



REVIEW

COVID-19 and environment: a poignant reminder of sustainability in the new normal

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Abstract

The nexus of COVID-19 and environment is conspicuously deep-rooted. The roles of environmental factors in the origin, transmission and spread of COVID-19 and the mutual impact of the pandemic on the global environment have been the two perspectives to view this nexus. The present paper attempts to systematically review the existing literature to understand and explore the linkages of COVID-19 with environment and proposes conceptual frameworks to underline this nexus. Our study indicates a critical role of meteorological factors, ambient air pollutants and wastewater in severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission-spread dynamics. The study also focuses on the direct and indirect impacts of COVID-19 on the regional and global environment. Most of the indirect environmental effects of COVID-19 were attributed to global human confinement that resulted from the implementation of the pandemic containment measures. This worldwide anthropogenic ‘pause’ sent ripples to all environmental compartments and presented a unique test bed to identify anthropogenic impacts on the earth’s natural systems. The review further addresses emerging sustainability challenges in the new normal and their potential solutions. The situation warrants critical attention to the environment-COVID-19 nexus and innovative sustainable practices to address the ramifications of short- and long-term environmental impacts of the COVID-19 pandemic.

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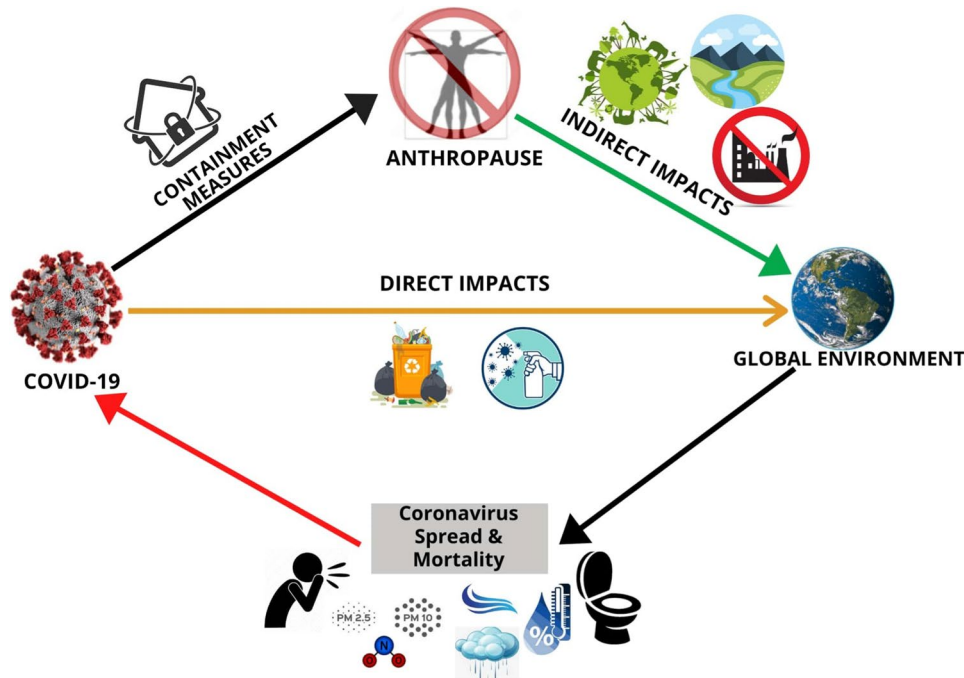
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Graphical abstract



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Introduction

Infectious diseases have been known to exist since humans lived as foragers. Though, it was only after the shift to agrarian lifestyle some eleven thousand years ago, that the magnitude and spread of these diseases increased significantly (Dobson and Carper 1996, Wolfe et al., 2007). The threat of infectious disease outbreaks has been looming over the human civilization with epidemics and pandemics erupting and fading at regular intervals ever since. A pandemic is an epidemic with worldwide occurrence, spread over a vast geographical area, crossing international boundaries and affecting human populations globally (Feinleib 2001). As humans grew more civilized with proliferating urban areas, expanding global transport networks and increased contact with different populations, the probability of disease outbreaks amplifying into a pandemic increased concurrently (Tatem et al. 2006, Brockmann 2017). In the domain of infectious diseases, pandemics present worst case scenarios claiming millions of human lives, plummeting economies, and resulting in large scale socio-economic impacts. Some of the major outbreaks in the recent past include the Spanish Flu (1918), Mexican Smallpox (1967), Acquired Immune Deficiency Syndrome, AIDS (1980s), SARS (2002/03), Bird Flu (2005), Swine Flu (2009/10), Middle East respiratory syndrome-MERS

(2012), Avian influenza (2003–2019), Ebola (2014) and Nipah virus (1998–2018).

COVID-19

During the late November of 2019, a series of pneumonia like cases with inexplicable reasons appeared in Wuhan city situated in the Hubei province of China. Deep sequencing analysis performed on the lower respiratory tract samples suggested the presence of a novel coronavirus (Huang et al. 2020; Wu et al. 2020) which was named initially as the 2019 novel coronavirus (2019-nCoV) on 12 January 2020 by World Health Organization (WHO). On 11th February 2020, WHO officially named the disease as the coronavirus disease 2019 (COVID-19) and the International Committee on Taxonomy of Viruses (ICTV) named the causal virus as SARS-CoV-2. The SARS-CoV-2 is a type of β -coronavirus which was found to be like SARS-CoV-1 and MERS-CoV, responsible for the pandemics of 2003 and 2012 respectively. Coronaviruses belong to a large and diverse viral family of Coronaviridae and are known to have the potential to infect humans and animals. Coronaviruses are divided into four genera viz. alpha (α), beta (β), gamma (γ) and delta (δ). The SARS-CoV-2 which is contagious to humans, is a type of β -coronavirus, enveloped and with a

non-segmented positive-sense single-stranded ribonucleic acid (RNA). SARS-CoV-2 has 96% of its whole-genome similarity with a Bat-CoV, reported from *Rhinolophus affinis* (an intermediate horseshoe bat) sampled from Yunnan Province (Zhou et al. 2020), thereby suggesting its zoonotic origin. However, the exact source and location of origin of SARS-CoV-2 remains unclear. The source of infections for most of the initial cases were found to be linked to a seafood market in Wuhan, though bats were not available for sale therein (Zhou et al. 2020).

The disease quickly spread out from Wuhan, engulfing several countries, and increasing death tolls. Taking cognizance of the burgeoning cases of the coronavirus illness in various countries and the sustained risk of further global spread, the WHO on 11th March 2020, declared COVID-19 a pandemic.

SARS-CoV-2 was observed to be transmitted between humans by direct, indirect, or close contact with infected people. Transmission occurred through infected individuals by their secretions such as saliva, respiratory secretions or respiratory droplets which are propelled by talking, coughing, or sneezing (WHO 2020a; Gorbalenya 2020; Wang and Du 2020; Stadnytskyya et al. 2020). The heavier droplets usually descend on the ground or other environmental surfaces and were not reported to travel through air over long distances. However, smaller droplets remain suspended in air columns for lengthier time periods and exhibited potential for SARS-CoV-2 transmission (Morawska and Cao 2020; Galbada et al. 2020; Jayaweera et al. 2020; Samet et al. 2021; Chirizzi et al. 2021). Recently, WHO acknowledged the ‘evidence emerging of airborne spread of coronavirus’ (WHO 2020a; Wilson et al. 2020). Common symptoms of coronavirus infection are fever, dry cough, fatigue, breathing difficulties and change in chemosensory modalities such as taste and smell (Gane et al. 2020). Pneumonia and acute respiratory distress syndrome are the further complications that might occur (Matthay et al. 2020). Preventive measures recommended for COVID-19 include wearing a face mask in public settings, hand washing and sanitizer use, maintaining social distancing, disinfecting environmental surfaces, increasing ventilation, enhancing indoor air filtration and isolating individuals suspected of infection (Mahmood et al. 2020; Thu et al. 2020; Golin et al. 2020; Velavan and Meyer 2020; Hu et al. 2020).

The environment-pandemic nexus

Environment, social and demographic factors along with globalization and health system capacities are established drivers of emerging infectious diseases (Semenza et al. 2013; Suk and Semenza 2011; Arthur et al. 2017). Amongst these determinants the role of environment-epidemic nexus in the

emergence and spread of infectious diseases has increasingly been acknowledged (Patz et al. 2003; Metcalf et al. 2017). Distal (viz. deforestation, climate change) and proximal (viz. Air temperature, humidity, faecal contamination) environmental characteristics and associated changes are known to impact transmission dynamics of infectious pathogens (Eisenberg et al. 2007; Schneider and Machado 2018). The present linkages of environment and COVID-19 with respect to disease emergence spread and impacts are evident as well, with its ramifications affecting several environmental compartments. A conceptual framework to explore the COVID-19 and environment nexus has been presented in Fig. 1. Several epidemiological investigations in the transmission mechanism of SARS-CoV-2 have already shed light on its spread primarily through the atmospheric compartments. Meteorological factors of the atmosphere such as air temperature, humidity, precipitation were reported to play a key role in COVID-19 transmission (Jahangiri et al. 2020; Zhang et al. 2020). Additionally, associations of ambient air pollutants with COVID-19 spread and related mortality was observed in several studies (Ogen 2020; van Doremalen et al. 2020). Particulate matter in particular was reported to be an aid to the airborne transmission of SARS-CoV-2 (Setti et al. 2020; Cai et al. 2020). Apart from several reports of SARS-CoV-2 transmission via the atmospheric compartment, an alternative route of its spread was speculated through wastewater (Ahmed et al. 2020). With the detection of SARS-CoV-2 RNA in excreta specimens, such as faeces and anal/rectal swabs (Gu et al. 2020; Song et al. 2020; Gao et al. 2020) and subsequently in wastewater (Ahmed et al. 2020; Lodder and de Roda Husman 2020), there was an increased concern to better understand wastewater as potential sources of transmission and associated human health risks (Gormley et al. 2020).

While the environmental determinants mediated the transmission dynamics of SARS-CoV-2, the pandemic of COVID-19 presented mutual environmental impacts via reduced modern human activity. As we advance in the Anthropocene with increasing human alterations as drivers for global environmental change (Lewis and Maslin 2015; Nava et al. 2017), a wide range of impacts are anticipated upon the infectious diseases in human populations via the interplay of pathogens, host and environment (Jones et al. 2008; Engering et al. 2013). In view of the profound influence of the ongoing human activity on the global environment, it is also implied that any large-scale impact on modern human activities will send ripples in all the environmental compartments. The COVID-19 associated widespread human confinement had many short as well as long term indirect effects on the global environment. The pandemic has impacted the humankind with such an enormity that probably has no parallel in the recent past; the most challenging crisis since the Second World War (UN 2020).

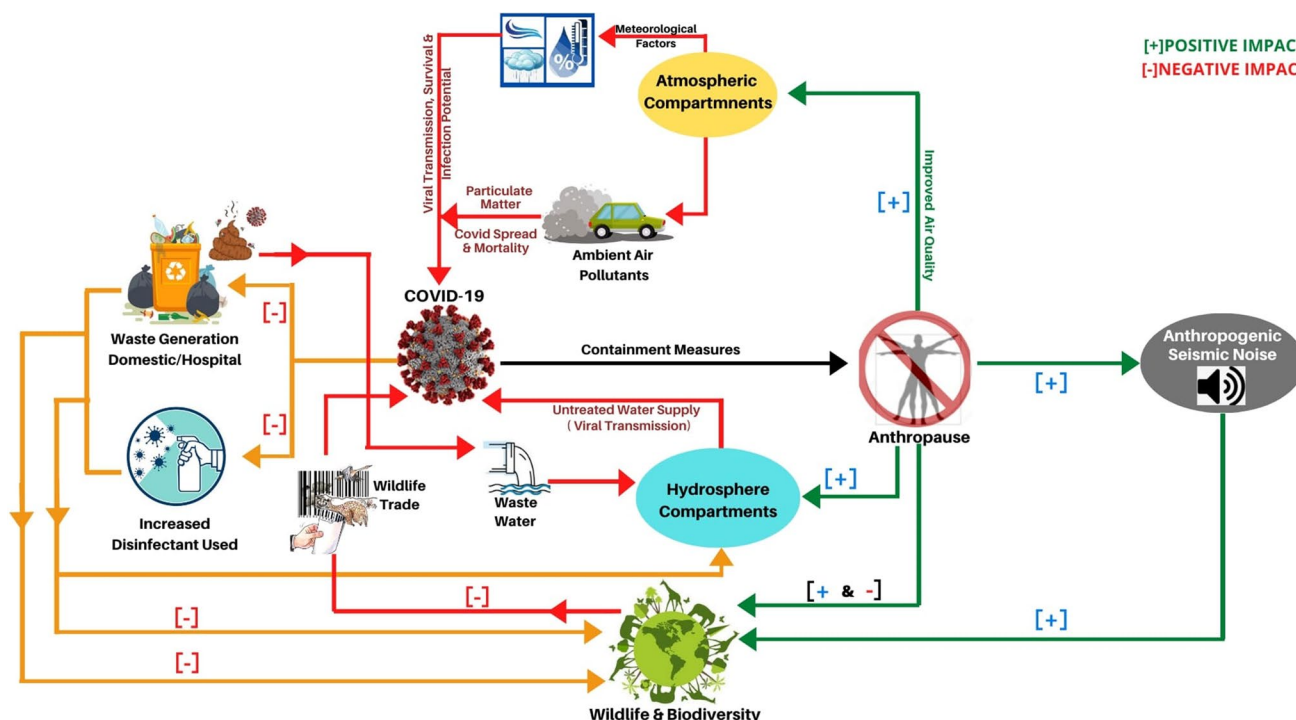


Fig. 1 A conceptual framework for the COVID19 and Environment nexus. Yellow lines indicate direct impacts of Covid-19 pandemic on the environment. Green lines indicate indirect impacts of Covid-19 pandemic on the environment. Red lines indicate transmission/origin

of SARS-CoV-2 via environmental compartments. [+] sign indicates positive impact on environment. [-] sign indicates negative impact on environment

Although, the effects of the pandemic outbreaks on public health, society and economy have been frequently discussed (Huremović 2019), their larger, long lasting, unforeseen and strong impacts on environment have so far been neglected. The environmental perspectives of COVID-19 pandemic, though, has received significant scientific attention as is evident from several peer-reviewed and preprint publications in a brief period of time (Chakraborty and Maity 2020; Muhammad et al. 2020a,b; Paital 2020; Saadat et al. 2020; Shakil et al. 2020; Zambrano-Monserrate et al. 2020; Nature Index 2020). The COVID-19 pandemic brought the world to a standstill with countries implementing strict lockdowns, travel bans and several other restrictions. This initial period witnessed unusual global slowdown of modern human activities, notably travel and was aptly referred to as anthropause (Rutz et al. 2020). The ‘anthropause’ set up the stage for a natural experiment where researchers and scientist could disentangle the anthropogenic impacts from their naturogenic analogues. Dramatic environmental alterations were reported throughout the world in a brief period of time. Ancient populations restricted to their homes, tiding over the pandemics of the distant past might not have been a witness to such an immediate environmental impact. Since the record of the pandemic history, such an opportunity, though poignant, has perhaps never been presented before.

The environment-pandemic nexus: lessons from the past

The role of environmental determinants such as climate, temperature, humidity in the transmission and pathogen dynamics of epidemics and pandemics in the near and distant pasts have been widely discussed (Stenseth et al. 2006; Schmid et al. 2015; Xu et al. 2019; Tennant et al. 2020). In comparison, studies pertaining to the impact of pandemics on environment are scarce, though few investigations have unravelled these aspects of the past pandemics as well. The series of bubonic plagues (1499–1720 AD) for example, have been known to leave their signatures on the global environment. Ruddiman (2003) observed correlations between plague pandemics and decreased carbon dioxide (CO₂) concentrations from reconstructed ice cores. These correlations were attributed to mass human deaths which caused widespread abandonment of farms and rural villages. As new forests started to reclaim abandoned farmlands, they sequestered huge amounts of carbon leading to significant decrease in carbon dioxide (CO₂) concentrations of the atmosphere. On the contrary, coupled climate–carbon simulation studies have indicated minor global impacts of pandemics on atmospheric CO₂ between 800–1850 AD (Pongratz et al. 2011).

Studies pertaining to quantitative estimates of environmental impacts of epidemics and pandemics of the recent past such as the Spanish Flu, SARS, and MERS are scanty. This could be attributed to the fact that most of the past outbreaks, but for Spanish Flu, did not escalate to the scale of COVID-19 pandemic, had more regional than global impacts, and thereby attracted less scientific attention with respect to their environmental perspectives. The Spanish Flu of 1918 which caused nearly 50 million deaths worldwide was a pandemic in true sense, comparable in enormity to the present pandemic humanity is going through (Johnson and Mueller 2002). Emerging transportation networks, which are established drivers of infectious diseases spread (Khan et al. 2009; Nakata and Röst 2015), seem to have played a pivotal role in the quick spread of Spanish Flu. The invention of airplanes in 1903 and their widespread use as military aircraft during the World War I (1914–1918) was perhaps the major cause of the rapid spread of Spanish Flu to several countries in a brief period of time. However, the pandemic of Spanish Flu and associated global impacts failed to attract required scientific attention probably due to the scientific and technological constraints, economic breakdown followed by global depression and the overarching effects of the World War I during that era (Clay et al. 2018). While the scale of impact of past pandemics on the then global environment is debatable, the imprint of the present pandemic on the world environment is not. COVID-19 has caused an upheaval in the major compartments of global environment. While some of these impacts are explicit and evident, others are obscure and shall gradually unravel as investigations continue.

The present paper is an attempt to review the existing literature to understand the role of environmental factors in COVID-19 transmission and spread and to account for the direct and indirect impacts of the pandemic on the immediate and global environment. Conceptual frameworks have been developed to address the linkages of COVID-19 and environment. The review further aims to address the environmental sustainability challenges closely associated with the crisis and their potential solutions. As we adapt to the new normal, it is intended that the critical review would reiterate the importance of the encompassing aspects of environment on the COVID-19 pandemic along with redefined sustainability measures.

Methodology

The methodology adopted in the present study includes a detailed literature search in the popular databases such as Web of Science, Science Direct, Google Scholar, Pub Med and Research Gate. The keywords and strings used for the database search were COVID-19 OR SARS-CoV-2 OR Epidemics in combination with Environment OR Air Pollution

OR Carbon emissions OR Water Pollution OR Biodiversity OR Wastewater OR Disinfectant OR Sustainability OR Meteorology OR Transmission OR Spread.

All results of the search were manually scrutinized to extract information relevant to the topic of the paper. Further the screened references were used to search additional publications that might be of larger relevance. A total of 518 papers and several other reports were examined, out of which 240 were extracted for the present paper. The themes of scholarly articles were coded manually after going through and including relevant texts. Manuscripts in the preprint form were also reviewed along with peer-reviewed articles and anecdotal evidence.

COVID-19 and the atmosphere

Strong linkages between COVID-19 and the atmospheric environment have been revealed with respect to coronavirus transmission and indirect impacts of the pandemic on ambient air quality (Fig. 2). With the eruption of coronavirus disease, lockdown measures were first implemented in Wuhan City, the epicentre of the outbreak, on January 23, 2020 and were later extended to other parts of China. Transportation and various industrial activities were majorly suspended. These restrictions together with Spring Festival effects and a ban on fireworks resulted in improved air quality (Ming et al. 2020). In an effort to curb the rapid spread of the pandemic, several risk reduction measures such as partial to complete industrial shutdown, lockdowns and extensive travel bans were implemented globally. It prompted several investigations under the assumption that such a massive reduction of modern human activities would bring about considerable alterations in emissions of anthropogenic origin thereby impacting ambient air quality and reducing air pollution. Marked improvements in air quality, particularly from countries with high levels of air pollution, were reported by media. Several scholarly studies noted reduction in major air pollutants that include nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO), PM with aerodynamic diameter of $\leq 2.5 \mu\text{m}$, PM₁₀, PM with aerodynamic diameter of $\leq 10 \mu\text{m}$ (PM₁₀, PM_{2.5}), (Jain and Sharma 2020; Sharma et al. 2020; Sicard et al. 2020; Tobías et al. 2020; Zambrano–Monserrate et al. 2020). Nitrogen oxide, that is majorly added to the atmosphere by vehicular emissions serves as an important precursor for tropospheric ozone as well as secondary aerosol formations (Manisalidis et al. 2020). Significant drop in tropospheric NO₂ concentrations received significant early attention (NASA 2020, Dutheil et al. 2020; Muhammad et al. 2020a, Muhammad et al. 2020b Baldasano 2020; Biswal et al. 2020; Hashim et al. 2021). Several studies focussed on PM concentrations in ambient air, aiming not only to analyse the impact

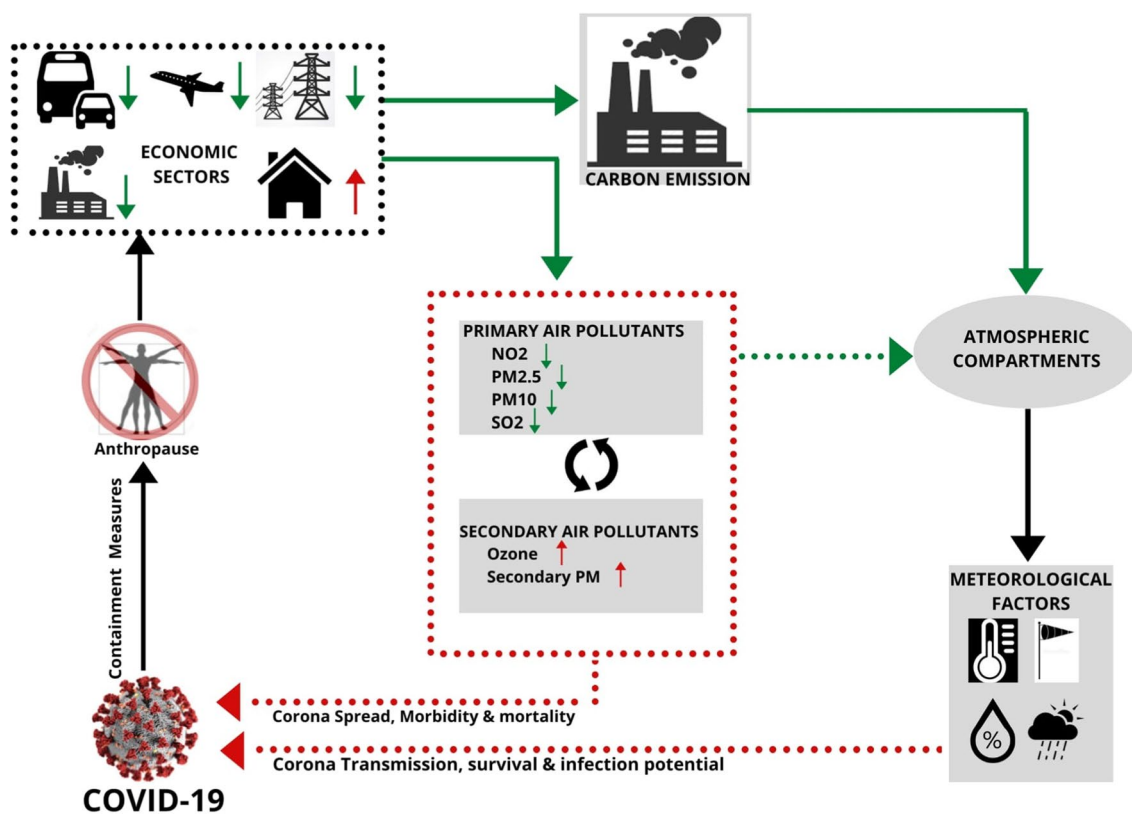


Fig. 2 Outline of the linkages of COVID19 and the atmosphere. Green arrows indicate positive impacts of Covid-19 pandemic on the atmospheric compartments. Red dotted lines indicate transmission of

SARS-CoV-2 via atmospheric compartments. Red solid lines with arrows indicate negative impacts of Covid-19 pandemic on the atmospheric compartments

of lockdowns and shutdowns on PM but also to investigate its potential for the transmission of SARS-CoV-2 (Zheng et al. 2020a).

Cities with high levels of air pollution observed significant reductions in air pollutants during the lockdown period (Shi and Brasseur 2020; Jain and Sharma 2020; Sharma et al. 2020; Sicard et al. 2020; Bao and Zhang 2020; Wang et al. 2020a) relating primarily to reductions in vehicular emissions (Collivignarelli et al. 2020; Abdullah et al. 2020; Cadotte 2020; Kambalagere 2020; Tobías et al. 2020; Zambrano-Monserrate et al. 2020; Zheng et al. 2020a). Large scale studies at the global level also reported significant decline in air pollutants (Saadat et al. 2020; Chauhan and Singh 2020; Muhammad et al. 2020a, Muhammad et al. 2020b; Kanniah et al. 2020; Lal et al. 2020). In general most of the studies compared pollutant concentrations before and after lockdown or from the data of previous years (Wang and Su 2020; Saadat et al. 2020; Jain and Sharma 2020; Sharma et al. 2020). It was also noted that in regions where transport emissions had minor impacts compared to emissions from other sources such as coal-fired thermal power plants, lockdown may not have clearly contributed to ambient air quality improvements (Kerimray et al. 2020; Dantas et al. 2020).

Contrary to the reports of overwhelming reductions in air pollutants, unexpected air pollution events were also reported during lockdown phase. Despite emission reductions, an enhanced pollution episode over Northern China was observed and was attributed to aerosol-chemistry-meteorology interactions (Le et al. 2020a). Similarly, residual pollutants were still high over the Yangtze River Delta, the majority of which was contributed from the industry, residential sectors, and other long-range transport (Li et al. 2020).

While there were worldwide reports of dramatic reductions in primary air pollutants, increase in secondary air pollutants like ozone and secondary particulate matter was observed in several studies (Huang et al. 2020). Amongst the secondary pollutants, tropospheric ozone concentrations observed a marked increase in most parts of the world during the execution of shutdown phases of the COVID-19 pandemic (Tobías et al. 2020; Sicard et al. 2020; Sharma et al. 2020) and was majorly attributed to unprecedented reduction in NO_x emissions (Nakada and Urban 2020; Sicard et al. 2020). Plummeted vehicular transport during the lockdown period resulted in a drastic reduction of NO_x emissions from road traffic. The decrease of oxides of nitrogen (NO_x) in a

volatile organic compounds- ‘VOC-limited’ environment of large urban settlements coupled with a lower ozone titration by NO led to an increase in ozone concentrations (Tobías et al. 2020; Sicard et al. 2020; Sharma et al. 2020; Li et al. 2020; Dantas et al. 2020). A similar phenomenon of the “weekend effect” has been widely studied worldwide where increased ozone concentrations are reported on weekends attributed to reduced traffic and consequent NO_x reductions (Blanchard et al. 2008; Adameet al. 2014; Zou et al. 2019). It is also speculated that the decrease of particulate matter due to transport and industrial restrictions led to more penetration of solar radiations through the atmosphere which in turn favoured increased ozone formation in some regions (Sicard et al. 2020; Sharma et al. 2020).

The anthropause of COVID-19 thus served as a natural experiment to evaluate air quality responses to a dramatic emissions reduction and to comprehend the interrelationships between emissions, meteorological conditions, and atmospheric chemistry.

In view of the rapid spread of the coronavirus disease, several etiological studies have been undertaken to understand the relevant environmental components that affect the transmission of COVID-19 along with associated mortality and morbidity. Meteorological parameters like relative humidity, air temperature, precipitation and wind speed have been well correlated with increasing transmission rates (Jahangiri et al. 2020; Zhang et al. 2020; Sobral et al. 2020; Qi et al. 2020; Ma et al., 2020; Pirouz et al. 2020; Şahin 2020; Zhu et al. 2020). A correlation of COVID-19 spread with ambient air temperature was addressed in several studies (Sobral et al. 2020; Prata et al. 2020; Xie and Zhu 2020; Shi et al. 2020; Jahangiri et al. 2020). During the initial period of COVID-19 pandemic it was speculated that high temperatures would negatively impact SARS-CoV-2 transmission. However, further investigations yielded mixed results with temperatures having either positive/negative or insignificant impacts on SARS-CoV-2 transmissions, as reported from different areas (Briz-Redón, 2020; Prata et al. 2020; Shi et al. 2020; Xie and Zhu 2020).

Ambient air pollutants have received maximum attention with reference to their correlations and further impacts on disease severity, spread and associated mortality rates. Ambient air pollution is chiefly attributed to mixtures of PM_{2.5}, PM₁₀, NO₂, CO, ozone, and volatile organic compounds which have their origins from vehicular traffic, industrial emissions and indoor air pollution sources. Ambient air pollution has been recognized to enhance human morbidity and mortality and has been established as a leading contributor to global disease burden (Cohen et al. 2017). With the backdrop of plentiful scientific evidence linking chronic exposure to air pollution with increased morbidity and mortality (Pope et al. 2011; Cohen et al. 2017), there is a growing concern that air pollutants may affect the severity of

COVID-19 by impacting spatio-temporal patterns in disease spread, directly affecting the lungs’ ability to clear pathogens and indirectly by exacerbating underlying cardiovascular or pulmonary diseases (Brandt et al. 2020). Moreover, the rapid initial spread of SARS-CoV-2 in densely populated and polluted city of Wuhan and subsequently to the heavily industrialized area of Northern Italy further drew the attention towards the speculative nexus of air pollution and COVID-19 (Fattorini and Regoli 2020, Contini and Costabile 2020).

Further studies revealed correlations between COVID-19 infection and mortality rates and concentrations of NO₂, CO, O₃ and PM (Zhu et al. 2020). Associations between COVID-19 infection rate and related fatality with NO₂ exposure levels have been recorded (Ogen 2020; Filippini et al. 2020). PM in particular has received significant attention, not only in view of increasing susceptibility to and morbidity from SARS-CoV-2 related respiratory infections (Comunian et al. 2020; Zoran et al. 2020), but also being an aid to the airborne transmission of SARS-CoV-2 (Setti et al. 2020a (Setti et al. 2020b, van Doremalen et al. 2020; Cai et al. 2020). Additionally, reductions in air pollution and related mortality benefits during the lockdowns and shutdowns have also been documented (Chen et al. 2020; Yoo and Managi, 2020).

It is noteworthy that the implication of chronic exposure to air pollution as a contributor to coronavirus infection rates and associated mortality can be misleading as the air pollution-COVID-19 link may be obscured by a number of factors such as population mobility, density and misrepresentation of COVID-19 confirmed cases (Riccò et al. 2020; Benmarhnia 2020).

COVID-19 and carbon emissions

The confinement measures internationally implemented during the COVID-19 pandemic had profound impact on fossil fuel consumption and CO₂ emissions with an unprecedented decrease of 7.8% in global fossil-based CO₂ emissions when compared with the same period last year (Liu et al. 2020). Daily global CO₂ emissions have been reported to decrease by –17% by early April 2020 compared to the mean levels of 2019 (Le Quéré et al. 2020). With restricted use of vehicles, temporary shutdowns of industries, offices, shopping complexes, theatres, and educational institutions during the lockdown phase, carbon emissions were significantly reduced from all sectors in general with largest emission reductions observed from ground transport, electric power and industrial sectors (Le Quéré et al. 2020). Though the confinement of human populations to their homes, throughout the world, resulted in an increase of household energy consumption, an overall net electricity decline was observed due to the plummeted demand of industrial electricity (Abu-Rayash

and Dincer 2020). A dramatic plunge of around 60% was observed in emissions related to aviation industry since strict domestic and international travel restrictions were imposed by and large by most countries. The airplane emissions, though, contribute only a small fraction to the global carbon emissions, yet a single transatlantic flight can add as much carbon footprint as a typical year's worth of driving (Flaherty and Holmes 2020).

As compared to the readily available data of air pollutants such as NO₂ and ozone from satellite measurements and real time monitoring stations, there has been a lack of measurements of CO₂ emissions in real time and are often reported as annual values (Friedlingstein et al. 2019). Moreover, large uncertainties are known for satellite measurements for the column CO₂ inventory which also reflect the variability of the natural CO₂ fluxes and hence are not suitable to determine anthropogenic emissions in near-real time (Le Quéré et al. 2020). Therefore, supplementary analyses such as the carbon footprint (CF) indicator and confinement index (CI) have been used to estimate CO₂ emissions during the pandemic with the available daily data of activity for selected economic sectors (Rugani and Caro 2020; Le Quéré et al. 2020). These estimates, though not free of uncertainties, offer insights into the quantitative estimation of the impacts in carbon emissions during the COVID-19 related shutdowns and the ensuing climate variability and vulnerability.

While the COVID-19 pandemic seems to indirectly cause a sudden plunge in global greenhouse gas emissions, the global CO₂ concentrations hit a record high of 417 ppm in the month of May 2020 (National Oceanic and Atmospheric Administration-NOAA 2020). It is known that CO₂ has a long atmospheric residence time of two hundred years (Harde 2017 IPCC) and its concentrations in the atmosphere are driven by cumulative factors of anthropogenic and natural nature (Yue and Gao 2018). As such, the impact of a relatively brief lockdown period on CO₂ concentrations built-up over decades is expected to be negligible (Rugani and Caro 2020).

It is estimated that by the end of 2020, global emissions will decline by about 8% (almost 2.6 gigatonnes) compared to 2019 and would equate to levels that of 10 years ago (IEA, 2020). Le Quéré et al. (2020) have projected the drop to be somewhere between 4 and 7%, depending on how the resumption of activities at all levels takes place over the rest of the year. Though a reduction in carbon emissions has been recorded during world wars and economic recessions (Andres et al. 1999), such a rapid and massive emission decline has never been witnessed in the recent past. Yet there seems to be a consensus that the drop in emissions which was evident in the initial part of the year would be short lived and would bounce back once the resumption of normal activities is accelerated (Brief Carbon 2020). The emission

data generated during the post lockdown phases seems to corroborate with this supposition. The carbon emissions which had declined by an estimated 25% in the six weeks following the lockdown in China, have already climbed back to pre-pandemic levels with European countries following suit (Zheng et al. 2020b).

Systematic and structural changes such as increased reliance on green energy, major plunges in deforestation rates seem to be the plausible solutions to combat futuristic climate change scenarios. Atmospheric levels of CO₂ are cumulative and it will not decrease until anthropogenic activities and natural processes can together remove more greenhouse gases than what is going into the atmosphere. The coronavirus pandemic though, offered a glimpse of the massive cuts in global carbon emissions that would be required in times to come for the realization of Paris Agreement goals under the United Nations Framework Convention on Climate Change (UNFCCC). Nevertheless, it shall depend how nations and the international community takes lessons from this poignant opportunity.

COVID-19 and hydrosphere

The partial or complete cessation of modern human activities during the initial phase of COVID-19 pandemic resulted in improved conditions of various spheres of environment (Lal et al. 2020). In response to the industrial shutdown and business lockdown, the hydrosphere compartment too showed marked improvement albeit to a lesser degree than its atmospheric counterpart. COVID-19 pandemic surely provided aquatic bodies some breathing space with marked reductions in plastic waste, cleaner ponds, and irrigation canals (Kannadasan 2020). As Italy went under lockdown to fight the spread of COVID-19 in the early half of March 2020, numerous pictures and videos surfaced up in social media showing the Venetian canals with clear blue waters sans its usual boat traffic. The unprecedented increased water transparency reported from the Venetian canals was regarded as a positive environmental impact of the curtailment measures of COVID-19 pandemic. Braga et al. (2020) used Sentinel-2 imagery for qualitative visual interpretation and satellite-derived turbidity for quantitative analysis of suspended matter patterns in the lagoon of Venice. The authors considered the increased water transparency as an ephemeral phenomenon governed by the impacts of COVID-19 restrictions and a combination of natural seasonal factors. Water traffic, which causes particle re-suspension, was greatly reduced along with a decrease of wastewater discharges in the canals contributing to the marked increase in transparency. Natural factors such as a lower runoff from lagoon tributaries and phytoplankton phenology augmented the transparency levels (Braga et al. 2020). Similar improvements in water

quality were also reported from Vembanad Lake in South India (Yunus et al. 2020). Application of remote sensing data for suspended particulate matter (SPM) estimation indicated a significant decrease (15.9% on average) in 18 out of 20 zones of the lake during the lockdown phase. This decrease in SPM concentrations was attributed to the reduction in tourism and effluent discharge from industries which are a major source of pollution in the Vembanad lagoon system.

Improved water quality was reported from some of the most polluted rivers such as the river Ganges in India, which still runs severely polluted even after the implementation of several high budget government schemes such as Ganga Action Plan and Namami Gange (National Mission on Clean Ganga). About 80% of the pollution in Ganges River has been attributed to domestic sewage discharge from villages and cities situated on the banks of 2500 km river that crosses different states and agro-climatic zones of the country. Numerous industries located along the banks of Ganges such as tanneries, distilleries, sugar mills, rubber and pesticide factories, further discharge huge amounts of biochemical oxygen demand (BOD) load into the river (Chaudhary and Walker 2019). A nearly complete industrial shutdown prevented industrial effluents from entering the Ganges along with suspension of other anthropogenic activities such as bathing, recreation etc. resulted in improved water quality. The Ganges was reported to recover as 27 out of 36 real-time water monitoring units set up by CPCB (Central Pollution Control Board, India) along the river showed significant improvement with reference to dissolved oxygen (DO), pH, BOD and ammonia (Singhal and Matto 2020) and were found suitable for bathing and propagation of fishery. Many stretches of the Ganges were reported to have met the standards of drinking water (Mohapatra 2020). Additionally, reduced turbidity was observed in selected stretches of the Ganges River during the lockdown phase (Garg et al. 2020). In another study by CPCB, a comparative assessment of water quality of river Ganga during pre and post lockdown was carried out, after the collection of data from 8 real time water quality monitoring systems (Somani et al. 2020). Significant reductions were observed in BOD and chemical oxygen demand (COD) in most stations. However, at a few sites' local meteorological conditions such as precipitation seem to impact the DO concentrations. Owing to limited agricultural and industrial activities, a significant decrease in nitrate levels was also observed in the river water.

Investigations carried out by Delhi Pollution Control Centre (Patel et al. 2020) at three sites along River Yamuna revealed improvement in water quality with respect to DO, BOD and COD when compared with pre-lockdown and lockdown period. Similarly, Mandaland Pal (2020) reported considerable improvement in water quality of Dwarka River which flows through Eastern India with areas dominated by stone quarrying and crushing industries. The investigators

recorded water quality parameters such as temperature, pH, turbidity, total dissolved solids (TDS) and DO during lockdown period and compared it from the data of their previous study in the year 2019. The improvement in water quality was ascribed to complete shutdown of mining industries which prevented huge amount of dust from entering the Dwarka River through drains.

Improved water quality of rivers due to Covid-19 lockdown was observed from other parts of the world as well such as Turkey (Tokatli and Varol 2021), China (Liu et al. 2021), Malaysia (Najah et al. 2021) and Peru (Custodio et al. 2021).

The impacts of lockdown measures seem to permeate to sub-surface water bodies as well, which should hypothetically take a longer duration to respond to the anthropogenic restraint as compared to surface water ecosystems. Improved chemical and biological water quality was observed from twenty two groundwater samples of a coastal industrial city of Southern India during the lockdown period (Selvam et al. 2020). Concentrations of arsenic, iron, selenium, and lead along with total coliforms and fecal coliforms decreased due to suspension of activities of metal related industries and reduction of fisheries related organic sewage generation during the period of the lockdown. Alterations in *Escherichia coli* and faecal streptococci were not observed due to lack of any significant change in domestic sewage production during the lockdown.

The state of sewage management in developing and underdeveloped countries is not very encouraging wherein still a lot of untreated wastewaters is directly offloaded in lakes, rivers and wetlands. With the detection of SARS-CoV-2 in wastewater (Lodder and de RodaHusman 2020; Ahmed et al. 2020), densely populated countries like India with less advanced sewage treatment facilities, can face major challenges with respect to contamination and subsequent control of COVID-19. SARS-CoV-2 is known to survive up to several days in untreated sewage thereby increasing the risk of transmission several folds in such countries (Bhowmick et al. 2020).

COVID-19 and the hydrosphere compartment were thus found to be critically linked. Figure 3 denotes the conceptual framework to address this linkage.

COVID-19 and noise pollution

As countries one after the other went into lockdown and shutdown mode to contain the coronavirus spread several anecdotal reports of the descent of an unusual silence with 'songs of birds replacing car horns' surfaced up. With fewer transport networks, the absence of the hum of public life, changing city 'soundscapes', there were indications that the world was less noisy at least for a while. With cruises

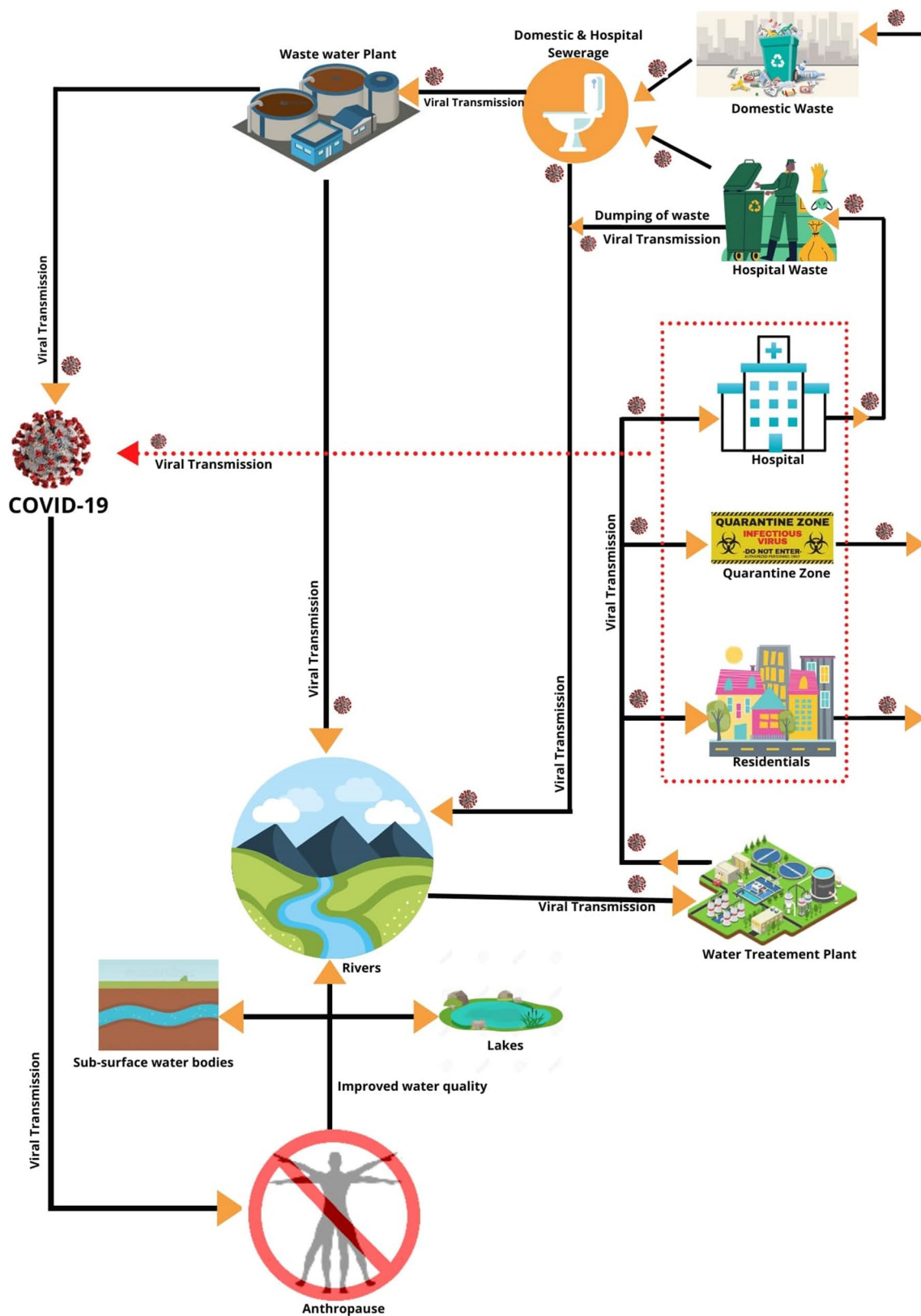


Fig. 3 Framework exploring the nexus of COVID19 with water and wastewater. Viral transmissions through water and wastewater have been depicted by arrows accompanied by pictures of SARS-CoV-2

temporarily on hold, even the oceans were reported to be more tranquil (Dugald et al. 2020).

Human activity is known to cause vibrations that propagate into the ground as high-frequency seismic waves that can carry ample energy in the 1–10 Hz frequency band (Inbal et al. 2018). Over the past few decades, this anthropogenic seismic noise has gradually increased with the growth in economies and populations. A recent study revealed that widespread global lockdowns and reduced human mobility during the COVID-19 pandemic has reduced the amount of anthropogenic seismic noise to drop by an average of 50% in 77 countries between March and May 2020 (Lecocq et al. 2020). This seismic noise quiet period of 2020 is the longest and most notable global reduction in ever recorded in human history. The study also recorded strongest reductions by surface seismometers in populated areas like New York and Singapore. However, the seismic quiescence was reported to extend several kilometres radially and hundreds of meters in depth, thereby affecting remote areas as well.

Apart from providing unique opportunities to probe the impacts of massive cut downs of greenhouse gas emissions and ambient air pollutants, the pandemic also offered to pick up the Earth's natural vibrations without confounding human inputs. The ambient seismic wavefield has been explored with reference to its natural sources, a probing signal for the solid Earth and earthquake ground motion prediction (Riahi and Gerstoft 2015). In comparison, the anthropogenic seismic noise has received little attention (Groos and Ritter 2009). COVID-19 presented an opportunity to perceive subtle signals from subsurface seismic sources that would otherwise be obscured sans pandemic induced anthropause. Correlations between seismic noise and human mobility further suggested that real-time estimates of population dynamics can be aptly provided by seismology.

COVID-19 and biodiversity

Most of the emerging infectious diseases in humans are zoonoses (caused by pathogens that spread from animals to humans) and about 70% of these zoonoses originate from wild animals (Jones et al. 2008; Wood et al. 2012). Drivers of infectious disease outbreaks mainly include increased human activities in natural areas, deforestation, disruptions to natural ecological relationships and the commodification of wild animals and other natural resources (De Sadeleer and Godfroid 2020). The origin of SARS-CoV-2 has been indicated to be zoonotic, with horseshoe bats as the primary reservoir (Andersen et al. 2020), while the number and identities of intermediate hosts still remains uncertain (Lu et al. 2020). The tracing of the origin of SARS-CoV-2 to the wet markets of Wuhan and subsequent global focus on associated zoonotic diseases invigorated wildlife experts,

conservationists, and organisations which for long have been urging governments to ban live animal markets, stop illegal trafficking and poaching of wild animals. The pandemic of COVID-19 threw a spotlight on this insidiously sustaining wildlife trade of several countries which remains as one of the greatest threats to biodiversity (Ripple et al. 2016; Benítez-López et al. 2017; Symes et al. 2018). Calls to discontinue wildlife trade were echoed by many international organizations during the pandemic which has pushed China and the global wildlife trade controlling organisations, towards a re-evaluation of the relationship with wildlife. Changes in legislation of China led to the prohibition of commercial breeding and trade in most terrestrial wild animal species for the purpose of consumption as food (Zhu and Zhu 2020). However, the trade of wildlife for non-food uses such as medicines has not been banned, which could present opportunities for wildlife traffickers who may exploit the non-food exemptions to sell or trade live wildlife. The legal global trade in wildlife and wildlife products comprise an economic value that has been estimated to be around US \$300 billion per annum (Smith et al. 2017; WWF/Dalberg 2012), whereas the illegal aspect of wildlife trade is estimated to be a US \$5–20 billion-dollar industry (Smith et al. 2017). During the COVID-19 pandemic wildlife trade bans can render millions of people unemployed resorting to illegal trafficking, thereby alleviating the beneficial effects of the imposed bans.

As the world focuses on wildlife trade and related prohibitory policies increase, it is worthwhile to mention the dramatic surge in the usage of traditional herbal medicines against COVID-19 (Mirzaie et al. 2020; Timoshyna et al. 2020). An estimated 60,000 plant species are known to be utilized for their aromatic, nutritional and medicinal properties and trade of such plant material constitutes to a staggering 5,00,000 tons annually (UN COMTRADE 2013). Unmonitored plant trade, increasing recollection and habitat loss have put severe stress on the plant populations growing in the wild (Hamilton 2004). Habitat alteration, overharvesting, and climate change have already caused severe decline in several commercially important wild plant resources used in food and medicines (Barata et al. 2016). With the unavailability of vaccines and specific antiviral drugs, initially there was sudden upsurge in the usage of traditional herbal medicines against COVID-19, particularly in the Southeast Asian countries (Kumar et al. 2020). Current research has focussed more on the efficacy of Chinese herbal medicines and Ayurveda for health care support. Ensuring the sustainability of supply chains providing herbal ingredients requires immediate attention to save several threatened species from extinction (Vandebroek et al. 2020; Timoshyna et al., 2020). The explosive demand of herbal medicines, many of which are sourced from the wild, is likely to cause significant pressure and unsustainable gathering or harvesting of wild

plant populations. It is imperative to assess and monitor the escalated plant trade for reiterating the objectives of species conservation and their sustainable use as per the guidelines proposed by Convention on International Trade in Endangered Species (CITES), Trade Record Analysis of Flora and Fauna In Commerce (TRAFFIC), International Union for Conservation of Nature (IUCN) and Adis Ababa principles.

The initial months of the COVID-19 pandemic spread witnessed one of the harshest lockdowns in several countries. With humans withdrawing to the safety of their houses, invasion of wild animals was observed in urban-forest interfaces. Deserted public places seemed to throw a lucrative opportunity for wild animals to venture beyond their usual area during their foraging activities and increasing their breeding success (Manenti et al. 2020). Numerous sightings of wild animals were reported from urban areas such as sea lions on the street of Mar del Plata, Argentina; coyotes walking down San Francisco streets and peacock sightings in urban areas of New Delhi, India. Similar behaviour has been documented in national parks and sanctuaries wherein wildlife has been spotted in areas they typically don't frequent. Additionally, several misleading videos and photographs of wildlife sightings in urban areas such as dolphins in Venice canals, elephants strolling in the streets of Dehradun, India, were found to be unrelated to lockdown and were eventually debunked. The near absence of humans during the lockdown phase did not only prompt an inquisitive loiter for the wildlife around unfamiliar terrain but also generated crisis situations for certain species. Animals such as stray dogs and monkeys adapted to urban environments and grown heavily dependent on humans for their sustenance, found it very difficult to pull through the pandemic (Bhardwaj 2020). Many Southeast Asian countries, where certain animals are catered for by humans, due to their religious beliefs and sentiments, reported man-animal conflicts (Roy 2020).

The COVID-19 pandemic has drastically affected the global tourism industry leading to the closure of many protected and conserved areas and an estimated 75 million job losses (World Travel and Tourism Council, 2020, World Economic Forum 2020). Wildlife tourism helps to secure long-term conservation of wildlife and wildlife habitats by financial and non-financial contributions and socio-economic incentives (Higginbottom 2004). These tourism programmes are usually well managed and contribute in wildlife protection for better conservation outcomes and support local livelihoods (Newsome 2020). The COVID-19 pandemic engendered dramatic declines in wildlife tourism causing massive unemployment and inadequate protected area management (Weber et al. 2020). Many locals who had lost their livelihoods turned to poaching in order to fend themselves. There have been reports of a surge in deforestation activities in the Amazon (López-Feldman et al. 2020) and increased unsustainable harvest of bushmeat in parts

of Africa as well as Cambodia (Price 2020; Meseko et al. 2020). With the spread of the coronavirus, countries focused on enforcement of lockdowns and maintenance of public health, the diversion of law enforcement to the pandemic related duties and reduced ranger patrols served as ideal opportunities for poachers and criminals involved in wild life trafficking. Africa and south east Asian countries such as India, Pakistan and Nepal observed a considerable rise in reports of illegal wildlife trade (Lindsey et al. 2020; Lappan et al. 2020). So severe was the increased poaching crisis in certain countries that dozens of rhinos were dehorned controversially in South Africa to prevent the surged-up poaching during the lockdown (Siyabonga and Cocks, 2020). Contrastingly, the negative pressures of over-tourism and inappropriate use of the protected areas seemed to ease off (Buckley 2020). Visitation is known to render cumulative and substantial detrimental effects on wildlife and their natural habitats (Marion and Reid 2007) such as interference to foraging, nesting or breeding behaviour and destruction or modifications of animal habitats (Ballantyne et al. 2009, 2011). Owing to the near absence of tourists, it is expected in all its probability that such detrimental impacts might have decreased in protected areas, though these aspects need further investigation.

COVID-19 has significantly impacted global biodiversity with several short term as well as long term effects (Fig. 4). The initial lockdown phase of the pandemic witnessed several anecdotal reports of reduced human pressures on wildlife (Bates et al. 2020). Enthusiastic narratives of 'nature hitting the reset button' and 'reclaiming territories' seems to invoke a sense of exhilaration during the otherwise testing times of the pandemic. This effect soon faded out with the gradual relaxation of the lockdowns imposed in various countries. Nevertheless, it apparently increased the public support for wildlife conservation policies. However, the imminent global economic crisis is expected to reduce funds available with national governments and conservation foundations which in turn may cause a significant decline in grants for conservation research. Challenges in wildlife and conservation research with already disrupted field work and cancelled conferences during the pandemic, may be augmented in times to come (Corlett et al. 2020).

COVID-19 and waste management

The COVID-19 pandemic will have profound impacts on the waste sector which may not be initially evident but shall manifest in due course of time. The present situation demands the need to highlight the essential role that solid waste management must play as a humanitarian response towards growing public health disaster risks (Kalina and Tilley 2020). The informal settlements especially in

	Short term impacts	Long term impacts
Negative Impacts	<ul style="list-style-type: none"> ➤ Urban animal crisis ➤ Increased Poaching and deforestation 	<ul style="list-style-type: none"> ➤ Impacted Wildlife Tourism ➤ Medicinal Plant Exploitation ➤ Hampered wildlife research ➤ Uncertain Conservation Programmes ➤ Increased Wildlife trafficking
Positive Impacts	<ul style="list-style-type: none"> ➤ Increased sighting of wildlife ➤ Public Support for wildlife conservation ➤ Wildlife trade bans 	<ul style="list-style-type: none"> ➤ Drop in consumer demand will positively impact Natural resource conservation

Fig. 4 The short and long-term impacts of COVID19 on biodiversity and wildlife

underdeveloped and developing countries were least prepared for the pandemic since basic amenities of potable water, toilets, sewage, drainage systems, waste collection, segregation and disposal, along with safe, secure and adequate housing are either inadequate or almost non-existent (Coburn et al. 2020). A fast generation of a massive amount of medical waste globally has occurred during the pandemic as increased number of people started wearing masks, using gloves, and applying hand sanitizers and soaps on a daily basis as precautionary measures against COVID-19 spread (Zambrano-Monserrate et al. 2020). Recent reports of unsafe disposal of medical waste in landfills or water bodies' further raise concerns on the contamination of soil, water and marine ecosystems (Saadat et al. 2020).

Initially, during the first stage of pandemic progression and lockdown being imposed in many countries, public authorities and municipal waste operators had the challenge to rapidly adapt their waste management systems and procedures to meet and address the globally emerging grave situation. The pandemic along with many other growing environmental consequences, presented issues related to overuse of plastic and follow-up waste. Urgent public health care demands have so far been overshadowed particularly in reference to the waste and its potential impacts on immediate environment that includes landfills, soil, water bodies and marine environment. The discharge of hospital wastes and wastewater, especially without appropriate treatment in many countries have exposed the public towards a greater risk of infection (Wang et al. 2020a, b). There have been negative secondary impacts of pandemic and lockdown that

largely include reduction in waste segregation as well as recycling and reuse of the waste. The increase in waste has further endangered the contamination of physical spaces (water and land), in addition to air (Zambrano-Monserrate et al. 2020). The energy, carbon and environmental footprints of public health related product systems have also increased rapidly and tremendously in response to the huge surge in COVID-19 cases across the world. Critical hazardous waste management issues have also emerged due to the growing need to ensure reduction and management of residual pathogens in household, public spaces and medical waste in hospitals and quarantine centers. A sudden shift in waste composition has been clearly observed and the quantity highlights the demands for a dynamically responsive waste management system (Klemes et al. 2020).

So far, there has been a dearth in studies that highlight and provide a broad overview with focus on the design of an epidemic reverse logistics network to deal with the medical waste during epidemic outbreaks. While if this waste is improperly treated, may largely accelerate the risk of the disease spread and pose huge risk to both the medical staffs and patients (Yu et al. 2020). There are important core issues related to waste management during the pandemic (Fig. 3), which include insights on the half-life of the virus on waste containers and in wastewater and further possible transmission via contaminated waste surfaces and aerosols generated from wastewater systems (Nghiem et al. 2020). Rag pickers and waste segregators involved in waste collection and segregation will be part of this larger risk in developing and underdeveloped countries where proper

precautions have not been taken care of during the process. Pandemic has enhanced the global supply for face masks and personal protective equipment (PPE), however, the production capacity is severely limited in many countries. This calls for the Research and Development community, especially in the waste management, polymer degradation and stability field for finding extended, reuse and recyclability options (Dargaville et al. 2020). Larger risk to soil, aquatic and marine ecosystems warrants attention of nations to more trans boundary cooperation in order to address the issue to protect the already fragile marine environment and biota from further degradation.

COVID-19 and disinfectants

Amongst the safety measures to contain the spread of COVID-19, hand hygiene by frequent soap wash and sanitizer use is highly recommended (Golin et al. 2020; WHO 2020b). Consequently, there was a surge in the use of alcohol based hand sanitizers with ethanol, isopropyl alcohols and hydrogen peroxides used in varying proportions for effective transmission reduction of SARS-CoV-2 (Berardi et al. 2020). However, sanitizer preparations have been reported to be toxic to human health (Moon et al. 2006; Gormley et al. 2012; Barrett and Babl 2015) and hazardous to environment when released by evaporation or other methods (Slaughter et al. 2014). Overuse of alcohol-based hand sanitizer during COVID-19 may incur toxic health effects apart from the possibility of rendering the microbes resistant (Mahmood et al. 2020; Morgan 2020). Soap hand wash is preferable over sanitizer use and should be frequently practiced as a preventive measure.

In order to reduce the role that fomites might have in the transmission and consequent spread of COVID-19, several countries have already opted for disinfecting surfaces of private and public settings. Among the curtailment measures in infectious disease control, chemical disinfectants are considered to play a key role in disrupting transmission and are recognized as an effective strategy for controlling the spread of pathogens (Ha et al. 2016). To reduce the transmission of SARS-CoV-2 in the early phases of the pandemic, exhaustive disinfection of environmental surfaces in urban settings was practised by several countries including China, South Korea, France and Spain (Roth 2020). Fleets of trucks, drones, and robots were used to spray copious amounts of disinfectant throughout densely populated urban areas which included houses, offices, schools, publicly accessible buildings, religious community centres, markets, and restaurants (Palmer et al. 2020; You 2020). Majority of disinfectants have active components which are generally corrosive and harmful chemicals such as chlorine and iodine releasing agents, aldehydes, oxidizing agents and quaternary

ammonium ions (Nabi et al. 2020; Al-Sayah 2020; Yari et al. 2020). Apart from having detrimental health impacts on humans, these chemicals can cause toxic effects on urban wildlife as well (Nabi et al. 2020). During the early phase of the pandemic in China, indiscriminate use of disinfectants had resulted in abnormal deaths of wild animals including wild boars, weasels, blackbirds and other birds (You 2020; Yingzi and Xiaomin 2020). Chlorine disinfectants are known to be toxic to aquatic and terrestrial organisms by causing cell damage (Sedlak and Gunten 2011) affecting respiratory and digestive systems (Bull et al. 1990), giving rise to secondary carcinogenic chemicals (Marine et al., 2019) apart from exhibiting potential for bioaccumulation (Barghi et al. 2018). The introduction, persistence and probable transfer of such toxic chemicals in the interconnected food webs of terrestrial and aquatic ecosystems raise grave concerns. Unrestrained use of such chemicals may contaminate drinking water resources, lakes and rivers through sewage systems affecting human and wildlife (Fig. 1). It is thus recommended that indiscriminate spraying of high volumes of disinfectants should be avoided, and more attention should be paid to research addressing the toxicological effects of disinfectants in order to develop an effective environmental safety and prevention system.

COVID-19 and sustainability

The pandemic of COVID-19 has severely impacted the political, social, economic, religious and financial infrastructures throughout the world and has given sustainability a novel dress rehearsal when the world has already entered a new normal. While COVID-19 initially created some short-term headwinds for sustainability; it also generated strong tailwinds for future. It was seen as a dress rehearsal for dealing with climate change and biodiversity losses (Peccoud and Branden 2020).

Prior to COVID-19, the world had been witnessing increasing environmental degradation that many believed mostly arose from controversial economic policies and global trade. Anthropogenic land use changes, climate change, unsustainable wildlife exploitation and globalization have been the conspicuous drivers for emergence of novel zoonoses in the human populations (Daszak et al. 2001). The risk of a new zoonotic disease emerging in the future is higher than ever and COVID-19 may just be one of the many deadly pandemics to show up in coming time. The discontinuation of the unsustainable wildlife trade by enforcement of strict regulations, upgrading food safety and providing alternative livelihood opportunities to locals reliant on wildlife resources could be the critical measures to prevent future emergence of zoonotic diseases.

The impacts of the COVID-19 pandemic have ramified to all macrosystems with economies plummeting to record lows and huge threats of recession and further global depression loom large to worsen the situation. Economic rescue packages are being rolled out with high priority for public health care support and prevent the collapse of various businesses and economic sectors. While public health is of utmost importance, thoughtful attention should also be paid to sustainable utilization of several long-term packages for economic revival. The outbreak caused very serious problems in the renewable energy sector and policies need to be modified accordingly (Hosseini 2020; Eroglu 2020). The trajectory of recovery from the pandemic should essentially include the rebuilding of human habitats in a sustainable way. Renewal of built environment, prioritizing multimodal transport, innovative waste management practices, encouraging conservation programmes and funding, reinstatement of sustainable energy and resilient global supply chains will help in progression to the achievement of UN Sustainable Development Goals (Megahed and Ghoneim 2020; Simon 2020; Sarkis et al. 2020; Kuzemko et al. 2020; Dente and Hashimoto, 2020). The attainment of these sustainability goals shall be more challenging for developing countries due to considerable reduction in international support (Barbier and Burgess 2020; Leal Filho et al. 2020).

The pandemic made the world realize that health should not only be treated as a demographic or an individual issue, rather its large-scale global impacts demands the creation of a fourth pillar of global sustainability (Hakovirta and Denuwara 2020). A preliminary analysis carried out by Institute for Global Environmental Strategies (IGES), Japan to understand the environmental and sustainability challenges associated with the crisis, and their potential solutions suggests categorizing core issues that require attention in “short-term by addressing Urgent Concerns (medical waste, air quality, and sustainable lifestyles)”, “medium-term for paving the way for Post-Crisis Green Recovery by promoting green recovery”, and “long-term by creating a Resilient and Sustainable Society that includes integrated approaches, sustainable cities, climate adaptation planning and management of global risks” (Mori et al. 2020). It has been globally acknowledged that sustainable recovery and development is only possible in the new normal when innovative sustainable practices, plans and policies are given due importance.

Human mental health was another area which was severely affected, though it was overlooked during the major phase of the pandemic (Dubey et al. 2020). There was increased stress, fear, anger and other negative feelings due to several economic and social changes induced by COVID-19 (Roy et al. 2020, Duan and Zhu 2020). However, the pandemic also taught us to live with restricted resources and strive for a greener world.

Conclusion

The COVID-19 pandemic is critically linked to the environment. With respect to SARS-CoV-2 transmission, spread and consequent mortality various meteorological factors played an integral role. The pandemic also brought about both positive and negative impacts on the global environment. However, the long-term negative impacts seem to eclipse the short term positive environmental effects of the pandemic. Enormous generation of biomedical waste and indiscriminate use of disinfectants has posed a formidable challenge to the sustainability. In the new normal, the situation warrants the rebuilding of society in a sustainable way along with redefining sustainability. Development of virtual infrastructure and green buildings along with a clear shift to energy efficient designs particularly in the industrial and transport sectors is the need of the hour. Comprehensive waste management policies suitable for the pandemic management should be prioritized. Finally, we should nurture the eco-centric view and should develop more eco-friendly sustainable practices.

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References

- Abdullah S, Mansor AA, Napi NNLM, Nurdiana W, Mansor W, Ahmed AN, Ismail M, Ramly ZTA (2020) Air quality status during 2020 Malaysia Movement Control Order (MCO) due to 2019 novel coronavirus (2019-nCoV) pandemic. *Sci Total Environ* 729:139022. <https://doi.org/10.1016/j.scitotenv.2020.139022>
- Abu-Rayash A, Dincer I (2020) Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic. *Energy Res Soc Sci* 68(2020):101682. <https://doi.org/10.1016/j.erss.2020.101682>
- Adame JA, Hernández-Ceballos MÁ, Sorribas M, Lozano A, De la Morena BA (2014) Weekend-weekday effect assessment for O₃, NO_x, CO and PM₁₀ in Andalusia, Spain (2003–2008). *Aerosol Air Qual Res* 14:1862–1874
- Ahmed W, Angel N, Edson J, Bibby K, Bivins A, Brien JWO, Choi PM, Kitajima M, Simpson SL, Li J, Tschärke B, Verhagen R, Smith WJM, Zaugg J, Dierens L, Hugenholtz P, Thomas KV, Mueller JF (2020) First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: a proof of concept for the wastewater surveillance of COVID-19 in the community. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138764>
- Al-Sayah MH (2020) Chemical disinfectants of COVID-19: an overview. *J Water Health*. <https://doi.org/10.2166/wh.2020.108>
- Andersen KG, Rambaut A, Lipkin WI, Holmes EC, Garry RF (2020) The proximal origin of SARS-CoV-2. *Nat Med*. <https://doi.org/10.1038/s41591-020-0820-9>
- Andres RJ, Fielding DJ, Marland G, Boden TA, Kumar N, Kearney AT (1999) Carbon dioxide emissions from fossil-fuel use, 1751–1950. *Tellus b: Chem Phys Meteorol* 51(4):759–765. <https://doi.org/10.3402/tellusb.v51i4.16483>

- Arthur RF, Gurley ES, Salje H, Bloomfield LSP, Jones JH (2017) Contact structure, mobility, environmental impact and behaviour: the importance of social forces to infectious disease dynamics and disease ecology. *Phil Trans R Soc B* 372:20160454. <https://doi.org/10.1098/rstb.2016.0454>
- Baldasano JM (2020) COVID-19 lockdown effects on air quality by NO₂ in the cities of Barcelona and Madrid (Spain). *Sci Total Environ* 741:140353. <https://doi.org/10.1016/j.scitotenv.2020.140353>
- Ballantyne R, Packer J, Hughes K (2009) Tourists' support for conservation messages and sustainable management practices in wildlife tourism experiences. *Tour Manage* 30(5):658–664
- Ballantyne R, Packer J, Sutherland LA (2011) Visitors' memories of wildlife tourism: Implications for the design of powerful interpretive experiences. *Tour Manage* 32(4):770–779
- Bao R, Zhang A (2020) Does lockdown reduce air pollution? Evidence from 44 cities in northern China. *Sci Total Environ* 731:139052. <https://doi.org/10.1016/j.scitotenv.2020.139052>
- Barata AM, Rocha F, Lopes V, Carvalho AM (2016) Conservation and sustainable uses of medicinal and aromatic plants genetic resources on the worldwide for human welfare. *Ind Crops Prod* 88:8–11
- Barbier EB, Burgess JC (2020) Sustainability and development after COVID-19. *World Dev* 135:105082. <https://doi.org/10.1016/j.worlddev.2020.105082>
- Barghi M, Jin X, Lee S, Jeong Y, Yu JP, Paek WK, Moon HB (2018) Accumulation and exposure assessment of persistent chlorinated and fluorinated contaminants in Korean birds. *Sci Total Environ* 645:220–228
- Barrett MJ, Babl FE (2015) Alcohol-based hand sanitiser: a potentially fatal toy. *Med J Aust* 203(1):43–44
- Bates AE, Primack RB, Moraga P, Duarte CM (2020) COVID-19 pandemic and associated lockdown as a “Global Human Confinement Experiment” to investigate biodiversity conservation. *Biol Conserv*. <https://doi.org/10.1016/j.biocon.2020.108665>
- Benítez-López A, Alkemade R, Schipper AM, Ingram DJ, Verweij PA, Eikelboom JAJ, Huijbregts MAJ (2017) The impact of hunting on tropical mammal and bird populations. *Science*. 356(6334):180–183
- Benmarhnia T (2020) Linkages between air pollution and the health burden from COVID-19: methodological challenges and opportunities. *Am J Epidemiol*. <https://doi.org/10.1093/aje/kwaa148>
- Berardi A, Perinelli DR, Merchant HA, Bisharat L, Bashedi IA, Bonacucina G, Cespi M, Palmieri GF (2020) Hand sanitisers amid CoViD-19: a critical review of alcohol-based products on the market and formulation approaches to respond to increasing demand. *Int J Pharm* 584:119431. <https://doi.org/10.1016/j.ijpharm.2020.119431>
- Bhardwaj M (2020) COVID-19 lockdown effect: Dogs, people killing Karnataka wildlife for food. <https://www.newindianexpress.com/states/karnataka/2020/apr/25/covid-19-lockdown-effect-dogs-people-killing-karnataka-wildlife-for-food-2135043.html> Accessed on July 12, 2020
- Bhowmick GD, Dhar D, Nath D, Ghangrekar MM, Banerjee R, Das S, Chatterjee J (2020) Coronavirus disease 2019 (COVID-19) outbreak: some serious consequences with urban and rural water cycle. *NPJ Clean Water* 3(1):1–8. <https://doi.org/10.1038/s41545-020-0079-1>
- Biswal A, Singh T, Singh V, Ravindra K, Mor S (2020) COVID-19 lockdown and its impact on tropospheric NO₂ concentrations over India using satellite-based data. *Heliyon*. <https://doi.org/10.1016/j.heliyon.2020.e04764>
- Blanchard CL, Tanenbaum S, Lawson DR (2008) Differences between weekday and weekend air pollutant levels in Atlanta; Baltimore; Chicago; Dallas-Fort Worth; Denver; Houston; New York; Phoenix; Washington, DC; and surrounding areas. *J Air Waste Manage Assoc* 58:1598–1615
- Braga F, Scarpa GM, Brando VE, Manfè G, Zaggia L (2020) COVID-19 lockdown measures reveal human impact on water transparency in the Venice Lagoon. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139612>
- Brandt EB, Beck AF, Mersha TB (2020) Air pollution, racial disparities, and COVID-19 mortality. *J Allergy Clin Immunol*. <https://doi.org/10.1016/j.jaci.2020.04.035>
- Briz-Redón A, Serrano-Aroca A (2020) A spatio-temporal analysis for exploring the effect of temperature on COVID-19 early evolution in Spain. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138811>
- Brockmann D (2017) Global connectivity and the spread of infectious diseases. *Nova Acta Leopoldina* 419:129–136
- Buckley R (2020) Pandemic travel restrictions provide a test of net ecological effects of ecotourism and new research opportunities. *J Travel Res*. <https://doi.org/10.1177/0047287520947812>
- Bull RJ, Gerba C, Trussell RR (1990) Evaluation of the health risks associated with disinfection. *Crit Rev Environ Control* 20(2):77–113. <https://doi.org/10.1080/10643389009388392>
- Cadotte MW (2020) Early evidence that COVID-19 government policies reduce urban air pollution. [WWW document]. URL. <https://eartharxiv.org/nhgj3>
- Cai J, Sun W, Huang J, Gamber M, Wu J, He G (2020) Indirect virus transmission in cluster of COVID-19 cases, Wenzhou, China, 2020. *Emerg Infect Dis* 26(6):1343–1345. <https://doi.org/10.3201/eid2606.200412>
- Brief Carbon (2020) Analysis: China's CO₂ emissions surged past pre-coronavirus levels in May. *Global Planet Change* 152:19–26
- Chakraborty I, Maity P (2020) COVID-19 outbreak: migration, effects on society, global environment and prevention. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138882>
- Chaudhary Walker MT et al (2018) River Ganga pollution: Causes and failed management plans (correspondence on Dwivedi. Ganga water pollution: a potential health threat to inhabitants of Ganga basin. *Environment International* 117, 327–338). *Environ Int* 126:202–206
- Chauhan A, Singh RP (2020) Decline in PM_{2.5} concentrations over major cities around the world associated with COVID19. *Environ Res*. <https://doi.org/10.1016/j.envres.2020.109634>
- Chen K, Wang M, Huang C, Kinney PL, Anastas PT (2020) Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. *The Lancet Planet Health* 4(6):e210–e212. [https://doi.org/10.1016/S2542-5196\(20\)30107-8](https://doi.org/10.1016/S2542-5196(20)30107-8)
- Chirizzi et al (2021) SARS-CoV-2 concentrations and virus-laden aerosol size distributions in outdoor air in north and south of Italy. *Environ Int*. <https://doi.org/10.1016/j.envint.2020.106255>
- Clay K, Lewis J, Severnini E (2018) Pollution, infectious disease, and mortality: evidence from the 1918 Spanish influenza pandemic. *J Econ Hist* 78(4):1179–209
- Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, Balakrishnan K, Brunekreef B, Dandona L, Dandona R, Feigin V, Freedman G, Hubbell B, Jobling A, Kan H, Knibbs L, Liu Y, Martin R, Morawska L, Pope CA, Forouzanfar MH (2017) Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *Lancet (London England)* 389(10082):1907–1918. [https://doi.org/10.1016/S0140-6736\(17\)30505-6](https://doi.org/10.1016/S0140-6736(17)30505-6)
- Collivignarelli MC, Abba A, Bertanza G, Pedrazzani R, Ricciardi P, Miino MC (2020) Lockdown for COVID-2019 in Milan: What are the effects on air quality? *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139280>
- Comunian S, Dongo D, Milani C, Palestini P (2020) Air pollution and COVID-19: the role of particulate matter in the spread and

- increase of COVID-19s morbidity and mortality. *Int J Environ Res Public Health* 17:4487. <https://doi.org/10.3390/ijerph17124487>
- Coticcini E, Frediani B, Caro D (2020) Can atmospheric pollution be considered a cofactor in extremely high level of SARS-CoV-2 lethality in Northern Italy? *Environ Pollut* 261:114465. <https://doi.org/10.1016/j.envpol.2020.114465>
- Corburn J, Vlahov D, Mberu B, Riley L, Caiaffa WT, Rashid SF, Ko A, Patel S, Jukur S, Martínez-Herrera E, Jayasinghe S (2020) SlumHealth: arresting COVID-19 and improving well-being in urban informal settlements. *J Urban Health*. <https://doi.org/10.1007/s11524-020-00438-6>
- Corlett RT, Primack RB, Devictor V, Maas B, Goswami VR, Bates AE, Koh LP, Regan TJ, Loyola R, Pakeman RJ, Cumming GS (2020) Impacts of the coronavirus pandemic on biodiversity conservation. *Biol Conserv*. <https://doi.org/10.1016/j.biocon.2020.108571>
- Custodio M, Peñaloza R, Alvarado J, Chanamé F, Maldonado E (2021) Surface water quality in the Mantaro river watershed assessed after the cessation of anthropogenic activities due to the COVID-19 pandemic. *Pol J Environ Stud* 30(4):3005–3018. <https://doi.org/10.15244/pjoes/130988>
- Dantas G, Siciliano B, França BB, da Silva CM, Arbilla G (2020) The impact of COVID 19 partial lockdown on the air quality of the city of Rio de Janeiro Brazil. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139085>
- Dargaville T, Spann K, Celina M (2020) Opinion to address a potential personal protective equipment shortage in the global community during the COVID-19 outbreak. *Polymer Degrad Stability*. <https://doi.org/10.1016/j.polyimdegradstab.2020.109162>
- Daszak P, Cunningham AA, Hyatt AD (2001) Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Actatropica* 78(2):103–116. [https://doi.org/10.1016/s0001-706x\(00\)00179-0](https://doi.org/10.1016/s0001-706x(00)00179-0)
- De Sadeleer N, Godfroid J (2020) The Story behind COVID-19: animal diseases at the crossroads of wildlife, livestock and human health. *Euro J Risk Regul* 11(2):210–227. <https://doi.org/10.1017/err.2020.45>
- Dente S, Hashimoto S (2020) COVID-19: a pandemic with positive and negative outcomes on resource and waste flows and stocks. *Resour Conserv Recycl* 161:104979. <https://doi.org/10.1016/j.resconrec.2020.104979>
- Dobson AP, Carper ER (1996) Infectious diseases and human population history. *Bioscience* 1996(46):115–126
- Duan L, Zhu G (2020) Psychological interventions for people affected by the COVID-19 epidemic. *Lancet Psychiatr* 7:300–302
- Dubey S, Biswas P, Ghosh R, Chatterjee S, Dubey MJ, Chatterjee S, Lahiri D, Lavie CJ (2020) Psychosocial impact of COVID-19. *Diabetes Metab Syndr* 14:779–788
- Dugald J, Thomson M, Barclay DR (2020) Real-time observations of the impact of COVID-19 on underwater noise. *The J Acoustic Soc Am* 147:3390. <https://doi.org/10.1121/10.0001271>
- Dutheil F, Baker JS, Navel V (2020) COVID-19 as a factor influencing air pollution? *Environ Pollut*. <https://doi.org/10.1016/j.envpol.2020.114466>
- Eisenberg JN, Desai MA, Levy K, Bates SJ, Liang S, Naumoff K, Scott JC (2007) Environmental determinants of infectious disease: a framework for tracking causal links and guiding public health research. *Environ Health Perspect* 115(8):1216–1223. <https://doi.org/10.1289/ehp.9806>
- Engering A, Hogerwerf L, Slingenbergh J (2013) Pathogen-host-environment interplay and disease emergence. *Emerg Microbes Infect* 2(2):e5. <https://doi.org/10.1038/emi.2013.5>
- Eroglu H (2020) Effects of Covid-19 outbreak on environment and renewable energy sector. *Environ Develop and Sustain*. <https://doi.org/10.1007/s10668-020-00837-4>
- Fattorini D, Regoli F (2020) Role of the chronic air pollution levels in the covid-19 outbreak risk in Italy. *Environ Pollut*. <https://doi.org/10.1016/j.envpol.2020.114732>
- Feinleib M (2001) *A Dictionary of Epidemiology, Fourth Edition* - Edited by John M. Last, Robert A. Spasoff, and Susan S. Harris [J]. *Am J Epidemiol* 154(1):93–94
- Filippini T, Rothman KJ, Goffi A, Ferrari F, Maffei G, Orsini N, Vinceti M (2020) Satellite-detected tropospheric nitrogen dioxide and spread of SARS-CoV-2 infection in Northern Italy. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.140278>
- Flaherty GT, Holmes A (2020) Will flight shaming influence the future of air travel? *J Travel Med*. <https://doi.org/10.1093/jtm/taz088>
- Friedlingstein P, Jones M, O'sullivan M, Andrew R, Hauck J, Peters G, Peters W, Pongratz J, Sitch S, Le Quéré C, DBakker O (2019) Global carbon budget 2019. *Earth System Science Data* 11(4):1783–1838
- Galbadage T, Peterson BM, Gunasekera RS (2020) Does COVID-19 spread through droplets alone? *Front Public Health*. <https://doi.org/10.3389/fpubh.2020.00163>
- Gane SB, Kelly C, Hopkins C (2020) Isolated sudden onset anosmia in COVID-19 infection. *A Novel Syndr Rhinol*. <https://doi.org/10.4193/Rhin20.114>
- Gao QY, Chen YX, Fang JY (2019) Novel coronavirus infection and gastrointestinal tract. *J Dig Dis* 21(3):125–126. <https://doi.org/10.1111/1751-2980.12851>
- Garg V, Aggarwal SP, Chauhan P (2020) Changes in turbidity along Ganga river using Sentinel-2 satellite data during lockdown associated with COVID-19. *Geomat Nat Haz Risk* 11(1):1175–1195. <https://doi.org/10.1080/19475705.2020.1782482>
- Golin AP, Choi D, Ghahary A (2020) Hand sanitizers: A review of ingredients, mechanisms of action, modes of delivery, and efficacy against coronaviruses. *Am J Infect Control*. <https://doi.org/10.1016/j.ajic.2020.06.182>
- Gorbalenya AE, Baker SC, Baric RS, de Groot RJ, Drosten C, Gulyaeva AA, Haagmans BL, Lauber C, Leontovich AM, Neuman BW, Penzar D (2020) The species severe acute respiratory syndrome related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2. *Nat Microbiol*. <https://doi.org/10.1038/s41564-020-0695-z>
- Gormley M, Aspray TJ, Kelly DA (2020) COVID-19: mitigating transmission via wastewater plumbing systems. *Lancet Glob Health* 8(5):e643. [https://doi.org/10.1016/S2214-109X\(20\)30112-1](https://doi.org/10.1016/S2214-109X(20)30112-1)
- Gormley NJ, Bronstein AC, Rasimas JJ, Pao M, Wratney AT, Sun J, Austin HA, Suffredini AF (2012) The rising incidence of intentional ingestion of ethanol-containing hand sanitizers. *Crit Care Med* 40(1):290–294. <https://doi.org/10.1097/CCM.0b013e31822f09c0>
- Groos JC, Ritter JRR (2009) Time domain classification and quantification of seismic noise in an urban environment. *Geophys J Int* 179(2):1213–1231
- Gu J, Han B, Wang J (2020) COVID-19: Gastrointestinal manifestations and potential fecal-oral transmission. *Gastroenterology* 158(6):1518–1519. <https://doi.org/10.1053/j.gastro.2020.02.054>
- Ha J, Choi C, Lee H, Ju I, Lee J, Ha S (2016) Efficacy of chemical disinfectant compounds against human norovirus. *Food Control* 59:524–529
- Hakovirta M, Denuwara N (2020) How COVID-19 redefines the concept of sustainability. *Sustainability* 12:3727
- Hamilton AC (2004) Medicinal plants, conservation and livelihoods. *Biodivers Conserv* 2004(13):1477–1517. <https://doi.org/10.1023/B:BIOC.0000021333.23413.42>
- Harde H (2017) Scrutinizing the carbon cycle and CO2 residence time in the atmosphere. *Global Planet Change*. <https://doi.org/10.1016/j.gloplacha.2017.02.009>
- Hashim BM, Al-Naseri SK, Al-Maliki A, Al-Ansari N (2021) Impact of COVID 19 lockdown on NO2 O3 PM25 and PM10

- concentrations and assessing air quality changes. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.141978>
- Higginbottom K (2004) Wildlife tourism: an introduction. In: Higginbottom K (ed) *Wildlife tourism: Impacts, management and planning Australia*. Common Ground Publishing in Association with the Cooperative Research Centre for Sustainable Tourism
- Hosseini SE (2020) An outlook on the global development of renewable and sustainable energy at the time of Covid-19. *Energy Res Soc Sci.* <https://doi.org/10.1016/j.erss.2020.101633>
- Hu X, Xing Y, Ni W, Zhang F, Lu S, Wang Z, Gao R, Jiang F (2020) Environmental contamination by SARS-CoV-2 of an imported case during incubation period. *Science Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.140620>
- Huang X, Ding A, Gao J, Zheng B, Zhou D, Qi X, He K (2020) Enhanced secondary pollution offset reduction of primary emissions during COVID 19 lockdown in China. *Natl Sci Rev.* <https://doi.org/10.1093/nsr/nwaa137>
- Huremović D (2019) Brief History of Pandemics (Pandemics throughout History). *Psychiatr Pandem: a Mental Health Res Infect Outbreak.* https://doi.org/10.1007/978-3-030-15346-5_2
- IEA (2020) *Global Energy Review 2020*. IEA, Paris <https://www.iea.org/reports/global-energy-review-2020>. Accessed 12 Oct 2020
- Inbal A et al (2018) Sources of long range anthropogenic noise in Southern California and implications for tectonic tremor detection. *Bull Seism Soc Am* 108:3511–3527
- Jahangiri M, Najafgholipour M (2020) The sensitivity and specificity analyses of ambient temperature and population size on the transmission rate of the novel coronavirus in different provinces of Iran. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.138872>
- Jain S, Sharma T (2020) Social and travel lockdown impact considering coronavirus disease (COVID-19) on air quality in megacities of India: present benefits, future challenges and way forward. *Aerosol Air Quality Res* 20:1222–1236
- Jayaweera M, Perera H, Gunawardana B, Manatunge J (2020) Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. *Environ Res.* <https://doi.org/10.1016/j.envres.2020.109819>
- Johnson N, Mueller J (2002) Updating the Accounts: Global Mortality of the 1918–1920 “Spanish” Influenza Pandemic. *Bulletin History Med*, 76(1), 105–115. <https://www.jstor.org/stable/44446153>. Accessed on August 12, 2020
- Jonathan et al (2021) Airborne transmission of SARS CoV 2 What We Know. *Clin Infect Dis.* <https://doi.org/10.1093/cid/ciab039>
- Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, Daszak P (2008) Global trends in emerging infectious diseases. *Nature* 451(7181):990–993. <https://doi.org/10.1038/nature06536>
- Kalina M, Tilley E (2020) “This is our next problem”: cleaning up from the COVID 19 response. *Waste Manag.* <https://doi.org/10.1016/j.wasman.2020.05.006>
- Kambalagere Y (2020) A study on air quality index (AQI) of Bengaluru, Karnataka during lockdown period to combat coronavirus disease (Covid-19): air quality turns ‘better’ from ‘hazardous.’ *Stud Indian Place Names* 40:59–66
- Kannadasan A (2020) Lockdown due to COVID-19: How our waterbodies are cleaner. *The Hindu* (May 6, 2020 04:53 PM IST). <https://www.thehindu.com/sci-tech/energy-and-environment/lockdown-due-to-covid-19-how-our-waterbodies-are-cleaner/article31518267.ece>. Accessed on 23 Sept 2020
- Kanniah KD, Zaman NAFK, Kaskaoutis DG, Latif MT (2020) COVID-19’s impact on the atmospheric environment in the Southeast Asia region. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.139658>
- Kerimray A, Baimatova N, Ibragimova OP, Bukenov B, Kenessov B, Plotitsyn P, Karaca F (2020) Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.13917>
- Khan K, Arino J, Hu W, Raposo P, Sears J, Calderon F, Heidebrecht C, Macdonald M, Liauw J, Chan A, Gardam M (2009) Spread of a novel influenza A (H1N1) virus via global airline transportation. *N Engl J Med* 2009(361):212–214. <https://doi.org/10.1056/NEJMc0904559>
- Klemeš JJ, Van Fan Y, Tan RR, Jiang P (2020) Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. *Renew Sustain Energy Rev.* <https://doi.org/10.1016/j.rser.2020.109883>
- Kong SF, Li L, Li XX, Yin Y, Chen K, Liu DT, Yuan L, Zhang YJ, Shan YP, Ji YQ (2015) The impacts of firework burning at the Chinese spring festival on air quality: insights of tracers, source evolution and aging processes. *Atmos Chem Phys* 15:2167–2184
- Kumar V, Singh SB, Singh S (2020) COVID-19: environment concern and impact of indian medicinal system. *J Environ Chem Engin.* <https://doi.org/10.1016/j.jece.2020.104144>
- Kuzemko C, Bradshaw M, Bridge G, Goldthau A, Jewell J, Overland I, Scholten D, Van de Graaf T, Westphal K (2020) Covid-19 and the politics of sustainable energy transitions. *Energy Res Social Sci* 68:101685. <https://doi.org/10.1016/j.erss.2020.101685>
- Lal P, Kumar A, Kumar S, Kumari S, Saikia P, Dayanandan A, Adhikari D, Khan ML (2020) The dark cloud with a silver lining: Assessing the impact of the SARS COVID-19 pandemic on the global environment. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.139297>
- Lappan S, Malaivijitmond S, Radhakrishna S, Riley EP, Ruppert N (2020) The human–primate interface in the New Normal: challenges and opportunities for primatologists in the COVID-19 era and beyond. *Am J Primatol.* <https://doi.org/10.1002/ajp.23176>
- Le Quéré C, Jackson RB, Jones MW, Smith AJ, Abernethy S, Andrew RM, De-Gol AJ, Willis DR, Shan Y, Canadell JG, Friedlingstein P (2020) Temporary reduction in daily global CO₂ emissions during the COVID-19 forced confinement. *Nat Clim Chang.* <https://doi.org/10.1038/s41558-020-0797-x>
- Le T, Wang Y, Liu L, Yang J, Yung YL, Li G, Seinfeld JH (2020) Unexpected air pollution with marked emission reductions during the COVID-19 outbreak in China. *Science.* <https://doi.org/10.1126/science.abb7431>
- Leal Filho W, Brandli LL, Lange Salvia A, Rayman-Bacchus L, Platje J (2020) COVID-19 and the UN sustainable development goals: threat to solidarity or an opportunity? *Sustainability* 12(13):5343
- Lecocq T, Hicks SP, Van Noten K, Van Wijk K, Koelmeijer P, De Plaen RS, Massin F, Hillers G, Anthony RE, Apoloner MT, Arroyo-Solórzano M (2020) Global quieting of high-frequency seismic noise due to COVID-19 pandemic lockdown measures. *Science.* <https://doi.org/10.1126/science.abd2438>
- Lewis SL, Maslin MA (2015) Defining the Anthropocene. *Nature* 519(7542):171–180
- Li L, Li Q, Ling H, Wang Q, Zhu A, Xu J, Ziyi L, Li H, Shi L, Li R, Azari M, Wang Y, Zhang X, Zhiqiang L, Zhu Y, Zhang K, Xue S, Ooi MCG, Zhang D, Chan A (2020) Air quality changes during the COVID-19 lockdown over the Yangtze River Delta region: an insight into the impact of human activity pattern changes on air pollution variation. *Sci Total Environ* 732:139282. <https://doi.org/10.1016/j.scitotenv.2020.139282>
- Lindsey P, Allan J, Brehony P, Dickman A, Robson A, Begg C, Bhammar H, Blanken L, Breuer T, Fitzgerald K, Flyman M (2020) Conserving Africa’s wildlife and wildlands through the COVID 19 crisis and beyond. *Nat Ecol Evol.* <https://doi.org/10.1038/s41559-020-1275-6>
- Liu D, Yang H, Thompson JR, Li J, Loisele S, Duan H (2021) COVID-19 lockdown improved river water quality in China.

- Sci Total Environ, Vol 802, 2022. ISSN 149585:0048–9697. <https://doi.org/10.1016/j.scitotenv.2021.149585>
- Liu Z, Ciais P, Deng Z, Lei R, Davis SJ, Feng S, Zheng B, Cui D, Dou X, He P, Zhu B, Lu C, Ke P, Sun T, Wang Y, Yue X, Wang Y, Lei Y, Zhou H, Cai Z, Wu Y, Guo R, Han T, Xue J, Boucher O, Boucher E, Chevallier F, Wei Y, Zhong H, Kang C, Zhang N, Chen B, Xi F, Marie F, Zhang Q, Guan D, Gong P, Kammen DM, He K, Schellnhuber HJ (2020) COVID-19 causes record decline in global CO₂ emissions. arXiv: General Economics. [arXiv:2004.13614](https://arxiv.org/abs/2004.13614)
- Lodder W, de RodaHusman AM (2020) SARS-CoV-2 in wastewater: potential health risk, but also data source. *HepatoL. Lancet Gastroenterol*. [https://doi.org/10.1016/S2468-1253\(20\)30087-X](https://doi.org/10.1016/S2468-1253(20)30087-X)
- López-Feldman A, Chávez C, Vélez MA, Bejarano H, Chimeli AB, Féres J, Robalino J, Salcedo R, Viteri C (2020) Environmental impacts and policy responses to covid-19 (2020): a view from Latin America. *Environ Resource Econ*. <https://doi.org/10.1007/s10640-020-00460-x>
- Lu R, Zhao X, Li J, Niu P, Yang B, Wu H, Wang W, Song H, Huang B, Zhu N, Bi Y, Ma X, Zhan F, Wang L, Hu T, Zhou H, Hu Z, Zhou W, Zhao L, Chen J, Tan W (2020) Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *Lancet (london, England)* 395(10224):565–574. [https://doi.org/10.1016/S0140-6736\(20\)30251-8](https://doi.org/10.1016/S0140-6736(20)30251-8)
- Ma Y, Zhao Y, Liu J, He X, Wang B, Fu S, Yan J, Niu J, Zhou J, Luo B (2020) Effects of temperature variation and humidity on the death of COVID-19 in Wuhan, China. *Sci Total Environ* 724:138226. <https://doi.org/10.1016/j.scitotenv.2020.138226>
- Mahmood A, Eqan M, Pervez S, Alghamdi HA, Tabinda AB, Yasar A, Brindhadevi K, Pugazhendhi A (2020) COVID-19 and frequent use of hand sanitizers; human health and environmental hazards by exposure pathways. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.140561>
- Mandal I, Pal S (2020) COVID-19 pandemic persuaded lockdown effects on environment over stone quarrying and crushing areas. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139281>
- Manenti R, Mori E, Di Canio V, Mercurio S, Picone M, Caffi M, Brambilla M, Ficitola GF, Rubolini D (2020) The good, the bad and the ugly of COVID-19 lockdown effects on wildlife conservation: Insights from the first European locked down country. *Biol Cons*. <https://doi.org/10.1016/j.biocon.2020.108728>
- Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E (2020) Environmental and health impacts of air pollution: a review. *Front Public Health* 8:14. <https://doi.org/10.3389/fpubh.2020.00014>
- Marine D, Mónica FS, Tom B (2019) Disinfection byproducts potentially responsible for the association between chlorinated drinking water and bladder cancer: a review. *Water Res*. <https://doi.org/10.1016/j.watres.2019.07.014>
- Marion JL, Reid SE (2007) Minimising visitor impacts to protected areas: the efficacy of low impact education programmes. *J Sustain Tour* 15(1):5–27
- Matthay MA, Aldrich JM, Gotts JE (2020) Treatment for severe acute respiratory distress syndrome from COVID-19. *Lancet Respir Med*. <https://doi.org/10.1016/S2213>
- Megahed NA, Ghoneim EM (2020) Antivirus-built environment: lessons learned from Covid-19 pandemic. *Sustain Cities Soc*. <https://doi.org/10.1016/j.scs.2020.102350>
- Meseko C, Shittu I, Adedeji A (2020) The bush meat trade thrives in Nigeria despite anxiety over coronavirus. *Transact The Royal Soc Tropical Med Hygiene*. <https://doi.org/10.1093/trstmh/traa060>
- Metcalf CJE, Walter KS, Wesolowski A, Buckee CO, Shevliakova E, Tatem AJ, Boos WR, Weinberger DM, Pitzer VE (2017) Identifying climate drivers of infectious disease dynamics: recent advances and challenges ahead. *Proc R Soc B* 284:20170901. <https://doi.org/10.1098/rspb.2017.0901>
- Ming W, Zhou Z, Ai H, Bi H, Zhong Y (2020) COVID-19 and air quality: evidence from China. *Emerg Mark Financ Trade* 56(10):2422–2442. <https://doi.org/10.1080/1540496X.2020.1790353>
- Mirzaie A, Halaji M, Dehkordi FS, Ranjbar R, Noorbazargan H (2020) A narrative literature review on traditional medicine options for treatment of corona virus disease 2019 (COVID-19). *Complement Ther Clin Pract*. <https://doi.org/10.1016/j.ctcp.2020.101214>
- Mohapatra S (2020) As COVID locks factories, 2% of India's water needs trickles down to reservoirs. In: *The Federal*. <https://thefederal.com/news/as-covid-locks-factories-2-of-indias-water-needs-trickle-down-to-reservoirs/>. Accessed on 10 Jul 2020
- Moon JM, Chun BJ, Min YI (2006) Hemorrhagic gastritis and gas emboli after ingesting 3% hydrogen peroxide. *Int J Emerg Med* 30(4):403–406
- Morawska L, Cao J (2020) Airborne transmission of SARS-CoV-2: The world should face the reality. *Environ Int*. <https://doi.org/10.1016/j.envint.2020.105730>
- Morgan W (2020) Heavy use of hand sanitizer boosts antimicrobial resistance. *PhysOrg* April 17. Retrieved from. <https://phys.org/news/2020-04-heavy-sanitizer-boosts-antimicrobial-resistance.html>. Accessed 30 Sept 2020
- Mori H, Takahashi Y, Zusman E, Mader A, Kawazu E, Otsuka T, Moinuddin M, King P, Elder M, Takai E (2020) Implications of COVID-19 for the Environment and Sustainability; Institute for Global Environmental Strategies: Hayama, Japan, 2020; Available online: <https://www.iges.or.jp/en/pub/covid19-e/en> Accessed on 18 June 2020
- Muhammad S, Long X, Salman M (2020) COVID-19 pandemic and environmental pollution: a blessing in disguise? *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138820>
- Muhammad S, Long X, Salman M (2020b) COVID-19 pandemic and environmental pollution: A blessing in disguise? *Sci Total Environ* 728:138820. <https://doi.org/10.1016/j.scitotenv.2020.138820>
- Nabi G, Wang Y, Hao Y, Khan S, Wu Y, Li D (2020) Massive use of disinfectants against COVID-19 poses potential risks to urban wildlife. *Environ Res* 188:109916. <https://doi.org/10.1016/j.envres.2020.109916>
- Najah A, Teo FY, Chow MF, Huang YF, Latif SD, Abdullah S, Ismailel-Shafie MA (2021) Surface water quality status and prediction during movement control operation order under COVID-19 pandemic: case studies in Malaysia. *Int J Environ Sci Technol* 18:1009–1018. <https://doi.org/10.1007/s13762-021-03139-y>
- Nakada LYK, Urban RC (2020) COVID-19 pandemic: impacts on the air quality during the partial lockdown in São Paulo state. *Total Environ Brazil Sci*. <https://doi.org/10.1016/j.scitotenv.2020.139087>
- Nakata Y, Röst G (2015) Global analysis for spread of infectious diseases via transportation networks. *J Math Biol*. <https://doi.org/10.1007/s00285-014-0801-z>
- NASA (2020) Airborne nitrogen dioxide plummets over China. National Aeronautics and Space Administration. NASA: Earth Observatory. Available at: <https://www.earthobservatory.nasa.gov/images/146362/airborne-nitrogen-dioxide-plummets-over-china>. Accessed 16 Oct 2020
- Nature index (2020) <https://www.natureindex.com/news-blog/the-top-coronavirus-research-articles-by-metrics>. Accessed 17 Sept 2020
- Nava A, Shimabukuro JS, Chmura AA, Luz S (2017) The impact of global environmental changes on infectious disease emergence with a focus on risks for Brazil. *ILAR J* 58(3):393–400. <https://doi.org/10.1093/ilar/ilx034>
- Newsome D (2020) The Collapse of Tourism and Its Impact on Wildlife Tourism Destinations. *J Tourism Futures*. <https://doi.org/10.1108/JTF-04-2020-0053>

- Nghiem LD, Morgan BS, Donner E, Short MD (2020) The COVID-19 pandemic: considerations for the waste and wastewater services sector. *Case Studies Chem Environ Engin* 1:100006–100006
- NOAA (2020). <https://www.esrl.noaa.gov/gmd/ccgg/covid2.html>. Accessed 17 Oct 2020
- Ogen Y (2020) Assessing nitrogen dioxide (NO₂) levels as a contributing factor to coronavirus (COVID-19) fatality. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138605>
- Paital B (2020) Nurture to nature via COVID-19, a self-regenerating environmental strategy of environment in global context. *The Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139088>
- Palmer M, Barth D, Barth D (2020) Chinese cities are rolling out disinfectant tunnels and spray trucks to ward off the Coronavirus - but experts don't think it will work. *Business Insider*. <https://www.businessinsider.in/science/news/chinese-cities-are-rolling-out-disinfectant-tunnels-and-spray-trucks-to-ward-off-the-coronavirus-160but-experts-dont-think-it-will-work/articleshow/74305925.cms>. Accessed on 28 Feb 2020
- Patel PP, Mondal S, Ghosh KG (2020) Some respite for India's dirtiest river? Examining the Yamuna's water quality at Delhi during the COVID-19 lockdown period. *Sci Total Environ* 744: <https://doi.org/10.1016/j.scitotenv.2020.140851>
- Patz JA, Githeko AK, McCarty JP, Hussain S, Confalonieri U, de Wet N (2003) Climate change and infectious diseases. In: McMichael A, Campbell-Lendrum D, Corvalán C, Ebi K, Githeko A, Scheraga J, Woodward A (eds) *Climate Change and Human Health: Risks and Response*. World Health Organization, Geneva
- Peccoud DJ, van den Branden J-C (2020) Covid-19 gives sustainability a dress rehearsal. <https://www.bain.com/insights/covid-19-gives-sustainability-a-dressrehearsal>. Accessed 02 Sept 2020
- Pirouz B, Haghshenas SS, Pirouz B, Haghshenas SS, Piro P (2020) Development of an assessment method for investigating the impact of climate and urban parameters in confirmed cases of COVID-19: a new challenge in sustainable development. *Int J Environ Res Public Health*. <https://doi.org/10.3390/ijerph17082801>
- Pongratz J, Caldeira K, Reick CH, Claussen M (2011) Coupled climate-carbon simulations indicate minor global effects of wars and epidemics on atmospheric CO₂ between AD 800 and 1850. *The Holocene* 21:843–851. <https://doi.org/10.1177/0959683610386981>
- Pope CA, Burnett RT, Turner MC, Cohen A, Krewski D, Jerrett M, Gapstur SM, Thun MJ (2011) Lung cancer and cardiovascular disease mortality associated with ambient air pollution and cigarette smoke: shape of the exposure-response relationships. *Environ Health Perspect* 119(11):1616–1621. <https://doi.org/10.1289/ehp.1103639>
- Prata DN, Rodrigues W, Bermejo PH (2020) Temperature significantly changes COVID-19 transmission in (sub) tropical cities of Brazil. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138862>
- Price K (2020) Poaching, deforestation reportedly on the rise since COVID-19 lockdowns. <https://www.conservation.org/blog/poaching-deforestation-reportedly-on-the-rise-since-covid-19-lockdowns> Accessed on 2 July 2020
- Qi H et al (2020) COVID-19 transmission in Mainland China is associated with temperature and humidity: a time-series analysis. *Sci Total Environ*. 728: <https://doi.org/10.1016/j.scitotenv.2020.138778>
- Riahi N, Gerstoft P (2015) The seismic traffic footprint: tracking trains, aircraft, and cars seismically. *Geophys Res Lett* 42(8):2674–2681. <https://doi.org/10.1002/2015GL063558>
- Riccò M, Ranzieri S, Balzarini F, Bragazzi NL, Corradi M (2020) SARS-CoV-2 infection and air pollutants: correlation or causation? *The Sci Total Environ* 734:139489. <https://doi.org/10.1016/j.scitotenv.2020.139489>
- Ripple WJ, Abernethy K, Betts MG, Chapron G, Dirzo R, Galetti M, Levi T, Lindsey PA, Macdonald DW, Machovina B, Newsome TM, Peres CA, Wallach AD, Wolf C, Young H (2016) Bushmeat hunting and extinction risk to the world's mammals. *Royal Soc Open Sci* 3(10):160498. <https://doi.org/10.1098/rsos.160498>
- Roth A (2020) Wildlife deaths from coronavirus disinfectant use alarm scientists. <https://www.nationalgeographic.com/animals/2020/08/disinfectant-public-cities-pandemic-urban-wildlife-cvd>. Accessed 29 Sept 2020
- Roy D, Tripathy S, Kar SK, Sharma N, Verma SK, Kaushal V (2020) Study of knowledge, attitude, anxiety and perceived mental healthcare need in Indian population during COVID19 pandemic. *Psychiatry Asian J*. <https://doi.org/10.1016/j.ajp.2020.102083>
- Roy S (2020) Wildlife during a pandemic: The other side of the coin. <https://www.downtoearth.org.in/blog/wildlife-biodiversity/wildlife-during-a-pandemic-the-other-side-of-the-coin-72547> Accessed on 30 July 2020
- Ruddiman WF (2003) The anthropogenic greenhouse era began thousands of years ago. *Climatic Change*. <https://doi.org/10.1023/B:CLIM.0000004577.17928.f>
- Rugani B, Caro D (2020) Impact of COVID-19 outbreak measures of lockdown on the Italian Carbon Footprint. *Sci Total Environ*. <https://doi.org/10.1016/j.ajp.2020.102083>
- Rutz C, Loretto MC, Bates AE, Davidson SC, Duarte CM, Jetz W, Johnson M, Kato A, Kays R, Mueller T, Primack RB (2020) COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. *Nature Ecol Evol* 4(9):1156–1159
- Saadat S, Rawtani D, Hussain CM (2020) Environmental perspective of COVID-19. *Sci Total Environ* 728:138870. <https://doi.org/10.1016/j.scitotenv.2020.138870>
- Şahin M (2020) Impact of weather on COVID-19 pandemic in Turkey. *Sci Total Environ* 728:138810. <https://doi.org/10.1016/j.scitotenv.2020.138810>
- Samet JM, Prather K, Benjamin G, Lakdawala S, Lowe JM, Reingold A, Volckens J, Marr L (2021) Airborne transmission of SARS-CoV-2: what we know. *Clin Infect Dis*. <https://doi.org/10.1093/cid/ciab039>
- Sarkis J, Cohen MJ, Dewick P, Schröder P (2020) A brave new world: Lessons from the COVID-19 pandemic for transitioning to sustainable supply and production. *Resour Conserv Recycl* 159:104894. <https://doi.org/10.1016/j.resconrec.2020.104894>
- Schmid BV, Büntgen U, Easterday WR, Ginzler C, Walløe L, Bramanti B, Stenseth NC (2015) Climate-driven introduction of the Black Death and successive plague reintroductions into Europe. *Proc Natl Acad Sci USA* 112(10):3020–3025. <https://doi.org/10.1073/pnas.1412887112>
- Schneider MC, Machado G (2018) Environmental and socioeconomic drivers in infectious disease. *Lancet Planet Health* 2(5):198–199
- Sedlak DL, von Gunten U (2011) The Chlorine Dilemma. *Science*. <https://doi.org/10.1126/science.1196397>
- Selvam S, Jesuraja K, Venkatramanan S, Chung SY, Roy PD, Muthukumara P, Kumar M (2020) Imprints of pandemic lockdown on subsurface water quality in the coastal industrial city of Tuticorin A revival perspective. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139848>
- Semenza JC, Sudre B, Oni T, Suk JE, Giesecke J (2013) Linking environmental drivers to infectious diseases: the European environment and epidemiology network. *PLoS Negl Trop Dis* 2013(7):e2323. <https://doi.org/10.1371/journal.pntd.0002323>
- Setti L, Passarini F, De Gennaro G, Barbieri P, Perrone MG, Borelli M, Palmisani J, Di Gilio A, Torboli V, Fontana F, Clemente L, Pallavicini A, Ruscio M, Piscitelli P, Miani A (2020) SARS-CoV-2 RNA found on particulate matter of Bergamo in Northern Italy: First evidence. *Environ Res*. <https://doi.org/10.1016/j.envres.2020.109754>

- Shakil MH, Munim ZH, Tasnia M, Sarowar S (2020) COVID-19 and the environment: a critical review and research agenda. *The Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.141022>
- Sharma S, Zhang M, Gao J, Zhang H, Kota SH (2020) Effect of restricted emissions during COVID-19 on air quality in India. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.138878>
- Shi P, Dong Y, Yan H, Zhao C, Li X, Liu W, He M, Tang S, Xi S (2020) Impact of temperature on the dynamics of the COVID-19 outbreak in China. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.138890>
- Shi X, Brasseur GP (2020) The response in air quality to the reduction of Chinese economic activities during the COVID-19 outbreak. *Geophys Res Letters.* <https://doi.org/10.1029/2020GL088070>
- Sicard P, De Marco A, Agathokleous E, Feng Z, Xu X, Paoletti E, Rodriguez JJD, Calatayud V (2020) Amplified ozone pollution in cities during the COVID-19 lockdown. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.139542>
- Simon M (2020) The Coronavirus Lockdown Is a Threat for Many Animals, Not a Blessing. *Wired*, Conde Nast. Available online: www.wired.com/story/coronavirus-lockdown-conservation/ Accessed on 12 April 2020
- Singhal S, Matto M (2020) COVID-19 lockdown: a ventilator for rivers. In: Somani M, et al (eds) *DownToEarth*, Bioresource technology reports, 11, p. 100491. <https://www.downtoearth.org.in/blog/covid-19-lockdownventilator-for-rivers-70771>. Accessed 20 May 2020
- Siyabonga S, Cocks T (2020) South Africa dehorn dozens of rhinos to prevent lockdown poaching surge. <https://in.reuters.com/article/us-world-environmentday-safrica-rhinos/south-africa-dehorns-dozens-of-rhinos-to-prevent-lockdown-poaching-surge-idUSKBN23C00B> Accessed on 2 July 2020
- Slaughter RJ, Mason RW, Beasley DMG, Vale JA, Schep LJ (2014) Isopropanol poisoning. *Clin Toxicol* 52:470–478
- Smith KM, Zambrana-Torrel C, White A, Asmussen M, Machalaba C, Kennedy S, Lopez K, Wolf TM, Daszak P, Travis DA, Karesh WB (2017) Summarizing US wildlife trade with an eye toward assessing the risk of infectious disease introduction. *Eco Health* 14:29–39. <https://doi.org/10.1007/s10393-017-1211-7>
- Sobral MFF, Duarte GB, da Penha Sobral AIG, Marinho MLM, de Souza Melo A (2020) Association between climate variables and global transmission of SARS-CoV-2. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.138997>
- Somani M, Srivastava AN, Gummadivalli SK, Sharma A (2020) Indirect implications of COVID-19 towards sustainable environment: an investigation in Indian context, *Bioresource Technol* Volume 11, 2020. ISSN 100491:2589–3014. <https://doi.org/10.1016/j.biteb.2020.100491>
- Song Y, Liu P, Shi XL, Chu YL, Zhang J, Xia J, Gao XZ, Qu T, Wang MY (2020) SARS-CoV-2 induced diarrhoea as onset symptom in patient with COVID-19. *Gut* 69(6):1143–1144. <https://doi.org/10.1136/gutjnl-2020-320891>
- Stadnytskyi V, Bax CE, Bax A, Anfinrud P (2020) The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission. *Proc Natl Acad Sci* 117(22):11875–11877
- Stenseth NC, Samia NI, Viljugrein H, Kausrud KL, Begon M, Davis S, Leirs H, Dubyanskiy VM, Esper J, Ageyev VS, Klassovskiy NL, Pole SB, Chan KS (2006) Plague dynamics are driven by climate variation. *Proc Natl Acad Sci USA* 103(35):13110–13115. <https://doi.org/10.1073/pnas.0602447103>
- Suk JE, Semenza JC (2011) Future infectious disease threats to Europe. *Am J Public Health.* <https://doi.org/10.2105/AJPH.2011.300181>
- Symes WS, Edwards DP, Miettinen J, Rheindt FE, Carrasco LR (2018) Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. *Nat Commun.* <https://doi.org/10.1038/s41467-018-06579-2>
- Tatem AJ, Rogers DJ, Hay SI (2006) Global transport networks and infectious disease spread. *Adv Parasitol* 2006(62):293–343. [https://doi.org/10.1016/S0065-308X\(05\)62009-X](https://doi.org/10.1016/S0065-308X(05)62009-X)
- Tennant WSD, Tildesley MJ, Spencer SEF, Keeling MJ (2020) Climate drivers of plague epidemiology in British India, 1898–1949. *Proc R Soc B* 287:20200538. <https://doi.org/10.1098/rspb.2020.0538>
- Thu TPB, Ngoc PNH, Hai NM, Tuan LA (2020) Effect of the social distancing measures on the spread of COVID-19 in 10 highly infected countries. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.140430>
- Timoshyna, A., Xu, L., Ke, Z., 2020. COVID-19—the role of wild plants in health treatment and why sustainability of their trade matters. <https://www.traffic.org/news/covid-19-the-role-of-wild-plants-in-health-treatment/> Accessed on 2 July 2020
- Tobías A, Carnerero C, Reche C, Massagué J, Via M, Minguillón MC, Alastuey 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.* <https://doi.org/10.1016/j.scitotenv.2020.138540>
- Tokatlı C, Varol M (2021) Impact of the COVID-19 lockdown period on surface water quality in the Meriç-Ergene River Basin. *Northwest Turkey Environ Res* 197:111051. <https://doi.org/10.1016/j.envres.2021.111051>
- UN COMTRADE (2013) Data analyzed from <http://comtrade.un.org/>. Accessed 30 Sept 2020
- UN (2020) This is a time for science and solidarity. <https://www.un.org/en/un-coronavirus-communications-team/time-science-and-solidarity>. Accessed 17 Sept 2020
- van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, Tamin A, Harcourt JL, Thornburg NJ, Gerber SI, Lloyd-Smith JO, de Wit E, Munster VJ (2020) Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *N Engl J Med* 382(16):1564–1567. <https://doi.org/10.1056/NEJMc2004973>
- Vandebroek I, Pieroni A, Stepp JR, Hanazaki N, Ladio A, Alves RRN, Picking D, Delgoda R, Maroyi A, Van Andel T, Quave CL (2020) Reshaping the future of ethnobiology research after the COVID-19 pandemic. *Plants Nat.* <https://doi.org/10.1038/s41477-020-0691-6>
- Velavan TP, Meyer CG (2020) The COVID-19 epidemic. *Tropical Med Int Health* 25(3):278–280. <https://doi.org/10.1111/tmi.13383>
- Wang J, Du G (2020) COVID-19 may transmit through aerosol. *Irish J Med Sci* 1971:1–2
- Wang J, Shen J, Ye D, Yan X, Zhang Y, Yang W, Li X, Wang J, Zhang L, Pan L (2020) Disinfection technology of hospital wastes and wastewater: Suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China. *Environ Pollut.* <https://doi.org/10.1016/j.scitotenv.2020.140430>
- Wang Q, Su M (2020) A preliminary assessment of the impact of COVID-19 on environment a case study of China. *Sci Total Environ.* <https://doi.org/10.1016/j.scitotenv.2020.138915>
- Wang Y, Yuan Y, Wang Q, Liu C, Zhi Q, Cao J (2020) Changes in air quality related to the control of coronavirus in China: Implications for traffic and industrial emissions. *Total Envi Sci.* <https://doi.org/10.1016/j.scitotenv.2020.139133>
- Weber A, Kalema-Zikusoka G, Stevens NJ (2020) Lack of Rule-Adherence during Mountain gorilla tourism encounters in bwindi impenetrable national park, Uganda, places gorillas at risk from human disease. *Front Public Health* 8:1
- WHO (2020a) Transmission of SARS-CoV-2: implications for infection prevention precautions. <https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions>
- WHO (2020b) WHO guidelines on hand hygiene in health care: first global patient safety challenge clean care is safer care. Geneva: the Organization [cited 2020 Apr 08] <https://apps.who.int/iris/>

- [bitstream/handle/10665/44102/9789241597906_eng.pdf](https://doi.org/10.1038/nature05775) External Link.
- Wilson NM, Norton A, Young FP, Collins DW (2020) Airborne transmission of severe acute respiratory syndrome coronavirus-2 to healthcare workers: a narrative review. *Anaesthesia* 75(8):1086–1095. <https://doi.org/10.1111/anae.15093>
- Wolfe ND, Dunavan CP, Diamond J (2007) Origins of major human infectious diseases. *Nature* 447(7142):279–283. <https://doi.org/10.1038/nature05775>
- Wood JL, Leach M, Waldman L, Macgregor H, Fooks AR, Jones KE, Restif O, Dechmann D, Hayman DT, Baker KS, Peel AJ, Kamins AO, Fahr J, Ntiamoa-Baidu Y, Suu-Ire R, Breiman RF, Epstein JH, Field HE, Cunningham AA (2012) A framework for the study of zoonotic disease emergence and its drivers: spillover of bat pathogens as a case study. *Philos Transact Royal Soc London Series B Biol Sci*. <https://doi.org/10.1098/rstb.2012.0228>
- World Bank Report (2020) Global Economic prospects: Chapter 1 Pandemic, Recession: The Global Economy In Crisis.
- World Economic Forum (2020) The COVID-19 recession could be far worse than 2008 – here’s why”, available at: www.weforum.org/agenda/2020/04/mapping-covid19-recession Accessed on 20 May, 2020.
- World Travel and Tourism Council (2020) WTTC messaging, available at: www.wttc.org/members-hub/ Accessed on 9 April 2020.
- Wu F, Zhao S, Yu B, Chen YM, Wang W, Song ZG, Hu Y, Tao ZW, Tian JH, Pei YY, Yuan ML, Zhang YL, Dai FH, Liu Y, Wang QM, Zheng JJ, Xu L, Holmes EC, Zhang YZ (2020) A new coronavirus associated with human respiratory disease in China. *Nature* 579(7798):265–269. <https://doi.org/10.1038/s41586-020-2008-3>
- WWF/Dalberg (2012) Fighting illicit wildlife trafficking: a consultation with governments. WWF International, Gland
- Xie J, Zhu Y (2020) Association between ambient temperature and COVID-19 infection in 122 cities from China. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138201>
- Xu L, Stige LC, Leirs H, Neerinckx S, Gage KL, Yang R, Liu Q, Bramanti B, Dean KR, Tang H, Sun Z, Stenseth NC, Zhang Z (2019) Historical and genomic data reveal the influencing factors on global transmission velocity of plague during the Third Pandemic. *Proc Natl Acad Sci USA* 116(24):11833–11838. <https://doi.org/10.1073/pnas.1901366116>
- Yari S, Moshammer H, Asadi AF (2020) Side effects of using disinfectants to fight COVID-19. *Asian Pacific J Environ Cancer*. <https://doi.org/10.31557/apjec.2020.3.1.9-13>
- Yingzi T, Xiaomin Z (2020) Wildlife unexpected outbreak casualty <https://www.chinadaily.com.cn/a/202002/19/WS5e4cfb14a310128217278bfb.html>. Accessed 30 Oct 2020
- Yoo S, Managi S (2020) Global mortality benefits of COVID-19 action. *Technol Forecast Soc Chang*. <https://doi.org/10.1016/j.techfore.2020.120231>
- You T (2020) More than 100 wild animals drop dead near coronavirus epicentre in china after workers’ sprayed too much disinfectant’ to prevent coronavirus. Mail Online. <https://www.dailymail.co.uk/news/article-8029271/100-wild-animals-drop-dead-near-coronavirus-epicentre.html>. Accessed 13 Oct 2020
- Yu H, Sun X, Solvang WD, Zhao X (2020) Reverse logistics network design for effective management of medical waste in epidemic outbreaks: insights from the coronavirus disease 2019 (COVID-19) Outbreak in Wuhan (China). *Int J Environ Res Public Health* 17(5):1770. <https://doi.org/10.3390/ijerph17051770>
- Yue XL, Gao QX (2018) Contributions of natural systems and human activity to greenhouse gas emissions. *Adv Clim Chang Res* 9(4):243–252. <https://doi.org/10.1016/j.accre.2018.12.003>
- Yunus AP, Masago Y, Hijioka Y (2020) COVID-19 and surface water quality: Improved lake water quality during the lockdown. *Sci Total Environ* 731:139012. <https://doi.org/10.1016/j.scitotenv.2020.139012>
- Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L (2020) Indirect effects of COVID-19 on the environment. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138813>
- Zhang Z, Xue T, Jin X (2020) Effects of meteorological conditions and air pollution on COVID-19 transmission: Evidence from 219 Chinese cities. *Sci Total Environ* 2020(741):140244. <https://doi.org/10.1016/j.scitotenv.2020.140244>
- Zheng B, Geng G, Ciais P, Davis SJ, Martin RV, Meng J, Wu N, Chevallier F, Broquet G, Boersma F, Van der AR (2020b) Satellite-based estimates of decline and rebound in China’s CO₂ emissions during COVID-19 pandemic. Preprint at arXiv <https://arxiv.org/abs/2006.08196v1> (2020).
- Zheng H, Kong S, Chen N, Yan Y, Liu D, Zhu B, Xu K, Cao W, Ding Q, Lan B, Zhang Z, Zheng M, Fan Z, Cheng Y, Zheng S, Yao L, Bai Y, Zhao T, Qi S (2020) Significant changes in the chemical compositions and sources of in Wuhan since the city lockdown as COVID-19. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.140000>
- Zhou P, Yang XL, Wang XG, Hu B, Zhang L, Zhang W, Si HR, Zhu Y, Li B, Huang CL, Chen HD, Chen J, Luo Y, Guo H, Jiang RD, Liu MQ, Chen Y, Shen XR, Wang X, Zheng XS, Shi ZL (2020) A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature* 579(7798):270–273. <https://doi.org/10.1038/s41586-020-2012-7>
- Zhu Y, Xie J, Huang F, Cao L (2020) Association between short-term exposure to air pollution and COVID-19 infection: evidence from China. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.138704>
- Zhu A, Zhu G (2020) Understanding China’s Wildlife Markets: Trade and Tradition in an Age of Pandemic. *World Develop* 136:105108. <https://doi.org/10.1016/j.worlddev.2020.105108>
- Zoran MA, Savastru RS, Savastru DM, Tautan MN (2020) Assessing the relationship between surface levels of PM_{2.5} and PM₁₀ particulate matter impact on COVID-19 in Milan, Italy. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139825>
- Zou Y, Charlesworth E, Yin CQ, Yan XL, Deng XJ, 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

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