants carried simultaneously on particulate matter act in an additive, synergistic way to increase the severity of COVID-19-like diseases.

4. Environmental factors and the spread of SARS-CoV-2

The main form of SARS-CoV-2 transmission that has been identified is person-to-person, which occurs by touching infected surfaces and then touching the mouth, nose, or eyes (Peng et al., 2020). However, virus transmission probably also occurs through inhaling respiratory droplets exhaled by animals and humans (Qu et al., 2020). The influence of environmental factors on SARS-CoV-2 transmission has been examined. Chin et al. (2020) reported that SARS-CoV-2 viruses can survive for a long time at temperatures between -2 and $4\,°C$, while they can survive only 5 min at $70\,°C$. They are also stable at ambient temperature at a pH range of 3–10 (Chin et al., 2020).

The relationships between confirmed cases or deaths by COVID-19 and environmental factors has been studied in Europe, Middle East, and Asia (mainly China, Table 2). Temperature appears to be the environmental factor most related to COVID-19 spreading. However, those recent results should be weighed with caution. A study performed in several locations of China found that environmental factors by themselves could not explain variations in those cases of confirmed COVID-19 (Poirier et al., 2020). Interestingly, environmental variables have been found to be crucial just in the initial phase of the COVID-19 infection, during which time the dynamics of transmission are more affected by airborne viral infectivity rather than human-to-human transmission (Coccia, 2020). Other studies from Indonesia (Tosepu et al., 2020), USA (Bashir et al., 2020b), Spain (Briz-Redón and Serrano-Aroca, 2020), Iraq (Amin and Amin, 2020), Singapore (Pani et al., 2020), Chile (Correa-Araneda et al., 2020), Mexico (Méndez-Arriaga, 2020), Brazil (Prata et al., 2020), Germany (Biktasheva, 2020), Turkey (Şahin, 2020), Norway (Menebo, 2020), Ghana (Iddrisu et al., 2020), Iran (Ahmadi et al., 2020) and Japan (Hirata et al., 2020) support this finding.

Although SARS-CoV-2 RNA has been detected in the air (Liu et al., 2020c), the way environmental factors may affect COVID-19 transmission is not well established. It is necessary to assess whether environmental factors really have a cause-and-effect relationship for infection cases or deaths by COVID-19. The spread of SARS-CoV-2 is very complex, because the factors involved, including climatic factors, are very heterogeneous

Table 1
Air pollution variation due to COVID-19 lockdown measures in different countries.

Author	Country	Area covered	Environmental pollution	Conclusions
Wu et al., 2020a	USA	3000 cities	PM2.5	An increase of 1 μg/m^3 of PM2.5 explained an 8% increase of COVID-19 mortality rate
Bashir et al., 2020a	USA	California	PM2.5, PM10, SO$_2$, NO$_2$, Pb, VOC and CO	PM2.5, PM10, SO$_2$, NO$_2$, and CO have a significant correlation with COVID-19
Yongjian et al., 2020	China	120 cities	PM2.5, PM10, NO$_2$ and O$_3$	Confirmed cases increase by 2.24%, 1.76%, 6.94% and 4.76%, respectively
Yao et al., 2020	China	49 cities	PM2.5 and PM10	PM2.5 and PM10 increased 0.24% and 0.26% the case fatality of COVID-19, respectively
Zhang et al., 2020	China	219 cities	Air quality index	Air pollution has exerted a positive impact on the transmission and infection by COVID-19
Xu et al., 2020a	China	33 locations	Air quality index (AQI)	There is a direct correlation between AQI and confirmed COVID-19 cases
Fattorini and Regoli, 2020	Italy	71 provinces	NO$_2$, O$_3$, PM2.5 and PM10	Significant correlation between poor air quality and COVID-19 cases
Zoran et al., 2020	Italy	Milan	PM2.5 and PM10	New COVID-19 cases have positively correlated with PM2.5 and PM10
Filippini et al., 2020	Italy	28 provinces of Northern Italy	NO$_2$	High NO$_2$ levels were associated with COVID-19 spread
Saha et al., 2020	India	25 cities	PM2.5, PM10, NO$_2$, SO$_2$, CO, and O$_3$	Significant correlation between poor air quality and COVID-19 deaths
Pansini and Fornacca, 2020	China, Italy and USA	Countrywide	PM2.5, PM10, O$_3$, NO$_2$, SO$_2$ and CO	Significant correlation between air quality and COVID-19 spread and mortality
Travaglio et al., 2020	England	Countrywide	O$_3$, NO and NO$_2$	Ozone, nitrogen oxide and nitrogen dioxide are significantly associated with COVID-19 deaths
Andree, 2020	Netherlands	355 municipalities	PM2.5 and PM10	PM2.5 can be a significant predictor of the number of confirmed COVID-19 cases
Magazzino and Schneider, 2020	French	Paris, Lyon, and Marseille	PM2.5 and PM10	Suggests that there are certain conditions that increase the likelihood of the spread and aggravation of the disease
Suhaimi et al., 2020	Malaysia	Kuala Lumpur	PM2.5, PM10, SO$_2$, NO$_2$, CO and O$_3$	Air pollutant influenced the incidence of COVID-19 cases
Ogen, 2020	Italy, Spain, France and Germany	66 administrative regions	NO$_2$	The long-term exposure to nitrogen dioxide may contribute to fatality caused by COVID-19

Table 2
Environmental factors linked to COVID-19 cases, and associated deaths.

Climate parameters	Country	Conclusions	Authors
Temperature	Worldwide	COVID-19 fast-spreading has an association with average high and low temperatures	Iqbal et al., 2020a
	166 countries	Temperature was negatively correlated with daily new cases and deaths by COVID-19	Wu et al., 2020b
	China	At low temperatures, a raise of 1 °C increased the number of COVID-19 confirmed cases by a rate of 0.83, while at higher temperatures each 1 °C increase reduced the number of confirmed cases by a rate of 0.86	Wang et al., 2020a
	China	Low temperature and mild daytime temperature range promote SARS-CoV-2 transmission	Liu et al., 2020b
	China	An increase of 1 °C decreases between 36% and 57% COVID-19 infested cases	Qi et al., 2020
	China	An increase of 1 °C increased COVID −19 deaths by 2.92%	Ma et al., 2020
	China	Temperature played no role on COVID-19 at Wuhan (China)	Iqbal et al., 2020b
	China	Positive relationship (Hubei, Hunan and Anhui provinces) and negative relationship (Zhejiang and Shandong provinces) between temperature and COVID-19	Shahzad et al., 2020
	China	The incidence of COVID-19 decreased with an increase of temperature	Shi et al., 2020
	China	Ambient temperature has a significantly negative effect on COVID-19 transmission	Zhang et al., 2020
	China and Italy	Moderate relationship with COVID-19 confirmed cases	Bhattacharjee, 2020
	USA	Average and minimum temperatures have significant correlation with COVID-19 at New York City.	Bashir et al., 2020
	Indonesia	Temperature average was significantly correlated with COVID-19	Tosepu et al., 2020
	Spain	No correlation between COVID-19 cases and temperature was found	Briz-Redón and Serrano-Aroca, 2020
	Iraq	Low temperatures might enhance COVID-19 infection risk	Amin and Amin, 2020
	Singapore	Temperature showed positive significant associations with SARS-CoV-2 transmission	Pani et al., 2020
	Chile	Lower temperature can favor COVID-19 transmission speed	Correa-Araneda et al., 2020
	Mexico	Temperature associates negatively with the local confirmed COVID-19 cases	Méndez-Arriaga, 2020
	Brazil	1 °C rise was associated with a 4.9% decrease in the number of daily cumulative COVID-19 confirmed cases	Prata et al., 2020
	Turkey	Temperature have high impacts on COVID-19 cases	Şahin, 2020
	Italy	Warm season promotes COVID-19 spreading	Zoran et al., 2020
	Norway	Maximum and normal temperature are positively associated with COVID-19	Menebo, 2020
	Ghana	Maximum temperature significantly predict COVID-19 new cases	Iddrisu et al., 2020
Humidity	166 countries	Relative humidity was negatively related to daily new cases and deaths by COVID-19	Wu et al., 2020b
	China and Italy	No relationship between humidity and COVID-19 confirmed cases	Bhattacharjee, 2020
	China	1% increase in relative humidity decreased 11–22% COVID-19 infected cases	Qi et al., 2020
	China	Relative humidity is negatively associated with COVID-19 daily deaths	Ma et al., 2020
	China	Low humidity promotes the transmission of SARS-CoV-2	Liu et al., 2020b
	Iraq	Increased relative humidity might enhance virus infection risk	Amin and Amin, 2020
	Singapore	Humidity showed positive significant associations with SARS-CoV-2 transmission	Pani et al., 2020
	Japan	The absolute humidity affected SARS-CoV-2 spread duration	Hirata et al., 2020
	Chile	Lower humidity can favor coronavirus transmission speed	Correa-Araneda et al., 2020
	Germany	Lower humidity increased Covid-19 mortality	Biktasheva, 2020
	Italy	Dry air supports COVID-19 transmission	Zoran et al., 2020
	Norway	Precipitation are negatively associated with COVID-19	Menebo, 2020
	Ghana	Relative humidity was significantly associated with daily new cases and new deaths of COVID-19	Iddrisu et al., 2020
	Iran	Low humidity associated with high SARS-CoV-2 infection rate	Ahmadi et al., 2020
Wind	China and Italy	No relationship between wind and COVID-19 confirmed cases	Bhattacharjee, 2020
	Chile	Higher wind speed can favor a higher disease transmission speed	Correa-Araneda et al., 2020
	Turkey	Wind speed have high impacts on COVID-19 cases	Şahin, 2020
	Iran	Low wind speed associated with high rate of infection of SARS-CoV-2	Ahmadi et al., 2020

and dynamic, even confining observations to a single city during daylight hours. This heterogeneity of climatic factors generates dynamic scenarios that influences the number of confirmed cases (Sarkodie and Owusu, 2020b). This dynamic in the factors involved and the political decisions taken to address them (e.g. as effective containment, Asamoah et al., 2020) influence on environmental health and economic systems in the different countries (Sarkodie and Owusu, 2020a).

5. Indirect impact of COVID-19 on the environment

There is evidence for an indirect effect (negative/positive) of COVID-19 on environmental outcomes, mainly related to preventive confinement measures on the population imposed worldwide by various authorities (Fig. 1, Braga et al., 2020, Corlett et al., 2020, Saadat et al., 2020, Zambrano-Monserrate et al., 2020).

5.1. Indirect impact on air quality

The worldwide COVID-19 pandemic has caused various positive impacts on the environment and the climate (Sarkodie and Owusu, 2020a). A global daily CO_2 emission decrease about 17% has been estimated, reaching CO_2 emission levels similar to those in 2006 (Le Quéré et al., 2020). In China, the reduction in the use of coal (50%) and oil (20–30%) caused a 25% CO_2 decrease, equivalent to 6% of global emissions (Myllyvirta, 2020). Ten cities in China exhibited a 20% decrease of PM2.5 (Wang et al., 2020b). In Kazakhstan, a reduction of CO (49%) and NO_2 (35%) was found (Kerimray et al., 2020), whereas a 50% and 62% reduction of NO_2 concentrations was reported from Barcelona and Madrid, respectively (Baldasano, 2020). Also, a significant reduction of NO_2 was noted in Turkey (Kaplan and Avdan, 2020). In USA, NO_2 declined around 25% during the COVID-19 pandemic as compared to 2017–2019 levels (Berman and Ebisu, 2020). In Brazil, a decrease of CO (64.8%), NO (77.3%), NO_2 (54.3%) was found in São Paulo (Nakada and Urban, 2020), and significant reductions of CO and NO_2 in Rio de Janeiro (Dantas et al., 2020). In Morocco, a 5% decrease of PM10, 49% of SO_2, and 96% of NO_2 were reported (Otmani et al., 2020). Other studies have indicated a PM2.5 decrease in Asian (India, China) and European (Spain, France, and Italy) countries (Gautam, 2020). Prior to the COVID-19 pandemic, greenhouse gases raised average global temperatures, causing melting of glaciers and rising sea levels. The reduction of economic activities during this pandemic has temporary
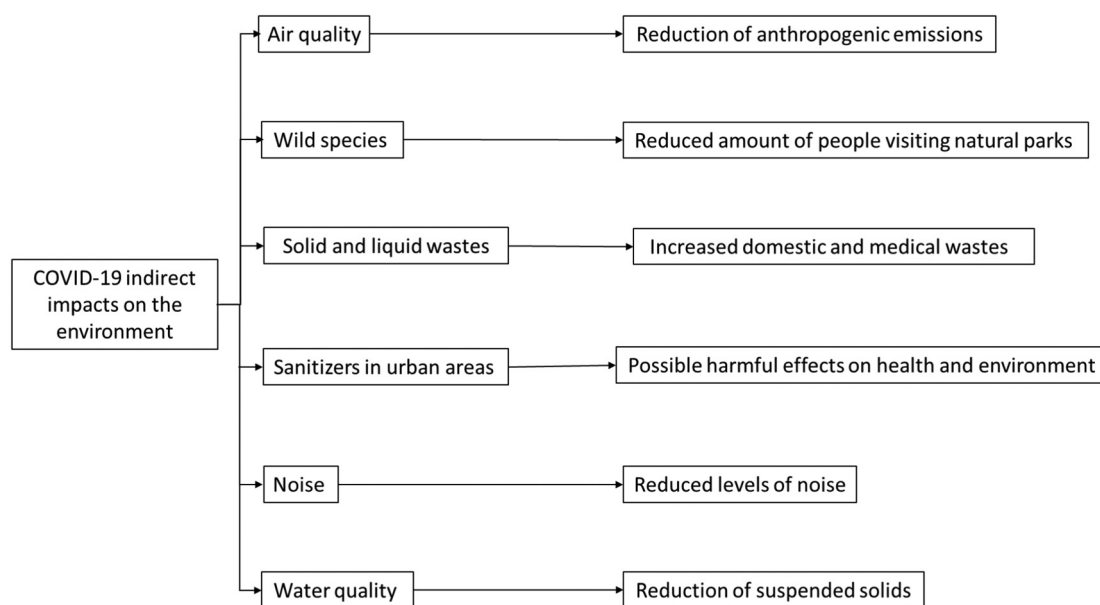
Fig. 1. Schematic representation of COVID-19 indirect impacts on the environment.

stopped global warming as well as air and marine pollution, allowing the environment slowly flourish (Sarkodie and Owusu, 2020a). Another positive impact is the environmental protection through the European Union's seven-year recovery plan called "Next Generation EU", which seeks to reserve 25% of EU spending for climate-friendly expenditures (Jones et al., 2020). However, these partial improvements are unlikely to mitigate pollution in the long term. Adverse weather conditions (low wind, high humidity, and a greater number of foggy days) may stop the reduction of air pollution and thus have a significant impact (Wang et al., 2020b). Some locations in the Southern Hemisphere use mostly wood for heating during the cold season or for daily cooking (Sanhueza et al., 2009). The use of wood for heating, along with other commonly used fossil fuel, probably increases outdoor and/or indoor air pollution, which is worrisome considering that air pollution is associated with COVID-19 (Setti et al., 2020; Wu et al., 2020b).

5.2. Indirect impact on wildlife species

Restriction measures during this pandemic have notably reduced the number of people visiting natural parks, thus diminishing stress on wild fauna (Corlett et al., 2020). Wild animals have been returning towards suburban areas from which they previously fled because of the human presence (Corlett et al., 2020). On the other hand, some countries are allowing tourists to visit protected areas as a measure for reducing the stress generated by the pandemic (Corlett et al., 2020). Hence, it will be crucial to have regulations for protecting wildlife, as more visitors may increase stress and pollution within protected areas. In light of these observations, it is expected that most countries will develop strict protocols concerning X before confinement orders are lifted.

5.3. Indirect impact on solid and liquid waste

During the recent periods of confinement, people have stopped attending entertainment and recreation areas (parks, beaches, ski centers, music concerts, among others). Consequently, waste in public places and natural and urban areas has been reduced (Zambrano-Monserrate et al., 2020). People are expected to return to social recreation activities after confinement, probably causing a dramatic increase of waste in public places.

Now, domestic and hospital waste has increased due to the difficulty of satisfactory solid and liquid waste management (Platon et al., 2020). In the case of domestic waste, food delivery containers have notoriously increased in number. Some countries have suspended their recycling to reduce possible virus infection and protect workers (Zambrano-Monserrate et al., 2020). Only a part of the plastic waste is being recycled, while the rest goes to landfills or is thrown into the environment (Klemeš et al., 2020). In Wuhan (China), clinical waste increased four times, reaching 200 tons per day (Saadat et al., 2020). To prevent the possible spread of the virus, hospitals have stopped recycling glass-made medical materials, although they may be biologically harmless to workers.

Hospital wastewater usually contains high levels of drugs, and one would expect that their concentrations and diversity has increased during the COVID-19 pandemic due to a higher demand by patients (Escher et al., 2011; Jelic et al., 2011; Ort et al., 2010). Hydroxychloroquine and chloroquine are some of the drugs that have been used to treat COVID-19 (Liu et al., 2020a). These drugs have been described as persistent, bioaccumulative, and dangerous to aquatic organisms (Ramesh et al., 2018), and they are considered emerging pollutants (Daughton, 2014; Zurita et al., 2005). This is highly relevant since it is known that wastewater treatment systems do not have adequate processes for treatment these drugs, which will enter into freshwater ecosystems (Ashfaq et al., 2017).

As of July 2020, there are more than 15 million confirmed COVID-19 cases around the world, and an unknown number of negative cases (Dong et al., 2020). Confirmation has generally taken place in diagnostic laboratories. Those laboratories usually use disposable supplies, generating large amounts of plastics and chemicals that pollute soil and water (Corman et al., 2020). Most personal prevention equipment, such as reusable masks and disinfectant containers, contain plastic (Das et al., 2020; Fadare and Okoffo, 2020; Saadat et al., 2020). Devices that are used as physical barriers to control people near restricted areas are made of methacrylate (a transparent, flexible and resistant plastic material), which comes from propylene (an oil derivative). When ending their useful life, those products reach landfills or the environment. In Asian countries, an increase of disposable masks and gloves has been reported on beaches (Saadat et al., 2020) and the sea floor (CNN, 2020). Along with plastic waste, disposable masks can reach land and aquatic systems, where animals may become entangled or eat them by mistake (Sigler, 2014; Vegter et al., 2014). Recent evidence has shown that

microplastics can reach remote regions of the planet, and also end up in our bodies through food intake and breathing (Allen et al., 2020).

The incineration of contaminated medical wastes is a source of pollution as well, which can have a significant impact on Public health (Tait et al., 2020; Walker and Cooper, 1992). The use of this technique to eliminate coronavirus may have indirect health consequences over time.

5.4. Other indirect impact

The use of sanitizers in public environments has been a practice employed by some countries during the pandemic (Atolani et al., 2020). For example, triclosan is a universal antimicrobial used in drugs and personal care products, as well as growth promoting antibiotics in food animal production (Daughton and Ternes, 1999). Therefore, triclosan is classified as an emerging contaminant (Wang et al., 2018). Excessive use of this and other sanitizers can have harmful effects on health and environment.

Confinement has also led to a reduction of noise, mainly due to the reduction of traffic congestion, airflights, and commercial activities (Zambrano-Monserrate et al., 2020). Noise reduction might help birds, as noise has been shown to have negative effects on physiology, nesting, and reproduction of birds in urban areas (Zollinger et al., 2019).

In addition, water quality improvement has been reported in Venice (Italy), where clear waters were observed due to the reduction of suspended solids, because of lesser use of motorboats (Braga et al., 2020).

Considering all of the above, it is expected that when the confinement around the planet is finally over, all anthropogenic activities will return to their pre-pandemic state, and the present reduction of human impacts will no longer prevail on Earth (McCloskey and Heymann, 2020). On the contrary, plastics and drugs in wastewater produced during this pandemic by COVID-19 will persist longer, particularly those are not biodegradable.

6. Recommendations for future epidemic threats

Certainly, people's confinement has limited the possibilities for data collection concerning the relationship between indoor air quality parameters and human health status. Based on technological advances, we believe that "smart care", "smart home", and "health monitoring gadget" can be powerful allies to collect data remotely. Data standardization and the accessibility of data from any platforms should help smart technology to be valuable in the event of a pandemic (Allam and Jones, 2020).

There are key lessons that can be learned from COVID-19, which relate to the need to be prepared and environmentally responsible. Following them will help control future pandemics. The "one health" approach, which integrates environmental science, veterinary science, and health science research, should be pivotal (Bonilla-Aldana et al., 2020). Having good interaction between these areas might guarantee quick and timely feedback in case of future epidemic episodes. In addition, researchers, medical personnel and social leaders need to work together to design strategies based on environmental and socio-economic terms, and not only on health sciences. This pandemic provides an opportunity to remember that human beings are linked to a healthy environment, especially in countries that are highly dependent on their natural resources.

In order to prevent any future pandemics, proper environmental management to avoid the transmission of viruses from wild species to humans will be required (Zohdy et al., 2019). More studies on wildlife virology and wildlife immunology should be carried out to identify potential pathogens and how wild animals cope with them.

Urban management is vital and must be taken into consideration when designing cities. Urban land-use planning must give more emphasis to the positive benefits that ecosystem services provide so that they can help to reduce infection and disease. The megacities model must be reformulated. Fortunately, technological advances allow us to carry out activities remotely, which helps us to interact despite distance. Small village models should be considered, thus decreasing population density and helping to avoid saturating an ecosystem, giving it the possibility to cope with low atmospheric emissions. Governments should enforce environmental and sustainable policies based on the use of green energies in order to reduce air pollution. In the end, public health will benefit from a natural environment, with all that this entails.

Chemical management should be integrated, not only motivated by the direct adverse effects that a pollutant individually may have on wildlife and human health but also the synergistic effects as a whole associated with infectious agents. The environmental impacts that this pandemic will bring are of global scope (Saadat et al., 2020), and the attention the pandemic has commanded should be redirected towards controlling anthropogenic pollution, towards improvements in waste management during periods of extreme confinement, and towards confronting increases in medical waste. The potential rebound of pollutant emissions may be generated after confinement as an attempt to revive the global economy is worrisome (Sarkodie and Owusu, 2020a). On the other hand, massive amounts of domestic and hospital waste have been generated during this pandemic, mostly plastics; this increase might hinder actions currently ongoing to reduce plastic usage and it is dumping into the environment. Initiatives to seek alternatives to plastic for routine domestic and medical tasks should be encouraged. It is necessary to establish preventive epidemiological models (e.g., monitoring of domestic wastewater) to detect the occurrence of COVID-19 in advance. Wastewater plants should include effective treatments for dealing with a high concentration of drugs. All these actions could help to design protocols according to environmentally sustainable practices for facing a pandemic in the future.

CRediT authorship contribution statement

Winfred Espejo: Conceptualization, Investigation, Resources, Writing - original draft. **José E. Celis:** Writing - original draft. **Gustavo Chiang:** Writing - review & editing. **Paulina Bahamonde:** Investigation, Resources, 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

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