



On the emergence of a health-pollutant-climate nexus in the wake of a global pandemic

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Abstract

COVID-19 has wreaked havoc throughout the planet within a short time frame, inducing substantial morbidity and mortality in the global population. The primary procedures commonly used to manage the pandemic can produce various environmental pollutants, primarily contaminants of emerging concern such as plastics, chemical disinfectants, and pharmaceutical waste. There is a huge influx of various environmental pollutants due to the pandemic effect. We, therefore, introduce the term “envirodemics” depicting the exacerbated surge in the amount of pandemic-induced pollutants. The general toxicity pattern of common chemical ingredients in widely used disinfectants shows negative impacts on the environment. We have identified some of the significant imprints of the pandemic on localizing the Sustainable Development Goals—environment interaction and their implications on achieving the goals in terms of environmental benefits. Climate change impacts are now widespread and have a profound effect on pollutant fluxes and distribution. The climate change signatures will impact the pandemic-induced enhanced fluxes of pollutants in the global waters, such as their transport and transformation. In this study, possible interactions and emerging pathways involving an emerging climate-health-pollutant nexus are discussed. The nexus is further elaborated by considering plastic as an example of an emerging pollutant that is produced in huge quantities as a by-product of COVID management and disaster risk reduction. Additionally, regulatory implications and future perspectives concerning the unleashed nexus are also discussed. We hope that this communication shall call for incisive investigations in the less explored realm concerning the health-pollutant-climate nexus.

Keywords COVID · Envirodemics · Environment · Plastic · Sustainable Development Goals

Introduction

Numerous pandemics, pestilences, and plagues have challenged the existence of humanity in the historical past. Still,

the COVID-19 obtrudes among the pandemics due to the spatial and temporal pace with which it unfolded worldwide. The current pandemic is happening when the planet is most populated, technologically advanced, climatically challenged, and environmentally deteriorated now more than at any time. Since the advent of COVID-19, humanity faces various abrupt and gradual challenges and transformations in every sector within a short period of the recent past. The emerging patterns (Sarkar et al. 2021) reveal that the COVID-19 and environment are tightly coupled like warp and weft. The pandemic has now been widely recognized as bringing in some turning point in the global social-ecological system (Kish et al. 2021). This juncture is crucial for the planet, and understanding the subsequent events and processes resulting from the pandemic effect on the Earth system is very important.

In recent times, anti-contagion policies, sheltering orders, and lockdowns are implemented globally to control the COVID-19 transmission risks. Hsiang et al. (2020) observed that these consequential policy decisions are often made with

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limited information and are designed to slow the contagion of the virus. Initially, these policies are hailed as reviving the degraded environmental matrices due to reduced anthropogenic activities (VishnuRadhan et al. 2020), leading to reports of improved air (Mahato et al. 2020) and water (Selvam et al. 2020) quality in formerly polluted regions. The environmental benefits, if any, were short-lived, and recent reports showed an increase in air pollution post-lockdown (Wang et al. 2020) and more negative impacts than positives (Kumar et al. 2021). The re-emergence of higher pollution levels is a likely scenario for the other environmental realms, too. The seesaw in pollution levels pre-lockdown, during lockdown, and post-lockdown periods is an expected impact of the sheltering orders imposed worldwide. What was not expected is the quantity of various pollutants generated and the scale of its pervasive impacts during the race to manage and control the spread of the infection in the absence of very promising pharmaceutical interventions against COVID-19 during the initial phase of the pandemic. The primary impact of the pandemic was immediately reflected in the morbidity and mortality rates due to COVID-19, which forced nations across the world to divert their immediate attention and resources in saving lives. The progression of the pandemic and its global spread within a limited time frame warranted various non-pharmaceutical interventions (NPIs) (Seale et al. 2020) as prescribed by regulatory agencies. The NPIs, both in hospitals and households, generate substantial environmental pollutants of such types and quantities that the effects will persist in the environment for a longer time. Various steps to prevent and manage the etiology and transmission of COVID-19 generate various pollutants synonymous with the number of COVID cases. The pollutants include residuals from various single-use plastic materials used in hospitals, disinfection agents and associated chemicals, environmental residues from pharmaceutical compounds used as drugs and therapeutic agents employed in treating the symptoms, and off-label and compassionate therapies, for example, antiviral agents, corticosteroids, or immunomodulatory drugs. Once these substances are out in the environment through multiple pathways, including wastewater, these come under the category of Contaminants of Emerging Concern (CECs) (USEPA 2008). The effect of climate change on the global distribution and fate of CECs is well established (Snyder et al. 2012; Gouin et al. 2013; Bunke et al. 2019) and is known to exacerbate the environmental ill-effect of the CECs by creating transformation products and their widespread distribution in environmental compartments. The pandemic has also created an enormous influx of single-use plastic material into various environmental compartments. Since the advent of the pandemic, observational evidence of plastic pollution has appeared in aquatic and coastal ecosystems around the globe (Adyel 2020). Also, the production and consumption of fossil fuels have increased in recent years, and conventional plastic production using petroleum by-

products has also increased during this period. Globally, there were many progressive and promising decisions recently to reduce the consumption of conventional plastic products such as single-use plastics. However, with the advent of a pandemic like COVID-19, global agencies and governance systems cannot effectively draw these decisions into practical purposes.

This paper analyzes a different perspective of the environmental pollution fueled by the pandemic, specifically concentrating on CECs. We highlight the problems instigated by pollutants emanating as the by-products of the pandemic prevention, management, and care procedures. The impact of the pandemic-induced environmental issues on United Nations Sustainable Development Goals (SDGs) is also explored. We emphasize the need for special attention and strategies for tackling an evolving nexus between health, pollutants, and climate on account of the pandemic. This nexus is further explained by considering plastic pollutants as an example. Strategies and regulatory implications to better understand the compounding effects of multiple stressors contributing to the evolution of the nexus are discussed. We hope that this work will generate interest among researchers and policy-makers regarding the nexus, and the enlisted caveats will guide us to the journey towards a more sustainable future.

COVID-19 and environmental pollution: a case of renewed age-old environmental problems

In terms of unsanitary conditions (Hutton 1929), the perils of environmental pollution wreaked havoc as early as 1347 in the late middle ages in the form of the bubonic plague dubbed as the Black Death. The pollution issues paced in conjunction with the progress and development of human societies around the world. The seminal book “Silent Spring” (Carson 1962) marked the dawn of an era of enhanced environmental consciousness and led to the creation of agencies such as the US Environmental Protection Agency in the 1970s. The agency and the environmental standards put forward by it acted as a forerunner for various legislations and standards across the world. Some pollutants which are extensively investigated in recent years were first detected as early as the 1970s, for example, pharmaceutical compounds (Garrison et al. 1976), plastics (Carpenter and Smith 1972), and disinfection by-products (Rook 1974). Since 1974, one billion more people are being added to the global population every 12–13 years. But, the crude death rate (per 1000 people) during 1970–1975 was 11.6, and it has decreased to 7.58 during 2015–2019 (UN 2019).

The surge in population will have an impact on the generation of anthropogenic pollutants and ensuing associated effects. It is now well-known that societal development significantly affects the emission of new and emerging substances to the environment (Bunke et al. 2019). During the recent

decades, anthropogenically induced novel substances are being increasingly detected in the environmental matrices, partly due to the improved analytical capabilities and related breakthroughs lately. When used on the current global scale, a substantial amount of these pollutants can find their way to the water bodies and subsequently to the coastal ocean. The sudden, massive influx of pollutants of these categories can impact prevailing ecosystem balances as the assimilative capacity of the environment or water bodies for CECs is negligible. Globally, pollutants in the environment and water bodies pose significant public health problems, and the CECs are of great concern (Landrigan et al. 2018). Pollutants produced due to the pandemic are not new or novel additives to the environment but are present in substantial quantities in recent years. The volume of these contaminants produced within a short time frame since the beginning of COVID-19 is alarming. This is similar to the way by which the viral infection became a pandemic. The potential sources of these pollutants are produced in enormous amounts during the life-saving race to manage the pandemic. The pandemic has aggravated the already prevalent issues regarding the environmental pollutants at the crossroads, and various underpinned and intertwined cascading effects are yet to reveal in evidential forms. During the initial phase of the pandemic, the lockdowns were proclaimed as bringing unforeseen positive feedback to the environment, which acted as a precursor for a media frenzy. For example, there were reports regarding the Himalayas visible from parts of India for the first time in 30 years (Picheta, 2020). Studies reported improved water quality due to the lockdowns, for example, improvement of the water quality of the Ganges (Dutta et al. 2020), the Venice Lagoon (Braga et al. 2020), the Yamuna (Patel et al. 2020), and improved coastal water quality across the globe among others. The gains, however minor, showed the role of controlled discharge of the environmental pollutants in reverting the once prevailed ambient qualities of the environmental matrices. It should be noted that classical pollutant flux remains unabated from domestic wastewater, food production, and agricultural activities during the lockdown period.

Pollution is already identified as a major cause of mortality and morbidity among the global population. Fig. 1 shows the number of deaths per 100,000 people globally that are creditable to all forms of pollution. Figs. 2 and 3 show the number of confirmed cases and deaths per 100,000 people. The current trends in the population, death per 100,000 of population, total counts of death due to pollution, number of documented COVID-19 cases, and deaths per 100,000 of the population were analyzed using scattergrams, and Pearson correlation coefficients were recorded. The analysis is carried out after removing the observations, which were outliers (extreme observations) and not available for the current period. All the variables were log-transformed prior to analysis to remove the effect of extreme (low and high) records. The total death

from pollution followed a positive association with the population records in 100,000 (0.94 , $P < 0.01$), and the regression equation indicated a strong correspondence of death from pollution on population records ($y = 1.0496x + 4.2171$, $R^2 = 0.88$). The COVID-19 cases and deaths due to COVID-19 also showed a positive correlation and a strong one-to-one correspondence ($y = 0.9744x - 4.0086$, $R^2 = 0.84$). When all the 188 countries are considered, no significant correlations were observed between (1) COVID-19 deaths vs. population, (2) COVID-19 deaths vs. deaths due to pollution, (3) COVID-19 cases vs. deaths due to pollution, and (4) COVID-19 cases vs. population. However, we have yet to receive the actual counts of cases and corresponding figures on the number of deaths due to the pandemic as new spatial and temporal patterns evolve. The data indicate that many countries that have high death rates due to pollution issues also have high confirmed COVID-19 cases and deaths. Asian countries such as India, China, Pakistan, Bangladesh top the list of number of deaths due to pollution. This is followed by Nigeria, Indonesia, Russia, the USA, Ethiopia, DR Congo, and Brazil. Out of the listed 11 countries, many have the highest recorded COVID-19 cases and ensuing deaths as of August 2021. For example, the USA has the highest cases and deaths, followed by India, Brazil, and Russia. The higher number of COVID-19 cases can be considered as directly proportional to the amount of pollutants generated, including CECs. This interaction is potentially creating strong feedback loops involving pollutants and the pandemic.

The anthropogenic activities post-the initial lockdown period resulted in the return of the pre-lock down scenario of environmental pollution, with initial reports of an increase in air pollution post-lock down (Ikhlasse et al. 2021). After the initial positive environmental effects during the global sheltering orders, the earth system is reverting to its anthropogenic influenced mode, this time creating an “envirodemic” phase, which may persist for years to come. Here, we introduce the term “envirodemics,” the unforeseen surge in the amount of environmental pollutants induced by the pandemic. This will be an immediate environmental health impact of the ongoing COVID-19 crisis; some insignias are already appearing, such as the appearance of face masks in water bodies, solid waste management system failure, and pollution of coastal systems (Aragaw 2020; Kulkarni and Anantharama 2020; Ormazá-González and Castro-Rodas 2020). Eventually, these impacts will be reflected in most of the environmental matrices. For example, sanitation and disinfection practices during the initial months of the pandemic were unscientific. Haug et al. (2020) ranked the effectiveness of worldwide NPIs; environmental measures such as cleaning and disinfection of shared surfaces are rated least effective. Though plausible, catching the virus from surfaces appears rare (Goldman 2020), and deep cleaning and disinfection due to the fear of fomite transmissions are uncalled for (Lewis 2021). The unscientific and

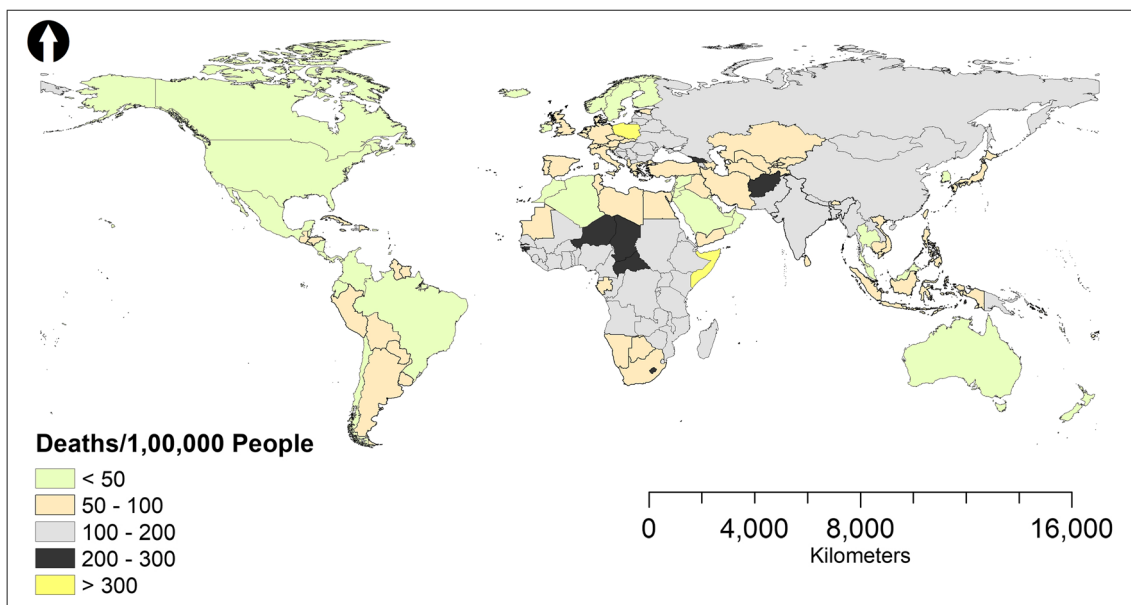


Fig. 1 Number of deaths per 100,000 people that are accreditable to all forms of pollution (Data source: The Lancet Commission on Pollution and Health: October 19, 2017 <https://www.thelancet.com/commissions/pollution-and-health>)

excessive use of disinfectants and cleaning agents threaten living organisms (Ghafoor et al. 2021) and the environment (Celebi et al. 2021). We have collated the approved list of disinfectants by the USEPA, which are expected to kill the coronavirus SARS-CoV-2 when used according to the label directions. As of July 2021, there are 570 total entries of different products on the list. Table 1 shows the individual ingredients in these products and their general toxicity pattern. The toxicity pattern of these effective chemicals against coronavirus indicates that their imprudent usage can create long-running environmental issues.

In addition to these pollutant issues, the United Nations SDGs, a 2030 agenda having 169 targets (UN 2016), can be substantially impacted by these pandemic-induced environmental problems. The SDGs integrate social, economic, and environmental dimensions and provide guidance for humanity to prosper in the long term (Hourneaux 2021). The environmental issues are directly or indirectly involved in the sub-goals of all the 17 goals. Before the advent of the COVID-19 pandemic, SDGs were expected to impact climate and health positively. However, there are recent discourses regarding whether the SDGs are fit for the post-pandemic age, and

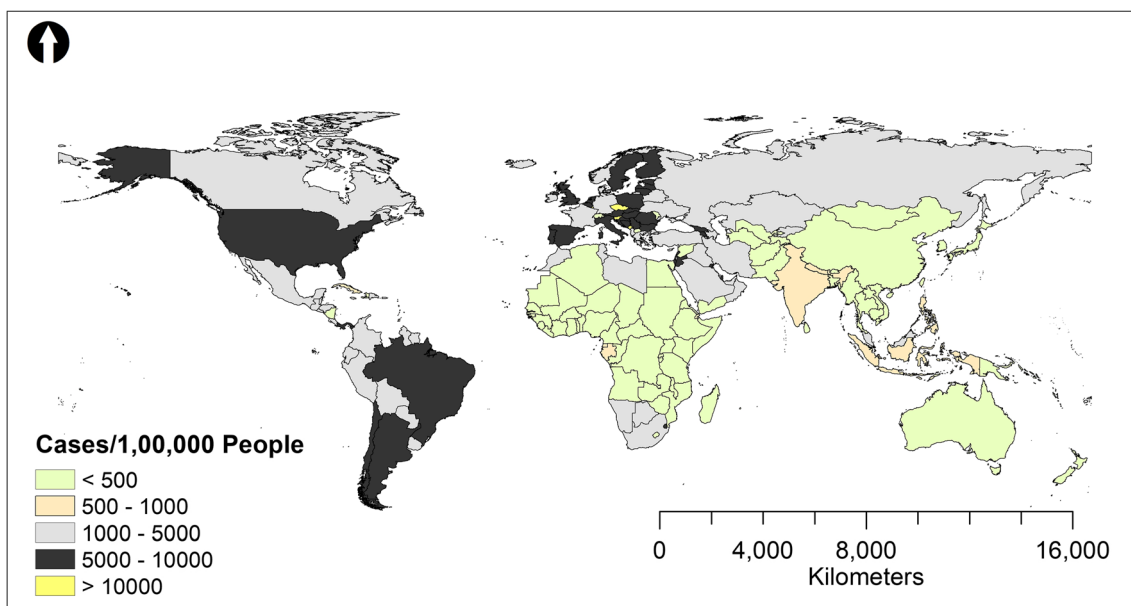


Fig. 2 Number of confirmed global COVID-19 cases as of April 2021 (Data source: WHO Coronavirus (COVID-19) Dashboard <https://covid19.who.int>)

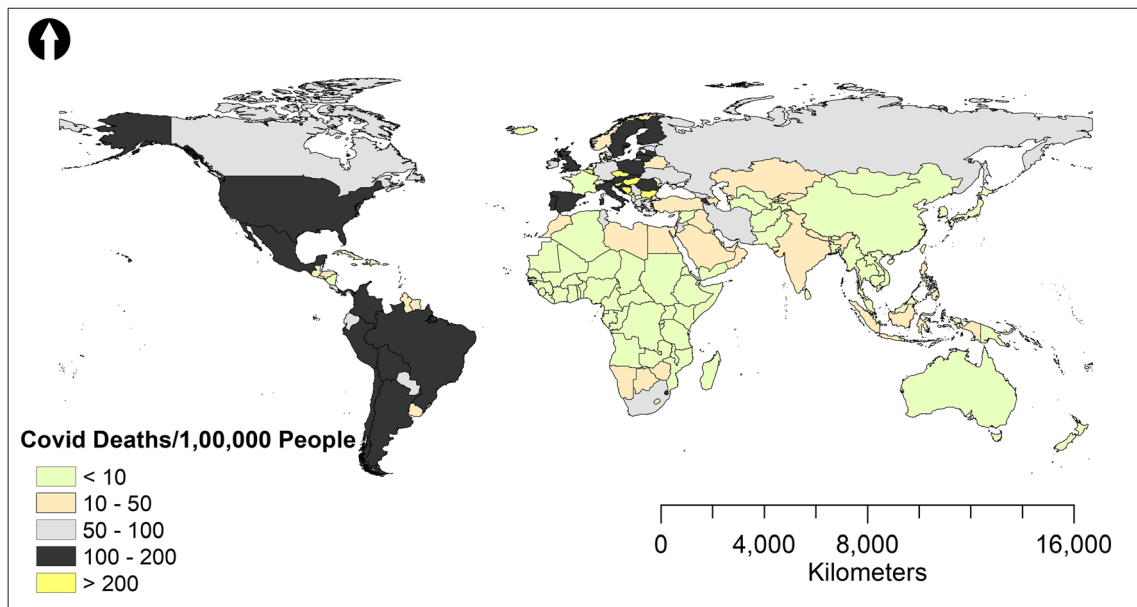


Fig. 3 Number of COVID-19 deaths per 100,000 people (Data source: WHO Coronavirus (COVID-19) Dashboard <https://covid19.who.int>)

certain SDG targets might be counter-productive (Heggen et al. 2020). We have identified some of the major trails of the pandemic on SDGs and factors involved in SDGs-environment interaction. Though fragmentary due to the narrow temporal scale of the pandemic, these interactions are relevant due to the endless virtuous and vicious circles involving the pandemic and the environment. Table 2 shows SDGs and relevant factors involved in SDGs-pandemic interaction and their impacts on the environment.

One of the primary defenses against the pandemic, especially for the frontline workers and health professionals, is the personal protective equipment (PPE). The majority of PPE and similar products are made up of polymers like polyurethane (PU), polypropylene (PP), polycarbonate (PC), low-density polyethylene (LDPE), and polyvinyl chloride (PVC). Among these polymer materials, LDPE is rarely recycled, and PVC and PP are often not recycled (Parashar and Hait 2020). Further, the medical care of patients involves a lot of single-use plastic materials, which countries have planned to regulate or phase out gradually during the pre-COVID era. The halt of waste management systems worldwide combined with the surge in plastic waste has taken a toll during the pandemic. In addition to medical use, single-use plastic has made a comeback through packaging material, disposable food, and drinks containers. Reports during the pandemic show that customers refuse to use reusable food containers. These single-use plastic items start surfacing in places where it was previously banned or restricted. Take away food that has increased during this period generates a lot of plastic wastes. The plastics used in the packaging materials mainly consist of HDPE, LDPE, PS, PET, etc. (Parashar and Hait 2020). The pollutant problem enhanced by the pandemic is now intertwined strongly with social-economic entities.

The pandemic has reinstated the “use and throw” and “disinfection mentality” among the populace, who has faced the wrath of various socio-economic issues created by the pandemic. Combined with multiple climatic drivers such as changing weather patterns, these can have far-reaching consequences for the coupled human-earth system. Climate change is predicted to increase human exposure to many environmental pollutants (Balbus et al. 2013). Further, contaminant fluxes between the ocean and the atmosphere will also be altered, affecting their distribution and availability for uptake at lower trophic levels in the marine environment (AMPA 2016), potentially creating imbalances in the existing global biogeochemical processes. Further, climate change-induced impacts such as ocean acidification have a considerable impact on environmental pharmaceuticals (Mezzelani et al. 2021), and changing environmental factors such as water pH, temperature, and UV-B irradiation have a profound effect on the acute toxicity of the emerging pollutants such as pharmaceuticals in the aquatic environment (Kim et al. 2010).

Plastic-climate-health nexus as an emerging example

Plastic pollution is often referred to as comparable to the climate change in terms of public fear and the problems they pose to the environment (VishnuRadhan et al. 2019). Apart from being a potential fomite for infectious microbes and directly affecting respiratory health (VishnuRadhan et al. 2021), plastic particles in the environment can be linked to the climatic impacts on the planet. Plastic pollutants (micro and nano) found in the environment have been recently attributed

Table 1 Common chemical ingredients in disinfectants approved by the USEPA, which are expected to inactivate SARS-CoV-2. Data regarding product name, company, and the ingredients are available from <https://www.epa.gov/coronavirus/list-n-advanced-search-page-disinfectants-coronavirus-covid-19>

Active ingredient common in disinfection products	General toxicity pattern	Reference
1,2-Hexanediol	High cytotoxicity and phytotoxicity	(Song and Kim 2020)
Ammonium carbonate	Irritant and a threat to the environment	(NCBIa 2021)
Ammonium bicarbonate	Irritant, hazardous to the aquatic environment	(NCBIb 2021)
Chlorine dioxide	Highly toxic for the aquatic organisms	(WHO 2002)
Citric acid	Very low aquatic toxicity and high biodegradability	(NCBIc 2021)
Dodecylbenzenesulfonic acid	Corrosive and irritant, acute and chronic health hazards	(NJ 2003)
Ethanol (ethyl alcohol)	Minimally toxic, generally safe	(Kramer et al. 2007)
Glutaraldehyde	Toxic to the aquatic organisms	(Leung 2001)
Glycolic acid	Causes nephro- and renal toxicities	(Lim et al. 2019)
Hydrochloric acid	Irritant, toxic to the aquatic organisms	(NCBI d 2021)
Hydrogen peroxide	Toxic to the aquatic organisms	(Sunday et al. 2020)
Hypochlorous acid	Low toxicity	(BDJ 2018)
Iodine	Low toxicity	(Southern and Jwayyed 2020)
Isopropanol (isopropyl alcohol)	Slightly toxic to practically non-toxic to most taxa	(USDA 2014)
L-lactic acid	Non-toxic to non-target organisms	(USEPA 2009)
Octanoic acid	Harmful to the aquatic life with long-lasting effects	(TFS 2021)
Peroxyacetic acid (peracetic acid)	Corrosive, highly toxic to the aquatic life	(ECHA 2016)
Peroxyoctanoic acid	Hazardous to the aquatic environment	(NCBIe 2021)
Phenolic	Toxic to the humans and the aquatic environment	(Anku et al. 2017)
Potassium peroxymonosulfate	Corrosive, highly toxic to the aquatic organisms	(USEPA 1993)
Quaternary ammonium	Toxic to the aquatic life	(Zhang et al. 2015)
Silver	Minimal risk at low doses	(Drake and Hazelwood 2005)
Silver ion	Highly toxic	(Ratte 1999)
Sodium carbonate	Slightly toxic to the aquatic life	(NCBIf 2021)
Sodium carbonate peroxyhydrate	Generally safe for non-target organisms	(Geer et al. 2016)
Sodium chloride	Less toxic	(NCBIg 2021)
Sodium chlorite	Corrosive, hazardous to the aquatic environment	(NCBIh 2021)
Sodium dichloroisocyanurate	Hazardous to the aquatic environment	(NCBIi 2021)
Sodium dichloroisocyanurate dihydrate	Hazardous to the aquatic environment	(NCBIj 2021)
Sodium hypochlorite	Hazardous to the aquatic environment	(NCBIk 2021)
Tetraacetyl ethylenediamine	Low toxicity	(HERA 2002)
Thymol	Moderate toxicity to the aquatic organisms	(Bullangpoti et al. 2018)
Triethylene glycol	Low toxicity	(NOAA 1999)

The total number of product entries is 570, and the number of ingredients is 33 as of July 27, 2021. Relevant reference is mentioned against a brief description of the general environmental toxicity pattern of each ingredient

as carbon reservoirs, potentially contributing to the total organic carbon (Hu et al. 2019). This type of carbon reservoir is ever increasing in the environmental matrices, and the contribution of a freely available source of carbon will have direct implications towards the climate. A recent discourse (Dees et al. 2021) on the impact of anthropogenic carbon from plastics and degradation by-products on marine and terrestrial environments due to the annual flow of plastic carbon into the global carbon cycle concluded that the carbon amounts are

enormous and concerning. Considering the widespread and increasing production of plastic pollutants, this concern applies to these pollutants as a component of the global carbon pool. The climatic situation resulting from the plastic pollutants is primarily due to the well-known fact that the base materials for plastic production are fossil fuel and their potential for greenhouse gas emission. This apprehension becomes reliable and exacerbated as discarded plastics produce greenhouse gases such as methane and ethylene when exposed to

Table 2 Evolving SDGs-environment nexus induced by COVID-19 and their impacts and effects on economic, social, and environmental dimensions of SDGs framework

SDGs	General theme	Major scenarios induced by the pandemic	Relevant factors involved in SDGs-environment nexus
Goal 1	Poverty reduction	<ul style="list-style-type: none"> • Troubling setback in efforts to eradicate extreme poverty (Valensisi 2020). • First rise in poverty since 1998. • South Asia and sub-Saharan Africa will be most affected. • Creation of a new, bigger under-class. • Making migrants and women poorer and less safe (UNDP 2020a). 	<ul style="list-style-type: none"> • Ecosystem services are directly related to well-being. • Healthy environment aids in poverty reduction.
Goal 2	Food, nutrition security	<ul style="list-style-type: none"> • Affect the food security and nutrition of poor people, women, children, and migrants (Swinnen and McDermott 2020). • Childhood malnutrition and nutrition-related mortality (Headey et al. 2020). 	<ul style="list-style-type: none"> • Availability and accessibility of food are directly related to environmental quality.
Goal 3	Health	<ul style="list-style-type: none"> • Global health crisis. • Drastic changes in health care delivery and accessibility. • Increased medical expenses (Wapner 2020). • Negative effect on non-COVID patients in terms of medical access (Rosenbaum 2020). 	<ul style="list-style-type: none"> • Environmental pollution has a direct relation to human health hazards.
Goal 4	Education	<ul style="list-style-type: none"> • Partial or complete closure of educational institutes and increased popularity of online learning (UNESCO 2020). • Wider acceptance towards asynchronous learning. • Largest disruption of education systems in the history and significant dropout rates anticipated (UN 2020). 	<ul style="list-style-type: none"> • Knowledge and skills are essential for a sustainable environment, specifically younger generation.
Goal 5	Gender equality	<ul style="list-style-type: none"> • Perceived as advancing gender equality (King et al. 2020). • Gender disparities in many fields and increased risk for women (UN Women 2020). 	<ul style="list-style-type: none"> • Access, use, and control of natural resources. • Right to a clean, safe and healthy environment.
Goal 6	Water, sanitation	<ul style="list-style-type: none"> • Shared sanitation increases the risk of infection (Caruso and Freeman 2020). • Enhanced water insecurity (Stoler et al. 2020). • Enhanced pollution scenarios. 	<ul style="list-style-type: none"> • Direct and reciprocal relationship. • Water quality. • Wastewater discharge.
Goal 7	Access to energy	<ul style="list-style-type: none"> • Energy insecurity (Graff and Carley 2020). • Impact on energy demand and consumption (Jiang et al. 2021). • Slow-down of global progress on energy efficiency (IEA 2020) 	<ul style="list-style-type: none"> • Involve externalities. • Environmental pollution issues.
Goal 8	Economic growth, employment	<ul style="list-style-type: none"> • Noticeable impact on global economic growth (Jackson et al. 2020). • Job loss and reduced income as immediate impacts. • Turbulent days in the financial markets (Kinatader et al. 2021). • Economic uncertainty (Hassan et al. 2021). 	<ul style="list-style-type: none"> • Provide resources, raw materials, and ecosystem services. • Environmental policies affect employment.
Goal 9	Industry, innovation, infrastructure	<ul style="list-style-type: none"> • More opportunities are fueled by the pandemic, but the economic impacts will have negative effects. 	<ul style="list-style-type: none"> • Clean and green technologies help in achieving environmental sustainability.
Goal 10	Inequality reduction	<ul style="list-style-type: none"> • Inequality is exacerbated in terms of health, race, economy (Abedi et al. 2020). • Inequality in digital access. 	<ul style="list-style-type: none"> • Inequality has an impact on resource consumption, biodiversity loss, waste generation. • Directly impact environmental sustainability. • Environmental impact of cities.
Goal 11	Sustainable cities and communities	<ul style="list-style-type: none"> • Excess waste generation (Haque et al. 2021). • Sanitation issues. • Epicenters of infection. 	<ul style="list-style-type: none"> • Environmental impact of cities.
Goal 12	Sustainable consumption and production	<ul style="list-style-type: none"> • Changes to the global dietary pattern (Eftimov 2020). • Global production and supply chain systems are mainly disrupted (Kumar et al. 2020). 	<ul style="list-style-type: none"> • Use of natural resources and toxic materials. • Emissions of waste and pollutants.
Goal 13	Climate change	<ul style="list-style-type: none"> • Share commonalities, converging effects (Lancet 2021). 	<ul style="list-style-type: none"> • Direct relationship.
Goal 14	Oceans, seas, marine resources	<ul style="list-style-type: none"> • Increased marine litter pollution. 	<ul style="list-style-type: none"> • Direct relationship.

Table 2 (continued)

SDGs	General theme	Major scenarios induced by the pandemic	Relevant factors involved in SDGs-environment nexus
Goal 15	Terrestrial ecosystems	<ul style="list-style-type: none"> • Impact on ocean observation systems and their maintenances. • Reduced marine noise from maritime traffic. • Increased interests in zoonotic diseases. • Impact on ecosystem services. 	<ul style="list-style-type: none"> • Direct relationship.
Goal 16	Peace, justice, strong institutions	<ul style="list-style-type: none"> • Rise in domestic violence, labor disputes, impact on the rights and liberties (UNDP 2020b). 	<ul style="list-style-type: none"> • Environmental crimes. • Environmental laws.
Goal 17	Partnership for sustainable development	<ul style="list-style-type: none"> • Increased multi-stakeholder partnerships. For example, vaccine development and distribution. • Shared responsibilities in local, national and global levels. 	<ul style="list-style-type: none"> • Environmental protection and effective management.

SDG indicators, SDG-oriented scenarios, and relevant factors involved in SDGs-environment nexus are listed

ambient solar radiation (Royer et al. 2018), a real-time scenario in landfills and municipal dump yards. Plastic recycling is also known to produce greenhouse gases (Zheng and Suh 2019). The greenhouse gas emissions from the plastic life cycle seriously threaten the remaining carbon budget and contribute to the climate change (Shen et al., 2020). Plastic particles are recently identified as having the ability to impact the ocean's capacity to absorb carbon dioxide (Wieczorek et al. 2019). Further, the plastic pollutants compromise the growth and photosynthetic capacity of *Prochlorococcus* sp., the ocean's most abundant photosynthetic bacteria (Tetu et al., 2019). Floating plastics in the near-surface layer can interact with the incoming solar radiation and affect water-column light availability (VishnuRadhan et al. 2019). All these recent pieces of evidence testify to the irrefutable capacity of the plastic pollutants to act as a significant emerging component in the prevailing climate system of the planet.

The central finding from the 2015 Lancet Commission on Health and Climate Change is that tackling climate change could be the greatest global health opportunity of the twenty-first century (Watts et al. 2015). The commission's 2021 report specifies that the changing climate has already produced considerable global shifts in the underlying social and environmental determinants of health (Watts et al. 2021). The complex interactions between health and the climate change and their importance in global socio-economic and environmental systems are well perceived in recent years. Plastic is a new addition to this nexus, and many of the associated processes and mediating factors need further investigations. Non-pharmaceutical health care interventions are known to produce a considerable amount of single-use plastic wastes. For example, the recent COVID-19 outbreak contributes to worldwide plastic pollution (Silva et al. 2021). The real-time reverse transcription-polymerase chain reaction (RT-PCR) for confirmation of COVID-19 generates 37.27 g of plastic residues per sample and has generated (till August 2020) 15,439.59 tons of plastic residues worldwide (Celis

et al. 2021). It is speculated that airborne microplastics from waste contaminated with the virus may transmit and extend the transmission of SARS-CoV-2 (Liu and Schauer 2021). Similarly, with the advent of effective vaccines against COVID-19, many overarching questions arise about the sustainable disposal of post-vaccination medical wastes such as plastic syringes, vaccine packaging materials such as disposable plastic, and expanded polystyrene foam (Phadke et al. 2021). The manufacturing and transport of these materials produce a substantial amount of plastic pollutants. Further, the recent detection of mutant strains and increased virulence led to the suggestion of double masking (Brooks et al. 2021), where a fabric mask is worn over a disposable surgical mask. This can increase the amount of used masks, paving ways for their enhanced infiltration into the environmental matrices.

The compounding effects emanating from the interactions of various factors involved in the emerging plastic-climate-health nexus are mostly unexplored. Yet unexplored, a plethora of biosphere processes can directly relate to the health-plastic-climate nexus in a complex manner. The ability of plastic pollutants to entangle themselves with the already existing foremost challenges in the biosphere can bring forth unforeseen implications. It is clear from the above discussion that the pandemic is unfurling an emerging nexus involving climate, health, and pollutants, the dynamics of which are still evolving according to the spatial and temporal waves of the ongoing pandemic.

Conclusions and way forward

The global influx of vast amounts of pollutants in different environmental compartments fueled by the pandemic is a potential emerging environmental issue. In the past 50 years, the vigorous anthropogenic activities synonymous with the surging global population have initiated the dawn of an era of emerging contaminants on the planet. This further enhanced

the complexities in prevailing resource management strategies at the regulatory level for associated stakeholders and governmental agencies. Currently, emerging pollutants have crept into the entire environmental compartments, making it surplus on Earth. The failure to protect the environment or modify it beneficially can induce the risk of failure to break the chains of pathogenic transmission (Pirtle and Beran 1991). Therefore, it is suggested that the discussed context (climate-health-pollutant nexus and the pandemic) should be considered as an explicit risk at various levels of governance to the existing sensitivity and dynamics of regulating the adaptation and mitigation strategies to combat climate and emerging pollutants. The pandemic has unleashed an emerging nexus involving climate, health, and pollutants, which may need novel state-of-the-art science-policy instruments to control the further propagation of this nexus. Also, this nexus warrants a dedicated field of transdisciplinary studies as the interaction between this emerging nexus and various socio-economic systems is largely unknown. Further, the nexus can impact and interact with the SDGs creating more pressure and resistance towards achieving multiple goals already affected by the pandemic.

The pandemic can create various transboundary issues, such as pollution of transboundary water resources, which can create tension among various parties involved. There are many regulations and laws in force around the globe regarding CECs, plastics, and pharmaceutical pollutants. But, the pandemic has overridden the capability of nations to manage and tackle waste generation and emanating pollutants. Regulations are the need of the hour, designed explicitly after a thorough understanding of the dynamics of pollutants fueled by the pandemic in various environmental compartments. Injudicious use of disinfectants is a worldwide occurrence since the advent of the pandemic in 2020. There are reports and pictorial evidence from many countries regarding disinfectants sprayed in enormous quantities, even in food markets. Citizens should be informed about the disinfectant type and ingredients before use in public places and crowded areas. The pandemic has provided undeniable lessons and patterns concerning its impact on the environment. We should utilize all these and prepare for the sustainable management of similar threats in the future. This can be achieved partly by applying novel scientific tools and techniques tailored for tackling the pandemic-induced emerging threats currently faced by the humanity.

Wastewater-based epidemiology (WBE) (Bivins et al. 2020) is gaining pace as a tool to detect and evaluate the epidemiology during the ongoing pandemic (Fuschi et al. 2021). The method is lauded for its capability to indirectly detect and understand the prevailing dynamics of the pandemic in a given region or community where the deployment of conventional testing methods is not very successful or feasible among the population. Various research groups worldwide are dedicating substantial resources to this cause and achieving

excellent results lately (Amoah et al. 2020). We suggest that the environmental sampling for CECs, specifically those related to the COVID-19, should be carried out together with WBE as this coupling coproduces the beneficial effect of exponential technologies and will reveal interesting prevailing patterns in space and time. Such practices can also impart resource and schedule feasibilities and timely preparation to tackle and mitigate potential adverse effects emanating from the “envirodemics.” The local to global scale impacts of the “envirodemics” will eventually start reflecting in small inland water bodies to coastal oceans. The pandemic acts as an undeniable forcing function that sets forth various fault lines and cascading effects on the global environment and the momentum of prevailing regional policies, for example, policies related to plastic pollution and health. Systematic analytical and critical perspectives backed by cohesive political strategies and scientific rationale are required to unleash the following sequels. An intelligent transdisciplinary approach and framework for action is the need of the hour to tackle various uncharted paths and convoluted rebound effects induced by the pandemic. We further endorse the need for systematic investigations on the disruption of existing regulatory frameworks and their implications for such complex nexus due to pandemic-related scenarios.

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Data availability The datasets analyzed in the current study are available as open source data.

Declarations

Ethics approval and consent to participate Not applicable.

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