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RESILIENT AND SUSTAINABLE WATER MANAGEMENT IN AGRICULTURE

Understanding of environmental pollution and its anthropogenic impacts on biological resources during the COVID-19 period

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Abstract

The global outbreak of the COVID-19 pandemic has given rise to a significant health emergency to adverse impact on environment, and human society. The COVID-19 post-pandemic not only affects human beings but also creates pollution crisis in environment. The post-pandemic situation has shown a drastic change in nature due to biomedical waste load and other components. The inadequate segregation of untreated healthcare wastes, chemical disinfectants, and single-use plastics leads to contamination of the water, air, and agricultural fields. These materials allow the growth of disease-causing agents and transmission. Particularly, the COVID-19 outbreak has posed a severe environmental and health concern in many developing countries for infectious waste. In 2030, plastic enhances a transboundary menace to natural ecological communities and public health. This review provides a complete overview of the COVID-19 pandemic on environmental pollution and its anthropogenic impacts to public health and natural ecosystem considering short- and long-term scenarios. The review thoroughly assesses the impacts on ecosystem in the terrestrial, marine, and atmospheric realms. The information from this evaluation can be utilized to assess the short-term and long-term solutions for minimizing any unfavorable effects. Especially, this topic focuses on the excessive use of plastics and their products, subsequently with the involvement of the scientific community, and policymakers will develop the proper management plan for the upcoming generation. This article also provides crucial research gap knowledge to boost national disaster preparedness in future perspectives.

Keywords COVID-19 · Biomedical waste · Water pollution · Soil pollution · Environment

Abbreviations

COVID-19	Coronavirus disease 2019
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
WHO	World Health Organization
GHG	Greenhouse gas
DO	Dissolved oxygen
BOD	Biological oxygen demand
COD	Chemical oxygen demand
TC	Total concentration
IEA	International Energy Agency
PPE	Personal protective equipment
CPCB	Central Pollution Control Board
TB	Tuberculosis
CHC	Community Health Center
PHC	Primary Health Care
BMW	Biomedical waste
VOC	Volatile organic compounds

Introduction

Plastic is mostly used for packaging, equipment, and disposable and medical appliance due to its high strength and durability. Plastic has a significant role in the healthcare industry and public health security, as the COVID-19 outbreak has shown (Parashar and Hait 2021). The novel coronavirus creates an unprecedented and dramatic universal calamity; it is the 3rd zoonotic eruption of the twenty-first century. That disease was first reported in India in January 2020 in the state of Kerala. More than 4 crore people affected by SARS-CoV-2 infection in India up to the month of September 2022 and 5 lakhs of death cases were reported till now.

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The COVID-19 outbreak has given rise to a global health crisis with an adverse impact on biodiversity, as well as on the economy and human society (Tripathi et al. 2020). The lockdown period was declared on the 24th of March 2022 in India with 4 phases, i.e., 21 days, 19 days, 14 days, and another 14 days (Fig. 1a). Post-COVID-19 pandemic not only affects human beings but also creates various challenges on regulations and management practices of single-used plastic pollution crisis worldwide. Even though, air pollution and environmental noise reduction have been reported during the COVID-19 pandemic because people were confined at home and followed waste management strategies (Jena and Patnaik 2021). Assessment of the many crucial environmental effects of the COVID-19 pandemic has grown to be a high priority for academics and research personnel all around the world. It also noted during the lockdown period that our system can readjust to its pure or virtually pristine form. The lockdown has been shown to have numerous positive benefits, providing a doable corrective action for improving the standard of various natural resources. Consequently, typical production of single-use waste products (gowns, masks, PPE kits, hand sanitizers, and gloves) from

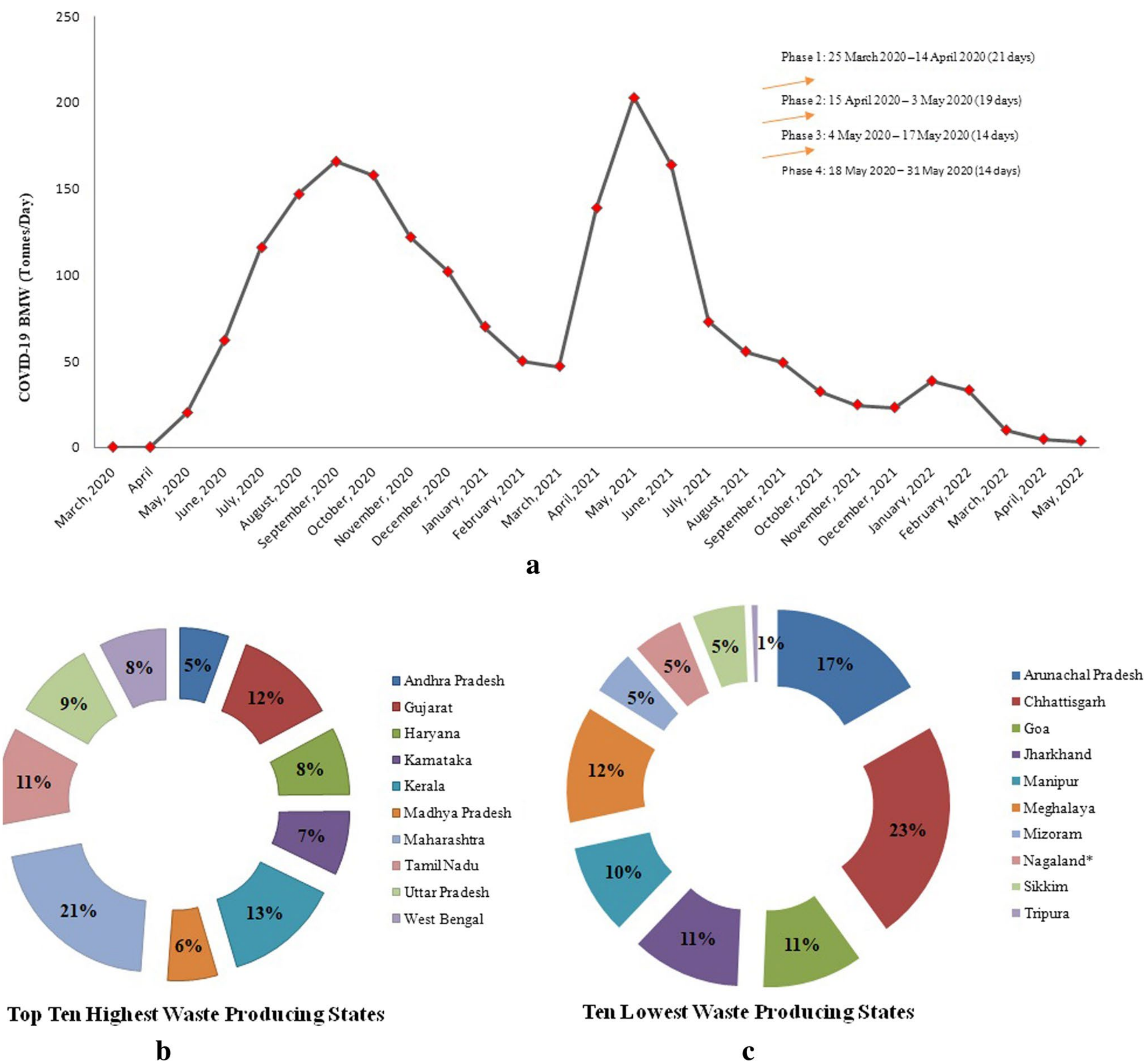

Fig. 1 The graphical representation of COVID-19 biomedical waste generation scenario of India and its different state provinces. **a** Monthwise average COVID-19 biomedical waste generation in India during the period from May 2020 to March 2021 with four phases of lockdown period. **b** Top ten highest waste-producing states during the period from May 2020 to March 2021. **c** Ten lowest waste-producing states during the period from May 2020 to March 2021

both health amenities and households lately emerged to be a waste emergency to a drastic change in nature. Inappropriate management of households and medical waste may lead to serious damage to present flora and fauna and when it is directly discharged into the ambient environment. Untreated solid or liquid waste from both medical and household can create serious concern about environmental pollution (water and soil) and can induce severe health threat that ultimately causes infectious disease like TB, cholera, other respiratory and abdominal infection, AIDS, and hepatitis (Aggarwal and Kumar 2015). In India, about 0.34 kg of solid waste is created per capita on daily basis. Whereas, approximately 75% of biomedical waste does not recover, 40% of waste goes to landfills, and 32% leaks out of the collection system. The COVID-19 pandemic directs as consequence of a 40% increase in the global production of biomedical waste. Remarkably, 8% of biomedical waste was generated and that changed soil quality on dumping sites. According to WHO, nearly about 85% are non-hazardous wastes which exist in the open environment. The remaining 10% may be infectious or hazardous in nature, and 5% of toxic or chemical and radioactive waste may enter into the water, air, and soil bodies. It also noted that the COVID-19 pandemic wave generates 20% of biomedical waste on any given day in India (Fig. 1a). The global outbreak of COVID-19 increased healthcare waste production undesirably in our environment. In this critical situation of the pandemic, the number of quarantine policies has been encouraged like online shopping and home delivery for every public daily need which also eventually increases household wastes (Somani et al. 2020). Whereas, the disposal of general municipal wastes is not much dangerous as the biochemical wastes increase the level of pollutants in nature. The disposal of biochemical wastes needs proper treatment before being discarded as they can be potent elements to spread infections. Contact with hazardous chemicals and radioactive wastes can be responsible for carcinogenic health issues in human beings. A rapid increase of hospitalized patients in this pandemic situation has produced a huge amount of healthcare wastes (Kulkarni and Anantharama 2020). On the other hand, due to a lack of proper knowledge about infectious waste management practices, most of these wastes from hospitals and isolation centers are dumped in open places (Singh et al. 2020). Some of these wastes are directly discarded in the nearest water sources, although a sudden rise in waste due to pandemic situations is a big challenge for the local waste management authorities in every place. Dumping and burning of untreated biochemical and domestic wastes are the main reasons for pollution and infections in the locality. Heavy metals such as lead, cadmium, and mercury are one of the most dangerous elements of biochemical wastes. When they get absorbed by plants and enter the food chain, it results in deadly effects on lives. Thus, it becomes very necessary to study the harmful effect of environmental pollution and its anthropogenic impact on human beings after the pandemic situation. Therefore, awareness should be created among people and prepare us for every worse situation in the future days. The anthropogenic activities of untreated biomedical waste (BMW) have various sources like toxicity, infectious, and radioactivity. Various medical wastes are made up of single-use plastic materials and these untreated materials cause contamination and COVID-19 infection. The SARS-CoV-2 virus remains in single-used plastic and other materials for several time periods and up to several days (Nghiem et al. 2020). A huge number of viral tests and the admission of infected persons into hospitals or home isolation for their own safety led to a rise in the quantity of single-use plastic. Lockdowns, social exclusion, and prohibitions on public gatherings also rapidly increase the reliance on Internet purchasing, and packaging of frequently used plastics (Thakur 2021; Picheta 2020). Consequently, the amount of plastic garbage being treated is not keeping up with the daily rise in plastic product demand. Particularly in health centers, waste processing is very difficult, and not all single-used biomedical materials and packed products are managed or recycled. Subsequently, this inadequately handled biomedical plastic waste is released into the open ecosystem (Woodall et al. 2014). Several studies and research outputs find that the excess use of beauty products and pharmaceuticals contains antibacterial and fungicide molecules, and are progressively increased in the environment (Du et al. 2019). These agents are extremely toxic and create serious endocrine disruption and other neurological disorders. These substances adversely affect the aquatic flora and fauna (Capoor and Parida 2021a, b). Numerous works of research discovered that COVID-19 waste can cause a number of ailments and may have long-term effects on daily living. It might have a serious effect on species invasion, emergence of new illnesses, eventual demise of living things, and even the ability to endanger the whole environmental system.

While few existing studies are looking at the long-term detrimental effects of COVID-19 on the environment and other waste management practices, there are multiple investigations and articles detailing the beneficial consequences of COVID-19 on the environment. The COVID-19 immediate and long-term ramifications on the ecology, waste disposal, and health practices of human beings are covered in the current article. For upcoming initiatives and goal-specific policies, it is also crucial to assess the long-term harmful effects of COVID-19 on the ecosystem. All data analysis can also be utilized to evaluate immediate and long-term mitigation strategies against the potential negative effects of COVID-19.

Main sources' effects on environmental pollution and anthropogenic contributions

COVID-19 waste: what is it?

Generally, biomedical waste known as infectious waste or medical waste is described as trash produced during the diagnosis, immunization, and treatment of animals or humans in research and clinical testing in hospitals as well as biological research facilities. The generated total amount of waste is 85% and the rest is hazardous waste. Some of the 10% of the waste is considered potentially dangerous waste, which includes radioactive, lethal, chemical, and sharps trash, like infectious waste (Prüss et al. 2014; Chand et al. 2020). Any trash product produced by the isolation, treatment, quarantine, and diagnosis of SARS-CoV-2-infected individuals is referred to as BMW during the COVID-19 epidemic. The COVID-19 patients who contaminated those wastes render contagious; otherwise, these are handled by the solid waste management rules from 2016. Between March 2020 and November 2021, the WHO analyzed about 87,000 tonnes of PPE, 140 million test kits (approximately 2600 tonnes of plastic), 731,000 l of chemical waste, and an additional 14,000 tonnes of vaccine-related waste that have been produced worldwide.

Immensity of the BMW problems worldwide

The World Health Organization (WHO) reported that a total of 24 countries have 58% facilities of proper management practices of BMW before COVID-19 (Capoor and Parida 2021a, b). About 10,000 tonnes of extra medical waste are produced around the world, as per the WHO report. In developing countries, COVID-19 has created several major problems in BWM management due to increases in hazardous waste. During the COVID-19 infection period, China produced 247 tonnes of BMW per day; at the same time, India, Bangladesh, and the USA generated BMW was ~ 101 metric tonnes, 2.5 million tonnes, and 206 tonnes per day respectively (Singh et al. 2020; Rahman et al. 2020; Dehal et al. 2022). According to National Green Tribunal, the capital of India increases daily by 11% of COVID-19 BMW than pre-COVID-19 period. However, during the pandemic period, BMW production increases 5 times within the healthcare system worldwide (WHO 2020a, b).

At the time of the COVID-19 outbreak worldwide, the frontline worker utilizes around 89 million masks, 1.59 million face shields, 30 million gowns, and 76 million gloves each month. According to the WHO, 40% of protective care was produced during the initial stages of the epidemic. From June to July 2020, this equipment steadily rose from 5.5 to 50.4 million (Haque et al. 2021). Due to the enormous demand for protective gear, China has offered 150 nations and 7 international organizations 1.73 billion protective garments and 17.9 billion masks through the month of October 2020 (Table 1) (https://www.ebmg.online/plastics). Regrettably, the epidemic causes a significant amount of microplastic garbage to be produced daily. The presence of plastic in freshwater, marine water, and soil habitats poses a significant threat to our ecosystem and public health aspects. In the pandemic period in India, about 7.3 lakh tonnes are hospital waste, 26,787 tonnes are test kits, 5 lakh tonnes are face masks, of which 4 lakh tonnes are medical masks, and the remaining 1 lakh tonnes are N95 and express delivery packaging plastics, which is equivalent to about 3 lakh tonnes of BMW. The details of such produced BMW are listed in Table 1.

The situation with plastic trash linked to COVID-19 epidemic

Population and the total number of confirmed COVID-19 cases data were collected from 30 districts of the state of Odisha, India (data source: https://statedashboard.odisha.gov.in/). Additionally, the baseline information about the total population in each district and the percentage of the urban population was collected (data source: https://www.populationu.com/in/odisha-population). This model has used a spatial variation of the pandemic in different countries. These crucial data are important to evaluate the post-COVID-19-related various waste generation in Odisha state, India (Table 2).

Table 1 During the COVID-19 outbreak, the proportion of each nation's mask production (data source: https://www.ebmg.online/plastics)

Country	Mask production (million/day)	% mask production
China	200.00	71.92
USA	50.00	17.98
Japan	20.00	7.19
Germany	2.85	1.02
Russia	1.60	0.58
France	1.33	0.48
Vietnam	0.80	0.29
Italy	0.70	0.25
India	0.68	0.24
Australia	0.13	0.05
Total	278.09	100.00

Table 2 Production of incorrectly handled plastics as a result of the COVID-19 outbreak in India under both low- and high-stress conditions from a variety of sources (hospital medical waste, test kits, PPE, and online packaging) (data source: https://www.ebmg.online/plastics)

Sources	ABS	PVC	PE	PS	PP	PU
Hospital	51,047	3,471,972.3	1,167,106	2,096,604	557,845.6	0
Test kits	10,675	0	673.5	0	13,130.5	2308
General population PPE	0	0	0	0	446,544.2	105,135.8
Express delivery packaging	0	0	323,062.5	5152.5	68,132	0

Medical waste estimation

In low- and high-income areas, 0.2 and 0.5 kg/day of hazardous biomedical waste are produced each day, respectively, according to World Health Organization (WHO). Odisha reflects a yearly biomedical waste growth rate of more than 7%, and by 2021, it is predicted that the state's daily biomedical waste production might reach 6.65 metric tonnes (Das et al. 2020). The most BMWs were produced in different states like Andhra Pradesh, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Tamil Nadu, Uttar Pradesh, and West Bengal between May 2020 and March 2021 (Fig. 1b). Moreover, the Arunachal Pradesh, Chhattisgarh, Goa, Jharkhand, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura are the states having with the lowest BMW generation (Fig. 1c). However, Delhi generates more than 2978 tons of BMW rather the other union territory regions' combined condition (Fig. 2). The average waste created per individual bed and the numbers of infected individuals are directly related to the amount of medical waste produced in diverse locations. For example, in Odisha state, there are 9274 beds in 56 hospitals, 7251 beds in quarantine camps or COVID-19 centers, a total of 31 RT-PCR testing laboratories, all Community Health Center (CHC) and Primary Health Care (PHC) collection sites, and 36 TrueNAT testing labs responsible for the generation of COVID-19 waste materials (Fig. 3). Our current study assesses the BWM production, collection, and scientific management on a daily basis during the COVID-19 pandemic in 30 districts of Odisha state. Because of this, the predicted values for BMW in numerous cities in Odisha showed the yearly average value per day has climbed from 0.3 kg/bed/day in 2019 to 1.6 kg/bed/day in 2021 (Goswami et al. 2021). A significant partial correlation exists between the SARS-CoV-2-infected individuals and the average output of BMW in Odisha during the COVID-19 pandemic period. Khordha district of Odisha state is the place where the maximum BMWs are produced, and Deogharh is where 14.03 tons of single-use products is produced in daily basis (Fig. 4) (Table 3). As a result, when evaluating the medical waste, the earlier studies estimated BMW of 1.6 kg/bed/day during the COVID-19 period and was given more focus (Sangkham 2020; Saxena et al. 2021).

$$M_w = N_{cc} \times M_{wgr}/1000$$

where M_w = medical waste (tons/day), N_{cc} = number of COVID-19 cases (infected persons), and M_{wgr} = medical waste generation rate, that is, 1.6 kg/bed/day.

Using the weblink (https://statedashboard.odisha.gov.in), you may view the number of confirmed COVID-19 cases throughout numerous districts in the Odisha area, as well as the infected individuals receiving medical treatment or home quarantine, along with the individuals who have passed away after contracting the COVID-19.

Short- and long-term impacts of the pandemic period on environment

Both positive and negative effects impacted the global environment and climate disruption caused by COVID-19. Several researchers confirmed that levels of air quality gases of NO_2, CO, SO_2, NOx, PM2.5, VOCs, and water quality index improved worldwide during the pandemic period (Yunus et al. 2020). Furthermore, due to movement restrictions of the people and slow social and economic activities, the quality of water has improved in several urban and rural areas, with improved air quality in different parts of India (Selvam et al. 2020). However, a huge amount of BMW generation shows negative impacts on biodiversity.

COVID-19 pandemic environmental benefits: a near-term reality

Reduction of air pollution and GHG emission

Unlike before COVID-19, air quality analysis decreased throughout the lockdown period. Industries, businesses, and

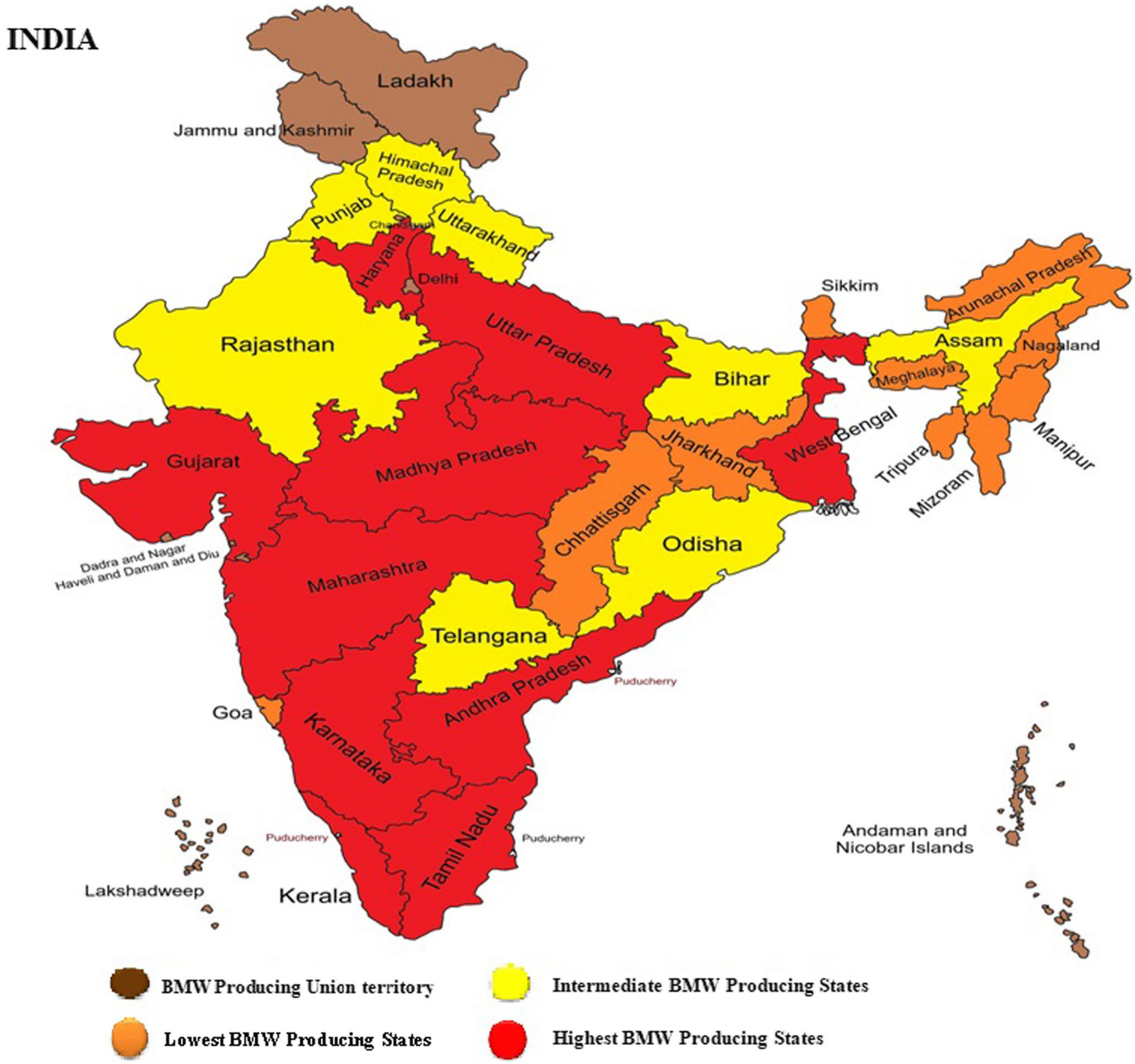

Fig. 2 State and union territory categories by generation of COVID-19 biomedical waste during the period from May 2020 to March 2021

transportation mechanisms also contributed to a sharp decline in air pollutants and other greenhouse gas (GHG) emissions during nationwide lockdowns. There has been a roughly 50% decrease in CO and N_2O enhanced the O_2 level by 16–48% in India because power plant operations have been partially shut down (Biswal et al. 2020; Selvam et al. 2020). Throughout the lockdown period, air pollutions fall down and were reported by the Central Pollution Control Board (CPCB) in various parts of the industrialized state of Gujarat, India. The concentration level of PM2.5 plummeted by 38–78%; subsequently, the PM10 level decreased in the range of 32–80% than before the lockdown, respectively (Lokhandwala and Gautam 2020). One of the key gases of NO_2 emission has been reduced by 70% in the capital of India, which is emitted from the burning of fossil fuels (Ghosh 2020). The level of NO_2, PM10, and PM2.5 was reduced by 46–50% during the nationwide lockdown in the entire Odisha (IEP 2020; Thiessen 2020; Mekonnen and Aragaw 2021). Correspondingly, 72% and 11% of key contributors in transport sectors are vehicles and aviation which emit GHG gases. According to IEA, 7% of CO_2 emission has been reduced during the COVID-19 pandemic (Henriques 2020; IEA 2020).

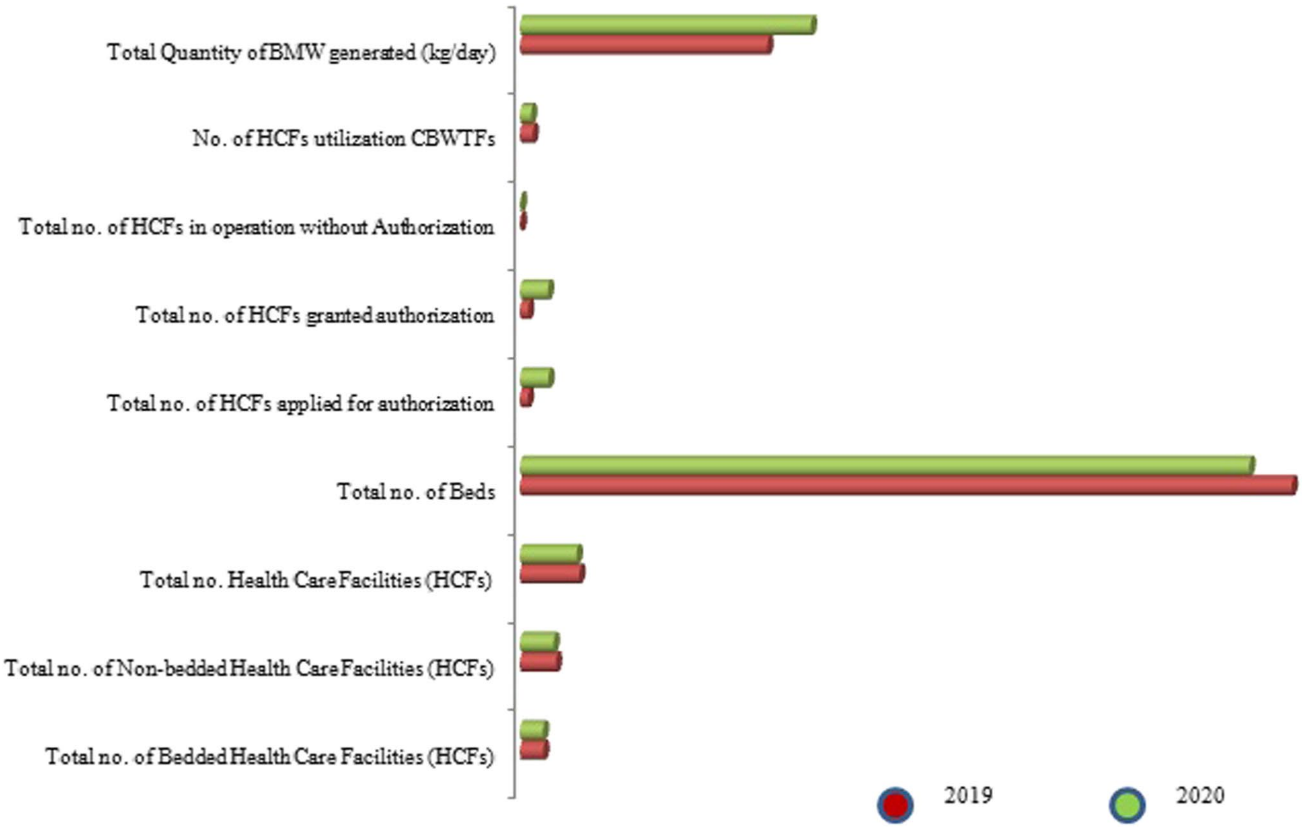

Fig. 3 Annual report information on the management of biomedical waste in Odisha in 2019 and 2020

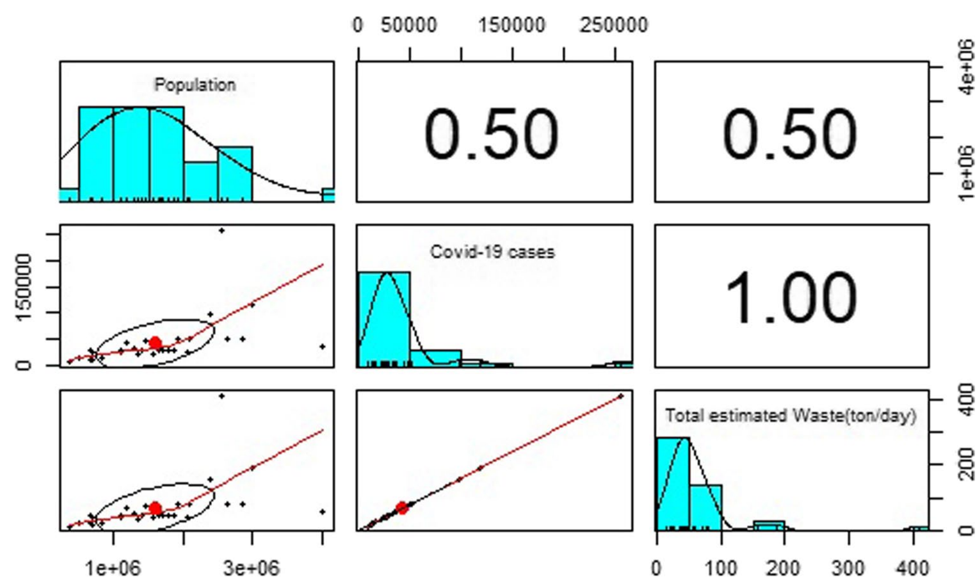

Fig. 4 Correlation plot showing the total estimated waste product in tons per day directly depended on confirmed case with total population of Odisha, India, during the COVID-19 outbreak

Reduction of water pollution

In Odisha, water pollution is a common case, where industrial and domestic wastes are dumped into the sea and rivers. During the lockdown period, the export and import businesses have stopped and a sudden drop in sewage and industrial effluents caused reduction of the pollution load in rivers and marine water (Yunus et al.2020).

Table 3 Estimated medical waste produce per day in several districts of Odisha with confirmed COVID-19 cases on 14.09.2022 (data source: https://statedashboard.odisha.gov.in/)

Districts	Population	COVID-19 cases	Total estimated waste (ton/day)
Bargarh	1,688,631	35,509	56.8144
Jharsuguda	660,636	29,061	46.4976
Sambalpur	1,186,853	44,780	71.648
Deogarh	356,273	8834	14.1344
Sundargarh	2,386,518	98,158	157.0528
Kendujhar	2,053,976	24,585	39.336
Mayurbhanj	2,872,501	50,669	81.0704
Baleshwar	2,645,403	49,775	79.64
Bhadrak	1,717,224	29,819	47.7104
Kendrapara	1,642,012	28,314	45.3024
Jagatsinghapur	1,296,147	32,559	52.0944
Cuttack	2,991,896	117,435	187.896
Jajapur	2,082,999	51,109	81.7744
Dhenkanal	1,359,805	22,448	35.9168
Anugul	1,452,156	48,152	77.0432
Nayagarh	1,097,579	29,371	46.9936
Khordha	2,566,907	255,563	408.9008
Puri	1,936,552	50,758	81.2128
Ganjam	4,023,095	36,931	59.0896
Gajapati	658,711	13,445	21.512
Kandharnal	835,745	14,011	22.4176
Boudh	502,925	15,145	24.232
Subanapur	695,609	17,298	27.6768
Balangir	1,879,857	30,083	48.1328
Nuapada	695,835	27,473	43.9568
Kalahandi	1,797,631	29,778	47.6448
Rayagada	1,103,419	25,301	40.4816
Nabarangapur	1,391,878	28,201	45.1216
Koraput	1,572,798	24,036	38.4576
Malkangiri	699,039	12,894	20.6304

Reduction of noise pollution

Noise pollution adversely affects living organisms due to undesired human activities like machines, vehicles, and construction sites. Due to noise pollution, nearly about 360 million people are affected by hearing loss worldwide. During this pandemic, travel and vehicular restrictions have considerably changed the level of noise pollution in Delhi City of India around 50–60 dB, out of 100 dB (Gandhiok and Ibrar 2020; Somani et al. 2020).

The closure of numerous industrial and commercial operations that rely on fossil fuels resulted in a notable decrease in GHG emissions, VOCs, and other particulate matter. The bulk of global investigations has shown that the air, water, and noise quality significantly improved during the shutdown conditions. The worldwide lockdown had a huge influence on the energy supply, which resulted in lowering of GHG emissions and noticeable reductions in energy usages. The findings unequivocally demonstrated the long-term positive effects on the potential for global warming. Decreased demand for all fossil fuel–related energy sources and heavily relying on other renewable resources are also essential needs.

Environmental consequences of the COVID-19 pandemic: a terrifying trip

Issues with the handling of uprising biomedical waste

The current BMW collection and recycling infrastructure is under a lot of stress, which has resulted in inefficient waste reduction techniques like portable incinerations and open-air disposal of single-use plastics; these are also crucial factors for the safety of frontline workers (Basu and Basu 2021). In the face of mounting concern, the manufacturing line for single-use plastics is working to seize the moment and revitalize a once-thriving but now failing sector (Mousazadeh et al. 2021). Currently, many supermarkets prohibited customers from bringing their own cloth bags because they worry people might decide to buy their things in single-use plastic packaging substitutes. Additionally, a rise in online food orders has contributed to an increase in plastic consumption per person, illustrating how the COVID-19 pandemic has intensified environmental harm on a worldwide basis. As a result, there has been undoubtedly a large increase in the use of plastics, which will aggravate the leakage of microplastics into the environment. The use of plastic has increased dramatically (40%), as have other applications (17%), such as medical equipment and other associated ones. During COVID-19, the generation of BMW suddenly increased all over the world, which is considered an important threat to public health and biodiversity. In COVID-19, the BMW is generated from infected people, sample collection site, and diagnosis centers (Zambrano-Monserrate et al. 2020). In India, during the 1st lockdown period, medical waste has increased from 550 to 600 kg/day to around 1000 kg/day. Science COVID-19, the production of single-use plastic is increased globally. It is reported that about 14,607,834 face masks are used and a large number of BMW are produced during the COVID-19 period in Odisha; for a long period, these masks release dioxin and various toxic elements that pollute land and water ecosystem (Selvam et al. 2020).

The concerning issues of microplastic contamination in our environment have grown significantly. These are typically located in natural settings. In addition, individuals are utterly dependent on plastic and its other form (microplastic) produced by numerous events of pandemics (Oyedotun et al. 2020). Microplastic has a higher COVID-19 viral persistence rate than other materials. Therefore, it has been suggested that a potential source of microplastic in the surroundings is single-use plastic-based protective gear (Knowlton 2020; Sridharan et al. 2021). The N-95 masks are erected by polypropylene, whereas Tyvek is used to make the safety gloves and face shields. Dioxin was released into the surroundings by such two microplastics (Wang et al. 2021a, b). Polypropylene fibers make up the bulk of the microplastic released from different types of face masks (Chen et al. 2021). Organic waste and household protective equipment are also responsible for spreading several viral infections to regular people. Due to the absorption of heavy metals and organic contaminants by the natural environment, microplastics have a significant role to hinder this phenomenon. These microplastics affect the endocrine system and are considered harmful. By 2025, it is predicted that there will be 250 million metric tons of microplastic in marine waste worldwide (Jambeck et al. 2015; Ye et al. 2020).

Impact of biomedical waste on water

As COVID-19 spreads very rapidly because of close contact from one individual to another, more production of personal healthcare equipment is necessary to stop the harmful impact of biomedical waste on water. Dumping of healthcare wastes without proper treatment measures not only affects soil but also affects the groundwater level of that particular site as liquid toxic pollutants leach out and get mixed with groundwater. From hospitals to COVID care centers, direct disposal of medical wastes into the nearest pond or river has been noticed worldwide during the COVID-19 pandemic situation (Aggarwal and Kumar 2015). The toxic metals of these wastes alter the biology of water, which has a number of negative impacts on the water ecosystem. Plastic wastes in water bodies harm aquatic lives which eventually affects human beings. Additionally, this polluted water can spread infections very rapidly in the nearby locality. Research laboratories release various non-biodegradable chemical and radioactive elements in liquid form having carcinogenic effects on human health (Patil and Pokhrel 2005). In contact with air or water, the antibacterial substances (triclocarban and triclosan) found in laundry and cleaning products also create a protective surface layer. These contaminants have an adverse effect on both the habitats of humans and marine life (Ion et al. 2019). Chloroquine and hydroxychloroquine are released into the water system in huge amounts, which has significant ecotoxicological effects on living things (Kuroda et al. 2021). The components of the environment interact with one another. Handwashing soap contains bisphenol A (BPA), which has several negative impacts on soil and water quality. BPA has been shown to affect the endocrine system in a number of different organ systems in laboratory experiments (Dodson et al. 2012; Kim et al. 2021).

All major rivers of Odisha link up with the Bay of Bengal, in the northeastern part of the Indian Ocean. Inadequately treated water released microplastics into these waterways, finally transferring microplastic into the Indian Ocean. The basic water qualities were analyzed throughout pre-COVID, COVID, and post-COVID periods like temperature of water, pH, DO, BOD, COD, TC, and FC, which have been shrivelled. During the COVID period, the TC and FC variables of the Bay of Bengal are relatively high than the pre- and post-COVID pandemic at the Paradeep region of Odisha (Fig. 5a). Principal component analysis (PCA) of the fundamental water quality indicators such as water temperature, pH, DO, BOD, COD, TC, and FC of three important lakes, i.e., Anshupa, Chilka, and Tampara, has been inspected. Tampara Lake has higher peak metrics in the pre-COVID period (Fig. 5b). The DO, TC, FC, and COD are peak in Chilka Lake but only BOD more in Tampara during the pandemic period (Fig. 5c). Throughout post-COVID, TC and FC are high in Anshupa Lake, BOD, and COD is high in Tampara Lake (Fig. 5d). Unlikely, the pH and water temperature are always showed elevated in Chilka. The major rivers in Odisha are the Mahanadi, Subarnarekha, Brahmani, Baitarani, Budhabalanga, and Rushikuly. The basic water quality parameters of these rivers were analyzed in-between pre-COVID, COVID, and post-COVID, and these parameters are water temperature, pH, DO, BOD, COD, TC, and FC, which have been consistently investigated. In pre-COVID time, the TC, FC, and BOD parameters are unsatisfactory in Mahanadi, Brahmani, Budhabalanga, and Rushikuly than other two rivers (Fig. 6). On the other hand, the TC and FC levels are high in Mahanadi, and only BOD and TC are unsatisfactory in Brahmani during the pandemic period (Fig. 6). Throughout the post-COVID, BOD, TC, and FC water quality parameters are higher in Mahanadi and Brahmani than in other rivers (Fig. 6). Unlikely, all these water parameter concentrations will increase in the future days due to the rise of single-use plastics.

Biomedical waste's effects on soil

According to the WHO, non-steroidal anti-inflammatory medicines (NSAIDs), such as ibuprofen, acetylsalicylate, and diclofenac, were utilized in pandemic outbreaks, while furosemide has been recommended for SARS-CoV-2-infected individuals (Brennecke et al. 2020; WHO 2020a, b). Solid waste management during pandemic situations especially during the COVID-19 outbreak has been a great challenge for many developing countries.

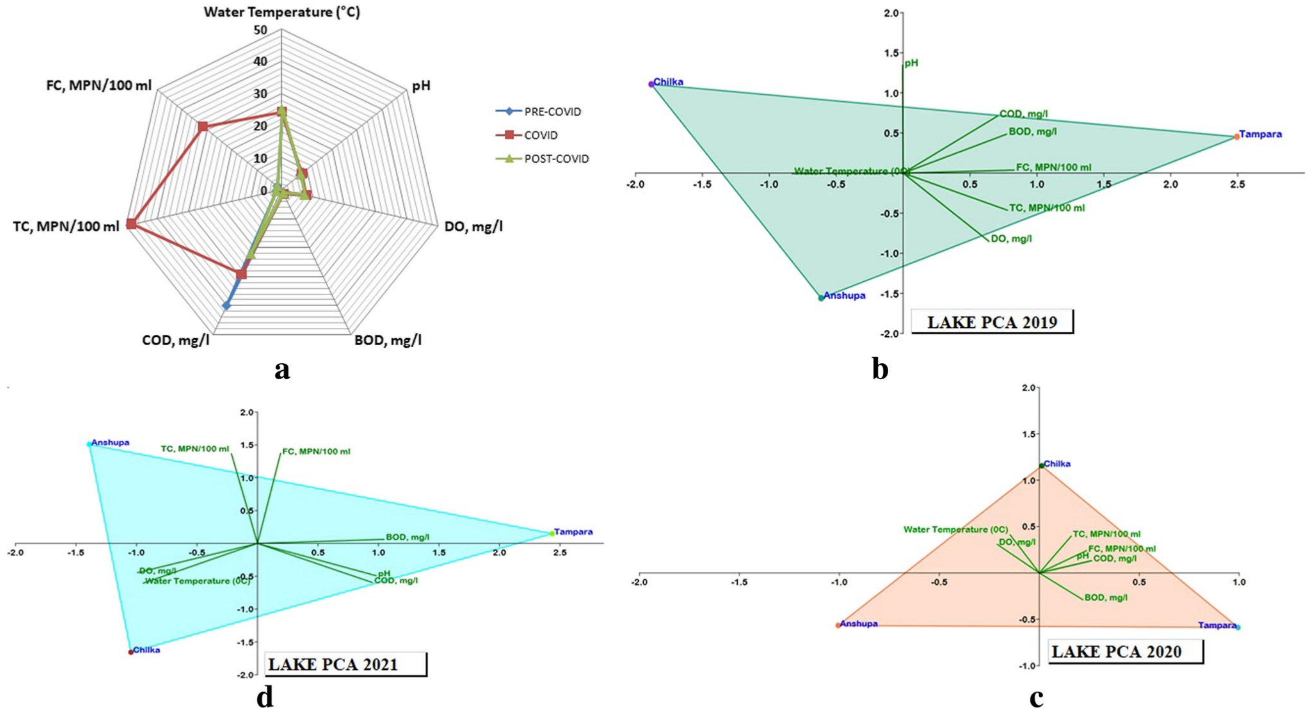

Fig. 5 Water quality assessment plots during pre-COVID, COVID, and post-COVID phases at three significant lakes of Odisha state, India. **a** The Bay of Bengal's paradeep coast's water temperature, pH, DO, BOD, COD, and TC are the primary water quality variables examined during pre-COVID, COVID, and post-COVID. **b** Anshupa, Chilka, and Tampara, three significant lakes were studied using principal component analysis (PCA) of basic water quality indicators such as water temperature, pH, DO, BOD, COD, TC, and FC at pre-COVID phase, **c** COVID phase, and **d** post-COVID phase (data source: http://ospcboard.org/environmental-monitoring-data/)

The global pandemic has reported the dumping of an unusual amount of contaminated PPE kits, masks, and gloves by healthcare workers. Numerous other wastes from the isolation wards near the municipal dumping sites have also been reported (Jena and Patnaik 2021). It not only changes the soil quality of that site but also becomes an unhygienic place for citizens. Improper disposal of medicines and patients' urine and feces during the treatment process not only infects the soil but also creates a nasty environment to the atmosphere (Shah et al. 2001). Alcohol-based products like hand sanitizers harm aquatic life when discharged into the environment. In addition, it affects groundwater indirectly through the soil. The soil and water ecology is impacted by triclosan, hydroxychloroquine, triclosan, and triclocarban. The anti-inflammatory medications also have an impact, exacerbating the negative effects of COVID-19 (Selvaranjan et al. 2021).

One-third of the ecosystem's components are made up of plastic garbages, and soil by which it enters the initial habitat (de Souza Machado et al. 2018). Numerous types of microplastics exist in the terrestrial ecosystems' soil, including agricultural systems, food plains, forests, and sands. These microplastics can come from various sources, including landfills, sewage sludge, composts, and wastewater-irrigation systems (Kumar et al. 2020; Scheurer and Bigalke 2018; Ng et al. 2021; Wang et al. 2020). Plastic garbage may modify the permeability and water-holding capacity of the soil and impair its bulk density and structural integrity (de Souza Machado et al. 2018; Wan et al. 2019). Additionally, it also affects various chemical and physical characteristics, such as enzyme activity and hydrogen ion concentration (Fei et al. 2020; Boots et al. 2019). The carbon, phosphorus, and nitrogen cycles in soil are crucial to the soil's fertility and nutrients; it may also be impacted by COVID-19 waste (Zhang et al. 2019). The microplastic-containing harmful chemical sinks may modify the soil's physicochemical qualities, bioavailability, and biodiversity as well as its mobility and adsorption capacity (Hüffer et al. 2019). The adsorption of microplastic by soil microorganisms and microbial communities may influence the possible dangers to both humans and animals (Zhang et al. 2019; Imran et al. 2019). There is still more research needed to access the possible effects and ecological concerns on terrestrial ecosystems of the interaction between protective equipment-associated microplastics and the COVID-19 virus in soils and waters.

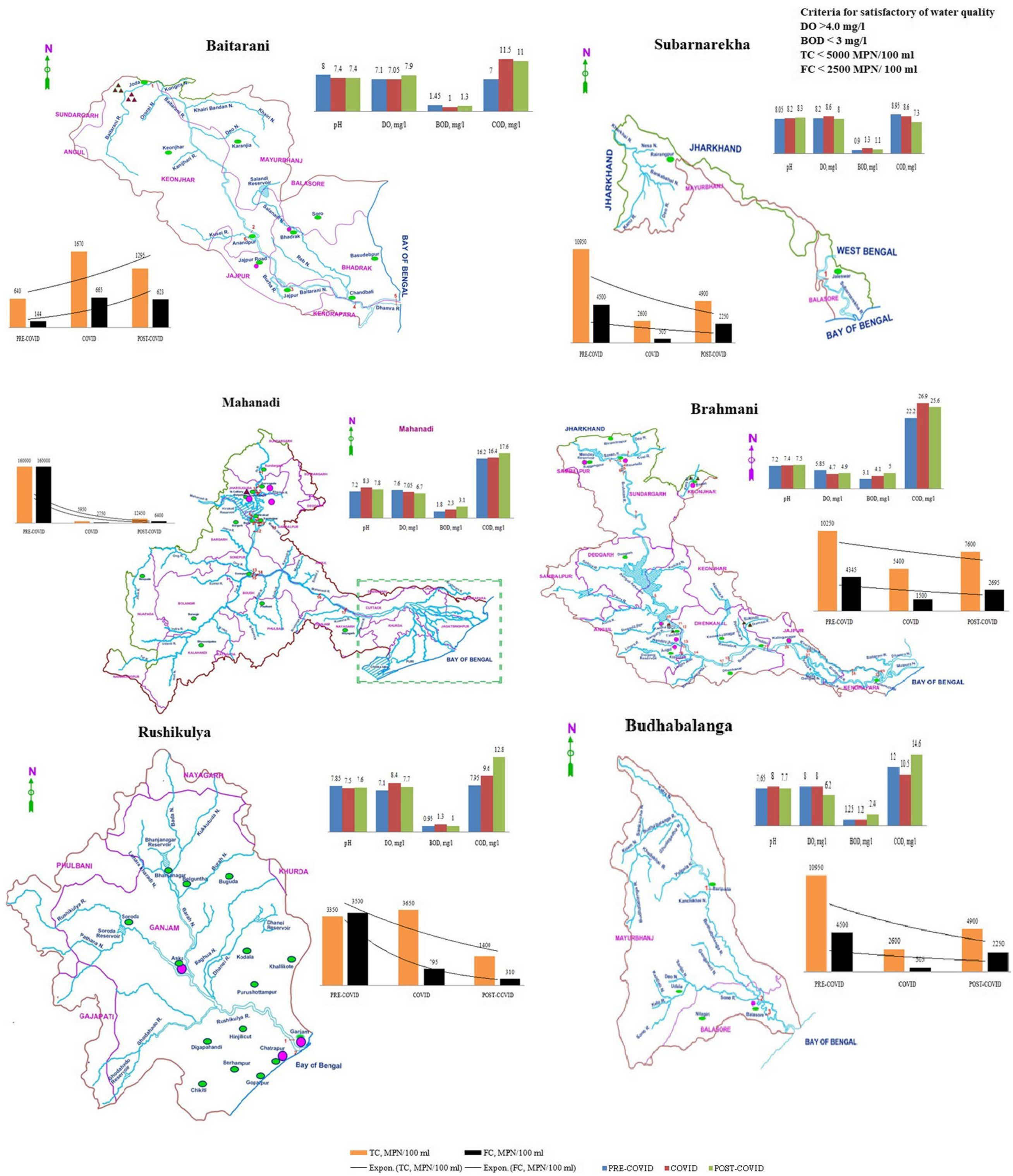

Fig. 6 Pre- and post-pandemic COVID-19 outbreak variations in physicochemical parameters, such as pH, DO, BOD, COD, TC, and FC concentration, were seen along the major rivers in Odisha, including the Mahanadi, Subarnarekha, Brahmani, Baitarani, and Rushikuly (data source: http://ospcboard.org/environmental-monitoring-data/)

Exposure and hazardous gas emissions during incineration

As biochemical wastes contain many infectious agents as well as hazardous chemical elements, improper disposal of this waste can lead to fatal effects on society. Open flaming of biochemical wastes produces injurious gases such as fly ash, carbon monoxide (CO), carbon dioxide (CO_2), and other toxic flue gases. These not only pollute our environment but also cause many respiratory and skin diseases. Exposure to dioxins and mercury emitted by the burning of plastic and other medical wastes leads to hormonal misbalance and reproductive and developmental problems in living animals. Moreover, the increased atmospheric carbon dioxide ultimately affects global climate change and the food chain process (Manzoor and Sharma 2019).

Impacts of microplastics on the atmosphere

COVID-19, at first glance, reduces greenhouse gas emissions and enhances air quality. On the other hand, as plastic waste pollution rises over time, a hidden catastrophe will be the real cause of increasing worldwide GHG emissions. Plastic garbage is responsible for 850 million metric tons of annual GHG emissions, which will rise to 56 billion tons by 2050. The single-use protective plastic emits 0.05 kg of CO_2 when shipping is not included, whereas the shipping emits 0.059 kg of CO_2 gas. The washing of single-use plastic contributed to the 0.36 kg of CO_2 that was released (Klemeš et al. 2020; Silva et al. 2021). Additionally, dangerous substances like dioxins and furans can be released during landfalls and the combustion of garbage from protective equipment, which can pollute the atmosphere (Vanapalli et al. 2021). Recent research has discovered that the protective gear can also fracture and linger in the air as microplastics (Zhang et al. 2021). As a result, the atmosphere plays a crucial role in the cycle of microplastics related to safety gear and contributes to the spreading of microplastics in various contexts. Additionally, the atmosphere contributes to producing protective gear made up of plastic through the microplastic cycle, and microplastic wastes degrade air quality, impact the climate, and absorb associated dangerous substances.

Effects of COVID-19 on energy sources

In the energy sector, the COVID-19 epidemic has caused serious problems. Coal accounts for around 40% of the electric energy produced by the major fuels globally. China, India, and Australia together generate 70% of the world's coal. About 8.1 billion tons of coal were produced year by 2019; however, during the pandemic, that quantity fell sharply to only 40,000 metric tons in 2020 (Rizou et al. 2020; Mousazadeh et al. 2021). Similarly to this, during the initial lockdown period, world oil consumption declines by around 5% (Atolani et al. 2020). Consequently, there has been a significant lowering in the global use of power. Reducing air pollution due to lower NO_2 production during COVID-19 leads to less electricity usage, which enhances the environment's well-being (Lian et al. 2020).

Animal and aquatic life's response to microplastics

Different detergents are released into water sources, creating foam. Some aquatic plants, including Potamogeton and *Ranunculus aquatilis*, cannot survive in a detergent level of 2.5 ppm (Kumar et al. 2021). In soils, harmful compounds build up and deteriorate the quality of the soil texture. Numerous aquatic ecosystems and biota are harmed by domestic water. The plasma of marine fish and some marine organisms has been found to include certain newly developed medicinal compounds (Vasquez et al. 2014). Ibuprofen, an anti-inflammatory drug, has been linked to substantial, long-lasting harmful effects on aquatic creature reproduction (De Girolamo et al. 2020; Carlsson et al. 2006).

Without any doubt, the COVID-19 epidemic causes water pollution around the planet. Low-density polymers in polystyrene and polypropylene cause them to float in seawater whereas high-density polymers such as polyethylene terephthalate, polyvinyl chloride, and polyvinyl alcohol readily sink on the bottom (De-la-Torre and Aragaw 2021). Therefore, key threats to its biodiversity are acidification of saltwater and microplastic degradation of the environment. Every year, seas are getting between 57,000 and 265,000 million metric tons of microplastic trash. In recent years, microplastics have been discovered in the groundwater, rivers, and lakes of India (Selvam et al. 2021).

Numerous studies have shown that face mask pollution impacted animals. However, the animal population and its habitat dramatically grew throughout the lockdown period. Conversely, inappropriate disposal of single-use plastics puts animals at the risk of suffocation and death by ingestion, trapping, and entanglement (Fig. 7a). Researchers also discovered that single-use plastic has an immediate and long-term impact on animal health, resulting in body deterioration, mobility issues that limit the feeding activity, changes in physiological blood parameters, strangulations, and considerable amount of reduction in biodiversity (Seif et al. 2018; Lavers et al. 2019). Consumption of microplastics can occasionally have an adverse impact on the animal's ability to reproduce and their nutritional needs (Tavares et al. 2016; Thompson et al. 2020). Microplastics interact with intestinal-active microorganisms, reducing mucus outputs and causing dysbiosis (Wang et al. 2021a, b). Microplastics

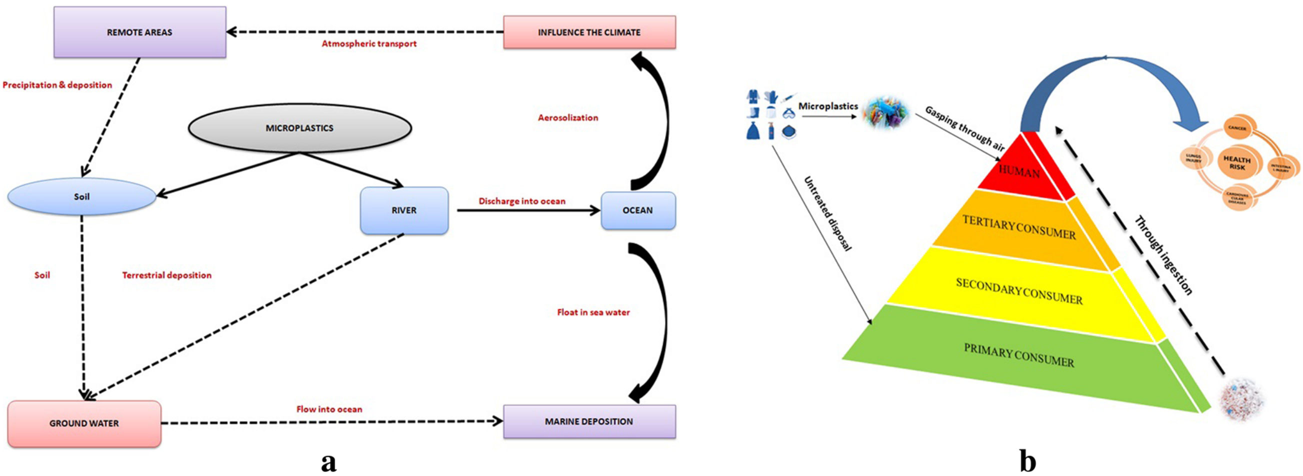

Fig. 7 The conceptual model of microplastic impacts in natural environment condition. **a** The cycle of plastic and microplastic is produced from protective equipment. Discarded protective gear causes a microplastic cycle and large accumulation of plastics and microplastics in many ecosystems, contaminating the aquatic, terrestrial, and atmosphere. **b** Possible health issues brought on by personal protective pollution. Humans can be exposed to the protective suits linked to nanoplastics by consumption and breathing, which can cause illnesses in various ways

may accumulate by organisms and move up the food chain from lower biota to higher consumers, making food sources the most important way to enter the body of animals. According to experts, at least one microplastic is accumulated by 67% of sharks (Parton et al. 2020). COVID-19 face mask–released elements (exposure polymers) inhibit the development and reproduction of young earthworms. The adult earthworms' spermatogenesis and intracellular esterase activities were similarly inhibited. The animal body's tissue and cellular levels can be negatively impacted by microplastic (Kwak and An 2021). As a result of their additive and synergistic effects, the chemical pollutants connected to microplastics can have more severe impacts that ultimately damage different animal systems (Roda et al. 2020). In general, the COVID-19 protective gears cause harm to exposure adjacent animals by trapping, entanglement, and ingestion.

Impact of microplastics on human

Understanding the harm to human health posed by COVID-19 protective equipment linked with plastics and microplastics presents significant hurdles due to the paucity of research on adsorption properties and toxicological assessment of contaminated components. There is proof that airborne viruses or respiratory droplets from patients can be directly deposited onto personal protective equipment and stay active for more than 72 h. In 2018, many researchers discovered microplastics for the first time in the human lungs, spleen, kidneys, and liver. Microplastic is ingested into the colon and placenta of humans (Ragusa et al. 2021). With commercial marine and freshwater species, edible fruits and vegetables, consumption of soft drinks, drinking of water, and commercial marine as well as freshwater species, the concentration of microplastics consumed in the human body rises possessively. On average, 0.1 to 5 g of microplastics may enter bodies every week globally (Senathirajah et al. 2021). Some researchers noted that presently human blood samples contain 1.6 g/ml of plastic particles (Leslie et al. 2022). Top consumers have a higher concentration of microplastics than lower tropic levels, making them more riskier (Fig. 7b) (Carbery et al. 2018). The intestinal function is destroyed by the oxidative stress and inflammation brought on by the interaction of microplastics with the gut floor (Huang et al. 2021). Inflammation promotes cell death, epithelial barrier degradation causes cardiovascular illnesses, diabetes, and cancers, and airborne microplastics can harm and cause oxidative stress (Dong et al. 2020; Prata 2018; Yang et al. 2021) (Fig. 7b). Therefore, more scientific research should be required to establish that protective gear made of microplastic may certainly absorb viruses but shows as the potential contaminant source.

Concluding thoughts, future vision, and perspectives

This article emphasized the relationship between hazards to those, directly and indirectly, connected to this profession, poor and non-scientific handling of biological waste materials. The COVID-19 epidemic has unprecedentedly impacted the environment, human life, and the global economy. The COVID-19 pandemic could provide short-term advantages for the natural environment. However, the long-term environmental problems brought on by this viral pandemic might have enduring impacts and provide difficulties for all nations. Due to the widespread use of anti-microbial hand sanitizers, disinfectants, and pharmaceuticals, including triclocarban, triclosan, and hydroxychloroquine, dangerous emergent pollutants such as COVID-19 have also had a severe impact on the water qualities and soil ecology. In addition, after the COVID-19 incident, the amount of plastic garbage has increased dramatically. Protective gear can lower the chance of contracting the COVID-19 virus during the pandemic, but repeated usage and inappropriate discarding make the polymer issue in severe condition. It poses significant risks to aquatic life and people by being a significant source of microplastic discharge and build-up in aquatic and terrestrial environments. Presently, not only is too much plastic garbage damaging the marine and terrestrial environments, but it will also eventually break down into tiny plastics called microplastic and nanoscale plastic. Even more severe, irrevocable harm to both people and the environment can be brought on by these micro- and nanoscale plastics. People should be mindful of the long-term effects of plastic consumption and disposal since the COVID-19 epidemic has worsened the plastic pollution situation. According to our condensed statistics and speculative estimation, the COVID-19 epidemic has caused to gear up a tremendous amount of plastic to be produced globally. The present technologies cannot handle the plastic overload situation; hence, innovative methods for managing plastic waste are urgently required. As a result, it is crucial to enact laws and regulations restricting plastic use and inform people on how to manage, reuse, and recycle their plastic trash. Work should be done in the future to develop backup strategies for managing plastic trash in emergency scenarios and preventing plastic pollution. Future studies should also concentrate on the destiny and transportation of micro- and nanoscale plastics since the discarded plastic eventually degrades into these sizes. Further study is necessary to understand how plastic sizes and surface characteristics affect their destiny and transport behavior. Considering the mitigation strategies, recovery of the previous environment during the COVID-19 lockdown period showed environmental degradation. Such undesired incidents are also caused by humans that might be reversible, and applied strategies should be implicated to rebuild the "accidentally positive" phenomenon. One of the best examples is the "smart green city" concept. Subsequently, steps should be taken to remove the conventional plastics with greener alternative components; adding a reliable disposal platform for PPE beyond incineration and the option of landfilling. However, it may be assumed that clustering in the surroundings will be a key factor controlling their activity and offer information on how they can be moved through the environment or eliminated in treatment facilities. That would enable more methodical management of the long-term effects of global plastic pollution. It serves as a reminder of our disregard for the environment and the consequences of human-caused climate change.

Author contribution Jiban Kumar Behera: data curation; analysis; investigation; original draft—writing and figure development. Pabitra Mishra: analysis, validation, and figure development. Anway Kumar Jena: validation, analysis. Manojit Bhattacharya: supervision, reviewing and editing, validation. Bhaskar Behera: validation and reviewing.

Data availability Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Declarations

Ethical approval Not required.

Consent to participate Not required.

Consent for pulication Not required.

Competing interests The authors declare no competing interests.

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