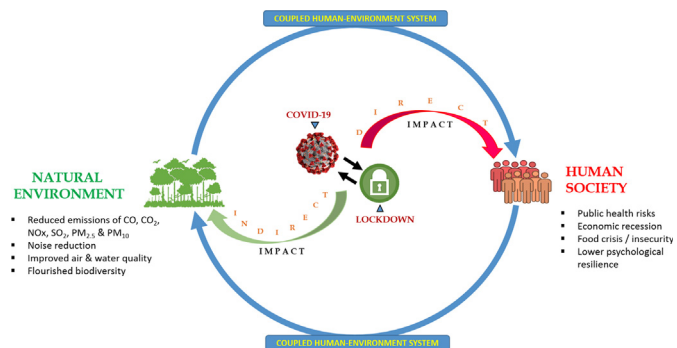Short Communication

Coupled human-environment system amid COVID-19 crisis: A conceptual model to understand the nexus

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HIGHLIGHTS

- A conceptual model to illustrate the complex interactions of the coupled human-environment system amid COVID-19
- The study identified the route of impacts of COVID-19 and governmental measures on the human-environment system
- The model may be considered as a baseline for further studies and may serve as a precursor towards quantitative modeling
- The model may aid in identifying priority areas for discussion and planning in similar crises

GRAPHICAL ABSTRACT

ABSTRACT

The world today is dealing with a havoc crisis due to the pervasive outbreak of COVID-19. As a preventive measure against the pandemic, government authorities worldwide have implemented and adopted strict policy interventions such as lockdown, social distancing, and quarantine to curtail the disease transmission. Consequently, humans have been experiencing several ill impacts, while the natural environment has been reaping the benefits of the interventions. Therefore, it is imperative to understand the interlinked relationship between human society and the natural environment amid the current crisis. Herein, we performed a meta-analysis of existing literature reporting the various impacts of COVID-19 on human society and the natural environment. A conceptual model was developed to portray and address how the interaction of the existing elements of both sub-components of the coupled human-environment system (CHES) – human society and natural environment – are impacted by the government interventions. Results revealed a suite of positive and negative impacts of COVID-19 on both the sub-components. Our model provides an explicit impression of the complex nexus of CHES amid the current crisis. The proposed conceptual model could help in understanding the complex nexus by identifying the route of short-term impacts of COVID-19 measures and thus may aid in identifying priority areas for discussion and planning in similar crises as well.

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1. Introduction

Coupled human-environment system (CHES) represents a complex, dynamic, interconnected, and integrated system in which humans and the natural environment interact with each other (Turner et al., 2003;

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Liu et al., 2007; Galvani et al., 2016). In recent centuries, humans have been remarkably intervening with the environment to fulfill the demands of the growing population and rapid economic development (Myers and Patz, 2009). Such a plethora of anthropogenic interventions poses long-term repercussions i.e., extreme climatic events and other natural calamities, food and water scarcity, increased exposure to infectious diseases, population displacement, etc. on the human society (Myers and Patz, 2009; Galvani et al., 2016). Therefore, understanding the complex CHES is important for recognizing and addressing the vulnerability of the situation on human society, and natural ecosystems amid any local or global crisis (Turner et al., 2003).

The world today is dealing with a havoc crisis due to the pervasive outbreak of coronavirus disease 2019 (COVID-19). The vicious COVID-19 is an infectious disease caused by a new strain of pre-existing coronavirus (Sood et al., 2020) originating from Wuhan Province of China in December 2019, and spreading over 210 countries worldwide (Paital et al., 2020). As of May 13, 2020, the deadly virus has infected 4,223,047 people including 291,519 deaths globally (ECDPC, 2020). The number of deaths caused by COVID-19 has greatly surpassed the other known coronaviruses namely, severe acute respiratory syndrome coronavirus, SARS-CoV, and Middle East respiratory syndrome coronavirus, MERS-CoV (Lin et al., 2020), and exhibits a higher human to human transmissibility (Chan et al., 2020). The pandemic has posed a great threat to the global- public health and economic recession and is still ongoing (Bogoch et al., 2020; Wu et al., 2020). So far, no proven pharmaceutical treatment has been developed to combat the pandemic (Singhal, 2020). Given its severe impact, the World Health Organization (WHO) has declared COVID-19 as a Public Health Emergency of International Concern on January 30, 2020.

As a preventive measure against the pandemic, the government authorities worldwide have implemented and adopted strict policy interventions to maintain social (physical) distancing to curtail the transmission of COVID-19. Almost one-quarter of the global population is now confined within their homes, experiencing several negative/ill impacts in terms of socio-economic and psychological well-being. On the contrary, there are several hidden benefits of the interventions on the environment or natural world. Therefore, it is imperative to understand and appreciate the mutually-affective relationship between human society and the natural environment amid the current crisis (Kumar, 2020a), and identify the priority areas for designing necessary action plans for a balanced state. Although, few studies have highlighted the impacts of COVID-19 and relevant policy actions on the environment and social aspects like economic and health consequences (Hevia and Neumeyer, 2020; Lin et al., 2020; Muhammad et al., 2020; Sharma et al., 2020; Zambrano-Monserrate et al., 2020), the complexity of CHES amid the current crisis has not been well understood. Unpredictability and vulnerability of CHES require a case or situation-specific assessment to consider appropriate relationships of variables with a set of standardized methods (Polsky et al., 2003; Turner et al., 2003). In this regard, our study attempted to understand the processes, responses, and feedbacks within the complex CHES amid the crisis through a conceptual model. Such models are valuable communication tools that represent the current knowledge of a system and illustrate its complex interactions in a simplified way (Gross, 2003; Imgraben et al., 2014). Conceptual models may thus assist in identifying the priority areas that require further research or monitoring and build a basis for discussion and planning (Roman and Barrett, 1999).

The specific objectives of the study were to (i) perform a meta-analysis of existing literature reporting various impacts of COVID-19 on human society and the natural environment, and (ii) develop a conceptual model to illustrate and understand the complex nexus of CHES amid the pandemic. Our conceptual model could be helpful in clearly portraying the complex and coupled nature of the system amid the current crisis. And, thus aid in identifying the priority areas and intrigue the discussion for further planning towards mitigating the effects of the current- as well as similar crisis.

2. Materials and methods

2.1. Data collection and analysis

We performed a systematic review of peer-reviewed scientific articles on the impact of COVID-19 on human society and the natural environment worldwide written in English using the ISI Web of Science (WoS) – Core Collection database published until April 30, 2020 (with an open initial date). A literature search was conducted using a combined search string with two topic fields. Search strings in the first topic field included different terms denoting COVID-19 outbreak, restrictions and their impacts ("COVID-19", 'coronavirus', "pandemic*", "lockdown*", "social distancing*", "positive impact*", "negative impact*"). The second field represented the sub-components of CHES ("human*", "environment*", "wildlife*", "biodiversity*"). The asterisk (*) used with the keywords allowed the flexibility in incorporating plurals (e.g., "impact" or "impacts") or alternative endings (e.g., "environment" or "environmental"). The search returned 354 unique articles (Fig. A.1). All the search returns were filtered through a careful scanning of the title, and abstracts of the peer-reviewed literature. Out of the 354 articles, only 72 studies focused on the various aspects of the COVID-19 pandemic. Of these 72 filtered articles, only 15 studies focused on the positive and negative impacts of COVID-19 on human society and the natural environment (Fig. A.1). Articles not relevant to the present study, e.g., studies describing new techniques to combat the pandemic, and/or studies focusing on the molecular level, transmission or pharmaceutical treatment, etc., were excluded. A list of the peer-reviewed scientific articles referred for model development is provided in Text A.1.

Due to limited peer-reviewed scientific literature on our subject of interest as returned by WoS search, we also considered grey literature (e.g., government documents) published (in the English language) by the Asian Development Bank (ADB), WHO, United Nations (UN), and other government policy briefs. Consideration of grey literature ensures comprehensive and representative inclusion of available research since much expert knowledge is informal and undocumented (Drescher et al., 2013; Haddaway and Bayliss, 2015). In addition, we selectively mined relevant information (in English) that appeared in articles/news by reputed media (e-press and e-magazines) outlets namely, British Broadcasting Corporation (BBC), Cable News Network (CNN), DownToEarth, euronews., Financial Express, India Today, The Atlantic, The Economic Times, The Hindu, The Guardian, The Statesman, The Times of India, The Verge, and Evening Standard, published until May 01, 2020 (with an open initial date). Such media information plays an essential role in keeping the public informed about the recent happenings globally, and are considered to be authoritative and truthful (Happer and Philo, 2013). The list of grey and news/articles referred to in the present study for model development is provided in Text A.2.

2.2. Development of the conceptual model

The conceptual model was developed based on the information collected from the literature review, and the previous experience and expertise of the first author on model development — 'Expert-based models' approach (Ferrier et al., 2016). This was followed by brainstorming amongst all the authors to improvise the model. During the entire process of model development, authors' practical experiences and in-depth understanding of the context of ecological and environmental studies, and associated socio-economic factors were advantageous.

3. Results

3.1. Various impacts of COVID-19 and lockdown/restrictions on CHES

The literature review revealed a suite of impacts (positive and/or negative) of COVID-19 and lockdown/restrictions on human society

and the natural environment (Table 1). Lockdown/restrictions refer to the various combination of policies including social (physical) distancing, quarantine, etc. Results revealed the negative impact of COVID-19 and lockdown/restrictions on the various elements of human society including global public health, global economic recession, the shutdown of workplaces, unemployment/job insecurity, poverty, food & water insecurity, etc. On the contrary, lockdown/restrictions had positive impacts on the natural environment as reflected by cleaner- air & water quality, environmental noise reduction, flourishing/liberating biodiversity/wildlife, etc. (Table 1).

Results also revealed simultaneous negative impacts of lockdown/restrictions on both human society and the natural environment. For instance, increased household & medical wastes, and the reduction in waste recycling due to COVID-19 & lockdown/restrictions had a negative impact on both human society and the environment. On the other hand, simultaneous positive impacts of lockdown/restrictions as reflected by reduced commercial/industrial/cultural wastes, reduced fuel consumption & environmental noise, etc. on both human society and the environment were also recorded (Table 1).

3.2. Description of the conceptual model

The proposed conceptual model comprises of two modules, (i) drivers of change: COVID-19 (direct driver) and lockdown/restrictions (indirect driver), and (ii) our focal point: coupled human-environment system (CHES) (Fig. 1). Drivers of change refer to the factors that directly or indirectly cause changes in nature and its components, anthropogenic assets, and good quality of life (IPBES, https://ipbes.net/glossary/driver). The conceptual model illustrates how the different elements of two sub-systems: human society and natural environment, interact with one another – directly and/or indirectly, through forming a network of associations. The relationship between

Table 1
Various impacts of COVID-19 pandemic and its preventive interventions on human society and the natural environment as revealed through the literature review

Impacts of COVID-19 and lockdown/restrictions	Impact on-		
	Human society	Natural environment	Both
Global public health	🟥		
Limited transportation/movement	🟥	🟩	
Limited mass social-cultural activities	🟥	🟩	
Shutdown of workplaces	🟥	🟩	
Global economic recession	🟥		
Poverty and food- crisis/insecurity	🟥		
Reduced commercial/industrial/cultural wastes			🟩
Increased household/unmanageable wastes			🟥
Increased medical wastes/unmanageable wastes			🟥
Reduced fuel consumption			🟩
Psychological resilience	🟥		
Unemployment/job insecurity	🟥		
Impact on research and education	🟩🟥		
Improved water quality			🟩
Environmental noise reduction			🟩
Reduced emission of CO, CO₂, NOₓ, and SO₂			🟩
Reduced conc. of PM2.5 and PM10			🟩
Improved air quality			🟩
Flourished biodiversity/wildlife		🟩	

the elements of the two sub-systems are depicted by arrows, which also shows the direction of impacts, positive and/or negative (Fig. 1). For example, for the sub-system: human society, limited transportation had a positive impact in containing the disease, thus lowering infection & death. Similarly, limited transportation due to lockdown resulted in reduced fuel consumption, generating positive impacts on the sub-system: natural environment, characterized by reduced- air pollution (lower conc. of CO_2, CO, NOx, PM2.5, PM10) and environmental noise leading to flourished biodiversity/wildlife.

The conceptual model also displays two feedbacks – (i) between the primary and secondary drivers i.e., COVID-19 and lockdown/restrictions, and, (ii) between COVID-19 and the health workers. To illustrate, the spread of the virus has mandated the implementation of lockdown inducing grief to human society worldwide, which on the other hand, had a positive impact on suppressing the pandemic. Fig. 2 summarizes how the individual influences of the current crisis on both human society and the natural environment have impacted CHES interactions and its outcomes.

4. Discussion

4.1. Understanding the complex interactions of CHES amid COVID-19

COVID-19 is considered as one of the worst pandemics in history which has further complicated the entire CHES. Lower adaptability of human society to various socio-environmental crises arises mainly due to the poor understanding of the complex and interconnected nature of the human-environment system (Dearing et al., 2006). Hence, understanding the complexity of any system is pressing to avoid any environmental ensue on a regional or global scale (Roberts et al., 2002). Conceptual models assist in envisioning the complex interactions in a simplified manner and recognize priority areas for the implementation of necessary management strategies. Our conceptual model explicitly illustrates the impacts of COVID-19 and lockdown/restriction – directly or indirectly – against the pandemic on the various elements of the intricate and coupled human-environment system and/or the feedbacks amongst them as described below:

4.1.1. COVID-19 and global public health

As depicted in the model, COVID-19 has a direct negative impact on human health owing to its high risk of infection and death. The fatal impact of COVID-19 on global human health has surpassed the number of infections and deaths caused by its ancestors and is still accelerating (Bogoch et al., 2020; Chan et al., 2020; Lin et al., 2020; Wu et al., 2020). Grech (2020) suggested that the pandemic may lead to half a billion deaths i.e., ~ 6% of the global population or more; likely due to the absence of a concrete approved treatment to combat the pandemic (Singhal, 2020). The pandemic has led to the increased generation of tons of medical/healthcare wastes several folds compared to before the disease outbreak (ADB, 2020; Calma, 2020; ISDM, 2020; Saadat et al., 2020). As highlighted in the model, increased generation of medical wastes, in turn has led to unmanageable medical waste triggering other human health risks (Alverson, 2020; Jiangtao and Zheng, 2020; Zambrano-Monserrate et al., 2020). For example, the health & sanitation workers, rag pickers, trash cleaners, etc. are at high risk of infection due to close contact with the patients and/or unmarked medical wastes such as discarded masks, gloves, etc. (Mallapur, 2020; Saadat et al., 2020).

In addition, the model also depicts the existence of feedback between COVID-19 and health workers. For instance, while the health workers are at the front line of the pandemic outbreak, their exposure to the virus has put them at the risk of infection and death, coupled with other health risks such as fatigue, occupational burnout, psychological distress, etc. making them vulnerable to the current crisis. As of April 12, 2020, the WHO reported that the pandemic has already hit over 22,000 health workers across 52 countries (The Economic Times, 2020a). On the contrary, health workers stand as an important potential
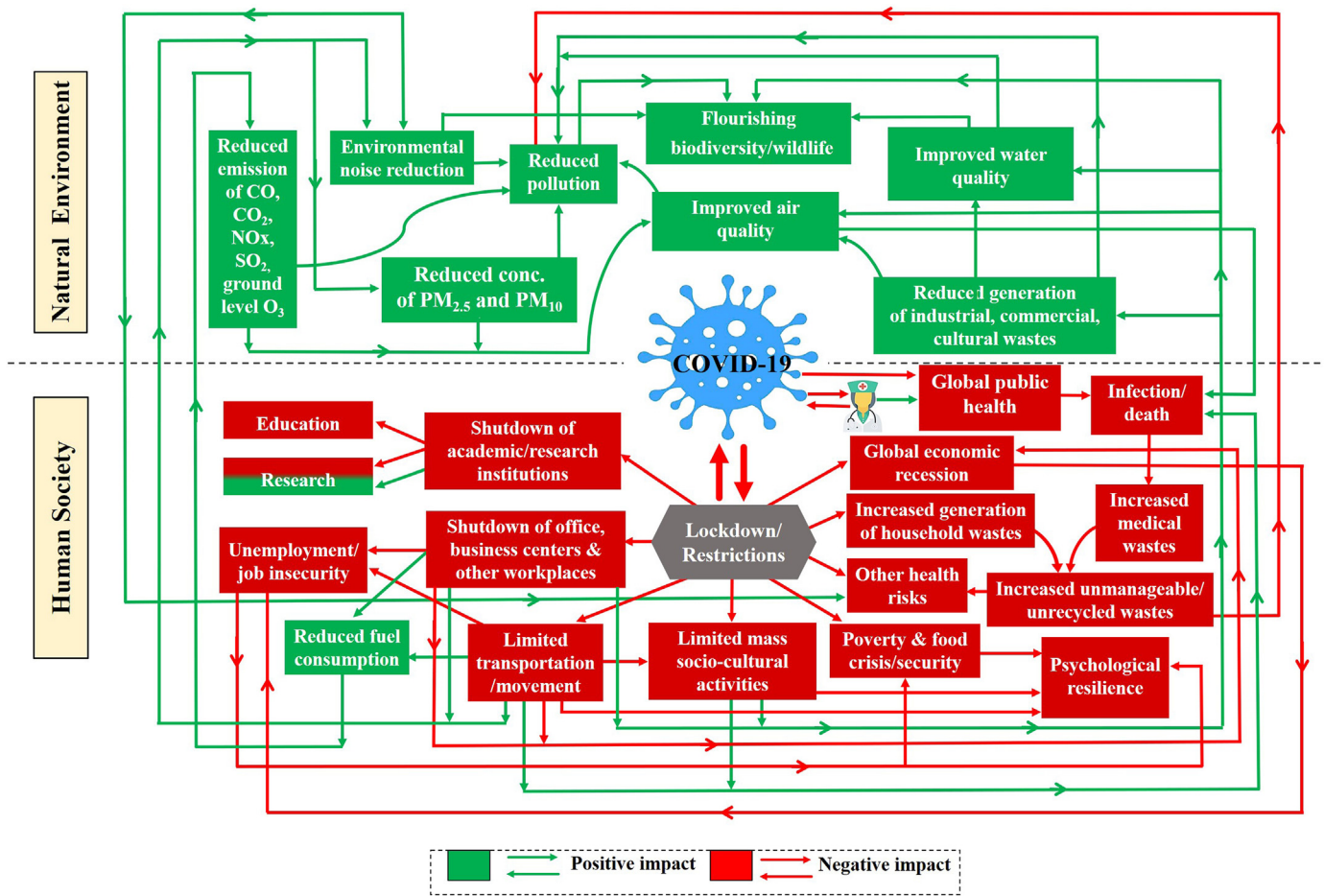
Fig. 1. Conceptual model illustrating the complex nexus of the coupled human-environment system (CHES) amid COVID-19. Arrows represent the direction of impacts and feedback amongst the identified attributes within each sub-component

barrier to minimize the risk of COVID-19 infections and death as feedback and contribute largely to the well-being of the global public.

4.1.2. Lockdown and global economic recession

The pandemic has plunged the entire world into a looming global economic recession (Corlett et al., 2020; Giles et al., 2020; Ozili and Arun, 2020). As depicted in the model, the shutdown of industries, transportation, other workplaces, etc. due to the lockdown against COVID-19 has severely affected the workers leading to unemployment/job insecurity affecting their psychological resilience/mental

Fig. 2. Flow diagram to unfold the individual impact of the current crisis on both human society and natural environment amid COVID-19.

well-being. Billions of poor people engaged in informal employment such as day labor, migrating workers, small-scale producers in the agricultural and non-agricultural sectors, etc. are facing severe repercussions of lockdown in terms of job & income losses. The International Monetary Fund (IMF) reported that the lockdowns have pushed the global economy to the brink faster and is more severe than the 2008 global financial crisis and the Great Depression in the 1930s (Nathan, 2020; Roubini, 2020). According to the UN Department of Economic and Social Affairs (DESA), the pandemic is disrupting global supply chains and international trade, and may shrink the global economy by almost 1% in 2020.

Factors contributing to the economic fallout includes the global stock market, banking and fintech, and major industries – travel, hospitality, oil, sports, entertainment, mining, etc. (Laing, 2020; Ozili and Arun, 2020). Such economic spillover has hit hard on unemployment and job insecurity (Jones et al., 2020; Nathan, 2020), as millions of employees are facing the bleak prospect of losing their jobs as reported by the UN Department of Economic and Social Affairs. According to the Centre for Monitoring Indian Economy (CMIE), as of May 03, 2020, the COVID-19 crisis spiked the country's unemployment rate to 27.11%, which was under 7% before the pandemic outbreak in India. This has imparted a negative impact on the psychological resilience of human society (Li et al., 2020; Qiu et al., 2020; Wang et al., 2020).

4.1.3. Lockdown and poverty & food-crisis/insecurity

The model depicts a direct negative impact of lockdown on human society in terms of inducing poverty and food insecurity/crisis. However, the impact of lockdown on the poor and wealthy sections of
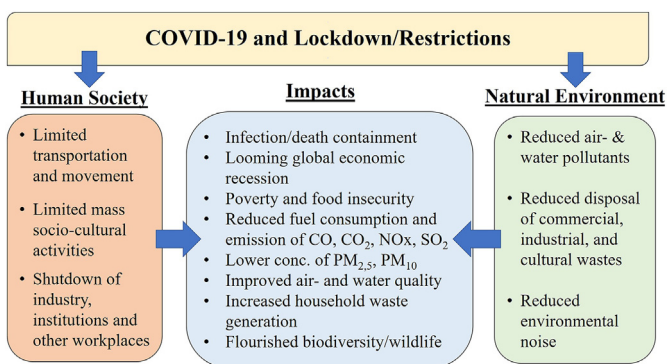
society has been disparate. For instance, while the period of total lockdown has been easier for the rich and middle-class society to pull through with assured incomes, health insurance, adequate spaces at home to maintain physical distancing and running water supplies, daily sustenance of the weaker section of the society has been very miserable. Insecure sources of income for billions of poor people worldwide due to loss of jobs amid lockdown as discussed in Section 4.1.2 have severely affected their livelihoods pushing them towards extreme poverty. In addition to the instability of food availability due to the disrupted supply chains of agricultural inputs and processing of food and other critical goods, the increased food prices have caused food insecurity for the economically weaker section of the society. Studies suggest severe food crisis/insecurity for the poor section of the society due to the prolonged lockdown (Miles, 2020; Richards and Rickard, 2020). These people with low/no income amid lockdown are starving and are unable to afford their daily nutritional supplements to boost their immune system, making them more susceptible to the virus. This would further push the poor towards socio-economic bankruptcy, ultimately affecting their psychological well-being as portrayed in the model. According to an estimate by the UN, the number of people facing severe food insecurity as a result of the lockdown might double to 265 million people by the end of 2020 (Laborde et al., 2020).

4.1.4. Lockdown/restrictions and limited transportation/movement

Our model highlights both positive and negative impacts of lockdown due to the limited- transportation and movement. The model depicts the positive impact of lockdown through limiting movement/ transportation, thus ceasing all events – social, political, sports, academic, and other gatherings (breeding grounds of the virus) to maintain social distancing and curtail the disease transmission as mandated by government authorities worldwide (Financial Express, 2020). More than 3.9 billion people or half of the world's population are currently under containment (Sandford, 2020). Consequently, the lockdown has posed a negative impact on the psychological resilience of people (Holmes et al., 2020; Li et al., 2020; Qiu et al., 2020; Wang et al., 2020). However, it is worth mentioning that homestay due to limited movement may likely bring a positive impact in terms of enhancing the family bonding.

As shown in the model, paralyzed transportation due to lockdown has negatively impacted the global economic recession. For instance, lockdown against COVID-19 has caused the shutdown of national borders in nearly 100 countries which have dropped air travel by 96% (Wallace, 2020), causing a loss of US$ 113 billion to the air travel industry (Appleton, 2020). The tourism industry has also come to halt, causing 1% global economic contraction as reported by the UN (The Statesman, 2020). Similarly, the lockdown has also hit the railway industry in terms of financial loss as reported by Western Railways, Govt. of India (The Economic Times, 2020b). Limited transportation has also caused unemployment and job insecurity for people involved in the private transport sector, which would ultimately affect their psychological resilience.

On the contrary, our model indicates a positive effect of limited transportation/movement in reducing death/infection. Because higher mobility results in a higher risk of infection (Coven and Gupta, 2020). Studies suggest that travel restrictions on the local scale had a marked effect in containing the disease spread on an international scale (Chinazzi et al., 2020; Kraemer et al., 2020). Similarly, restricted congregations for cultural/religious events through the ban of mass social-cultural activities positively impacted on reducing the transmission, thus containing the disease outbreak. In addition, a worldwide halt of transportation due to lockdown has a high positive impact on the natural environment. For example, reduced fuel consumption due to halted transportation has reduced the consumption of fossil fuel by 60% (Business Today, 2020) leading to reduced emission of greenhouse gases such as NOx, SOx, CO, CO_2, and O_3 (the ground-level ozone) (Cadotte, 2020; Dutheil et al., 2020; Huang et al., 2020; Muhammad

et al., 2020; Paital et al., 2020; Shrestha et al., 2020). Also, restricted transportation has contributed to lowering the atmospheric concentration of particulate matters such as PM2.5, PM10 (Cadotte, 2020; Sharma et al., 2020; Shrestha et al., 2020), overall imparting a positive impact on improving the air quality and enhanced visibility. For example, in some of the epicenters of COVID-19 such as Wuhan (China), Italy, Spain, and the USA, the lockdown has reduced the air pollution by 30% as per the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) (Muhammad et al., 2020). ESA also reported the changing density of harmful gases emitted due to fossil fuel burning (Child, 2020). In addition, the carbon emissions in China, the epicenter of the COVID-19 pandemic, has dropped by ~25% over four weeks at the beginning of 2020 (Child, 2020). In northern India, the residents now could view the Himalayan mountain range due to increased visibility, which otherwise has been concealed by pollution for ~30 years (Child, 2020). The air quality index (AQI) in Delhi and NCR's, India, has reduced to 60, which otherwise scores an AQI of 600 during the smoggy winter months (The Economic Times, 2020c). While in Venice, Italy, restrained tourism industries have improved the water quality of winding canals (Child, 2020). Moreover, paralyzed transportation has also plummeted environmental noise due to the slowdown of traffic (Gibney, 2020; Schuster, 2020). All these factors are likely to contribute to the flourishing and liberation of biodiversity and wildlife.

Our model also shows an indirect positive impact of improved air quality in containing the disease transmission and death. Air pollution is known to have a strong association with a high incidence of various respiratory infections (Cipolla et al., 2018; Silva et al., 2014; Zhang et al., 2020), and higher mortality rates (Lelieveld et al., 2015). Evidence shows high cases of COVID-19 in highly polluted areas of China, Italy, and the United States, the countries with higher cases (Pansini and Fornacca, 2020).

4.1.5. Lockdown, waste generation, and other health risks

In addition to the impact of COVID-19 in terms of infection and death as discussed in Section 4.1.1, extended lockdown and stay-at-home regulations against the pandemic has associated human health risks such as weight gains due to sedentary lifestyle, psychological/behavioral changes, etc. (Lippi et al., 2020) as also portrayed in the model. Besides, the restricted movement has led to an amplified generation of household wastes (both organic and inorganic) as a result of increased demand for home delivery of packaged food and other essentials (Zambrano-Monserrate et al., 2020). Waste recycling has come to a grinding halt in the USA and European countries to avoid the risk of contamination and transmission (Zambrano-Monserrate et al., 2020). Higher generation of such unmanaged household wastes in addition to medical wastes (as discussed in Section 4.1.1) has negatively impacted human health by polluting the natural environment in the long run (Zambrano-Monserrate et al., 2020).

4.1.6. Lockdown/restrictions and limited mass socio-cultural activities

Government authorities worldwide have restricted mass socio-cultural activities by restraining cultural/religious functions & congregations, and also other social gatherings (Financial Express, 2020). Our model depicts a positive impact of limited social gatherings due to lockdown in containing the disease transmission. Elsewise, unrestricted religious congregations are known to act as the 'super-spreaders' of COVID-19 infections as witnessed from the South Korea religious convenes (Han and Zhou, 2020), and the Tablighi Zamat Congregation in New Delhi, India (Jeelani et al., 2020), thereby posing substantial challenges in terms of public health (McCloskey et al., 2020). The model also shows a positive impact of limited mass social and religious activities by reducing the generation of cultural wastes including floral waste, idol immersion, and other activities. Studies suggest a positive contribution of limited social and economic activities on environmental pollution reduction (Dutheil et al., 2020). This otherwise, generates tones of solid waste especially in the countries with rich cultural values like

India (Ganga Action Parivaar, Govt. of India, https://www.gangaaction.org/actions/issues/solid-waste/). All these activities are very likely to contribute to flourishing biodiversity/wildlife.

4.1.7. Lockdown and shutdown of workplaces

The shutdown of offices, business centers, industries, and other workplaces due to the pandemic (Muhammad et al., 2020; Richards and Rickard, 2020) has both negative and positive impacts on the CHES as identified in the model. Nickle (2020) suggested that 86% of industry members such as the growers, shippers, retailers have been reported to be affected due to the lockdown. This instigated a high negative impact through a looming global economic recession, leading to unemployment/job insecurity and lower psychological resilience.

On the contrary, the model also identifies the positive impact of the shutdown of workplaces on the natural environment. For example, reduced generation of industrial and commercial wastes contributed to the improvement of air quality, creating a similar situation like halted transportation as discussed in Section 4.1.4. In addition, the shutdown of the industrial sector that releases a huge quantity of pollutants has contributed to improving the air and water quality as identified in the model. For some years now, the River Ganga and Yamuna of India were considered amongst the most polluted water bodies. However, due to the lockdown, the rivers have been reported to appear cleaner and brighter owing to the temporary shutdown of the chemical industries; the major source of river pollution in India (Times of India, 2020; The Economic Times, 2020c). All these factors are likely to contribute to enhancing the overall environmental quality and flourishing biodiversity/wildlife.

4.1.8. Lockdown and environmental noise reduction

Adoption of policy measures like lockdowns and social distancing worldwide have contributed to the reduction of environmental noise as shown in the model. Birdsongs in cities and urban areas have replaced horns and other traffic noises due to fewer cars, trains, buses, planes, etc. as a result of limited transportation and shutdown of construction works (Das, 2020; Koren, 2020; Ro, 2020). In addition, reduced noise levels have brought in other benefits for the wildlife in terms of higher reproductive success, less migration, and lower mortality rates (Ro, 2020). Seismologists suggest that such noise reductions have resulted in less seismic noise, or vibrations in the Earth's crust by ~ one-third compared to pre-lockdown levels (Ro, 2020). Moreover, decreased noise in oceans due to halted cruises is likely to decrease the production of stress hormones in sea fauna (Koren, 2020). As shown in the model, humans are also likely to be beneficial given the harmful physical effect of chronic noise such as high stress, disrupted sleep, high blood pressure, cognitive impairment in children, hearing loss, heart disease, etc. (Ro, 2020).

4.1.9. Lockdown and biodiversity

Owing to the indirect positive impact of lockdown on the natural environment as discussed above, nature is reviving, thereby contributing to flourished wildlife and biodiversity as depicted in the model. Due to the improved water quality in rivers, many of the rare animals have been spotted in the places not seen earlier. For example, the Indian Gangetic dolphins (one of the four freshwater dolphin species in the world and is an IUCN endangered species) could be spotted more in Vikramshila Gangetic Dolphin Sanctuary, Bihar, India, as a result of limited human activity along the River Ganga due to lockdown (Khan, 2020). The presence of dolphins is a bio-indicator of a healthy river ecosystem (Khan, 2020) and hence, the lockdown in human society has turned to be a 'blessing in disguise' for the dolphins. Elsewise, degradation of water quality in Indian rivers due to dumping of municipal and industrial wastes is known to have a negative impact on human health and other aquatic fauna (Ganga Action Plan, Govt. of India, https://www.gangaaction.org/actions/issues/solid-waste/). Das (2020) reported mass nesting of the endangered Olive Ridley sea turtles at Rushikulya rookery in Odisha, India due to the shutdown of touristic activities. In Thailand, restriction of fishing and touristic activities has favored the increased spawning of rare Leatherback sea turtles (a vulnerable IUCN species) (The Guardian, 2020). Basu (2020) reported that restricted transportation due to nationwide lockdown has led to flourishing bird diversity in Kolkata, India.

4.1.10. Lockdown/restrictions and Education & Research

Our model identified the negative impacts of lockdown on education. For instance, government authorities worldwide have mandated shutdown of academic sectors including schools, colleges, and universities in 166 countries to maintain social distancing to curtail the transmission (Corlett et al., 2020). As a result, more than 1.52 billion students, and nearly 60.2 million teachers are no longer in the classroom (UN, 2020), postponing and/or canceling of examinations and subsequent delay in graduating. Nevertheless, the lockdown of academic institutions has provided an opportunity and platform for digital education and online/e-learning. Yet, the negative impacts of lockdown on education is more overpowering on its positive aspect.

On the other hand, we identified both positive and negative impacts of lockdown on research. For instance, the lockdown has frozen many laboratories, and field-based research, thus halting the ongoing research and instigation of new research as well (Corlett et al., 2020). Moreover, travel restrictions have canceled and/or postponed many national and international conferences, meetings, and research stays. Yet, the lockdown has also provided ample time for research and innovations (Paital et al., 2020), and to collaborate amongst the experts globally.

4.2. Uncertainties of COVID-19 on CHES and the health-wealth trade-off

Given the complexity of CHES, the emergence of unprecedented uncertainties is inevitable for a pandemic like COVID-19 which was not evidenced in the last century (WHO, 2020). Uncertainties mainly arise due to limited current knowledge about the virus and how people across the globe modify their behaviors in response to the pandemic (Chater, 2020). Hence, uncertainty can accelerate fear, stress, panic, anxiousness and loss of trust amongst human society, making us powerless over the direction of life (Robinson and Smith, 2020; WHO, 2020). In absence of the COVID-19 vaccine, it is uncertain if the virus will flare up as restriction gets relaxed; or, whether the lockdown & personal safety measures in addition to contact-tracing and testing, might be able to stamp it out. Over time, the ongoing restrictions due to the current crisis are likely to surge the uncertainty over the various elements of human society such as the economy, health, psychological well-being, etc. As discussed in Section 4.1.1, governmental intervention such as strict lockdown has potentially impeded the spreading of the virus saving billions of lives worldwide. However, this has come at the cost of doomed economy and income loss due to the shutdown of industry and transportation sectors, etc. as discussed in Section 4.1.2, creating a 'health–wealth trade-off'. In the opposite scenario, the relaxation of lockdown would involve a reverse trade-off where the economy recovers at the expense of an increased threat of mass contamination and death. It is therefore uncertain or unclear to decide the best policy measure yet as COVID-19 would take a toll either way. This scenario is likely to be worse especially in the developing countries due to the differences in population structure, fiscal capacity, healthcare capacity, higher prevalence of "hand-to-mouth" households, and the size of the informal sector (Alon et al., 2020). Herein, the quantification of trade-offs for a better understanding of the current crisis is urgent for the decision-makers to develop effective policy measures that account for different resource allocation strategies (Daher and Mohtar, 2015). Such quantitative analyses may also assist in understanding how the different policy response priorities to the current pandemic should differ in the developed and developing nations (Alon et al., 2020).

Another important instance worth mentioning amid the current crisis is the differential scenario of water security in the developed and

developing world. Until the discovery of medicine or vaccine to control the disease, the WHO has recommended basic protection measures such as the frequent washing of hands and the use of face masks & hand gloves to curtail/spread the virus infection, in addition to maintaining social (physical) distancing. While frequent hand washing is well-practiced in the rich/developed societies/countries having better availability of safe water, millions of people especially in the poor countries/societies are highly susceptible to the virus due to the lack of safe water supply (Ndaw, 2020). However, in a world with the frequent outbreak of similar pandemics, it is uncertain if only the countries/communities with low/no access to safe water would be affected more. There is a high chance of water scarcity due to water overuse for domestic and hygiene-related practices to prevent or suppress the potential pandemics throughout the world irrespective of its economic stability (Kumar, 2020b; Rohila, 2020).

The abatement of air pollution due to lockdown is another instance with high uncertainty. Although the emission of CO_2 has reduced due to the lockdown/restrictions as discussed in Section 4.1.4, such short-term drops in gas emissions are likely to have very little impact on the overall CO_2 concentration in the atmosphere given its relentless pile-up and longer residence in the atmosphere.

As mentioned in Section 4.1.9, flourished biodiversity due to governmental interventions has been one of the bright sides of the current crisis for the natural environment. However, it is uncertain if such liberation would be favorable for the wildlife in the long run. As wild animals venture into settlement areas and human-modified landscapes in search of food and resources, unexpected threats such as human-animal conflicts might arise. This may favor the poachers and opportunistic delinquents as the lockdown prevails, ultimately leading to conservation threats. In addition, the toll on the global economies might also reflect in reduced funding for wildlife conservation and management. Illegal encroachment of forested lands is also likely to arise when the forest officials split their time between regular duties and helping out with the COVID-19 situation. Another instance could be the risk for biodiversity and natural habitat by forcing poor people to adopt hunting and illicit lopping of trees for daily livelihood sustenance as a result of the loss of employment as mentioned in Section 4.1.7. In-depth and country-tailored assessment & quantification of such uncertainties through developing multiple scenarios for both the developed and developing nations is therefore important to better understand the long-term impacts of such crises on CHES. Future studies may consider quantifying the trade-offs and uncertainties of the current crisis on CHES to assist the decision-makers for better policy-making process.

Overall, our study demonstrates how the different policy actions i.e., lockdown, social-distancing, quarantine, etc. against COVID-19 has changed the way CHES interacts and influences each other. Although the crisis has instigated severe ill impacts on human society, it has proved to be a 'blessing in disguise' for the natural environment as discussed in Sections 4.1.6, 4.1.8, & 4.1.9. Restricted/regulated anthropogenic interventions against COVID-19 have given rise to a better natural environment for which governments and scientists worldwide have been investing time and money for decades. On the contrary, the current situation urges for the adoption of preventive measures to mitigate ill effects faced by human society as discussed in Sections 4.1.1–4.1.5, 4.1.7, & 4.1.10. However, the recent situation does not reflect sustainable earth, given the overpowering negative impact of the current crisis on human society. Thus, even if the natural environment is benefited due to the ongoing crisis, several uncertainties persist as discussed in Section 4.2. The situation is likely to reverse once the lockdown is withdrawn, and both the sub-systems would be affected – the worst-case scenario. Over the centuries, humans have imposed dazzled pressure on nature and experienced its repercussions from time to time. Thus, in both cases, the benefits are short-term, which is likely to lead to a pessimistic future where both the sub-system of CHES is negatively affected. Thus, with a prolonged crisis, it is likely that the aspects of CHES would give rise to several trade-offs and many more uncertainties as

discussed in Section 4.2. Our study, therefore recommends that new policies should aim to convert the short-term gains into long-term benefits, creating an optimistic post-coronavirus world, beneficial for both the sub-systems. Given the fact that the human sub-component of CHES is experiencing the worst impacts of the crisis, policy actions should primarily focus on mitigating the ill impacts faced by human society. In this regard, our model could help identify the priority areas to understand the vulnerability of the current situation. However, incorporating the perspective of the local stakeholders and policymakers is important while developing a conceptual model. This allows covering the gaps and variations in external political and economic forces on the regional and local environment, which is a limitation of the present study given the sensitivity of the current crisis.

5. Conclusion

The COVID-19 crisis might be an 'eye-opener' for humanity. The current predicament reflects that nature has the potential to revive itself given that the anthropogenic interventions are checked. Therefore, it is high time to understand and appreciate the complexity of CHES and adopt appropriate measures towards tackling the current crisis while maintaining harmony with nature. The main purpose of the study was to propose a conceptual model to portray and address how the interaction of the existing elements of both sub-components of CHES – human society and natural environment – are impacted by the various governmental interventions i.e., lockdown, social distancing, quarantine, etc. towards combating the crisis. The merit of our model is that it comprises all possible elements of CHES and provides an explicit impression of complex CHES amid the crisis. The proposed conceptual model provides an insight into the intricate linkage of CHES and helps in understanding the complex nexus by identifying the route of short-term impacts of COVID-19 measures. Thus, our model may be considered as a baseline for further studies and may serve as a precursor towards building quantitative modeling. The model thus may aid in policymaking by identifying the priority areas for discussion and planning in similar crises as well. Future studies may focus on forecasting the long-term impacts of the current crisis through developing scenarios considering the different components of the CHES identified in the present study.

CRediT authorship contribution statement

Priyanka Sarkar: Conceptualization, Data curation; Formal analysis, Methodology, Model Development, Writing - original draft, review & editing. **Nirmal Debnath:** Conceptualization, Data curation, Formal analysis, Contribution in Model Development, Writing- Reviewing, and Editing. **Demsai Reang:** Data curation, Formal analysis, Contribution in Model Development, Writing- Reviewing, and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.141757.

References

Alon, T.M., Kim, M., Lagakos, D., VanVuren, M., 2020. How Should Policy Responses to the COVID-19 Pandemic Differ in the Developing World? (No. w27273). National Bureau of Economic Research https://www.nber.org/papers/w27273 (Last accessed on July 25, 2020).

Alverson, K., 2020, April 9. Healthcare waste: what to do with it? UN environment Programme. https://www.unenvironment.org/news-and-stories/story/healthcare-waste-what-do-it.

Appleton, P., 2020, March 9. Potential for Revenue Losses of $113bn Due to COVID-19 "Crisis". Airlines https://airlines.iata.org/news/potential-for-revenue-losses-of-113bn-due-to-covid-19-%E2%80%9Ccrisis%E2%80%9D Last accessed on April 29, 2020.

Asian Development Bank, 2020. Managing infectious medical waste during the COVID-19 pandemic. https://www.adb.org/sites/default/files/publication/578771/managing-medical-waste-covid19.pdf.

Basu, J., 2020, April 06. COVID-19: Sounds of Birds Replace Noise Pollution in Kolkata. DownToEarth https://www.downtoearth.org.in/news/environment/covid-19-sounds-of-birds-replace-noise-pollution-in-kolkata-70241 Last accessed on April 26, 2020.

Bogoch, I.I., Watts, A., Thomas-Bachli, A., Huber, C., Kraemer, M.U.G., Khan, K., 2020. Pneumonia of unknown etiology in Wuhan, China: potential for international spread via commercial air travel. J. Travel Med. 27, 008. https://doi.org/10.1056/NEJMoa2002032.

Business Today, 2020, April 17. Lockdown impact: Indian fuel consumption drop 60% in April. https://www.businesstoday.in/sectors/energy/lockdown-impact-indian-fuel-consumption-drop-60-in-april/story/401318.html.

Cadotte, M., 2020. Early Evidence That COVID-19 Government Policies Reduce Urban Air Pollution. EarthArXiv preprints. https://doi.org/10.31223/osf.io/nhgj3.

Calma, J., 2020, March 26. The COVID-19 Pandemic is Generating Tons of Medical Waste. The Verge https://www.theverge.com/2020/3/26/21194647/the-covid-19-pandemic-is-generating-tons-of-medical-waste Last accessed on April 22, 2020.

Chan, J.F., Yuan, S., Kok, K.H., To, K.K., Chu, H., Yang, J., et al., 2020. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. Lancet 395, 514–523. https://doi.org/10.1016/S0140-6736(20)30154-9.

Chater, N., 2020. Facing up to the uncertainties of COVID-19. Nat. Hum. Behav. 4, 439. https://doi.org/10.1038/s41562-020-0865-2.

Child, D., 2020, April 03. The Positive Impacts on the Environment since the Coronavirus Lockdown Began. Evening Standard. https://www.standard.co.uk/news/world/positive-impact-environment-coronavirus-lockdown-a4404751.html.

Chinazzi, M., Davis, J.T., Ajelli, M., Gioannini, C., Litvinova, M., Merler, S., et al., 2020. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. Science 368, 395–400. https://doi.org/10.1126/science.aba9757.

Cipolla, M., Sorgenti, M., Gentile, C., Bishara, M.M., 2018. Air pollution and lung diseases. Clinical Handbook of Air Pollution-Related Diseases. Springer, Cham, pp. 327–339.

Corlett, R.T., Primack, R.B., Devictor, V., Maas, B., Goswami, V.R., Bates, A.E., et al., 2020. Impacts of the coronavirus pandemic on biodiversity conservation. Biol. Conserv. 246, 108571. https://doi.org/10.1016/j.biocon.2020.108571.

Coven, J., Gupta, A., 2020. Disparities in mobility responses to COVID-19. NYU Stern Working Paper.

Daher, B.T., Mohtar, R.H., 2015. Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making. Water Int. 40, 748–771. https://doi.org/10.1080/02508060.2015.1074148.

Das, S.K., 2020, April 26. Undisturbed Mass Nesting of Olive Ridleys at Odisha's Rushikulya Rookery. The Hindu. https://www.thehindu.com/sci-tech/energy-and-environment/coronavirus-lockdown-undisturbed-mass-nesting-of-olive-ridleys-at-odishas-rushikulya-rookery/article31166566.ece. Last accessed on April 29, 2020.

Dearing, J.A., Battarbee, R.W., Dikau, R., Larocque, I., Oldfield, F., 2006. Human-environment interactions: learning from the past. Reg. Environ. Chang. 6, 1–16. https://doi.org/10.1007/s10113-005-0011-8.

Drescher, M., Perera, A.H., Johnson, C.J., Buse, L.J., Drew, C.A., Burgman, M.A., 2013. Toward rigorous use of expert knowledge in ecological research. Ecosphere 4, 1–26. https://doi.org/10.1890/ES12-00415.1.

Dutheil, F., Baker, J.S., Navel, V., 2020. COVID-19 as a factor influencing air pollution? Environ. Pollut. 263, 114466. https://doi.org/10.1016/j.envpol.2020.114466.

ECDPC (European Centre for Disease Prevention and Control), 2020. An agency of the European Union. Geographical distribution of 2019-nCov cases. https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases. (Accessed 13 May 2020).

Ferrier, S., Ninan, K.N., Leadley, P., Alkemade, R., Acosta, L.A., Akçakaya, H.R., et al., 2016. IPBES: the methodological assessment report on scenarios and models of biodiversity and ecosystem services. Secretariat of the intergovernmental science-policy platform on biodiversity and ecosystem services, Bonn, Germany. www.efdinitiative.org.

Financial Express, 2020, April 15. Lockdown 2.0: Centre bars all social, political, religious activities till may 3. https://www.financialexpress.com/india-news/lockdown-2-0-centre-bars-all-social-political-religious-activities-till-may-3/1928855/?fbclid=IwAR0JJtQXpZtFYLLCusFo3xcbEIH8TA3p5V6wiwe_aQ0rC50wu4FHMmW-b1M. (Accessed 29 April 2020).

Galvani, A.P., Bauch, C.T., Anand, M., Singer, B.H., Levin, S.A., 2016. Human–environment interactions in population and ecosystem health. Proc. Natl. Acad. Sci. U. S. A. 113, 14502–14506. https://doi.org/10.1073/pnas.1618138113.

Gibney, E., 2020, March 31. Coronavirus Lockdowns Have Changed the Way Earth Moves. Nature; https://www.nature.com/articles/d41586-020-00965-x. accessed 15 April, 2020.

Giles, C., Greeley, B., Arnold, M., 2020, March 15. Global Recession Already Here, Say Top Economists. Financial Times https://www.ft.com/content/be732afe-6526-11ea-a6cd-df28cc3c6a68. (Accessed 11 April 2020).

Grech, V., 2020. Unknown unknowns – COVID-19 and potential global mortality. Early Hum. Dev. 144, 105026. https://doi.org/10.1016/j.earlhumdev.2020.105026.

Gross, J.E., 2003. Developing conceptual models for monitoring programs. http://npshistory.com/publications/interdisciplinary/im/conceptual-model-overview.pdf. (Accessed 13 July 2020).

Haddaway, N.R., Bayliss, H.R., 2015. Shades of grey: two forms of grey literature important for reviews in conservation. Biol. Conserv. 191, 827–829. https://doi.org/10.1016/j.biocon.2015.08.018.

Han, G., Zhou, Y., 2020. Possibly critical role of wearing masks in general population in controlling COVID-19. J. Med. Virol. 2020, 1–3. https://doi.org/10.1002/jmv.25886.

Happer, C., Philo, G., 2013. The role of the media in the construction of public belief and social change. J. Soc. Pol. Psychol. 1, 321–336. https://doi.org/10.5964/jspp.v1i1.96.

Hevia, C., Neumeyer, A., 2020. A conceptual framework for analyzing the economic impact of COVID-19 and its policy implications. UNDP Latin America and the Caribbean, COVID 19 | policy documents series. https://www.latinamerica.undp.org/content/rblac/en/home/library/crisis_prevention_and_recovery/a-conceptual-framework-for-analyzing-the-economic-impact-of-covi.html?cq_ck=1585494945358. (Accessed 6 May 2020).

Holmes, E.A., O'Connor, R.C., Perry, V.H., Tracey, I., Wessely, S., Arseneault, L., et al., 2020. Multidisciplinary research priorities for the COVID-19 pandemic: a call for action for mental health science. Lancet Psychiat 7, 547–560. https://doi.org/10.1016/S2215-0366(20)30168-1.

Huang, X., Ding, A., Gao, J., Zheng, B., Zhou, D., Qi1, X., et al., 2020. Enhanced Secondary Pollution Offset Reduction of Primary Emissions During COVID-19 lockdown in China. EarthArXiv preprints. https://doi.org/10.31223/osf.io/hvuzy.

Imgraben, S., Auricht, C., Baskerville, L., Walker, K., 2014. Development of conceptual models for major social and ecological systems in the South East NRM Region. Report Prepared for SE NRM Board by Auricht Projects, Brighton, South Australia.

Indian School of Development Management, 2020, April 10. Another Crisis in the Making: COVID-19 and India's Bio-Medical Waste. Youth Ki Awaaz https://www.youthkiawaaz.com/2020/04/another-crisis-in-the-making-covid-19-and-indias-bio-medical-waste/. (Accessed 11 April 2020).

Jeelani, G., Pandey, M.C., Haider, T., 2020, April 1. Coronavirus in India: Tablighi Jamaat meet turns Covid-19 super spreader. India Today. https://www.indiatoday.in/mail-today/story/coronavirus-in-india-tablighi-jamaat-meet-turns-covid-19-super-spreader-1661958-2020-04-01. (Accessed 1 May 2020).

Jiangtao, S., Zheng, W., 2020, March 5. Coronavirus: China Struggling to Deal with Mountain of Medical Waste Created by Epidemic. South China Morning Post https://www.nationalobserver.com/2020/04/17/opinion/10-lessons-covid-19-could-help-us-save-planet. (Accessed 11 April 2020).

Jones, L., Palumbo, D., Brown, D., 2020, April 30. Coronavirus: A Visual Guide to the Economic Impact. BBC https://www.bbc.com/news/business-51706225. (Accessed 1 May 2020).

Khan, M.I., 2020, April 15. COVID-19 Lockdown a Blessing for the Endangered Gangetic Dolphin in Bihar: Experts. DownToEarth https://www.downtoearth.org.in/news/wildlife-biodiversity/covid-19-lockdown-a-blessing-for-the-endangered-gangetic-dolphin-in-bihar-experts-70470. (Accessed 29 April 2020).

Koren, M., 2020, April 02. The Pandemic Is Turning the Natural World Upside Down. The Atlantic https://www.theatlantic.com/science/archive/2020/04/coronavirus-pandemic-earth-pollution-noise/609316/. (Accessed 29 April 2020).

Kraemer, M.U., Yang, C.H., Gutierrez, B., Wu, C.H., Klein, B., Pigott, D.M., et al., 2020. The effect of human mobility and control measures on the COVID-19 epidemic in China. Science 368, 493–497. https://doi.org/10.1126/science.abb4218.

Kumar, P., 2020, Mrch 31a. COVID-19 and the Nature Trade-off Paradigm. UN Environment Programme https://www.unenvironment.org/news-and-stories/story/covid-19-and-nature-trade-paradigm. (Accessed 25 April 2020).

Kumar, S.T.R., 2020, March 29b. COVID-19: Water Scarcity Lurking in Crisis? Deccan Herald https://www.deccanherald.com/national/covid-19-water-scarcity-lurking-in-crisis-818856.html. (Accessed 31 July 2020).

Laborde, D., Martin, W., Vos, R., 2020, April 20. Poverty and Food Insecurity Could Grow Dramatically as COVID-19 Spreads. International food policy research institute https://www.ifpri.org/blog/poverty-and-food-insecurity-could-grow-dramatically-covid-19-spreads. (Accessed 28 April 2020).

Laing, T., 2020. The economic impact of the coronavirus 2019 (Covid-2019): implications for the mining industry. Extr. Ind. Soc. 7, 580–582. https://doi.org/10.1016/j.exis.2020.04.003.

Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., Pozzer, A., 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525, 367–371. https://doi.org/10.1038/nature15371.

Li, S., Wang, Y., Xue, J., Zhao, N., Zhu, T., 2020. The impact of COVID-19 epidemic declaration on psychological consequences: a study on active Weibo users. Int. J. Environ. Res. Public Health 17, e2032. https://doi.org/10.3390/ijerph17062032.

Lin, Q., Zhao, S., Gao, D., Lou, Y., Yang, S., Musa, S.S., et al., 2020. A conceptual model for the coronavirus disease 2019 (COVID-19) outbreak in Wuhan, China with individual reaction and governmental action. Int. J. Infect. Dis. 93, 211–216. https://doi.org/10.1016/j.ijid.2020.02.058.

Lippi, G., Henry, B.M., Bovo, C., Sanchis-Gomar, F., 2020. Health risks and potential remedies during prolonged lockdowns for coronavirus disease 2019 (COVID-19). Diagnosis 7, 85–90. https://doi.org/10.1515/dx-2020-0041.

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., et al., 2007. Complexity of coupled human and natural systems. Science 317, 1513–1516. https://doi.org/10.1126/science.1144004.

Mallapur, C., 2020, April 09. Sanitation Workers at Risk From Discarded Medical Waste Related To Covid-19. Bloomberg Quint https://www.bloombergquint.com/coronavirus-outbreak/sanitation-workers-at-risk-from-discarded-medical-waste-related-to-covid-19. (Accessed 22 April 2020). .

McCloskey, B., Zumla, A., Ippolito, G., Blumberg, L., Arbon, P., Cicero, A., et al., 2020. Mass gathering events and reducing further global spread of COVID-19: a political and public health dilemma. Lancet 395, 1096–1099. https://doi.org/10.1016/S0140-6736(20)30681-4.

Miles, A., 2020. If we get food right, we get everything right: rethinking the food system in post-COVID-19 Hawai'i. http://hdl.handle.net/10790/5248. (Accessed 13 July 2020). .

Muhammad, S., Long, X., Salman, M., 2020. COVID-19 pandemic and environmental pollution: a blessing in disguise? Sci. Tot. Environ. 728, 138820. https://doi.org/10.1016/j.scitotenv.2020.138820.

Myers, S.S., Patz, J.A., 2009. Emerging threats to human health from global environmental change. Annu. Rev. Environ. Resour. 34, 223–252. https://doi.org/10.1146/annurev.environ.033108.102650.

Nathan, N., 2020, April 21. Impact of the Coronavirus Pandemic on the World Economy and how India is Placed. The Economic Times https://economictimes.indiatimes.com/wealth/personal-finance-news/impact-of-the-coronavirus-pandemic-on-the-world-economy-and-how-india-is-placed/articleshow/75217253.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst. (Accessed 29 April 2020). .

Ndaw, F., 2020, April 30. COVID-19: Solving Africa's Water Crisis is More Urgent than Ever. World Bank Blogs https://blogs.worldbank.org/nasikiliza/covid-19-solving-africas-water-crisis-more-urgent-ever. (Accessed 31 July 2020). .

Nickle, A., 2020, March 13. How the Coronavirus is Affecting the Produce Industry. The Packer https://www.thepacker.com/article/how-coronavirus-affecting-produce-industry?. (Accessed 11 April 2020). .

Ozili, P.K., Arun, T.G., 2020. Spillover of COVID-19: impact on the global economy. MPRA Paper 99317. University Library of Munich, Germany https://doi.org/10.2139/ssrn.3562570.

Paital, B., Das, K., Parida, S.K., 2020. Inter nation social lockdown versus medical care against COVID-19, a mild environmental insight with special reference to India. Sci. Tot. Environ. 728, 138914. https://doi.org/10.1016/j.scitotenv.2020.138914.

Pansini, R., Fornacca, D., 2020. Initial Evidence of Higher Morbidity and Mortality Due to SARS-CoV-2 in Regions With Lower Air Quality. MedRxiv preprint. https://doi.org/10.1101/2020.04.04.20053595.

Polsky, C., Schroter, D., Patt, A., Corell, R. W., Eckley, N., Gaffin, S., et al., 2003. Assessing Vulnerabilities to the Effects of Global Change: An Eight-Step Approach. Research and Assessment Systems for Sustainability Program Discussion Paper 2003–05. Cambridge, MA: Environment and Natural Resources Program, Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University. https://www.belfercenter.org/sites/default/files/files/publication/2003-05.pdf. accessed July 20, 2020.

Qiu, J., Shen, B., Zhao, M., Wang, Z., Xie, B., Xu, Y., 2020. A nationwide survey of psychological distress among Chinese people in the COVID-19 epidemic: implications and policy recommendations. Gen. Psychiatr. 33, e100213. https://doi.org/10.1136/gpsych-2020-100213.

Richards, T., Rickard, B., 2020. COVID-19 impact on fruit and vegetable markets. Can. J. Agr. Econ. 68, 189–194. https://doi.org/10.1111/cjag.12231.

Ro, C., 2020, April 19. Is Coronavirus Reducing Noise Pollution? Forbes https://www.forbes.com/sites/christinero/2020/04/19/is-coronavirus-reducing-noise-pollution/#7544462766f4. (Accessed 29 April 2020).

Roberts, C.A., Stallman, D., Bieri, J.A., 2002. Modeling complex human–environment interactions: the Grand Canyon river trip simulator. Ecol. Model. 153, 181–196. https://doi.org/10.1016/S0304-3800(01)00509-9.

Robinson, L., Smith, M., 2020. Dealing with Uncertainty During the Coronavirus Pandemic. HelpGuide https://www.helpguide.org/articles/anxiety/dealing-with-uncertainty.htm. (Accessed 25 July 2020).

Rohila, S.K., 2020, March 21. COVID-19 Outbreak: More Hand Washing Can Increase India's Water Woes. DownToEarth https://www.downtoearth.org.in/blog/water/covid-19-outbreak-more-hand-washing-can-increase-india-s-water-woes-69900. (Accessed 31 July 2020). .

Roman, C.T., Barrett, N.E., 1999. Conceptual Framework for the Development of Long-Term Monitoring Protocols at Cape Cod National Seashore. USGS Cooperative Park Study Unit. University of Rhode Island, Narragansett, RI.

Roubini, N., 2020, April 06. This is What the Economic Fallout from Coronavirus Could Look like? World Economic Forum https://www.weforum.org/agenda/2020/04/depression-global-economy-coronavirus/. (Accessed 29 April 2020).

Saadat, S., Rawtani, D., Hussain, C.M., 2020. Environmental perspective of COVID-19. Sci. Total Environ. 728, 138870. https://doi.org/10.1016/j.scitotenv.2020.138870.

Sandford, A., 2020, April 03. Coronavirus: Half of Humanity Now on Lockdown as 90 Countries Call for Confinement. euronews https://www.euronews.com/2020/04/02/coronavirus-in-europespain-s-death-toll-hits-10-000-after-record-950-new-deaths-in-24-hou. (Accessed 29 April 2020). .

Schuster, K., 2020, March 16. Coronavirus Lockdown Gives Animals Rare Break from Noise Pollution. DW https://www.dw.com/en/coronavirus-lockdown-gives-animals-rare-break-from-noise-pollution/a-53106214. (Accessed 25 April 2020). .

Sharma, S., Zhang, M., Gao, J., Zhang, H., Kota, S.H., 2020. Effect of restricted emissions during COVID-19 on air quality in India. Sci. Total Environ. 728, 138878. https://doi.org/10.1016/j.scitotenv.2020.138878.

Shrestha, A.M., Shrestha, U.B., Sharma, R., Bhattarai, S., Tran, H.N.T., Rupakheti, M., 2020. Lockdown Caused by COVID-19 Pandemic Reduces Air Pollution in Cities Worldwide. EarthArXiv preprints. doi:10.31223/osf.io/edt4j.

Silva, D.R., Viana, V.P., Müller, A.M., Livi, F.P., Dalcin, P.T., 2014. Respiratory viral infections and effects of meteorological parameters and air pollution in adults with respiratory symptoms admitted to the emergency room. Influenza Other Respir. Viruses 8 (1), 42–52. https://doi.org/10.1111/irv.12158.

Singhal, T., 2020. A review of coronavirus disease-2019 (COVID-19). Indian J. Pediatr. 87, 281–286. https://doi.org/10.1007/s12098-020-03263-6.

Sood, A., Barwal, A., Gupta, A.K., Kishore, J., 2020. Novel coronavirus epidemic: new dimension for disaster management and health resilience. Curr. Sci. 118, 1149–1150.

The Economic Times, 2020, April 12a. WHO says over 22,000 healthcare workers across 52 countries infected by COVID-19. https://health.economictimes.indiatimes.com/news/industry/who-says-over-22000-healthcare-workers-across-52-countries-infected-by-covid-19/75107238.

The Economic Times, 2020, April 30b. Coronavirus: Western railway suffers Rs 178 crore loss due to lockdown. https://economictimes.indiatimes.com/industry/transportation/railways/coronavirus-western-railway-suffers-rs-178-crore-loss-due-to-lockdown/articleshow/74891666.cms?from=mdr. (Accessed 1 May 2020). .

The Economic Times, 2020, April 08c. Covid-19 pandemic: water in Yamuna river looks cleaner as industries remain shut due to lockdown. https://economictimes.indiatimes.com/news/politics-and-nation/covid-19-pandemic-water-in-yamuna-river-looks-cleaner-as-industries-remain-shut-due-to-lockdown/videoshow/75041602.cms. (Accessed 28 April 2020). .

The Guardian, 2020, April 20. Coronavirus lockdown boosts numbers of Thailand's rare sea turtles. https://www.theguardian.com/environment/2020/apr/20/coronavirus-lockdown-boosts-numbers-of-thailands-rare-sea-turtles. (Accessed 29 April 2020). .

The Statesman, 2020, April 02. Global Economy Could Shrink by Almost 1% in 2020 Due to COVID-19 Pandemic. United Nations https://www.thestatesman.com/business/covid-19-pandemic-shrink-global-economy-almost-1-says-un-1502872880.html. (Accessed 29 April 2020). .

Times of India, 2020, April 6. COVID-19 impact: Delhi's Yamuna River undergoes makeover, looks cleaner during lockdown. https://timesofindia.indiatimes.com/travel/destinations/covid-19-impact-delhis-yamuna-river-undergoes-makeover-looks-cleaner-during-lockdown/as74999501.cms. (Accessed 28 April 2020). .

Turner, B.L.I.I., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., 2003. Illustrating the coupled human-environment system for vulnerability analysis: three case studies. Proc. Natl. Acad. Sci. U. S. A. 100, 8080–8085. https://doi.org/10.1073/pnas.1231334100.

United Nations, 2020. Shared responsibility, global solidarity: responding to the socio-economic impacts of COVID-19. https://unsdg.un.org/sites/default/files/2020-03/SG-Report-Socio-Economic-Impact-of-Covid19.pdf. (Accessed 28 April 2020). .

Wallace, G., 2020, April 09. Airlines and TSA Report 96% Drop in Air Travel as Pandemic Continues. CNN https://edition.cnn.com/2020/04/09/politics/airline-passengers-decline/index.html. (Accessed 29 April 2020). .

Wang, C., Pan, R., Wan, X., Tan, Y., Xu, L., Ho, C.S., Ho, C.R., 2020. Immediate psychological responses and associated factors during the initial stage of the 2019 coronavirus disease (COVID-19) epidemic among the general population in China. Int. J. Environ. Res. Public Health 17, 1729. https://doi.org/10.3390/ijerph17051729.

WHO, World Health Organization, 2020, May 27. Communicating and managing uncertainty in the COVID-19 pandemic: a quick guide. https://www.who.int/docs/default-source/searo/whe/coronavirus19/managing-uncertainty-in-covid-19-a-quick-guide.pdf?sfvrsn=270e4ac8_4. (Accessed 12 July 2020). .

Wu, J.T., Leung, K., Leung, G.M., 2020. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. Lancet 395, 689–697. https://doi.org/10.1016/S0140-6736(20)30260-9.

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

Zhang, Y., Ding, Z., Xiang, Q., Wang, W., Huang, L., Mao, F., 2020. Short-term effects of ambient PM1 and PM2.5 air pollution on hospital admission for respiratory diseases: case-crossover evidence from Shenzhen, China. Int. J. Hyg. Environ. Health 224, 113418. https://doi.org/10.1016/j.ijheh.2019.11.001.