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Review

Environmental externalities of the COVID-19 lockdown: Insights for sustainability planning in the Anthropocene



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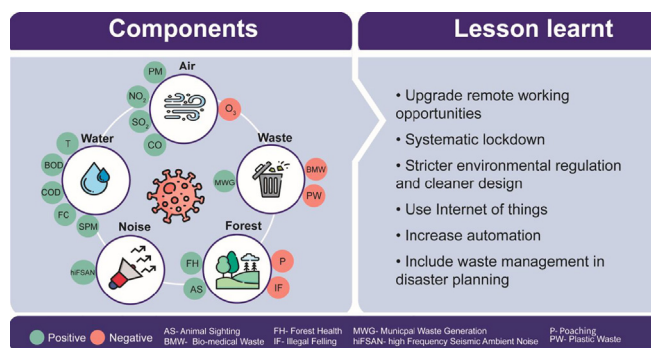
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HIGHLIGHTS

- Critically evaluated externalities of COVID-19 lockdown on environmental parameters.
- Air, water, noise, waste, forest flora and fauna parameters showed substantial changes in magnitude.
- *Anthropause* showed more positive environmental impacts than adverse ones.
- Prioritized SDG targets to reinvigorate global environmental sustainability policies.
- Provided insights to consider a global change for a sustainable post-pandemic world

GRAPHICAL ABSTRACT



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ABSTRACT

The COVID-19 pandemic has abruptly halted the Anthropocene's ever-expanding reign for the time being. The resulting global human confinement, dubbed as the *Anthropause*, has created an unprecedented opportunity for us to evaluate the environmental consequences of large-scale changes in anthropogenic activities. Based on a methodical and in-depth review of related literature, this study critically evaluates the positive and negative externalities of COVID-19 induced lockdown on environmental components including air, water, noise, waste, forest, wildlife, and biodiversity. Among adverse impacts of the lockdown, increased amount of healthcare waste (300–400%), increased level of atmospheric ozone (30–300%), elevated levels of illicit felling in forests and wildlife poaching were prominent. Compared to the negative impacts, significant positive changes in various quality parameters related to key environmental components were evident. Positive impacts on air quality, water quality, noise level, waste generation, and wildlife were apparent in varying degrees as evaluated in this study. By presenting a critical overview of the recommendations given in the major literature in light of these documented impacts, this paper alludes to potential policy reforms as a guideline for future sustainable environmental management planning. Some of the key recommendations are e.g., enhance remote working facilities, cleaner design,

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SDGs
Anthropause

use of internet of things, automation, systematic lockdown, and inclusion of hazardous waste management in disaster planning. The summarized lessons of this review, pertinent to the dynamic relationship between anthropogenic activities and environmental degradation, amply bring home the need for policy reforms and prioritization of Sustainable Development Goals in the context of the planetary boundaries to the environmental sustainability for a new post-pandemic world.

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1. Introduction

A well-fitting analogy to contextualize the transience of human civilization compared to its impact on global systems would be to condense the entire geological time scale into 24 hours. In doing so, the very first of the primitive *Homo sapiens* species does not appear until the absolute last minute and the start of civilization occurs exactly 2 seconds before midnight. In these two measly seconds where humans realized their ability to utilize resources around them unscrupulously, the entire planet was transformed so drastically that the subsequent epoch has been marked as the “Anthropocene” (Crutzen, 2006). In Anthropocene, a world with declining human interventions is utterly unimaginable. Selfish human nature has dominated every facet of this planet, and pushed mankind well past the permissible planetary boundaries (Crutzen, 2006; Steffen et al., 2015). The ever-accelerating technological advancements after the *industrial revolution* have augmented exploitation of natural resources leading to pollution with impacts calamitous enough to leave permanent scars on the planet (Barca, 2011). This leaves one to wonder, would it be possible to undo the damage done to the environment? What if the anthropogenic pursuit of infrastructural and economic growth came to a halt? What if humans stopped their pestering and let the earth be? These thoughts have always been mere abstractions and hypotheses left to the imagination. That is until a single deadly virus caused a global pandemic and forced the people of the entire planet to stop what they were doing and stay home literally.

After its initial emergence in Wuhan, China, the severe acute respiratory syndrome coronavirus (SARS-CoV) that causes coronavirus disease (COVID-19) spread rapidly throughout the entire world leading to the most notorious pandemic of recent time (Lai et al., 2020; Gates, 2020). COVID-19 spreads exponentially via airborne droplets or direct contact, targeting mainly the respiratory organs and can be fatal for people with

pre-existing health complications and/or weak immunities (Lai et al., 2020; Paital, 2020). Since preventing its spread is the most efficient way to suppress it, the immediate course of action adopted globally was to impose lockdowns and compel citizens to quarantine themselves (Flaxman et al., 2020; Wilder-Smith and Freedman, 2020). Accordingly, the anthroposphere virtually halted as the international borders were closed, air travel stopped, the shutdown of institutions, workplaces, commercial entities, and both public and private transportation became a bare minimum, while industries, power plants and factories underwent temporary shutdown (Flaxman et al., 2020; Wilder-Smith and Freedman, 2020). Besides effectively suppressing the virus for the sake of human health, the lockdown revealed another positive side effect: environmental improvement (Paital et al., 2020; Flaxman et al., 2020).

While pandemics are normal occurrences in nature, this is the first time one has happened in the middle of the Anthropocene, where human activity is more potent and environmentally detrimental than ever before. This pandemic-induced hiatus of anthropogenic activities has been termed as the *Anthropause* and is a demonstration of a seemingly impossible “global human confinement experiment” (Rutz et al., 2020; Bates et al., 2020). Quite predictably, the environment began to show consequent improvements. However, these remained overshadowed by the lockdown induced economic devastation to billions as markets and businesses suddenly stopped (Wilder-Smith and Freedman, 2020). Profiteers of the world tend to only view the COVID-19 pandemic as an economic recession and disruption towards consumerism instead of assessing the potential for environmental regeneration. The imminence of environmental degradation amid the pursuit for economic growth is a cause for great concern among environmentalists, and as a response to this concern, the concept of “ecological civilization” has been proposed as a means to keep the best interest of biotic components while achieving sustainable development (Gu et al., 2020).

The lockdowns have presented us with evidence of considerable environmental improvements as well as a few drawbacks. Several studies (Paital, 2020; Arora et al., 2020; Saadat et al., 2020; Shakil et al., 2020) have already attempted to compile the environmental benefits caused by the COVID-19 lockdown; however, we are yet to see a literature that systematically pulls together the existing information and attempts an assessment of its implications addressing both positive and negative impacts through the lens of environmental sustainability. This study attempts to contribute to this void. Although some of past studies have been pioneering in precisely capturing the positive environmental impacts of initial lockdown situation, these were primarily based on non-peer-reviewed reports compiled at a time when the information was scarce. This review, on the other hand, has been attempted after the availability of reliable peer-reviewed literature of adequate quantity. The execution of lockdowns paused specific sources of pollution and anthropogenic activities which explained their role in harming specific parameters of the environment. The understanding gained from this termination of anthropogenic activities can be used as a rubric to design policies using novel approaches previously unimaginable. This can also assist in retrofitting global environmental sustainability initiatives for mending the damages done to the planetary boundaries and achieving sustainable development. Furthermore, during this time of constant addition of new data and information, it is important to collect and organize them all in one, orderly space for future reference. This study critically reviews both positive and negative changes vis-à-vis a wide range of quality parameters for various environmental components and the associated consequences induced by the COVID-19 lockdown across multiple nations. It also performs a scrutiny of recommendations and lessons noted in the relevant past studies, and attempts to suggest new insights for retrofitting global environmental sustainability policies for a new post-pandemic world.

2. Methods

The approach for this research comprises of six steps (Fig. 1). The first step was to search for literature to identify key environmental components that reportedly have been influenced by the lockdown. An exhaustive search distilled air, water, noise, waste, forest, wildlife, and biodiversity. In the second step, Google Scholar and Scopus databases were queried using a search string consisting of the basic keyword

‘COVID-19 lockdown’ and adding each of the selected components. After the search, initially, 120 relevant studies were found and then the studies were filtered based on the following criteria:

- Studies that specifically addressed the shortlisted environmental components - air, water, noise, waste, forest, wildlife, and biodiversity. Studies addressing environmental components beyond the stated ones were excluded.
- Studies that were published between January 2020 to August 2020
- Studies that were published in well-reputed and peer-reviewed journals.
- Studies that addressed either positive or negative impacts on the environmental components due to lockdown.

Based on these criteria, 95 peer-reviewed studies were shortlisted. In addition to this, grey literature published in reputable platforms were also consulted to complement and further validate the information presented in the scientific literature.

In the third step, an in-depth review was performed for the selected studies on the methodology, data source, key findings (i.e., duration of lockdown, activities paused, and magnitudes of changes of parameters) and recommendations. In the fourth step this information was systematically compiled in a tabular form (see **Table S1** in supplementary material). **Table S1** (in supplementary material) served as the pivotal instrument for conducting this research and it documents a rich assortment of condensed information on the changes that occurred during the lockdown period. It was observed that only the parameters for air could be quantitatively analyzed due to the availability of a substantial number of peer-reviewed studies; for other components the reported changes in the parameters have been qualitatively analyzed. For the analysis of the impact of lockdown on air quality, the altered air quality parameters (of the lockdown period) were compared with air quality standards of the countries mentioned in **Section 3.1.1** (further details regarding the data sources have been provided in **Fig. 2**).

Lastly in the fifth and sixth steps, the lessons learnt from the pandemic lockdown were used to construct policy suggestions for improving environmental sustainability planning of a post-pandemic world. The insights address global governance frameworks such as SDG, planetary boundaries and also the concept of ecological civilization. In the case of the SDG, we recommend considering a few of the

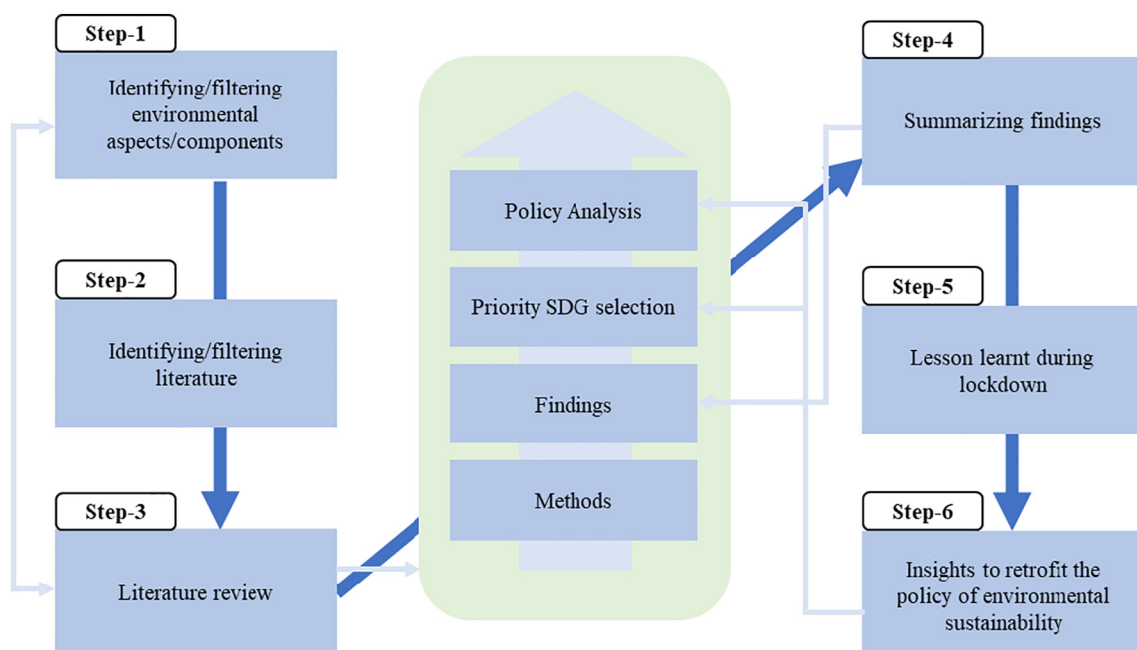


Fig. 1. Key steps of the research approach utilized in the current study.

targets under the already existing SDGs for improving environmental sustainability planning. For filtering these specific targets, an exercise similar to Naidoo and Fisher (2020) was adopted (for further details see Table S3 in Supplementary material).

3. Results and discussion

3.1. Positive outcomes of the COVID-19 lockdown on the global environment

3.1.1. Lockdown improved air quality

The COVID-19 lockdown brought newfound options for countries to minimize air pollution. Studies concerning air quality parameters were abundant owing to its apparent visibility and data availability. The data were collected from a wide array of sources; most articles used station recorded geospatial data, multiple studies (Pei et al., 2020; Lal et al.,

2020; Filonchik et al., 2020) assessed air parameters solely through satellite observations, and some used both (Ranjan et al., 2020; Wang and Su, 2020; Griffith et al., 2020). While most studies were regional or city-based reported for China, India, Brazil, Italy, Kazakhstan, Taiwan, Morocco, and the USA, a few global-scale studies were also performed (detailed information on all the studies has been recorded and tabulated in Table S1 in Supplementary material).

Criteria air pollutants were mostly assessed, while other explored variables included air quality index, volatile organic compounds, lightning, and hydrocarbons such as benzene and toluene. Considering their recurrence in almost every article reviewed and their classification as Group 1 pollutants due to their precariousness (World Health Organization, 2016), this endeavor focuses on particulate matter (PM), Nitrogen dioxide (NO₂), Sulphur dioxide (SO₂) Carbon monoxide (CO) and Ozone (O₃). Among the aforementioned countries, the most prevalent ones included China, India, and Brazil; countries accounting for

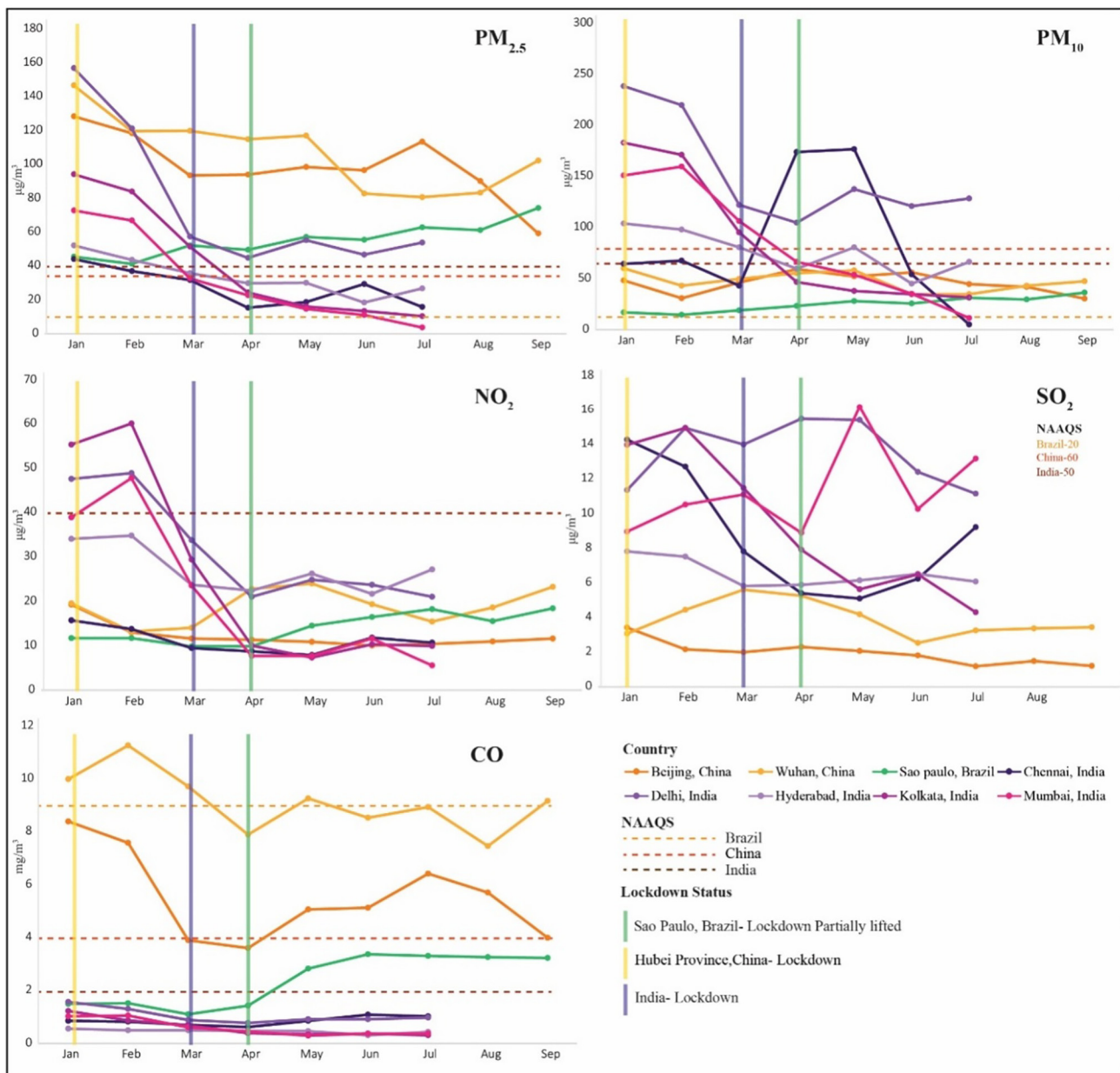


Fig. 2. Comparison of Group 1 air pollutants for cities of China, Brazil and India throughout 2020 (region wide concentration trend of pollutants: particulate matters (PM2.5 and PM10), nitrogen dioxide (NO₂), sulphur dioxide (SO₂) and carbon monoxide (CO) considering different lockdown periods and compared to the National Ambient Air Quality Standards (NAAQS) of each city). (Source: CETESB (Environmental Company of the State of São Paulo), 2020 (Brazil); AQICN, 2020 (China); CPCB (Central Pollution Control Board), 2020 (India))

nearly 40% of the global population on top of their booming economic and industrial activities. For these three countries, an external rigorous analysis using national air quality databases has been performed (Fig. 2) encapsulating the city-scale average emissions and aerial concentrations of the Group 1 pollutants in these countries before and during the lockdown period to capture a global scenario. Likewise, these countries have their state-mandated standards for air pollution and emissions, and Fig. 2 illustrates that the lockdown readings are lower than the preceding years for all Group 1 pollutants which are in harmony with the reviewed articles of this study.

Every article that compared the levels of PM reported a substantial decrease in the lockdown levels compared to their pre-lockdown concentrations. For instance, the reduction in PM_{2.5} ranged from 47.1–47.4% for the metropolitan city of Milan, Italy, while 37% for Wuhan, China (Table 1). PM composition is source-dependent, so it varies greatly depending on which anthropogenic activity, namely vehicular, power plant and industrial operations, is most prevalent in the area (Mazzei et al., 2008). Considering that these are the main activities that plunged due to the COVID-19 lockdowns, the drastic drop in PM level is justified.

SO₂ and NO₂ both showed a decrease in concentration in every study, as evident in Fig. 2. SO₂ is the most common derivative from the combustion of sulphur-based fuels, primarily from coals and crude oil (World Health Organization, 2006). The lockdown induced industrial shutdowns led to decreasing SO₂ emissions, especially in the coal-dependent countries China and India (You and Xu, 2010). Similarly, NO₂ is formed from the combustion of coal and other fuels, albeit not as amply (World Health Organization, 2016). NO₂ predominantly forms via secondary reactions where nitric oxide reacts with ozone. Decreased emissions in lockdown lowered the nitric oxide concentration which explains the decline in NO₂ levels (World Health Organization, 2006). Based on a study for 34 countries, Venter et al. (2020) estimated that during the lockdown period, the average ground level NO₂ concentrations were 60% lower than that have been expected provided the prevailing weather and time of year.

Carbon monoxide, a pollutant with dreadful health impacts (Miller, 2017), is produced mainly due to the incomplete combustion of fossil fuels (World Health Organization, 2006; Ernst and Zibrak, 1998).

Hence, the reduction in vehicle movement and burning of fuels explains the decline in CO levels as observed in Fig. 2 for China, India and Brazil.

Normally a positive correlation has been expected between the length of the lockdown and improvement in air quality. Le Quéré et al. (2020) suggest that the impact on 2020 annual emissions of CO₂ depends on the confinement duration, with a low estimate of –4% (–2 to –7%) considering the return of pre-pandemic conditions by mid-June, and a high estimate of –7% (–3 to –13%) considering some restrictions remain worldwide until the end of 2020. The lockdown duration and the magnitude of changes in air quality parameters data presented in Table S1 in supplementary material could be utilized to mathematically express/model the relationship for other parameters. Reduction in GHG emissions also reported as Forster et al. (2020) estimated a negligible direct effect of the pandemic-driven response with 0.01 ± 0.005 °C cooling by 2030 compared to a baseline scenario that follows current national policies.

3.1.2. Lockdown improved water quality

The continuation of the business-as-usual scenario of anthropogenic degradation of global water resources would put 52% of the global population and 45% of the global gross domestic product at risk by 2050 (UN Water, 2018). Human confinement has created an exceptional opportunity for minimizing the pressure on global water resources. Several studies, mostly reported from India (a prominent riverine country in South Asia), have comprehended the positive impact of lockdown on the water resources. Examples of ceased water polluting activities that brought positive externalities include a reduction in boat traffic and tourism in Venice, Italy (Braga et al., 2020), halt in industrial operations in Southern India (Yunus et al., 2020; Selvam et al., 2020), shrinkage in commercial, pilgrimage and development activities in Ganga river catchment in India (Dutta et al., 2020; Garg et al., 2020), declined agricultural runoff, water extraction, and sewage dumping in Yamuna river catchment in India (Patel et al., 2020), and plunge in stone quarrying and crushing in Eastern India (Mandal and Pal, 2020).

Commonly reported water quality parameters among the reviewed studies are dissolved oxygen (DO) (Dutta et al., 2020; Mandal and Pal, 2020; Lokhandwala and Gautam, 2020), biological oxygen demand (BOD) (Dutta et al., 2020; Patel et al., 2020; Lokhandwala and Gautam,

Table 1

Changes in the magnitudes of various air quality parameters induced by lockdown in different countries. Here, '↓' indicates a decrease and '↑' indicates an increase.

Reference	Location	Country	Percent (%) change in the quantity of air quality parameters ^a							
			PM10	PM2.5	NO2	SO2	CO	O3	AQI	AOD
Chowdhuri et al., 2020	Kolkata, India	India	↓51.01		↓68.4	↓40.4			↓42.6	
Jain and Sharma, 2020	India	India	↓41.8	↓26.6	↓55.2		↓29		↑4.8	
Kumari and Toshniwal, 2020	Delhi	India	↓55	↓49	↓60	↓19			↑37.3	
	Mumbai		↓44	↓37	↓78	↓39				
Ranjan et al., 2020	India	India								↓45
	Chennai		↓19–43							↓29
	Delhi		↓41–53							↓11
Kumar, 2020	Hyderabad	India	↓26–54							
	Kolkata		↓24–36							↓4
	Mumbai		↓10–39							↓1
Li et al., 2020	Yangtze River Delta region	China		↓33.2	↓27.2	↓7.6				
Lian et al., 2020	Wuhan, China	China	↓40.2	↓36.9	↓53.3	↓3.9	↓3.2–34.5	↑116.6	↓33.9	
Liu et al., 2020	China	China			↓48					
Filonchik et al., 2020	East China, China	China			↓30		↓20			
Bao and Zhang, 2020	Jing-jin-ji metropolitan circle, China	China	↓13.7	↓5.9	↓24.7	↓6.8	↓4.6			↓7.8
Zheng et al., 2020	Wuhan, China	China	↓33.7	↓37	↓55.5	↓26.5				
Wang and Su, 2020	China	China	↓20.5	↓14.8	↓5	↓21.4	↓6.2			
Zinke, 2020	China	China		↓17	↓20					↓17
Griffith et al., 2020	East Asia (China and Taiwan included)	China and Taiwan			↓24					
Kerimray et al., 2020	Almaty, Kazakhstan	Kazakhstan		↓21	↓35	↑7	↓49		↑15	
Chen et al., 2020	USA	USA			↓49		↓37			
Collivignarelli et al., 2020	Milan	Italy		↓47.1–47.4	↓41.3	↓25.4	↓57.6		↑293.5	
Dantas et al., 2020	Rio De Janeiro, Brazil	Brazil	↓15–33.3		↓28.5		↓40.3			
Nakada and Urban, 2020	Sao Paolo, Brazil	Brazil		↓29.8	↓54.3		↓64.8		↑30	
Otmani et al., 2020	Sale City, Morocco	Morocco	↓75		↓96	↓49				

^a Particulate matter (PM), Nitrogen dioxide (NO₂), Sulphur dioxide (SO₂) Carbon monoxide (CO), Ozone (O₃), Air quality index (AQI), and Aerosol optical depth (AOD).

2020), chemical oxygen demand (COD) (Dutta et al., 2020; Patel et al., 2020), fecal coliform (Dutta et al., 2020; Patel et al., 2020; Selvam et al., 2020) and turbidity (Braga et al., 2020; Yunus et al., 2020; Garg et al., 2020; Patel et al., 2020; Hallema et al., 2020). Besides, there is also a report on lockdown-induced reduction in water consumption (Cheval et al., 2020). In most studies, data for chemical parameters were generated based on the collection of water samples and laboratory analysis, while remote sensing/satellite images were used for measuring turbidity/suspended solids (see **Table S1** in Supplementary material).

This review identifies a substantial increase in DO and decrease in BOD, fecal coliform, and turbidity. For instance, Arora et al. (2020) reported a 79% increase in some sites of the Ganga river in India, while Dutta et al. (2020) observed a 4% increase of DO in other sites of the same river. A substantial decrease in BOD (ranging from 19% to 30%) for various sites of the Ganga river was also reported (Arora et al., 2020; Dutta et al., 2020; Lokhandwala and Gautam, 2020). In the case of fecal coliform, an 80% reduction was observed for the same river (Dutta et al., 2020). These changes in the water quality parameters enabled water in the upper stretches of the river to become drinkable while in the middle and lower stretches, the declined pollution made the water suitable for outdoor bathing (Arora et al., 2020; Dutta et al., 2020; Garg et al., 2020). In the Yamuna, another major Indian river, a mean concentration reduction of approximately 43% for BOD, 39% for COD and a 40% decline in fecal coliform was reported (Patel et al., 2020). Lockdown-induced improvements helped the water in the Yamuna river to become clearer, odorless and aesthetically pleasing (Patel et al., 2020). Besides, in Tuticorin Southern India, a 48% reduction in fecal coliform for groundwater was observed (Selvam et al., 2020). Other examples include Italy, where turbidity in the Venice lagoon reduced from about 50 FNU (formazin nephelometric unit) to 1–10 FNU during the lockdown period causing the water to become transparent (Braga et al., 2020). Although other natural factors such as rainfall and snow melting might have contributed to the improvement in water quality in some instances, the role of lockdown cannot be less emphasized. Similar improvements in water quality in other parts of the world could be anticipated.

3.1.3. Lockdown decreased noise intensity

The COVID-19 lockdown gifted the modern world with an unprecedented opportunity to enjoy the serenity of silence. Significant reduction in noise levels and associated positive environmental outcomes have already been reported for India (Arora et al., 2020; Mandal and Pal, 2020; Somala, 2020), Italy (Aletta et al., 2020a; Poli et al., 2020), UK (Aletta et al., 2020b; Randall, 2020; Sims, 2020), Germany (Deutsche Welle, 2020), Sweden (Rumpler et al., 2020), Ireland (Basu et al., 2020), Canada (leBrasseur, 2020), Australia (Miller, 2020), and New Zealand (NZ Herald, 2020). For instance, noise level reduced up

to 35%–68% worldwide (Table 2), while individual countries saw different ranges of decrease (for further details, see **Table S1** in supplementary material). In many instances, daytime road traffic noise went below the 53 dB limit recommended by World Health Organization. Such reductions are the results of reduced traffic (road, rail, and air) movements and human gatherings. Data from 268 seismic stations across the globe indicates a 50% reduction in the global median high-frequency (4–14 Hz) Seismic Ambient Noise (hiFSAN) during lockdown between March and May 2020 (Lecocq et al., 2020). This pioneering study implies that the quiet period allowed the detection of previously concealed subtle signals from subsurface seismic sources, which helped in benchmarking the sources of anthropogenic noise. Moreover, a reduction in noise in the marine environment was observed due to decreased commercial shipping traffic (Thomson and Barclay, 2020).

Positive bearings of reduced noise levels on wildlife or ecosystems were observed worldwide. For instance, changes in birds' behavior i.e., singing more softly (Deutsche Welle, 2020) and having higher reproductive success and less migration (Ro, 2020). Wildlife began roaming into quiet cities like how a puma entered the center of the Chilean capital Santiago (The Irish Times, 2020). A quieter marine environment allowed better sound communication by whales to coordinate feeding and other social behavior (NPR, 2020). In the Waitemata Harbour in New Zealand, various marine species were reportedly sighted after decades (Miskell, 2020). Moreover, coral reef species that communicate and interact through sounds can do so more effectively (Jacob, 2020). Similarly, humans were free from various physical and mental health risks of high noise exposure which might substantially reduce annoyance and stress to ultimately lessen the risk of cardiovascular disease (Dutheil et al., 2020). The drop in noise due to the lockdown might help people realize that cities and urban areas could be a lot quieter and more peaceful (Ro, 2020).

3.1.4. Lockdown decreased municipal waste generation

The lockdown has distorted consumption patterns and changes in the types, quantity, composition, frequency, and spatial distribution of waste produced were evident due to restricted anthropogenic activities. It ultimately influenced the waste management systems worldwide as evident from the range of studies, for instance, municipal solid waste as a whole (Van Fan et al., 2020; Ragazzi et al., 2020; Kulkarni and Anantharama, 2020), biomedical waste (Sharma et al., 2020; You et al., 2020; Singh et al., 2020; Rahman et al., 2020), plastic waste (Silva et al., 2020; Klemeš et al., 2020; Prata et al., 2020; Vanapalli et al., 2020), food waste (Aldaco et al., 2020; Jribi et al., 2020; Sharma et al., 2020) and wastewater (Adelodun et al., 2020; La Rosa et al., 2020; Bogler et al., 2020) (for details see **Table S1** in Supplementary material).

Focusing on the quantitative picture, the production of municipal solid waste (MSW) in March 2020 was 4058 t in Trento, Italy, which

Table 2

Changes in the magnitudes of noise level induced by lockdown. This figure presents the percent change and actual quantitative information on noise level for some studies are presented in Table S1.

Studies	Location	Types of noise	Human activities (sources of noise) that reduced due to lockdown	Percent (%) reduction in noise level
Arora et al., 2020	Global (several countries)	Noise intensity	Stone quarrying and crushing, commercial shipping, traffic noise, industrial activities	35–68
Lecocq et al., 2020	Global (several countries)	High-frequency (4–14 Hz) Seismic ambient noise	Traffic, schools and universities, flights, tourist activity, population mobility	50
Mandal and Pal, 2020	Catchment of Dwarka river basin Eastern India	Noise intensity	Stone quarrying and crushing	25
Aletta et al., 2020a	Rome, Italy	Noise intensity	Urban traffic (private trip reduced up to 64.6%)	9
Poli et al., 2020	Northern Italy	Seismic ambient Noise (in the 1–10 Hz frequency range)	Reduced vehicle traffic and nonessential industrial activities	50
Aletta et al., 2020b	Camden Town, London, UK	Noise intensity	Public and private traffic	7

was 18.5% lower than the previous 10 years average for the same month (Ragazzi et al., 2020) and could be attributed to the closure of restaurants, bars, and production activities. Van Fan et al. (2020) reported a 23% reduction in MSW for Shanghai in China and a 40% reduction for business and industrial wastes for Brno in the Czech Republic. Increased conscious buying of more non-perishable items may reduce household food waste generation, evident in the 34% reduction in household food waste observed for the UK (Sharma et al., 2020; WRAP, 2020). Social surveys in Germany and the UK (Global Ag Media, 2020), Australia (NSW EPA, 2020), and Canada (National Zero Waste Council, 2020) indicate that consumers showed heightened concerns about wasting food during the COVID-19 pandemic. A similar attitude was observed for households in Tunisia, albeit driven mostly by the socio-economic concern than a pro-environmental attitude (Jribi et al., 2020). Interestingly, Aldaco et al. (2020) found a higher rate (12% more) of food loss and waste (FLW) generation in Spain during the initial stages of the outbreak, however, when extra-domestic consumption absorbed by households during the outbreak was considered, the overall FLW remained like that of 2019.

3.1.5. Lockdown improved forest ecosystem

Since the inception of civilization, forests have cradled humans; at present providing income and nutritional diversity to 20% of the global population (FAO, 2018). But the essence of Anthropocene has propagated pathways to degrade those ecosystem services which might aid to hinder pestilence (Everard et al., 2020) - bringing us to the recent surge of the pandemic, purveyed from the wet markets of Wuhan (Maron Fine, 2020), rather than squeezing the world into a 'Half-Earth' (Fletcher et al., 2020). Human confinement has created an unprecedented opportunity in comprehending whether radical changes in human behavior may result in extensive positive responses in the natural systems (Cohen, 2020). A broad overview on the impact of

lockdown on wildlife biodiversity has been illustrated in Fig. 3 (for details see Table S2 in supplementary material).

Field data and social media reported frequent observations of red fox and wild boar in the urban areas of Italy, along with sightings of rare wolf and several deer species (Manenti et al., 2020). Ocelots and tapirs were viewed wandering in Brazilian cities, elephants from African safari compounds entering human settlements, elks meandering in Norwegian pavements, Kashmiri goats grazing the lawns of Wales, UK (Jain, 2020), peacocks and deer waltzing in the roads of India (Singh, 2020), while pumas were found roaming in the downtown of Santiago, jackals in the urban parks of Tel Aviv, Israel (Rutz et al., 2020) and coyotes in San Francisco (Charnock, 2020). Such sightings of diverse wildlife is a clear sign of improvements from reduced human interference. Initial impacts of the lockdown on biodiversity seem positive, with less manufacturing and commercial exploitation of natural resources, air and water quality improved, noise pollution declined (Muhammad et al., 2020); since April 2020, daily CO₂ emissions steeply fell by 17% (Le Quéré et al., 2020). Incidents of single forest fires are reported to be diminished in Nepal by 4.54% (Paudel, 2020) and about 80% declination in the forest fire incidents of Western Himalayas (Supriya, 2020).

Presumably, fewer disruptions by the noisy engines of cargo ships and fishing trawlers have lowered stress on dolphins and whales and enhanced their communication (Jain, 2020). Indian Gangetic dolphins, a bio-indicator of healthy rivers, were sighted more in the Vikramshila Gangetic Dolphin Sanctuary, Bihar (Sarkar et al., 2020). Restricted transportation has proliferated bird diversity in Kolkata (Basu, 2020), Jammu and Kashmir (Bhat et al., n.d.), and significantly abated road killings of mammals, amphibians, and reptiles (Manenti et al., 2020; Goldfar, 2020). For instance, using traffic and collision data from three states (California, Idaho, and Maine) of the USA, Nguyen et al. (2020) estimated that road killing of large mammals including mountain lion decreased by 21–58% due to a reduction in traffic from early March to mid-April 2020.

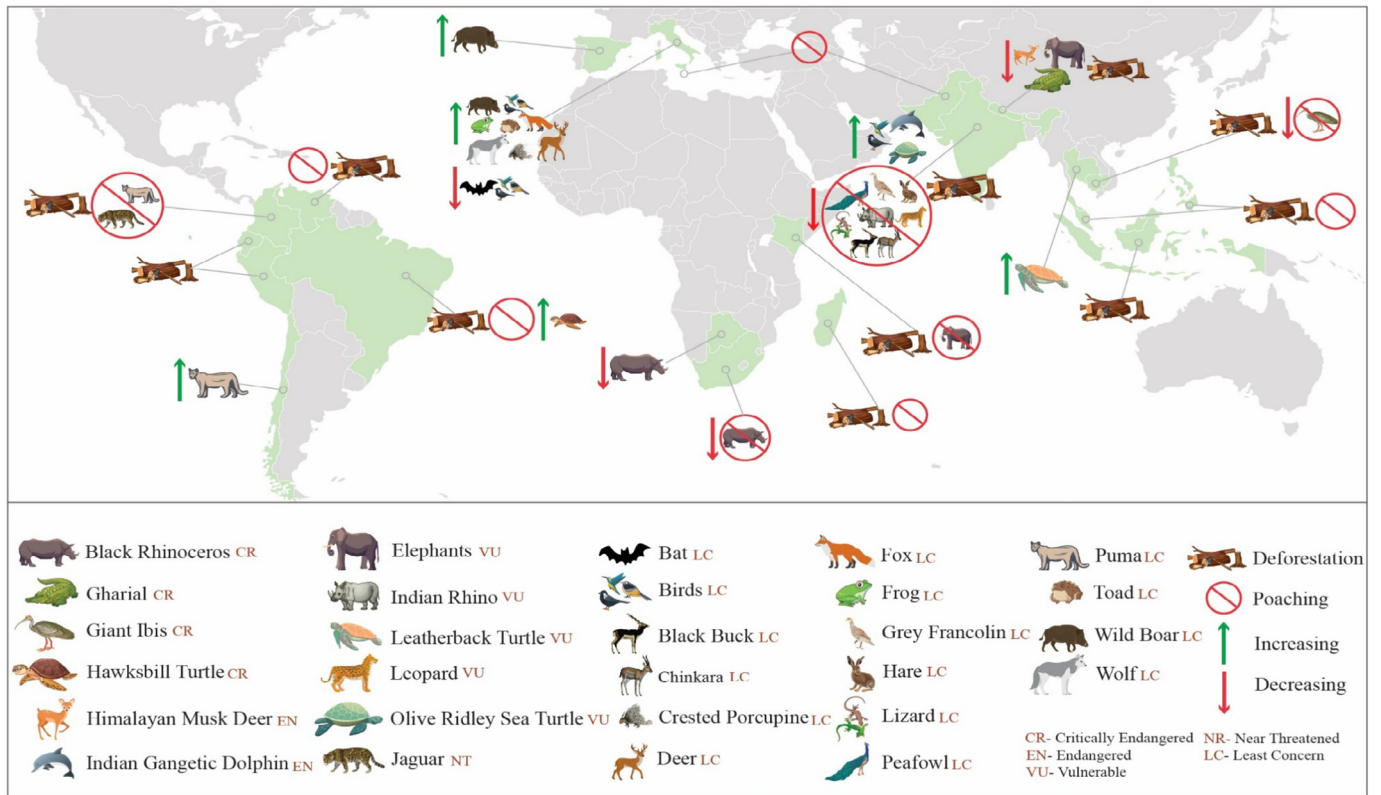


Fig. 3. Worldwide fauna status during the COVID-19 lockdown (considering the indicator of IUCN Red List and whether the species in each country has been declining, increasing or poached in specific countries. For further details see Table S2 in in the supplementary material).

The newly afforded seclusion has upraised the breeding of many species. Bird nests of Kentish plover, a conservation priority in Europe, were surveyed in several new sites (Goldfar, 2020). Mass nesting of the endangered Olive Ridley Sea turtles in Odisha (Das, 2020), Leatherback turtles in Thailand (Kittiwatanawong, 2020) and Hawksbill turtles in Brazilian beaches (Phillips, 2020) were reported from restricted fishing and touristic activities.

The Pandemic has brought Global wildlife trade and poaching into the spotlight. China's Congress has already adopted legislation against the wildlife consumption trade (Chakraborty and Maity, 2020; Yang et al., 2020), however conservationists worldwide rightly urge for a universal and permanent ban (Bwambale, 2020; Moulds, 2020). The *Anthropause* has facilitated a once-in-a-lifetime opportunity of Global Human Confinement Experiment to test the extents of human mobility affecting wildlife (Cohen, 2020); coordinated global research will make contributions in reinventing the synergetic coexistence of humans and wildlife (Rutz et al., 2020).

3.2. Negative consequences of the COVID-19 lockdown on the global environment

3.2.1. Lockdown increased ozone levels

While each air pollutant dramatically plummeted in concentration, aerial ozone levels increased throughout the lockdown i.e. 30% in Sao Paulo, Brazil (Nakada and Urban, 2020) and 37% in Delhi, India (Kumari and Toshniwal, 2020) and a dramatic rise of nearly 300% in Milan, Italy (Collivignarelli et al., 2020) (Table 1). This is due to the natural mechanism of the removal of ozone from the air; it is mediated via several titration reactions triggered by nitric oxide where NO breaks down ozone into NO₂ and oxygen (Li et al., 2020; World Health Organization, 2006). These reactions simultaneously create NO₂ and eliminate ozone from the air. Hence, the decreased concentration of NO, as evident in Fig. 2, has led to an increased concentration of O₃. Increased ozone exposure may have many health effects (World Health Organization, 2016) but with such a small study time and with most of the population staying indoors or wearing masks its true repercussions cannot be fathomed accurately.

3.2.2. Lockdown increased biomedical, plastic, and supply chain wastes

In the case of the waste sector, an alarming increase in the medical, plastic and supply chain food waste was observed. In terms of biomedical/healthcare waste, for instance, nearly 400% increase for Wuhan in China (Singh et al., 2020) and 300–350% for Madrid and Catalonia in Spain (Arevalo, 2020) were observed, all of which are the worst COVID affected cities. Al Amin (2020) reported the generation of approximately 14,500 t of health care wastes (including used gloves, masks, hand sanitizer containers and polythene) in Bangladesh. Other Asian cities like Manila, Kuala Lumpur, Hanoi, and Bangkok also experienced an increased generation of roughly 154–280 t of medical wastes per day during the outbreak (You et al., 2020; ADB, 2020). Management of biomedical wastes appeared as a big challenge in many developing nations (Al Amin, 2020; ADB, 2020), mainly due to public health concerns.

A substantial increase in plastic wastes (face mask, PPE, packaging materials) generation was also reported in Thailand (NNT, 2020), China (Adyel, 2020), Singapore (Bengali, 2020), and the USA (Heiges and O'Neill, 2020). For Thailand, the increment was 300% (NNT, 2020), while a 370% increase was observed for medical waste containing a high proportion of plastic in Hubei, China (Klemeš et al., 2020). The plastic waste increase was mainly in the form of packaging, which could be attributed to increased online purchases of food and daily necessities (Sharma et al., 2020; Rattner, 2020). For example, in South Korea, online food shopping increased by 93% (MuMu-Hyun, 2020). From takeout packaging and food delivery alone, Singapore's 5.7 million residents generated an additional 1470 t of plastic waste during an eight-week lockdown period (Bengali, 2020; Elangovan, 2020). Based on empirical

evidence, the pandemic has influenced the waste generation dynamics along with waste management practices throughout the world. These changes could create a significant environmental burden, particularly on soil and the marine environment.

Moreover, instances of dumping massive amounts of food products by farmers, producers, and suppliers have been reported for several nations like the USA (Yafe-Bellany and Corkery, 2020); India (Kamal, 2020); Pakistan (Latif and Niazi, 2020); Singapore (Lim, 2020) and Netherlands (NSW EPA, 2020; Langhout, 2020), mainly due to restriction in vehicle movements, and lack of workers in the warehouse for handling the food products (Sharma et al., 2020).

3.2.3. Lockdown increased poaching of wildlife

As per anecdotal observations whilst many wildlife species relish the solitude, others are doomed by substantial endangerment. A surge of poaching has been reported in African, Latin American, South Asian, and Southeast Asian countries. Reported poaching cases include that of black rhinos in Botswana (Clark, 2020) and South Africa, of pumas and jaguars in Colombia and ivory and bushmeat in Kenya (Dalton, 2020). Similar cases were reported in Malaysia, the Philippines, Venezuela, and Madagascar (Brown, 2020). Escalation of illegal hunting of endangered species and rare birds was observed in India, Pakistan, and Nepal, while poached animals from several natural reserves in India included leopards, rhinos, blackbuck, spiny-tailed lizards, desert hare, peafowl, monitor lizards and grey francolin (Saeed et al., 2020). Illegal bird killing was reinvigorated in many Italian strongholds and fear of contagion killing of bats was reported in Italy, Eurasia, South America, and Africa (Manenti et al., 2020).

3.2.4. Lockdown increased deforestation and illegal extraction of resources

The lockdown elevated global poverty driving 34.3 million losing employment (Sen, 2020), have impacted human displacements worldwide (Manenti et al., 2020), resulting in more people turning towards forest even at the cost of further exploitation (Buckley, 2020; Diffenbaugh et al., 2020). Indonesia witnessed a spiking 50% forest loss in the first 20 weeks of 2020 compared to 2019 (Chloe, 2020), putting at risk the habitats of critically endangered Sumatran tigers, orangutans, and rhinos (Fair, 2020). In Ecuador increased illegal mining was reported in Choco and Amazon rainforest. Peru (López-Feldman et al., 2020), Brazil, Colombia, Cambodia, Indonesia, Nepal, and Madagascar have been reported for increased illegal felling since the pandemic broke out (Fair, 2020). Despite military enforcement, the forest loss in Amazon in the first four months of 2020 rose to 55% (Brown, 2020; Fair, 2020) compared to 2019, one of the worst years on record (Rampietti, 2020). Illicit timber is much cheaper than those legally harvested, and thus the trade of legal hardwood is declining with China's import of tropical hardwood falling by 26% by volume compared to 2019 (Fair, 2020). An influx of visitors was reported in Germany, posing threats to forest management and policy implications due to recreational activities (Derks et al., 2020).

The confinement exacerbated unemployment and economic insecurity (Wood, 2020), with mounting evidence of illegal wildlife persecution growing, increases in raptor persecution in Europe, swelling rates of illegal deforestation in Africa and Asia as enforcement agencies are deployed due to COVID-19 (Evans et al., 2020; Lindsey et al., 2020).

3.2.5. Lockdown decreased ecotourism and conservation activities

Travel and tourism dropped by 60–80% in 2020, aggregating loss of hundreds of billions of euros worldwide (Chakraborty and Maity, 2020; World Tourism Organization, 2020) and resulting in livelihood loss of countless individuals in the ecotourism industry who resort to farming or other ecosystem degrading measures for income - often fueling up human-wildlife conflicts (Greenfield and Muiruri, 2020). Contest for humanitarian aids and the collapse in the global ecotourism sector will generate conservation funding deficit and financial emergencies in nature reserves and wildlife rehabilitation centers, subsequently

endangering many species (Rondeau et al., 2020). Reduced funding may restrain conservation practitioners to manage protected areas (Lindsey et al., 2020) and suspend management of pest control leading to outbreaks like the upheaval of desert locusts in Africa and Yemen which augmented food shortages for millions of people and caused substantial environmental damage (Bates et al., 2020).

2020 was proclaimed to be the 'super year' for reshaping biodiversity conservation through discussions of key policy agendas and conservation targets in the global meetings (Fletcher et al., 2020). However, the progress in conservation science and policy platforms has been stagnated as all the meetings are now postponed or canceled.

4. Recommendations and the way forward

4.1. Review of strategies recommended for improving environmental management in relevant COVID-19 studies

Comprehending the aftermath of the lockdown on environmental parameters can unveil prospects of pragmatic implementation of the knowledge attained from the reviewed literature to enhance the reforms in the environment. The gist of the compiled studies portrays the potential of minimized human mobility in curtailing pollution levels and anthropogenic stress on the environment (Ranjan et al., 2020; Bao and Zhang, 2020; Mandal and Pal, 2020). Remote working could be a potential strategy for reducing human movements, hence should be expanded (Pata, 2020). Structural adjustments are required in the modes of work and education towards an efficient virtual infrastructure which fully supports online arrangements in compliance with sustainable green consumption policies (Jain and Sharma, 2020; Bashir et al., 2020). Industrial and transportation sectors, being mammoth contributors of pollution, must accommodate more efficient and cleaner designs, shift to renewable energy sources and reduce vehicular movements to lessen the emissions of harmful gases and PM levels ensuring improved air quality (Bao and Zhang, 2020; Nakada and Urban, 2020; Li et al., 2020; Pata, 2020) as well as reduced noise pollution (Aletta et al., 2020a). Li et al. (2020) suggests more stringent and robust adjustments in the energy and industrial structures. Improving policies and infrastructures for green commuting (i.e. using bicycles instead of cars) is crucial for reducing both air and noise pollution, and is already being implemented in some major cities i.e. Berlin, Paris, Bogota (Marie, 2020). Considering the hotspots of air pollution, strategically selective lockdown could be imposed at local levels to control pollution levels (Ranjan et al., 2020).

Restricted tourism activities would revive watershed areas, ameliorate river health and aquatic biodiversity (Patel et al., 2020; Braga et al., 2020); whereas proper decontamination practices in wastewater treatment plants and the shift from chemical to biological fertilizers will aid in water quality improvement (Adelodun et al., 2020; Selvam et al., 2020). In addition to terminating point sources of pollution, assessment policies should also extend to areas where air pollutants may disperse through wind or other meteorological factors (Bashir et al., 2020; Dantas et al., 2020), and surrounding water flow streams can mop up the contaminants and control over-flooding, waterlogging and extreme sedimentation (Patel et al., 2020). Integration of waste management in disaster management planning will result in inclusive response measures and guidelines to better operate in the dynamics of a future pandemic (Sharma et al., 2020; Klemeš et al., 2020; Kulkarni and Anantharama, 2020), prioritizing the formulation and implementation of homogenous plastics, eco-friendly bio-plastics, and circular technologies while phasing out single-use plastic through taxation (Sharma et al., 2020; Silva et al., 2020). To safely manage biomedical wastes, an automated system of waste storage, collection, treatment, and disposal should be developed using advanced technologies and the internet of things (Sharma et al., 2020; Singh et al., 2020). Initiatives such as social campaigns or awareness programs (Jribi et al., 2020) and shortening the food supply chain through purchasing from local producers/suppliers (Aldaco et al., 2020) could help to minimize food wastes.

Rigorous eco-centric decision-making, inclusive of local communities and intergovernmental organizations, must tend to reverse the existing norms of degrading ecosystem services and biodiversity habitat (Bhat et al., n.d.; Everard et al., 2020; Pearson et al., 2020). Evaluating the sustainability of green socio-ecological consumption and production model implications would advance nature's restoration (Kulkarni and Anantharama, 2020; Rodríguez-Urrego and Rodríguez-Urrego, 2020; Rugani and Caro, 2020).

4.2. Retrofitting environmental policies relating to the sustainable development goals for a new post-pandemic world

This pandemic, caused by a single virus, has paralyzed nations irrespective of their socio-economic and technological status. The outcome is mankind's morphing into a "new normal" way of life due to the adverse unanticipated changes across individual lifestyles and global economies. The pandemic exposed inefficacies of contemporary frameworks for sustainability which did not consider global crises of this extent in their design. One such instrument for environmental sustainability, the Sustainable Development Goals (SDGs) framework has suffered an existential blow due to these new circumstances (Naidoo and Fisher, 2020), exemplifying how the environment truly encompasses every aspect of existence to synergistically benefit human and nature, and cannot be compromised especially from a policy perspective. The importance of prioritizing environmental goals which were previously stated by Griggs et al. (2013) still applies in a post-pandemic scenario. Few of the goal targets proved to be especially significant from a pandemic context; lockdowns helped achieve and/or prevent future environmental disasters. To identify these priority targets, an instrument similar to Naidoo and Fisher (2020) was used to score each target (for further details see **Table S3** in Supplementary material). Targets with the highest scores have been deemed a priority owing to whether lockdowns helped accomplish them or for their high efficacy to mitigate future catastrophes, and the results of this exercise are shown in **Table 3**. Prioritizing those targets of each goal would strengthen the global governance arrangement and better align it with the needs of a post-pandemic world.

The current statistics indicate individuals with pre-existing non-communicable diseases are more susceptible to COVID-19 (Centers for Disease Control and Prevention, 2020) and lockdowns instigated environmental regeneration that may help achieve this goal. Environmental degradation will amplify ecological vices like pollution and the spread of pests so we must maintain them in the future as well. This can be achieved by ensuring improved air quality and waste management practices. The coronavirus crisis has also reinforced the significance of water in sanitation, hygiene, and human health. Therefore, community collaboration in water resource management through regulated human movement to conserve and restore these vital finite water resources and associated aquatic ecosystems is indispensable. These points cover the priority targets in goal 3 and 6 (**Table 3**) and further advance to promote goal 11 in the long run.

Protecting both aquatic and terrestrial ecosystems are of utmost importance; however, the instances of plastic pollution and increased wildlife poaching mentioned in **Section 3.2** stand as proof of how much the lockdown has increased the threats on natural ecosystems as a whole. With 75% of the emerging infectious diseases being zoonotic (UN, 2020), the pandemic demonstrated the repercussions of unchecked wildlife consumption and the need for global scale pragmatic initiatives to check it. On the contrary, regulated human mobility, for example, reduced boat traffic, declined human encroachment, etc. has been beneficial for some marine and wild species. Since these goals emphasize improving terrestrial natural habitats and preventing illegal trade and consumption of wildlife, they should be prioritized. In the context of plastic pollution, focusing on sustainable consumption and production which is supported by the targets under goal 12 is undoubtedly a prime concern. The pandemic triggered people to think conservatively and ensuring this

Table 3

Priority SDG Targets for the sustainable environmental management in a post-pandemic world as determined based on the lessons learnt from this research. Refer to Table S3 for detailed assessment.

Priority SDG Targets	
3.4	Reduce mortality from non-communicable diseases and promote mental health
6.3	Improve water quality, wastewater treatment and safe reuse
6.4	Increase water-use efficiency and ensure freshwater supply
6.6	Protect and restore water-related ecosystems
6.b	Support local engagement in water and sanitation management
11.6	Reduce the environmental impact of cities
11.a	Strong national and regional development planning
12.1	Implement the 10-year sustainable consumption and production framework
12.3	Halve global per capita food waste
12.4	Responsible management of chemicals and waste
12.5	Sustainably reduce waste generation
12.8	Promote universal understanding of sustainable lifestyle
14.2	Protect and restore ecosystems
15.1	Conserve and restore terrestrial and freshwater ecosystems
15.2	End deforestation and restore degraded forests
15.4	Ensure the conservation of mountain ecosystems
15.5	Protect biodiversity and natural habitat
15.7	Eliminate poaching and trafficking of protected species

for future developments will better operate the dynamics of lifestyle and the environment for posterity.

Another such framework for sustainability would be the planetary boundary (PB). While we prioritize what goals to achieve globally, we must also be mindful of the PBs. As these indicate the levels of anthropogenic perturbation below which the stability of earth systems remains resilient (Steffen et al., 2015). As Section 4 of the study comprehends the ramifications of the lockdown on the environmental parameters, it opens a new avenue for evaluating the extent of restricted human activities that can be accommodated, and hence adjusting the very limit of the safe anthropogenic operating space. Apart from this, a model *Earth3* evaluated the environmental degradation for the business as usual (BAU) (pre-pandemic) scenario and quantified the output in the context of world development using indicators SDGs, PBs and wellbeing index (Randers et al., 2019). However, the distortion brought to BAU due to the pandemic has now made it incompatible to be used as a foundation. Therefore, while formulating global governance policies using models such as *Earth3*, the directive should be to keep the pandemic/lockdown scenario under consideration by default.

A paradigm shift is required in the ways of how the world functions. This reorientation warrants replacing the capitalism-fueled consumerist mindset with an eco-centric mindset to promote development containing deep ecological foundations. Hence, the approach of ecological civilization - where the political, cultural, and socio-economic spheres of human civilization will be governed by ecological principles - will act as the ideal foundational strategy for a post-pandemic world. For instance, expanding digital workplaces and e-learning are proven to be effective in the face of the pandemic. Going towards a sociocultural shift to allow wider adoption of these can significantly reduce the environmental footprint of urban societies without compromising institutional productivity. Furthermore, from a political standpoint, a fundamental reorientation is needed towards the adoption and application of eco-centric policies and decision-making strategies. For example, the ongoing economic recession has caused a collapse in the global ecotourism sector, resulting in conservation fund deficits in nature reserves and wildlife rehabilitation centers in a blow to conservation efforts, exacerbating the condition of endangered species. In this case, reducing the dependency of conservation funds on tourism and introducing diversified sources of funding such as taxation on environmental pollution and ecological damage (Gu et al., 2020) could be an apt alternative.

As we slowly lose the stability of earth systems that Holocene had to offer, thinking about limits is important. The human confinement experiment manifested the power of nature to regenerate and heal herself. Contrary to the current reactive measures which remedy detrimental

anthropogenic consequences, if humankind begins to limit their actions which we now know is possible due to the pandemic, the environment can get a repose period to synergistically exist within an Anthropocene. Even those that are unaware or ignorant of *The Silent Spring* (Carson, 2002), *The Limits to Growth* (Meadows et al., 1972) and all the pro-environmental initiatives which followed are bound to have at least wondered if their known way of living is sustainable; the scale of this pandemic has made it clear that human species as a whole share one finite planet. Those who have been reflecting on the futility of consumerism at the cost of scarce resources are also agitated by the thought of returning to the BAU world of greed. If we fail to preserve and reinforce the pandemic-imposed austere living to retain the positive externalities from the COVID-19 lockdown, it will be a great loss indeed.

5. Conclusion

This study concludes that the sudden reduction in anthropogenic activities induced by COVID-19 lockdown has resulted in both positive and negative impacts on the quality parameters of key environmental components. Although the positive impacts outweighed the negative impacts, some of the adverse impacts were significant. Through systematic planning based on the findings of this study, it is possible to enhance the positive impact and minimize the adverse impact of the lockdown caused by future pandemic or disastrous events like COVID-19. Main recommendations that could be given for future environmental planning are e.g., enhance remote working facilities, cleaner design, use of internet of things, automation, systematic lockdown, and inclusion of hazardous waste management in disaster planning. The prioritization of the SDG targets presented based on the findings of the current study could be utilized for the sustainable environmental management in a post-pandemic world. The knowledge of the impact of COVID-19 lockdown on environment is evolving, and once adequate literature become available, a meta-analysis of related COVID-19 literature data should be performed to gain further insights on the environmental externalities of the COVID-19 lockdown. This present study is a stepping-stone for such meta-analysis.

CRedit authorship contribution statement

Rubel Biswas Chowdhury: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing. **Ayushi Khan:** Data curation, Formal analysis, Investigation, Visualization, Writing - original draft, Writing - review & editing. **Tashfia Mahiat:** Data curation, Formal analysis, Investigation, Visualization, Writing - original draft, Writing - review & editing. **Hillool Dutta:** Conceptualization, Formal analysis, Investigation, Writing - original draft. **Tahana Tasmeea:** Formal analysis, Investigation. **Afra Bashira Binth Arman:** Formal analysis, Investigation. **Farzin Fardu:** Formal analysis, Investigation, Writing - original draft. **Bidhan Bhuson Roy:** Formal analysis, Visualization. **Mohammad Mosharrif Hossain:** Writing - original draft, Writing - review & editing. **Niaz Ahmed Khan:** Writing - original draft, Writing - review & editing. **ATM Nurul Amin:** Writing - original draft, Writing - review & editing. **Mohammad Sujauddin:** Conceptualization, Investigation, Methodology, Resources, Supervision, Writing - original draft, Writing - review & editing.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2021.147015>.

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