Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Environmental impacts of coronavirus disease 2019 (COVID-19)

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ABSTRACT

The coronavirus disease (COVID-19), a variant of Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) originated in Wuhan city of China and has now transmitted over the world. Till the April 24, 2020, nearly 144,367,284 confirmed positive cases with 3,066,270 deaths worldwide. The recent studies have reported that SARS-CoV-2 is transmitted through respiratory droplets. Several vaccines are available now. However, the vaccination process has not completed yet. Worldwide lockdown was initiated to restrict gathering, transport and industrial activities. Lockdown due to COVID-19 showed reduction in environmental pollution. The quality of air and water improved in metro cities and in rivers during COVID-19. This review not only provides the updated information related to impact of COVID-19 on air, water and noise pollution, generation of biomedical waste and global environmental sustainable development but also it covers the basic mechanism of COVID-19 transmission.

1. Introduction

The SARS-CoV-2 originated in the Wuhan animal market, China, in December 2019 (Walls et al., 2020) and by now has spread over worldwide infecting over 144,367,284 people till April 2020 (WHO, 2021; Wang et al., 2020). The World Health Organization (WHO) has named it as coronavirus disease 2019 (COVID-19) and the International Committee on Taxonomy of Viruses (ICTV) has given the nomenclature as SARS-CoV-2 (Serve Acute Respiratory Syndrome Coronavirus-2) to the novel coronavirus (Kandeel et al., 2020). The higher transmission and infectious rates of the SARS-CoV-2 are due to genetic modification at S protein of receptor-binding domain (RBD) region and long incubation period (2–14 days) (Shereen et al., 2020). The recent investigation has reported that the mortality rate also depends on the level of environmental pollution. As per WHO, mortality due to COVID-19 is more pronounced in elderly people (60+ age) suffering from diabetes, high blood pressure and kidney troubles (Hackethal, 2020).

The transmission of COVID-19 in humans is caused by droplets due to sneezing, coughing or through physical direct contacts like hand shaking (Li et al., 2020). The transmission of SARS-CoV-2 second wave 2021 in India was more infectious than the first one in 2020. During the year 2020, the maximum cases were detected in the month of September 12, 2020 as 97,570 cases/day. During the second wave, the infection rate was much higher and total 346,786 positive cases were reported in a single day as on April 24, 2021 (WHO, 2021; Pandey and Nazmi, 2021). The higher infection rate in the India has challenged several medical facilities such as availability of medical oxygen, ventilators and shortage of COVID-19 medicines in the hospitals (Mehrotra and Sharma, 2021). Table 1 depicts the number of COVID-19 affected persons and deaths caused in various countries of the world.

Currently, several vaccines such as Covishield (AstraZeneca and Serum Institute of India), Covaxin (Bharat biotech), Sputnik (Russia) etc., are available in the market and vaccination process is in a progressive state. The existing drugs like lopinavir, remdesivir, umifenovir and chloroquine have been identified as potential candidates by drug repurposing strategies and take an important part in COVID-19 treatment (Lu, 2020; Song et al., 2020).

Governments have restricted several activities like outing of people, transportation and industrial processes (Zambrano-Monserrate et al., 2020) by imposing lockdown. The environmental pollution (air, water, soil and noise pollution) has decreased due to COVID-19 induced lockdown. The emission of greenhouse gases, nitrogen dioxide and black carbon has dropped substantially (Muhammad et al., 2020). Several industrial units have shut down during lockdown period which is responsible for reduction in water pollution (Barouki et al., 2021). A decrease in noise pollution due to restriction in movement of vehicles has been reported (Asensio et al., 2020). Besides this, the volume of biomedical waste has increased in the COVID-19 pandemic due to tremendous hospitalization of COVID-19 patients. In the pandemic period, large number of quarantine centers were constructed for confirmed and suspected COVID-19 patients. The large amount of biomedical waste like mask, gloves and other COVID-19 safety materials

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Table 1
Spread of COVID-19 in various countries (since December 2019 till April 24, 2021).

Country	Number of infected persons	Number of recorded deaths
USA	31,530,214	564,091
India	16,263,695	186,920
Brazil	14,122,795	381,475
France	5,325,495	101,513
Russian Federation	4,744,961	107,501
Spain	3,456,886	77,496
Italy	3,920,945	118,357
Turkey	4,501,382	37,329
Germany	3,245,253	81,158
Colombia	2,701,313	69,596
Argentina	2,769,552	60,083
Mexico	2,315,811	213,597
Poland	2,742,122	64,707
Iran	2,335,905	68,366
South Africa	1,571,348	53,995
Ukraine	2,004,630	41,700
Indonesia	1,626,812	44,172
Peru	1,726,806	58,261
Czechia	1,615,461	28,863
Netherland	1,435,772	17,002
Canada	1,147,463	23,763
Chile	1,148,320	25,532

Source: WHO, 2021.

were discarded from these quarantine centers (Ilyas et al., 2020). During COVID-19 lockdown, people stayed in their home and preferred online shopping to routine one which was responsible for the generation of waste such as plastic waste (packaging material) (Parashar and Hait, 2021).

This review aims at summarizing and critically assessing the available information on COVID-19 environmental impact and its transmission mechanism.

2. Environmental impact of COVID-19

Mass gathering and close contacts are the major causes for COVID-19 transmission. The WHO has suggested for maintaining a social distance (6 ft) in gatherings or at work place (WHO, 2020b). Most of the COVID-19 affected countries have taken necessary remedial measures including lockdown to combat against COVID-19. The complete lockdown and sealing of hotspots have reduced unnecessary movement. Moreover, complete lockdown in the country (India) with social distancing also helped in breaking the chain of COVID-19 transmission (Srivastava and Dasgupta, 2020). The lockdown has been found to be the most effective step in reducing the COVID-19 transmission by minimizing person-to-person interaction (Srivastava and Dasgupta, 2020; Lamba, 2020). The Indian Government enforced country wide lockdown in four steps from 25th March, 2020 to 31st May, 2020 during the early stage of COVID-19 transmission. In this period, the Indian Government restricted several industrial activities, transportation and sealed tourist places as well as needless movement of people. During lockdown period, the water quality of rivers including Ganga, Yamuna improved due to shutdown of many industrial processes (Elsaid et al., 2021). The noise and air pollution was also reduced during lockdown period due to restricted movement of motor vehicles and shutdown of coal and gas-fired power stations (Liu et al., 2021; Kumar and Managi, 2020).

It has been reported that the level of greenhouse gases decreased for the first time during lockdown after World War II. In the industrial cities, there has been a decrease in air pollution during lockdown period (He et al., 2020). This pandemic is responsible for better air and water quality along with several negative waves such as generation of tremendous volume of hospital and household waste with disturbed solid waste recycling process. Besides these environmental impacts, COVID-19 pandemic also affected the sustainable development goals (SDGs). World leaders adopted 2030 agenda for sustainable development and committed to a shared vision to set the world on sustainable path for people, planet, partnership, peace and prosperity. Due to COVID-19 pandemic crisis, the 2030 agenda of UNSDGs has been affected.

2.1. Positive impacts of COVID-19

COVID-19 pandemic out broke in December 2019 and lockdown was initiated in many countries since March 2020. During the lockdown several human and industrial activities remained suspended to minimize human to human interaction. Several positive effects of lockdown due to COVID-19 on environment like reduction in air pollution, improvement in water quality and minimum noise pollution (Ghosh, 2020) were observed.

2.1.1. Air quality improvement

The industries, vehicles and companies were closed during lockdown and this was responsible for the sudden drop of greenhouse gas emission. In New York, the air pollution was reduced up to 50% in 2020 as compared to 2019 due to COVID-19 induced lockdown. NO_2 is generated from burning of fossil fuels (diesel and petrol) (US EPA, 2016). NO_2 present in the atmosphere is the major cause of acid rain and is responsible for human respiratory diseases (EEA, 2020). European Environmental Agency (EEA) reported that NO_2 emission condensed up to 60% in the major cities of Europe during COVID-19 (EEA, 2020). N_2O and CO emission were also observed to be decreased worldwide during COVID-19 lockdown due to closure of the most of the industries. In China, N_2O and CO emission was reduced up to 50% (Biswal et al., 2020). The NO_2 level in the Ontario (Canada) was also reduced (Adams, 2020). The NO_2 level in the Delhi (India) decreased up to 70% during nationwide lockdown. The air quality parameters during lockdown and their comparison with unlock period have been shown in the Table 2.

According to the Central Pollution Control Board (CPCB), India, the air quality was improved as compared to normal situation (CPCB, 2021). The concentration of $PM_{2.5}$, PM_{10}, NO, NO_2, SO_2, CO and toluene decreased and ozone concentration was found to be enhanced up to standards of CPCB (Table 2). The increase in ozone concentration was attributed to reduction in NO_2 emission during lockdown. This investigation indicated that COVID-19 mediated lockdown was responsible for reduction in air pollution.

The overall NO_2 emission in India was found to be 50% less during nationwide COVID-19 lockdown (Thiessen, 2020). Nigam et al. (2021) compared the air quality data of normal situation with lockdown period and reported that PM_{10}, $PM_{2.5}$, CO, NO_2, O_3, and SO_2 emission decreased during lockdown period from March 2020 to June 2020.

2.1.2. Reduction in water pollution

The availability of fresh water is a big challenge worldwide (Singh and Mishra, 2021). The industrial and domestic wastewater is

Table 2
Comparison between air quality data of lockdown and unlock period (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing).

Parameters	May 31, 2019	May 31, 2020	Standards (CPCB)
$PM_{2.5}$ ($\mu g/m^3$)	98.49	28.61	0.00–60.00
PM_{10} ($\mu g/m^3$)	439.14	39.44	0.00–100.00
NO ($\mu g/m^3$)	125.16	4.57	0.00–80.00
NO_2 ($\mu g/m^3$)	113.59	16.89	0.00–80.00
NO_x (ppb)	149.73	12.71	0.00–200.00
NH_3 ($\mu g/m^3$)	48.06	21.03	0.00–400.00
SO_2 ($\mu g/m^3$)	19.63	11.97	0.00–80.00
CO (mg/m^3)	2.30	2.97	0.00–4.00
Ozone ($\mu g/m^3$)	45.95	83.48	0.00–180.00
Benzene ($\mu g/m^3$)	4.62	2.33	0.00–5.00
Toluene ($\mu g/m^3$)	25.41	26.38	0.00–5.00

discharged into the rivers and other water sources without or with partial treatment (Singh et al., 2021a; Singh et al., 2021b). During COVID-19 pandemic, most of the industries were completely shut down. This was a major reason for improvement in the water quality. For instance, water of some of the major rivers in India like the Ganga and Yamuna achieved a good purity level (Yunus et al., 2020). The water quality parameters of the Ganga river, Prayagraj city, India are given in the Table 3. (Source: Pollution Control Board, Uttar Pradesh, India) (UPPCB).

The water quality of the river Ganga in the Prayagraj indicated that bacterial population of coliform and fecal coliform decreased during COVID-19 pandemic. Sangam, Prayagraj is one of the most popular religious and tourist place in the India where large number of pilgrims visit throughout the year. When COVID-19 lockdown was implemented, the tourist and religious places were totally closed for people. This resulted in the reduction in water pollution in the river Ganga. Several real time monitoring stations were constructed on banks of the river Ganga and 27 out of 36 stations reported water quality under permissible limit during lockdown period (Singh et al., 2020). Water quality data obtained from real time monitoring stations of Uttarakhand Pollution Control Board (UPCB), India, showed that the pH (7.4–7.8), total coliform microbes (40–90 MPN/100 mL), DO (9.40–10.60 mg/L) and BOD (0.60–1.20 mg/L) of the Ganga river were much below the permissible limit as demarcated by the Indian Government (Rume and Islam, 2020) during lockdown. In the Grand Canal city of Italy, the water quality improved substantially and many rare aquatic species reappeared during lockdown (Clifford, 2020). The water quality in beach area of Malaysia, Thailand, India, Indonesia and Bangladesh improved as most of the places were closed for visitors and other water activities. The water and soil quality also improved due to absence of waste food at tourist places (Kundu, 2020).

2.1.3. Reduction of noise pollution

The noise pollution is responsible for hearing loss in about 300 million people worldwide (Sims, 2020). WHO reported that one of the major noise pollution source is road traffic and around 40% European population suffers from high noise pollution. The noise pollution in Dublin was monitored at 12 noise pollution monitoring station between January and May 2020. Among these, 80% of stations reported 60% reduced noise in the lockdown period in comparison to normal situation (Basu et al., 2021). Asensio et al. (2020) monitored the reduction in noise pollution from March to June 2020 in the City of Madrid, USA. Authors reported 4–6 dB noise level was reduced during lockdown period as compared to unlock period. Curovic et al. (2021) investigated effect of COVID-19 mediated lockdown on noise pollution level. Authors analyzed noise pollution data in the various traffic areas in the Koper city, Slovenia during January 2018, February 2020 and April 2020, and authors reported the reduction in noise pollution by 2.2 dB to 5.7 dB due to COVID-19.

2.1.4. Positive impacts on SDGs

COVID-19 decreased the progress of SDGs by affecting all 17 goals during the year 2020–21. However, pandemic also brought positive hopes in many ways like reduction in environmental pollution, climatic changes and decline in global warming by drop in emission of greenhouse gases. Additionally, during pandemic situation, digitalization and consolidation of healthcare system was enhanced. People were motivated for helping others, for performing social service and started working in collaboration for research, medical science and social welfare.

The pandemic guided and encouraged for adjusting the negative effect of COVID-19 and provided us an outline where effective leadership and responsibility of group members are required for fulfilling 2030 agenda of SDGs [Schmidt-Traub, 2020]. The priorities of member states of SDGs are shifted towards the effective management of medical facility and protection of people from COVID-19. However, to avoid risk in the progress to be achieved by 2030, the COVID-19 pandemic can be used as an opportunity to attain a goal of sustainable development [Leal-Filho et al., 2020]. This crisis provided a better solution to the future crisis by implying stronger health system, with a view to achieve the aim of SDG3 (health and well-being). The present crisis also gave an appropriate response for healthier natural environment and gender inequality. Balanced ecosystem is much important for disease control and also highlights the importance of interdependencies between human and biosphere [Di Marco et al., 2020; Bodin et al., 2019].

Table 3
The comparative water quality of the river Ganga before and during lockdown.

Parameters	Before lockdown	During lockdown
DO (mg/L)	11.50	8.00
BOD (mg/L)	2.60	2.30
Total coliform (MPN/100 mL)	8400.00	2400.00
fecal coliform (MPN/100 mL)	3300.00	790.00

2.2. Negative environmental impacts of COVID-19

COVID-19 induced lockdown showed various positive impacts along with few negative influence. The negative impacts COVID-19 are enlisted below.

2.2.1. Generation of biomedical waste

Biomedical waste consists of pathogenic microbial consortia. Several medical facilities and equipment are required for COVID-19 patients during their treatment, which result in the generation of various types of biomedical waste like disposable PPE kits, gloves, face masks, medicines, dressing materials, blood and serum samples etc. (Haque et al., 2021). India suffered as the second most affected country with COVID-19 after USA (https://www.worldometers.info/coronavirus/#countries). Some of the most populated cities of India like Delhi, Chennai, Mumbai, Bangalore and Hyderabad showed maximum COVID-19 cases. On the basis of report published on September 18, 2020, India generated biomedical wastes more than 180 tons/day (https://www.thehindu.com/news/national/coronavirus-india-witnesses-surge-in-covid-19-related-biomedical-waste/article34563675.ece). The Maharashtra alone contributed to around 17% portion of the biomedical waste in India. The volume of biomedical waste generated during COVID-19 from June to September 2020 is shown in Fig. 1.

It is evident from Fig. 1 that the volume of biomedical waste gradually increased from June to September 2020 due to month-wise increase in COVID-19 cases. The maximum cases (about 98,000 per day) were reported in September 2020 (https://www.worldometers.info/coronavirus/#countries). Among these, a large fraction of patients needed hospitalization. Surge in COVID-19 cases in the month of September 2020 involved more medical facilities as compared to normal situation. The generation of biomedical waste from hospitals and quarantine centers increased due to surge in COVID-19 cases. CPCB and Ministry of Environment, Forestry and Climate (MoEFC), India have issued guidelines for the management of biomedical waste generated during isolation, diagnosis and treatment of COVID-19 patient (NCDC, 2020).

2.2.2. Reduction in waste recycling and municipal waste generation

This type of waste consists of packaging materials, glasses, detergents, kitchen waste, etc. Urban sector contributes more municipal waste than rural society. The municipal waste consists of both liquids and solids (Somani et al., 2020). During the lockdown period, people stayed in their home and most of them did online shopping. These activities are responsible for the generation of household waste from packaging materials (Zambrano-Monserrate et al., 2020). The generation of large amount municipal waste adversely affects the environment (Islam and Azam, 2015). However, waste management is an effective

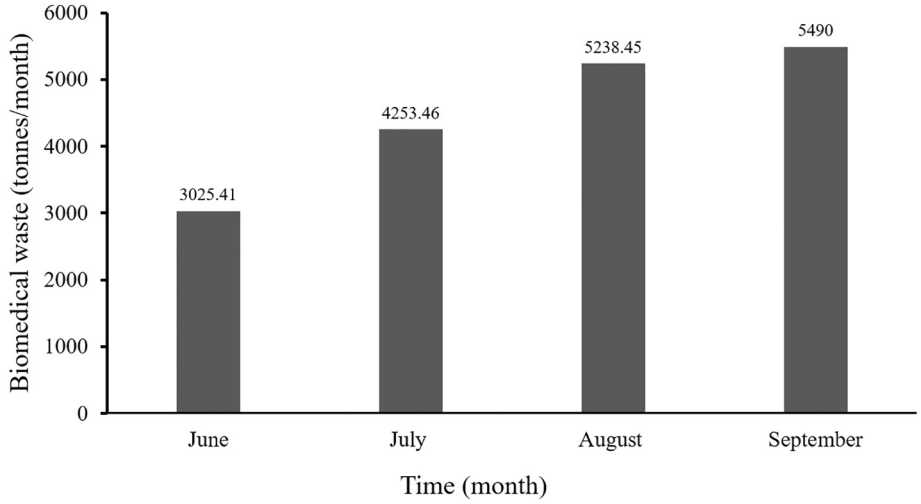

Fig. 1. Volume of biomedical waste engendered during COVID-19 pandemic from June to September 2020.

method for the reducing environmental pollution and conserving nature. During COVID-19 pandemic, most of the countries decreased waste recycling in order to reduce COVID-19 transmission. For example, in USA waste recycling was diminished in its many cities (up to 46%) to prevent COVID-19 transmission in workers involved in such operations. Waste pickers collect re-usable waste from roads and waste dumping area and sell it on low profit for recycling. These waste pickers play an important role in the waste management and circular economy especially for developing countries [Moreno-Sanchez and Maldonado, 2006]. During COVID-19, about 8000 waste pickers were banned by the Turkey Government as part of pandemic measures. Due to restriction in waste collection, the waste recycling and management process became affected (Hikmet, 2020). Other countries like Italy, United Kingdom, Spain, France, etc., also restricted waste management process during pandemic. Due to disruption in proper waste management activities and waste recycling, the environmental pollution increased worldwide (Somani et al., 2020; Islam and Azam, 2015).

3. Lessons learnt from COVID-19 and strategies for environmental sustainability

COVID-19 is a worldwide global health emergency which is responsible for large number of deaths (Singh and Mishra, 2021). Along with its lethal effect, COVID-19 brought positive environmental impacts that might serve as an example and inspiration for future behavior of human towards nature. The current pandemic showed a direct relationship between level of environmental pollution and economic activities like transportation, energy production and industrial operations (Cheval et al., 2020). The pandemic taught us that eco-friendly energy based system is far more beneficial and waste materials should be of biodegradable type. The lockdown period brought us a hope that there are possibilities of minimizing unnecessary anthropogenic activities in the environment (Singhal, 2020). In order to make positive changes in the environment, individuals and Governments may follow the following strategies

i. regular maintenance of vehicles,
ii. well-organized public transport system,
iii. improved traffic management system,
iv. reduced emission of chlorofluorocarbons (CFCs),
v. use of eco-friendly products,
vi. well organized and effective waste management system,
vii. promotion of reused and recycled waste materials and
viii. proper treatment of wastewater before discharging in the environment

Praveena and Aris (2021) investigated the effect of COVID-19 on air, water and noise pollution. Authors collected environmental data from Southeast Asian region before and during COVID-19. Authors reported an improvement in air and water quality, lower noise level and reduction in the surface land temperature. In the lockdown period, social and economy activities were highly affected. However, this pandemic was also responsible for the decline in oil exploration and overall improvement in environmental quality (Abubakar et al., 2021). COVID-19 showed several short and long term environmental impacts which play an important role in the environmental sustainable development. Impacts of COVID-19 for global environmental sustainable development are shown in Fig. 2.

The reduction in pollution level, ecological restoration and climatic change is a global issue that are considered under political boundaries. So, strengthening of global cooperation is a part of 2030 agenda of the SDGs. Moreover, learning from current COVID-19 related experiences, management system and policies are lessons learned for dealing with the climate and environmental issues. The 2030 agenda of SDGs for environmental sustainable development, which covers sustainability in all forms, can be a useful agenda to form guidelines for sustainable ecological future (Shulla et al., 2021).

It is the need of the hour that important strategies such as sustainable industrialization, use of renewable energy sources and international cooperation should be adopted for environmental sustainability (Cheval et al., 2020).

3.1. Sustainable industrialization

The sustainable industrialization plays an important role in energy savings as well as environmental protection. It is necessary to adopt less energy consumption technologies in industries together with the use of renewable energy (Li et al., 2021). Moreover, the industries may be positioned at specific places, where the effluent or waste of one industry can be utilized as raw material for another industry (Hysa et al., 2020). After a defined period, old industries may be shut down/demolished in a circular way to reduce unnecessary emission of pollutant without affecting the economy. In few industries like readymade garments manufacturing unit where people work in group, the physical distance and aseptic condition must be assured in order to avoid COVID-19 transmission (Booth, 2020).

3.2. Use of renewable energy and public transport

The policy 'The Road to Sustainable Transport' provides important recommendations regarding structural changes to achieve minimum

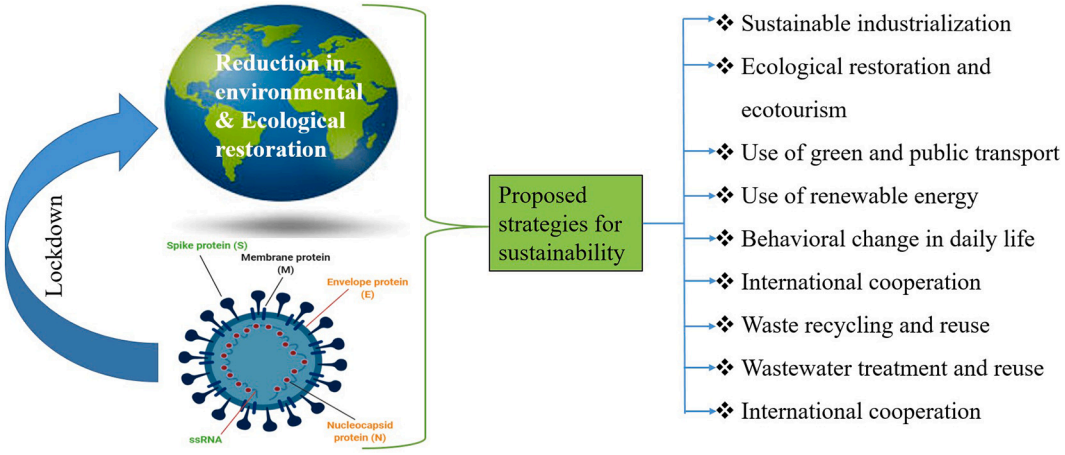

Fig. 2. COVID-19 impacts and strategies for environmental sustainable development.

emission of greenhouse gases. The Government of Colombia recommended the use of transit systems during pandemic. It could solve several problems linked to vehicular pollution, road accidents, deaths and issues related to economic, social and environment (IISD, 2021).

3.3. Wastewater treatment and reuse

Trace amount of SARS-CoV-2 virus was also reported in the wastewater samples in the USA, Europe (Finland, Netherlands, Sweden and Switzerland) and Israel. The COVID-19 virus can multiply in high generation number and can cause COVID-19 infection. Therefore, it is necessary to monitor coronaviruses contamination in the wastewater which must be treated before reuse (UNEP, 2021).

3.4. Waste management: recycling and reuse

The circularity process should be used to minimize waste production and maximum utilization of raw materials (Yousefi Oskoei et al., 2021). The hazardous medical wastes should be properly treated as per WHO guidelines (WHO, 2020a). Majority of people do not have sufficient knowledge about waste disposal and waste segregation (Rahman et al., 2020). In pandemic, the Governments and healthcare system allow the single use of plastic made PPE kits, gloves and disposable syringes which increased while dealing with COVID-19. It is needful to understand the management of these plastic wastes in order to get maximum benefit without affecting ecosystem (Benson et al., 2021). It can be achieved by adopting proper disposal and approved medical waste management procedures for single use medical waste like mask, gloves, surgical suits and PPE kits. US FDA recommended to the healthcare providers to implement the re-usable surgical gowns and avoid PPE kits. In addition, personal COVID-19 protective materials should be disposed in the separate bins and followed by its recycling at authorized medical waste management facility (US FDA, 2020). These practices can be useful in decrease of plastic pollution which is mediated by single use plastic during pandemic.

4. Conclusion

The nation wise lockdown was observed as an effective option to stop transmission of pandemic due to lack of therapeutic facilities of COVID-19 during initial transmission phase. The lockdown period minimized environmental pollution, which improved the water and air quality and brought reduction in noise pollution due to shut down of industrial process. COVID-19 taught us to improve healthcare system for future and provided a clue to achieve 2030 agenda of UNSDGs. The environmental sustainability can be achieved by using green and clean energy, sustainable industrialization, well organized waste management system, wastewater treatment and its reuse.

CRediT authorship contribution statement

Veer Singh wrote the manuscript and prepared graphs and figures. Vishal Mishra supervised the complete work including data management, added more technical facts and complied the manuscript.

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Declaration of competing interest

The authors declare that there is no conflict of interest.

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